Lithostratigraphic nomenclature of the UK North Sea

Editors:

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3. JURASSIC OF THE CENTRAL AND NORTHERN NORTH SEA

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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 As a result, the earlier standard schemes have become increasingly outdated.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. HUGHES, O.B.E.
Director-General, UKOOA

November 1992

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EDITORS' PREFACE

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 biostratigraphic 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 stratigraphic framework that will facilitate stratigraphic communication and the assimilation of stratigraphic information obtained through the exchange of well data.

Emphasis has been placed on developing 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, drillers, 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.

In addition, stratigraphic 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 companies for whom they were intended. In such cases 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 wider 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 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 lithostratigraphy 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.

The type section is included except where it is regarded as atypical of the formation or member as defined in this study.

**DISTRIBUTION MAPS**
They are based primarily on well data. However, some up-dip (i.e. western) limits are based on shallow seismic data. Where the up-dip limit is uncertain, the known distribution is shown on a block-by-block basis.

**STRATIGRAPHIC SYNOPSIS**
These summarize the lithostratigraphic relationships within each group.

‘Key biomarkers’ are those of particular relevance to lithostratigraphic assignment.

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**STRUCTURAL NOMENCLATURE**

Structural terms in this study are shown on the accompanying map, which is modified from the map "Structural framework of the North Sea area", issued by the Petroleum Exploration Society of Great Britain (revised edition, March 1992). The terms ‘Central North Sea’ and ‘Northern North Sea’ are used as follows:

The **UK Central North Sea** encompasses the Central Graben, Outer Moray Firth and Inner Moray Firth, 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.

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The first comprehensive, formal lithostratigraphic nomenclature for the Jurassic of the North Sea was proposed by Deegan & Scull (1984). Most of the formal lithostratigraphic terms used in this study are derived from this work. The scheme is comprehensive, formal and has been widely accepted. However, Deegan & Scull (1984) did not define genetic sequence stratigraphic units, so that there is a need for formal subdivision of the reservoirs, particularly at the base of the North Sea Jurassic. This need has been met by the definition of genetic sequence stratigraphic units and their relationship to wireline-log signatures. Several studies on the regional sequence stratigraphy of the North Sea Jurassic have been published (e.g. Mitchener et al. 1992; Cockings et al. 1993; Harker et al. 1993; Partington et al. 1993; Price et al. 1993). These studies have increased the emphasis on the identification of maximum-flooding surfaces, which are used to define genetic sequence stratigraphic units on the basis of their dominant facies (e.g. Mitchener et al. 1992; Cockings et al. 1993; Harker et al. 1993; Partington et al. 1993; Price et al. 1993). This has been reflected in the publication of new, formally defined, names for specific parts of the succession (e.g. Mitchener et al. 1992; Harker et al. 1987) and in a proposal for a comprehensive, formal lithostratigraphic nomenclature for the North Sea Jurassic. This proposal has been widely accepted and is reflected in the publication of new, formally defined, names for specific reservoir units in the Northern North Sea. A revised Triassic and Jurassic lithostratigraphic nomenclature for the Norwegian North Sea has been published (O'Driscoll et al. 1984; Harker et al. 1987). This proposal, however, is based on the recognition that a formal subdivision of the reservoirs is necessary because of the differing needs of exploration, production and geological interpretations. The need for formal subdivision of the reservoirs is also reflected in the publication of new, formally defined, names for specific reservoir units in the Northern North Sea. The proposal for a comprehensive, formal lithostratigraphic nomenclature for the North Sea Jurassic has been widely accepted and is reflected in the publication of new, formally defined, names for specific reservoir units in the Northern North Sea.
The nomenclature scheme is illustrated in Figure 2 (p.3). Stratigraphic relationships between the formations are more complex than shown on the chart, and, for a fuller account, reference should be made to the descriptions of individual units. Only major unconformities are shown, although it is known that numerous additional (mostly local) unconformities occur within the Jurassic succession.

The formations are assigned to six groups. Five of these (Banks, Dunlin, Dunrobin Bay, Fladen and Brent) comprise formations of shallow-marine and/or continental facies. The Humber Group, however, includes shelf facies and deeper water hemipelagic mudstones and submarine-fan sandstones. The distribution of individual groups is shown in Figure 1.

Because the relative scarcity of cored sections precludes identification of the standard ammonite zones within the North Sea Jurassic, the stages and zones can be identified only indirectly, using palynomorph and microfossil biomarkers. Assessment of the biostratigraphic schemes currently applied to the North Sea Jurassic succession indicates that palynomorphs are the fossil group most widely used to define the chronostatigraphic boundaries. A detailed biomarker scheme is presented in the Appendix.

Figure 1. Areal distribution of Jurassic groups
Figure 2. Lithostratigraphic nomenclature scheme for the Jurassic of the UK Central and Northern North Sea.
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The Humber Group was defined by Deegan & Scull (1977) for the mudstone-dominated unit lying above the coal-bearing, generally sandy Brent Group. The zonal definition of the Humber Group has not been changed, although several new units are defined within it. The Humber Group is of particular economic significance in the Central and Northern North Sea, since it includes the main hydrocarbon source rocks as well as several major reservoirs. The group occurs throughout the basinal areas of the Central and Northern North Sea, and attains a maximum thickness of about 1.7km in the South Viking Graben.

Deegan & Scull (1977) defined two major, mudstone-dominated units within the Humber Group: the Heather Formation and the Kimmeridge Clay Formation. These are retained here, but with their mutual boundaries more precisely defined. Four sandstone-dominated units (Brae, Emerald, Fulmar and Piper) are defined at formation level within the Humber Group. The Emerald, Fulmar and Piper formations consist of shallow-marine, shelf sandstones of tubular geometry. The Brae Formation represents a large-scale complex fan system, interdigitating with, rather than enclosed by, mudstones. For this reason, and because the proximal facies probably straddle the Kimmeridge Clay / Heather Formation boundary, the Brae sandstones are given formation status. All other sandstones of probable submarine-fan origin (Birch, Bruce, Burns, Dirk, Claymore, Freshney, Ling, Magnus and Parmigan) occur as discrete units within mudstone-dominated successions, and are accorded member status within the enclosing mudstone formations. A comparison with the terminology used in the Norwegian sector is given in the accompanying table.

Most of the proposed formations have long been in use, and were established before their stratigraphic and geographic relationships were fully understood. With the benefit of hindsight, it is possible to identify two pairs of formations that would perhaps not be separated if a wholly new scheme were to be established. These are the Kimmeridge Clay and Heather formations and the Fulmar and Piper formations, which are discussed below.

The Kimmeridge Clay and Heather formations

Vollset & Doré (1984) and Doré et al. (1985) considered the name Kimmeridge Clay Formation to be inappropriate for the upper division of the Humber Group in the Central and Northern North Sea. The main reason was the existence of a separate type section in Dorset, and because the time span covered by the unit as applied offshore extends substantially beyond that of the type Kimmeridge Clay. Despite these arguments, it has become clear downstream that there is a strong preference within the UK industry to retain the terms Heather Formation and Kimmeridge Clay Formation in preference to the Norwegian subdivisions or to the substitution of a single new formation name to encompass all of the Humber Group mudstones, i.e. both the Heather and Kimmeridge Clay formations.

However, it is evident that no single criterion is being consistently used to define the Heather/Kimmeridge boundary in different parts of the basin. Recent detailed stratigraphic studies in the area have also highlighted the complexities of correlation within the Humber Group (Riley et al. 1989; Price et al. 1993; Clark et al. 1993; Partington et al. 1993).

The difficulty in consistently subdividing the Humber Group mudstone succession arises because it represents a period of more or less continuous marine sedimentation that took place within a range of bathymetric settings. Most sections show a series of well defined gamma-sonic wireline-log markers, but the associated lithological changes are for the most part not sufficiently distinctive to be lithostratigraphically diagnostic. The wireline-log signatures show a large-scale division into a series of units, the boundaries of each being defined by a more or less sharp downward decrease in gamma-ray values and increase in velocity (e.g. 16/3A-3, Panel 14; 11/36-2, Panel 18; 30/8-1, Panel 16). The relatively high-gamma mudstones that overlie these markers are attributed to major marine flooding events and/or deoxygenation of the bottom waters (see Partington et al. 1993). The most consistently conspicuous wireline-log markers occur in the Middle Oxfordian (associated with the Racemula biomarker), in the basal Kimmeridgian (associated with the S.cystallinum biomarker), and in the Upper Kimmeridgian (with no distinctive biomarker, but believed to fall within the end-oxic Zone).

The transition from the Kimmeridge Clay Formation to the Heather Formation has always been associated with a downward change from high-gamma, organic-rich mudstones to low-gamma, sometimes calcareous, mudstones. Consequently, the boundary, as defined in completion reports, has almost always been taken at one of the wireline-log markers referred to above. However, these boundary picks can be calibrated against available chronostratigraphic data, and it is evident that the log markers that have been used to establish the boundary are not the same throughout the basin. Thus, the base of the Kimmeridge Clay Formation has been taken at several levels ranging from mid Oxfordian to late Kimmeridgian.

Confusion over the lithological definition and significance of the Kimmeridge Clay / Heather formation boundary, has resulted in increasing use of sequence stratigraphy to subdivide the Humber Group mudstones. This is based on the recognition of a series of biostratigraphically calibrated wireline-log features, which are regarded as basinwide isochronous events, and are mostly regarded as reflecting maximum-flooding surfaces (MFS). The most comprehensive of these schemes is that proposed by Partington et al. (1993), in which thirty-two such surfaces have been identified in the North Sea Jurassic. However, documentation of the precise wireline-log signatures of the individual flooding surfaces is awaited.

It also appears that there are discrepancies between different sequence stratigraphic schemes with respect to identification and interpretation of specific biostratigraphic markers. In many instances, this results in a conflict between biostratigraphic data and apparently straightforward wireline-log correlations. Clearly, the sequence-stratigraphic approach offers considerable potential in the subdivision of the Humber Group mudstones into isochronous units. However, it needs fuller documentation, and the apparent contradictions need to be resolved before a regional subdivision can unequivocally be effected by this method.

Nevertheless, the conclusion reached in this review is that an unambiguous and consistent lithostratigraphic subdivision of the Humber Group mudstones cannot be achieved solely on the basis of lithology and wireline-log character.

Furthermore, consideration of gross facies associations does not help in differentiating the formations, since although the Heather Formation is commonly perceived as representing shelf facies, the formation as currently recognized in different parts of the basin includes mass-flow sandstones of slope or basin association. Faced with these difficulties, a division of the Humber Group mudstones into Kimmeridge Clay and Heather formations is of necessity somewhat arbitrary. A pragmatic decision has, therefore, been taken to select one of the most widely recognized marker horizons as defining the base of the Kimmeridge Clay Formation in the Central and Northern North Sea, as discussed below.

The first offshore use of the term Kimmeridge Clay Formation was by Rhys (1974) for the Southern North Sea, using well 47/1-1 as the ‘type’ section. No comprehensive definition was given, and the section is anomalous in showing a thin Kimmeridge Clay Formation resting directly on oolitic limestone (Corallian Formation). When Deegan & Scull (1977) applied the term to the Central and Northern North Sea, they defined the Kimmeridge Clay Formation as having a ‘very high gamma response and an anomalously low velocity’, and considered the boundary with the Heather Formation to be diachronous, ranging in age from Oxfordian to Kimmeridgian.

Although Deegan & Scull (1977) thus gave a clear definition of the Kimmeridge Clay / Heather boundary in terms of wireline-log response, many sections do not show the required clear differentiation into a high-gamma, low-velocity section and a low-gamma, high-velocity section. Indeed, it is inevitable that defining the boundary purely on wireline-log character and lithology would be open to uncertainty, since neither displays a consistent range of characters across the basin.

To effect a more widely applicable definition of the Heather/Kimmeridge formation boundary, it is, therefore, necessary to use criteria that lie outside the strict limits of lithostratigraphic practice. It is proposed that the base of the Kimmeridge Clay Formation be taken at the wireline-log marker that immediately underlies the S.cystallinum EDO biomarker. This boundary has been used by Partington et al. (1993) and Price et al. (1993). There are four reasons for favouring this marker over the others. (1) It commonly occurs at the base of the first sustained upward increase in gamma-ray values, though it occurs within a section of upward-decreasing velocity in the East Shetland Basin. (2) It is the marker most commonly selected as the base of the Kimmeridge Clay Formation in completion logs in several parts of the Central and Northern North Sea. (3) The associated S.cystallinum (dinoflagellate cyst) biomarker is one of the most widely and consistently recognized in the region. (4) It is more or less time equivalent (intra baylei,...
The Fulmar and Piper formations

The Piper Formation, as originally envisaged by Deegan & Scull (1977, p. 19), encompassed Late Jurassic shallow-marine sandstones in the Piper Field area. Reference was made to the possibility of extending the term to include the sandstones of the Claymore Field, but no formal name was proposed for Upper Jurassic sandstones in the Central Graben. The term ‘Fulmar Sands’ was introduced informally by Shell for sandstones in the Fulmar Field area (Johnson et al. 1986) and has since been used more widely for sandstones in the Central Graben. Sandstones of shallow-marine facies are now known to occur over much of the Central Graben area, extending northwards into the Fisher Bank Basin (Clark et al. 1993) and onto the southern flank of the Fladen Ground Spur (Fraser & Tonkin 1991). These sandstones are all included in the Fulmar Formation. Some sandstone sections have been given informal lithostratigraphic names on the assumption that they represent geographically or stratigraphically discrete sandstone developments. However, the geographic and stratigraphic separation may be more apparent than real, since the sandstones are known mainly from structural highs, with little information available on sections in the intervening areas. Furthermore, no clear lithological basis has yet been established for the lithostratigraphic subdivision of these sandstones.

Fulmar and Piper formations could therefore be regarded as belonging to the same formation, since they are separated only by a narrow zone in which the Upper Jurassic has not been penetrated. However, because of the established geographic restriction of the term Piper Formation to the Outer Moray Firth, an arbitrary division into two sandstone formations is maintained (see accompanying diagram).

References


Name. From the Humber estuary.

Constituent formations

BRAE FORMATION

EMERALD FORMATION

FULMAR FORMATION

HEATHER FORMATION

KIMMERIDGEE CLAY FORMATION

PIPER FORMATION

Age

Bathonian to late Ryazanian.
BRAE FORMATION

The term Brae Formation (Turner et al. 1987) is applied to a heterolithic coarse clastic unit within the Kimmeridge Clay Formation in the South Viking Graben. The formation was defined by Turner et al. (1987) to describe the generally coarse-grained clastic reservoir sediments, of probable Oxfordian to mid-Volgian age, that interfinger with mudstones of the Kimmeridge Clay Formation along the western faulted margin of the South Viking Graben. Commonly used informal synonyms include the 'Tiffany Conglomerate Member', 'East Thelma Member' and 'Upper Jurassic Sand Formation'.

Type section
16/7a-8 (Turner et al. 1987, p.855, fig.3): 3679.5-4271m TD (12071-14008ft TD) below KB.

Reference sections
9/9b-5: 3920-4153.5m (12861-13627ft)
16/7a-16: 3768-4139m (12362-13580ft)
16/8-1: 3859-4025m (12660-13198ft)

Name. From the Brae Field (Turner et al. 1987, p.856).

References
Lithology
The Brae Formation comprises dominantly greyish brown, medium to coarse grained sandstone and conglomerate interbedded with fine-grained sandstones, mudstones, and mud-matrix supported breccias. Six major facies identified by Turner et al. (1987) in the Brae Formation of the southern part of Block 16/7 (South Brae Field), as described below.

**Sand-matrix conglomerate facies.** This consists of a matrix of fine to coarse grained sandstone enclosing clasts of granule to boulder grade, up to 2m across, composed dominantly of Devonian? sandstone, but with common quartz pebbles. The clasts are generally of variable angularity, poorly sorted, and generally unorientated with respect to bedding. Bivalve, gastropod and echinoderm shell fragments are recorded locally, as are siliceous sponge spicules and woody debris.

**Mud-matrix breccia facies.** This consists of angular pebble to boulder grade clasts of quartz-feldspathic sandstone set in a variably sandy mudstone matrix.

**Medium to thick bedded sandstone facies.** This consists of very fine to very coarse grained sandstone, sometimes containing granules and small pebbles. The sandstones are commonly structureless but crude lamination, cross-bedding and both normal and inverse grading are recognised. Intraformational mudstone clasts and bioclastic material are present in places. Mudstones are interbedded with the sandstones and comprise up to 20 per cent of the facies.

**Alternating thin-bedded sandstones and interlaminated sandstone-mudstone facies.** This contains 50-80 per cent sandstone in laminae and thin beds, with mudstone making up the remainder. These have been informally termed 'tiger stripe' deposits.

**Interlaminated mudstone-sandstone facies.** Mudstone forms up to 80 per cent of this facies, with the sandstones occurring in sporadic, thin beds. *Laminated mudstone facies.* This consists largely of planar laminated, non-bioturbated, dark grey to black, micaceous and carbonaceous mudstones typical of the Kimmeridge Clay Formation in sand-free sections.

Comparative lithologies have been described by Cherry (1993) from Block 16/17.

**Upper boundary**
The top of the Brae Formation is usually defined by a downward change from mudstones with few interbedded sandstones (undifferentiated Kimmeridge Clay Formation) to sandstones or interbedded sandstones, conglomerates, and mudstones. It is marked by a downward decrease in gamma-ray values and increase in velocity.

In a few sections, particularly in the Beryl Embayment, the Brae Formation sandstones are directly overlain by limestones or low-gamma mudstones of the Cromer Knoll Group (e.g. 9/2b-5).

**Lower Boundary**
The base of the Brae Formation has been penetrated in only a few wells in the South Viking Graben, where the formation is in dominantly sandy rather than conglomeratic facies. Definition of the base is somewhat arbitrary, as there is a progressive downward decrease in the proportion of sandstone to mudstone. However, it is most consistently taken at a downward change from sandstones with minor mudstones to a more complex succession of interbedded sandstones and mudstones, marked by a downward change from a relatively consistent, low-gamma response to a more variable gamma-ray response. Sporadic, unnamed sandstones thus occur below this level.

**Lithostratigraphic subdivision**
It is possible to subdivide the Brae Formation both geographically, because of the physical separation of some fan lobes, and stratigraphically, using biostratigraphic data. However, such subdivisions are currently possible on a local basis only, and no formal members are proposed here.

**Distribution and thickness**
The Brae Formation is found along the western, fault-bounded margin of the South Viking Graben and along parts of the faulted margin of the East Shetland Basin. The formation wedges out eastwards within the basinal mudstones. The formation is not continuous along these fault-bounded margins, but is developed in relation to a number of point sources at the intersection of N-S and ENE-WSW trending faults, producing a complex series of partially overlapping sand systems. The Brae Formation attains a maximum thickness of about 760m adjacent to the basin margin faults but thins eastwards towards the axis of the graben.

**Regional correlation**
The Brae Formation sandstones and conglomerates pass laterally into mudstones of the Kimmeridge Clay Formation and possibly of the uppermost part of the Heather Formation.

**Genetic interpretation**
The Brae Formation was deposited by a variety of gravity-flow processes in overlapping, partly channelized, submarine-fan systems (Turner et al. 1987).

**Biostratigraphic characterization**
The *G.dimmerum, Muderongia* sp.A, *C.longicorn*, *E.luridum*, and *S.crystallinum* biomarkers are found within the Brae Formation.

**Age**
Kimmeridgian to mid-Volgian, but possibly ranging into the Oxfordian.

**References**


See also Correlation Panels 13, 14.
DISTRIBUTION MAP

BRAE FORMATION

LITHOLOGY
- Marl
- Marlstones / silstones
- Sandstone
- Siltstone
- Conglomerate
- Limestone

KEY BOUNDARIES
- Lower Kimmeridge Clay Formation
- Brae Formation
- Heather Formation

See also Correlation Panel 13
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**EMERALD FORMATION**

(new)

The term Emerald Formation describes a thin sandstone unit that locally overlies Lower Jurassic or older rocks in the Emerald Field area, East Shetland Basin.

The sandstones of the Emerald Formation have been described by Wheatley et al. (1987, p.988) and Stewart & Faulkner (1991, p.114). The former referred the sandstones to an informal 'Emerald Sandstone' unit. On some completion logs, however, the Emerald Formation has been assigned to the Brent Group.

**Type section**

2/10-8: 2706.5-2734m (8880-8970ft) below KB.

**Reference sections**

2/15-1: 1705-1725m (5593-5660ft)
3/1lb-3: 1672-1686.5m (5485-5533ft)

**Name.** From the Emerald Field (Wheatley et al. 1987).

**References**


Lithology
The Emerald Formation consists of very fine to medium grained sandstone and subordinate siltstone, often with a thin basal conglomerate. Bivalve shell and belemnite fragments are common, and carbonised wood and plant fragments are also recorded. Biosturbation has destroyed most sedimentary structures. Some beds are calcite cemented, and glauconite has been recorded. In many sections, the lower part of the formation is coarser grained and cleaner than the upper part (e.g. 3/11-3). In other sections, however, the formation displays log signatures indicative of upward coarsening (e.g. 2/10-8).

Upper boundary
The top of the Emerald Formation is defined by a downward change from grey mudstones and siltstones (Heather Formation) to sandstones. It is marked by a downward decrease in gamma-ray values and a downward increase in velocity.

Lower boundary
The Emerald Formation rests on a variety of strata, including Lower Jurassic sandstones, Devonian sandstones and siltstones, and Lower Palaeozoic or Precambrian metamorphics.

Over the northern part of the Transitional Shelf, where the Emerald Formation rests unconformably on Lower Jurassic sandstones, the base is defined by a basal-lag conglomerate (e.g. 2/10-8) and on logs by a distinct downward increase in velocity (e.g. 2/10-6—not illustrated).

In the southeastern part of the Emerald Field, where the Emerald Formation overlies Devonian sediments, the base is defined by a downward change from clean, brownish sandstones to red or varicoloured sandstones, siltstones or limestones. It is marked by a downward increase in gamma-ray values and a downward increase in velocity (e.g. 3/1 Ib-3).

Where the formation rests on the Lower Palaeozoic or Precambrian, the base is defined by a downward change from clean sandstone to gneiss, and is usually accompanied by a downward increase in gamma-ray values and a downward decrease in velocity (e.g. 2/15-1).

Distribution and thickness
The Emerald Formation occurs in the area of the Transitional Shelf, being particularly well developed around the Emerald Field. It ranges in thickness from about 10m to 30m, averaging about 15m thick in the Emerald Field.

Regional correlation
The Emerald Formation passes laterally into Heather Formation.

Genetic interpretation
The Emerald Formation is interpreted as a transgressive sand sheet, deposited under nearshore to offshore conditions (Wheatley et al. 1987; Stewart & Faulkner 1991). It was deposited during a later phase of the transgression that led to deposition of the Tarbert Formation sandstones over the rest of the East Shetland Basin.

Biostratigraphic characterization
The P.prolongata, C.hyalina and A.aldorfensis biomarkers are recorded from the Emerald Formation.

Age
Late Bathonian to early Oxfordian, but predominantly Callovian (Stewart & Faulkner 1991).

References

EMERALD FORMATION

LITHOLOGY
- Sandstone
- Mudstone
- Siltstone
- Breccia

DISTRIBUTION MAP

Key Formations
- CHALK GROUP
- KIMMERIDGE CLAY FORMATION
- HEATHER FORMATION
- EMERALD FORMATION
- DEVONIAN

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The term Fulmar Formation is introduced for all the Upper Jurassic shallow-marine sandstones in the UK Central Graben. The sandstones pass laterally into the Kimmeridge Clay and Heather formations in axial portions of the graben, and span the Callovian to Ryazanian. The term ‘Fulmar Sands’ has been used informally by Shell U.K. for sandstones in the Fulmar Field area (Johnson et al. 1986). The term is now extended to include Upper Jurassic sandstones throughout the Central Graben and thus includes the following informally named sandstones: ‘Puffin Formation’ (29/4, Price et al. 1993), ‘Hugin Formation equivalent’ and ‘Frigate Formation’ (Fisher Bank Basin, Clark et al. 1993), ‘Angus sands’ (31/21, Hall 1992), and ‘Duncan sands’ (30/24, Robson 1992).

The formation is also provisionally extended to include the late Kimmeridgian to Volgian shallow-marine ‘Glamis Sandstone’ of Fraser & Tonkin (1991). This unit is present on the southern tip of the Fladen Ground Spur (Block 16/21-8), and is separated from the main development of Fulmar Sands by a narrow zone in which the Upper Jurassic has not been penetrated.

**Type section**

30/16-6: 3147.5-3423m (10326-11230ft) below KB.

**Reference wells**

- 22/5b-2: 3386-3660m (11108-12008ft)
- 21/18-3: 3084-3148m (10119-10328ft)
- 21/30-3: 2580.5-2663m (8466-8738ft)

**Name.** From the Fulmar Field (Block 30/16, Johnson et al. 1986).

**References**


Lithology

The Fulmar Formation consists dominantly of olive-grey to pale grey, fine to medium grained, occasionally pebbly, generally argillaceous or carbonate-cementsed, glauconitic sandstones. In some sections, they are seen to be either massive with few structures or, in more distal sections, to be argillaceous and strongly bioturbated with a range of burrow types, including the distinctive forms Chondrites, Ophiomorpha and Thalassinoides. Soft-sediment deformation and water-escape structures also occur in the thicker sequences. Large-scale upward-coarsening or upward-fining successions are displayed in some sections. The sandstones are generally arkosic. Spicles of the siliceous sponge *Rhusella* are common and bioclastic debris locally abundant.

Upper boundary

The top of the Fulmar Formation is defined by a downward transition from mudstone (Heather or Kimmeridge Clay formations) to sandstone. It is marked by a downward decrease in gamma-ray values and an overall increase in velocity.

Lower boundary

In the area of the Fulmar Field, the Fulmar Formation rests on Triassic red-beds of mudstone or silty sandstone facies (e.g. 30-16-5). The boundary is marked by a pronounced downward increase in gamma-ray and velocity values. The lithological variability of the units underlying the Fulmar Formation sandstones in other areas precludes the definition of a ‘typical’ log response. In well 21/18-3 in the Kittiwake Field area, the boundary between the Fulmar Formation sandstones and underlying Triassic sandstones is difficult to place on log responses and colour change alone, and the boundary has been confirmed from core and petrographic data. In the Fisher Bank Basin (e.g. 22/25-2), the Fulmar Formation rests on coal-bearing paralic sediments of the Pentland Formation and the boundary is placed at a downward change from marine sandstones to paralic sediments, accompanied by a change to more serrated wireline-log responses. On the southern end of the Fladen Ground Spur (Glamis Field), the formation rests on Devonian strata (Fraser & Tonkin 1991).

Regional correlation

The Fulmar Formation includes equivalents of the Piper Formation of the Moray Firth, from which it is separated on arbitrary grounds (see p.5). In the Norwegian sector of the North Sea, on the eastern limb of the graben, the equivalent shallow-marine sandstone developments are assigned to the Ula Formation (Oxfordian to Ryazanian; Vollset & Dore 1984).

Genetic interpretation

Deposition of the sandstones occurred in a shallow-marine, low to moderately high energy, storm-influenced, nearshore to offshore marine setting. The thickened sandstone successions occur in the hinge-wall area of the graben-margin faults, sourced from erosion of the uplifted fault blocks. The distribution of sand may also have been influenced by subidence related to salt withdrawal (Johnson et al. 1993). The oldest Fulmar sandstones in the Central Graben locally include thin coals, indicating that they represent coastal plain as well as shallow-marine deposits (Donovan et al. 1993).

The sandstones of the Fulmar Formation represent a complex amalgamation of the products of several discrete progradational phases. The relative importance of eustatic sea-level change or local tectonism in causing these progradational phases is not yet established.

Biostratigraphic characterization

The Fulmar Formation yields variably poor to relatively rich palynofloras, and a poor microflora. All palynomorph biomarkers from the early Oxfordian *P.prolongata* biomarker to the mid-Volgian *Galinophora* biomarker have been reported from the Fulmar Formation succession in the Central Graben and Fisher Bank Basin areas. No details have been published on the biostratigraphy of the late Kimmeridgian to Volgian sandstones (*Glimas Sands*) of Block 16/21.

Age

Callovian to Volgian.

Donovan et al. (1993) recognized a ‘lower Fulmar member’ of Callovian to early Oxfordian age and an ‘upper Fulmar member’ of early Kimmeridgian age in the Central Graben. This indicates that correlations of the ‘Hugin Formation equivalent’ and the lower part of the ‘Frigate Formation’ of the Fisher Bank Basin are present as far south as Quadrant 29.

Distribution and thickness

The Fulmar Formation is present over much of the UK Central Graben. It is most thickly developed along the fault-bounded graben margins. The sandstones pass axially into mudstones of the Kimmeridge Clay and Heather formations and, on the limited evidence presently available, appear to be absent from the deepest, axial part of the graben.

The sandstones of the Fulmar Formation reach a maximum thickness about 366m (1200ft) in the Fulmar Field, on the fault-bounded western margin of the Central Graben (Stockbridge & Gray 1991). In general the formation is much thinner, reaching only 60m in the Fisher Bank Basin (Clark et al. 1993), 65m in the Kittiwake Field (Glenne & Armstrong 1991) and 110m in the Anglo Field (Hall 1992). The Fulmar Formation thins southwards from the Central Graben onto the Mid North Sea High.

References


HEATHER FORMATION

The term Heather Formation was introduced by Deegan & Scull (1977) for a unit of grey, silty mudstones lying between the coarse clastics of the Brent and Fladen groups and the more organic-rich marine mudstones of the Kimmeridge Clay Formation. Deegan & Scull (1977) recognized a two-fold division in the East Shetland Basin: an upper unit of dark grey, variably carbonaceous silty mudstone with limestone stringers and a lower unit of hard, pale to dark grey, micaceous, calcareous silty mudstone.

Following redefinition of the base of the Kimmeridge Clay Formation (see p.5), the top of the Heather Formation is here taken at a regional wireline-log marker of earliest Kimmeridgian age, with the Scrystalinium (FDO) biomarker usually occurring up to a few metres higher in the section. The range of lithologies within the Heather Formation is similar to that of Deegan & Scull (1977). Several additional, newly named sandstone members are, however, included within the formation.

The Heather Formation, as defined here, includes mudstones assigned by some authors to the Sgiath Formation or Piper Formation (Outer Moray Firth). These include the ‘Saltoe Member’ and part of the ‘Skene Member’ of Harker et al. (1993) and the ‘Paralic Unit’ and ‘Marine Shale Unit’ of Boldy & Brealey (1990). Mudstones previously referred to the Uppat Formation in the Inner Moray Firth (Andrews & Brown 1987) are also included within the Heather Formation, following Stevens (1991), as are mudstones referred to as the ‘Renee Mudstone’ by Andrews & Brown (1987, p.790). Many informal names have been used for these Inner Moray Firth mudstones on completion logs, including ‘Brora Argillaceous Formation’ (e.g. 12/27-1, Burmah), ‘Brora Arenaceous Formation’ (e.g. 12/27-2, Burmah) and ‘Balintore Formation’ (e.g. 12/28-2, Tenneco).

Type section
211/21-1A (Deegan & Scull 1977, p.18, fig.21): 2769-2840m (9083-9317ft) below KB (revised depths). Illustrated in Correlation Panel 12.

Reference sections
3/1-2: 3535-3717m (11598-12194ft)
9/10c-2: 4201-1533m (13783-14872ft)
11/30-2: 1638.5-1929.5m (5375-6330ft)
30/8-1: 3990-1542.5m (13090-14994ft)

Formal subdivisions
Alness Spiculite Member p.23
Bruce Sandstone Member p.25
Freshney Sandstone Member p.27
Gorse Member (new) p.29
Ling Sandstone Member p.31

References


The Heather Formation is composed dominantly of medium to dark grey to brown, marine mudstones and siltstones with sporadic thin stringers or concretions of pale grey-brown limestone or dolomitic limestone. The mudstones are commonly poorly fissile, soft to firm, and, because of the presence of calcareous microfossils, slightly to moderately calcareous. Locally, they are pyritic and carbonaceous. In the East Shetland Basin, the lower part of the formation is generally composed of hard, micaceous, calcareous silt mudstones, while the upper part is more carbonaceous and has more limestone stringers. The limestones are generally microcrystalline and hard, producing low-gamma/high-velocity spikes.

Thin sandstone stringers are locally interbedded with the Heather Formation mudstones. They are typically friable, fine-grained, and quartzose, locally with glauconite and mica. The thicker intra-formational sandstones, constituting the Bruce, Freshney and Ling sandstone members, are generally very fine to fine grained, but locally medium to coarse grained, poorly to well sorted, sometimes micaceous, and occasionally calcite cemented.

**Upper boundary**

The Heather Formation is generally overlain by mudstones of the Kimmeridgian Clay Formation. The boundary between the two formations is difficult to define on lithological grounds alone (see discussion on p.5), and is taken at a relatively sharp downward decrease in gamma-ray values, sometimes associated with a decrease in resistivity and increase in velocity. However, the thicker, basinal sections commonly display several lithological and wireline-log markers that could be confused with the formation boundary (e.g. 16/3a-3, Panel 14; 30/6-3, 30/8-1, Panel 16). The precise nature of the wireline-log changes across the boundary varies from region to region, reflecting differing facies and differing degrees of stratigraphic condensation in the lower part of the Kimmeridgian Clay Formation. The boundary is commonly associated with a general downward lightening in colour of the mudstones, a decrease in organic content, and an increase in the proportion of thin limestone beds.

In some sections the Heather Formation is overlain by sandstones (Bruce, Fulmar and Piper formations).

**Lower boundary**

The precise nature of the lower boundary of the Heather Formation differs according to which formation underlies it. It is, however, normally marked by a downward transition from mudstones or siltstones to sandstones or interbedded sandstones, siltstones and coals. It is marked by a downward decrease in both gamma-ray values and velocity.

In the East Shetland Basin, Eribey Embayment and South Viking Graben, the Heather Formation generally overlies the Tarbert or Hugin Formation, respectively. Locally, however, the Heather Formation rests on older formations.

In the Outer Moray Firth and Central Graben, the Heather Formation commonly lies unconformably on the Pentland Formation. In such cases the lower boundary is generally marked by the passage from mudstones to thinly interbedded sandstones, mudstones and coals (Stroma Member), and is marked by a sharp downward decrease in gamma-ray values and increase in velocity. Where these coal-bearing sediments are absent, the Heather Formation unconformably overlies reddish and grey-brown mudstones of the Triassic Smith Bank Formation.

In the Inner Moray Firth, the Heather Formation rests on sandstones of the Beatrice Formation (e.g. 11/30-2).

**Lithostratigraphic subdivision**

Deegan & Scull (1977) recognized two informal mudstone/siltstone units within the Heather Formation in the East Shetland Basin: an upper unit characterized by dark grey, carbonaceous mudstone and a lower unit characterized by pale to dark grey, micaceous, calcareous silty mudstone. Sections elsewhere in the basin do not, however, show such a clear lithological division, and no formal nomenclature is proposed for these units.

Wireline-log signatures provide a more consistent means of subdividing the Heather Formation, with a particularly distinctive signature occurring in association with the mid-Oxfordian *R.aemula* (FDO) biomarker (e.g. 11/30-2, c.1830m). This signature is traceable in many basinal successions (e.g. Panel 12) and may be used to separate, informally, upper and lower Heather units. Further subdivisions can be recognized within each unit on the basis of biostratigraphy (e.g. *Kryostephanites* acme and *R.aemula* acme biomarkers), coupled with wireline-log markers of varying prominence. These divisions of the Heather Formation mudstones are not given formal status here. However, formal status is given to the thin, but distinctive, paralic mudstone (Gorse Member) occurring at the base of the Heather Formation in parts of the Outer Moray Firth.

Three other sandstone-dominated units have here been accorded member status within the Heather Formation. These are the Bruce Sandstone, Freshney Sandstone and Ling Sandstone members. Thin, impermanent, sandstones occurring elsewhere within the Heather Formation are not formally named. A unit of sandy siltstone occurring in the Inner Moray Firth is also given formal status as the Alnash Spiculite Member.

**Distribution and thickness**

The Heather Formation is widely distributed across the East Shetland Basin, Viking Graben and Central North Sea, but is absent over some intra-basinal highs as a result of erosion. In all areas, the distribution of the formation is more or less controlled by the main basin-margin bounding faults.

The Heather Formation attains a maximum drilled thickness of about 350m in the East Shetland Basin, about 600m in the South Viking Graben and about 700m in the Central North Sea.

**Regional correlation**

In the Northern North Sea, the Heather Formation mudstones probably pass laterally into the sandstone-dominated units of the Hugin and Tarbert formations. In parts of the Central North Sea, they pass laterally into the sandstones constituting the lower part of the Fulmar and Piper formations.

**Genetic interpretation**

With the exception of the Gorse Member, the Heather Formation was deposited in fully marine environments, in which bottom waters were generally aerobic. Although much of the formation appears to have been deposited on the shelf, it locally includes sandstones of mass-flow origin, indicating a slope or basin setting. Basinal mudstones in the South Viking Graben display relatively high gamma-ray values, indicating the occurrence of dysaerobic bottom waters in that region.

In the Central North Sea, the Heather Formation mudstones pass laterally into extensive shelf sandstones. The thin and areally restricted sandstones that occur in basinal sections represent redistribution of the shelf sands by mass-flow processes.

**Biostratigraphic characterization**

The formation yields diverse marine microplankton, and includes the *Kryostephanites* acme, *C.polonicum, R.aemula, R.aemula* acme, *Wamaea* spp., *P.prolongata*, and *C.hyalina* biomarkers. Agglutinating foraminifera dominate the microfauna, with calcareous benthonic species forming a small proportion of the population. The *Locypta* biomarker has been reported from near the top of the formation.

**Age**

Bathonian to latest Oxfordian.

**References**


See also Correlation Panels 11-16, 18, 20.
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**Alness Spiculite Member (new)**

The term Alness Spiculite Member is introduced for sandy spiculite and spiculitic sandstones that occur within the lower part of the Heather Formation in the Inner Moray Firth area. The term 'Alness Member' was first used in an unpublished report by the Robertson Group (1985) (now Simon Robertson Ltd). Andrews & Brown (1987) referred the sandstones to the Alness Spiculite Formation, but the unit is given member status here.

**Type section**

11/25-1: 2751.5-2811 m (9027-9223 ft) below KB.

**Reference section**

12/22-2: 1281.5-1324.5 m (4205-345 ft).

**Name.** From the town of Alness on the Cromarty Firth, Scotland.

**Lithology**

The Alness Spiculite Member consists of sandy spiculite, grading to spiculitic sandstone. The spicules are largely ovoidal spicules, being derived from the siliceous sponge *Rhaxella*. The spicules are of very fine to fine sand grade, and associated with subordinate detrital sand grains. In the type well, wavy horizontal laminae are preserved at the base of the formation, but the sandstone is generally characterized by intense bioturbation. Bivalves, belemnites and an ammonite have been recorded from the type section. The member generally displays an overall upward coarsening from sandy spiculite to spiculitic sandstone. The spicules are largely ovoidal spicules, being derived from the siliceous sponge *Rhaxella*. The spicules are of very fine to fine sand grade, and associated with subordinate detrital sand grains. In the type well, wavy horizontal laminae are preserved at the base of the formation, but the sandstone is generally characterized by intense bioturbation. Bivalves, belemnites and an ammonite have been recorded from the type section.

The member generally displays an overall upward coarsening from sandy spiculite to spiculitic sandstone. Two large-scale upward-coarsening cycles can be recognized in many sections. An upward-coarsening unit grading from sandy spiculite to spiculitic siltstone is commonly present at the top of the member (e.g. 11/25-1).

**Upper boundary**

The top of the Alness Spiculite Member is defined in some sections (e.g. 12/22-2), by an abrupt downward change from Heather Formation mudstones to spiculites, marked by a sharp decrease in gamma-ray values and decrease in velocity. In other sections, the boundary is more transitional (e.g. 11/25-1).

**Lower boundary**

The base of the Alness Spiculite Member is defined by a downward change from spiculites to undifferentiated Heather Formation mudstones. The boundary is transitional, falling within an overall upward-coarsening succession. It is marked on wireline logs by an inflection on the gamma-ray and sonic logs.

**Lithostratigraphic subdivision**

A thin mudstone unit is commonly present within the Alness Spiculite Member (e.g. 11/25-1), and can be used to define upper and lower units within the member (see Stephen et al. 1993, fig.3). In sections where a true mudstone is not developed, a higher gamma, presumably argillaceous section, probably marks the same two-fold subdivision (e.g. 12/22-2).

**Distribution and thickness**

The Alness Spiculite Member is most thickly developed in the centre and north of the Inner Moray Firth. In the Beatrice Field (e.g. 11/30-2, Panel 18) and in the extreme south of Quadrant 12, the spiculites are absent through lateral passage into spiculitic siltstones and mudstones. A maximum thickness of 90m is encountered in well 12/21-3.

**Regional correlation**

The Alness Spiculite Member correlates with the Brora Sandstone and Ardassie Limestone onshore (Stephen et al. 1993).

**Genetic interpretation**

The spiculite accumulated as an extensive subtidal shoal (Andrews & Brown 1987). The upper and lower spiculite units represent separate progradational phases, with the intervening mudstone unit representing a flooding surface (Stephen et al. 1993, fig.3).

**Biostratigraphic characterization**

The Alness Spiculite Member yields abundant palynotostras including the dinoflagellate cyst *Riguidella aemula*. Calcareous benthonic foraminifera dominate the microfauna.

**Age**

Mid Oxfordian (Stephen et al. 1993, fig.3).

**References**


See also Correlation Panel 18.
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The term Bruce Sandstone Member is introduced for sandstones that lie within the mudstone-dominated succession of the Heather Formation of the Beryl Embayment area. It has been informally named by Mobil in many well sections from the Beryl Embayment, and subdivided into a lower 'Nevis Member' (Callovian) and an upper 'Katrine Member' (Oxfordian). These terms are not formally adopted here.

**Type section**
9/12a-5: 2805.5-2915m (9202-9562ft) below KB.

**Reference section**
9/13a-34: 3322.5-3392.5 (10900-11130ft)

**Name.** From the Bruce Field, in Block 9/8.

**Lithology**
The Bruce Sandstone Member is characterized by white to brown, generally very fine to fine, occasionally medium to coarse grained sandstones. They are poorly to well sorted, sometimes micaceous and locally calcite cemented. The formation includes both massive sandstones, several tens of metres thick (e.g. 9/12a-5), and thinly bedded sandstones alternating with mudstones (e.g. 9/13a-4).

**Upper boundary**
The top of the Bruce Sandstone Member is marked by a downward change from Heather Formation mudstones to sandstones. It is marked by a downward decrease in gamma-ray values and, in many wells (e.g. 9/12a-5), by an increase in velocity.

**Lower boundary**
The base of the Bruce Sandstone Member is marked by a sharp or transitional downward change from sandstones to mudstones. It is marked by a downward increase in gamma-ray values but often lacks a distinctive velocity signature.

**Lithostratigraphic subdivision**
The Bruce Sandstone Member is informally divided on many completion logs into an upper Katrine unit (Oxfordian) and a lower Nevis unit (Callovian) age, with a mudstone separating the two in places.

**Distribution and thickness**
The Bruce Sandstone Member occurs interbedded with Heather Formation mudstones in various places along the western, faulted margin of the Beryl Embayment, and is also recorded on the eastern sides of some intra-basinal faults. It is always bounded to the west by the footwall of a fault block/platform area, and to the east by a depositional pinch-out. The sandstones occur at various stratigraphic levels within the Heather Formation, and display complex interdigitation with the mudstones. The maximum thickness of these composite sandstone successions (including the relatively thin intervening mudstones) is about 95m.

**Genetic interpretation**
The sandstones of the Bruce Sandstone Member are considered to have been deposited as turbidites in a relatively deep marine basin.

**Biostratigraphic characterization**
The Bruce Sandstone Member yields relatively abundant palynofloras, with the *P.prolongata* and *Wanaea* spp. biomarkers often identifiable in the upper part of the member.

**Age**
Callovian to Oxfordian.
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Freshney Sandstone Member (new)

The term Freshney Sandstone Member is introduced for a thin deep-water sandstone unit that lies within Heather Formation mudstones in block 30/6, southern Central Graben. It equates with the 'Jacqui Sandstone' in Phillips Petroleum completion reports.

Type section
30/6-3: 4773–4833.5 m (15660–15858 ft) below KB.
Remarks: this is the only released well to penetrate the Freshney Sandstone Member.

Lithology
The Freshney Sandstone Member comprises moderately thick beds of fine to medium grained, poorly to moderately cemented sandstones, separated by dark grey-brown, carbonaceous mudstone units. The sandstones pass laterally into mudstones.

Upper boundary
The top of the Freshney Sandstone Member is defined by a downward change from Heather Formation mudstones to sandstones, marked by a sharp decrease in gamma-ray values and a slight increase in velocity.

Lower boundary
The base of the Freshney Sandstone Member is defined by a sharp downward change from sandstones to Heather Formation mudstones, marked by a downward increase in gamma-ray values and a slight decrease in velocity.

Distribution and thickness
The Freshney Sandstone Member is at present known from only a few wells in a limited area of the UK Central Graben. Thin, unnamed, sandstones are known to occur at a comparable stratigraphic level in adjacent areas. The formation is 60.5 m thick in well 30/6-3.

Regional correlation
The Freshney Sandstone Member passes laterally into mudstone facies. Its age relationships with other sandstone units in the Central Graben area are poorly understood.

Genetic interpretation
The Freshney Sandstone Member was probably deposited in a deep-water marine setting.

Biostratigraphic characterization
No age-diagnostic taxa have been recorded.

Age
?Late Oxfordian.

See also Correlation Panel 16.
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Gorse Member (new)

The term Gorse Member is introduced for a unit of paralic of the Skene Member (Sgatha Formation) as originally overlies coal-bearing sandstones of the Stroma Member Formation in parts of the Outer Moray Firth area. It overlies coal-bearing sandstones of the Stroma Member Formation in parts of the Outer Moray Firth area. It is usually a few metres to tens of metres thick, attaining a maximum thickness of about 60m.

Regional correlation

The absence of the Gorse Member in many Stroma/Heather/Piper sections has been interpreted as reflecting lateral passage into the coal-bearing sediments of the Stroma Member (Harker et al. 1993). Alternatively, it may reflect condensation or reworking.

Genetic interpretation

The Gorse Member is characterized by a dominance of terrestrial palynomorphs, and is interpreted as a paralic deposit (O’Driscoll et al. 1990; Harker et al. 1993).

Biostratigraphic characterization

The Gorse Member yields palynofloras dominated by pteridophyte spores. Agglutinating foraminifera are also common (Harker et al. 1993).

Age

Probably mid Oxfordian.

References


Distribution and thickness

The Gorse Member has been identified in several isolated areas within the Witch Ground Graben and in the South Halibut Basin. It is usually a few metres to tens of metres thick, attaining a maximum thickness of about 60m.

Type section

20/8-1: 2764-2783.5m (9068-9132ft) below KB.

Reference section

15/21-4: 2556.5-2569.5m (8387-8430ft)

Name

From the moorland shrub.

Lithology

The Gorse Member consists of brownish black mudstones, in which coaly fragments are locally abundant. It is characterized by high resistivity values coupled with low velocity.

Upper boundary

The top of the Gorse Member is defined by a downward change from grey to brownish black mudstones. It is marked by a downward increase in resistivity and decrease in velocity, and often by a temporary downward increase in gamma-ray values.

Lower boundary

The Gorse Member commonly lies conformably on the Stroma Member or unconformably on older units of the Pentland Formation. In either case, its base is generally marked by a downward passage from mudstones to thinly interbedded sandstones, mudstones and coals. It is marked by a sharp downward decrease in gamma-ray and velocity-log responses. Elsewhere, where the coal-bearing sediments are absent, the Gorse Member unconformably overlies reddish and grey-brown mudstones of the Smith Bank Formation (Triassic).
Ling Sandstone Member (new)

The term Ling Sandstone Member describes a thin unit of sandstones within the Heather Formation of the South Viking Graben. The name is formalized from the usage of Cockings et al. (1992).

Type section
16/8a-4 (Cockings et al. 1992): 4757.488 lm (15607-16014ft) below KB.

Name. From the moorland plant (Cockings et al. 1992).

Lithology
The Ling Sandstone Member is characterized by medium to coarse grained (rarely fine-grained) sandstones. Individual beds are usually between 1 and 10m thick. Mudstone rip-up clasts, water-escape features and gravel lags have been described (Cockings et al. 1992). The sandstones are interbedded with relatively thin units of dark grey to black mudstone.

Upper boundary
The top of the Ling Sandstone Member is defined by a downward transition from mudstone (Heather Formation) to sandstone. It is marked by a downward decrease in gamma-ray values and often by an increase in velocity.

Lower boundary
The base of the Ling Sandstone Member is defined by a downward change from sandstone to mudstone. It is marked by a sharp increase in gamma-ray values and often by a decrease in velocity.

Distribution and thickness
The Ling Sandstone Member is thickest adjacent to the graben-bounding fault in Block 16/8, and probably has a depositional pinchout to the east, north and south. The member has a drilled thickness of 124m in the type well and probably thins eastwards.

Genetic interpretation
The sandstones of the Ling Sandstone Member were probably deposited as turbidites in a slope or basin environment.

Biostratigraphic characterization
The P.prolongata biomarker occurs at, or immediately above, the top of the Ling Sandstone Member.

Age
Probably of mid to late Callovian age.

References

See also Correlation Panels 13, 14.
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The term Kimmeridge Clay has for long been used for an onshore succession of organic-rich marine mudstones of Kimmeridgian (sensu anglico) age, the type section being in Kimmeridge Bay, Dorset. Rhys (1974) subsequently applied the term Kimmeridge Clay Formation to comparable sediments of late Jurassic age in the Southern North Sea. Deegan & Scull (1977) extended formal usage of the name into the Central and Northern North Sea, following the informal use of the term there by Bowen (1975). The term is now widely applied in the UK sector of the North Sea, although the formation as defined offshore clearly includes sediments of mid-Volgian to late Ryzanian age, which onshore are excluded from the Kimmeridge Clay.

The base of the Kimmeridge Clay Formation in the Central and Northern North Sea is here redefined (see p.5). It is taken at a regional wireline-log marker of earliest Kimmeridgian age. The S. crystallinum (FDO) biomarker usually occurs a few metres above the base of the formation in Central North Sea sections. The 'Lower Kimmeridge Clay' of Turner et al. (1987) and Riley et al. (1989) is included within the Heather Formation. The range of lithologies within the Kimmeridge Clay Formation here defined is similar to that described by Deegan & Scull (1977).

Several sandstone members are now formally recognized within the offshore Kimmeridge Clay Formation, using, in some cases, existing informal names. The 'Magnus Sandstone Member' was introduced by De'Atth & Schuylerman (1981) for sandstones in the East Shetland Basin. The term 'Burns Member' has been used in completion reports for a heterolithic sandstone-dominated succession in the Inner and Outer Moray Firth areas. However, the same sediments have been referred in publications to the 'Helsdale Member' or the 'Ettrick Sands' (including subdivisions, such as upper, middle and lower, etc). The terms 'Helsdale Boulder Beds', 'Claymore Sandstone Member' and 'Cromarty Sand Member' have also been used. The Claymore Sandstone Member was defined by Turner et al. (1984) for sandstones elsewhere referred to as the 'Main Claymore Member', 'Low Gamma Sands', 'High Gamma Sands' and 'Galley Sands'. The Ribble Sandstone Member is equivalent to the 'Ribble reservoir unit' defined by Johnson et al. (1986) in the Fulmar Field area.

Several attempts have been made to subdivide the mudstones of the Kimmeridge Clay Formation on the basis of gamma-ray logs. Bowen (1975) recognized a 'non-radioactive' and a 'radioactive' unit within the Kimmeridge Clay Formation. Andrews & Brown (1987) recognized a 'lower hot shale unit' an 'upper warm shale unit' and a 'lower warm shale unit'. Their 'lower warm shale unit' equates with the Heather Formation as defined here. Turner et al. (1987) recognized a 'lower Kimmeridge Clay Formation', which includes strata assigned in this study to the upper part of the Heather Formation, overlain by Brae Formation sandstones and an 'upper Kimmeridge Clay Formation' adjacent to and above the sandstones. Mather & Harker (1987) recognized a 'mid-Volgian Kimmeridge Clay Formation Silt Unit', lying above the 'Claymore sandstones' and capped by a higher gamma-ray interval that they termed the 'late Volgian Kimmeridge Shale Unit'. Price et al. (1993) divided the Humber Group mudstones into nine named biostratigraphic units, using a combination of biostratigraphic and biostratigraphic parameters. Seven of these fall within the Kimmeridge Clay Formation as defined here.

### Type section

Kimmeridge Bay, Dorset, is regarded as the type section for the Kimmeridge Clay Formation, although no comprehensive formal definition has been published.

### Reference sections

The Kimmeridge Clay Formation consists dominantly of dark grey brown to black, non-calcareous or slightly-calcareous, partly fossiliferous, moderately to highly organic-rich mudstones. Thin laminae and streaks of grey siltstone and sandstone occur locally. Belemnites and ammonites are recorded from cores. Sandstones and conglomerates are interbedded at various levels within the mudstones, and locally constitute the entire vertical succession (see descriptions of individual members for details). Thin sandstones (unnamed) occur locally (e.g. 3/30-2, not illustrated). These are generally very fine grained, with sharp bases and cross-lamination displayed in some cases.

**Upper boundary**
The top of the Kimmeridge Clay Formation is defined by a downward change from marls, calcareous mudstones, sandstones or limestones (Cromer Knoll Group) to grey mudstones. It is marked by a downward increase in gamma-ray values and decrease in velocity. In restricted areas of the Central North Sea, the boundary occurs within a continuous sandstone succession. In such sections, the boundary is difficult to define, but can usually be drawn at a downward change from relatively thickly bedded and/or calcareous sandstones to relatively thinly bedded sandstones.

**Lithology**

The Kimmeridge Clay Formation overlies Heather Formation mudstones in most basins but occurs above Piper Formation or Fulmar Formation sandstones in parts of the Central North Sea. The formation may also rest unconformably on older strata over the crests of some eroded and tilted fault blocks. Where the formation overlies mudstones of the Heather Formation, the base is difficult to define on lithological grounds alone (see discussion on p.5). It is here taken at a relatively sharp downward decrease in gamma-ray values, sometimes associated with an increase in velocity. A decrease in resistivity also occurs at this level in some sections. However, the thicker, basinal sections commonly display several lithological and wireline-log markers that could be confused with the formation boundary (e.g. Panels 12 and 16). The precise nature of the wireline-log changes across the boundary varies from region to region, principally reflecting differing degrees of stratigraphic condensation in the lower part of the Kimmeridge Clay Formation. The boundary is commonly associated with a general downward lightening in colour of the mudstones, a decrease in organic content, and an increase in the proportion of thin limestone beds.

Where Kimmeridge Clay Formation mudstones overlie Piper Formation or Fulmar Formation sandstones, the lower boundary is clearly identified at the downward change from organic-rich mudstone to sandstone, accompanied by a decrease in gamma-ray values and increase in velocity.

Several subdivisions of the Kimmeridge Clay Formation are possible in most successions, based on a combination of wireline-log and biostratigraphic data. Price et al. (1993) defined seven such units within the Kimmeridge Clay Formation (as defined here). However, currently available biostratigraphic data are insufficient to determine whether these units are consistently traceable throughout the Central and Northern North Sea. The most consistent wireline-log marker is provided by an upward increase in gamma-ray values, marking a transition into 'hot shales' (see Panel 12).

Seven, formally defined, coarse clastic units are recognized: the Birch Sandstone Member, Burns Sandstone Member, Claymore Sandstone Member, Dirk Sandstone Member, Magnus Sandstone Member, Przamian Sandstone Member and the Ribble Sandstone Member.

**Distribution and thickness**
The Kimmeridge Clay Formation is widely distributed in the UK North Sea Basin. It attains maximum thicknesses of over 350 m in the East Shetland Basin, over 1100 m in the South Viking Graben, about 1400 m in the Moray Firth and about 300 m in the Central North Sea. The formation generally thickens markedly towards the fault bounded margins of the basins and thins over the crests of intra-basinal fault blocks.

**Regional correlation**
The Kimmeridge Clay Formation is the direct equivalent of the Draupne Formation in the Norwegian sector of the North Sea and of the Mandal and Farsund formations in the Central North Sea (Vollset & Doré 1984). Jensen et al. (1986) suggested usage of the term Farsund Formation in the Danish sector also.

**Genetic interpretation**
The Kimmeridge Clay Formation mudstones represent marine hemipelagic deposition in an environment where bottom waters were generally anoxic, favouring the preservation of organic material (Miller 1990). The interbedded sandstones and conglomerates reflect the erosion of adjacent areas, especially during lowstand phases. They were probably deposited as submarine fans by gravity-flow processes.

The upper boundary of the Kimmeridge Clay Formation is generally regarded as representing an unconformity (the so-called Late Cimmerian Unconformity) in many wells. Curiously, Rawson & Riley (1982) suggested that there is often no unconformity at this level. They considered that the facies change across the boundary reflects disruption of the stratified anoxic bottom waters during the a sea-level rise in late Ryazanian times. However, they identified hiatuses at the boundary in wells at the crests of tilted fault blocks, and suggested that these may represent an amalgamation of a succession of minor discontinuities within the thicker, off-structure, successions.

**Biostratigraphic characterization**
The Kimmeridge Clay Formation yields an abundant, well-preserved and diverse palynoflora: the R.batula, E.expiratum, G.dimorphum, Muderongia sp.A, C.longicorne, and Eluridium biomarkers are all represented, with the S.crystallinum biomarker occurring close to the base of the formation. The microfauna is largely restricted to agglutinated species of foraminifera and include the H.eumai, T.etithaca, T.precisa and A.deceptus biomarkers.

**Age**

Kimmeridgian to late Ryazanian.

**References**


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The term Birch Sandstone Member is introduced for a thin unit of deep-water sandstones that occurs within the mudstones of the Kimmeridge Clay Formation in the South Viking Graben area.

Type section
16/12-8: 3954-4017m (12972-13180ft) below KB.

Reference section
16/12a-4: 4215.5-4286.5m (13830-14064ft)

Name. From the tree.

Lithology
The Birch Sandstone Member comprises fine to medium grained, moderately to well sorted sandstones. Beds of mudstone are sporadically intercalated with the sandstones, attaining a thickness of several metres.

Upper boundary
The top of the Birch Sandstone Member lies immediately beneath mudstones or marls of the Comer Knoll Group. In the type and reference wells, the uppermost sandstone unit is overlain by a very thin bed of Kimmeridge Clay mudstone, which is here included within the Birch Sandstone Member. In sections with a thicker bed of mudstone at the top, the upper boundary of the member should be taken at the top of the uppermost sandstone.

The wireline-log expression of the boundary varies according to the thickness of the mudstone unit above the sandstone.

Lower boundary
The base of the Birch Sandstone Member is defined by a downward transition from sandstones to organic-rich mudstones (undifferentiated Kimmeridge Clay Formation), marked by a sharp increase in gamma-ray values and decrease in velocity.

Distribution and thickness
The Birch Sandstone Member is largely restricted to a small part of block 16/12, but thin sandstone beds at the same stratigraphic level may occur in adjacent blocks.

The thickness of the Birch Sandstone Member is highly variable, attaining a maximum thickness of about 55m.

Genetic interpretation
The Birch Sandstone Member was probably deposited by gravity-flow processes in an anoxic, relatively deep water marine setting.

Biostratigraphic characterization
No data are available for these sandstones.

Age
Ryazanian.
Burns Sandstone Member
(new)

The term Burns Sandstone Member is introduced for a thick, sandstone unit within the Kimmeridge Clay Formation. The sandstones have been assigned several informal names on company completion logs. For example, in the type well (12/24-2), Occidental applied the term 'Helmsdale Boulder Beds equivalent', whereas Britoil included sandstones here assigned to the Burns Sandstone Member in their informal 'Lower Hot Shale', 'Siltstone', 'Ettrick Sandstone' and 'Upper Hot Shale' members of the Kimmeridge Clay Formation (e.g. 20/2-5). In the Kimmeridge Clay Formation of the Beatrice Field (Block 11/30), Stevens (1991) recognized an informal 'Cromarty Sand Member' of Ryazanian age, but left associated Volgian sandstones unnamed.

Type section
12/24-2: 1538-2882m (5046-9456ft) below KB.

Reference sections
12/23-2: 957.5-1382.5m (3142-4535ft)
20/2-2: 3191.5-3263m (10470-10706ft)
20/2-5: 2927-3285.5m (9603-10779ft)

Name. After Robert Burns, the 18th century Scottish lyric poet and songwriter.

References
The Burns Sandstone Member consists of sandstones interbedded with siltstones and mudstones. The sandstones occur as beds up to a few metres in thickness or in composite units that locally exceed more than 80m in thickness. They are predominantly very fine to medium grained, but coarse to very coarse grained locally. They are variably cemented with carbonate and are poorly to moderately sorted. The interbedded grey and brown to black mudstones and siltstones are typical of the Kimmeridge Clay Formation.

**Lithology**

The Burns Sandstone Member is overlain by the Kimmeridge Clay Formation, the top is defined by a downward decrease from mudstones to sandstones, or interbedded sandstones and mudstones. It is marked by a downward decrease in gamma-ray values and increase in velocity. Thin sandstones may occur within the Kimmeridge Clay Formation above this log break but are not included in the Burns Sandstone Member. Locally, the Burns Sandstone Member is overlain by sandstones of the Cromer Knoll Group (e.g. 20/2-5), in which case its top can be difficult to recognize without recourse to detailed biostratigraphy. However, in some sections, the boundary is marked by a change from thickly bedded sandstones to thinly bedded sandstones interbedded with mudstones (e.g. 20/2-5). Also, mudstones associated with the Cromer Knoll Group sandstones are generally more calcareous than those associated with the Burns Sandstone Member, with correspondingly lower gamma-ray values and higher velocities.

**Upper boundary**

Where the Burns Sandstone Member is overlain by the Kimmeridge Clay Formation, the top is defined by a downward transition from sandstones to mudstones or interbedded sandstones and mudstones. It is marked by a decrease in gamma-ray values and an increase in velocity. Thin sandstones may occur within the Kimmeridge Clay Formation above this log break but are not included in the Burns Sandstone Member. Locally, the Burns Sandstone Member is overlain by sandstones of the Cromer Knoll Group (e.g. 20/2-5), in which case its top can be difficult to recognize without recourse to detailed biostratigraphy. However, in some sections, the boundary is marked by a change from thickly bedded sandstones to thinly bedded sandstones interbedded with mudstones (e.g. 20/2-5). Also, mudstones associated with the Cromer Knoll Group sandstones are generally more calcareous than those associated with the Burns Sandstone Member, with correspondingly lower gamma-ray values and higher velocities.

**Distribution and thickness**

The Burns Sandstone Member is widely distributed throughout the Inner Moray Firth, extending eastwards onto the Halibut Shelf and into the northwestern part of the South Halibut Basin. Its distribution is related to major faults that were active during its deposition (e.g. the Smith Bank, Wick and Helmsdale faults).

The Burns Sandstone Member shows rapid thickness variations, with marked thickening towards major synsedimentary faults. It is over 1300m thick in well 12/24-2, with thicker successions probably developed immediately adjacent to the hanging walls of major synsedimentary faults.

**Regional correlation**

The Burns Sandstone Member passes laterally into the Kimmeridge Clay Formation. In the Inner Moray Firth it occupies much of the formation, whereas in the Outer Moray Firth it is restricted to the middle and upper parts. Onshore equivalents crop out along the Sutherland coast, and include the Allt na Cuille Sandstones, Loth River Shales and Helmsdale Boulder Beds of basal cymodoce Zone to albani or goweri Zone age (Lam & Porter 1977; Riley 1980; Wignall & Pickering 1993).

**Genetic interpretation**

According to Brown (1990), lateral changes in Upper Jurassic sedimentary facies and thickness in the Inner Moray Firth may largely be related to the variation in the supply of coarse clastics into the marine basin from active fault scarps.

On the basis of seismic data, Underhill (1991) interpreted Upper Jurassic sediments in the Moray Firth Basin as submarine-fan deposits. Linsley et al. (1980) considered the thin sandstones in the Kimmeridge Clay Formation of the Beatrice Field (Block 11/30) as deep-water deposits that accumulated in a distal channel and fan environment.

**Biostratigraphic characterization**

The Burns Sandstone Member yields relatively abundant palynomorph associations and includes the E.hirundum, C.longicorn, Muderongia sp. acme, G.dimorphum, E.expiratum and R.thula biomarkers.

**Age**

Kimmeridgean to late Ryazanian.

**References**


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Claymore Sandstone Member

The term Claymore Sandstone Member is applied to all significant occurrences of Kimmeridian to Middle Volgian mass-flow sandstones within the Kimmeridge Clay Formation of the Witch Ground Graben.

Based on the limited amount of data available at the time, Deegan & Scull (1977) suggested that the Upper Jurassic marine sandstones of the Claymore Field could probably be included within the Piper Formation. However, Turner et al. (1984) referred sandstones and interbedded mudstones of Kimmeridian to mid-Volgian age in the north western Witch Ground Graben to a formally defined Claymore Sandstone Member, and proposed UK well 14/19-4 as the type section.

Harker et al. (1987) adopted the term Claymore Sandstone Member but extended it to include a 3m turbidite sandstone bed that occurs in the type section near the base of the Kimmeridge Clay Formation. According to Harker et al. (1987), the age of the Claymore Sandstone Member ranges from Late Kimmeridian to intra-mid Volgian. Maher & Harker (1987), Harker & Maher (1988) and Harker et al. (1991) recognized a lower 'Low Gamma Ray Sands' unit and an upper 'High Gamma Ray Sands' unit.

Harker et al. (1987) recognized additional, locally developed, sandstone members within the Kimmeridge Clay Formation of the Witch Ground Graben. They introduced the informal term 'Galley Sands' for sandstones that range in age up to as late as the latest Middle Volgian (oppressus Zone).

According to O’Driscoll et al. (1990), the Claymore Sandstone Member is essentially of Early Volgian age, whereas the Galley Sandstone ranges in age from earliest to Middle Volgian. O’Driscoll et al. (1990) correlated the upper part of the Galley Sandstone with the informal 'Silt Unit' recognized within the Kimmeridge Clay Formation of the Claymore Field area by Maher & Harker (1987) and Harker & Maher (1988).

Andrews & Brown (1987) noted sandstones within the Kimmeridge Clay Formation of the Claymore (block 14/19), Galley (block 15/23) and South Piper (block 15/17) areas of the Witch Ground Graben and commented that their lateral continuity along strike could not be confirmed. Similarly, O’Driscoll et al. (1990) recognized a number of separate sandstone developments within the Kimmeridge Clay Formation of the Witch Ground Graben. However, Boute & Gustav (1987) suggested that there is an overlap in the distribution of the Claymore and Galley fan systems.

According to O’Driscoll et al. (1990), the informal Tartan 'Hot Lens A member' and 'Hot Lens B member' sandstones recognized in the Kimmeridge Clay Formation of the Tartan Field area (Coward et al. 1991) are coeval with the Claymore Sandstone Member. Equivalents of the 'Hot Lens' sandstones have been recognized in the Petronella Field and the Highlander Field (Waddams & Clark 1991; Whitehead & Pinnock 1991).

The Claymore Sandstone Member as defined by Turner et al. (1984), together with the 'Galley Sands' of Harker et al. (1984).

**Type section**

14/19-4 (Turner et al. 1984): 2484.2566.5m (8150-8420ft) below KB (revised depths).

**Remarks:** the proposed depths differ from those given by Turner et al. (1984) in the text, but agree with those shown on the accompanying figure.

**Reference sections**

14/19-2: 2483.2699.5m (8146-8856ft)
15/17-8A: 3781.5-3891m (12407-12766ft)
15/23-4B: 4133.5-4419.5m (13562-14500ft)

**Name:** From the Claymore Field (Block 14/19), where the member is the main hydrocarbon reservoir (Turner et al. 1984).

**References**


**Claymore Sandstone Member**

**Name:** From the Claymore Field (Block 14/19), where the member is the main hydrocarbon reservoir (Turner et al. 1984).

**References**


HARKER, S.D. & MAHER, C.E. 1988. Late Jurassic sedimentation and tectonics, main area Claymore reservoir, North Sea. In: Giant oil and gas fields. SEPM Core Workshop No.12, 395-458.


Lithology
The Claymore Sandstone Member is generally composed of well sorted, non-grained and structureless sandstones with rare interbedded mudstones. Boote & Gustav (1987) recognized three main facies associations within the Claymore Sandstone Member. (1) Medium-grained, internally structureless sandstones, with rare thin mudstone beds, commonly arranged in amalgamated sets up to about 5m thick. Rare graded bedding occurs in this facies. (2) Medium to thin bedded, fine to medium grained sandstones with common interbedded mudstone interbeds. These sandstones are internally massive or have planar or ripple lamination. The interbedded mudstones locally contain abundant carbonaceous detritus. (3) Medium to thick bedded, medium-grained sandstones in amalgamated sets, with beds of finely laminated and sporadically bioturbated mudstones.

Turner et al. (1984) noted that load casts, flame structures, dish structures, small-scale slump structures, soft-sediment faults and water-escape structures are locally preserved in otherwise massive sandstones in the Claymore Sandstone Member, and that matrix-supported, angular mudstone clasts up to about 2cm across are locally common.

In addition to the main lithofacies of the Claymore Sandstone Member described above, Turner et al. (1984) recorded coarse to very coarse grained sandstones with dispersed matrix-supported pebbles of sandstone up to 6mm in diameter, and a stratigraphically restricted facies consisting of bioturbated, very fine to fine grained sandstone seen in core from near the top of the Claymore Sandstone Member in well 14/19-9 (not illustrated). Vertical and high-angle oblique burrows with concave upwards backfill structures are common in these sandstones and U-shaped burrows are also present.

In the Claymore Field, the sandstones of the Claymore Sandstone Member are subarkose (Maher & Harker 1987). According to O'Driscoll et al. (1990), sandstones (of early Volgian age) in the lower part of the Claymore Sandstone Member in the Galley field area are quartz-arenitic in composition, although the overlying sandstones (of mid-Volgian age) are more feldspathic. Very localized carbonate concretions are present within sandstones of the Claymore Sandstone Member (Maher & Harker 1987).

Gamma-ray log signatures within the Claymore Sandstone Member reflect the range of lithofacies present. Thick-bedded and amalgamated sandstones produce a ‘blocky’ gamma-ray log response (e.g. 15/17-8A), whereas thin-bedded sandstones with mudstones result in a ‘ratty’ log character (e.g. between 4230.6 and 4419.6m in well 15/23-4B).

Upper boundary
The top of the Claymore Sandstone Member is defined by a downward change from organic-rich, dark grey mudstones to sandstones. It is marked by a downward decrease in gamma-ray values and an increase in velocity. On local structural highs, within the Claymore Field, the Claymore Sandstone Member is unconformably overlain by calcareous mudstones of the Lower Cretaceous Valhall Formation (Maher & Harker 1987).

Lower boundary
The base of the Claymore Sandstone Member is defined by a change from sandstone, or interbedded sandstone and mudstone, to mudstone. It is marked by a downward increase in gamma-ray values and decrease in velocity, or, where interbedded mudstones are present in the lower part of the formation, by a change to consistently high gamma-ray values. Thin sandstones within the Kimmeridge Clay Formation below this level are not included within the Claymore Sandstone Member. A 3-metre turbidite sandstone bed that occurs near the base of the Kimmeridge Clay Formation in some sections (e.g. 14/19-2, 14/19-4) is thus excluded.

Distribution and thickness
The Claymore Sandstone Member is widely distributed throughout the Witch Ground Graben. The Claymore Sandstone Member is locally absent due to erosion over the crests of some major structural highs, e.g. the Claymore Field.

The member shows rapid thickness variations. It is commonly between 50 and 250m thick, but greater thicknesses occur near major synsedimentary faults. The thickest known sections are adjacent to the Halibut Horst (e.g. 372.5m in well 15/21-2, not illustrated).

Regional correlation
The Claymore Sandstone Member passes laterally into Kimmeridge Clay Formation mudstones.

Depositional environment
Turner et al. (1984) interpreted the sandstones of the Claymore Sandstone Member as gravity-flow deposits, with the bioturbated sandstones near the top of the member in well 14/19-9 (not illustrated) possibly representing reworking under relatively shallow conditions. Boote & Gustav (1987) identified submarine-channel, channel-fringe and submarine-fan lobe/sheet deposits within the Claymore Sandstone Member.

Biostratigraphic characterization
Although palynomorphs are of low diversity and generally poorly preserved, the G.limiferum, Muderongia sp.A acme, C.longicorne and E.luridum biomarkers have been identified within the Claymore Sandstone Member.

Age
Kimmeridgian to Middle Volgian.

References

See also Correlation Panels 19, 20.
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The term Dirk Sandstone Member is introduced for a thin sandstone unit lying within the uppermost part of the Kimmeridge Clay Formation.

Type section
15/23-2: 3900-3928.5m (12795-12889ft) below KB.

Reference section
Because of the very limited distribution of the Dirk Sandstone Member, no formal reference section is proposed.

Name
From the dagger used by Scottish Highlanders.

Lithology
The Dirk Sandstone Member is characterized by very fine to medium grained sandstones interbedded with dark coloured, organic-rich mudstones. The sandstones are well sorted, well cemented, locally carbonaceous and slightly calcareous. The mudstones are typical of the Kimmeridge Clay Formation.

Upper boundary
The top of the Dirk Sandstone Member is defined by a downward change from mudstone to sandstone interbedded with mudstone, marked by a decrease in average gamma-ray values and an increase in velocity.

Lower boundary
The base of the Dirk Sandstone Member is defined by a downward decrease in the proportion of sandstone to mudstone. It is marked by a downward increase in gamma-ray values. In the type section, a distinctly high-gamma mudstone unit separates the Dirk Sandstone Member from the Claymore Sandstone Member in the type section.

Distribution and thickness
The Dirk Sandstone Member is known only from the area of the Galley Field, in block 15/23. In the type well (the only released section) the member is 28m thick.

Regional correlation
The Dirk Sandstone Member passes laterally into dark grey mudstones of the Kimmeridge Clay Formation.

Genetic interpretation
The Dirk Sandstone Member sandstones are interpreted as mass-flow deposits within dysaerobic marine mudstones of the uppermost part of the Kimmeridge Clay Formation.

Biostratigraphic characterization
The Dirk Sandstone Member typically yields palynomorph assemblages of relatively low diversity. The *R.thula* biomarker has been recorded in the immediately overlying Kimmeridge Clay Formation mudstones.

Age
Latest mid Volgian to late Ryazanian.
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Magnus Sandstone Member (new)

The term Magnus Sandstone Member is introduced for a thick sandstone unit occurring within the mudstone-dominated succession of the Kimmeridge Clay Formation in the East Shetland Basin area.

Type section
211/12-3A: 3064.3-3121m (10053-10240ft.) below KB.

Reference section
211/12a-9: 3175.3-3377.5m (10417-11081ft)

Name. From the Magnus Field (De’Ath & Schuylerman 1981).

Lithology
The Magnus Sandstone Member consists predominantly of sub-arkosic to arkosic, fine to coarse grained, locally granulitic, generally poorly sorted sandstones (De’Ath & Schuylerman 1981). Beds of mostly structureless sandstone, up to 14m thick, constitute the bulk of the member in some wells. Thin-beded sandstones are also present, with sedimentary structures that include ripples and parallel lamination typical of Bouma-cycle deposits. Heterogeneous muddy sandstones or sandy mudstones are also present, displaying sandstone and mudstone clasts, contorted sub-vertical sandstone pipes, contorted beds, and balls of sandstone. This facies may form up to 20% of the member in some wells.

Upper boundary
The top of the Magnus Sandstone Member is defined by a downward change from high-gamma, Kimmeridge Clay mudstones to sandstones. It is marked by a downward increase in average gamma-ray values and commonly by a decrease in velocity.

Distribution and thickness
The Magnus Sandstone Member is restricted to the area around the Magnus Field in the northern part of the East Shetland Basin. Comparable sandstones of Kimmeridgian to Volgian age in Block 210/19 are not formally assigned to the Magnus Sandstone Member because of difficulty in accurately defining their distribution. They may merit inclusion within the member when more data are available.

The Magnus Sandstone Member attains a maximum thickness of about 200m, but shows rapid thickness variations over short distances.

Genetic interpretation
The Magnus Sandstone Member was deposited by gravity-flow processes in up to four sand-rich, partly overlapping submarine-fan lobes derived from the west or northwest (De’Ath & Schuylerman 1981).

Biostratigraphic characterization
The Magnus Sandstone Member generally yields relatively sparse palynofloras, with none of the diagnostic biomarkers yet recorded. Reworked Callovian to Oxfordian dinoflagellate cysts are occasionally recorded.

Age
Kimmeridgian to Volgian.

References

See also Correlation Panel 11(N).
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Ptarmigan Sandstone Member (new)

The term Ptarmigan Sandstone Member is introduced for a unit of thinly bedded sandstones that occurs within the mudstones of the Kimmeridge Clay Formation in the East Shetland Basin. The member lies below the Magnus Sandstone Member, and is separated from it by high-gamma mudstones of the Kimmeridge Clay Formation.

Type section
211/12-5: 3261-3295m (10699-10810ft) below KB.

Name. From the Scottish game-bird.

Lithology
The Ptarmigan Sandstone Member consists of thinly bedded sandstones interbedded with dark grey mudstones. The sandstones are light to medium grey-brown, fine to medium grained, quartzose, variably dolomitic, and moderately sorted. The member displays highly erratic wireline-log responses.

Upper boundary
The top of the Ptarmigan Sandstone Member is defined by a downward change from mudstones (undifferentiated Kimmeridge Clay Formation) to interbedded sandstone and mudstone. It is marked by a downward decrease in gamma-ray values and increase in velocity.

Lower Boundary
The base of the Ptarmigan Sandstone Member is defined by a downward change from sandstone with interbedded mudstone to a dominantly mudstone section. It is marked by a downward change to more uniform wireline-log responses.

Distribution and thickness
The Ptarmigan Sandstone Member is restricted to the area around the Magnus Field (Quadrant 211/12), in the northern part of the East Shetland Basin. Its lateral limits are probably depositional. The member attains a maximum thickness of about 150m, but the thickness varies rapidly over small distances.

Genetic interpretation
The Ptarmigan Sandstone Member was probably deposited by gravity-flow processes in submarine-fan lobes derived from the west or northwest.

Biostratigraphic characterization
No data available.

Age
Probably Kimmeridgian.

See also Correlation Panel 11(N).
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The term Ribble Sandstone Member is introduced for a thin sandstone unit within the lower part of the Kimmeridge Clay Formation in the Fulmar Field area (Block 30/16). It is a formalization of the term 'Ribble Unit' as used by Shell (Johnson et al. 1986; Meenni & Roodenburg 1990). The Ribble Sandstone Member constitutes the uppermost productive sandstone unit in the Fulmar Field. 

Type section 
30/16-7: 3262-3305m (10702-10843ft) below KB.

Reference sections 
30/16-25: 3087.5-3115m (10130-10220ft)

Name. From the River Ribble in Lancashire.

Lithology 
The Ribble Sandstone Member consists dominantly of thick-bedded, structureless sandstones which are fine to medium grained and non-bioturbated. The sandstones are poorly to well sorted, sub-arkosic in composition, contain clay clasts and are interbedded with thin laminated fissile mudstones (Johnson et al. 1986; Meenni & Roodenburg 1990; Stockbridge & Gray 1991).

Upper boundary 
The top of the Ribble Sandstone Member is defined by a sharp downward change from dark grey, fissile Kimmeridge Clay mudstones to sandstones. It is marked by a downward decrease in gamma-ray values and by a sharp or transitional downward decrease in velocity.

Lower boundary 
The base of the Ribble Sandstone Member is defined by a sharp downward change from sandstones to dark grey, fissile Kimmeridge Clay mudstones, shortly above the top of the Fulmar Formation. The boundary is marked by a sharp downward increase in gamma-ray values and a sharp and pronounced increase in velocity.

Distribution and thickness 
The Ribble Sandstone Member appears to be limited to the area of the Fulmar Field. It is thickest in the western part of the field where it is up to 180ft (55m) thick (Johnson et al. 1986).

Regional correlation 
The Ribble Sandstone Member passes laterally into mudstones of the Kimmeridge Clay Formation. The Eldfisk Formation, which is present in the adjacent Norwegian sector (e.g. N2/7-3, Vollset & Dore 1984, p.48, fig.40), is possibly a coeval turbiditic sand deposit derived from the eastern margin of the graben.

Genetic interpretation 
The sandstones of the Ribble Sandstone Member were deposited in relatively deep water, probably as a series of mass flows sourced from the Auk and adjoining platform areas. The organic-rich interbedded mudstones indicate anoxic bottom water conditions.

Biostratigraphic characterization 
The member is characterized by sparse to occasionally rich palynomorph associations. The Eluridum and C.longicorne biomarkers occur sporadically within the formation.

Age 
Late Kimmeridgian to Volgian.

References 


See also Correlation Panel 17.
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The term Piper Formation was introduced by Deegan & Scull (1977) for a marine, sandstone-dominated unit lying between the Kimmeridge Clay Formation and the continental sediments of Middle Jurassic age in the Outer Moray Firth area. Sandy siltstones and mudstones with thin coals occurring beneath the marine sandstones were included within the Piper Formation, and regarded as the initial deposits of the Late Jurassic marine transgression. The formation has since been described by numerous authors and its boundaries have been taken at a variety of places, as summarized in the accompanying table. In this report, the term Piper Formation is applied to the marine sandstones, with the underlying siltstones and mudstones being assigned to the Heather Formation and the coal-bearing strata being assigned to a newly defined Stroma Member of the Pentland Formation.

Maher (1981) recognized a ‘Piper Sand’ in the Piper Field, which he divided into 13 informal units, designated ‘A’ to ‘M’, in descending order. However, according to Schmitt & Gordon (1991), the ‘A’ and ‘B’ ‘Piper Sand’ units described by Maher (1981) are separate sandstones within the Kimmeridge Clay Formation. Maher also recognized a lower and upper division of the Piper Sand, separated by a persistent mudstone unit, the ‘I shale’. He believed that the lower division comprised of pregrading deltaic sands underlain by mudstones and coal-bearing, delta-plain deposits, all of Callovian age. The coal-bearing strata (assigned here to the Stroma Member of the Pentland Formation) were considered to rest unconformably on the overlying Piper Formation to be mid to late Oxfordian and younger.

A more substantial redefinition of the Piper Formation was proposed by Harker et al. (1987), in which the base of the Piper Formation was raised to the base of the ‘I shale’ of Maher (1981). The underlying beds, constituting the lower ‘Piper Sand’ division (units ‘F’, ‘G’, ‘H’, ‘I’ and ‘J’) of Maher (1981), were included in a newly proposed ‘Sgiath Formation’, believed to be of Oxfordian age. Harker et al. (1993) referred the ‘J’ sand unit of Maher (1981) to the ‘Stroma Member’ of the ‘Sgiath Formation’, and the ‘M’ unit of Maher (1981) to the ‘Skene Member’ of the ‘Sgiath Formation’. This splitting of the original Piper Formation was not, however, followed by Boldy & Brealey (1990) or Coward et al. (1991).

The Piper Formation as defined here comprises the marine sandstones of Deegan & Scull's original unit, and therefore includes both the 'Piper Formation' and 'Stroma Member' of Harker et al. (1993).

Type section


Remarks: the lower limit has been modified from that of Deegan & Scull (1977) to exclude strata here assigned to the Heather Formation and Stroma Member (Pentland Formation).

References

15/16-9: 3652.5-3879m (11983-12727ft)
15/17-9: 3939.5-3412.5m (12925-13492ft)
15/21a-15: 3383.5-3529.5m (11100-11580ft)


Lithology
The Piper Formation consists mainly of fine to coarse-grained, poorly cemented sandstone units, interbedded with sporadic dark marine mudstones. Sporadic very fine-grained sandstones are represented in core descriptions (e.g. 19/4F2-1; Turner et al. 1984), although they may not be distinguishable on wireline-log signatures (e.g. 15/21a-15: 3487.5m/14420f). Main lithofacies have been described from the formation: bioturbated, fossiliferous marine mudstones, with thin (1-2m), poorly sorted, very fine grained glauconitic sandstones at their base; bioturbated, silty, fine-grained sandstones with broken bivalves and belemnites; well sorted, massive to cross-beded, bioturbated, medium-grained sandstones with sporadic shelly debris; well sorted, massive to planar bedded, coarse-grained sandstones; and upward-fining, very coarse to coarse grained cross-bedded sandstones (Turner et al. 1984; Boote & Gustav 1987; Harker et al. 1993).

In many wells, the lithofacies of the Piper Formation are arranged in large scale upward-coarsening cycles up to c.00m thick (Turner et al. 1984), with overall upward-decreasing gamma-ray log profiles. Three or four cycles are developed in the Tarant Field (e.g. 15/16-9) and also in parts of blocks 14/19, 14/20, 15/11, 15/17, 15/21 and 15/22. In other areas (e.g. the Highlander Field, Whitehead & Pinnock 1991) and in well 15/21-25 (not illustrated) the Piper Formation is dominated by more uniform sandstone successions. In the Ivanhoe and Rob Roy fields (Block 15/21), successions of thin, upward-fining sandstones are stacked in sections up to 5m thick (Parker 1991).

Much of the Piper Formation is quartz-arenitic, as in the Piper Field (Maher 1981). However, in western quadrants, more feldspathic and arkosic and subarkosic to lithic subarkosic sandstones are recorded (Turner et al. 1984; O'Driscoll et al. 1990; Harker et al. 1993). Isolated granule-sized coal fragments occur within all of the sandstone facies (Turner et al. 1984). Local concentrations of heavy minerals, particularly zircon, may produce anomalously high values on gamma-ray logs (e.g. 15/17-4, c.2635m/3840f; see Deegan & Scull 1973, p.19), and a similar effect is produced locally by concentrations of glauconite in the uppermost part of the formation (e.g. 15/21a-15—the ‘Transgressive Unit’ of Boldy & Breatley 1990 and ‘Hot Sand’ of Coward et al. 1991).

Upper boundary
The top of the Piper Formation is commonly marked by the downward change from mudstones or siltstones into sandstones. It commonly appears transitional on wireline logs (e.g. 15/9-8); although over many structural highs the contact is sharp (e.g. 15/17-4). The gamma-ray log signature at the top of the sandstone can be deceptive, since in some sections include a glauconite-rich, high-gamma sandstone unit beneath the Kimmeridgian Clay mudstones (e.g. 15/21a-15, p.57). In other sections, a similar log signature is produced by silty mudstones at the base of the Kimmeridgian Clay Formation (e.g. 15/21a-11, p.65). In well 15/22-4, a well defined siltstone unit is present above the sandstones. This is here included within the Kimmeridgian Clay Formation, although its upward-coarsening character suggests that it is the lateral equivalent of the uppermost Piper Sandstone of adjacent wells.

The upper boundary of the Piper Formation may be difficult to recognize in uncored wells where the Piper Formation is overlain by sandstones of the Claymore Sandstone Member (e.g. 15/12-1, Schmitt & Gordon 1991). However, mudstones interbedded with the sandstones of the Claymore Member are generally darker in colour, less calcareous and more carbonaceous than those in the Piper Formation, and the two formations are often separated by a thin unit of Kimmeridgian Clay mudstone (e.g. 14/18-3, Panel 19).

Lower boundary
Where the Piper Formation overlies mudstones of the Heather Formation, the base is taken at a downward change from sandstone to mudstone. It is usually marked by a sharp downward increase in gamma-ray values (e.g. 15/17-4, 15/17-9), but in some sections, a more gradational boundary is indicated (e.g. 15/21a-15). Locally, the Piper Formation rests unconformably on coals or coal-bearing mudstones of the Pentland Formation (Strona Member) (e.g. 15/16-1; 14/9-4, p.45). Elsewhere, the Piper Formation rests unconformably on oil sands of the Ratray Volcanics Member (e.g. 15/23-3, Panel 20).

Lithostratigraphic subdivision
Two members, the Chanter and Pibrock Member, are proposed as formal subdivisions of the Piper Formation. Other subdivisions have been proposed for specific field areas (see table, p.55).

Distribution and thickness
The Piper Formation is most thickly developed in the Witch Ground Graben, but also extends into the Dutch Bank Basin, across the Halibut Shelf, and into the northernmost part of the South Halibut Basin. The eastern and northern limits of the Piper Formation are generally considered to be erosional, whereas the western and southern limits are marked by the lateral passage into mudstones.

The Piper Formation is commonly between 100 and 200m thick, with the greatest thicknesses occurring around the northeastern end of the Halibut Horst, where it reaches over 300m (O'Driscoll et al. 1990; Turner et al. 1984).

Regional correlation
The sandstones of the Piper Formation pass laterally into mudstones of the Heath and Kimmeridgian Clay formations.

Genetic interpretation
Deegan & Scull (1977) postulated that the bulk of the formation was deposited in barrier bar and other littoral and shallow-marine sand bodies. In contrast, Turner et al. (1984) suggested that the upward-coarsening cycles in the Piper Formation may be of deltaic origin. Boote & Gustav (1987) and Harker et al. (1993) proposed a wave-dominated delta environment of deposition for the Piper Formation. However, according to O'Driscoll et al. (1990), the Piper Formation wave-dominated delta was substantially affected by tidal processes.

Biostatigraphic characterization
The mudstone at the base of the Chanter Member (‘1 shale’ of Maher 1981 and Harker et al. 1993) includes the Scytosphaerites biomarker. These mudstones have also yielded a rich and varied assemblage of ammonites (Boldy & Breatley 1990). Age
Late Oxfordian to mid Kimmeridgian.

References
See also Correlation Panels, 19. 20.
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Chanter Member
(new)

The term Chanter Member is introduced for sandstones that constitute the upper part of the Piper Formation in the Outer Moray Firth area. It lies between the mudstones of the Kimmeridge Clay Formation and sandstones of the Pibroch Member of the Piper Formation, and includes a thin basal mudstone unit, often referred to as the '1 shale'. It is equivalent to the 'Piper Formation' of O'Driscoll et al. (1990), Schmitt (1991) and Harker et al. (1993) (see table, p.55).

Coward et al. (1991) recognized four informal members within the Chanter Member as defined here (see table, p.55). These are the 'Lower Shale member', 'Main Sand member', '15/16-6 Sand member' and 'Hot Sand member'. These units equate respectively with the '1 shale', 'Main Piper Sand', 'Tartan Upper Piper Sand' and 'Tartan Hot Sands' subdivisions of O'Driscoll et al. (1990). According to Harker et al. (1993), the informal 'transgressive unit' that Boldy & Brealey (1990) recognized at the top of the Piper Formation in the Rob Roy Field is laterally equivalent to the informal 'Hot Sand member' of Coward et al. (1991).

Type section
15/16-9: 3652.5-3849.5m (11983-12629ft) below KB.

Reference sections
15/16-6: 3612-3787.5m (11850-12426ft)
15/22-4: 3721.5-3776m (12210-12388ft)

Name. From the Chanter Field, Block 15/17 (Schmitt 1991), where the Chanter Member forms one of the principal reservoirs. The chanter is the pipe on which a bagpipe melody is played.

References
Lithology
Five main lithofacies have been described from the Chanter Member: (1) bioturbated, fossiliferous marine mudstones and siltstones with thin, poorly sorted very fine grained glauconitic sands at their base; (2) bioturbated silty fine-grained sandstones with broken bivalves and belemnites; (3) well sorted, massive to cross-bedded, bioturbated medium-grained sandstones with sporadic shell debris; (4) well sorted planar to cross-bedded coarse-grained sandstones; (5) upward-fining very coarse to coarse grained cross-bedded sandstones. Locally, the upper part of the Chanter Member includes sandstone intervals with relatively high gamma-ray log values (i.e. over 100 API). In the Petronella Field, this ‘Hot Sand member’ comprises argillaceous, heavily bioturbated sandstone (Waddams & Clark 1991).

In many wells, the lithofacies of the Chanter Member are arranged in a stacked succession of upward-coarsening cycles. In well 15/16-6, two large-scale upward-coarsening cycles up to 95m thick have been recognized (Turner et al. 1984). In the type well, three large-scale upward-coarsening and two upward-fining cycles, in the range 18-55m thick, can be recognized within the Chanter Member.

Mudstones within the Chanter Member are commonly dark grey, carbonaceous and micaceous. In the Ivanhoe and Rob Roy fields, the basal unit of the Chanter Member consists of organic-rich mudstones with pyritic nodules that pass up into intensely bioturbated mudstones and siltstones grading up to argillaceous sandstones (Parker 1991).

Upper boundary
The top of the Chanter Member is commonly marked by a downward change from mudstones or siltstones into sandstones. It commonly appears transitional on wireline logs (e.g. 15/16-9), although over many structural highs, the contact is very sharp (e.g. 15/17-4, p.57). The gamma-ray log signature at the top of the sandstone can be deceptive, since some sections include a glauconite-rich, high-gamma sandstone unit at the base of the Piper Formation (e.g. 15/16-6; 15/21a-15, p.57). In other sections, a comparable log signature is produced by silty mudstones at the base of the Kimmeridge Clay Formation (e.g. 15/22-4; 15/21a-II, p.65). The siltstone in well 15/22-4 is here included within the Kimmeridge Clay Formation, although its upward-coarsening character suggests that it is the lateral equivalent of the uppermost Piper Sandstone of adjacent wells.

The upper boundary of the Piper Formation may be difficult to recognize in uncored wells where the Piper Formation is overlain by sandstones of the Claymore Sandstone Member (e.g. 15/12-1—see Schmitt & Gordon 1991). However, mudstones interbedded with the sandstones of the Claymore Sandstone Member are generally darker in colour, less calcareous and more carbonaceous than those in the Piper Formation, and the two formations are often separated by a thin unit of Kimmeridge Clay mudstone (e.g. 14/18-3, Panel 19).

Lower boundary
The base of the Chanter Member, where the Piper Member is present, is taken at the base of a widespread marine mudstone, the ‘I shale’ of Maher (1981). Where the Piper Member is absent, the lower boundary of the Chanter Member is taken either at the base of the Kimmeridge shallow-marine sandstone section, or, at the base of a thin unit of Kimmeridge Clay mudstone (the ‘I shale’), where this can be positively identified (e.g. 14/18-3, Panel 19).

Lithostratigraphic subdivision
In the Piper Field, Maher (1981) and Schmitt & Gordon (1991) have recognized seven subunits (designated ‘C’ to ‘I’ in descending order) within the Chanter Member as defined here (see table, p.55).

Distribution and thickness
The Chanter Member is recognized in the central part of the Witch Ground Graben, between the northeastern end of the Halibut Horst and the western flank of the Fladen Ground Spur (Harker et al. 1993; O’Driscolll et al. 1990). The Chanter Member reaches up to about 300m adjacent to the northeastern end of the Halibut Horst in Blocks 14/24 and 14/25 (O’Driscolll et al. 1990).

Regional correlation
The Chanter Member passes laterally into mudstones of the Kimmeridge Clay Formation (see Panel 19).

Genetic interpretation
The Chanter Member probably accumulated in a wave-dominated delta environment, with open-marine, shoreface and distributary facies having been identified (Harker et al. 1993). According to O’Driscolll et al. (1990), tidal processes were an important influence on the delta.

Biostratigraphic characterization
The mudstones at the base of the Chanter Member include the S.crystallinum biomarker.

Age
Early to mid Kimmeridgian.

References

See also Correlation Panels 19, 20.
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The term Pibroch Member is introduced for the lower division of the Piper Formation. It is separated from the sandstones of the Chanter Member by a thin mudstone, often referred to as the ‘I shale’.

The Pibroch Member is equivalent to the Scott Member (Sgiath Formation) of Harker et al. (1993) (see discussion, p.55), and to the ‘Piper Formation Lower Sand Member’ of Coward et al. (1991), the ‘Main Piper Sandstone’ of Boldy & Brealey (1990) and the ‘J Sand’ of Maher (1981).

**Type section**

15/21a 1: 2399-2472.5m (7870-8112ft) below KB.

**Reference sections**

15/16-1: 3080-3093.5m (10105-10149ft)
15/21-3: 2474.5-2528.5m (8118-8295ft)

**Name.** From a type of music played on the bagpipes.

**References**


Lithology

The Pibroch Member consists mainly of fine to coarse grained sandstones, with subordinate dark grey, marine mudstones. Five main lithofacies have been recognized in the member: bioturbated, fossiliferous marine mudstones with thin (1-2m thick), poorly sorted glauconitic very fine grained sandstones at their base; bioturbated silty fine sandstones with broken bivalves and belemnites; well sorted, massive to cross-bedded, bioturbated medium-grained sandstones with sporadic shelly debris; well sorted, massive to planar bedded coarse-grained sandstones; and upward-fining, cross-bedded very coarse to coarse grained sandstones (Harker et al. 1993). Thin coals are locally present, for example at 2445.0m (8015ft) in well 15/21a-11 and at 3487.5m (11442ft) in well 15/21a-15 (p.57), though these are too thin to be detected on wireline logs. In many wells (e.g. 15/17-9, p.57), the lithofacies are arranged in a stacked succession of large-scale upward-coarsening cycles, which are about 20m thick (Harker et al. 1993).

Upper boundary

The top of the Pibroch Member is defined by the base of a widespread marine mudstone, the ‘I shale’ of Maher (1981). In most wells, this upper boundary of the Pibroch Member coincides with a marked downward decrease in gamma-ray values and increase in velocity.

Lower boundary

Where the Piper Formation overlies mudstones of the Heath Formation, the base is taken at a downward transition from sandstone to mudstone. The boundary is commonly gradational, but a distinct downward increase in gamma-ray values can usually be detected (e.g. 15/21-3). In other sections, the wireline-log expression is more gradational (e.g. 15/21a-11; 15/21a-15, p.57). Locally, the Piper Formation rests directly on coal or coal-bearing mudstones of the Pentland Formation (Stroma Member) (e.g. 15/16-1; 14/19-4, p.45). Elsewhere, the Piper Formation rests unconformably on volcanics of the Rattray Volcanics Member (e.g. 15/23-3, Panel 20).

Distribution and thickness

The Pibroch Member is recognized in the central part of the Witch Ground Graben, immediately east of the Halibut Horst (Harker et al. 1993; O’Driscoll et al. 1990). In some Piper Formation sections, the Pibroch Member appears to be absent (e.g. 14/18-3, Panel 19) although some cored sections indicate the presence of very thin Pibroch sandstones that could not be recognized with confidence from cuttings or wireline-log signatures (e.g. 14/19-4, p.45).

According to O’Driscoll et al. (1990), the Pibroch Member reaches a thickness of over 150m in a north-northeasterly trending belt in the middle of Block 15/21.

Regional correlation

The Pibroch Member is equivalent to the uppermost part of the Heather Formation.

Genetic interpretation

The Pibroch Member was deposited in a wave-dominated delta environment, with open-marine, shoreface and distributary channel facies having been identified within the delta system (Harker et al. 1993). O’Driscoll et al. (1990) suggested that distributary channel deposits in the Pibroch Member were tidally influenced. According to Parker (1991), a thin thick silica-cemented sandstone unit in the Pibroch Member of the Rob Roy Field is a silcrete, indicating exposure to meteoric water circulation.

Biostratigraphic characterization

None of the biomarkers has been identified within the Pibroch Member.

Age

Late Oxfordian.

References


See also Correlation Panels 19, 20.
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The Fladen Group was defined by Deegan & Scull (1977) to encompass the coal-bearing Pentland Formation and the volcanic Rattray Formation in the Central North Sea and South Viking Graben. The definition of the group is significantly changed in this study. Four formations (Pentland, Brora Coal, Beatrice and Hugin formations) and five members (Rattray Volcanics Member, Ron Volcanics Member, Stroma Member, Louise Member and Carr Member) are included within the revised Fladen Group.

The Pentland Formation has been expanded from its Deegan & Scull definition to include the Rattray Volcanics Member, previously termed the Rattray Formation, together with an additional volcanic unit, here termed the Ron Volcanic Member, in the southern part of the Central North Sea. In the Outer Moray Firth, the uppermost part of the Pentland Formation contains the newly defined Stroma Member, which equates with the arenaceous and coal-bearing part of the Skene Formation (Sgiath Formation) of Harker et al. (1993).

The newly defined Brora Coal Formation and Beatrice Formation in the Inner Moray Firth are also incorporated into the Fladen Group, as is the Hugin Formation in the Viking Graben, defined for the Norwegian sector by Vollset & Doré (1984).

The Fladen Group is also extended into the Unst Basin, where a suite of sediments similar to those in the Beryl Embayment are preserved (Richards 1990).

This expanded definition of the Fladen Group reflects the grouping together of all the Middle Jurassic coal-bearing units and overlying transgressive sandstone units, with the exception of the Brent Group deposits in the North Viking Graben and East Shetland Basin. The group therefore includes all strata outside the Brent province lying above the marine Lower Jurassic mudstones and below the marine Middle to Upper Jurassic mudstones.

The Fladen Group extends northwards to about 60°N in the Viking Graben. Beds of comparable facies in the East Shetland Basin (Ness Formation) are assigned to the Brent Group, which is differentiated from the Fladen Group by a distinctive vertical succession of marine and paralic units.

**References**


**Name.** From the Fladen Ground Spur (Deegan & Scull 1977, p.20)

**Constituent formations**

- **BEATRICE FORMATION** p.69
- **BRORA COAL FORMATION** p.77
- **HUGIN FORMATION** p.81
- **PENTLAND FORMATION** p.85

**Age**

Aalenian to Oxfordian.

<table>
<thead>
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<th>UK SECTOR</th>
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<th>NORWEGIAN SECTOR</th>
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<td>NORTHERN NORTH SEA</td>
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<td>CENTRAL GRABEN</td>
<td>HEATHER FM.</td>
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<td>INNER MORAY FIRTH</td>
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<td>HUGIN FM.</td>
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<td>PENTLAND FM.</td>
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BEATRICE FORMATION
(new)

The term Beatrice Formation is introduced for a predominantly sandstone sequence that lies between the Brora Coal Formation and the Heather Formation in the Inner Moray Firth. Andrews & Brown (1987) introduced the informal term 'Beatrice Formation' for the main reservoir strata in the Beatrice Field. Stevens (1991) introduced the informal term 'Brora Formation' for these strata and recognized three members, ascending in order the 'Fiddich Sand Member', 'Burghie Shale Member' and 'Farclas Sand Member'. Stevens (1991) equated the 'Fiddich Sand Member' and 'Farclas Sand Member' with the informal 'B Sand' and 'A Sand' reservoir units in the Beatrice Field, and the 'Burghie Shale Member' with the intervening 'mid shale' unit (see Table 1 in Stephen et al. 1993). However, Andrews & Brown (1987) and Andrews et al. (1990) included the 'mid shale' within the 'A Sand'.

**Type section**

11/30a-8: 2095-2156m (6873-7074ft) below KB.

**Reference sections**

11/25-1: 2921-2975m (9584-9760ft)
12/22-2: 1350.5-1379m (4430-4525ft)
12/21-2: 2136.5-2185m (7009-7168ft)

**Name.** From the Beatrice Field, where the formation constitutes the main oil reservoir (Andrews & Brown 1987).

**Formal subdivision**

<table>
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<tr>
<th>Member</th>
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<tr>
<td>Carr Member</td>
<td>p.73</td>
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<tr>
<td>Louise Member</td>
<td>p.75</td>
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</table>

**References**


Lithology
The Beatrice Formation consists of fine to medium grained sandstones interbedded with subordinate shelly mudstones. The succession generally consists of upward-coarsening units, commonly between five and seven in number. Upward-finining units are also present in some sections. In general, the upward-coarsening units display an upward transition from dark grey, micaceous, carbonaceous and pyritic mudstones, with local shell debris, through grey and brown, fine-grained, flaser-bedded and ripple-laminated silty sandstones to clean, fine to medium grained, locally oolitic, cross-bedded or parallel-laminated sandstones. However, in eastern sections (e.g. 12/28-1, Panel 9), upward-coarsening trends are not apparent in the lower part of the formation. A thin lignitic coal has been reported in the mudstone at the base of the Carr Member in a core from well 12/21-3 (Panel 9). Bioturbation is common, including bivalves, blemnites, and *Rhaxella* spicules, occur at many levels. Phosphatic nodules enclosing bivalve shells occur near the base of the Beatrice Formation.

Upper boundary
The top of the Beatrice Formation is defined by a sharp downward change from mudstone (Heather Formation) to sandstones. It is marked on wireline logs by one or two low-velocity spikes. In many sections, a discrete coal seam (believed to be equivalent to the Brora Coal) occurs at the top of this unit (e.g. 1/30a-9, p.77).

To the east of the Beatrice Field, where in some sections the Brora Coal Formation is missing, the Beatrice Formation rests on a wide range of stratigraphic units, including the Orrin Formation, the Lady's Walk Formation (e.g. 12/27-1, 12/22-2, Panel 8), the Mains Formation (e.g. 12/28-2, not illustrated), the Golspie Formation (e.g. 12/30-1, Andrews & Brown 1987, fig.4). However, in most sections the boundary can be identified at the base of a series of sandstone-dominated upward-coarsening units. In thin successions near the extreme eastern limit of the Beatrice Formation, the characteristic upward-coarsening motif is less well displayed (e.g. 12/30-1, Andrew & Brown 1987, fig.4).

Lithostratigraphic subdivision
A formal subdivision into the Carr Member (p.73) and Louise Member (p.75) is proposed. Some sections near the extreme eastern limit of the formation display a single upward-coarsening cycle, which is assigned to the Carr Member.

Distribution and thickness
The formation extends eastwards from the Helmsdale Fault across much of the Inner Moray Firth, but is absent from the extreme east (e.g. 13/12-1, 13/17-1, not illustrated) probably as a result of non-deposition. The formation is thickest in the area of the Beatrice Field, where it ranges up to about 60m.

Regional correlation

Genetic interpretation
The upward-coarsening sandstones of the Beatrice Formation have been interpreted as representing marine barrier-bar and offshore-bar environments (MacLennan & Trewin 1989; Stevens 1991; Stephen et al. 1995). The mudstone at the base of the Carr Member ('mid shale') in the Beatrice Field was interpreted as an open-marine deposit by MacLennan & Trewin (1989) and Stephen et al. (1993).

The mudstone at the base of the formation contains a rich assemblage of miospores, cuticle, vitrinite and inertinite, indicative of freshwater conditions (MacLennan & Trewin 1989).

Biosтратigraphic characterization
The *Aldorfensia* and *Chalyxina* biomarkers have been recognized within the formation.

Age
Early to mid Callovian. MacLennan & Trewin (1989) assigned mudstones near the base of the Beatrice Formation to the early Callovian (*callowianse Zone*). At Brora, the abundance of *Ctenidodinium sellwoodii* at the base of the Brora Roof Bed (probably equivalent to the base of the Beatrice Formation) may indicate that the *macrocephalus* Zone is represented (MacLennan & Trewin 1989). Mudstones immediately above the Beatrice Formation yielded a Callovian ammonite fauna.

References


See also Correlation Panel 9.
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**Carr Member** (new)

The term Carr Member is introduced for the upper division of the Beatrice Formation.

**Type section**

11/30a-9: 2786.5-2832m (9142-9291ft) below KB.

**Reference section**

12/21-2: 2136.5-2163.5m (7009-7098ft)

**Name.** After the wife (Beatrice Louise Carr) of Mr T. Boone Pickens, the former President of Mesa Petroleum (UK), after whom the Beatrice Field was also named.

**Lithology**

The Carr Member consists of sandstones and subordinate siltstones and mudstones. A basal mudstone-dominated unit, up to about 15m thick, consists of dark grey, calcareous, micaceous, carbonaceous and pyritic mudstone with belemnites and marine bivalves. The mudstone generally coarsens upwards via siltstone into fine to medium grained and occasionally coarse-grained sandstones of the overlying sandstone-dominated unit. The sandstones are commonly bioturbated. Locally, two or more well defined, upward-coarsening cycles are present within the sandstone unit. In the Beatrice Field, the upper cycle is up to about 20m thick (e.g. 11/25-1, 11/30-2, p.75). At the top of the upper sandstone cycle, calcareous ooliths, bivalves and belemnite guards are common (Linsley et al. 1980).

**Upper boundary**

The top of the Carr Member is defined by a sharp downward change from Heather Formation mudstones to sandstone. It is marked on wireline logs by a sharp downward decrease in gamma-ray values and increase in velocity.

**Lower boundary**

The base of the Carr Member is defined by a sharp downward change from mudstones to sandstones (Louise Member). It is marked by a sharp downward decrease in gamma-ray values and a sharp downward increase in velocity. Where the mudstone unit at the base of the Carr Member is poorly developed (e.g. 12/21-3, p.79 & Panel 9), it is difficult to recognize the Louise and Carr members without detailed biostratigraphy. In some sections near the extreme eastern depositional limit of the Beatrice Formation (e.g. 12/28-2, not illustrated), the Carr Member is believed to rest unconformably on the Dunrobin Bay Group.

**Lithostratigraphical subdivision**

No formal subdivision of the Carr Member is proposed, but an informal subdivision into a lower mudstone-dominated unit and an overlying sandstone-dominated unit can commonly be made.

**Distribution and thickness**

The Carr Member overlaps the Louise Member in easternmost sections of the Beatrice Formation. The member reaches a thickness of about 40m in the Beatrice Field.

**Genetic interpretation**

The upward-coarsening sandstones of the Carr Member have been interpreted as representing marine barrier-bar and offshore-bar environments (MacLennan & Trewin 1989; Stevens 1991). The basal mudstone in the Beatrice Field was interpreted as marine by MacLennan & Trewin (1989) and Stephen et al. (1993).

**Biostratigraphic characterization**

The miospores Chrysosphaeridia hyalina and Ceraster characterize the basal mudstones; Kalyptea stegasta is common in the overlying sandstones.

**Age**

Early to mid or late Callovian (Stephen et al. 1993, fig.3).

**References**


See also Correlation Panels 9.
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Louise Member (new)

The term Louise Member is introduced for the lower division of the Beatrice Formation.

Type section
11/30-2: 1963-1978.5m (6448-6491ft) below KB.

Reference section
11/25-1: 2959.5-2975m (9710-9760ft)

Name.
After the wife (Beatrice Louise Carr) of Mr T. Boone Pickens, the former President of Mesa Petroleum (UK), after whom the Beatrice Field was also named.

Lithology
The Louise Member consists of sandstones with minor interbedded mudstones. These lithologies are commonly arranged in a stacked succession of upward-coarsening units (e.g. 11/25-1), but thin upward-finings are also present in some sections (e.g. 11/30a-9, p.73). In the Beatrice Field area, four or more upward-coarsening units, up to about 6m thick, can commonly be identified from wireline-log signatures and/or core (e.g. 11/30-8, p.69). These commonly display an upward gradation from dark grey, micaceous, carbonaceous and pyritic mudstone, with local shell debris, to grey and brown, fine-grained, flaser-grey, micaceous, carbonaceous and pyritic mudstone, with wireline-log signatures and/or core (e.g. 11/30-8, p.69).

Depositional environment
The basal mudstones of the Louise Member in the Beatrice Field contain a rich assemblage of miospores, cuticle, vitrinite and inertinite, indicative of freshwater conditions (MacLennan & Trewin 1989). An upward increase in the abundance and diversity of dinoflagellate cysts in the overlying mudstones indicates a gradual increase in marine influence (MacLennan & Trewin 1989). The upward-coarsening sandstone units of the Louise Member represent marine barrier-bar or offshore-bar environments (MacLennan & Trewin 1989; Stevens 1991; Stephen et al. 1993).

Biostratigraphic characterization
MacLennan & Trewin (1989) reported the A.alderensis biomarker from the basal part of the Louise Member.

Age
Early Callovian.

References

See also Correlation Panel 9.
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BRORA COAL FORMATION

The term Brora Coal Formation is applied to a heterolithic unit of sandstones, mudstones and coals which lie between the Orrin Formation and the Beatrice Formation in the Inner Moray Firth. The name Brora Coal Formation was proposed for onshore Bathonian strata of the Moray Firth coast by Neves & Selley (1975). Hurst (1981) defined two members in the Brora Coal Formation: the 'Doll Member' and the overlying 'Inverbrora Member'. In their informal lithostratigraphic scheme, Andrews & Brown (1987) extended the Brora Coal Formation offshore to include coeval strata in the Inner Moray Firth. However, Stevens (1991) assigned equivalent strata in the Beatrice Field to the Pentland Formation, and recognized an informal 'Brora Coal Member' at the top of this formation. On some oil company logs the Brora Coal Formation has been assigned to the informal 'interbedded unit' of the Fladen Group (e.g. 12/21-2, Britoil) (see table 1 in Stephen et al. 1993).

Type section
The type locality is the foreshore south of the Brora Estuary, Sutherland. At outcrop, the lower part of the Brora Coal Formation is cut out by the Brora Fault, whereas the offshore sections include the full succession.

Reference sections
11/25-1: 2975-3141m (9760-10305ft)
11/30a-9: 2850-3033m (9350-9950ft)
12/21-3: 2805-2918m (9203-9574ft)

Name. After the village of Brora on the western shore of the Moray Firth (Neves & Selley 1975).

References
Lithology
The Brora Coal Formation consists of interbedded dark grey, carbonaceous, waxy mudstones and greenish grey sandy mudstones, sandstones and coals. The mudstones contain sideritic spheres up to 1mm in diameter and display convolute bedding. The sandstones are white to pale grey, well sorted and very fine to medium grained, with cross-beds and ripple lamination. They have sharp bases, and grade upwards into mottled, bioturbated and veined mudstone with coal units and coal seams. Individual sandstone units are generally up to about 6m thick, but locally combine to form composite units of up to about 20m thick (e.g. 11/25-1).
Linsley et al. (1980) recognized a five-fold cyclicity in the vertical distribution of sandstones in the Beatrice Field, but Stevens (1991) referred to four main sandstone units and two thinner units. According to Stevens (1991) the sandstone units have 'shoestring' geometries and are not correlatable across the whole field.
At the top of the formation is a thin coaly section which is probably age equivalent to the Brora Coal bed onshore. In some sections (e.g. 11/30a-9), the coal occurs as substantial in-situ beds, identifiable by the characteristic gamma-ray, velocity, and resistivity-log responses. The coal is about 1m thick in well 11/30-1, and described as pyritic and blocky with a dull laminated structure. In such sections, the coal probably occurs as thin layers within mudstone, as indicated by the association of high gamma-ray values and low velocities (e.g. 11/25-1). Thin, sporadic coals occur at other levels in some sections (e.g. 11/25-1).

Upper boundary
The boundary between the Brora Coal Formation and the overlying Beatrice Formation is defined by the top of a thin unit of coal-bearing mudstone, distinguished on wireline logs by one or two low-velocity spikes. In many sections, a discrete coal seam occurs at the top of this unit (e.g. 11/30a-9). Other sections show a coal seam at a lower level within the unit (e.g. 11/25-1), but in many sections any coals are too thin to be detected on wireline logs (e.g. 12/21-3).

Lower boundary
Where the Brora Coal Formation overlies the Orrin Formation (e.g. 11/25-1), the boundary is marked by a downward passage from interbedded mudstones and sandstones, with sporadic coaly levels, to massive sandstones. This boundary generally coincides with a downward transition from high average gamma-ray values and low velocities to low and variable gamma-ray values and a somewhat higher and less variable velocity signature.
In some sections, the bulk of the Brora Coal Formation is absent, and the thin coaly unit that elsewhere occurs at the top of the formation appears to rest directly on representatives of the Dunrobin Bay Group (e.g. 12/26-1, Panel 8).

Lithostratigraphic subdivision
A thin unit of coal-bearing mudstone, characterized by low-velocity spikes, is a consistently recognizable feature at the top of the formation, and is here given the informal name Brora Coal Unit. It consists of mudstone and coal in varying proportions, individual coal seams being sufficiently thick to be detectable on wireline logs in about half of the wells studied. A thin sandstone bed is locally present within the unit (e.g. 11/25-1, immediately above the coal).

Distribution and thickness
The Brora Coal Formation is mainly confined to the northwestern part of the Inner Moray Firth Basin, with the Brora Coal Unit extending eastwards beyond the limits of the underlying alluvial-plain deposits (e.g. 12/26-1, Panel 8). The western (onshore) and southern limits of the formation are erosional at outcrop; its eastern limit is erosional beneath Callovian strata (Beatrice Formation).
The Brora Coal Formation reaches a maximum thickness in the Beatrice Field area, where it ranges up to about 180m (e.g. 11/30a-9).

Regional correlation
The coal bed that locally occurs at the top of the Brora Coal Unit (e.g. 11/30a-9) is believed to be equivalent to the Brora Coal bed of onshore sections. The Inverbrora and Doll members of Hurst (1981) have not been identified in offshore sections.

Genetic interpretation
Linsley et al. (1980), Curry & Fisher (1982) and Stephen et al. (1993) described the succession in the Beatrice Field area in terms of coastal, alluvial flood-plain deposits. They interpreted the mudstones as floodplain deposits of a swamp environment. The sandstones are interpreted as fluvial channel levee and crevasse-splay sediments, deposited by dominantly meandering rivers. The presence of the freshwater/brauckish alga Botryococcus and a general absence of dinoflagellate cysts indicates that freshwater conditions were dominant, with minor brackish-marine influence near the top and base and also just above the middle of the formation (Curry & Fisher 1982). On the basis of dinoflagellate cyst assemblages and lithofacies evidence, MacLennan & Trewin (1989) contrasted the dominantly alluvial-plain deposits beneath the Brora Coal in the Beatrice Field with the more marine-influenced, lagoonal Inverbrora Member onshore.
The Brora Coal may have accumulated in a silted-up lagoon area, although initial organic deposition was probably from drifted plant material (MacLennan & Trewin 1989). Andrews & Brown (1987) proposed that erosion of Bathonian and older strata may have preceded the deposition of the Brora Coal and its offshore equivalents. The phase of widespread coal accumulation thus probably represents the onset of the early Callovian transgression, with the coal originating in a back-barrier setting (Andrews & Brown 1987).

Biot stratigraphic characterization
None of the specified biomarkers has been recorded, but dinoflagellate cyst indicative of the early Callovian are present near the top of the formation onshore (MacLennan & Trewin 1989).

Age
Bajocian to Bathonian, according to Linsley et al. (1980), Bathonian according to Lam & Porter (1977) and Stephen et al. (1993). MacLennan & Trewin (1989) assigned an earliest Callovian age (discus to early macrocephalus zones) to the uppermost part of the Brora Coal Formation. Sykes (1975) reported koeni Gi Zone ammonites from the overlying Brora Roof Bed onshore. Using biot stratigraphic data, Stephen et al. (1993) suggested that the base of the Brora Coal Formation marks a major, basin-wide unconformity which spans the latest Toarcian, Aalenian and Bajocian. However, in the Beatrice Field area, the boundary between the Orrin and Brora Coal formations appears conformable and possibly indicates no significant time break between these poorly dated formations (Stevens 1991).

References
See also Correlation Panels 8, 9.
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The term Hugin Formation was introduced by Vollset & Doré (1984) for a unit of marine sandstones and mudstones with thin coals, lying between the marine mudstones of the Heather Formation and the heterolithic continental deposits of the 'Steinper Formation' (Pentland Formation equivalent) in the Norwegian South Viking Graben. It is here extended to the UK South Viking Graben and the Unst Basin.

The term has previously been applied to UK sections by Harris & Fowler (1987) and Richards (1989), and in completion reports by some companies. However, the term 'Beryl Formation' has also been widely used by Mobil for the same strata. The term Hugin Formation is used in preference to Beryl Formation because of the demonstrable continuity with the Norwegian strata and on the grounds of nomenclatural priority. Other names in common use are 'Bruce A', 'Bruce B' and 'Bruce Upper Sands' (BP), 'Upper Beryl Sand', 'Young Upper Beryl Sandstone' and 'Angus Sand' (Mobil), 'Sand/Shale Unit' and 'Massive Sandstone' (Conoco).

**Type section**

N15/9-2 (Vollset & Doré 1987, p.37, fig.26): 3483-3657m below KB.

**UK reference sections**

1/4-1: 700-772m (2296-2533ft)
9/13-12: 3362-3501m (11030-11486ft)
9/19-5A: 3358.5-3650.5m (11018-11976ft)
16/18-1: 3667-3869.5m (12030-12695ft)

**Name.** From one of Odin's ravens in Norse mythology (Vollset & Doré 1984, p.37).

**References**


Lithology
The Hugin Formation consists of sandstones, siltstones and mudstones with minor coals and conglomerates. In the Beryl Embayment, the formation consists mostly of very fine to fine grained sandstones. The sandstones include two main facies: sharp-based, upward-fining, cross-bedded, more or less bioturbated sandstones and uniformly graded, rippled, bioturbated and possibly hummocky cross-laminated sandstones. Bioturbated and fluidized sandstones containing bivalve shells and belemnites shells are dominant in well 9/9-6 (not illustrated). The sandstones are interbedded with siltstones, which are more common in the lower part of the formation. Lenticular bedded siltstones are present, associated with thin coals, together with bioturbated sandy siltstones, which include thin beds of sharp-based, very fine grained sandstones containing infrequent burrows (e.g. 9/8-7, not illustrated). Two thin lag conglomerates are present, one at the base of the formation, the other near the middle.

In the South Viking Graben, immediately to the southeast of the Beryl Embayment (Blocks 9/18 and 9/19), the Hugin Formation comprises interbedded sandstones and siltstones which often contain bivalve debris, usually composed of Neomiodon and/or oyster shells. The sandstones are often sharp-based and fine upwards from medium to fine grained; they are cross bedded, sometimes bioturbated and infrequently slumped. Coals occur at some levels. In some wells (e.g. 9/19-5A) the succession appears to become sandier upwards. Further south, in Quadrant 16, the formation comprises very fine to fine grained, argillaceous, bioturbated, rippled and parallel-laminated, upward-coarsening sandstones interbedded with upward-fining, cross-bedded sandstones, grey mudstones, coals, and pebble-lag deposits.

In the extreme south of the Viking Graben, the Hugin Formation is dominated by sandstones with sporadic thin coal-seams. The Hugin Formation is variably fossiliferous, with non-marine and marine bivalves, belemnites and ammonites recorded.

Upper boundary
The top of the Hugin Formation is marked by a downward transition from mudstones or siltstones of the Heather Formation to sandstones with variable amounts of interbedded siltstone and mudstone. This transition is marked by a distinct downward decrease in gamma-ray values and increase in velocity.

Lower boundary
The base of the Hugin Formation is defined by a downward transition from marine sandstones and siltstones/mudstones with minor coals, to more frequently coal-bearing and/or volcanic strata of the Pentland Formation. There is no consistent change in the proportion of sandstone to mudstone, and consequently no consistent change in wireline-log signature (e.g. 9/19-5A, 16/18-1). The boundary can be difficult to define in sections where both the Hugin and Pentland formations contain abundant coals throughout, although cores help differentiate the predominantly marine strata of the Hugin Formation from the predominantly continental strata of the Pentland Formation.

Lithostratigraphic subdivision
Informal subdivisions are possible locally, based on the proportion of sandstone to mudstone, but no consistent regional subdivision is recognized.

Distribution and thickness
The Hugin Formation is recognized primarily in the Beryl Embayment and South Viking Graben, although Richards (1990) has recorded its presence in the Unst Basin. It extends northwards to about 60°N and southwards to about 58°20’N, although it is absent through erosion in many parts of the South Viking Graben. It extends eastwards into the Norwegian Viking Graben.

The formation attains a maximum thickness of about 300m in the Beryl Embayment and adjacent parts of the South Viking Graben and probably thins to the south.

Regional correlation
The Hugin Formation passes laterally and vertically into siltstones and mudstones of the Heather Formation and, in places, laterally into Pentland Formation. The sandstones with sporadic coal seams in the extreme south of the Viking Graben may pass laterally into marine sandstones of the Fulmar Formation.

Genetic interpretation
Richards (1989) interpreted the depositional setting of the Hugin Formation in the Beryl Embayment as a coastal barrier to shoreface/offshore system showing storm influence, whereas Mitchener et al. (1992) suggested that deposition took place in alluvial-fan, fan-delta and storm-influenced shelf environments. In the South Viking Graben, the formation was interpreted by Harris & Fowler (1987) as a barrier-shoreline system.

Biostratigraphic characterization
The P.prolongata, C.hyalina, A.aldorfensis and M.valdensis regional biomarkers have been recorded from the Hugin Formation.

Age
Late Bajocian to Bathonian in the Beryl Embayment; late Bajocian to Callovian and probably Oxfordian in the South Viking Graben.

References

See also Correlation Panel 10.
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PENTLAND FORMATION

The term Pentland Formation was introduced by Deegan & Scull (1977) for a coal-bearing heterolithic sequence of paralic sandstones, siltstones and mudstones that lay between non-marine Triassic sediments and marine Humber Group sediments. In this report, the top of the formation in the type well is redefined (following Turner et al. 1984) at the base of a thin transgressive unit of Heather Formation siltstones (see Correlation Panel 9).

Several synonyms have been used for the Pentland Formation. In the Beryl Embayment / South Viking Graben area, Vollset & Dore (1984) used the term Sleipner Formation, as part of the Vestland Group, whereas Richards (1989) used the Sleipner Formation as part of the Beryl Group. In the same area, Mobil used the terms ‘Middle Beryl Sandstone’ and ‘Linnhe Formation’ (as part of the ‘Beryl Embayment Group’), BP and Hamilton used ‘C Sands’, and Conoco used ‘Coal Unit’. In the Central North Sea, Vollset & Dore (1984) used the term Bryne Formation (Vestland Group), while the name ‘Parry Sandstones’ was used by Ultramarin in the Moray Firth.

A coal-bearing unit that overlies the main part of the Pentland Formation in the Outer Moray Firth is here referred to as the Stroma Member. This unit was included within the Piper Formation by Deegan & Scull (1977), but it was placed by Turner et al. (1984) in the Pentland Formation. It was included by Harker et al. (1987) in the bauld part of their new ‘Sgiath Formation’, and by Harker et al. (1993) in the lower part of the ‘Skenie Member’ of the Sgiath Formation (see table on p.55).

Volcanic rocks are a major component of the Pentland Formation, and are here assigned to two new members, the Rattray Volcanics Member and the Ron Volcanics Member. The Rattray Volcanics Member equates with the Rattray Formation of Deegan & Scull (1977). It is here downgraded to member status because of the difficulties of adequately defining its upper and lower boundaries due to its being interbedded with the sediments of the Pentland Formation. Deegan & Scull (1977) originally defined the Pentland/Rattray boundary on the basis of percentage of volcanic material, but such a definition is not considered practicable at formation level in this report.

The newly defined Ron Volcanics Member describes the intra-Pentland Formation volcanic rocks centred on the area of block 29/14 in the West Central Graben. These volcanics are related to the Puffin volcanic centre (Smith & Ritchie 1993); they have not previously been formally named, having been usually referred to the Pentland Formation on completion logs.

Type section
15/17-4 (Deegan & Scull 1977, p.21, fig.24): 2663.5-2777.5m (8739-9112ft) below KB (revised depths). Illustrated in Correlation Panel 9.

Reference sections
9/13-12: 3501-3584.5m (11486-11760ft)
9/19-5a: 3650.5-3767m (11976-12358ft)
16/18-1: 3869.5-4380.5m (12695-14372ft)
29/12-1: 2846.5-3078.5m (9339-10100ft)

Name. From the Pentland Firth (Deegan & Scull 1977, p.21).

Formal subdivisions
Rattray Volcanics Member p.89
Ron Volcanics Member p.93
Stroma Member p.95

References
Lithology

The Pentland Formation displays a complex association of sedimentary and volcanic rocks. The sediments consist of interbedded sandstones, siltstones, mudstones, and coals; the volcanic rocks include tuffs, lavas and intrusives.

In the Beryl and Bruce field areas of the Beryl Embayment the formation comprises variably interbedded sandstones, siltstones and shales with more minor coals developed near the top and base of the succession. The formation has a higher proportion of sandstone in the Bruce Field area than in the Beryl Field area, as reflected in the more uniform gamma-ray log signature. The sandstones are frequently sharp based, often fining upwards from coarse to very fine grained, and are sometimes cross-bedded. Parallel lamination and bioturbation occur in some of the very fine grained sandstones. Associated siltstones and mudstones are variable: some are lenticular bedded and more or less bioturbated, whereas others include rootlets and are waxy, with a blocky fracture. These sediments are largely free of volcanic debris.

In the South and Central Viking Graben, the Pentland Formation is developed in similar facies to those recognized within the adjacent Beryl Embayment, but coal beds occur at numerous levels throughout the succession, rather than just at the top and base of the formation. Volcanic and intrusive igneous rocks of the Rattray Volcanics Member are also found locally, particularly in block 16/17 and southwards.

In the Outer Moray Firth and Central Graben, the sedimentary succession of the Pentland Formation is similar to that of the South Viking Graben, with volcanic and igneous rocks of the Rattray Volcanics Member and Ron volcanics Member developed locally. In wells 30/1c-3 (Panel 10) and 30/1c-2, the Pentland Formation has a distinctive, upward-coarsening, lacustrine mudstone at its base. This is superficially similar in log character to the Fjerritslev Formation of nearby Danish sections, but contains a Bathonian freshwater microflora.

F101. The Rattray Volcanics Member is developed in the South Viking Graben, Outer Moray Firth and northern parts of the Central Graben, where it locally comprises much or all of the thickness of the formation. Individual lavas are 1 to 9 metres thick, and are commonly porphyritic, with abundant phenocrysts of olivine and clinopyroxene; microphenocrysts of plagioclase are also present, in a matrix which generally consists of plagioclase, titanugaitte, magnetite, ilmenite, apatite and rare analcime. The lavas are predominantly undersaturated, with alkali olivine basalt affinities, and include ankarite, alkali olivine basalt, hawaite and mugearite (Fall et al. 1982). The associated agglomerates, tuffs and fulfaceous claystones are varicoloured, pyritic, chloritic, sometimes felsic, calcareous and/or glassy. Sandstones and mudstones are interbedded with the volcanics in places.

The Ron Volcanics Member is developed in the southern part of the Central North Sea, and locally forms much, or all, of the Pentland Formation succession. The lavas and intrusives are undersaturated basalts considerably enriched in potassium and incompatible trace elements, forming part of an ultrapotassic series (Latin et al. 1990a, b).

Upper boundary

The Pentland Formation is generally overlain by Hugin Formation sandstones and mudstones in the Beryl Embayment and South Viking Graben, by Heather Formation mudstones in the Outer Moray Firth, and by Fulmar Formation sandstones or Heather Formation mudstones in the Central North Sea. In the Inner/Outer Moray Firth transition area, it is locally overlain by the Alness Spiculite Member. No single lithological or wireline-log definition of the top of the Pentland Formation can therefore be given, except that it is marked by a downward change to heterolithic, often coal-bearing sediments or to volcanics.

Lower boundary

The Pentland Formation unconformably overlies Permian, Triassic and Lower Jurassic sediments. Where the formation overlies Permian (e.g. 15/18-2, not illustrated), the base is marked by a downward change from coal-bearing sediments and/or volcanics to evaporite-bearing sediments, with an associated downward increase in gamma-ray values and increase in velocity.

Where the formation overlies Triassic strata (e.g. 16/18-1, 29/12-1), the boundary is picked at the downward transition from grey, coal-bearing sediments and/or volcanics to brick-red siltstones and sandstones. There is commonly no distinctive wireline-log break at this boundary, although the average gamma-ray values may increase downwards (e.g. 29/12-1).

Where the formation overlies Lower Jurassic strata (e.g. 9/13-12, 9/19-5A), the boundary is picked at the downward transition from interbedded sandstones, siltstones and coals to predominantly grey siltstones with minor sandstones.

Lithostratigraphic subdivision

The Pentland Formation as originally defined was undivided (Deegan & Scull 1977). Three new members are proposed within the newly revised Pentland Formation: the Stroma Member (p.95), comprising coaly sediments at the top of the formation in the Outer Moray Firth, the Rattray Volcanics Member (p.89), comprising volcanics in the Outer Moray Firth, and the Ron Volcanics Member (p.93), comprising volcanics in the southern Central Graben. It is suggested that the informal term Linthe unit may be used to describe the essentially non-volcanic sediments in the Beryl Embayment.

Distribution and thickness

The Pentland Formation is recorded in the Beryl Embayment, South Viking Graben, Central Graben, Outer Moray Firth and Unst Basin. It extends eastwards into Norwegian waters, where it is referred to the Sleipner and Bryne formations.

The formation attains a maximum thickness of about 500m in the Viking Graben, but is nearly 1,500m thick in well 21/3-3, where most of the section comprises volcanic and igneous rocks. Sediment-dominated successions in the Central North Sea attain a maximum thickness of about 550m, whereas sequences in the Outer Moray Firth are mostly less than 200m thick.

The western boundary of the formation is probably erosional in most places.

Regional correlation

In the South Viking Graben, the upper part of the Pentland Formation probably passes laterally northwards into Hugin Formation deposits.

Genetic interpretation

The Pentland Formation was probably deposited in a range of paralic to delta-plain/fluvial/plain-environments, with substantial accumulation of volcanogenic materials around the volcanic centres. Richards (1991) characterized the bulk of the formation in the Beryl Embayment as an estuarine deposit, and the succession in the Viking Graben as essentially alluvial.

Biot stratigraphic characterization

The Pentland Formation is dominated by long-ranging miozones, with marine algae and bivalves developed locally (Latin et al. 1990a,b). The N.gracilis biomarker is sporadically present.

Age

Toarcian/Aalenian to Oxfordian. In the Beryl Embayment and northern parts of the South Viking Graben, the top of the formation probably lies within the Bajociian, whereas in the south of the South Viking Graben it may range up to Callovian. In the Central North Sea, the Rattray Volcanics Member has been radiometrically dated as probably Callovian (Ritchie et al. 1988). In the Outer Moray Firth, the coal-bearing sediments are mostly referred to as Bajocian/Bathonian in completion logs, but the Stroma Member is believed to be of Oxfordian age (see p.96). Turner et al. (1984) and Smith & Ritchie (1990) suggested that locally the coaly succession may range from Aalenian to Oxfordian.

References

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Rattray Volcanics Member

The term 'Rattray Formation' was introduced by Deegan & Scull (1977) for a thick series of basaltic lava flows, with interbedded agglomerates, tuffs and tuffaceous sediments, lying between pre-Jurassic rocks and sediments of the Humber Group as then defined. The unit is now considered to have been associated with sedimentation of the Pentland Formation, and it is renamed the Rattray Volcanics Member.

Type section
21/10-1 (Deegan & Scull 1977, p.20, fig. 23): 2680-3422.5m (8792-11228ft) below KB. (Illustrated in Correlation Panel 10.)

Reference sections
16/17-6: 4874-5135m (15990-16847ft)
15/18-2: 2874-3045m (9428-9990ft)
21/3b-3: 2940-4148m (9646-13609ft)
22/5b-4: 3596.5-4121m (11799-13520ft)

Name. From Rattray Head on the eastern coast of Scotland (Deegan & Scull 1977, p.20).

References
Lithology
The Rattray Volcanics Member is composed of lavas, volcanics and subordinate clastics. Individual lava flows are 1 to 9m thick. The lavas are predominantly undersaturated, with alkali olivine basalt affinities, and include ankaramites, alkali olivine basalts, hawaiites and mugearites (Fall et al. 1982). They are commonly porphyritic, with abundant phenocrysts of olivine and clinopyroxene. Microphenocrysts of plagioclase are also present, in a matrix which generally consists of plagioclase, titanomagnetite, ilmenite, apatite and rare analcime. The associated agglomerates, tuffs and tuffaceous claystones are varicolored, pyritic, chloritic, sometimes felsic, calcareous and/or glassy. Sandstones and mudstones are interbedded with the volcanics in places.

Upper boundary
The Rattray Volcanics Member is variously overlain by coal-bearing sediments of the Pentland Formation, or by marine sandstones or mudstones of the Piper, Hugin, Heather or Kimmeridge Clay formations. The top of the member is therefore always recognized by the downward transition from a dominantly sedimentary succession to a dominantly volcanic succession.

Lower boundary
The member variously overlies coal-bearing sediments of the Pentland Formation, Lower Jurassic mudstones, Triassic red beds or Permian evaporites. Its basal boundary is therefore picked at the downward transition from predominantly volcanic rocks to sediments.

Distribution and thickness
The Rattray Volcanics Member is developed in the South Viking Graben and northern parts of the Central Graben. The member can occur anywhere within the vertical succession of the Pentland Formation, either overlying, underlying or interbedded with coal-bearing sediments. The local interfingering of volcanics with sediments means that the member may occur at more than one level within the Pentland Formation, even in individual sections. It attains a maximum thickness of nearly 1,500m in well 21/3b-3.

Genetic interpretation
The volcanics were extruded as lava flows over a range of paralic to fluvial/delta plain environments.

Age
The Rattray Volcanics Member has been dated by Ritchie et al. (1988) as 153±4 Ma using the 40Ar/39Ar method.

References
See also Correlation Panel 10.
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Ron Volcanics Member (new)

The term Ron Volcanics Member includes volcanic rocks that were formerly a part of the 'Rattray Formation' of Deegan & Scull (1977). The term is used for a thick sequence of geographically separate volcanic rocks that occur in several wells in blocks 29/9 and 29/14 in the Central Graben.

Type section
29/14b-3: 3121-3714m (10240-12185ft) below KB.

Reference section
29/14a-4: 3121-3714m (10240-12185ft)

Name. From the Ron lighthouse at Rattray Head, north-east Scotland.

References

Lithology
The Ron Volcanics Member is composed of variegated (purple-grey, greenish grey, red-brown, yellow-brown) porphyritic, alkaline basalt lava flows, interbedded with tuffaceous volcaniclastics and cut by igneous intrusions. The individual basaltic flows sometimes show an upward transition from an unweathered basal section, with dark green, fresh, pyroxene phenocrysts in a finer groundmass, to a more weathered and altered top, suggestive of sub-aerial eruption phases. Amygdaloidal and glasy textures are common to some flows, with the amygdalas often infilled with white zeolites. Fine veins of white to brown carbonate also cross-cut the flows.

The basalt flows generally show overall low-gamma / high-velocity responses but are interbedded with units showing much higher values. The latter units probably reflect the presence of either potassium-rich intrusive igneous rocks (see Fall et al. 1982) or interbedded argilaceous sediments.

Upper boundary
The Ron Volcanics Member is variably overlain by coal-bearing sediments of the Pentland Formation, marine mudstones of the Heather and Kimmeridge Clay formations and marine sandstones of the Fulmar Formation. Thus, although the top of the member is always recognized by an abrupt downward transition from sedimentary to volcanic rocks, the wireline-log response is variable, with some sections showing no distinctive features at the boundary (29/14a-4).

Lower boundary
The member variously overlies coal-bearing sediments of the Pentland Formation, Triassic red-beds or Zechstein evaporites. The base of the formation is picked at the abrupt downward change from volcanics to sedimentary sequences and may or may not be accompanied by marked log breaks (29/14b-3).

Distribution and thickness
The Ron Volcanics Member has a very restricted areal distribution within Quadrant 29 of the Central Graben. The member attains a maximum thickness of 1945m in well 29/14b-3.

Genetic interpretation
The volcanics were probably extruded sub-aerially as lava flows in association with a range of fluvial to paralic environments. Later intrusive igneous phases cross-cut the sequence.

Age
The Ron Volcanics Member is considered to be coeval with the Rattray Volcanic Member (Ritchie et al. 1988, Smith & Ritchie, 1993) and by analogy may be of Bathonian to Callovian age.

References
Stroma Member (new)

The term Stroma Member is introduced for a unit of heterolithic coal-bearing sediments that constitutes the uppermost part of the Pentland Formation in the Outer Moray Firth. It is believed to be separated from the remainder of the Pentland Formation by a substantial hiatus (Harker et al. 1993), although no specific biostratigraphic data are available on the Stroma Member itself. The Stroma Member is overlain by paralic and marine sediments of the Heather Formation, containing fossils of Oxfordian age.

The sediments of the Stroma Member were originally included in the Piper Formation by Deegan & Scull (1977). Turner et al. (1984) included them within the Pentland Formation. However, Harker et al. (1987) included them in a newly proposed ‘Sgiath Formation’, which has since been divided into members by Harker et al. (1993), with the Stroma sediments falling within the basal ‘Skene Member’.

The Stroma Member is equivalent to the lower part of the ‘Paralic Unit’ of O’Driscoll et al. (1990), to the ‘Coal Unit’ of Boldy & Brealey (1990), and to the ‘Coal Marker Member’ of Coward et al. (1991) (see table, p.55).

Type section
15/21a-15: 3584.5-3607m (11760-11834ft) below KB.

Reference sections
14/19-2: 2745.5-2770.5 (9007-9089ft)
15/17-9: 4144-4160.5m (13592-13650ft)
20/2-6: 3995.5-4035m (13108-13239ft)

Name. From the island of Stroma in the Pentland Firth.

References


Lithology
The Stroma Member consists dominantly of interbedded sandstones, carbonaceous silty mudstones and coals. The coals are over 6m thick locally, (e.g. 20/2-6). Six main lithofacies are recognized (Harker et al. 1993): (i) laminated silty mudstones with a thin poorly sorted basal lag sandstone, (ii) thinly interbedded sandstones and silty mudstones with abundant plant remains, (iii) fine-grained ripple and planar bedded sandstones, (iv) upward-coarsening, cross-beded and massive sandstones, (v) upward-fining cross-bedded sandstones, with gravel-lag bases and common plant rootlets in their upper parts, and (vi) silty coals grading to carbonaceous silty mudstones. In the Claymore Field area, these facies are arranged in overall upward-coarsening cycles which range from 3m to 10m in thickness (Harker et al. 1993). According to Maher & Harker (1987), the sandstones in the Claymore Field are subarkosic. Very locally, in blocks 15/17 and 15/18, to the east of the Piper Field, the Stroma Member contains reworked volcanics (Harker et al. 1993).

Upper boundary
The top of the Stroma Member in the type well (15/21a-15) is defined by a sharp downward transition from silty mudstones (Heather Formation) to coal. It is marked by a sharp downward decrease in gamma-ray values, decrease in velocity, and increase in resistivity. In the South Halibut Basin, the upper boundary of the Stroma Member commonly corresponds to the top of a coal (e.g. 20/2-6). However, in the Witch Ground Graben, the top of the Stroma Member is commonly marked by a downward transition from the mudstone-dominated succession of the Heather Formation to sandstones with interbedded mudstones and coals (e.g. 14/19-2, 15/17-9, 20/2-5, p.41); here, the boundary is best picked at the downward decrease in gamma-ray values. Carbonaceous sandstones of the Stroma Member are locally overlain directly by thin glauconitic marine sandstones of the Pibroch Member (Piper Formation) (e.g. 14/19-4, Panel 19, and see Harker et al. 1993, fig.5). By analogy, a thin Pibroch sandstone may be present in well 14/19-2, but, in the absence of evidence from core, the entire sandstone section is here assigned to the Stroma Member.

Lower boundary
The Stroma Member overlies a variety of lithofacies. In the type well (15/21a-15), the base is defined by a downward change from mudstones to tuffs and basaltic flows (Rattray Volcanics Member). It is marked by a downward decrease in average gamma-ray values and slight downward increase in velocity. Elsewhere in the Witch Ground Graben, coals, sandstones and mudstones of the Stroma Member rest on tuffaceous mudstones and sandstones of the Pentland Formation (e.g. 15/17-9), on grey, green and brown sandstones and siltstones of the Skagerrak Formation (e.g. 14/19-2) or reddish brown mudstones of the Smith Bank Formation (see Harker et al. 1993, fig.8). Where the Stroma Member overlies paralic sediments of the Pentland Formation (undifferentiated), the boundary cannot be placed with any certainty.

In the South Halibut Basin, interbedded sandstones, mudstones and coals of the Stroma Member commonly rest on sandstones of the Lossiehead Formation (e.g. 20/2-6) or reddish brown and grey Triassic mudstones of the Smith Bank Formation (e.g. 20/3-4, not illustrated). Locally, it overlies Permian carbonates and evaporites (e.g. 20/4-2, not illustrated).

Distribution and thickness
The Stroma Member is patchily distributed across the Witch Ground Graben and South Halibut Basin. Precise definition of its limits is hampered by the difficulty of distinguishing Stroma sediments from the older sediments of the Pentland Formation. Thus although Bajocian/Bathonian ages have been assigned to the thick successions of interbedded mudstones, sandstones and thick coal that overlie volcanics in wells 20/5-2 and 21/1-5, palaeontological reassessment may reveal that all or a significant proportion of these sections belong to the Stroma Member.

The thickness of the Stroma Member is highly variable, reaching a maximum of about 40m. The sandstones are thickest in the area of the Claymore Field in the Outer Moray Firth (e.g. 14/19-2) and in parts of the South Halibut Basin (e.g. 20/2-6).

Regional correlation
The Stroma Member interdigitates with the lower part of the Heather Formation in the Outer Moray Firth. Lateral equivalents of the Stroma Member are possibly present in the Central Gruben area (Smith & Ritchie, 1993). For example, parts or all of the coaly sections overlying volcanics of the Rattray Member in block 21/15 may equate with the Stroma Member.

Genetic interpretation
The Stroma Member was deposited in paralic, delta and lagoonal environments, and apparently represents drowning of a peneplaned surface of mid-Jurassic and older rocks during the mid-Oxfordian transgressive phase (Harker et al. 1987; Boote & Gustav 1987; Harker et al. 1993; Partington et al. 1993).

Biosтратigraphic characterization
The coal-bearing Stroma Member is dominated by long-ranging pteridophyte spores.

Age
Probably mid Oxfordian (Harker et al. 1993; Partington et al. 1993, table 1), on the basis of dating of the overlying marine mudstones.

References
Stroma Member

PENTLAND FORMATION

DISTRIBUTION MAP

LITHOLOGY

- Calcareous Sandstone
- Sandstone
- Mudstone
- Coal
- Tuff, occasional volcanic glass and basalt

Key Elements:

- Late Jurassic
- Middle Jurassic
- Early Jurassic

 formations:

- Pentland Formation
- Skagerrak Formation
- Kimmeridge Clay Formation

- Clays
- Shales
- Sandstones
- Coal beds

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- Stroma Member
- Stroma Member
The definition of the Brent Group used here follows that of Deegan & Scull (1977), but with the boundaries of some of the constituent formations slightly redefined. Five constituent formations are recognized: the Broom Formation, Rannoch Formation, Etive Formation, Ness Formation and Tarbert Formation. Deegan & Scull (1977) named the individual formations after Scottish lochs, arranging the names in ascending order to form the acronym BRENT. The group forms a broadly regressive-transgressive wedge of coastal and marine sediments, recording the progradational outbuilding and subsequent retreat of a deltaic system (Richards 1992). The basal Broom Formation represents laterally derived fan-delta deposits (Richards & Brown 1987), whilst the overlying Rannoch and Etive formations record shallow-marine shoreline and barrier-bar systems sourced dominantly from the south and southwest (Richards & Brown 1986; Brown et al 1987; Richards 1990). The heterolithic, coal-bearing Ness Formation, which overlies barrier-bar sediments of the Etive Formation, represents a delta-top succession deposited initially during progradation of the delta system, but subsequently during its landward retreat (Grau et al 1987). The Tarbert Formation, at the top of the group, represents the progressive drowning of the delta (Brown et al 1987).

The Brent Group is the major reservoir interval of the Northern North Sea, and extends across the East Shetland Basin into the North Viking Graben. The group is up to 300m or so thick in the structurally deepest parts of the East Shetland Basin, but may be somewhat thicker near the axis of the North Viking Graben. The lower part of the group (Broom, Rannoch and Etive formations) is dominantly very fine to coarse sandstone with only minor mudstone development. The Broom Formation is generally the coarsest grained unit, and the Rannoch and Etive formations form an upward-coarsening succession above it. The middle part of the group (the Ness Formation) comprises up to about 50 per cent mudstone and coal, while the Tarbert Formation at the top is dominated by very fine to fine grained sandstones similar to those of the Rannoch Formation.

Although the formations within the Brent Group are well established and routinely applied, precise definitions are hampered by a marked lateral variability in lithological succession and wireline-log character that is a reflection of complex facies relationships coupled with variation in stratigraphic completeness. These problems have been partly overcome through exceptional core coverage, which has allowed formation boundaries to be recognized on relatively detailed lithological criteria. In uncored sections, however, it is not uncommon to experience difficulty in the precise location of formation boundaries. These problems are discussed more fully in the following pages.

The Brent Group was originally named as the Brent Formation by Bowen (1975); there are no other common synonyms in general usage.

### References


### BRENT GROUP

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### Name

From the Brent field in the East Shetland Basin.

### Age

Aalenian to Bajociian.
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**BROOM FORMATION**

The term 'Broom Sub-unit' was introduced by Deegan & Scull (1977) for pebbly sandstones lying between mudstones of the Dunlin Group and sandstones of the 'Rannoch Sub-unit'. Deegan & Scull gave the unit formation status in the UK North Sea but member status in the Norwegian North Sea. The Broom Formation equates with the 'Basal Sand Bed' of Bowen (1975), and is referred to as the 'Basal Sand' on some composite logs.

**Type section**
211/29-3 (Deegan & Scull 1977, p.16, fig.20): 2818-2829m (9245-9283ft) below KB.
(Illustrated in Correlation Panel 3.)

**UK reference sections**
- 210/24-2: 2228-2244.5m (7310-7363ft)
- 211/11-1: 3139.5-3161m (10300-10371ft)
- 211/19-5: 3250-3255.5m (10662-10680ft)
- 2/5-3: 3447.5-3462.5m (11310-11360ft)

**Name.** From Loch Broom in Scotland (Deegan & Scull 1977, p.16).

**References**
Lithology
The Broom Formation in the type section is characterized by pale grey to brown, coarse-grained, poorly sorted conglomeratic sandstone containing mudstone clasts.

In the western part of the East Shetland Basin (e.g. 2/5-3), the formation is composed dominantly of medium to coarse grained, commonly carbonate-cemented sandstones with bifurcating, subparallel to wavy, carbonaceous streaks. Mud units with floating, coarse sand grains occur, and burrows, including *Arenicolites*, are found at some levels. Slightly further east, in the northwest Hutton Field area, the formation consists predominantly of moderately well sorted, medium to coarse grained sandstones with metre-scale planar cross bedding and some burrows. In the southeastern part of the basin, particularly in the North Alwyn Field area, the formation includes coarse sandstones and conglomerates that are interbedded with hummocky cross-stratified, micaceous sandstones more typical of the Rannoch Formation. In the northeastern part of the basin (e.g. 211/19-5), in the Dunlin Field area, the formation is represented by coarse-grained sandstones with ferruginous ooliths (Richards 1992; Giles et al. 1992).

Upper boundary
Where the base of the Rannoch Formation is in sandstone facies, the top of the Broom Formation is defined by a downward change from medium to coarse-grained pebbly sandstone. Where the Rannoch mudstone unit is present, the top of the Broom Formation is defined by a downward change from micaceous mudstones to coarse sandstones. In sections where facies of Broom-type and Rannoch-type are interbedded, the top of the Broom Formation is arbitrarily taken at the top of the uppermost coarse-grained or pebbly sandstone.

In all sections, the top of the Broom Formation is marked by a downward decrease in gamma-ray values. Although the boundary appears sharp on wireline logs, it is seen in cores to be gradational.

Lower boundary
The boundary between the Broom Formation and the underlying Drake Formation is marked by a distinct downward lithological change from medium to coarse sandstone to mudstone, with a corresponding increase in gamma-ray values. There is often an accompanying downward increase in velocity, although this is not consistently displayed. Although the boundary appears sharp on wireline logs, it is seen in cores to be gradational.

Distribution and thickness
The Broom Formation is recognized over most of the East Shetland Basin north of about 6° 40'N. It is bounded to the west by the East Shetland Platform and to the north by the Magnus Ridge. Its eastern limit is depositional.

The formation is thickest in the southwestern part of the East Shetland Basin, where it attains a maximum thickness of about 50 m. Although the formation shows an overall eastward decrease in thickness, Brown et al. (1987) noted that the formation increases in thickness on the eastern (downthrow) sides of some intra-basinal, syn-depositional faults.

Regional correlation
The formation is equivalent to the lower part of the Pentland Formation to the south, but there is no information on the nature of any transition.

Genetic interpretation
The formation has been interpreted as a transgressive tidal-flat deposit (Hay 1978), as offshore sheet sands (Budding & Inglis 1981), and as a clift-base beach (Eynon 1981). More recently, Richards & Brown (1987) proposed that deposition took place in a fan-delta setting.

Biostratigraphic characterization
Because of its coarse grain size, the Broom Formation is frequently devoid of microfossils, but the *Parvocysta* spp. biomarker is present locally in the lower part of the formation.

Age
Aalenian.

References


See also Correlation Panels 2-4.
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ETIVE FORMATION

The term 'Etive Sub-unit' was introduced by Deegan & Scull (1977) for a unit of fine to medium grained sandstones lying between the Rannoch 'Sub-unit' and the 'Ness Sub-unit'. Deegan & Scull gave the unit formation status in the UK North Sea and member status in the Norwegian North Sea.

The formation equates with the 'Massive Sand Bed' of Bowen (1975).

Type section
211/29-3 (Deegan & Scull 1977, p.16, fig.20): 2772-2783m (9095-9130ft) below KB. (Illustrated in Correlation Panel 3.)

UK reference sections
211/18a-21: 3455.5-3503m (11334-11493ft)
211/19-6c: 3240-3271.5m (10629-10733ft)
211/27-10: 3583-3597.5m (11755-11802ft)
3/3-3: 3198-3212.5m (10492-10540ft)

Name. From Loch Etive in Scotland (Deegan & Scull 1977, p. 16).

References

Lithology

In the type well (211/19-3, Panel 3) the Etive Formation consists of brown to grey, massive, fine to medium grained, clean, cross-beded sandstones (Deegan & Scull 1977). Although superficially uniform in character across the East Shetland Basin, the Etive Formation displays significant vertical grain-size variations, as reflected in the gamma-ray log signatures. Upward-coarsening sections (e.g. 3/3-3, 211/27-10) consist mostly of massive, poorly laminated sandstones, with, in some sections, rare rootlet traces near the top. Uniform or slightly upward-finings (e.g. 211/18a-21) consist of sharp-based, upward-finining beds of course to fine grained sandstone, often displaying parallel laminatation, cross bedding and ripple laminatation. Thin coal beds have been recorded from near the base of upward-finining successions in the northeastern part of the East Shetland Basin. Sections with erratic gamma-ray profiles (e.g. 211/19-6) consist of stacked, sharp-based beds of upward-finining, indistinctly laminated sandstone, mostly fine-grained but occasionally coarse-grained.

A distinct gamma-ray peak that is not associated with mudstone facies occurs near the middle of the formation in many sections (e.g. 3/3-3, 211/27-10) and is attributable to the presence of radioactive minerals within the sandstone itself.

Upper boundary

Over most of the East Shetland Basin, the boundary between the Etive Formation and the overlying Ness Formation is drawn at the base of the lowest significant mudstone or coal bed (Deegan & Scull 1977). This lithological break is usually accompanied by a significant downward decrease in gamma-ray values.

In the northeastern part of the East Shetland Basin, the formation is overlain by sandstones of the Ness Formation or Tarbert Formation, with no distinctive argillaceous interval between (e.g. 211/19-6, 211/18a-21). In this area, therefore, the boundary does not conform to the Deegan & Scull (1977) definition, and can be difficult to identify with certainty on wireline-log character alone (Cannon et al. 1992, p.97). The problem is compounded by the Etive Formation displaying an anomalously erratic gamma-ray signature in some sections, for example in well 211/19-4, where the top of the Etive sandstone has been taken at the base of a locally continuous, high-gamma micaceous sandstone (Brown & Richards 1989).

The Etive Formation is locally overlain unconformably by siltstones and mudstones of the Heather Formation.

Lower boundary

The lower boundary of the Etive Formation is picked at a downward change from less micaceous and/or coarser sandstones to finer, more micaceous sandstones. This is reflected by a downward increase in gamma-ray values. The gamma-ray log break often corresponds to a downward increase in velocity. In cored successions, the lower boundary is usually sharp, and in some wells is defined by a downward change from medium/coarse-grained, structureless or indistinctly laminated sandstone to very fine grained, laminated sandstone. In other sections, however, the grain-size contrast between the Rannoch and Etive formations is much less pronounced.

Distribution and thickness

The Etive Formation is recorded in the East Shetland Basin north of about 60° 30′N, and extends eastwards into the Viking Graben. The formation thickens from southwest to northeast within the East Shetland Basin, attaining a maximum thickness of about 40m in the northern part of the basin.

Regional correlation

The formation is equivalent to upper parts of the Pentland Formation further south in the Beryl Embayment, but there is no information on the nature of any transition between the coastal sand and continental facies.

Genetic interpretation

The Etive Formation is a polygenetic unit representing a barrier-bar/delta-front system transected by distributary channels and possibly tidal channels (Budding & Inglin 1981; Brown et al. 1987; Brown & Richards 1989; Morton et al. 1992).

Biostratigraphic characterization

The Etive Formation is largely devoid of microfossils but has yielded rare miospores (Whitaker et al. 1992).

Age

Probably late Aalenian to early Bajocian.

References


See also Correlation Panels 2-4.
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NESS FORMATION

The term 'Ness Sub-unit' was introduced by Deegan & Scull (1977) for carbonaceous and coal-bearing sandstones lying between the Ervie Formation and the Tarbert Formation. Deegan & Scull gave the unit formation status in the UK North Sea and member status in the Norwegian North Sea.

The boundary between the Ness Formation and the overlying Tarbert Formation was originally defined as 'the top of the last prominent argillaceous bed', with any overlying sandstones comprising the Tarbert Formation (Deegan & Scull 1977). However, this definition is now considered insufficiently rigorous (see below).

The formation equates with the 'Middle Brent Sand Member' of Bowen (1975).

**Type section**
211/29-3 (Deegan & Scull 1977, p.17, fig.20): 2633.5-2772m (8640-9095ft) below KB.
(Illustrated in Correlation Panel 3.)

**UK reference sections**
- 210/24-2: 2147-2178m (7044-7146ft)
- 211/16a-5: 2775.5-2793.5m (9106-9165ft)
- 211/27-10: 11535-11755m (3516-3583ft)
- 3/3-3: 3124-3198m (10250-10492ft)

**Name.** From Loch Ness in Scotland (Deegan & Scull 1977, p.17).

**References**


Lithology

The Ness Formation consists of a heterolithic sequence of interbedded sandstones, siltstones, mudstones and coals (e.g. Livera 1989). The sandstones are variable in character; those interbedded with siltstones and mudstones, particularly in the lower parts of the formation, are typically thinly bedded, parallel laminated, ripple laminated, or hummocky cross-laminated. They are also bioturbated and often micaceous. Thin beds, up to a few centimetres thick, of carbonaceous, flaser-bedded to wavy-bedded sandstones also occur, interbedded with mudstones and coals; they sometimes display burrows and/or rootlet traces. Thicker beds, up to 5m or so thick, of sharp-based, upward-fining, more or less micaceous and carbonaceous sandstones occur most frequently in the upper parts of the formation, but are recorded throughout, and are sometimes stacked in units up to about 20m thick. They display cross-bedding, ripple lamination and parallel lamination.

Siltstones and mudstones are generally grey coloured, frequently lenticular bedded, and bioturbated, with small-scale gutter-casts developed locally. Some mudstones are structureless, have a blocky fracture, and contain plant fragments and rootlet traces; they are often overlain directly by coal. Coals are generally a few centimetres to tens of centimetres thick. They are found throughout the formation, but are often more common in the lower part.

Upper boundary

In the majority of sections, the top of the Ness Formation is marked by a sharp downward change from micaceous and/or bioturbated sandstones of the Tarbert Formation to more thinly bedded heterolithic sediments (e.g. 2/5-3, p.119). This is associated with a sharp downward change to more erratic gamma-ray values.

Where the Tarbert sandstones are thin (e.g. 211/27-10), they can be difficult to distinguish from the Ness Formation without the aid of core. Where core is not available, it is recommended that any thin sandstone at the top of the Brent succession be arbitrarily assigned to the Ness Formation (e.g. 210/24-2).

Recent studies have shown that the lower part of the Ness/Tarbert boundary may be complicated by local facies variations in either formation. For example, in well 211/16a-5 both the Ness and Tarbert formations are dominated by sandstones. In other sections, minor coals and mudstones are interbedded with Tarbert sandstones. In many cored sections, the boundary between the Ness and Tarbert formations can be identified in cored sequences by a coarse-grained lag deposit (Brown et al. 1987).

Where Ness Formation sediments are overlain directly by the Heather Formation, the upper boundary is picked at a downward change from grey siltstone with minor limestone to an interbedded succession of sandstone, mudstone and coal. This corresponds to a sharp downward decrease in gamma-ray values.

Lower boundary

Over most of the East Shetland Basin (e.g. 211/27-10, 3-3/3), the boundary between the Ness Formation and the underlying Etive Formation is drawn at the base of the lowest significant mudstone or coal bed (Deegan & Scull 1977). This lithological break is usually accompanied by a significant downward decrease in gamma-ray values.

In the northeastern part of the East Shetland Basin, there is often no distinctive argillaceous interval between the Ness and Etive sandstones (e.g. 211/19-4, 211/19-6, Panel 4). The boundary does not, therefore, conform to the Deegan & Scull (1977) definition, and can be difficult to identify with certainty on wireline-log character alone (Cannon et al. 1992).

The problem is compounded by the Etive Formation displaying an anomalously erratic gamma-ray signature in some sections, for example in well 211/19-6, where the top of the Etive sandstone has been taken at the base of a locally continuous, high-gamma micaceous sandstone (Brown & Richards 1989).

Lithostratigraphic subdivision

An informal, three-fold subdivision into a lower interbedded unit, a middle mudstone unit (often informally termed the 'Mid Ness Shale'), and upper sandstone-dominated unit is often applied to the formation (e.g. Richards 1982). Cannon et al. (1992) elevated these informal units to member status, terming them the 'Enrich, Oich and Foyers members' respectively. Subdivision into the three units is, however, possible only in the central part of the East Shetland Basin between 61°N and 61°25'N. Even within this limited area, identification of the subdivisions is difficult in many wells because the log responses of the three units are frequently similar (e.g. 211/27-4A, Panel 3). Furthermore, the vertical position within the formation of the middle unit ('Mid Ness Shale', 'Oich Member') ranges from near the middle in the central part of the basin, to near or at the base in the north, further complicating both its identification and the three-fold subdivision of the formation.

The availability of cores helps identification of the dominantly argillaceous middle unit, and can often aid differentiation of the dominantly channel sandstone deposits of the upper unit from the backbarrier deposits of the lower unit. However, because the three-fold subdivision cannot be consistently recognized without core, the three units are not formally defined here. It is recommended that, where required, these subdivisions be termed Ness units 1, 2 and 3, in ascending stratigraphic order.

Distribution and thickness

The Ness Formation is recorded in the East Shetland Basin north of about 60°30'N, and extends eastwards into the Viking Graben. The formation is thickest in the area between the Ninian-Hutton and Brent fault trends, attaining a maximum thickness of about 180m. It thins locally over structural highs.

Regional correlation

The lower part of the Ness Formation (deposited during advance of the Brent delta) may pass laterally southwards into the upper parts of the Pentland Formation in the Beryl Embayment, while the upper parts of the formation (possibly deposited in part during delta retreat) may pass southeasternwards into Hugin Formation deposits.

Genetic interpretation

The Ness Formation was deposited in a delta-top setting, partly during progradation of the Brent delta and partly during its retreat (Graue et al. 1987). Sub-environments such as lagoons, distributary channels, levees, mouth bars and lagoonal shoals have all been recognized (Livera 1989).

Biotaxonomic characterization

The N.deictiobasmos and N.gracilis biomarkers occur within the Ness Formation. Miospore assemblages are rich throughout the formation. Botryococcus and tasmanitids are common locally.

Age

Probably Bajocian.

References


See also Correlation Panels 2-4.
NESS FORMATION

Key Biomarkers
- C. hyalina
- H. pokrovkaensis
- N. gracilis
- A. yonsonabensis
- Agglut. foraminifera
- Parvocysta spp.
- V. subvitreus
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RANNOCH FORMATION

The term 'Rannoch Sub-unit' was introduced by Deegan & Scull (1977) for a unit of fine-grained sandstones lying between the 'Broom Sub-unit' (below) and the 'Etive Sub-unit' (above). Deegan & Scull gave the unit formation status in the UK North Sea and member status in the Norwegian North Sea.

The Rannoch Formation equates with the 'Micaceous Sand Bed' of Bowen (1975), and is referred to as the 'Micaceous Sand' on some composite logs. The term 'Rannoch Shale' is used on some composite logs for a mudstone unit that constitutes the basal part of the formation in some sections. This unit is here referred to informally as the Rannoch Mudstone unit.

Type section
211/29-3 (Deegan & Scull 1977, p.16, fig.20): 2783-2818 m (9130-9245ft) below KB.
(Illustrated in Correlation Panel 3.)

UK reference sections
211/13-7: 3695.5-3798.5m (12125-12462ft)
211/18-7: 3311.5-3360m (10865-11023ft)
211/27-10: 3597.5-3620.5m (11802-11878ft)
3/1-2: 3783.5-3801 m (12413-12471ft)

Name. From Loch Rannoch in Scotland (Deegan & Scull 1977, p. 16).

References

Lithology

In the northern part of the East Shetland Basin, the Rannoch Formation consists of an upward-coarsening succession from mudstone (Rannoch Mudstone unit) to very fine or fine-grained sandstone. To the south, where the Rannoch mudstone is absent, the Rannoch Formation consists of an upward-coarsening sandstone succession.

The Rannoch sandstones are often parallel laminated and hummocky cross-stratified (Richards & Brown 1986), with abundant mica and carbonaceous debris concentrated along the laminations. Individual beds generally have sharp bases, and sometimes display an upward transition from laminated or hummocky cross-stratified sandstones to ripple-laminated sandstones, sometimes with extensive bioturbation. Some sandstone beds within the formation are structureless or only indistinctly laminated. Calcite-cemented beds occur sporadically, and are probably of restricted lateral extent (Giles et al. 1992).

The Rannoch Mudstone unit comprises a heterolithic succession of interbedded mudstones, siltstones and sandstones. The mudstones and siltstones are dark grey, carbonaceous and micaceous, the micas being dominantly concentrated along well-developed, parallel laminations. Low-angle scours truncate the lamination fabric in places. Very fine-grained, micaceous sandstones and less micaceous siltstones up to about 15 cm thick are interbedded with the micaceous mudstones, and are commonly ripple cross-laminated or parallel laminated. Bioturbation is locally intense. This mudstone-dominated unit passes gradationally upwards into sandstones.

In the southwestern part of the East Shetland Basin, the Rannoch Formation is generally slightly coarser grained than elsewhere, being dominantly fine (sometimes medium) grained. In some wells (e.g. 3/1-2), the formation is fine to medium grained in its lower part and very fine grained in the upper part.

Upper boundary

The boundary between the Rannoch Formation and the overlying Etive Formation is marked by a sharp downward change from coarser, less micaceous sandstones to finer micaceous sandstones. It is marked by a downward increase in gamma-ray values, reflecting the higher mica content of the Rannoch Formation compared with the underlying Broom Formation.

In the southeastern part of the East Shetland Basin (e.g. 211/13-7), where the Broom Formation is absent, the Rannoch Formation (specifically the Rannoch Mudstone unit) directly overlies mudstones of the Drake Formation (Dunlin Group). In such instances, the base is defined by a downward change from micaceous to poorly micaceous mudstones. This is marked by a slight downward decrease in gamma-ray values and increase in velocity.

Lithostratigraphic subdivision

A lower, mudstone-dominated, section of the Rannoch Formation is informally differentiated as the Rannoch Mudstone unit (see Correlation Panel 4).

Distribution and thickness

The Rannoch Formation is recorded in the East Shetland Basin north of about 60° 30', and extends eastwards into the Viking Graben. The formation is bounded to the west by the East Shetland Platform and to the north by the Magnus Ridge.

The formation thickens from southwest to northeast within the East Shetland Basin, attaining a maximum thickness of about 100 m in the northern part of the basin.

Regional correlation

The formation is laterally equivalent to part of the Pentland Formation further south in the Beryl Embayment, but there is no information on the nature of any transition between the shallow marine sandstone of the Rannoch Formation and the continental/coastal facies of the Pentland Formation.

Genetic interpretation

The Rannoch Formation was deposited in a marine offshore to shoreface setting under the influence of storm waves (Richards & Brown 1986, Brown & Richards 1989).

Biostratigraphic characterization

The formation is largely devoid of palynomorphs, but the freshwater alga Botryococcus is locally abundant.

Age

Late Aalenian to early Bajocian.

References


See also Correlation Panels 2-4.
TARBERT FORMATION

The term 'Tarbert Sub-unit' was introduced by Deegan & Scull (1977) for a unit of fine to medium grained sandstones that lay between the Ness Formation below and the Heather Formation above. Deegan & Scull gave the unit formation status in the UK North Sea but member status in the Norwegian North Sea.

For sections in which a complete or partial Tarbert Formation succession overlies the Ness Formation, the lower boundary was originally defined by Deegan & Scull (1977) as 'the top of the last prominent argillaceous bed', with any overlying sandstones comprising the Tarbert Formation (Deegan & Scull 1977). However, this definition is now considered inadequate (see p. 118).

The formation equates with the 'Upper Brent Sand Member' of Bowen (1975). The formation is partly age equivalent to the Hugin Formation of the Beryl Embayment and South Viking Graben, and occupies a comparable stratigraphic position above coal-bearing sediments. The Tarbert and Hugin formations are geographically separate (occurring in the East Shetland Basin and South Viking Graben, respectively). They also differ in that the Tarbert Formation always occurs above the Ness Formation and associated Brent Group strata such as the Rannoch and Etive formations, whereas the Hugin Formation overlies the Pentland Formation.

Type section
211/29-3 (Deegan & Scull 1977, p. 17, fig. 19): 2602.5-2633.5m (8539-8640ft) below KB. (Illustrated in Correlation Panel 3.)

UK reference sections
211/18a-21: 3444.5-3454.5m (11300-11334ft)
2/5-3: 3350-3372.5m (10991-11065ft)
3/2-2: 3566-3585m (11700-11762ft)
3/9a-2: 3202.5-3277.5m (10506-10753ft)

Name. From Loch Tarbert in Scotland (Deegan & Scull 1977, p. 17).

References
The Tarbert Formation typically consists of grey to brown, relatively massive, fine to medium grained, locally calcite-cemented sandstone, with subordinate thin siltstones, mudstones and coals. The formation is lithologically variable across the East Shetland Basin, but in general is dominated by very fine to fine grained, bioturbated sandstone or, where bioturbation is less intense (usually higher in the vertical succession), by micaceous, parallel-laminated to hummocky cross-stratified, very fine to fine grained sandstone. Sharp, erosively based granule lags or coarse-grained sandstone layers are often found in the basal part of the formation, but also occur at higher levels in some sections (Brown et al. 1987). Locally, in the Viking Graben immediately east of the East Shetland Basin, characteristic Tarbert sandstones are interbedded with siltstones and coals (Running & Steel 1987).

### Upper boundary

The top of the Tarbert Formation is marked by a downward change from grey siltstones with minor limestones of the overlying Heather Formation to sandstones. This corresponds to a downward decrease in gamma-ray values and, in a few sections, to a downward increase in velocity.

### Lower boundary

The Tarbert Formation usually overlies interbedded sandstones, siltstones, mudstones and coals of the Ness Formation, although in the northeastern part of the East Shetland Basin, the Tarbert Formation locally rests directly on sandstones of the Etive Formation.

In the majority of sections, the base of the Tarbert Formation is marked by a sharp downward change from micaceous and/or bioturbated sandstones to more thinly bedded heterolithic sediments of the Ness Formation (e.g. 2/3-3). This change is associated with a sharp downward change to more erratic gamma-ray values. Where the Tarbert sandstones are thin (e.g. 211/27-10, p.111), they can be difficult to differentiate from the Ness Formation without the aid of core. Where core is not available, it recommended that any thin sandstone at the top of the Brent succession be assigned to the Ness Formation (e.g. 210/24-2, p.111).

Recognition of the Tarbert/Ness boundary may be complicated by local facies variations in either formation. For example, in well 211/16a-5 (p.111) both the Ness and Tarbert formations are dominated by sandstones. In other sections, minor coals and mudstones are interbedded with Tarbert sandstones. In many cored sections, the boundary between the Ness and Tarbert formations can be identified by a coarse-grained lag deposit (Brown et al. 1987; Running & Steel 1987). In the northeastern part of the East Shetland Basin, the Tarbert Formation rests directly on the Etive Formation, with no distinctive argillaceous interval between (e.g. 211/18a-21). In this area, therefore, the boundary does not conform to the Deegan & Scull (1977) definition, and can be difficult to identify with certainty on wireline-log character alone (Cannon et al. 1992).

The problem is compounded by the Etive Formation displaying an anomalously erratic gamma-ray signature in some sections, for example in well 211/19-4 (p.107).

### Distribution and thickness

Although the formation is found over much of the East Shetland Basin north of about 60° 30’N, it is absent due to erosion in about 50 per cent of the exploration and appraisal wells, including some within the distribution area shown (e.g. 210/24-2, 3/3-3, p.111). Eroded sections occur mostly on the crests of tilted fault-blocks. The formation attains a maximum thickness of about 75m in the southwestern part of the East Shetland Basin.

### Regional correlation

The Tarbert Formation passes laterally in places into Ness Formation and/or Heather Formation deposits in the East Shetland Basin. In the Beryl Embayment, it may pass laterally northwards into the lower parts of the Hugin Formation although there is no information on the nature of any such transition.

### Genetic interpretation

The bioturbated and laminated or hummocky cross-stratified sandstones of the Tarbert Formation were deposited under shallow-marine conditions during transgression of the underlying Brent delta deposits. The sharp-based, coarse sandstone or gravel-lag deposits that often occur at the base of the formation probably represent ravinement surfaces formed during the transgression. Running & Steel (1987) suggested that the crudely graded sandstones, siltstones and coals interbedded with the marine sandstones represent backbarrier and lagoonal deposits.

### Biostratigraphic characterization

Much of the formation is devoid of polyomorphs, but gymnospermous pollen occurs in large proportions at some levels, and dinoflagellate cysts are also present sporadically.

### Age

Probably late Bajocian to Bathonian.
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The term Dunrobin Bay Group is introduced for the Lower Jurassic arenaceous and argillaceous sediments of the Inner Moray Firth. It comprises the newly defined Golspie, Mains, Lady's Walk and Orrin formations. The group is broadly equivalent to the onshore Dunrobin Bay Formation, as defined by Neves & Selley (1975) and later revised by Batten et al. (1986) to include the Dunrobin Pier Conglomerate Member (see accompanying table). Facies equivalents of the Dunrobin Pier Conglomerate Member are, however, not recorded offshore, where mudstones of the Golspie Formation constitute the basal sediments of the Dunrobin Bay Group. The top of the Dunrobin Bay Formation is not exposed onshore, where strata equivalent to the Orrin Formation are not seen.

The informal term ‘Dunrobin Group’ has been used for much of the Lower Jurassic in the Inner Moray Firth, in both published work (e.g. Stevens 1991) and on oil company completion logs. However, the lithostratigraphic definition of the group has been varied, with, for example the Golspie Formation being included within the group in some instances but excluded in others. The Orrin Formation was included in the Fladen Group by Stevens (1991). It is here included within the Dunrobin Bay Group.

The Golspie Formation is dominated by red-brown and variegated mudstones and passes up into upward-fining sandstones with interbedded dark grey mudstones and siltstones of the Mains Formation. The overlying Lady’s Walk Formation typically consists of dark grey, richly fossiliferous, marine mudstones with minor upward-fining sandstones and siltstones. In the Beatrice Field area, stacked, upward-coarsening sandstones with minor siltstones of the Orrin Formation generally overlie the Lady’s Walk Formation. The Dunrobin Bay Group extends over the western part of the Inner Moray Firth. It reaches a maximum thickness of about 180m in the Beatrice Field. It thins eastwards and is truncated by strata dated as Callovian by Andrews & Brown (1987) but as Bathonian by Stephen et al. (1993).

The Golspie, Mains and Lady’s Walk formations, and equivalent strata onshore, are interpreted as alluvial-plain, marginal-marine / estuarine channel, and shallow to open marine deposits, respectively (Linsley et al. 1980; Batten et al. 1986; Stephen et al. 1993) and represent either a single long-term transgressive cycle (Linsley et al. 1980; Andrews & Brown 1987) or part of two shorter cycles (Stephen et al. 1993). The overlying Orrin Formation has been interpreted as a regressive delta-front/lagoonal and beach/barrier-bar deposit (Linsley et al. 1980; Stevens 1991).

References


Name. From the Dunrobin Bay Formation (Neves & Selley 1975; Batten et al. 1986) on the coast of the Moray Firth, to which it is laterally equivalent.

Constituent formations

Golspie Formation p. 123
Lady’s Walk Formation p. 127
Mains Formation p. 131
Orrin Formation p. 135

Age

Rhaetian to Toarcian
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GOLSPIE FORMATION (new)


Type section
11/30-1: 2117-2175m (6945-7136ft) below KB.

Reference sections
12/22-2: 1420.5-1487m (4660-4878ft)
12/26-1: 1257.5-1295.5m (4125-4250ft)

Name. From the town of Golspie, on the western shore of the Moray Firth.

References

Lithology

The Golspie Formation consists dominantly of variegated, mottled mudstones with sporadic, thin, fine-grained sandstones. However, sections in the southeast (e.g. 12/28-1, Panel 8) are more sand-rich than those in the west. The mudstones are green, brick red, light grey and occasionally yellowish, although they become predominantly red-brown with depth. They are occasionally calcareous, variably silty, and fissile, with desiccation cracks, rootlet horizons and rare plant material (Linsley et al. 1980; Stephen et al. 1993). Sparadic, highly bituminous, finely laminated mudstones are present (Stephen et al. 1993). The mudstones contain sporadic limestone stringers. In the Beatrice Field, each bed is rarely more than 1.5m thick, according to Linsley et al. (1980). The sandstones are upward-fining, moderately to well cemented by authigenic silica, contain rare shell and ostracod fragments, and display a variety of planar and ripple cross-bedding structures. Locally (e.g. 12/28-1, Panel 8), sandstones near the base of the formation contain clasts of reworked limestone and these strata may be laterally equivalent to the Dunrobin Pier Conglomerate Member recognized onshore (Batten et al. 1986).

Upper boundary

The top of the Golspie Formation is generally marked by a downward passage from white to pale grey sandstones with siltstones (Mains Formation) into variegated mudstones. This somewhat gradational boundary is generally marked by an increase in average gamma-ray values and a decrease in velocity (e.g. 11/25-1, p.133; 12/21-3, 12/27-1, Panel 8). In the east, the formation is truncated beneath sandstones of the Beatrice Formation (e.g. 12/23-1—see Andrews et al. 1990, fig.28), the Stotfield Calcrete Formation (Late Triassic, ?Rhaetian or pre-Rhaetian) and their sedimentological and palynological content, Batten et al. (1986) suggested that laterally equivalent strata onshore are mainly of Hettangian age.

Lower boundary

Over most of the Inner Moray Firth Basin, the Golspie Formation overlies the Stotfield Calcrete Formation, the base being defined by a downward change from mudstones (e.g. 11/30-1) or interbedded sandstones and mudstones (e.g. 12/28-1, Panel 8) to microcrystalline limestone with chert inclusions (and locally with interbedded sandstones). In well 12/23-1 (see Andrews et al. 1990, fig.28), the Stotfield Calcrete Formation is possibly absent due to erosion (Linsley et al. 1980), and here the boundary is marked by a downward change from a dominantly mudstone succession to the dominantly sandstone succession of the Lossiehead Formation. There is generally a marked downward decrease in average gamma-ray values and an increase in average velocity at the base of the Golspie Formation.

Lithostratigraphic subdivision

In some areas (e.g. 12/22-2, 12/26-1; 11/25-1, p.133), the gamma-ray and sonic logs allow the recognition of two units in the Golspie Formation mudstones, which are here informally designated Golspie units 1 and 2 (abbreviated to G1 and G2). Unit G1 has lower average gamma values and higher average velocity than the overlying G2 subunit.

Distribution and thickness

The Golspie Formation is mainly confined to the western part of the Inner Moray Firth Basin. The formation is 54m thick in the type well and in the Beatrice Field it is up to about 60m thick. In well 18/5a-IA (Panel 8), to the east, the formation is only 15m thick. This conforms with the general NW/NE thickening of the formation towards the Helmsdale Fault. East of about 2°W, the formation is truncated by strata dated as Callovian by Andrews & Brown (1987) but as Bathonian by Stephen et al. (1993).

Regional correlation

The Golspie Formation passes laterally into the lower part of the onshore Dunrobin Bay Formation (Andrews & Brown 1987; Andrews et al. 1990) (see table, p.121).

Genetic interpretation

Equivalent strata onshore have yielded palynomorph assemblages of essentially freshwater aspect and include thin coals with rootlet beds (Neves & Selley 1975; Batten et al. 1986). However, the occurrence of the palynomorphs Microhystridium and Tanamiites (Lam & Porter 1977) indicates temporary marine influence on the depositional environment. Linsley et al. (1980) and Stephen et al. (1993) suggested that sediments of the Golspie Formation were deposited in alluvial flood-plain to lagoon or freshwater lake environments.

Biostratigraphic characterization

The presence of the spore Neovesispores bigranulatus in equivalent onshore strata (Batten et al. 1986) indicates an association with the O.pseudoalatus biomarker. The Golspie Formation is barren of calcareous microfossils.

Age

?Rhaetian to Hettangian. Linsley et al. (1980) and Fisher & Mudge (1990) assigned the beds of the Golspie Formation to the Rhaetian (Late Triassic), whereas Andrews & Brown (1987) and Stevens (1991) indicated a Rhaetian to Hettangian age. On the basis of their unconformable relationship with the underlying Stotfield Calcrete Formation (Late Triassic, ?Rhaetian or pre-Rhaetian) and their sedimentological and palynological content, Batten et al. (1986) suggested that laterally equivalent strata onshore are mainly of Hettangian age.

References


See also Correlation Panel 8.
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LADY'S WALK FORMATION
(new)


Type section
11/30-4: 2276.5-2305.5m (7469-7564ft) below KB.

Reference sections
12/21-2: 2339-2363.5m (7673-7754ft)
12/27-2: 1628.5-1653.5m (5343-5424ft)

Name. From Lady's Walk, a walkway within the grounds of Dunrobin Castle on the western shore of the Moray Firth [NC 855 010].

References
Lithology
The Lady's Walk Formation consists mainly of dark to medium grey calcareous, micaceous mudstones with thin-shelled bivalves, ammonites, crinoids and belemnites. One or more upward-fining units of fine-grained sandstone and siltstone is present in many sections (e.g. 11/30-4, 12/21-2, 12/21-3, Panel 8). The basal contacts of the upward-fining sandstones are burrowed (Linsley et al. 1980). Trace fossils, including Diplacanthurus and Teichichnus are present (Stephen et al. 1993). The Lady's Walk Formation typically has higher gamma-ray values and a lower velocity than the overlying Orrin Formation and the underlying Mains Formation.

Upper boundary
Where the Lady's Walk Formation is overlain by the Orrin Formation, the top is taken at the base of an upward-coarsening siltstone/sandstone unit. The boundary corresponds to the top of a low-velocity spike (e.g. 11/30-2, p. 137; 12/21-2). Where the Orrin Formation is absent, the Lady's Walk Formation is overlain either by sandstones and mudstones of the Brora Coal Formation (12/28-1, Panel 8) or, more commonly, by sandstones of the Beatrice Formation (e.g. 12/27-2; 12/22-2, p. 125; 12/27-1, Panel 8).

Lower boundary
The base of the Lady's Walk Formation is defined by a downward change from dark, fossiliferous mudstones to white to pale grey sandstones with interbedded mudstones (Mains Formation). This is commonly associated with a sharp downward decrease in average gamma-ray values and by an increase in velocity.

Distribution and thickness
The formation is mainly confined to western parts of the Inner Moray Firth Basin. The formation is 26m thick in the type well and in the Beatrice Field thicknesses range from 16m to 30m. In well 12/26-1 (Panel 18), the Lady's Walk Formation is cut out by the Orrin Formation (Linsley et al. 1980); this appears to be a local feature, and the boundary elsewhere appears to be conformable (Stephen et al. 1993). East of about 2°W, the formation is truncated by strata dated as Callovian by Andrews & Brown (1987) but as Bathonian by Stephen et al. (1993).

Regional correlation
The Lady's Walk Formation passes laterally into the informal Lady's Walk Shale member of the Dunrobin Bay Formation on the Moray Firth coast (Neves & Selley 1975; Batten et al. 1986).

Depositional environment
According to Linsley et al. (1980), the mudstones and sandstones of the Lady's Walk Formation in the Beatrice Field were deposited in a marine shelf environment. Coeval strata from the Dunrobin area of the Moray Firth coast contain a fully marine macrofauna (Lee 1925). Lam & Porter (1977) suggested that the rich palynoflora is typical of a shallow inshore marine environment.

Biostratigraphic characterization
The Lady's Walk Formation includes the L. variabile, N. issleri and V. denticyclata carinata biomarkers.

Age
Late Sinemurian to early Pliensbachian. Linsley et al. (1980) reported ammonites of early Pliensbachian age from the marine mudstones of the Beatrice Field. The microfauna is identical to that of the onshore Lady's Walk Shale Member, and indicates a late Sinemurian age for the lower claystone unit and an early Pliensbachian age for the remainder of the formation (Lam & Porter 1977).

References
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MAINS FORMATION  
(new)

The term Mains Formation is introduced for a heterolithic unit of sandstones, siltstones and mudstones that lies between the Golspie Formation and Lady's Walk Formation in the Inner Moray Firth. The formation equates with the 'White Sandstone unit' in the informal 'Dunrobin Bay Formation' of Andrews & Brown (1987). Stevens (1991) assigned these strata in the Beatrice Field to the informal 'Grant Sand Member' of the 'Dunrobin Bay Formation', which equates with the 'J Sand' reservoir unit (see table 1 in Stephen et al. 1993).

Type section  
11/25-1: 3210.5-3250m (10533-10663ft) below KB.

Reference sections  
12/21-2: 2363.5-2417m (7754-7930ft)  
12/27-1: 1132-1159m (3714-3803ft)

Name. From Dunrobin Mains [NC 842 014] on the Moray Firth coast.

References  


Lithology
The Mains Formation consists of interbedded white to pale grey sandstones, muddy siltstones and grey to black organic mudstones. The upward-fining sandstones are fine to coarse grained. They are locally very calcareous and more thickly bedded than sandstones in the underlying Golspie Formation (Linsley et al. 1980; Stephen et al. 1993), although in the Beatrice Field the sandstone beds are rarely more than 1.5m thick (Stevens 1991). The interbedded mudstones contain an abundant flora and fauna. In some wells (e.g. 11/25-1) the formation consists dominantly of sandstone whereas in others (e.g. 12/21-3, Panel 8) it contains a large proportion of mudstone. Core from the Mains Formation in well 11/30-2 (p. 137) shows cross-bedded and current-ripple bedded sandstones with burrowed mudstones and rootlet horizons. These lithologies are arranged in upward-fining cycles about 2m thick. In well 12/27-1 (Panel 8), core material and the gamma-ray log indicate that the formation consists two upward-fining units, each about 12m thick.

The Mains Formation displays variable wireline-log signatures, reflecting the interbedded nature of the sandstone and mudstone lithologies.

Upper boundary
The top of the Mains Formation is marked by a downward passage from dark, organic-rich, fossiliferous mudstones (Lady’s Walk Formation) to sandstones with mudstone interbeds. The boundary is marked by a very sharp downward decrease in average gamma-ray values and by an increase in velocity (e.g. 11/25-1; 11/30-2, p. 137). In southeastern wells, however, the Lady’s Walk Formation is absent due to erosion (Linsley et al. 1980; Andrews & Brown 1987) and the Mains Formation is overlain unconformably by upward-coarsening sandstones of the Orrin Formation (e.g. 12/26-1, Panel 8).

Lower boundary
The base of the Mains Formation is defined by a downward passage from sandstones with interbedded mudstones to varicoloured mudstones and thin sandstones (Golspie Formation). The boundary is either sharp (e.g. 11/25-1) or gradational (e.g. 12/21-2). It generally corresponds to a downward increase in average gamma-ray values and a decrease in average velocity.

Distribution and thickness
The Mains Formation is largely confined to the western part of the Inner Moray Firth Basin. The formation is 47m thick in the type well, and up to about 60m thick in the Beatrice Field, but only 13m thick in well 18/5a-lA (Panel 8), further to the east. East of about 2°W, the formation has been removed by erosion beneath an unconformity dated as Callovian (Andrews & Brown 1987) or Bathonian (Stephen et al. 1993).

Regional correlation
The Mains Formation passes laterally into the middle part of the onshore Dunrobin Bay Formation (Andrews & Brown 1987; Andrews et al. 1990).

Genetic interpretation
The flora and fauna of the Mains Formation reflect a change from a brackish-water environment in the Golspie Formation to a more marine environment (Linsley et al. 1980). Marine palynomorphs and a limited fauna of marine bivalves have been recorded in laterally equivalent strata of the onshore Dunrobin Bay Formation (Neves & Selley 1975; Lee 1925).

Biostratigraphic characterization
The Mains Formation generally yields relatively sparse palynofloras dominated by miospores. The D. priscum biomarker is recorded in some sections. The Mains Formation is barren of calcareous microfossils.

Age
Hettangian to Sinemurian (Linsley et al. 1980; Stevens 1991; Stephen et al. 1993).

References


See also Correlation Panel 8.
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The term Orrin Formation is introduced for a unit of sandstones that lies between the Lady's Walk Formation and the Brora Coal Formation (Fladen Group) in the Inner Moray Firth. The term was first used informally in 1985, in an unpublished report by the Robertson Group (now Simon Robertson Ltd). The term 'Orrin Formation' was subsequently used by Andrews & Brown (1987) in their informal stratigraphic scheme for the Inner Moray Firth Basin. Stevens (1991) assigned these strata in the Beatrice Field to his informal 'Beatrice Formation'. This was divided into two members, the 'Morangie Sand Member' and the overlying 'Livet Sand Member', corresponding to the 'I Sand' and 'H Sand' reservoir units, respectively (see table 1 in Stephen et al. 1993).

**Type section**
11/30-2: 2085.5-2143m (6842-7030ft) below KB.

**Reference sections**
11/25-1: 3141-3189m (10305-10462ft)
12/21-2: 2283-2339m (7490-7673ft)

**Name.** From Glen Orrin, west of Inverness.

**References**


Lithology

The Orrin Formation consists of pale to dark grey argillaceous siltstones, coarsening upwards into fine-grained, bioturbated, carbonaceous, kaolinitic sandstones and massive, fine to medium grained (occasionally coarse), siliciclastic sandstones with occasional cross-bedding. Haszeldine et al. (1984) described the sandstones as sub-arkosic to quartz-arenitic. Linsley et al. (1980) recognized two major upward-coarsening sandstone units, on the basis of gamma-log character, overlain by a thin but persistent fossiliferous mudstone that is in turn capped by a major cross-bedded sandstone unit. Thin coals and rootlet horizons are recorded within the mudstone unit (e.g. 12/21-2) (Stephen et al. 1993).

Upper boundary

The top of the Orrin Formation is placed at a downward change from interbedded mudstones, sandstones and coals (Brora Coal Formation) to predominantly clean sandstones. On wireline logs, this boundary is marked by a downward decrease in gamma-ray values and an increase in velocity and by a change to a more uniform wireline-log response.

Lower boundary

The base of the Orrin Formation is taken at the base of the lower upward-coarsening siltstone-sandstone unit. It is defined by a minor but distinct downward increase in mud content at the boundary with the underlying Lady's Walk Formation, reflected in a downward increase in gamma-ray values. A small low-velocity spike commonly occurs immediately below the boundary (e.g. 11/30-2, 12/21-2).

In well 12/26-1 (Panel 8), the Orrin Formation probably rests unconformably on the Mains Formation, although the immediately underlying mudstone may be a thin remnant of the basal Lady's Walk Formation. Here the boundary is marked by a downward change from sandstone to mudstone, and is marked by a sharp downward increase in gamma-ray values.

 Lithostratigraphic subdivision

The gamma-ray log allows the recognition of two units within the Orrin Formation, which are here informally designated Orrin unit 1 and Orrin unit 2 (abbreviated to 01 and 02). Both units consist of a siltstone overlain by sandstone. Unit 01 characteristically displays an overall upward-coarsening gamma-ray log signature at the base, and in some sections displays two upward-coarsening cycles within the sandstone (e.g. 12/21-2).

Units 01 and 02 correspond to the Morangie Sand and Livet Sand members (Stevens 1991) and the Beatrice Field 1 sand and H sand reservoir units, respectively (see table 1 of Stephen et al. 1993).

Distribution and thickness

The Orrin Formation is mainly restricted to the western part of the Inner Moray Firth Basin. Strata of equivalent age are not seen onshore due either to faulting or poor exposure. In the type well (11/30-2), the formation is 59m thick and in the Beatrice Field area thicknesses vary between about 45 and 60m. East of about 2.5°W the formation has been removed by erosion, beneath an unconformity dated as Caltovian (Andrews & Brown 1987) or Bathonian (Stephen et al. 1993).

Regional correlation

No strata equivalent to the Orrin Formation are exposed onshore in the Moray Firth coast.

Genetic interpretation

Linsley et al. (1980) interpreted the Orrin Formation as a succession of regressive, high-energy delta-front sands. The siltstone unit at the base of unit 02, contains a varied microflora of brackish-water algae as well as marine acritarchs and dinocysts; it is considered to be a lagoonal/delta-top deposit (Linsley et al. 1980) or a marshy, beach-ridge deposit (Stephen et al. 1993). The sandstone unit at the top of the formation is thought to be a major distributary-channel sand or a river-mouth bar (Linsley et al. 1980).

According to Linsley et al. (1980), Andrews & Brown (1987) and Stevens (1991), there is a distinct non-sequence between the Lady's Walk Formation and the Orrin Formation. Although the base of the Orrin Formation is clearly unconformable where it rests directly on the Mains Formation, elsewhere it appears to be more or less conformable (Stephen et al. 1993).

Biostratigraphic characterization

Much of the Orrin Formation is palynologically barren, but the L.spinosa biomarker has been reported from some sections.

Age

Mid-Pliensbachian to late Toarcian. Linsley et al. (1980), Andrews & Brown (1987) and Stevens (1991) assigned the formation to the latest Toarcian to early Bajocian. However, Stephen et al. (1993, table 2) give an age of mid-Pliensbachian to late Toarcian.

References


See also Correlation Panel 8.
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DUNLIN GROUP

FJERRITSLEV FORMATION
**DUNLIN GROUP**

The term Dunlin Group was introduced by Deegan & Scull (1977) to include four formations, the Amundsen, Burton, Cook and Drake formations. The group is extended to include two additional formations, the Speke Formation in the Unst Basin and the Darwin Formation in the Beryl Embayment. Deegan & Scull named the original four constituent formations after famous British or Norwegian explorers, and a similar theme has been followed here in the naming of the Speke and Darwin formations.

The five formations that occur in East Shetland Basin/Viking Graben/Beryl Embayment area are of marine facies, the Dunlin transgression having terminated the prolonged phase of non-marine sedimentation of the Heron Group. It probably reached its culmination in the Toarcian, with the deposition of the Drake Formation in the East Shetland Basin and North Viking Graben, and of the slightly shallower water Darwin Formation in the Beryl Embayment (Richards 1990). Marine conditions did not, however, reach the Unst Basin, where sediments of the Speke Formation are in non-marine facies (Johns & Andrews 1985).

The Dunlin Group was initially given formation status by Bowen (1975), who grouped the Amundsen, Burton and Cook formations together as the 'Dunlin Silt Unit', and named the Drake Formation the 'Dunlin Shale Unit', reflecting the essential lithological difference between the three lower and the uppermost formations in the East Shetland Basin.

The Dunlin Group possibly attains a thickness of one kilometre in the axial parts of the North Viking Graben, but in the East Shetland Basin varies from a few metres in the west to over 250m in the east.

**References**


**Name.** From the Dunlin Field in the East Shetland Basin.

**Constituent formations**

- **AMUNDSEN FORMATION** p. 141
- **BURTON FORMATION** p. 145
- **COOK FORMATION** p. 149
- **DARWIN FORMATION** p. 153
- **DRAKE FORMATION** p. 157
- **SPEKE FORMATION** p. 161

**Age**

Sinemurian to Toarcian or possibly earliest Aalenian.
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AMUNDSEN FORMATION

The term 'Amundsen Sub-unit' was introduced by Deegan & Scull (1977) for a unit of siltstones, mudstones and sandstones lying between the 'Nansen Member' and the Burton 'Sub-unit'. This definition is retained. Deegan & Scull gave the unit formation status in the UK North Sea but member status in the Norwegian North Sea.

The formation constitutes the lowermost part of the 'Dunlin Siltstone Member' of Bowen (1975).

Type section
211/29-3 (Deegan & Scull 1977, p. 14, fig. 17): 2993-3051m (9819-10009ft) below KB.

UK reference sections
211/18a-24: 3737.5-3762m (12262-12343ft)
3/3-3: 3300-3325m (10837-10908ft)
3/15-3: 3689-3794m (12103-12447ft)

Name. After the Norwegian polar scientist Roald Amundsen, the first man to reach the South Pole (Deegan & Scull 1977, p. 14).

References

Lithology
The Amundsen Formation consists dominantly of light to dark grey, non-calcareous to calcareous, bioturbated siltstones and mudstones which are locally carbonaceous and pyritic. In the easternmost part of the East Shetland Basin, the lower part of the formation frequently has more calcite-cemented beds than the upper part, as reflected in higher average velocities (e.g. 3/15-3). Sandstones, up to 3m or so thick, occur in the type well (211/29-3) and over much of the East Shetland Basin. The sandstones are more prominent in the upper parts of the formation, and attain a maximum thickness of 24m in well 3/15-3. They are usually white, grey or brown and are locally cemented by calcite or quartz. Kaolinite, glauconite and mica are present locally. Some beds display sand grains floating in a siltstone matrix, particularly near the base of the formation. In well 3/4-5 (Panel 6), highly bioturbated sandy siltstones are recorded.

Many sections display an overall upward-coarsening trend, reflected in an overall upward decrease in gamma-ray values (e.g. 211/18a-24). Some of these display a repetition of small-scale upward-decreasing gamma-ray cycles (e.g. 3/15-3).

Upper boundary
The top of the Amundsen Formation is defined by a downward change from mudstones (Burton Formation) to siltstones or sandstones. It is marked by a downward decrease in gamma-ray values and increase in velocity, though these signatures are not always pronounced.

Lower boundary
The base of the Amundsen Formation is marked by a downward change from mudstones or siltstones to variably cemented sandstones of the Nansen Formation. It is marked by a sharp downward decrease in gamma-ray values. Over much of the East Shetland Basin, it is also marked by a downward increase in velocity (e.g. 211/29-3). However, the characteristic velocity signature is not displayed where the basal mudstones are calcite cemented (e.g. 3/15-3) or where the immediately underlying sandstones are poorly cemented (e.g. 3/3-3).

Distribution and thickness
This formation is recognized over most of the East Shetland Basin north of 60° 30'N, and extends eastwards into the Viking Graben. It is, however, absent from the Transitional Shelf, where Middle or Upper Jurassic sediments overlie pre-Jurassic rocks. There is no information from the part of the Viking Graben adjacent to the Transitional Shelf because no wells have yet penetrated this stratigraphic level. The formation may, therefore, extend south of its presently known area. The formation thickens from west to east across the East Shetland Basin; it ranges from 6m to over 100m in thickness, but is thin or even missing over some structural highs.

Regional correlation
The mudstones of the Amundsen Formation pass southwards in the Beryl Embayment into the siltstones of the Darwin Formation.

Genetic interpretation
The Amundsen Formation was interpreted as a shallow-marine shelf deposit by Vollset & Doré (1984).

Biostratigraphic characterization
The formation includes the L.variabile and V.denticulatacarinata biomarkers.

Age
Sinemurian to Pliensbachian.

References
**AMUNDSEN FORMATION**

**LITHOLOGY**
- Sandstone
- Mudstone
- Siltstone
- Shale

**Key Biomarkers**
- *L. spinosa*
- *D. matutina*
- *L. variabile*
- *Parvocysta spp.*

**Distribution Map**

**Triassic**
- *V. subvitreus*
- *V. denticulata carinata*
- *L. semireticulata*
- *O. pseudoalatus*

**Jurassic**
- *Dunlin Group*
- *Heron Group*

**Banks Group**

**Brent Group**

**Groom Formation**
- *Drake Formation*
- *Cook Formation*
- *Burton Formation*
- *Amundsen Formation*
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BURTON FORMATION

The term 'Burton Sub-unit' was introduced by Deegan & Scull (1977) for a unit of mudstones lying between the 'Amundsen Sub-unit' and the 'Cook Sub-unit'. Deegan & Scull gave the unit formation status in the UK North Sea and member status in the Norwegian North Sea.

The formation equates with the middle part of the 'Dunlin Siltstone Member' of Bowen (1975).

Type section
211/29-3 (Deegan & Scull 1977, p.15, fig. 19): 2950.5-2993m (9680-9819ft) below KB.

UK reference sections
211/18a: 24: 3704.5-3737.5m (12154-12262ft)
211/27-4A: 3769-3787.5m (12366-12426ft)
3/4-8: 3526.5-3590m (11567-11778ft)

Name. After Sir Richard Francis Burton, the 19th century explorer (Deegan & Scull 1977, p. 15).

References

Lithology
In the type well (211/29-3), the Burton Formation consists of dark grey to reddish grey, soft, slightly carbonaceous, non-calcareous mudstones. Ooliths have been recorded in the mudstones in the upper part of the formation in well 3/4-8. Sandstones occur locally, but their distribution is patchy and difficult to predict. Individual sandstone units usually have an aggregate thickness of only a few metres or so. The sandstones vary from very fine to coarse grained and are varicoloured, argillaceous, and frequently kaolinitic and/or calcareous.

Upper boundary
The top of the Burton Formation is typically defined by a downward change from siltstone or sandstone to mudstone, accompanied by a distinct downward increase in gamma-ray values and decrease in velocity (e.g. 211/18a-24, 211/29-3). However, in central and southern parts of the East Shetlands Basin, the boundary is poorly defined as a result of the development of sandstones within the Burton Formation (e.g. 3/4-8). In other sections (e.g. 211/27-4A), the Cook Formation displays anomalously high gamma-ray values, so that the boundary is best defined on the downward decrease in velocity.

Lower boundary
The base of the Burton Formation is defined by a downward change from mudstones to the interbedded sandstones and siltstones of the Amundsen Formation. It is marked by a slight downward decrease in gamma-ray values and increase in velocity.

Distribution and thickness
The Burton Formation is recognized over most of the East Shetland Basin north of 60° 30'N, and extends eastwards into the Viking Graben. It is, however, absent from the Transitional Shelf, where Middle or Upper Jurassic sediments overlie pre-Jurassic rocks. Its western boundary near the margin of the East Shetland Platform is erosional. There is no information from the part of the Viking Graben adjacent to the Transitional Shelf because no wells have reached this stratigraphic level. The formation may, therefore, extend south of its currently known area.

The formation thickens from west to east across the East Shetland Basin, reaching a maximum of about 65m. However, it is absent over some structural highs.

Regional correlation
The mudstones of the Burton Formation probably pass southwards in the Beryl Embayment into the siltstones and sandstones of the Darwin Formation.

Genetic interpretation
The formation is interpreted as an open-marine, basinal deposit by Vollset & Doré (1984).

Biostratigraphic characterization
The Burton Formation yields sparse palynofloras. The D. matutina biomarker occurs within the formation.

Age
Probably Pliensbachian.

References
COOK FORMATION

The term 'Cook Sub-unit' was introduced by Deegan & Scull (1977) for a unit of siltstones and mudstones lying between the 'Burton Sub-unit' and the 'Drake Sub-unit'. This definition is retained in this report. Deegan & Scull gave the unit formation status in the UK North Sea but member status in the Norwegian North Sea. The formation equates with the upper part of the 'Dunlin Siltstone Member' of Bowen (1975).

Type section
211/29-3 (Deegan & Scull 1977, p. 15, fig. 19): 2887-2950.5m (9471-9680ft) below KB.

UK reference sections
211/13-7: 3822-3865m (12540-12681ft)
211/18a-24: 3661.5-3704.5m (12012-12154ft)
211/24-1: 2930.5-3005m (9614-9859ft)

Name. After Captain James Cook, the British circumnavigator, hydrographer and explorer (Deegan & Scull 1977, p. 15).

References
Lithology
In the type well (211/29-3) and over most of the East Shetland Basin, the Cook Formation consists dominantly of grey siltstones and silty mudstones. Streaks of very fine grained and well sorted sand occur at some levels, with traces of muscovite, chlorite and glauconite. Calcite cement is present locally. Locally (e.g. 3/4-8, p.147), the succession includes thin beds of very fine to coarse grained, often argillaceous, micaceous and chloritic sandstone that constitute up to 20 per cent of individual sections.

Upper boundary
The top of the Cook Formation is defined by a downward change from mudstones of the Drake Formation to siltstones with more or less subordinate sandstones. It is marked by a downward decrease in gamma-ray values, usually accompanied by an increase in velocity.

Lower boundary
The base of the Cook Formation is typically defined by a downward change from siltstone to mudstone, associated with a distinct downward increase in gamma-ray values and decrease in velocity. However, in central and southern parts of the East Shetlands Basin, the characteristic log signatures are not so clearly displayed, either because the Cook Formation has become less silty (e.g. 211/27-4A, p.159) or because the Burton Formation has become more sandy (e.g. 3/4-8, p.147).

Distribution and thickness
This formation is recognized over most of the East Shetland Basin north of 60° 30’N, and extends eastwards into the Viking Graben. Its western limit in the East Shetland Basin is probably erosional. It is absent from the Transitional Shelf, where Middle or Upper Jurassic sediments overlie pre-Jurassic rocks. There is no information from the part of the Viking Graben adjacent to the Transitional Shelf because no wells penetrate this stratigraphic level. The formation may, therefore, extend southwards from its currently known area.

The sandstones are more or less restricted to the area east of the Ninian-Hutton fault trend, and thus occur where the formation is thickest. Minor sandstones are found in isolated patches elsewhere in the East Shetland Basin. The formation thickens from west to east across the East Shetland Basin and ranges up to about 80m in thickness, but is missing over some intra-basinal highs.

Regional correlation
The formation probably passes southwards, in the Beryl Embayment, into the siltier deposits of the Darwin Formation.

Genetic interpretation

Biostratigraphic characterization
The L.spinosa biomarker occurs within the formation.

Age
Pliensbachian to ?Tourian.

References
COOK FORMATION

LITHOLOGY

- Siltstone
- Mudstone
- Sandstone

DISTRIBUTION MAP

COOK FORMATION

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See also Correlation Panel 2

Key Biomarkers

- D. matutina
- L. spinosa
- V. denticulata carinata
- L. variabile
- O. pseudolatus
- Parvocysta spp.

Jurassic

- Early Jurassic
- Mid Jurassic
- Late Jurassic

Triassic

- Early Triassic
- Late Triassic

BANKS GROUP

BRENT GROUP

GROOM FORMATION

COOK FORMATION

DRAKE FORMATION

BARTON FORMATION

AMUNDSEN FORMATION

COOK FORMATION

RANNOCH FORMATION

NANSEN FORMATION

CORMORANT FORMATION

HERON GROUP

BRENT GROUP

GROOM FORMATION
The Darwin Formation is introduced for a unit of bioturbated siltstones that lie between the Nansen Formation and Pentland Formation in the Beryl Embayment area.

The formation has previously been referred to informally as the 'Lower Beryl Shale' and 'Lower Beryl Floating Sand Grain Unit' (Mobil), 'Amundsen and Burton Formations' (Mobil), 'Dunlin Group' (BP and Hamilton), 'Darwin Formation' (Richards 1989), and 'upper formation' (Richards 1990; 1991).

**Type section**
9/13-19: 3564.5-3608m (11694-11837ft) below KB.

**Reference sections**
9/8a-10: 3951-4018m (12963-13182ft)
9/14b-2B: 4618-4666m (15150-15308ft)
9/19-5A: 3767-3842m (12359-12605ft)

**Name.** After Charles Darwin, British naturalist and marine explorer.

**References**


Lithology
The Darwin Formation is composed mainly of lenticular bedded grey siltstones and fine sandstones, although bioturbation has produced structureless sandy siltstones at some levels. Very fine to coarse grained, more or less structureless, sandstones occur in thin (up to 0.6m thick), sharp-based beds, some apparently representing gutter casts. Thicker units (up to 1.3m), of well laminated, rippled, and occasionally bioturbated, very fine grained sandstones also occur. The sandstones are mineralogically and texturally similar to those of the underlying Nansen Formation.

The heterolithic nature of the formation is reflected in erratic gamma-ray profiles, with many sections displaying successive upward-decreasing gamma-ray cycles indicative of upward-coarsening cycles (e.g. 9/14b-2b, 9/19-5A). Gamma-ray signatures also indicate that sandstones are least abundant at the top and bottom of the formation.

Upper boundary
The top of the Darwin Formation is defined by a downward passage from interbedded sandstones, siltstones and coals of the Pentland Formation to siltstones, and is marked by a sharp increase in gamma-ray values.

Lower boundary
The base of the Darwin Formation is defined by a downward passage from siltstones to sandstones (Nansen Formation), reflected in a marked decrease in gamma-ray values.

Distribution and thickness
The Darwin Formation is recognized in the Beryl Field and Bruce Field areas of the Beryl Embayment, and in adjacent parts of the Viking Graben, where the East Shetland Basin type subdivisions of the Dunlin Group cannot be identified.

The formation ranges in thickness from zero to about 80m in the Beryl Embayment and the immediately adjacent part of the Viking Graben. It thickens into the broadly NE-SW trending lows adjacent to syn-depositional faults. The thickest sections penetrated to date occur in the eastern part of block 9/19.

Regional correlation
The Darwin Formation may be age equivalent to the Drake, Cook and Burton formations of the East Shetland Basin.

Genetic interpretation
This formation is interpreted as a shallow-marine shelf deposit (Richards 1989).

Biostratigraphic characterization
The *L.variabile* biomarker has been recorded from near the base of the Darwin Formation but may be reworked from the underlying Nansen Formation. The formation also includes the *L.spinosa* biomarker.

Age
Probably Pliensbachian to Toarcian.

Reference

See also Correlation Panel 7.
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DRAKE FORMATION

The term 'Drake Sub-unit' was introduced by Deegan & Scull (1977) for a unit of sandy calcareous mudstones lying between the 'Cook Sub-unit' and the Brent Group. Deegan & Scull gave the unit formation status in the UK North Sea but member status in the Norwegian North Sea. The formation equates with the 'Dunlin Shale Member' of Bowen (1975).

Type section
211/29-3 (Deegan & Scull 1977, p. 15, fig. 19): 2829.5-2887m (9283-9471ft.) below KB.

UK reference sections
211/13-7: 3798.5-3822m (12462-12540ft)
211/24-1: 2878.5-2930.5m (9444-9614ft)
211/27-4A: 3730-3743.5m (12238-12282ft)

Name. After Sir Francis Drake, the 16th century British admiral and circumnavigator (Deegan & Scull 1977, p. 15).

References
Lithology
The Drake Formation typically consists of medium grey to dark grey, variably silty and sandy and variably calcareous mudstone. The uppermost few metres or so locally contain mudstone clasts, floating sand grains, or thin beds of sandstone. In some sections, a discrete bed of coarse-grained sandstone of ‘Broom-type’ is developed some 0.15 to 0.20m below the top of the formation. Thin beds of olistic ironstone are recorded from some sections. These are composed of iron silicate and siderite, and sometimes contain belemnite guards. Unfossiliferous, non-oolitic, sideritic beds are also occur in some sections.

Upper boundary
The top of the Drake Formation is normally defined by a sharp downward change from sandstones (Broom Formation) to mudstones (e.g. 211/24-1, 211/29-3), although thin beds of ‘Broom-type’ sandstone occur within the uppermost Drake mudstones in some sections. It is marked by a sharp downward increase in gamma-ray values.

In the northeastern part of the East Shetland Basin, where the Drake Formation is overlain directly by the Rannoch mudstone unit, the boundary is defined by a downward change from micaceous to poorly micaceous mudstones (e.g. 211/13-7). It is marked by a slight downward decrease in gamma values and an increase in velocity.

Lower boundary
The base of the formation is defined by a downward change from mudstones to siltstones with subordinate sandstones (Cook Formation), and is marked by a downward decrease in gamma-ray values and an increase in velocity. The formation usually has distinctly higher overall gamma-ray values than the underlying Cook Formation.

Distribution and thickness
The Drake Formation is recognized over most of the East Shetland Basin north of 60° 30’N, and extends eastwards into the Viking Graben. It is, however, absent from the area of the Transitional Shelf, where Middle or Upper Jurassic sediments overlie pre-Jurassic rocks. There is no information from the part of the Viking Graben adjacent to the Transitional Shelf because no wells have penetrated this stratigraphic level. The formation may, therefore, extend southwards from its presently known area, but there appears to be a stratigraphic hiatus at this level to the south in the Beryl Embayment.

The formation thickens from west to east across the East Shetland Basin, reaching a maximum of 65m. However, it is thin or missing over some intra-basinal highs.

Genetic interpretation
The formation is of marine origin, and may have been deposited during the acme of the early Jurassic transgression of the Northern North Sea (Richards 1991). Nagy et al. (1984) and Vollset & Doré (1984) interpreted the formation as a prodeltaic succession deposited in front of the Brent Group deltaic sediments. However, Brown et al. (1987) argued that the mudstones at the base of the Rannoch Formation, and not those of the Drake Formation, are the prodeltaic equivalents of the Brent Group.

Vail & Todd (1981) suggested that the upper boundary of the Drake Formation coincides with a sequence boundary and is an unconformity, while Hallet (1981) suggested the presence of local unconformities. Other workers (e.g. Richards 1992) have suggested that the boundary is essentially conformable.

Biostratigraphic characterization
The V.subvitreus biomarker occurs near the top of the formation.

Age
Probably Toarcian to possibly earliest Aalenian.

References


The term Speke Formation is introduced for a heterolithic unit of sandstones, siltstones and mudstones. The unit was correlated with the Dunlin Group of the East Shetland Basin by Johns & Andrews (1985).

**Type section**
1/4-1: 844-945m (2769-3100ft) below KB.

**Reference section**
1/4-2: 731.5-821.5m (2400-2695ft)

**Name.** After John Hanning Speke, the 19th century British explorer.

**References**

**Lithology**
The formation is characterized by interbedded, varicoloured but often grey-green sandstones, mudstones and siltstones with minor marls and limestones. The sandstones are fine to coarse grained, variably sorted and micaceous, and in wells 1/4-1 and 1/4-2 form about 65 per cent of the formation.

**Upper boundary**
The top of the Speke Formation is defined by a sharp downward change from sandstone-dominated, coal-bearing strata (Fladen Group) to more argillaceous, coal-free strata. It is marked by a sharp downward increase in gamma values.

**Lower boundary**
The base of the Speke Formation is defined by a downward change from varicoloured, but usually green or grey, sediments to red Triassic sediments. In wells 1/4-1 and 1/4-2, the colour change is associated with a slight downward increase in gamma values.

**Distribution and thickness**
The Speke Formation is recognized only in the Unst Basin. It is 100.9m thick in the type well, but thins towards the margins of the Unst Basin.

**Regional correlation**
The Speke Formation may represent a lateral equivalent of the marine Dunlin Group strata of the East Shetland Basin.

**Genetic interpretation**
Johns & Andrews (1985) suggested that this unit represents an essentially continental environment.

**Biostratigraphic characterization**
There are no biostratigraphic data available for this interval.

**Age**
Lower Jurassic, as inferred by the formation’s position above Triassic red beds and below Middle Jurassic coal-bearing sediments (Johns & Andrews 1985).

**References**
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**FJERRITSLEV FORMATION**

The term Fjerritslev Formation was originally introduced for the Jurassic succession in onshore Denmark, but Deegan & Scull (1977) extended usage of the term into the North Sea area. They considered that Norwegian well 7/9-1 best illustrated the characteristics of the formation, proposing this well as a reference section (Deegan & Scull 1977, p.21, fig.26). In the U.K. sector of the Central Graben, the Fjerritslev Formation has been positively identified in only one well (22/5b-5).

**Type section**

The Danish onshore well Fjerritslev No.2, Jutland: 1320-2300m (4331-7546ft) (Larsen 1986; Michelsen 1989).

**UK reference section**

22/5b-5: 3111.5-3127.5 m (10208-10260ft) below KB.

**Name.** After the village of Fjerritslev, Jutland, Denmark (Larsen 1966).

**Lithology**

The Fjerritslev Formation consists, in the type well, of grey to dark grey, calcareous mudstones with frequent beds of argillaceous limestone and sporadic fine-grained sandstones. In well N7/9-1, the offshore reference well proposed by Deegan & Scull (1977, p.21, fig.26), it consists of dark grey to grey-brown mudstone grading to siltstone in places. The characteristic grey mudstones are also present in well 22/5b-5, but appear to pass upwards into sandstones, which are here included within the Fjerritslev Formation.

**Upper boundary**

The top of the Fjerritslev Formation in well 22/5b-5 is defined by a sharp downward change from mudstones of the Cromer Knoll Group to sandstones. In the Danish sector, the upper boundary is often unconformable, with the formation being overlain by a variety of stratigraphic units.

**Lower boundary**

In well 22/5b-5, the base of the formation is defined by a downward transition from grey mudstones to white sandstones interbedded with red-brown calcareous mudstones (Triassic).

**Distribution and thickness**

The Fjerritslev Formation is most completely preserved in the Norwegian-Danish Basin and has, to date, only been sporadically proved in the Central Graben, where it occurs as eroded remnants. It has been identified in only one well in the UK sector.

**Regional correlation**

The Fjerritslev Formation is the lateral equivalent of part of the Dunlin Group of the North Viking Graben, of the Dunrobin Bay Group of the Moray Firth, and of the Lias Group south of the Mid-North Sea High.

**Genetic interpretation**

Microfaunal and microfloral assemblages in Fjerritslev Formation mudstones suggest that deposition occurred in a low-energy, open-marine setting.

**Biostratigraphic characterization**

In well 22/5b-5, the Liasidium variabile biomarker occurs near the top of the mudstone section, where it is associated with rare specimens of the foraminifera Marginula prima. Typical early Jurassic miospores have been recorded in cuttings samples from the overlying sandstone section.

**Age**

The Fjerritslev Formation in the type well section in the Danish Basin is Hettangian to Aalenian in age (Michelsen 1978, 1989). In the Central Graben area, however, the formation is less completely preserved and ranges from Hettangian to Sinemurian (Jensen et al. 1986). The presence of the Liasidium variabile biomarker in well 22/5b-5 confirms that the unit includes beds of Late Sinemurian age.

**References**


BANKS GROUP
CORMORANT & SKAGERRAK FORMATIONS
BANKS GROUP
(new)

The term Banks Group is introduced to include the revised Statfjord and Nansen formations. These units were assigned by Deegan & Scull (1977) to the Raude-Eirikson and Nansen members, respectively, of the Statfjord Formation, and were not assigned to a group. The term 'Statfjord Group' has been applied informally to the Banks Group in some Beryl Embayment wells.

The Banks Group represents a dominantly arenaceous, essentially fluvial/coastal depositional system (Roe & Steel 1985). The sediments are transitional between the continental red beds of the underlying Triassic Cormoran Formation and the marine mudstones, siltstones and minor sandstones of the Dunlin Group. The early Jurassic marine transgression took place from north to south, with marine conditions becoming established earlier in the East Shetland Basin than in the Beryl Embayment (Richards 1991).

Sediments of Statfjord and Nansen facies are thus younger in the Beryl Embayment than in the East Shetland Basin.

The group is recognized in the East Shetland Basin, in the Beryl and Bruce field areas of the Beryl Embayment, and in immediately adjacent parts of the Viking Graben. Its western boundary is partly depositional and partly erosive.

References

UK SECTOR

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<thead>
<tr>
<th>Deegan &amp; Scull (1977)</th>
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NORWEGIAN SECTOR

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Name. After Sir Joseph Banks, the British naturalist and explorer.

Constituent formations
NANSEN FORMATION p. 167
STATFJORD FORMATION p. 171

Age
Probably Rhaetian to Sinemurian in the East Shetland Basin and Hettangian to Pliensbachian in the Beryl Embayment.
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The term 'Nansen Member' was introduced by Deegan & Scull (1977) for a unit of white sandstones lying above the interbedded sandstones, siltstones and minor coals of what is here referred to the Statfjord Formation (the Raude and Eiriksson members of the Statfjord Formation of Deegan & Scull), and below the Amundsen Formation (East Shetland Basin) or the newly defined Darwin Formation (Beryl Embayment). This definition is retained, but the unit is assigned formation status.

Although the term Nansen Formation (or Nansen Member) is already widely applied in the East Shetland Basin, lithologically similar sediments in the Beryl Embayment and adjacent parts of the South Viking Graben area have previously been assigned to a variety of names: the 'Lower Beryl Sandstone 2' (Mobil), the 'Statfjord Formation' (BP), the 'Banks Formation' (Richards 1989), and the 'middle formation' (Richards 1990; 1991).

In the type well (211/24-1), Deegan & Scull (1977) recognized at the top of the 'Nansen Member' a prominent unit of calcareous sandstone, which they referred to informally as the 'calcareous sandstone bed'. This unit was perceived as providing a means of correlation within the East Shetland Basin. However, calcite-cemented beds occur at other levels within the formation, and the concept of a uniquely correlatable 'calcareous sandstone bed' cannot therefore be sustained.

**Type section**

211/24-1 (Deegan & Scull 1977, p.13): 3112-3158.5 m (10210-10362 ft) below KB.

**UK reference sections**

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<td>9/13-15</td>
<td>3600-3651m  (11810-11979ft)</td>
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<tr>
<td>9/19-5A</td>
<td>3842-3910.5m(12605-12830ft)</td>
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**Name.** After Fridtjof Nansen, the Norwegian polar scientist, explorer and statesman (Deegan & Scull 1977, p.13).

**References**


Lithology
In the East Shetland Basin, the Nansen Formation consists of fine to coarse grained, fairly well sorted, occasionally calcite-cemented, more or less pebbly/granulitic, white to light brown sandstones. In cored sections, individual beds are often seen to fine upwards above sharp bases. Quartzose granules and pebbles are frequently concentrated as basal lags in such upward-fining beds. Cross-bedding is recorded in places. Roe & Steel (1985) reported the presence of horizontal and vertical burrows and wave-ripple lamination. Thin mudstone beds containing marine fossils occur in places, and correspond to distinct gamma-ray peaks, often including a prominent peak near the middle of the formation.

In the Beryl Embayment and in adjacent parts of the South Viking Graben, the Nansen Formation is composed almost entirely of sandstones. Most of the sandstones are fine to coarse grained, quartzose, apparently mud-free and often kaolinitic. They occur in amalgamated and stacked units up to about 8m thick, normally with uniform grain-size profiles, although upward-fining cycles are observed in some sections. Quartz granules and small clasts of red sandstone occur locally. Sedimentary structures are rare, but include ripple lamination and planar or inclined laminae. Bioturbation is rare, but mud-lined traces are recorded. Near the top of the formation, a unit of muddy sandstone is often present, reflected in relatively high gamma-ray values. These sandstones are mineralogically similar to the underlying clean sandstones, but are characterized by muddy, carbonaceous wisps and laminae, frequently with indistinct burrows. Distinct gamma-ray peaks near the base and the middle of the formation correspond to thin beds of more or less pebbly, silty mudstone.

Upper boundary
In the East Shetland Basin, the top of the Nansen Formation is defined by a downward change from mudstones of the Amundsen Formation to sandstones, reflected in a distinct downward decrease in gamma-ray values (e.g. 211/27-1A). In the Beryl Embayment and adjacent parts of the South Viking Graben, it is represented by a downward change from mudstones of the Darwin Formation to sandstones, also associated with a downward decrease in gamma-ray values (e.g. 9/13-15). This is associated with a downslope increase in velocity where calcite cement occurs at the top of the Nansen Formation (e.g. 211/27-1A).

Lower boundary
In the Beryl Embayment and easternmost parts of the East Shetland Basin (e.g. 3/15-2, 9/13-15), the base of the formation is defined by a downward change from sandstone to interbedded sandstone, mudstone and minor coals of the Statfjord Formation. This is marked by a downward increase in gamma-ray values and by a downward change from a relatively low, uniform gamma-ray response to a more erratic gamma-ray response.

In the East Shetland Basin, west of the Ninian-Hutton fault trend, the Statfjord Formation is absent, and the Nansen Formation rests with possible unconformity on the Cormorant Formation (Triassic). In this area (e.g. 211/27-1A), the boundary is defined as the downward change from white or light brown, more or less calcite cemented, sandstones to red, predominantly argillaceous strata.

Distribution and thickness
The Nansen Formation is recognized over most of the East Shetland Basin to the north of 60° 30’N, and extends eastwards into the Viking Graben. It is also recognized in the Beryl and Bruce field areas of the Beryl Embayment, and in the Viking Graben immediately to the east and southeast. It is, however, absent from the Transitional Shelf, where Middle or Upper Jurassic rocks overlie pre-Jurassic strata. In the Viking Graben immediately adjacent to the Transitional Shelf, some wells indicate that Upper Jurassic strata rest directly on the Devonian, but most released wells do not reach the base of the Jurassic.

The formation thickens from west to east across the East Shetland Basin, attaining a maximum thickness of about 60m. In the Beryl Embayment and immediately adjacent parts of the Viking Graben, it attains a maximum thickness of 75m.

Regional correlation
The Nansen Formation is diachronous. The lower part of the formation in the East Shetland Basin is time equivalent to the upper part of the Statfjord Formation of the Beryl Embayment, and the lower part of the formation in the Beryl Embayment is equivalent to the lower part of the Amundsen of the East Shetland Basin.

Genetic interpretation
The Nansen Formation was deposited in a shallow-marine environment in the East Shetland Basin (Deegan & Scull 1977). Roe & Steel (1985) suggested that in the Tampey Spur area, the formation represents a marine-reworked deposit of shoreline and nearshore origin. Upward-fining beds, particularly near the base of the formation in the East Shetland Basin, may represent coastal channel deposits. Richards (1991) has suggested that the predominantly upward-fining sandstones in the Beryl Embayment area were deposited in fan deltas, with pebbly siltstones representing debris-flow deposits, and the muddy sandstones at the top of the formation being of shallow-marine origin.

Vail & Todd (1981) suggested that over most of the East Shetland Basin, the base of the Nansen Formation shows onlap over truncated strata, and is therefore a sequence boundary. However, it is possible that a conformable relationship may exist in places where red-bed sedimentation continued into the early Jurassic.

Biostratigraphic characterization
Dinoflagellate cysts and acritarchs are rare, although the L. variabile biomarker has been recorded in places from sediments coincident with the mid-formation gamma-ray peak. The formation contains the earliest marine microfaunas of the North Sea Jurassic, including the L. semireticulata biomarker.

Age
Probably Hettangian to Sinemurian age in the East Shetland Basin and Hettangian to early Pliensbachian age in the Beryl Embayment.

References

See also Correlation Panel 1.
The term Statfjord Formation was introduced by Deegan & Scull (1977) for a heterolithic unit of sandstones, siltstones and mudstones lying between Triassic beds and the Dunlin Group, and was modified from the 'Statfjord Sand Formation' of Bowen (1975).

Deegan & Scull (1977) subdivided their Statfjord Formation into three members. In ascending order, these were the 'Raude Member', the 'Eiriksson Member', and the 'Nansen Member'. The Nansen unit is here removed from the Statfjord Formation and assigned separate formation status within the Banks Group (p. 165).

Deegan & Scull (1977) suggested that the subdivision of the Statfjord Formation into Raude and Eiriksson members was possible only in the area of the Brent and Statfjord fields. Vollset & Dore (1984) also noted the difficulty of subdividing the succession into Eiriksson and Raude members over most of the North Viking Graben. The Eiriksson and Raude are therefore no longer considered appropriate in the UK sector, and no subdivision is proposed for the Statfjord Formation, as defined here.

In the Beryl Embayment, the formation has been referred to as the 'Lower Beryl Sandstone 1' (Mobil), the 'Eiriksson Formation' (Mobil and Hamilton), the 'Scott Formation' (Richards 1989), and the 'lower formation' (Richards 1990; 1991).

The Raude Formation / Ruadh Shale unit, recognized by Mobil in the Beryl Embayment area as part of their 'Statfjord Group', is here excluded from the Statfjord Formation, but is placed within the underlying Cormorant Formation because of its dominantly red coloration.

**Type section**
N33/12-2 (Deegan & Scull 1977, p. 12, fig. 17): 2719-2951 m (8919-9681 ft) below KB (revised depths).

**Remarks**: Deegan & Scull defined the formation in this well as containing a topmost 'Nansen member', the Nansen unit is here removed from the Statfjord Formation, resulting in revision of the upper boundary.

**UK reference sections**
- 211/24-1: 3158.5-3434 m (10362-11266 ft)
- 3/15-2: 3645.5-3997 m (11960-13113 ft)
- 9/8a-7: 4095-4118 m (13435-13510 ft)
- 9/13-19: 3663.5-3717.5 m (12020-12196 ft)

**Name**: From the Statfjord Field in Norwegian Quadrant 33 (Deegan & Scull 1977).

**References**
Lithology

The Statfjord Formation consists of interbedded sandstones, siltstones, mudstones and, in some sections, minor coals. In the East Shetland Basin, the sandstone beds are light grey to white, fine to very coarse grained, sometimes pebbly, micaceous, variably kaolinitic and sometimes cross-bedded. Sandstone beds are more easily correlatable between wells in the upper part of the formation than in the lower part (Roe & Steel 1985). Bed thicknesses average about 5m for the sandstones and about 5m for the mudstones and siltstones (Deegan & Scull 1977). Siltstones and mudstones are subordinate to sandstones, and are grey, green, reddish brown or occasionally red, micromicaceous and sometimes carbonaceous. Coal seams, up to about 3.5m thick, occur locally, particularly in the uppermost part of the formation in the East Shetland Basin, where Deegan & Scull (1977) also reported the presence of marine fossils.

In the Beryl Embayment, the sandstones usually have sharp bases, and frequently fine upwards from coarse or medium grained to fine or very fine grained, in bed-sets up to 3m thick. In some sections these are stacked vertically in units up to about 10m thick. Cross-bedding and unidirectional ripple lamination are recorded in places, and carbonized plant/woody fragments form sporadic basal lags. Thin-bedded sandstones (<10 cm up to about 0.5m thick) also occur interbedded with the siltstones, mudstones and coals, and display a range of sedimentary structures, such as parallel to sub-parallel lamination, ripple lamination and water-escape structures.

Associated siltstones and mudstones in the Beryl Embayment are mid-grey, mostly blocky and massive, but sometimes fissile; they occur in units up to a few metres thick. Minor coals are recorded interbedded with the siltstones and mudstones.

Upper boundary

The top of the Statfjord Formation is defined by a downward change from sandstones (Nansen Formation) to interbedded sandstones, mudstones and minor coals. It is marked by a downward increase in gamma-ray values and by a downward transition to a more erratic gamma-ray log response. A slight downward decrease in velocity is observed in some sections.

Lower boundary

The base of the formation is defined by a gross downward change from predominantly grey, white and green colours to predominantly red colours and by a change to more argillaceous facies (Cormorant Formation). This lithological change is accompanied in some sections by a downward increase in gamma-ray values. The exact position of the lower boundary can, however, be difficult to locate precisely in some wells because of the variable nature of the lithologies and colours in the boundary zone.

Distribution and thickness

The Statfjord Formation occurs in the eastmost parts of the East Shetland Basin, in the Beryl Embayment, and in adjacent parts of the Viking Graben. Steel & Ryseth (1990) noted that the formation occurs only to the east of the Ninian-Hutton fault trend. In the Beryl and Bruce field areas of the Beryl Embayment, the formation is bounded by faults and has an erosional limit to the west and to the north; it probably extends eastwards into the Norwegian sector.

The formation attains a maximum thickness of over 300m in the East Shetland Basin and about 80m in the Beryl Embayment area.

Genetic interpretation

Deegan & Scull (1977) interpreted the succession as a braided stream system passing up to coastal barriers, mouth bars and backswamps. Kirk (1980), Chauvin & Valachi (1980) and Skarpnes et al. (1980) postulated depositional environments similar to those of Deegan & Scull (1977) for the lower part, but suggested that the upper part includes a significant proportion of fluvial facies.

Roe & Steel (1985) re-interpreted the succession in the Tampen Spur area as a coastal fan-delta system, consisting of channelized sandstones associated with coastal-plain facies. The formation is interpreted as a channelized coastal-plain deposit in the Beryl Embayment (Richards 1991).

Biostratigraphic characterization

The O.pseudoalatus biomarker has been identified within the Statfjord Formation.

Age

Probably Rhaetian or Hettangian to Sinemurian. The youngest representatives occur in the Beryl Embayment area.

References


See also Correlation Panel 1.
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CORMORANT FORMATION

A brief account of the Cormorant Formation is included here since, although largely of Triassic age, it is believed to extend locally into the early Jurassic.

The term Cormorant Formation was introduced by Deegan & Scull (1977, p.9) for the argillaceous sandstones, siltstones and sandy mudstones of red-bed fades that lie beneath sediments of the Banks Group over much of the East Shetland Basin. In Part 4 of this revision, the formation is extended into the Beryl Embayment, with the laterally equivalent Skagerrak Formation occurring in adjacent parts of the South Viking Graben. The transition takes place across the intervening Crawford Spur.

The Cormorant Formation is composed of white, pale grey, greenish grey, brown, and reddish brown sandstones, with red, reddish brown, greenish grey, and minor dark grey, purple, and white mudstones, and sporadic thin limestones. Sections at the centre of the East Shetland Basin and Beryl Embayment are mudstone dominated, whereas those near the East Shetland Platform and Crawford Spur are sandstone dominated.

The Cormorant Formation is overlain conformably by sediments of the Starfjord Formation over large parts of the Beryl Embayment, and in the east of the East Shetland Basin. In such sections, the boundary is defined by the uppermost occurrence of predominant red beds (Deegan & Scull 1977; Johnson et al., in press), and often by a downward increase in the proportion of mudstone, as indicated by a change to higher and more erratic gamma-ray values. Elsewhere, the formation underlies younger Jurassic or Cretaceous strata (Lervik et al. 1989, fig.3), and the boundary is marked by a sharp lithological and wireline-log break.

The sandstones and mudstones of the Cormorant Formation were deposited in fluvial, alluvial and lacustrine environments. The thin limestones are calcretes, formed during periods of relatively high aridity. The Cormorant Formation is largely of Triassic (Scythian to Rhaetian) age, but is believed to extend into the early Hettangian in places.

References


SKAGERRAK FORMATION

A brief account of the Skagerrak Formation is included here since, although largely of Triassic age, it is believed to extend locally into the early Jurassic.

The term Skagerrak Formation was introduced by Deegan & Scull (1977) for red, brown, grey, and green Middle and Late Triassic arenaceous sediments that overlie monotonous red and brown mudstones of the Smith Bank Formation in the Norwegian sector of the South Viking Graben and Central Graben. In Part 4 of this revision, the formation is extended into the UK South Viking Graben and parts of the UK Central Graben, following the proposals of Fisher & Mudge (1990). In the UK Northern North Sea, the formation is limited to the southern part of the South Viking Graben, with the laterally equivalent Cormorant Formation occurring in the Beryl Embayment.

The transition takes place across the intervening Crawford Spur.

In the South Viking Graben, the Skagerrak Formation comprises a monotonous continental red-bed sequence of fluvial sandstones and subsidiary thinly bedded siltstones and mudstones. The sandstones of the Skagerrak Formation are generally argillaceous, fine to medium grained and grey, white, brown or reddish brown in colour. The siltstones and mudstones are micaceous, and reddish brown, or, less commonly, greenish grey or white. Many of the siltstones are slightly calcareous, but the mudstones are generally non-calcareous. The Skagerrak Formation is unconformably overlain by Middle Jurassic, Upper Jurassic or Cretaceous rocks in all sections.

The sediments of Skagerrak Formation were deposited in fluvial setting, with the coarse detritus being derived mainly from the east (Fisher & Mudge 1990). In the Crawford Field area, the Skagerrak Formation includes fluvial channel-fill sandstones, sheetflood sandstones, lacustrine deposits and pedogenic carbonates (Yaliz 1991). The formation is largely of Middle to Upper Triassic age, but is believed to extend into the Jurassic in the South Viking Graben.

References


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CORRELATION PANELS
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DUNLIN GROUP

CORRELATION PANEL 6

DUNLIN GROUP

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LITHOLOGY

Mudstone / Siltstone

Sandstone

DRAKE FORMATION

COOK FORMATION

BURTON FORMATION

AMUNDSEN FORMATION
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APPENDIX
INTRODUCTION

The aim of this review is to describe the most important Jurassic biostratigraphic markers for the Central and Northern North Sea. The order of presentation, i.e. palynomorphs, foraminifera, radiolaria and ostracods, follows convention.

The biomarkers selected are, in general, commonly and consistently used by industry, non-proprietary, well-known and easily identifiable. Their selection is pragmatic, and the biomarker scheme does not attempt to provide the most definitive or refined biostratigraphic subdivision of the Jurassic succession. Other schemes exist that provide a detailed breakdown of part or all of the North Sea Jurassic succession (e.g. Riley et al. 1989; Mitchener et al. 1992; Partington, Copestake et al. 1993; Partington, Mitchener et al. 1993).

The biomarkers are defined mostly as first downhole occurrence (FDOs), although four are defined as first downhole occurrence (FDAs). Since cuttings samples are the most usual source of the data, first uphole occurrences cannot be routinely determined and are, therefore, excluded. The biomarkers selected have been widely illustrated, in particular by Riding & Thomas (1992) for the dinoflagellate cysts, Jenkins & Murray (1989) for the foraminifera, and Bate & Robinson (1978) for the ostracods.

Many of the biomarkers described below have never been fully derived. 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. Different criteria are undoubtedly operated at different times. Similarly, the definition of an occurrence may be problematical. However, a revision and formal definition of the biomarkers is outside the scope of this synthesis.

The scheme presented is primarily concerned with the relative order of the biomarkers, rather than with their precise chronostratigraphic calibration. Nevertheless, data acquired from both onshore and offshore sections allow a tentative correlation with the ammonite zonation (see Fig. A1).

For completeness, biomarkers have been included for the entire Kimmeridgian Clay Formation in this study, even though the formation extends into the Ryazanian.

PALYNOMORPHS

Dinoflagellate cysts provide the majority of the palynomorph biomarkers selected. A historical review of the use of dinoflagellate cysts in Jurassic North Sea stratigraphy has been given by Riding & Thomas (1992). By the 1970s, Mesozoic dinoflagellate cysts were being used widely in North Sea Basin exploration, with zonal schemes being proposed by Davey (1979), Fisher & Riley (1980) and Morby (1978). A dinoflagellate cyst biozonation for the entire Jurassic System, based on accurately dated English outcrop and borehole material, was proposed by Woolall & Riding (1983). Subsequent work by Noth-Hansen (1986), Riding (1984) and Riding & Thomas (1988; 1992) resulted in the refinement of this zonation.

Other relevant zonations include those of Rawson & Riley (1982) and Riley & Fenton (1982). Zonal schemes for the Middle and Upper Jurassic strata of the North Sea were published by Riley et al. (1989) and Van der Zwan (1989, 1990). Local palynostratigraphic schemes for the Brent Group (Northern North Sea) have been formulated by Helland-Hansen et al. (1992), Mitchener et al. (1992), Whitaker et al. (1992) and Williams (1992).

Twenty-four palynomorph biomarkers are defined in this study (Figure A1). In the absence of the named biomarker index taxon, the majority of these biomarkers can be recognized using the alternative marker forms cited. The informally named and undescribed mid-Jurassic morphotypes used in works such as Fitt et al. (1989) and Mitchener et al. (1992) are not included in this study, although they have clear potential in refining correlations in the Northern North Sea.

FORAMINIFERA

Jurassic foraminifera have been widely utilized in North Sea Basin stratigraphy, but the data remain largely unexplored. King et al. (1989) described Kimmeridgian Clay Formation faunas of Ryazanian age. Morriss & Coleman (1989) and Morriss & Dyer (1990) are the only contributions on mid-Jurassic foraminifera from offshore Europe. Significant studies of North Sea early and mid-Jurassic faunas have recently been published by Copestake & Johnson (1989), Nagy (1985a, b), Nagy & Johansen (1989; 1991) and Nagy et al. (1984).

Because benthonic foraminifera are particularly dependent on environmental factors such as facies, palaeobathymetry and oxygenation of bottom waters, they have a more sporadic areal distribution than planktonic forms, with the result that certain taxa are of only local biostratigraphic significance. For this reason, it is not possible to establish a single scheme for the entire UK North Sea, and the biomarkers are consequently described in terms of two regional schemes (see Fig. A1). Twenty biomarkers are defined for the Northern North Sea (East Shetland Basin and Viking Graben), and twelve for the Central North Sea (Inner Moray Firth, Outer Moray Firth and Central Graben).

In the northern province, the dysaerobic Kimmeridge Clay Formation yields sparse, long-ranging agglutinating species. The underlying Heather Formation faunas are also dominated by agglutinating taxa, but with some calcareous benthonic species also present. The Oxfordian to Volgian foraminiferal biomarkers are largely derived from the work of Shipp (1989). Bathonian and Callovian biomarkers are derived from the work of Morriss & Coleman (1989).

These apply only to the Northern North Sea, where the index taxa are stratigraphically restricted; elsewhere, the taxa have relatively long ranges.

APPENDIX

Jurassic biostratigraphic markers

by J.B. Riding, J.E. Thomas and I.P. Wilkinson

OXFORDIAN TO VOLGIAN

Jurassic biostratigraphic markers for the southern province are applicable only to the Inner and Outer Moray Firth, because of a locally developed benthos.

Early Jurassic North Sea faunas are for the most part dominated by small agglutinating species, reflecting the prevalence of dysaerobic bottom water conditions.

RADIOLARIA

Radiolaria have only recently received attention and little has been published (Cox 1990). The best known studies are on the Kimmeridgian and Volgian. Gregory (1986) recorded a low-diversity assemblage from the early Kimmeridgian (cymodoce Zone) of eastern Scotland, which Dyer & Copestake (1989) confirmed as including Orthoceratinae mclaughlini Perssagno, Parvicingula blowi Perssagno and Heussa sp.1 sensu Dyer & Copestake. The value of radiolaria in the Kimmeridgian-Volgian stratigraphy of the North Sea was demonstrated by Dyer & Copestake (1989), who recorded 13 bioevents based on FDOs, LDOs and acmes. These bio-events are included in Figure A1, but, because they have not been defined in detail, they are not described in this report. Some will be included in the ‘key microfaunal events’ identified by Partington, Mitchener et al. (1993, table 2).

OSTRACODS

Despite the relatively refined Jurassic ostracod biostratigraphy for onshore northwest Europe, these microfossils have not been extensively utilized offshore. This is largely a reflection of their relative rarity compared to foraminifera and of their poor preservation in areas of deep burial.

For the late Jurassic, the most comprehensive scheme is that proposed for northwest Europe by Christensen & Kilényi (1979), and subsequently refined by Wilkinson (1983a, b). Specific offshore studies include those of Christensen (1988), on the late Jurassic faunas of the Viking Graben and Central Graben, and Heggroen & Wong (1989), on Volgian faunas from the Dutch Central Graben.

Mid-Jurassic faunas have been reported by Christensen (1988) from the Viking Graben and Central Graben, and by Heggroen & Wong (1989) from the Cellovian of the Dutch Central Graben.

Early Jurassic faunas have been reported by Male & Nagy (1989) from the Torcian and Pliensbachian of the Stavfjord Field, and by Michelsen (1978) from the Danish sector of the Central Graben. Although the ostracod biomarkers described by these authors have been reported only from the Norwegian and Danish sectors, they are included in the current scheme because they will undoubtedly apply in the immediately adjacent UK Viking Graben and Central Graben areas.
1) Rotosphaeropsis longicorne
Definition: The FDAO of Rotosphaeropsis longicorne (Davey) Riding & Davey.
Remarks. Davey (1989) noted isolated reworked occurrences of E. spirituans from the late Ryazanian. The FDAO of Rotosphaeropsis longicorne is coincident with this biomarker (Riding & Davey 1989).

2) Muderongia albani
Definition: The FDAO of Muderongia albani Loodey & Brealy.
Remarks. This event is also characterized by the FDAO of amorphous organic material and is a reliable marker for the uppermost Kimmeridgian, Clay Formation (Rawson & Riley 1982).

3) Gloeosiphon dimorphum
Definition: The FDAO of Gloeosiphon dimorphum De Clerk et al.
Remarks. Other species with coincident FDOs are Dichadogonyaulax pannua (Norris) Sarjeant and Senoniasphaeridium jurassica (Gilmour & Sarjeant) Lentin & Williams. Fenton & Riley (1987) reported isolated reworked occurrences of E. spirituans from the late Ryazanian. The FDAO of early Oxfordian (unpublished data).

4) Muderongia sp.A
Remarks. The only biomarker which does not have a formal Linnaean binomial name is Muderongia sp.A. There are some minor problems with the formalization of this species (Riding & Thomas 1994), but it is a widely known and easily recognized regional marker. The acme of Muderongia sp.A is distinct from the FDO, which lies between the late Oxfordian and early Kimmeridgian.

5) Compositophaeridium polonicum
Remarks. The precise age of this FDAO is not known. Fenton & Riley (1982, Riley et al. 1989) and Kunz (1990) placed the event at, or near, the early-middle Oxfordian boundary. Raynaud (1987) suggested that it falls within the top of the Kimmeridge Clay Formation. However, according to Huber et al. (1987) and Riding (1987), the youngest occurrence of common R. aequalis falls within the topseriense Zone. As this FDAO occurs consistently below the FDO of R. aequalis, the former event is unquestionably placed at the top of the distiphycus Zone. (see David et al. 1989) speculatively

6) Endocerium lilurum
Definition: The FDO of Endocerium lilurum (Deflandre) Lentin & Williams. Age. Late Kimmeridgian (Zoysiella Zone).
Remarks. The FDAO of Gonyaulacysta jurassica (Deflandre) Norris & Sarjeant subsp. jurassica is coincident with this biomarker (Harker et al. 1987, Riding & Thomas 1992).

7) Seriniodinium crystallinum
Definition: The FDAO of Seriniodinium crystallinum (Deflandre) Klement.
Remarks. The FDAO of Early Bathonian.

8) Seriniodinium crystallinum acme
Definition: The FDAO of Seriniodinium crystallinum. Age. Latest Oxfordian (rosekrantzi Zone). Remarks. Seriniodinium crystallinum is present in the earliest Kimmeridgian in relatively small proportions. However, in the Oxfordian, this species is common to abundant (Riding 1984; Riding & Thomas 1992), so that the FDAO of the species may be used to define the Early Oxfordian boundary. When palynomorph recovery is poor, it may be difficult to differentiate between the FDO (see above) and the FDAO of Seriniodinium crystallinum.

9) Compositophaeridium polonicum

10) Rigadella aequalis
Definition: The FDO of Rigadella aequalis (Deflandre) Below. Age. Mid-Oxfordian (teniuserrestatum Zone). Remarks. Three species with coincident FDOs are Chrystroemia varians (Deflandre) Davey, Gonyaulacysta jurassica subsp. adacta Sarjeant var. longicornis (Deflandre) Sarjeant and Liesbergia scabrumgigantum (Sarjeant) Berger (often quoted as Acanthophalx xentula Drugg) (see Riding & Thomas 1992).

11) Rigadella aequalis acme
Definition. The FDO of Rigadella aequalis. Age. Mid-Oxfordian (1 densiphycus Zone). Remarks. The precise age of this FDAO is not known. Fenton & Riley (1982, Riley et al. 1989) and Kunz (1990) placed the event at, or near, the early-middle Oxfordian boundary. Raynaud (1987) indicated that it falls within the distiphycus Zone. However, according to Huber et al. (1987) and Riding (1987), the youngest occurrence of common R. aequalis falls within the topseriense Zone. As this FDAO occurs consistently below the FDO of R. aequalis, the former event is unquestionably placed at the top of the distiphycus Zone.

12) Wanaea spp.

13) Parvocysta longiprolata
Remarks. Fait et al. (1989) speculatively referred the FDO of N. gracilis in the Northern North Sea as being close to the Bajocian/Bathonian boundary. The FDAO of N. gracilis was stated by Fait et al. (1989) to be coincident with the Aalenian-Bajocian boundary, yet these authors reported (p. 194) that “a small increase in the abundance of N. gracilis may be observed at the top of the Lower Bajocian”. The latter probably equates with the biomarker as defined here. The FDAO of Mucronia semitubulata Morgenroth is coincident with this biomarker (Riding 1984).

15) Aldrosea alderdensis

16) Cenotelidium spp. acme
Definition. The FDAO of Cenotelidium spp. Age. Late Bathonian. Remarks. This intra late Bathonian biomarker refers principally to the FDAO of Cenotelidium sellwoodii (Sarjeant 1975) Stover & Evitt 1975, but includes other representatives of the genus Cenotelidium and closely related forms such as Korystocysta gocchi (Sarjeant 1976) Woollam 1983. This biomarker is traceable throughout the North Viking Graben.

17) Meiothermogonyaulax vallesi
Definition. The FDAO of Meiothermogonyaulax vallesi Sarjeant. Age. Early Bathonian (teniplicatus Zone).

18) Nannoceratopsis gracilis

20) Parvocysta spp.
Definition. The FDO of Parvocysta spp. Age. Earliest Aalenian (spallum Zone). Remarks. This biomarker coincides with a major regression event, the base of the LZA megacycle of Haq et al. (1987).

21) Luehdorfia spinosa

22) Liassicum variabile
Definition. The FDAO of Liassicum variabile Drug. Age. Late Sinemurian (aricostatum Zone).

23) Dacopodium priscum
Definition. The FDAO of Dacopodium priscum Evitt. Age. Early Sinemurian (taberni Zone). Remarks. As the index species is present sporadically in the Hettangian and early Sinemurian, this biomarker may not be consistently discernible.

24) Ovalippus pseudolatus
Definition. The FDAO of Ovalippus pseudolatus (Thiergart) Schuermann. Age. Latest Rhaetian (Triassic).
Remarks. The FDAO of the pollen grain O.pseudolatus is one of a suite of miozones that mark the Triassic-Jurassic boundary; others include Gyrolipaculapollis rudis (Venkatachala & Goczan) Morby, Newesportites bigranulatus (Levet-Carette) Morby, Rhaetipollis germanicus Schulz and Ricciopites tabulatulatus Lundblad. The FDAO of the dinoflagellate cyst Rhabdopolyssaculidae rhacidea (Sarjeant) Loeblich & Loeblich is coeval with this biomarker (Riding & Thomas 1992).

FORAMINIFERA
a) Northern North Sea
1) Hapaloplagiommae cannu
Definition. The FDO of Hapaloplagiommae cannu Canu. Age. Late Ryazanian.
Remarks. The FDAO of this biomarker coincides with a major regression event, the base of the LZA megacycle of Haq et al. (1987).

2) Trochammina cf. lathetic
3) Textularia jurassica
Definition: The FDO (reappearance) of rare agglutinating species, including Textularia jurassica (Guenbel) and Haplophragmium pokrovkaensis. Age: Mid-Bathonian.
Remarks: This FDO is stratigraphically younger in the Central North Sea (Morris & Dyer 1990).

4) Lenticulina spp.
Definition: The FDO of diverse faunas, dominated by agglutinating taxa and comprising rare calcareous benthonic forms, including species of Lenticulina. Age: Early Kimmeridgian (baylei Zone to cymodoce Zone).

5) Ammobaculites deęctorius
Definition: The FDO of Ammobaculites deęctorius (Haeusler). Age: Earliest Kimmeridgian to latest Oxfordian.

6) Lenticulina ectypa
Definition: The FDO's of Lenticulina ectypa (Loeblich & Tappan) and Epistomina stelligera (Reus). Age: Late to mid-Oxfordian. Remarks: The FDO of Lenticulina ectypa is stratigraphically younger in the Central Graben (Fig. A3).

7) Lenticulina ectypa costata
Definition: The FDO of L. ectypa costata Cordey and a downhole increase in diversity. Age: Mid-Oxfordian (?tenus eraturn Zone).

8) Verneuilinoides sp. 1
Definition: The FDOs of Verneuilinoides sp. 1 of Morris & Coleman (1989) and Recurvoides sublustris Dain. Age: Mid-Callovian (coronatum Zone). Remarks: The FDOs of Haplophragmoides infcallovienensis Dain and Haplophragmoides sp. cf. H. sp.143 Brooke & Braun (1981) are coincident with this FDO.

9) Verneuilinoides typhera
Definition: The FDOs of Verneuilinoides typhera Loeblich & Tappan and Haplophragmoides spp. Age: Early Callovian.

10) Haplophragmium pokrovkaensis
Definition: The FDO of Haplophragmium pokrovkaensis Kosrove. Age: Mid-Bathonian.

11) Sparse interval
Definition: The top of an interval in which only rare foraminifera are present. Age: Early Bathonian. Remarks: The paralic Brent Group and Pentland Formation are typically devoid of foraminifera.

12) Ammodiscus yonubakensis
Definition: The FDOs of Ammodiscus yonubakensis Nagy et al. and Trochammina espaura Nagy & Johansen, coupled with a downhole increase in diversity. Age: Aalenian or early Bajoician.

13) Agglutinating foraminifera
Definition: The FDO of sparse, low-diversity faunas dominated by small agglutinating representatives of the suborder Textulariina. Age: Early Aalenian.

14) Verneuilinoides subvitreus

15) Barren interval
Definition: The top of a section of barren strata. Age: Hettangian.

16) Haplophragmium pokrovkaensis
Definition: The FDOs of Haplophragmium pokrovkaensis (d'Orbigny) and Lenticulina mucronata acutangulata (Terquem). Age: Late Pliensbachian (margaritatus Zone).
Remarks: The FDOs of Haplophragmium pokrovkaensis spp., including H. lincolnensis Copestake, and Nodosaria metensis Terquem, are coincident with this biomarker.

17) Vaginalinopsis denticulatacarinata
Definition: The FDO of Vaginalinopsis denticulatacarinata (Franke). Age: Early Pliensbachian (davoezi Zone).

18) Lenticulina semirenticula
Definition: The FDOs of Lenticulina semirenticula Fuchs and/or Reinholdella margarita (Terquem). Age: Early Sinemurian.

19) Barren interval
Definition: The top of a section of barren strata. Age: Oxfordian.

20) Central North Sea
1) Haplophragmium casui
Definition: The FDOs of Haplophragmium casui and other agglutinating species. Age: Late Ryazanian.

2) Epistomina stelligera
Definition: The FDO of Epistomina stelligera. Age: Early Kimmeridgian (margaritatus Zone).

3) Textularia jurassica
Definition: The FDO of Textularia jurassica and a downhole increase in diversity. Age: Early Kimmeridgian (baylei Zone). Remarks: The FDO of Textularia jurassica is stratigraphically younger in the Northern North Sea (Fig. A3).

4) Lenticulina ectypa
Definition: The FDO of Lenticulina ectypa. Age: Late Oxfordian (regularize Zone).

5) Ammobaculites coprolithiformis
Definition: The FDO of Ammobaculites coprolithiformis (Schwager). Age: Mid-Oxfordian (Identiplicatula Zone).
Remarks: This event is equivalent to the Northern North Sea Lenticulina ectypa costata biomarker.

6) Lenticulina quenstedtii
Definition: The FDO of Lenticulina quenstedtii (Guembel). Age: Earliest Oxfordian (margaritatus Zone).

7) Marginalina prima
Definition: The FDOs of Marginalina prima and Saracenaria sublaevi and a downhole increase in diversity. Age: Earliest Toarcian (tenuscostatum Zone).
Remarks: This event is equivalent to the Northern North Sea Marginulina prima biomarker.

8) Dentalina matutina
Definition: The FDOs of Dentalina matutina and Lenticulina muensteri acutangulata. Age: Late Pliensbachian (margaritatus Zone).

9) Vaginalinopsis denticulatacarinata
Definition: The FDO of Vaginalinopsis denticulatacarinata. Age: Early Pliensbachian (davoezi Zone).
Remarks: This datum is equivalent to the Northern North Sea Dentalina matutina biomarker.

10) Dentalina stelligera
Definition: The FDO of Dentalina stelligera (Klingler & Neuweiler). Age: Late Sinemurian (obtusum Zone).

11) Progonoidea reticulata
Definition: The FDO of Progonoidea reticulata (Klingler & Neuweiler). Age: Early Sinemurian (turneri Zone).

12) Ogmoconchella aspinata
Definition: The FDOs of Ogmoconchella aspinata (Drexler), Ogmoconchella hagenowi Drexler and Ogmoconchella asp 

13) Lenticulina semirenticula
Definition: The FDOs of Lenticulina semirenticula and/or Reinholdella margarita. Age: Early Sinemurian. Remarks: This event is equivalent to the Northern North Sea Vaginalinopsis denticulatacarinata biomarker.

14) Ogmoconchella aspinata
Definition: The FDOs of Ogmoconchella aspinata (Drexler), Ogmoconchella hagenowi Drexler and Ogmoconchella asp

15) Dentalina matutina
Definition: The FDOs of Dentalina matutina and Lenticulina muensteri acutangulata. Age: Late Pliensbachian (margaritatus Zone).

16) Marginalina prima
Definition: The FDOs of Marginalina prima (d'Orbigny) and Saracenaria sublaevi (Franke) and a downhole increase in diversity. Age: Earliest Toarcian (tenuscostatum Zone) or latest Pliensbachian (spinatum Zone).

17) Vaginalinopsis denticulatacarinata
Definition: The FDO of Vaginalinopsis denticulatacarinata (Franke). Age: Early Pliensbachian (davoezi Zone).
Remarks: This event is equivalent to the Northern North Sea Vaginalinopsis denticulatacarinata biomarker.

18) Nodosaria issleri
Definition: The FDO of Nodosaria issleri. Age: Early Sinemurian (obtusum Zone).

19) Dentalina matutina
Definition: The FDOs of Dentalina matutina and Lenticulina muensteri acutangulata. Age: Late Pliensbachian (margaritatus Zone).

20) Barren interval
Definition: The top of a section of barren strata. Age: Hettangian.
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<th>CHRONOSTRATIGRAPHY</th>
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Figure A1. Jurassic and earliest Cretaceous biomarkers for the UK Central and Northern North Sea. *Applicable only to the Inner and Outer Moray Firth. Key biomarkers (see p.1) shown in red.
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