Lithostratigraphic nomenclature of the UK North Sea

Editors:

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7. POST-TRIASSIC OF THE SOUTHERN NORTH SEA

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FOREWORD

This publication is one of a series of seven volumes that provide comprehensive and up-to-date information on North Sea lithostratigraphic nomenclature, together with details of all nomenclature revisions. Such information is vital to anyone concerned with the geology of the North Sea, especially those involved in the search for oil and gas, and the volumes have been designed to serve as practical desk-top or well-site reference manuals for operational geologists.

The British Geological Survey has always played a major role in studies related to the petroleum geology of the North Sea. Indeed its pioneering work in the North Sea in the early 1960s provided the basis for early exploration and the licensing of the region for exploration. The BGS has been pleased to work with the United Kingdom Offshore Operators Association (UKOOA) to compile and jointly fund the first five volumes in the series, which together covered the Central and Northern North Sea plus the Carboniferous of the Southern North Sea. However, this project did not cover the post-Carboniferous sequences of the Southern North Sea and therefore the BGS decided on its own initiative to fund two extra volumes (Volumes 6 and 7) in order to extend the post-Carboniferous nomenclatural scheme to the entire UK sector of the North Sea. The comprehensive and systematic descriptions, coupled with the copious illustration of individual well sections, should form the basis for extending the lithostratigraphic scheme used here to other sectors of the North Sea. No doubt North Sea lithostratigraphic nomenclature will continue to evolve in the years ahead as oil and gas exploration proceeds, but I believe that this volume, together with its six companion volumes, will serve as the standard reference work for many years to come.

One of the essential elements in the successful compilation and publication of this vast amount of lithostratigraphic data has been the close co-operation between the BGS and the member companies of UKOOA who provided data and allowed their staff to serve on steering committees for the volumes.

In the recent Government White Paper on the future of science and technology in Britain, stress was placed on the role that science has to play in the creation of wealth. In no area of science is this more apparent than the geosciences in general, and petroleum science in particular, for it is geology that provides the data and the knowledge that together produce the new ideas on where to search for oil and gas. The British Geological Survey in partnership with industry looks forward to contributing to the future success of one of Britain's most important industrial endeavours this century — the UK offshore oil and gas industry.

Peter J Cook, Director, BGS

September 1994

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

The original UKOOA plan was to publish the revision in five volumes, concentrating on prospective parts of the succession that were considered to be most in need of lithostratigraphic revision. However, coverage of the UK North Sea succession has been completed by the addition, by BGS, of two further volumes 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 unpublished post-completion reports made available by UKOOA member companies.

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

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 and sonic log signatures. Lateral variation within units is displayed in a series of correlation panels at the end of the volume.

The lithostratigraphic procedures adopted in this review 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 following conventions have been adopted for the lithostratigraphic units:

- A formation must be mappable and must possess a distinct lithostratigraphic signature. Additional information has been obtained from published papers and unpublished sources, including BGS reports, consultants' reports, and unpublished post-completion reports made available by UKOOA member companies.

References


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

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

DISTRIBUTION MAP

STRATIGRAPHIC SYNOPSIS
These summarize the lithostratigraphic relationships within each group.

'Key biomarkers' are those of particular relevance to lithostratigraphic assignment.

STRUCTURAL NOMENCLATURE
Structural terms in this study are shown on the accompanying map. They are taken from the map "Structural framework of the North Sea area", issued by the Petroleum Exploration Society of Great Britain (revised edition, March 1994).
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INTRODUCTION

The first formal lithostratigraphic scheme for the post-Triassic successions of the UK Southern North Sea was proposed by Rhys (1974), as part of a general account of the lithostratigraphy of that area. Rhys formalized a number of lithostratigraphic terms for the Cretaceous succession (see table p.35) and Jurassic succession (see table p.83) but provided no formal divisions for the Paleogene succession. The Rhys nomenclature, while widely applied to the Southern North Sea post-Triassic successions, was based on data from a limited number of wells. Subsequently, extensive drilling in the basin, both by companies and by the BGS, has allowed a more refined lithostratigraphic scheme to be developed. This largely new lithostratigraphic scheme is presented here.

The Jurassic successions of the UK Southern North Sea lie conformably on the beds of the Triassic Penarth Group (Johnson et al. 1994) throughout most of the UK sector, except where faulting or salt intrusion has occurred. The Triassic-Jurassic boundary interval has been drilled in many wells but cored in only a single BGS offshore borehole (Lott & Warrington 1988; see Johnson et al. 1994, p.7). In the UK onshore successions, the base of the Jurassic is placed at the level of the lowest occurrence of ammonites of the genus Psiloceras. This typically occurs a few metres above the base of the Lias Group, the lowest beds of which are therefore assigned a latest Triassic age. In the commercial, uncored wells these criteria are not applicable and for practical purposes the Triassic-Jurassic boundary is therefore taken at the base of the Lias Group in this report.

Biostratigraphic control for the post-Triassic of the UK Southern North Sea is extremely limited in comparison with adjacent onshore areas and with the Central North Sea (Johnson & Lott 1993). The few regionally identifiable biostratigraphic markers are described in the Appendices.

Reference


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PALEOGENE
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INTRODUCTION

The Paleogene succession of the UK Southern North Sea (Fig.1, p.5) can be described entirely in terms of formations defined in the Central and Northern North Sea (see Knox & Holloway 1992). However, only in the extreme northeast of the region, in Quadrant 39, is a full 'Central North Sea' succession displayed. Elsewhere the succession is attenuated and stratigraphically incomplete. Because the Paleogene is non-prospective throughout the area, lying within a few hundred metres of the surface, wireline-log coverage is often incomplete or of poor quality. Cuttings samples have not always been collected and biostratigraphic data are sparse. For these reasons, the Paleogene units are given abbreviated coverage in this volume, with illustration being limited to a series of regional correlations panels.

The distribution and thickness of the Paleogene succession is strongly influenced by regional structure (see Fig.2, p.5), with widespread uplift in the west of the area resulting in the total removal of the Paleogene succession. The early effects of this uplift are reflected in the north of the area, where early Eocene sediments overstep the Paleocene Lista Formation to rest on the Chalk (e.g. 36/15-1, Panel 1, p. 17; see also Lott et al. 1983). The Paleogene succession is most complete in the northeast of the area, close to the Central Graben, where it reaches a maximum thickness of c. 1150m (39/7-1, Panel 1, p. 17). A thicker, but less complete succession is found in a restricted area along the quadrant 44/49 boundary, with a maximum thickness of c. 1300m in well 49/1-2 (Panel 3, p.23).

The oldest Paleogene unit, the early Paleocene Ekofisk Formation, is absent from most of the region, being restricted to three small and widely separated areas (Fig.2, p.5). Except in the northeast of the area, where a complete Central North Sea succession is present, the distribution of the Ekofisk Formation is unrelated to that of the remainder of the Paleocene, indicating that deposition of the Chalk and Montrose groups was separated not only by a hiatus but also by a significant change in tectonic regime. The distribution of younger formations reflects the regional uplift coupled with the development of local structures, some salt-related, in the southeast.

NORDLAND GROUP

The Nordland Group displays a rapid southward change from a thick, mudstone-dominated succession of Miocene to Recent age, to a relatively thin, sandstone-dominated succession of dominantly Pliocene to Pleistocene age. In the thicker sections of Quadrants 38 and 39, the base of the group is marked by the presence of high-gamma, glauconite-rich mudstones of late Miocene age, resting on relatively low-gamma Oligocene mudstones (e.g. 39/7-1, Panel 1, p.17). Over the most of the area, however, mudstones or sandstones of Pliocene age rest with marked non-sequence on Oligocene, Eocene or older strata (see Panels 2 and 3, pp. 19-23).

References


Figure 1. Lithostratigraphic nomenclature scheme for the Paleogene of the UK Southern North Sea

Figure 2. Areal distribution of Paleogene groups and formations
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The Westray Group consists of two formations that extend southwards from the Central North Sea (see Knox & Holloway 1992). These are the Lark Formation, consisting of marine shelf mudstone facies, and the marginal Skade Formation, in which mudstones alternate with units of sandstone. The group reaches a maximum thickness of about 300m in Quadrant 39 (Panel 1, p. 17) and locally in Quadrants 44, 48 and 49 (Panel 3, p.23).

**LARK FORMATION**

The Lark Formation of the UK Southern North Sea is thin and relatively incomplete compared with that of the Central North Sea. Two reference sections have been selected: well 44/28-1 for its display of characteristic wireline-log signatures and well 37/12-1 for its biostratigraphic control, based on analysis of sidewall cores.

**UK reference sections (Southern North Sea)**

44/28-1 (Panel 3, p.23): 455-766.5m (1493-2515ft)
37/12-1 (Panel 1, p. 17): 444-581m (1457-1906ft)

**Lithology**

In northernmost sections, the Lark Formation displays a succession of brown-grey to olive-grey mudstones, glauconitic in part, with local glauconitic sandstones. It thins rapidly to the south (Panel 1, p.17) and becomes increasingly sandy and glauconitic. The mudstones are commonly calcareous.

**Upper boundary**

The top of the Lark Formation is defined by a downward change from glauconite-rich sandstone and mudstone to brown or grey glauconitic mudstone. It is generally characterized by a sharp decrease in gamma-ray values.

**Lower boundary**

The base is defined by a downward change from grey-brown to olive-grey mudstone to more consistently olive-grey or green-grey mudstone, with a distinct increase in silt content. It is characterized by a downward decrease in gamma-ray values. Sonic log responses are variable, with a marked downward increase in velocity.

**SKADE FORMATION**

The term Skade Formation was applied by Knox & Holloway (1992) to a sandstone-dominated succession that occurs within the Westray Group along the western margin of the UK Central and Northern North Sea. These shelf sandstones are believed to have extended southwards from the Central North Sea into the Southern North Sea, but because of widespread erosion along the western basin margin, they now occur in isolated sections.

**UK reference section (Southern North Sea)**

49/1-4 (Panel 3, p.23): 320-617.5m (1050-2026ft)

**Lithology**

The Skade Formation consists of very fine to fine grained, glauconitic sandstones interbedded with brown-grey to olive-grey mudstones. The sandstones display upward-decreasing gamma-ray log signatures interpreted as upward-coarsening cycles.

**Upper boundary**

The top of the Skade Formation is defined by a downward change from poorly consolidated, glauconite-rich sandstone or silty mudstone of the basal Nordland Group to brown or grey glauconitic sandstone or mudstone. It is generally characterized by a sharp decrease in gamma-ray values, with the basal sediments of the overlying Nordland Group commonly displaying distinctly high gamma-ray values.

**Lower boundary**

The base of the Skade Formation is defined by a downward change from brown or grey silty mudstone to firmer, green-grey mudstone of the Lark Formation, and is characterized by a downward decrease in gamma-ray values.

**DISTRIBUTION AND THICKNESS**

Biostratigraphic records indicate that the Lark Formation extends over much of the area of Paleogene subcrop. In the northern part of the area, the western limit of the formation is defined by lateral passage into the sandstone-dominated succession of the Skade Formation. The maximum recorded thickness is about 300m in Quadrant 39 (see Panel 1, p.17) and in Block 44/28 (Panel 3, p.23).

**Regional correlation**

Mudstones of the Lark Formation pass laterally into the sandstone-dominated succession of the Skade Formation in westernmost sections in the north of the area (Panel 1, p.17 and Panel 3, p.23).

**Genetic interpretation**

The Lark Formation represents deposition in an inner shelf setting.

**Age**

Latest Eocene to early mid Miocene in the most complete sections.

**SKADE FORMATION**

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**Genetic interpretation**

The Lark Formation represents deposition in an inner shelf setting.

**Age**

Latest Eocene to early mid Miocene in the most complete sections.

**Reference**

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The Stronsay Group consists of two formations that extend southwards from the Central North Sea (see Knox & Holloway 1992). These are the Horda Formation, consisting entirely of mudstone, and the Prestwich Formation, consisting of alternating sandstone and mudstone units.

HORDA FORMATION

UK reference section (Southern North Sea)
44/28-1 (Panel 3, p.23): 766.5-1568m (2515-5145ft)

Lithology
The Horda Formation consists almost exclusively of mudstone, with only sporadic thin sandstones occurring in a few sections. The mudstones are mostly silty, green-grey to grey-green, and poorly fissile, but are finer grained and more fissile, in the lower part of the formation, with distinctive red-brown or variegated colours characterizing the basal 10 to 20m.

Upper boundary
In complete sections, the top of the Horda Formation is defined by a downward change from grey or brown-grey mudstones of the Lark Formation to green-grey or grey-green mudstone, marked by a downward decrease in gamma-ray values. In truncated sections, the mudstones of the Horda Formation are overlain by silty mudstones or sandstones of the Nordland Group.

Lower boundary
The base of the Horda Formation is defined by a downward change from red-brown or variegated claystones to the relatively silty, carbonaceous grey mudstones of the Balder Formation.

Lithostratigraphic subdivision
A downward change from grey-green silty mudstones to finer grained, more fissile, grey-green and variegated mudstones marks the top of Horda unit 1 (H1) as defined in the Central North Sea (Knox & Holloway 1992). This lithological change is marked by a downward increase in gamma-ray values.

Distribution and thickness
The Horda Formation extends throughout the area of Southern North Sea Paleogene subcrop. The formation reaches a maximum recorded thickness of 1,880m in well 44/28-1 (Panel 3, p.23) and is around 700m thick in Quadrant 39 (Panel 1, p.17). Thicknesses of between 200 and 400m are more typical. Most of the Horda Formation sections are incomplete as a result of successive phases of late Paleogene to Neogene erosion.

Biorepositories
Biofacies data indicate that the mudstones are marine throughout. The variegated claystones of the early Eocene (H1) represent slow sedimentation in relatively deep water, probably in depths of 200 to 300 m. The overlying silty mudstones (H2-3), which are dominantly of mid Eocene age; represent a phase of relatively rapid mud deposition that led to the formation of a thick northward-prograding sediment wedge (Knox & Holloway 1992, fig.1, A, p.2).

Biostratigraphic characterization
In complete sections, the top of the Horda Formation occurs a little above the late Eocene FDQs of A. diktyoplokus and G. index. Where the Upper Eocene is missing, the top of the formation lies at different levels within the Middle Eocene. The E. aculeolae and Cenosphera biomarkers are recorded close to the H1/H2 boundary.

Regional correlation
The mudstones of the upper part of the Horda Formation (late mid Eocene) locally display a westward passage into the sandstone-dominated succession of the Prestwich Formation. Onshore, in the London Basin, the Horda Formation is represented by the bulk of the London Clay Formation (divisions B to E of King 1981) and the overlying Bagshot Sands.

Age
Early to late Eocene.

PRESTWICH FORMATION (new)

The term Prestwich Formation is introduced for a unit of sandstone and mudstone that occurs along the western limit of the Stronsay Group in the north of the area. It is broadly equivalent to the Mousa Formation of the Central and Northern North Sea (Knox & Holloway 1992), but occupies a more restricted stratigraphic range (late mid Eocene as opposed to early to late Eocene).

Name.
After Sir Joseph Prestwich (1812-1896) who laid the foundation for modern lithostratigraphic subdivision of the Paleocene and Eocene strata of southern England, and who made the first correlation of the succession in southern England with that of the Paris Basin.

Type section
49/1-2 (Panel 3, p.23): 838-1285.5m (2749-4217ft)

Lithology
The Prestwich Formation consists of an alternation of fine to medium grained sandstones with green-grey to grey-green silty mudstones. Two sandstone units are present. The lower sandstone displays wireline-log signatures indicative of upward coarsening, whereas the upper sandstone possess a sharp base and displays a more or less consistent log character.

Distribution and thickness
The Prestwich Formation is best represented close to the boundary between quadrants 44 and 49 (Panel 3, p.23). The formation probably extends northwesterly into Quadrant 36, although information is limited to a single section in well 36/15-1 (Panel 1, p.17). This section shows a series of sandstone units in the upper part of the Tertiary succession; the thicker sandstone units are tentatively assigned to the Nordland Group and Westray Group (Skade Formation) and only the thin, basal sandstone unit is here assigned to the Prestwich Formation. This interpretation is based on regional trends in thickness distribution.

The Prestwich Formation is about 450m thick in well 49/1-2. Genetic interpretation
The sandstones are believed to represent deposition in sublittoral conditions. The upward-coarsening trend inferred for the lower sandstone unit suggests deposition during a period of shoreline progradation, whereas the upward-fining trend in the upper sandstone unit may reflect transgression related to a sea-level rise, heralding the change to mud deposition associated with the overlying Lark Formation.

Regional correlation
In southeast England, comparable nearshore sandstone facies occur in the Bagshot Beds (early mid Eocene) and Bracklesham Formation (mid to late mid Eocene) (see Curry et al. 1978, table 1). The Prestwich sands were part of a sublittoral sand sheet that extended southwards from Scotland, via eastern England, into the Paris Basin.

Age
Late mid Eocene, possibly extending into the late Eocene.

References
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The Moray Group in the Southern North Sea comprises three formations: the Balder Formation, the Lambeth Formation and the Sele Formation (see overleaf). The first two extend southwards from the Central North Sea with little change in character. The Lambeth Formation is, by contrast, restricted to the Southern North Sea, extending southwards into the London Basin, where the succession attains group status (Lambeth Group of Ellison et al. 1994). The Lambeth Formation is time-equivalent to the Dornoch Formation of the Central and Northern North Sea, and displays similar facies. However, the Lambeth succession is relatively thin, and lacks the large-scale progradational section that is characteristic of the Dornoch Formation. Furthermore, the two formations are separated geographically as a result of post-Lists, pre-Balder uplift and erosion in the northwest of the Southern North Sea area.

**BALDER FORMATION**

**UK reference section (Southern North Sea)**
49/15-1 (Panel 5, p.27): 848.5-870.5m (2783-2856ft)

**Lithology**
In the Southern North Sea, the Balder Formation displays the typical lithological association of grey, micaceous and carbonaceous mudstones, with abundant basaltic tuff layers in the lower part. The formation displays a characteristic bow-shaped gamma response, with relatively low gamma-ray values associated with the tuff-bearing mudstones. In the north of the region these typically show a high-velocity, spiky log signature (e.g. 38/25-1, Panel 4, p.25, but further south the unit becomes increasingly silty, with an associated decrease in velocity (e.g. 49/15-1, Panel 5, p.27). Some southern sections also display a thin, low-gamma sandstone unit at the base (e.g. 53/16-1, Panel 7, p.31).

**Upper boundary**
The top of the Balder Formation is defined by a downward change from grey-green or red-brown claystones of the basal Horda Formation to relatively silty, carbonaceous grey mudstones. On wireline logs it is typically taken at the base of a high-gamma spike. However, in some sections the wireline log pick is poorly developed (e.g. 38/22-1, Panel 4, p.25).

**Lower boundary**
The base of the Balder Formation is defined by a downward change from mudstone with tuff to mudstone, marked by a sharp increase in gamma-ray values.

**Lithostratigraphic subdivision**
The Balder Formation may be divided into a lower unit 1 (B1) with abundant tuff layers and an upper unit 2 (B2) with only a few thin, argillized tuff layers (e.g. 38/25-1, Panel 4, p.25).

**Distribution and thickness**
The Balder Formation extends throughout the area of Southern North Sea Paleogene subcrop, ranging in thickness between 20 and 30m.

**Regional correlation**
Unit B1 is equivalent to the tuff-rich part of the Harwich Formation (London Clay division A1 of King 1981) and to the upper part of the Oldhaven Sand Member. Unit B2 is equivalent to the lower part of the London Clay Formation (divisions A2 and A3 of King 1981).

**Genetic interpretation**
The Balder Formation of the Southern North Sea represents deposition under restricted marine conditions, in water depths of 100-200 m. The abundant tuff layers are the product of North Atlantic volcanism.

**Biostratigraphic characterization**
The formation is characterized by a sparse and restricted microfauna, consisting mainly of diatoms. The Coscinodiscus sp.1 biomarker occurs at the top of the formation.

**Age**
Early Eocene.

**LAMBETH FORMATION (new)**

**Type section**
49/15-1 (Panel 5, p.27): 875-908.5m (2870-2980ft)

**Lithology**
The Lambeth Formation is represented by a poorly known and variable succession of brown, yellow, grey and red mudstones with locally developed sandstones. The mudstones and claystones appear to represent interbedded or colour-mottled lithologies, and are typically soft and poorly bedded. The sandstones are mostly non-glauconitic, medium to fine grained but locally with flint pebbles. In some sections these display blocky wireline-log character, but locally in the thicker successions of quadrants 48, 49, 50 and 53, they display upward-coarsening cycles. In some sections a thin unit of glauconitic sandstone is present near the base.

**Upper boundary**
The top of the Lambeth Formation is defined by a downward change from grey mudstone (Sele unit 3) to sandstone or brown or yellow mudstone, and is marked by a downward decrease in gamma-ray values.

**Lower boundary**
The base of the Lambeth Formation is defined by a downward change from sandstone or yellow, brown or red-brown mudstone to green grey or grey mudstone of the Lista Formation. It commonly lies beneath a thin low-gamma or high-velocity mudstone unit (e.g. 49/1-3, Panel 6, p.29), which passes locally into sandstone (see Panels 6 and 7). It is also commonly identified by a downward change to relatively high and consistent resistivity values.

**Regional correlation**
No consistent subdivision is possible, although in some sections it is possible to recognize equivalents of units S1 and S2 on the basis of log signatures (e.g. 49/15-1, Panel 5, p.27) or biostratigraphy (*Apectodinium acme*). Sandstones are commonly present at the top and bottom of the formation, with a third unit locally developed in the middle (Panel 8, p.33).

**Distribution and thickness**
The Lambeth Formation is present over much of the Paleogene subcrop. The thickness is generally between 10 and 30m, but reaches c.45m in well 44/11-3 (Panel 5, p.27).

**Regional correlation**
The Lambeth Formation is represented onshore by the Lambeth Group, equivalent to the informal ‘Woolwich & Reading Beds’ and comprising the Upnor, Woolwich and Reading formations (Ellison et al. 1994). Differentiation of the onshore formations is not consistently possible offshore, although it seems likely that all three are represented.

**Genetic interpretation**
The basal, transgressive marine sandstone of the Upnor Formation (‘Bottom Bed’) is probably represented in most sections, and possibly constitutes the thick sandstone of well 49/1-4 (Panel 6, p.29). The upward-coarsening cycles displayed by sections in parts of Quadrants 49 and 53 (e.g. 49/28-7, Panel 8, p.33) probably relate to the lagoonal to marine facies of the Woolwich Formation. Elsewhere, the common occurrence of yellow and brown mudstones suggests the presence of continental facies (Reading Formation equivalent).

**Biostratigraphic characterization**
The *Apectodinium acme*, accompanied by the FDO of *A. augustum*, has been recorded from a level close to the top of the Lambeth Formation, indicating that the formation is equivalent to Sele unit 1 of the Central North Sea.

**Age**
Late Paleocene to early Eocene.

**Lithostratigraphic subdivision**

**References**
SELE FORMATION

UK reference section (Southern North Sea)
53/5-2 (Panel 7, p.31): 640-646m (2100-2120ft)

Lithology
The Sele Formation is most typically developed in the extreme northeast of the area (Quadrant 38 north and Quadrant 39), where it consists of several tens of metres of dark grey, carbonaceous, variably laminated mudstone. Wireline-log signatures are directly comparable to those displayed in sand-free sections of the southern Central Graben (e.g. 39/7-1, Panel 4, p.25). Elsewhere, the formation is represented by a thin grey to brown-grey mudstone unit that forms a high-gamma peak immediately below the Balder Formation (e.g. 37/23-1, Panel 4, p.25).

Upper boundary
The top of the Sele Formation is marked by a downward change from low-gamma mudstone with tuff (Balder Formation) to high-gamma mudstone.

Lower boundary
Where the Sele Formation overlies the Lista Formation, the base is typically defined by a downward change from grey mudstone to either green-grey, red-brown or variegated mudstone of the Lista Formation, and marked by a downward decrease in gamma-ray values. Locally, a thin, low-gamma, sandy unit is present at the base (e.g. 38/25-1, Panel 4, p.25). Where the Sele Formation overlies the Lambeth Formation, it is defined by a downward change to grey-orange or yellow-brown mudstone (e.g. 44/19-3, Panel 5, p.27) or, locally, to sandstone (e.g. 53/5-2, Panel 8, p.33).

Lithostratigraphic subdivision
In the complete sections of Quadrant 39, three units (S1-3) can be recognized within the Sele Formation, based on gamma-ray response (see also Knox & Holloway 1992, p.64). Over most of the area, however, only unit S3 is present in Sele facies (e.g. Panel 5, p.27).

Distribution and thickness
The full Sele succession is restricted to northeasternmost sections. However, the uppermost unit (S3) extends over the entire region. Locally, Sele unit 3 oversteps older Paleogene units to rest directly on Cretaceous chalk (e.g. 36/15-1, Panel 4, p.25; see also Lott et al. 1983).

Regional correlation
Sele units 1 and 2 pass southwards into the Lambeth Formation and are represented onshore by the ‘Woolwich & Reading Beds’ or, in the new terminology of Ellison et al. (1994), the Upnor, Woolwich and Reading formations. Sele unit 3 is represented onshore by the Hales Clay (Knox et al. 1990), which constitutes the lowest part of the Harwich Formation (see Ellison et al. 1994).

Genetic interpretation
The mudstones of the Sele Formation were deposited in restricted marine conditions, with water depths ranging from c.50m in the south and west to over 200m in the northeast.

Biostratigraphic characterization
In the thicker, more complete sections of Quadrant 39, a downward influx of large leiospheres occurs close to the top of unit S2 and the Apectodinium acme is recognized at the top of unit S1.

Age
Late Paleocene to Eocene.

References
MONTROSE GROUP & EKOFIG FORMATION

As in the Central North Sea (Knox & Holloway, 1992), the Montrose Group comprises two formations, the Lista Formation and the Maureen Formation. The early Paleocene Ekofisk Formation (see overview) is the youngest formation of the Chalk Group, the remainder being of Cretaceous age (see 'Cretaceous' section p.35).

LISTA FORMATION

The Lista Formation is little changed from its type development in the Central North Sea except that deep-water sandstones are absent.

UK reference section (Southern North Sea) 53/5-2 (Panel 7, p.31): 669.5-698m (2197-2290ft)

Lithology

The Lista Formation is characterized in northeastern sections by green-grey to grey-green and red claystones. Further south, the formation is represented by relatively dark green-grey or olive-grey, variably silty mudstones, glauconitic in part, and with trace amounts of green claystone. Aggulinated foraminifera are particularly conspicuous in northeastern sections. In southern and western sections, the Lista Formation becomes relatively sandy at the base, with the local development of glauconitic fine sandstones and with a widespread basal conglomerate of glauconitized flints.

Upper boundary

In the northeast of the area (Panel 4, p.25), the top of the Lista Formation is defined by a downward change from grey mudstone of the Sele Formation to grey-green mudstone, marked by a sharp downward increase in gamma-ray values. Elsewhere (e.g. Panel 5, p.27), it is defined by a downward change from yellow-brown or red-brown mudstones or sandstones of the Lambeth Formation to green-grey or olive-grey mudstone, and is generally marked by a downward increase in gamma-ray values. It is also commonly identified by a downward change to relatively high and consistent resistivity values.

Lower boundary

Where the Lista Formation overlies the Maureen Formation, its base is defined by a downward change from grey-green or olive-grey mudstone to grey mudstone. It is marked by a sharp downward decrease in gamma-ray values, often accompanied by a distinct gamma-ray spike, accompanied by an increase in velocity (e.g. 39/7-1, Panel 4, p.25; 44/24-1, Panel 6, p.29). Where the formation rests directly on chalk, its base is normally marked by a sharp downward decrease in gamma-ray values, commonly with a distinct high-gamma peak at the base of the formation. In some sections, however, a unit of relatively low-gamma, low-velocity mudstone intervenes beneath the high-gamma peak and the base of the formation. In most sections (e.g. 44/19-3, Panel 5, p.27), this probably reflects the presence of a basal sandy unit, but it is possible that in some sections (e.g. 38/22-1, Panel 1, p.17) the low gamma unit may represent a thin development of the Maureen Formation.

MAUREEN FORMATION

UK reference section (Southern North Sea) 44/24-1 (Panel 6, p.29): 793.5-808.5m (2603-2652ft)

Lithology

The Maureen Formation in Quadrant 39 (e.g. 39/7-1, Panel 4, p.25) consists of grey calcareous mudstones (unit M1 of Knox & Holloway 1992), overlain by non-calcareous mudstones (unit M2). It displays an overall upward increase in gamma-ray values and decrease in velocity. Elsewhere, the formation is represented by local occurrences of silty, glauconitic mudstone, probably equivalent to unit M2 (e.g. 44/24-1, Panel 6, p.29; 54/1-2, Panel 8, p.33).

Upper boundary

The top of the Maureen Formation is defined by a downward change from green-grey or olive-grey mudstone. It is marked by a sharp downward decrease in gamma-ray values, often below a distinct gamma-ray spike, generally accompanied by an increase in velocity.

Lower boundary

The base of the Maureen Formation is defined by a sharp downward change from grey mudstone to chalky limestone of the Chalk Group, marked by a downward decrease in gamma-ray values.

Biostratigraphic subdivision

The Maureen Formation is fully developed only in the northeast of the region (Quadrant 39), where it reaches a maximum thickness of about 25m. Elsewhere, it occurs as isolated sections up to c.15m thick. The presence of a thin low-gamma unit at the base of the Lista Formation in some sections (e.g. 38/22-1, Panel 1, p.17) may possibly indicate the existence of thin Maureen Formation representatives beyond the limits shown in Figure 2 (p.5).

Regional correlation

The Maureen Formation is not represented onshore in southern England, where the Ormesby Clay Formation (equivalent to the Lista Formation) rests unconformably on Cretaceous Chalk.

Genetic interpretation

The Maureen Formation of the Southern North Sea was deposited in a shelf environment.

Biostratigraphic characterization

In the northeast of the region, the top of the formation (i.e. the top of unit M2) is characterized by the downward appearance of abundant Cenophaeus, with the incoming of calcareous foraminifera at the top of unit M1. No biostratigraphic information is available from the thin and sporadic sections in central and southern parts of the area.

Age

Early to late Paleocene.

References

EKOFISK FORMATION (CHALK GROUP)

UK reference section (Southern North Sea)
49/9-1 (Panel 7, p.31): 810-820m (2658-2690ft)

Lithology
The Ekofisk Formation consists of chalky limestone, often fine grained and compact. It is typically chert-free, although chert may be present in some southernmost sections. The formation is typically characterized by relatively high gamma-ray values and, more diagnostically, by a relatively consistent velocity signature compared with the underlying chalk (e.g. 39/7-1, Panel 4, p.25; 49/9-1, Panel 7, p.31). Gamma-ray values alone are not sufficient to identify the Ekofisk Formation, as relatively high gamma-ray values are commonly displayed in the uppermost part of the Cretaceous chalk section (e.g. 39/1-3, Panel 6, p.29; 54/1-4, Panel 8, p.33). The uppermost part of the Rowe Formation section also commonly displays distinctive velocity signatures, reflecting abundant chert (e.g. 49/1-4, Panel 6, p.29), and has been mistakenly assigned to the Ekofisk Formation on some composite logs. In some of the most southerly sections, wireline signatures are more variable, and the formation is difficult to identify without the aid of biostratigraphy (e.g. 49/5-2, Panel 3, p.23).

Upper boundary
The top of the Ekofisk Formation is defined by a sharp downward change from mudstones of the Maureen or Lista formations to chalky limestone. It is marked on wireline logs by a sharp downward decrease in gamma-ray values and increase in velocity.

Lower boundary
Over most of the area, the base of the Ekofisk Formation is defined by a change from chert-rich chalky limestone, marked by a change from a relatively smooth to a relatively spiky velocity signature (e.g. 39/7-1, Panel 1, p.17), although this feature is not shown in all sections (e.g. 49/5-2, Panel 3, p.23), perhaps because the Ekofisk Formation rests on different levels within the Maastrichtian. The underlying Cretaceous chalk usually displays lower gamma-ray values, reflecting a lower clay content. The sonic log signature is, however, variable with some sections showing a downward increase in velocity (e.g. 39/7-1, Panel 1, p.17) and others showing a downward decrease (e.g. 44/28-1, Panel 3, p.23).

Distribution and thickness
The Ekofisk Formation is most widespread in the extreme northeast, where the succession is in continuity with that of the Central Graben (see Knox & Holloway 1992, p.81). Further south, the formation appears to be restricted to two main areas, one around the quadrant 44/49 boundary, the other in the north of Quadrant 53. Isolated sections may, however, occur outside these areas. For example, the wireline-log signature at the top of the Chalk Group in well 49/36-1 (Panel 2S, p.21) is strongly suggestive of the Ekofisk Formation. The formation is thickest in the northeast, reaching c.55m in well 39/2-1 (Panel 1, p.17). Elsewhere, the thickness is generally between 10 and 30m.

Regional correlation
The Ekofisk Formation is not represented onshore in southern England, where the Ormesby Clay Formation (equivalent to the Lista Formation) rests unconformably on Cretaceous Chalk.

Age
Early Paleocene. Limited data indicate that the early Paleocene may locally extend below the base of the Ekofisk Formation as defined by gamma-ray and sonic log signatures. Thus Danian assemblages were recorded from a sidewall core c.2.5m below the base of the Ekofisk Formation in well 49/9-1 (Panel 7, p.31), within a thin, high-velocity limestone unit.

Reference
CORRELATION PANELS
(PALEOGENE)
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CRETACEOUS
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The first formal lithostratigraphic nomenclature for the Cretaceous of the Southern North Sea was proposed by Rhys (1974). His scheme recognized two units of group status, the Chalk Group and Cromer Knoll Group. The Chalk Group was essentially synonymous with the chalk lithologies of the Lower Cretaceous and the Cromer Knoll Group with the marine clastics of the Lower Cretaceous.

With continuing exploration, in both the Southern North Sea and adjacent areas of the UK sector, a considerable amount of new stratigraphic data has become available allowing extensive revision of the Rhys (1974) scheme. The recognition that chalk sedimentation continued into the Early Paleocene became available allowing extensive revision of the Rhys (1974) scheme. The proposed scheme recognizes that there was a substantial continuity of sedimentation extending the recently established Central North Sea scheme (Johnson & Lott 1993) into the Southern North Sea area.

Proposed scheme
The proposed nomenclature scheme for the Cretaceous is summarized in Figure 3 (p.37). The two lithostratigraphic groups recognized by Rhys (1974), the Chalk Group and Cromer Knoll Group, are retained but their subdivisions and boundaries have been revised (see tables p.39 & p.61). The proposed scheme recognizes that there was a substantial continuity of sedimentation between the two basins during the Cretaceous, which requires a similar continuity of nomenclature. The chronostratigraphic position of many of the formation boundaries, particularly within the Chalk Group, is uncertain because of a lack of detailed biostratigraphic data. However, within the Cromer Knoll Group detailed biostratigraphic studies on a few significant sequences have enabled a more precise delimitation of some of the formation boundaries (Crittenden 1984, 1987a & b; Lott et al. 1986, 1989; Banner et al. 1993).

Correlation of the Chalk Group between the Central Graben and Southern North Sea
The proposed scheme for the Chalk Group of the Southern North Sea recognizes six subdivisions—Ekofisk, Rowe, Jukes, Lamplugh, Herrring and Hidra formations. Three of these units—Ekofisk, Herrring and Hidra formations—were originally recognized and defined in the Central North Sea (see Johnson & Lott 1993).

The Ekofisk Formation, though relatively poorly developed in the Southern North Sea area, is recognized sporadically (p.13) and the lowermost units of the Chalk Group, the Herring and Hidra formations, separated by the thin but persistent Black Band bed, are also traceable across the Mid-North Sea High into the southern North Sea area (pp. 41 & 43), where they are widely developed.

Problems arise, however, in correlating the Tor and Mackerel formations into the Southern North Sea because of a marked change in character of the lithological succession and consequently in log responses between the two basins. Biostratigraphically, both successions are known to span the same interval (late Turonian to Maastrichtian) but a number of factors can be suggested that in combination make log correlations difficult. The chalks of the Southern North Sea were generally deposited in somewhat shallower water than those of the Central Graben (shelf and bathyal ‘fades’ of King et al. 1989; Cameron et al. 1992, p.96) and, in contrast to those to the north of the Mid North Sea High, contain abundant cherts. They have also undergone a shallower though much more varied burial history, associated with the extensive salt tectonics and inversion phases that have occurred in the basin. Consequently their sonic velocity profiles, in particular, appear very different from those developed in the deeply buried chalks of the Central Graben.

A possible correlation between the schemes for the two basins is presented in the accompanying table (p.39).

Chronostratigraphy
Because many of the marker macrofossil species that define the standard Cretaceous biozones are lacking from North Sea successions, and because of a general scarcity of core, the stage and zonal boundaries can be identified only indirectly, using palynomorph and microfossil biomarkers. A detailed biomarker scheme is presented in the Appendix 2.

References


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Figure 3. Lithostratigraphic nomenclature scheme for the Cretaceous of the Southern North Sea.

Figure 4. Areal distribution of the Cretaceous groups.
CHALK GROUP
<table>
<thead>
<tr>
<th>Age</th>
<th>Groups</th>
<th>Southern North Sea</th>
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<tbody>
<tr>
<td>Jurassic</td>
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<tr>
<td>Volgian</td>
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<td>Ryzanian</td>
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<td>Hauterivian</td>
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<td>Valanginian</td>
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<td>Albian</td>
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<td>Aptian</td>
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<td>Barremian</td>
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<td>Cenomanian</td>
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<td>Turonian</td>
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<td>Coniacian</td>
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<td>Santonian</td>
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<td>Campanian</td>
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<td>Maastrichtian</td>
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<td>Paleocene</td>
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<tr>
<td>Danian</td>
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<tr>
<td>Chalk Group</td>
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</tbody>
</table>

- **Exofisk Formation**
- **Jukes Formation**
- **Valhall Formation**
- **Hidra Formation**
- **Herring Formation**
- **Black Band**
- **Lamplugh Formation**
- **Rowe Formation**
- **Maureen Formation**
- **Spilsby Sandstone Formation**
- **Ekofisk Formation**
- **Carrack Formation**
- **Cromer Knoll Group**
- **Spilsby Formation**
- **Cromer Knoll Group**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**
- **Upper Cretaceous**
- **Lower Cretaceous**

Legend:
- **S**: South
- **N**: North
The Chalk Group was introduced by Rhys (1974) in the UK Southern North Sea for a unit of Upper Cretaceous chalky limestone of Cenomanian to Maastrichtian age, lying between the Cromer Knoll Group below and a then undivided succession of Tertiary sediments above (now known as the Montrose Group p.13). Subsequent drilling has shown that these chalky limestone lithologies extend into the Danian (Ekofisk Formation) in some areas (p.13).

Rhys (1974) did not formally subdivide the Chalk Group but noted that a thin bed of dark mudstones commonly occurred about 30m above the base of the group in many wells. On some composites and in a few published papers (e.g. Crittenden 1982) this bed has been referred to as the Plenus Marl; however in this report the unit has been informally termed the Black Band bed following the terminology introduced by Johnson and Lott (1993, p.95; see also accompanying discussion regarding the age and stratigraphic placement of this unit p.95).

Since the establishment of the Rhys scheme few papers have been published which have defined any further lithostratigraphic subdivisions of the Chalk Group in the Southern North Sea Basin. However, on some company logs there has been an extension of the usage of the terminologies used for the Central North Sea Chalk Group into the southern basin (Deegan & Scull 1977; Johnson & Lott 1993). In particular, where the Black Band is recognisable, the chalky and argillaceous limestones below have commonly been referred to the Hidra Formation and the beds immediately overlying the Black Band to the Herring Formation.

This practice is considered to be justifiable in this report as these two units are readily recognisable in many wells in the Southern North Sea Basin. Consequently the usage of the terms Hidra and Herring formations, established in the Central North Sea area (see Johnson & Lott 1993), are also recommended in this present scheme.

Similarly the youngest chalky limestone lithologies, of Danian age, are assigned to the Ekofisk Formation (p.13). The remaining formations of the Central North Sea Chalk Group (i.e. Mackerel and Tor formations) are, however, difficult to recognise south of the Mid North Sea High because of a marked change in log character, particularly of the sonic log response (see discussion p.35). Three new formation names are therefore introduced (Rowe, Jukes and Lamplugh) which are stratigraphically largely equivalent to the Mackerel and Tor formations but differ somewhat in their lithologies and log responses.

The Chalk Group is widely distributed over the southern North Sea area subcropping thin Pleistocene sediments west of the Sole Pit Inversion but lying beneath a thick Tertiary and Pleistocene cover in the Cleaver Bank basin area east of the structure. The group varies greatly in thickness, locally reaching over 1200m in rim synclines adjacent to major salt diapir developments east of the Sole Pit Inversion. It thins northwards over the Mid North Sea High, before thickening into the Central Graben and also thins southwards across the Anglo-Brabant High into the eastern English Channel (Cameron et al. 1992). Thinning, condensation and onlap relationships over some diapiric structures and tectonic highs are apparent from some wells.

Over the stable East Midland Shelf the youngest chalk unit are of Campanian or early Maastrichtian age, age with Maastrichtian (early only) sequences proved in the south east of the area, adjacent to the North Norfolk coast (e.g. Peak & Hancock 1970; see accompanying table). The Chalk Group is absent through erosion over much of the Sole Pit Inversion structure but thickens eastwards into the Cleaver Bank Basin, where Maastrichtian chalks are widely present and some Danian chalky limestone units also occur sporadically (see map p.5). Further eastwards the Chalk Group continues to increase in thickness into the Dutch sector (Hancock 1986).

References


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The term Herring Formation was introduced by Deegan & Scull (1977), in the Central North Sea area, to describe a unit of hard, chalky limestones and interbedded calcareous mudstones lying between a thin mudstone unit, the Plenus Marl Formation, and the overlying chalks of the Flounder Formation. These terms were subsequently revised by Johnson & Lott (1993) and as the unit is recognizable into the Southern North Sea basin their definitions are followed here. The Herring Formation now includes the thin mudstone unit at the base of the formation, the Black Band (see Johnson & Lott, 1993; p.95), formerly known as the Plenus Marl Formation and is overlain by the newly defined Lamplugh Formation (p.49) and underlain by the Hida Formation (p.43).

**Type section.**
22/1-2A: (Deegan & Scull 1977): 3655-3738m
(111870-122653ft) below KB (revised depth).

**UK reference sections (Southern North Sea)**
49/20-1: 1433-1495m (4701-4905ft)
53/4-2: 1515-1573m (4970-5161 ft)

**Name.** From the sea-fish.

**Formal subdivision**
Black Band (bed status)

**Lithology**
The Herring Formation consists of hard, dense, chalky limestones with interbedded argillaceous chalks and mudstones. Chert is abundant in the unit. The limestones are pale grey, glauconitic and occasionally pyritic. The interbedded mudstones, including the Black Band, are soft to hard, dark grey to black or variegated, carbonaceous, non-calcareous and pyritic.

**Upper boundary**
The top of the Herring Formation is normally marked by a downward change from siltstone, more argillaceous chalks of the Lamplugh Formation to cleaner, harder chalky limestones. This change is marked on the downhole log responses by an increase in gamma ray and low velocity spikes, although, occasionally the gamma ray spikes are lacking.

**Lower boundary**
The base of the Herring Formation is normally marked by a sharp downward change from dark coloured mudstones (Black Band) to chalky limestones of the Hida Formation. The boundary is marked by a sharp downward decrease in gamma values and increase in velocity. The Black Band forms a key log marker throughout much of the basin (see Panel 1, p.57). Where the Black Band mudstones are poorly developed the boundary is often more difficult to identify without biostratigraphic control.

**Lithostratigraphic subdivision**
The four informal sub-units of the Herring Formation recognized by Johnson & Lott (1993) in the Central North Sea area are not, with the exception of GO—the Black Band, readily apparent in the wells south of the Mid-North Sea High.

The Black Band (formerly the Plenus Marl Formation of Deegan & Scull (1978)) consists of dark grey to black, biotite, carbonaceous and non-calcareous mudstones. The unit usually has characteristic high gamma ray and low velocity spikes, although, occasionally the gamma spike is not well developed (e.g. 49/24-1, Panel 2 p.95). The base of the Black Band is defined by a sharp downward change from black mudstones to argillaceous, white, chalky limestones of the Hida Formation.

**Distribution and thickness**
The Herring Formation can be recognized over most of the Southern North Sea Basin. The unit is absent over the Solo Pit Basin because of subsequent inversion and erosion, and is also missing over some contemporary tectonic highs and salt diapirs (e.g. 48/10-1, 52/5-3, not illustrated). The formation ranges up to 2-6m in thickness.

**Regional correlation**
The Herring Formation is the lateral equivalent, in part, of the Welton Chalk Formation of Eastern England which includes the Black Band bed (Wood & Smith 1978). The Black Band bed is widely recognized in Eastern England (Hart & Bigg 1981) and within the Dutch sector (NAM & RGD 1980). In the Dutch sector the equivalent beds form the basal portion of the Ommerlanden Chalk Formation; however, the Black Band equivalent is there placed at the top of the underlying Texel Chalk Formation (NAM & RGD 1980).

**Genetic interpretation**
The micritic, chalky limestones of the Herring Formation are pelagic sediments deposited as nano-fossil-rich zones in a well-oxygenated sea of moderate depth. The Black Band mudstones, in contrast, were deposited during a phase of bottom-water stagnation. It represents a widely documented global phase of anoxia close to the Cenomanian-Turonian boundary (e.g. Hart & Leary 1989).

**Biostratigraphic characterization**
The *Prageloboricaspis stephan* biomarker can be recognized towards the middle of the formation, together with other common planktonic foraminifers such as *Dicarina bugni*, *Prageloboricaspis globis*, *Dicarina umbilica* and *Margaritocassidula* event. Calcareous benthonic foraminifera are rare, but *Lampadorinaella globosa* and *Stenoceras granulatum* are occasionally found within the formation. The *Eptinosphaeridia nannofossil* biomarker is situated in the middle part of the formation. Palynological recovery in the Herring Formation is generally rather low, but by analogy with the Central North Sea and onshore areas, the *Lithopectinodinium siphoniphorum* biomarker should be present within the formation.

**Age**
Early to mid Turonian

**References**
The term Hidra Formation was introduced by Deegan & Scull (1977), in the Central North Sea area, for the unit of chalky limestones with interbedded argillaceous chalks lying between the Cromer Knoll Group below and the Plemun Marl Formation above (since renamed the Black Band by Johnson & Lott (1993)). This same unit is recognizable in the wells of the Southern North Sea Basin and it is recommended that the usage of the term Hidra Formation is therefore extended.

**Type section**
NI/3-1 (Deegan & Scull 1977, p.26, fig. 30): 4371–4414m (14340–145700) below KB (metric conversion slightly amended).

**UK reference sections (Southern North Sea)**
43/8a-2: 1261.5–1295.5m (4139–4250 ft)
49/25-2: 1949–1989.5m (6394–6227 ft)

**Name.** From the Hidra High in Norwegian blocks 1/3 and 2/1, which was named after an island off the southwest coast of Norway.

**Lithology**
The Hidra Formation consists of micritic chalky limestones with interbedded argillaceous chalks and mudstones. The unit becomes increasingly argillaceous in its lower part with thin beds of detrital clay becoming increasingly common towards the base of the formation. The chalky limestones are white to pale grey and occasionally pink, red-brown or green. The argillaceous chalks and mudstones are pale to dark grey or red-brown. Chert is only rarely recorded.

**Upper boundary**
The top of the Hidra Formation is normally marked by a sharp downward change from the basal black mudstone of the Herring Formation (Black Band) to white to pale grey chalky limestones. It is characterized on wireline log responses by a sharp downward decrease in gamma ray values and increase in sonic velocity response. Where the Black Band is absent or poorly developed the boundary is much more difficult to pick and biostratigraphic data may be required to define the boundary (e.g. 49/5-1, Panel 2, p.59).

**Lower boundary**
The base of the Hidra Formation is normally defined by a downward change from interbedded pale to dark grey and pink chalky, argillaceous limestones to red-brown chalky mudstones of the Rødby Formation. The boundary is marked on the wireline log responses by an increase in gamma ray values and decrease in velocity.

**Biostratigraphic subdivision**
The four sub-units (H1-H4) recognized by Johnson & Lott (1993) are not widely recognizable in Southern North Sea wells and the units are not, therefore, used in this area.

**Distribution and thickness**
The Hidra Formation occurs throughout most of the Southern North Sea area but is absent, due to subsequent inversion and erosion over the Sole Pit Basin and over some contemporary structural highs and salt diapirs. The Hidra Formation is ranges up to c.40m in thickness.

**Regional correlation**
The Hidra Formation is laterally equivalent to the upper part of the Chalky Marl Member of the Bythit Formation in eastern England (Wood & Smith 1978). In the Dutch sector the formation equates with the sequence of light grey chalks and argillaceous chalks of the Texel Chalk Formation and the persistent black mudstone bed (Black Band equivalent) is placed within the top of this formation (NAM & RG D 1980).

**Genetic interpretation**
The chalky limestones of the Hidra Formation were deposited in open marine environments as fine grained pelagic carbonate, containing abundant bioclastic, skeletal debris (dominated by coccolith plates).

**Biostratigraphic characterization**
The Rotalipora cushmani foraminiferal biomarker occurs near the top of the Hidra Formation where there is a major influx of planктонic foraminifera, notably Bulimina cowani, R. greenii, Hladocyclina trachyp feasibility and H. denticulata. The Lingulogavelinella coryniformis/Rotalipora wiericki biomarker occurs in the middle part of the formation and consistent and common Hladocyclina planipes and Quntiporella antiqua have their FDOs immediately above the base of the Hidra Formation at a similar horizon as the FDO of the ostracod Nonlooping amphipod. Of the nannofossil biomarkers, the following occur within the Hidra Formation: Dunk sidestart albumins, which forms a good marker for the top of the formation, Gartnerago theta, Gartnerago nanum and Bioculinidae conus acet. Palynological recovery in the Hidra Formation is variable, but generally low, but by analogy with the Central North Sea and onshore areas, the Eopolisphaeridrum spinosa biomarker is present within the formation.

**Age**
Cenomanian.

**References**
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JUKES FORMATION
(new)

The term Jukes Formation is introduced for a unit of hard, comparatively chert-free chalky limestones which underlie the Rowe Formation and overlie the more argillaceous chalks of the Lamplugh Formation.

Name. After the eminent survey geologist A. J. Jukes-Browne (1851-1914) who carried out extensive studies of the Cretaceous rocks of Britain.

Type section
49/24-1: 840-1060m (2756-3478ft)

Reference sections
38/24-1: 1448-1585.5m (4751-5202ft)
43/8a-2: 810-948m (2657-3110ft)
49/5-1: 1265.5-1679.5m (4152-5510ft)
Lithology
The Jukes Formation typically consists of moderately hard, white, occasionally greyish white, variably argillaceous, chalky limestones. Occasional harder limestone bands occur together with comparatively few nodular chert developments.

Upper boundary
The upper boundary of the Jukes Formation is characterized by a downward change from relatively soft chert-bearing argillaceous chalks to harder white chalks with fewer cherts. There is a corresponding slight downward decrease in gamma values and a more marked increase in sonic velocity. There is considerable variability in the sonic response over the formation as a whole as a result of the cyclic interbedding of thin argillaceous units, hard chalks and occasional hard chert-rich bands. The top of the unit is often marked by a thin, hard chalk unit (e.g. well 49/5-1).

Lower boundary
The base of the Jukes Formation is defined by a downward change from moderately hard, relatively chert-free chalks, to darker, consistently harder, argillaceous, cherty chalks of the Lamplugh Formation. This lithological change corresponds to a consistent increase in sonic velocity, sometimes accompanied by a slight downward increase in gamma values.

Thickness and distribution
The Jukes Formation is widely distributed throughout the Southern North Sea Basin but may vary in thickness due to intra-basinal tectonic controls and post-Cretaceous erosion. The Jukes Formation ranges up to 500m (Panel 2, p.59).

Regional correlation
The Jukes Formation passes eastwards into the Ommelanden Chalk Formation of the Dutch sector (NAM & RGD 1980). In the UK onshore the formation equates largely with the Flamborough Chalk Formation of Wood & Smith (1978; see also Whitham 1993).

Genetic interpretation
The chalky limestones of the Jukes Formation were deposited in an open marine setting as pelagic carbonates and consist primarily of fine bioclastic skeletal debris (dominated by coccolith plates). Thin more argillaceous beds present represent increased terrigenous input into the basin.

Biostratigraphic characterization
The FDOs of a number of taxa form good biomarkers within the formation: Stensioeina granulata incondita and Bolivinoides strigillatus in the mid Campanian; the radiolarian Cenosphaera sp. at the top of the Santonian (where Stensioeina exsculpta exsculpta is also found); and Stensioeina granulata polonica. The key calcareous nannofossil biomarkers within the formation are the FDOs of Broinsonia enormis, at the top of the early Santonian; and Watznaueria barnesae acme, which marks the mid-early Santonian boundary. Palynomorph recovery in the Jukes Formation is generally relatively low.

Age
Santonian to Early Campanian.

References
LAMPLUGH FORMATION
(new)

The term Lamplugh Formation is introduced for a unit of argillaceous, chert-bearing, chalky limestones which underlie harder relatively chert-free chalks of the Jukes Formation and overlie hard, chalky limestones of the Herring Formation.

Name. After the eminent geologist G.W. Lamplugh (1859-1926) who carried out detailed studies of the Cretaceous successions in Yorkshire in the late 19th century.

Type section
49/24-1: 1060-1242m (3478-4075ft)

Reference sections
38/24-1: 1585.5-1670.5m (5202-5481ft)
43/8a-2: 948-1189m (3110-3901ft)
49/5-1: 1679.5-1987m (5510-6519ft)
Lithology
The Lamplugh Formation consists of chalky limestones which are typically white to grey, soft to moderately hard, commonly argillaceous and characteristically chert-bearing. The presence of chert (flint) bands throughout the unit is a characteristic feature.

Upper boundary
The upper boundary of the Lamplugh Formation is marked by a downward change from the chalky limestones of the Jukes Formation into harder, more argillaceous chalks. It is marked by a sharp downward increase in velocity accompanied in some sections by a slight increase in gamma-ray values e.g. 49/24-1. In some wells the mid-part of the Lamplugh Formation is particularly argillaceous (e.g. well 42/29-C01 Panel 1, p.57; 53/4-2 Panel 2, p.59) giving the log profiles a 'waisted' appearance.

Lower boundary
The lower boundary of the Lamplugh Formation is characterized by a downward change from moderately hard, chalky limestones to the harder, clean, micritic limestones of the Herring Formation. There is a corresponding downhole decrease in gamma ray and increase in sonic velocity responses.

Thickness and distribution
The Lamplugh Formation is widely distributed throughout the Southern North Sea Basin but may vary in thickness due to intra-basinal tectonic controls and post-Cretaceous erosion. The Lamplugh Formation ranges up to 200m (e.g. well 49/25-1, not illustrated).

Regional correlation
The Lamplugh Formation passes laterally eastwards into the Ommelanden Chalk Formation of the Dutch (NAM & RGD 1980; Encl. 29). To the west, the in eastern England the formation equates largely with the Burnham Chalk Formation of Wood & Smith (1978, see also Whitham 1992).

Genetic interpretation
The chalky limestones of the Lamplugh Formation were deposited in an open marine setting as pelagic carbonates and consist primarily of fine bioclastic skeletal debris (dominated by coccolith plates). Terrigenous clay is present as thin beds and seams.

Biostratigraphic characterization
The FDO of Stensioeina granulata granulata marks the top of the formation and two intraformational biomarkers are Stensioeina granulata levis and Stensioeina granulata kelleri. Palynomorph recovery in the Lamplugh Formation is generally relatively low.

Age
Late Turonian to Coniacian.

References


LAMPLUGH FORMATION

DISTRIBUTION MAP

38 / 24-1

43 / 8a-2

49 / 5-1

49 / 24-1

LITHOLOGY

Chalky mudstone (Black Band only)

Chalk

100 m

100 km

LAMPLUGH FORMATION

DISTRIBUTION MAP

100 m

LAMPLUGH FORMATION

RoA FORMATION

JUKES FORMATION

LAMPLUGH FORMATION

LAMPLUGH FORMATION

THIN
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The term Rowe Formation is introduced for a unit of chert-bearing, chalky limestones forming the uppermost unit of the Chalk Group over much of the basin and which underlie either mudstones of the Maureen Formation or, where present (see p. 13), chalky limestones of the Ekofisk Formation (Danian age). The Rowe Formation overlies cherty and chert-free, chalky limestones of the Jukes Formation.

**Name.** After the eminent geologist A.W. Rowe who carried out extensive studies of the English Chalk successions in the early 1900s.

**Type section**

49/24-1: 635-840m (2083-2756ft) Chalk Group (see Panel 2, p.59).

**Reference sections**

44/28-1: 1651.5-1918.5m (5418-6294ft)
49/5-1: 1041.5-1265.5m (3417-4152ft)
47/10-1: 635-840m (2083-2756ft)
53/4-2: 858.5-1125.5m (2817-3693ft)
Lithology
The Rowe Formation consists of chalky limestones which are typically white to greyish white, friable to moderately hard, commonly argillaceous and chert-bearing. The presence of abundant chert (flint) bands throughout the unit is a characteristic feature. Terrigenous clay is present as darker coloured thin beds and seams. The formations both above and below the Rowe Formation, i.e. the Ekofisk and Jukes formations respectively, are generally chert-free.

Upper boundary
The character of the log responses for the top of the Rowe Formation is variable, depending on whether the unit is overlain by Paleogene or younger Tertiary or Pleistocene sequences. In a few wells the formation is overlain by Danian chalky limestones (Ekofisk Formation), with the boundary usually being marked by a downward decrease in gamma-ray values, reflecting a lower clay content. The sonic log signature is, however, variable, with some sections showing a downward decrease in velocity (e.g. 44/28-1) and others a downward increase (e.g. 39/7-1, Panel 1, p. 17). Where the Ekofisk Formation is absent, the Rowe Formation is overlain by Paleocene mudstones and there is a corresponding sharp downward decrease in gamma ray values and increase in velocity (e.g. 44/24-1: Panel 2, p. 59).

Lower boundary
The base of the Rowe Formation is defined by a marked downward increase in velocity but only shows a slight downward decrease in gamma ray values. The sharp increase in velocity is probably related to a significant basinwide regressive hardground surface.

Thickness and distribution
The Rowe Formation is widely distributed throughout the Southern North Sea Basin but may vary significantly in thickness due to intra-basinal tectonic controls and post-Cretaceous erosion notably around the Sole Pit Inversion structure. The Rowe Formation ranges up to 380m in thickness (e.g. well 49/25-1).

Regional correlation
The Rowe Formation passes to the east, into the upper part of the Ommelanden Chalk Formation of the Dutch sector and can be recognized in the type well De Pauwse-1 (822-c.985m) (NAM & RGD 1980; encl. 29). In eastern England the formation is known only in the subsurface where it overlies the Flamborough Chalk Formation of Wood & Smith (1978; see also Whittam 1993). In the Trunch borehole, on the north Norfolk coast, the base of the formation probably equates with the hardground development marking the base of the Basal Mucronata Chalk (base Belemnitella mucronata Zone) (McArthur 1993; BGS unpublished data).

Genetic interpretation
The chalky limestones of the Rowe Formation were deposited in an open marine setting as pelagic carbonates and consist primarily of fine bioclastic skeletal debris (dominated by coccolith plates). Microfaunas are dominated by planktonic foraminifera.

Biostratigraphic characterization
The top of the Rowe Formation is marked by the Pseudotextularia elegans foraminiferal biomarker and the Nephrolithus elegans calcareous nannofossil biomarker. In the middle part of the formation, Reussella szajnochae has its FDO, but it is rare and patchily distributed in the upper part of its range. However, within the formation the Reussella szajnochae acme biomarker, which may be accompanied by Tritaxia capitosa, is biostratigraphically important. In the lower part of the formation, the FDO of a number of species of Gavelinella and Bolivinoides miliaris forms a characteristic biomarker. At approximately the same horizon as the FDO of R. szajnochae, the FDO of Reinhardtites levis forms a key nannofossil biomarker at the early/late Maastrichtian boundary. The FDO of Reinhardtites anthophorus is within the early Maastrichtian. Palynomorph recovery in the Rowe Formation is generally relatively low.

Age
Late Campanian to Maastrichtian.

References
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CORRELATION PANELS
(CHALK GROUP)
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CROMER KNOLL GROUP
The term Cromer Knoll Group was introduced by Rhys (1974) for units of calcareous mudstone and sandstone in the Southern North Sea lying between the Humber Group below and Chalk Group above and is virtually synonymous with the Lower Cretaceous. Rhys (1974) subdivided the Cromer Knoll Group into the Red Chalk Formation, Speeton Clay Formation and Spilsby Sandstone Formation.

Few attempts have subsequently been made to improve on this simple subdivision of the Lower Cretaceous sediments of the Southern North Sea area Crittenden (1982, 1984 & 1987) has published a series of papers in which he nomenclatorial revision is to rationalise the plethora of lithostratigraphic schemes now available in the North Sea area and, as most of the newly defined units of the Cromer Knoll Group in the Central North Sea area (Johnson & Lott 1993) can be readily traced into the Southern North Sea, their usage has been extended and adopted in this report in preference to the Dutch terminology (see accompanying table p.61).

The term Rødby Formation directly replaces Red Chalk Formation and the Speeton Clay Formation is now divided into an upper non- or poorly calcareous mudstone unit (Carrack Formation) and a lower calcareous mudstone interval (Valhall Formation) (see Johnson & Lott 1993 for derivation of unit names). The term Spilsby Sandstone Formation is, however, retained as the constituent sandstones occur in complete geographic isolation from the stratigraphically equivalent basal sandstones of the Central North Sea Devils Hole Sandstone Member.

Name. From the Cromer Knoll buoy in the southern North Sea (Rhys 1974).

Constituent formations

- CARRACK FORMATION p.63
- RØDBY FORMATION p.67
- SPILSBY SANDSTONE FORMATION p.71
- VALHALL FORMATION p.75

Age

Late Ryazanian to Albian

References

CARRACK FORMATION

The term Carrack Formation was first defined by Johnson & Lott (1993) in the Central North Sea area as a unit of dark grey, essentially non-calcareous, marine mudstones lying between the Valhall and Redby formations. This unit has now been identified in the Southern North Sea area where it forms the poorly calcareous uppermost part of the Valhall Formation (Speeton Clay Formation as originally defined by Rhys 1974).

Name. From the large sailing merchant-ship, equipped for warfare.

Type section
14/20-8 (Johnson & Lott 1993, p.15) 2670.5-2771.5m (8762-9092ft).

UK reference sections (Southern North Sea)
44/24-1: 1393-1402m (4570-4600ft)
47/9b-6: 666-680m (2185-2231ft)
48/22-3: 420.5-430m (1380-1411ft)
49/25a-5: 1812-1853m (5945-6080ft)
The Carrack Formation consists essentially of poorly calcareous, occasionally sandy mudstones. These mudstones may be dark grey or red-brown or variegated. They characteristically display low velocities. Thin sandy beds and phosphatic pebbles may also occur in the unit, resulting in occasional high gamma peaks.

Upper boundary
The top of the Carrack Formation is defined by a downward change from the pale grey to red-brown, chalky mudstones of the Rodby Formation into darker, poorly calcareous mudstones. This change corresponds with a sharp downward increase in gamma ray values and decrease in velocity.

Lower boundary
The base of the Carrack Formation is normally characterized by a sharp downward change from dark, poorly calcareous mudstones to a paler, harder chalky mudstone development at the top of the underlying Valhall Formation. There is a corresponding decrease in gamma values and marked increase in velocity.

Distribution and thickness
The Carrack Formation though generally thin (~25m) is present over much of the Southern North Sea area. The formation may be absent over some intrabasinal highs and its western limit is difficult to define on currently available well data.

Regional correlation
The Carrack Formation passes laterally westwards into the upper part of the Speeton Clay Formation of the Cleveland Basin (Table, p.61). The formation equates in part with the A-beds of the Speeton Clay and further south with the Carstone Formation and Sutterby Marl. To the east, in the West Netherlands Basin, the formation is stratigraphically equivalent to the Middle Holland Claystone Member of the Holland Formation (NAM & RGD 1980; Crittenden 1982 & 1987; van Adrichem Boogaert & Kouwe 1993).

Genetic interpretation
The poorly calcareous marine mudstones of the Carrack Formation contain a moderately rich microfauna including benthonic foraminifera but dominated by agglutinating species (Crittenden 1987) suggesting a phase of basin restriction and bottom-water oxygen depletion.

Biostratigraphic characterization
The top of the Carrack Formation is dominated by calcareous benthonic foraminifera characteristic of the Globigerinelloides gyrooidinaeformis biomarker, although the biomarker itself is in the very basal part of the overlying formation, immediately above the Rodby-Carrack formational boundary. Agglutinated foraminifera are characteristic of the middle part of the formation and the Foramininoides chapmani biomarker is recognized by the influx of a diverse agglutinated assemblage. Near the base of the formation, the Gaudryina divisida biomarker, with calcareous benthonic foraminifera and the ostracod Saxothere tricostata have been recorded (e.g. Lott et al. 1985). The Micrantholithus bachalpaei / Micrantholithus obtusus and Rhagodiscus asper acme nannofossil biomarkers have been noted in the Carrack Formation. Dinoflagellate cyst floras from the Carrack Formation are abundant and diverse; the Subtilisphaera perlucida and Ceratbula tabulata biomarkers occur within this formation.

Age
Late Aptian to early Albanian.

References


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RODBY FORMATION

The definition of the Rodby Formation used in this report follows that set out by Johnson & Lott (1993) for the Central and Northern North Sea. Because of the ease with which this unit may be correlated into the Southern North Sea Basin, the usage of the term Rodby Formation is extended and replaces the term Red Chalk Formation formerly used for this unit by Rhys (1974). The Rodby Formation forms the topmost unit of the Cromer Knoll Group.

The Rodby Formation comprises a succession of chalky mudstones and calcareous mudstones which are commonly red-brown, light brown or grey-brown in colour. The Rodby Formation underlies grey to white pelagic chalks of the Hidra Formation (Chalk Group) and is itself underlain by the darker calcareous mudstones of the Valhall Formation.

Name. From the town of Rodby on the island of Lolland in southern Denmark (Larsen 1966).

Type section

Radby No. 1 (Larsen 1966): 459-469m (1506-1539ft) below ground level

UK reference sections (Southern North Sea)

44/24-1: 1365-1393m (4478-4570ft)
48/22-3: 397.5-420.5m (1304-1380ft)
49/24-1: 1292.5-1325m (4240-4347ft)—type section for Red Chalk Formation of Rhys (1974)
53/4-6: 1184-1236m (3886'-055ft)
Lithology

The Rødbø Formation consists of calcareous mudstones, chalky mudstones and chalky limestones. They range in colour from pink, pale red, red-brown to brown-grey and often show a variegated, colour-mottled appearance. The mudstones are firm to hard and become increasingly calcareous upwards before passing into the overlying pelagic white to pale grey chalced of the Chalk Group.

Upper boundary

The top of the Rødbø Formation is defined by a change from dominantly grey or white chalk lithologies into red-brown chalky mudstones. The boundary corresponds to a moderately sharp downward increase in gamma values and decrease in sonic velocity response.

Lower boundary

The base of the Rødbø Formation is taken at a change from reddened mudstones and chalky limestones to the grey calcareous mudstones of the Valhall Formation. It is marked on the geophysical logs by a moderately sharp increase in gamma ray and sharp decrease in sonic response. In some wells sited over structural highs the formation may rest directly on thin sandy sediments of Jurassic or older strata, (e.g. 49/9-1, Panel 2 p.81).

Lithostratigraphic subdivisions

The Rødbø Formation in the Central and Northern North Sea is commonly divisible into three informal units R1 to R3 upwards. In some wells within the Southern North Sea Basin (e.g. 53/4-6) these three divisions can be recognized but in the majority where the sequence is commonly much thinner and more condensed, only the basal R1 unit may be apparent (e.g. 49/24-1). Consequently the application of these subdivisions is not considered to be appropriate at present for most wells the southern North Sea area.

Distribution and thickness

The Rødbø Formation occurs throughout the basinal areas but may be absent over some intra-basinal highs (e.g. 53/2-5, Panel 1 p.79). The formation is generally between 20 and 30m in thickness but exceptionally may reach 50m in thickness (e.g. 53/4-6).

Regional correlation

The Rødbø Formation is widely correlative throughout much of the North Sea Basin. In eastern England the formation equates for the most part with the the Hunstanton Formation (formerly the Red Chalk) (Rawson 1992: see Table p.61). In the Dutch sector the formation equates directly with the Upper Holland Marl (NAM & RGD 1980; Crittenden 1982 & 1987; van Adrichem Boogaert & Kouwe 1993).

Genetic interpretation

The Rødbø Formation is a highly condensed sequence of sediments which were deposited in a well-oxygenated shallow-marine environment and which have a rich faunal assemblage. The formation marks a transitional phase of sedimentation between the hemipelagic mudstone dominated lithologies of the underlying early Cretaceous into the pelagic chalk-dominated lithologies of the overlying late Cretaceous. The characteristic red to red-brown coloration of much of the formation has been attributed to a variety of processes ranging from weathering of reddened lateritic soils to diagenetic changes (e.g. Jeans 1980).

Biostratigraphic characterization

Long-ranging planktonic foraminifera, particularly species of Hedbergella, are abundant in the Rødbø Formation. The top of the formation is characterized by the FDO of Arenoluticinum haroldi and the ostracode Isocythereis fissicostis. The following microfaunal biomarkers can be recognised within the formation: the Globigerinelloides bentonensis biomarker, the Noeocyclina ventrocostata biomarker and the Apectinolithus macfadyeni biomarker. The Globigerinelloides gyroidinaeformis biomarker, is at the base of the Rødbø Formation. Two calcareous nannofossil biomarkers are recognised in the Rødbø Formation, based on the FDOs of Hemipodorhabdus gorkae and Garmeragor pruobiquum. The dinoflagellate cyst florae of the Rødbø Formation are diverse and generally well preserved, and by analogy with the Central North Sea and onshore areas, the Oridinium scabrum and Apriodinium maculatum subsp. grande biomarkers occur at the top of the formation.

Age

Middle to late Albian.

References


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The term Spilsby Sandstone Formation was introduced by Rhys (1974) for a unit of fine grained marine sandstones that lay between the Speeton Clay Formation (Cretaceous: now renamed Valhall Formation, see p.75) calcareous mudstones above and Kimmeridge Clay Formation (Jurassic) variably calcareous mudstones below. Biostratigraphic data suggests that the lower part of the formation may span the Jurassic/Cretaceous boundary, as occurs in the equivalent onshore sandstone sequences of eastern England.

**Name.** From the village of Spilsby in Lincolnshire (Rhys 1974).

**Type section**
48/22-2 (Rhys 1974, pp. 7-9, fig. 7, table 5): 417-435m (1368-1427ft. — amended depths)

**Reference sections**
48/17a-2: 661-792m (2170-2600ft)
48/23-1: 769-905.5m (2523-2971ft)
53/2-5: 836-1104m (2744-3622ft)
Lithology
The Spilsby Sandstone Formation consists of grey to white, poorly to well-cemented, very fine to medium grained sandstone, with thin interbeds of green to blue-green, firm to fissile mudstone. Glauconitic and phosphatic grains commonly occur. Prominent gamma-ray spikes within and at the base of some sequences represent pebbly phosphatic horizons (e.g. 48/23-1).

Upper boundary
The upper boundary of the Spilsby Sandstone Formation is defined by a marked downward change from calcareous mudstone to sandstone lithologies which corresponds with a reduction in the gamma ray values and generally higher, irregular sonic log profile, the latter related to the amount of carbonate cement present.

Lower boundary
The lower boundary of the Spilsby Sandstone Formation is defined by a downward change from variably cemented sandstone to dark, variably calcareous mudstone lithologies. There is a corresponding marked increase in gamma values and the velocity becomes generally more regular.

Lithostratigraphic subdivisions
An informal subdivision into two units is possible with the lower unit (SP1) containing more mudstone interbeds than the upper, massive sandstone interval (SP2) (e.g. 48/17a-2).

Distribution and thickness
The Spilsby Sandstone Formation is largely restricted to the southwestern margins of the basin over the East Midlands Shelf and onto the Anglo-Brabant Massif. Isolated occurrences of basal Cretaceous sandstones have been proved further eastwards in wells 50/16-1 and 54/1-2. The formation is generally thin (<50m) over most of its subcrop area but thickens substantially along the western margin of the Sole Pit Inversion (Dowsing Fault zone) to >250m (e.g. 53/2-5).

Regional correlation
The Spilsby Sandstone Formation equates, at least in part, with the sandy Spilsby and Sandringham formations of eastern England (Rawson et al. 1978) which range from Ryazanian to Valanginian in age. To the east in the West Netherlands Basin a similar basal marine sandstone development is known as the Vlieland Sandstone Member (NAM & RGD 1980). In the UK sector of the Central North Sea area partly equivalent basal Cretaceous sandstone developments are termed the Devil’s Hole Sandstone Member (Howard & Lott 1993).

Genetic interpretation
The Spilsby Sandstone Formation was deposited in a well-oxygenated shallow marine shelf setting.

Biostratigraphic characterization
The Spilsby Sandstone Formation yields variably abundant dinoflagellate cyst assemblages. The Rotomyxipsis thula biomarker occurs within the formation.

Age
Late Volgian to Valanginian.

References


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The usage of the term Valhall Formation, which was introduced by Deegan and Scull (1977) and redefined by Johnson and Lott (1993) for the Central and Northern North Sea areas, is extended into the Southern North Sea area emphasizing the continuity of the sequence over the North Sea as a whole.

The Valhall Formation (together with the Carrack Formation see p.63) replaces the term Speeton Clay Formation, introduced by Rhys (1974), for the unit of grey to black, calcareous mudstone and chalky mudstone of early Cretaceous age. The mudstones lie below the reddened chalky mudstones of the Red Chalk Formation (Red Chalk Formation of Rhys (1974)) and may overlie a variety of lithotypes ranging from the sandstones of the Spilsby Sandstone Formation (Cretaceous) to mudstones of the Kimmeridge Clay Formation (Jurassic) or older Permo-Triassic strata. The Valhall Formation therefore forms only the lower part of the Speeton Clay Formation as originally defined by Rhys (1974) see below.

**Name.** From the Valhall Field in the Norwegian Central North Sea (Deegan & Scull 1977, p.24).

**Type section**
N2/11-1 (Deegan & Scull 1977, p.24, fig. 29) : 2954-3539m (9691-11611ft) below KB (revised depths).

**Speeton Clay Formation** 48/22-2 (Rhys 1974, pp.7-9, fig. 7, table 5): m (7- (3478f))

**UK reference sections (Southern North Sea).**
42/13-1: 839-1020m (2752-3346ft)
48/17-1: 402-559m (1318-1835ft)
48/22-3: 430-553.5m (1411-1816ft)
49/25a-5: 1853-1957m (6080-6420ft)
Lithology
The Valhall Formation consists of olive-grey to dark grey, calcareous mudstones with occasional off-white chalky mudstone units. The mudstones are firm to hard, highly fossiliferous, glauconitic with sporadic hard concretionary nodular bands. The sequence in some areas overlies sandstones of the Spilsby Sandstone Formation (p.71) but where these sands are absent the basal mudstones section is often characteristically silty and more fissile. A number of thin benthonic horizons are known from cored sequences to occur throughout the formation (e.g. Lott et al. 1985, 1986, 1989).

Regional correlation
The Valhall Formation as defined in this report, equates with part of the Speeton Clay Formation of the Cleveland Basin and the lithologically more varied marine Lower Cretaceous successions of the East Midlands and north Norfolk (Table p.61; Rawson 1992). To the east, in the West Netherlands Basin, the formation equates with the marine mudstone-dominated Villielen Claystone Formation and the lower part of the Holland Formation (Table p.61; NAM & RGD 1980; Crittenden 1982 & 1987; van Adrichem Boogaert & Kouwe 1993). The formation extends northwards over the Mid-North Sea High into the Central North Sea area (Johnson & Lott 1993) but is thin or absent over the Anglo-Brabant High to the south.

Upper boundary
The upper boundary of the Valhall Formation is marked by a downward change from the dark grey to brown, non-calcareous mudstones of the overlying Carrack Formation to pale to dark grey chalky mudstones. There is a corresponding downward decrease in gamma response and increase in velocity.

Lower boundary
The lower boundary of the Valhall Formation is marked by a downward change from dark calcareous mudstones to either sandstones of the Spilsby Sandstone Formation or to harder more variably calcareous olive-grey to black mudstones of the Kimmeridge Clay Formation. Where the formation is underlain by sandstones there is a marked downward decrease in gamma values and increase in velocity. Where the formation is underlain by mudstones of the Kimmeridge Clay Formation (e.g. 42/13-1) there is a downward increase in gamma and decrease in velocity.

Lithostratigraphic subdivision
No formal subdivision of the Valhall Formation is presented here for the Northern North Sea area. However, the presence towards the top of the formation, of a prominent, thin, low gamma/high velocity chalky unit, beneath which a marked gamma spike may sometimes be developed (e.g. 49/25a-5; 44/24-1 p.81) suggests a possible correlation with the V6 and V5 (‘Fischschief’er) units respectively, recognized more consistently in the Valhall Formation sequences of the Central North Sea area. Other chalky developments also occur, notably the thin unit at the base of the formation (‘V1’ equivalent), but are not formally named.

Distribution and thickness
The Valhall Formation is widely distributed across the UK sector of the Southern North Sea Basin but thins, both to the north and south, onto the Mid-North Sea and Anglo-Brabant highs respectively. Eastwards the formation thickens into the Cleaver Bank Basin. In general the formation is ~100m in thickness over most of its subcrop area. However, in rim synclines marginal to major salt diapirs and along the Dowsing Fault Zone thicknesses in the order of c.500m have been proved e.g. 33/2-5, p.79; Cameron et al. 1992).

References
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CORRELATION PANELS
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JURASSIC
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**JURASSIC**

The first formal stratigraphic nomenclature for the Jurassic of the Southern North Sea was proposed by Rhys (1974), as part of a general account of Southern North Sea Basin lithostratigraphy. The scheme recognised three units of Group status in the Jurassic but only the uppermost Humber Group was divided into named formations. The scheme was adopted widely by both industrial and academic stratigraphers and continues to form the basis for Jurassic nomenclature as currently applied.

With continuing exploration, a considerable amount of new stratigraphic information has become available, requiring some modification of the original Rhys scheme. Much of this modification involves the further subdivision of some of the existing groups based on the new data available.

**Scope of study**

Comprehensive reassessment of the lithostratigraphic nomenclature has been undertaken for the Jurassic of the UK sector. Reference is also made to the probable relationship between units proposed here and those established for the Dutch Sector by the NAM/RGD (1980) and Herngreen and Wong (1989). The Dutch lithostratigraphic schemes are currently being revised (van Adrichem Boogaert pers. comm.). It should be emphasised, however, that no detailed assessment of Dutch well data has been carried out during this study.

**Proposed scheme**

The proposed nomenclature scheme is illustrated in Figure 5 (p. 85). A full definition, discussion, and illustration of each lithostratigraphic unit is given on subsequent pages on a group-by-group basis. Three groups are here recognised within the Jurassic succession (see accompanying table p.85) and their distributions are shown in Fig. 6. Following the recommendations of Whittaker et al. (1991, p. 814), the groups have been defined in such a way as to bring together formations that display common lithological characteristics, and at the same time constitute important genetic packages.

**Chronostratigraphy**

The paucity of cored sections precludes the identification of many of the standard ammonite zones within the North Sea Jurassic, the stages and zones can be identified only indirectly using palynomorph and microfossil biomarkers. Few studies have dealt specifically with the Jurassic of the offshore part of the Southern North Sea Basin (Cox et al. 1987). However, there is a considerable body of work available on the biostratigraphic subdivision of the contiguous onshore eastern England Jurassic successions (for references see Cope et al. 1980a & 1980b; Riding & Thomas 1992; Jenkins & Murray 1989). Extensive biostratigraphic studies have also been undertaken on the Jurassic successions of the Central and Northern North Sea basins (see Appendix in Richards et al. 1993) and much of this work is equally applicable to the Southern North Sea. A detailed biomarker scheme is presented in Appendix 3.

**References**


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Figure 5. Lithostratigraphic nomenclature scheme for the Jurassic of the Southern North Sea.

Figure 6. Areal distribution of the Jurassic groups.
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The Humber Group was established by Rhys (1974, p.7) for the succession lying between the Cretaceous Cromer Knoll Group above and the West Sole Group below. The group was subdivided into three forms, in descending order, the Kimmeridge Clay, Corallian and Oxford Clay formations.

The Humber Group is a mudstone-dominated succession over most of the Southern North Sea. Rhys (1974, p.7) excluded the widely developed sandy lithologies at the top of the sequence, known in the adjacent onshore area to be partly of Jurassic age, from the Humber Group and assigned them to the Spilsby Sandstone Formation of the overlying Cretaceous Cromer Knoll Group. This subdivision is maintained in this report.

The upper part of the Humber Group is often truncated by early Cretaceous erosion. In more complete mudstone sequences the boundary is represented by a downward increase in gamma ray response corresponding to the change from carbonate-rich Cromer Knoll Group mudstones to organic-rich Kimmeridge Clay Formation mudstones. In the East Midlands Shelf area, where, as noted above, the basal part of the Cromer Knoll Group is a sandstone (Spilsby Sandstone Formation) the boundary corresponds to a lithological change from sandstones to mudstones.

Localised developments of oolitic limestone, siliciclastic sandstone and siltstone facies in the middle part of the Humber Group succession were assigned to a Corallian Formation by Rhys (1974) and the thin clay sequence below to an ‘Oxford Clay Formation’. The Corallian Formation is maintained in the new scheme. However, the term Oxford Clay Formation is abandoned because it has a very precise lithostratigraphic definition in onshore type sections (e.g. Cox et al. 1992) which cannot be matched in the offshore area at present. A new Seeley Formation is defined to include these Oxford Clay mudstones and undifferentiated siltstones that are lateral facies equivalents of the Corallian Formation oolites and clastics over the East Midlands Shelf (see accompanying table p.87).

In the offshore area the Middle/Upper Jurassic boundary (base Oxfordian stage) probably lies within or close to the base of the newly defined Seeley Formation of the Humber Group.

The mudstone units above the Corallian were all placed within the Kimmeridge Clay Formation by Rhys (1974). The availability of new offshore data, recent shallow drilling in the southern North Sea basin together with more refined log correlation has, however, proved that, as in the onshore area, the lowest part of this mudstone sequence is commonly of Oxfordian age. As the base of the Kimmeridge Clay Formation offshore is placed at the base of the Kimmeridgian (following Richards et al. 1993), when identified, these Oxfordian mudstones are placed within a newly defined Woodward Formation.

The Humber Group reaches a maximum thickness of 300m in the East Midlands Shelf area and within some rim synclinal structures to the east, but in general is less than 200m in thickness over much of the basin (Lott 1992). Northwards the group thins onto the Mid-North Sea High, where thin sandstone remnants have been proved in isolated wells, before thickening substantially into the Central Graben area of the Central North Sea (Heather and Kimmeridge Clay formations; Richards et al. 1993). To

The Humber Group consists of the Oxfordian mudstones that thins onto the London-Brabant Platform (Cope et al. 1992). To the east of the Cleaver Bank High, in the Dutch sector, Upper Jurassic sediments range from Callovian to Ryazanian in age. In the West Netherlands Basin they form the upper part of the marine Altena Group and the whole of the overlying paralic Delfland Group (NAM & RGD 1980; see also revision in Hemgreen & Wong 1989). In the Dutch Central Graben, Upper Jurassic sediments are genetically divided into two groups, the largely paralic Central Graben Group and the overlying marine-dominated sediments of the Scruff Group.

Name. From the Humber estuary in eastern England (Rhys 1974 p.12).

Constituent formations. Seeley Formation. Woodward Formation. Oxfordian to Kimmeridgian

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CORALLIAN FORMATION

The term Corallian Formation was introduced by Rhys (1974, p.7) for a unit of oolitic limestones and/or sandstones which lie between Oxford Clay Formation mudstones below (renamed Seeley Formation in this report, p.97) and Kimmeridge Clay Formation mudstones above (redefined as the Woodward and Kimmeridge Clay formations in this report, p.101). In the type well the formation consists of hard, grey to light grey or buff, oolitic and bioclastic limestones, with interbedded more argillaceous, calcareous units. Abundant ‘Rhabatella’ sponge spicules may occur in the formation. The limestones pass downwards into fine grained, cemented sandstones. There is a rapid lateral transition from oolitic limestones to coeval sandstone/siltstone/mudstone facies over much of the East Midlands Shelf (Lott 1992). These shallow marine clastics form part the newly defined Seeley Formation (p.97; Humber Group Panel 2, p.147).

References


Name. The term is derived from the Corallian Beds of onshore terminology (e.g. Arkell 1933).

Type section
47/15-1X: (Rhys, 1974, p.7, fig. 6): 919-995m (3014-3264ft)

UK reference sections
42/28-1: 727-816m (2385-2677ft)
48/14b-8: 1264-1337m (4147-4388ft)
48/17b-3: 1102-1152m (3615-3781ft)
Lithology
The Corallian Formation consists of light grey to buff, limestones, sandstones and thin mudstones. The limestones are calcite spar cemented oolites with occasional pisolithic horizons and abundant bioclastic debris. Moderately thick, fine to medium grained, variably cemented sandstone units underlie the main limestone developments and may also be thinly developed overlying the limestones. 'Rhzaxella' sponge spicules commonly occur in both the sandstone and limestone intervals (Lott 1992). On geophysical log responses the formation shows a characteristic funnel-shaped profile passing downwards from massive limestones with a cylindrical log profile to interbedded cemented and poorly cemented sandstones (with a serrated log response).

Over the East Midlands Shelf there is a rapid westward facies transition to the fine sandstone- siltstone- and mudstone-dominated lithologies of the Seeley Formation.

Upper boundary
The top of the Corallian Formation is defined by a change from the mudstone-dominated lithologies of the overlying Woodward or Kimmeridge Clay formations to the massive oolitic limestones of the Corallian Formation. There is a corresponding abrupt downward decrease in gamma values and increase in velocity.

Lower boundary
The base of the Corallian Formation is taken at a downward lithological change from carbonate-cemented sandstone lithologies to the mudstones of the Seeley Formation. This basal boundary is defined by an increase in gamma values and decrease in velocity.

Distribution and thickness
The Corallian Formation is present over much of the UK sector of the Southern North Sea and reaches a maximum thickness of c.100m (47/9-2, 3, not illustrated). It is best developed over the Sole Pit Inversion structure and contiguous areas to the north and east of the Dowsing Fault Zone. In the East Midlands Shelf area, west of the Dowsing Fault Zone, the formation passes fairly abruptly into fine sandstones and siltstones. The formation shows a characteristic funnel-shaped profile passing downwards from massive limestones with a cylindrical log profile to interbedded cemented and poorly cemented sandstones (with a serrated log response). Over the East Midlands Shelf there is a rapid westward facies transition to the fine sandstone- siltstone- and mudstone-dominated lithologies of the Seeley Formation.

Regional correlation
The Corallian Formation oolitic limestones pass into the Coralline Oolite Formation (Cope et al. 1980; 1992) in the Cleveland Basin area. South of the Market Weighton Block the Corallian Formation is coeval with the mudstone and sandstone-dominated Seeley Formation and its onshore equivalents the West Walton Beds and Oxford Clay Formation.

Eastwards, the formation is absent over the Cleaver Bank High. In the Dutch sector, coeval sediments form part of the upper portion of the Altena Group (Brabant Formation) which include an oolitic limestone facies known as the Oisterwijk Limestone (NAM & RGD 1980). Coeval sediments to the north of the Mid North Sea High, in the Central Graben include shallow-marine mudstones and sandstones of the Heather and Fulmar formations respectively.

Genetic interpretation
The Corallian Formation forms the final phase of a major upward-shallowing cycle of marine sedimentation. The oolitic limestone facies formed as a series of high-energy, shoals and banks as subsidence and clastic sediment supply to the Sole Pit Basin and adjacent areas slowed or ceased, prior to renewed subsidence in the succeeding Woodward Formation depositional phase. Away from the oolitic shoal areas, over the East Midlands Shelf, subsidence and sedimentation continued with the deposition of a more basinal shallow-marine mudstone/siltstone sequence with some sandstone developments (Seeley Formation).

Biostratigraphic characterization
The Corallian Formation is variably productive palynologically. Dinoflagellate cyst floras include E. luridum, E. dimorphum, Gonyaulacysta jurassica subsp. jurassica and Rhynchodiniopsis cladophora (Cox et al. 1987). The microfauna is similar to that of the Seeley Formation. Furthermore, the formation typically yields common Rhaxella perforata.

Age
Early to Mid-Oxfordian.

References
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KIMMERIDGE CLAY FORMATION

The term Kimmeridge Clay Formation was established by Rhys (1974, p.6) for the upper part of the Humber Group succession, lying between the Corallian Formation below and the Cretaceous, Cromer Knoll Group above. The formation is a hard, commonly fissile, dark brown-grey to black, mudstone-dominated succession, with minor thin calcareous beds. The type section chosen by Rhys (1974, fig. 6) in well 47/15-IIX comprises a thin grey to dark grey, shaly mudstones, however, the sequence has been severely truncated by erosion.

Subsequent drilling has revealed that the lowermost mudstones and siltstones of the formation are of probable Oxfordian age. Following the redefinition of the basal boundary of the formation by Richards et al. (1993) and because direct correlation between the underlying Heather Formation of the Central and Northern North Sea is not yet possible, these lowermost beds are placed within a newly defined Woodward Formation in the Southern North Sea Basin. These changes, together with the availability of more complete Kimmeridge Clay Formation sequences, have necessitated the selection of a new reference wells for this formations in the Southern North Sea Basin.

References

Name. The term is derived from the Kimmeridge Clay of onshore terminology (e.g. Arkell 1933).

Type section
Kimmeridge Bay, Dorset is the type section for the Kimmeridge Clay Formation.
Well 47/15-IIX was designated by Rhys (1974 p.7, fig. 6: 885-919m (2902-3014ft)) as the 'type well section'. However, this well displays a truncated succession and is not considered appropriate as a key section.

UK reference sections (Southern North Sea)
47/9b-4: 756-875m (2480-2870ft)
47/10-1: 1147-1334m (3763-4377ft)
47/18-1: 545-738m (1788-2421ft)
48/17a-2: 792-981.5m (2596-3220ft)
Lithology
The Kimmeridge Clay Formation comprises dark brown-grey to black, organic-rich fissile mudstones, with occasional thin, laminated carbonates common in the Central North Sea (see Richards et al. 1993). Correlation of offshore core sequences with the onshore succession of Eastern England confirms that the Kimmeridge Clay Formation offshore includes beds which chronostratigraphically can be assigned to the Oxfordian Amphitill Clay Formation (Rhys 1974; Cox et al. 1987).

To the east in the Dutch sector the coeval Upper Jurassic succession is dominantly a paraclastic sequence of sandstones and shales, with some coals, known as the Delfland Group, which in the more northerly parts of the Broad Fourteens Basin interfingers with marine mudstones of 'Kimmeridge Clay' facies (NAM & RGD 1980).

Upper boundary
The top of the Kimmeridge Clay Formation is often erosively truncated and may be overlain by mudstone, sandstone or chalky lithologies. The transition from sandstone or chalky lithologies is indicated on log responses by an increase in gamma values and decrease in velocity. Where two mudstone units are juxtaposed, the boundary of the formation is often less clear and may be best defined using biostratigraphic control. However, there is in general a downward change from the organic-poor, non-fissile, calcareous mudstones of the Valhall Formation (Cretaceous) to the organic-rich mudstones of the Kimmeridge Clay Formation. The wireline-log response is variable. The boundary is defined by a sharp downward increase in velocity (e.g. 47/9b-4), accompanied in some sections by a sharp downward increase in gamma values (e.g. 48/17-1, p.77). Truncated sections commonly show atypical log responses (e.g. 49/25a-5, p.77).

Lower boundary
The base of the Kimmeridge Clay Formation is marked by a sharp change from dark mudstones to the paler, more calcareous, silt mudstones of the Woodward Formation. There is a corresponding decrease in gamma ray values and increase in velocity.

Distribution and thickness
The Kimmeridge Clay Formation is present throughout much of the Southern North Sea in the UK sector where it may reach localized thicknesses of >260m in the Sole Pit Basin (e.g. 42/28-2 & 48/10-2—not illustrated), and 250m on the East Midlands Shelf (47/18-1, p.95). Elsewhere the formation has been extensively eroded and is generally less than 100m thick.

Regional correlation
Mudstones dominate the Kimmeridge Clay Formation in the offshore UK area. The formation thins northwards onto and over the Mid-North Sea High, before expanding rapidly in the Central Graben area of the Central North Sea (see Richards et al. 1993). Correlation of offshore core sequences with the onshore succession of Eastern England confirms that the Kimmeridge Clay Formation offshore includes beds which chronostratigraphically can be assigned to the Oxfordian Amphitill Clay Formation (Rhys 1974; Cox et al. 1987).

To the east in the Dutch sector the coeval Upper Jurassic succession is dominantly a paraclastic sequence of sandstones and shales, with some coals, known as the Delfland Group, which in the more northerly parts of the Broad Fourteens Basin interfingers with marine mudstones of 'Kimmeridge Clay' facies (NAM & RGD 1980).

Genetic interpretation
The mudstones of the Kimmeridge Clay Formation were deposited in a low-energy marine shelf environment. Relatively rapid sedimentation and anoxic bottom-water conditions lead to the preservation of much of the organic material present. As in the onshore area the formation comprises rhythmically interbedded small-scale sedimentary cycles, passing upwards from occasional thin oil-shale horizons to darker bituminous mudstone and finally into pale calcareous mudstone beds. In the more complete sequences the formation appears to become increasingly organic-rich in its upper part, though the well-known shale developments which occur in the Central and Northern North Sea basins do not occur.

Biostratigraphic characterization
The youngest microfaunal biomarker proved in the UK sector of the Southern North Sea is that marked by the FDO of the ostracod Galliacytheridea polita (which can be dated to the fittoni Zone onshore). It coincides with the FDO of the Conodiscus sp. 1 acme radiolarian biomarker in adjoining areas. There is an absence of primary data on radiolaria from the UK sector of the Southern North Sea, but extrapolation from the Central North Sea and the Dutch, German and Danish sectors indicates that a number of biomarkers should be identifiable. The Kimmeridge Clay Formation yields abundant, well-preserved and diverse palynomorph associations. The following biomarkers are characteristic of the formation:

Ostracods: Galliacytheridea polita, Galliacytheridea spinosa, Eucythereopteron aquitanum, Galliacytheridea elongata, Galliacytheridea munda*staria kliei, Galliacytheridea dorsetensis/Micromucatochore edmundi, Galliacytheridea diximilis and Macrovoides pulchra gallica.

Radiolaria: Conodiscus sp. 1 acme, Ornibaculifera lowreyensis, Praeconomyxyma hexagona acme, pyritized radiolaria, Hsuum sp. 1 (see Dyer & Copestake, 1989; Partington et al. 1993).

References

Polyanomorphs: The G. dimorphum, C. longicorne, E. luridum and S. crystallinum are all represented, the latter biomarker occurring close to the base of the formation.

Age
Kimmeridgian to Mid-Volgian.
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SEELEY FORMATION
(new)

The term Seeley Formation is introduced for a thin unit of marine calcareous sandstones and siltstones that underlie mudstones of the Woodward Formation and overlie sandstones of the Leckenby Formation. Eastwards the formation passes, in part, into the coeval, oolitic limestones of the Corallian Formation.

Type section
47/15a-3: 1066-1134.5m (3497-3722ft)

Reference sections
47/9a-7: 940.5-1012m (3086-3320ft)
47/14a-2: 966-1033m (3169-3389ft)
48/22-3: 720.5-763m (2364-2504ft)

Name. The unit is named after the Victorian geologist H. G. Seeley (1839-1909) who provided some of the earliest descriptions of the stratigraphically equivalent beds in Eastern England.
Lithology
The Seeley Formation is characterized by carbonate-cemented, fine sandstone and siltstone lithologies. Two main sandstone/siltstone units are present which form the topmost parts of two, variably developed coarsening-upward sedimentary cycles. Laterally to the east the sandstones become increasingly calcareous and eventually pass into the oolitic limestones of the Corallian Formation.

Upper boundary
The upper boundary of the Seeley Formation is characterized by a downward change from grey calcareous, silty mudstones of the Woodward Formation into calcareous sandstones and siltstones. There is an abrupt decrease in gamma values and sharp increase in velocity.

Lower boundary
The lower boundary of the Seeley Formation is marked by a downward change from mudstones to sandstones of the underlying Leckenby Formation. There is a corresponding decrease in gamma values and increase in velocity.

Distribution and thickness
The Seeley Formation is best developed over the East Midlands Shelf to the west of the Dowsing Fault Zone, where it reaches up to 70m in thickness.

Regional correlation
The Seeley Formation equates largely with the West Walton Beds (Gallois & Cox 1977) and Oxford Clay, and is largely coeval with the oolitic limestones of the Coralline Oolite Formation (Corallian Group of BGS usage) of onshore terminology. The Seeley Formation passes eastwards into the Corallian Formation (p.89, this volume).

Genetic interpretation
The Seeley Formation was deposited in a shallow-marine shelf setting. The sandstones form the upper part of a localized but distinct shallowing-upward cycle of sedimentation within the mudstone-dominated Humber Group. There is a relatively abrupt transition eastwards into the oolitic limestones and sandstones of the Corallian Formation.

Biostratigraphic characterization
The Seeley Formation typically yields well-preserved and diverse dinoflagellate cysts. Floras include *R. aemula* and *Trichodinium scarburghense*. The *R. aemula* and *Wanaea* spp. biomarkers occur within the formation. The Galliaocythereidae "praedissimilis" (sensu Witte) in Herngreen, Lissenberg & Witte (1991) biomarker is found in the lower part of the formation.

Age
Middle Oxfordian.

References
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WOODWARD FORMATION
(new)

The term Woodward Formation is introduced for a unit of calcareous mudstones, with thin interbedded siltstones and sandstones, which underlie the less calcareous more organic-rich mudstones of the Kimmeridge Clay Formation. The formation may variously overly either the oolitic limestones facies of the Corallian Formation or clastic facies of the Seeley Formation.

Name. After the eminent Survey geologist H.B. Woodward (1832-1921) who carried out an extensive review of the Jurassic rocks of Britain.

Type section
47/14a-2: 878-966m (2880-3169ft)

Reference sections
42/28-1: 674-728m (2210-2387ft)
47/9b-5A: 885.5-907.5m (2905-2978ft)
47/18-1: 739-820.5m (2425-2692ft)
Lithology
The Woodward Formation consists of pale to dark grey and calcareous mudstones, with occasional thin sandy or silty interbeds. The represent a transitional sequence between the underlying fully marine shallow-water sediments of the Corallian and Seeley formations and the overlying more anoxic mudstones of the Kimmeridge Clay Formation.

Upper boundary
The upper boundary of the Woodward Formation is characterized by a downward change from darker, harder mudstones of the Kimmeridge Clay Formation to paler more calcareous mudstones. In most sections, there is a corresponding decrease in gamma values, often accompanied by an increase in velocity (e.g. 42/28-1).

Lower boundary
The base of the Woodward Formation is defined by a downward change from pale silty mudstones to either hard oolitic limestones or sandstones of the Corallian and Seeley formations respectively. There is a corresponding sharp decrease in gamma-ray values and increase in velocity.

Thickness and distribution
The Woodward Formation is very variable in thickness. It appears to reach its maximum development over the East Midlands Shelf area (c.90 m in 47/14a-2) but is much thinner where it overlies the Corallian Formation oolitic facies (e.g. in 47/9b-5A; see also Cox et al. 1987).

Regional correlation
The Woodward Formation passes laterally westwards into the Amphill Clay Formation (Oxfordian) of the East Midlands and Cleveland Basin areas (Cope et al. 1980). To the east beyond the Cleaver Bank High there is no clear Oxfordian equivalent of the Woodward Formation recognized (NAM & RGD 1980). Northwards the formation is thin or absent over much of the Mid-North Sea High but is coeval with the upper part of the Heather Formation in the Central North Sea area (Richards et al. 1993).

Genetic interpretation
The mudstones, sandstones and siltstones of the Woodward Formation were deposited in oxic shallow-marine shelf setting.

Biostratigraphic characterization
The top of the formation is marked by the Galliaecytheridea punctata acme/Vernoniella sequana and the Scriniodinium crystallinum acme biomarkers. Lower in the formation, the Lenticulina ectypa biomarker is present. The Woodward Formation generally yields abundant, well-preserved and diverse palynofloras.

Age
Upper Oxfordian.

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The West Sole Group was established by Rhys (1974, p.7) for the succession lying between the top of the Lias Group below and the Humber Group above. Rhys made no attempt to subdivide the sequence except to comment that probable equivalents of the Lincolnshire Limestone oolites and the Cornbrash of eastern England had been proved offshore in some wells. In this revision of the West Sole Group four new subdivisions are recognized; in descending order these are the Leckenby, Hudleston, Strangways and Wroot formations.

The West Sole Group is characterized by a transition from fluvio-deltaic sandstone- and mudstone-dominated successions, in the north and east of the basin, to shallow marine carbonates and estuarine clastics in the south and west. In more complete sections the lower boundary of the group is characterized by a change from paralic sandstone-dominated lithologies to finer grained marine sandstones and siltstones of the underlying Phillips Member of the Cerdic Formation (Lias Group). However, over much of the basin there is evidence of extensive pre-Aalenian erosion which has truncated the underlying Lias Group so that the basal West Sole Group boundary is often marked by a significant erosive break.

The West Sole Group reaches a maximum thickness of 300m within rim synclinal developments adjacent to some Zechstein salt diapirs, but in general is less than 100m thick over the East Midlands Shelf, thickening to 200m in the Sole Pit Basin (Lott 1992). In onshore eastern England the West Sole Group sediments are coeval with those of the Ravenscar Group and Dogger Formation of the Cleveland Basin (Hemingway & Knox 1973) and the Redbourne Group of south Yorkshire and Lincolnshire (e.g. Gaunt et al. 1992) see table p.105.

Northwards the group thins onto the Mid-North Sea High and southwards against the Anglo-Brabant Massif. The West Sole Group sediments were deposited coevaly with the paralic Fladen and Brent Group successions of the Central and Northern North Sea areas (Richards et al. 1993).

Middle Jurassic sediments are absent over the Cleaver Bank High to the east but are known to occur in the Dutch sector where they form part of the Altena Group (Brabant Formation (in part) (NAM & RGD 1980; Cope et al. 1992).

Name. From the sea area west of the Sole Pit bathymetric feature (Rhys 1974, p. 12).

**WEST SOLE GROUP**
(revised)

The West Sole Group was established by Rhys (1974, p.7) for the succession lying between the top of the Lias Group below and the Humber Group above. Rhys made no attempt to subdivide the sequence except to comment that probable equivalents of the Lincolnshire Limestone oolites and the Cornbrash of eastern England had been proved offshore in some wells. In this revision of the West Sole Group four new subdivisions are recognized; in descending order these are the Leckenby, Hudleston, Strangways and Wroot formations.

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Northwards the group thins onto the Mid-North Sea High and southwards against the Anglo-Brabant Massif. The West Sole Group sediments were deposited coevaly with the paralic Fladen and Brent Group successions of the Central and Northern North Sea areas (Richards et al. 1993).

Middle Jurassic sediments are absent over the Cleaver Bank High to the east but are known to occur in the Dutch sector where they form part of the Altena Group (Brabant Formation (in part) (NAM & RGD 1980; Cope et al. 1992).

Name. From the sea area west of the Sole Pit bathymetric feature (Rhys 1974, p. 12).

**Constituent formations**

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**Age**

Aalenian to Callovian.

**References**


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**Diagram**

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HUDLESTON FORMATION
(new)

The term Hudleston Formation is introduced in this report for a heterogeneous unit of paralic mudstones with thin sandstones lying between the dominantly marine sandstones of the Leckenby Formation above and marine to paralic sediments of the Strangways Formation below.

Type section
47/3b-4: 930-979m (3052-3212ft)

Reference sections
42/24-1: 249-328m (817-1076ft)
47/10-1: 1503-1538.5m (4931-5047ft)
48/3-3: 895-995m (2935-3264ft)

Name. After the eminent Victorian geologist W.H. Hudleston (1828-1909) who carried out extensive studies of the Middle Jurassic in the Yorkshire Basin.
Lithology
The Hudleston Formation consists dominantly of mudstones with interbedded siltstone and sandstone beds. The mudstones are marginal marine to non-marine sequences, commonly variegated, grey-green, purple, red or yellow-brown and poorly calcareous to non-calcareous. The sandstones are poorly cemented, fine to coarse grained, grey to brown in colour. Carbonaceous material is common in some beds.

Upper boundary
The top of the Hudleston Formation is usually placed at the base of the thin limestone (Combrash equivalent) which forms the basal unit of the overlying Leckenny Formation. This corresponds, in most wells, to the base of a low gamma high / high velocity spike (e.g. 47/3b-4, p. 109; 47/15a-1, p.99). Beneath the spike there is a change to the more consistent high gamma values and low velocities that characterize the bulk of the Hudleston Formation. In a few wells the downward change in gamma values is less marked and only the sonic velocity spike is apparent (e.g. 47/14a-2, 47/9a-7). In well 42/28-1 (p.91) the top of the Hudleston Formation is picked on the change from sandstone to variegated mudstones, as there is no discrete basal limestone unit apparent.

Lower boundary
The base of the Hudleston Formation is marked by a change from dominantly mudstone to the dominantly sandstone lithologies of the underlying Strangways Formation. This lithological change corresponds to sharp downward decrease in gamma-ray values and increase in velocity.

Distribution and thickness
The Hudleston Formation is very variable in thickness depending on the structural setting of the well section studied. In rim synclinal or fault-bounded structures the formation may be thickly developed (e.g. 48/3-3) in more stable settings the formation may be comparatively thin (e.g. 47/10-1).

Regional correlation
The Hudleston Formation passes laterally into the paralic successions of the Scalby Formation (Yorkshire: Hemingway & Knox 1973) and of the Redbourne Group (Bilsnorth Clay and Upper Estuarine Series, Lincolnshire: Gaunt et al. 1992), in eastern England. To the east, in the West Netherlands Basin, coeval strata may form part of the interbedded sandstone and mudstones sequences of the Brabant Formation (NAM & RGD 1980). The formation is absent over the Mid North Sea High and is coeval, at least in part, with the Pentland Formation and Brent Group successions of the Central and Northern North Sea (Richards et al. 1995).

Genetic interpretation
The Hudleston Formation consists largely of paralic mudstones and sandstones which were deposited in a fluviodeltaic setting as channel sands and overbank muds.

Biostratigraphic characterization
The Micropneumatocythere/Glyptocythere spp. biomarker is situated just below the top of the formation and the Haplocytheridea pokrovkaensis biomarker is recognized in the middle part. The top of the Hudleston Formation is characterized by the incoming of abundant and diverse misopore associations.

Age
?Bajocian to Bathonian.

References


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The term Leckenby Formation is introduced for a thin unit of pale grey, variably carbonate-cemented, shallow-marine sandstones lying between Woodward Formation marine mudstones above and the variegated paralic mudstones with occasional sandstones of the Hudleston Formation below. The Leckenby Formation is the topmost unit of the West Sole Group.

**Name.** After the Victorian geologist J. Leckenby (1814-1877) who provided some of the earliest descriptions of the Callovian succession of the Yorkshire coast.

**Type section**
48/1 lb-4: 1007-1022m (3304-3352ft)

**Reference sections**
47/14a-2: 1033-1047m (3389-3435ft)
47/15a-3: 1134-1149m (3722-3770ft)
48/2-1: 603.5-621m (1980-2073ft)
Lithology
The Leckenby Formation comprises sandstones overlying a thin mudstone, with a thin but persistent basal limestone bed. The sandstones are glauconitic and variably carbonate cemented.

Upper boundary
The upper boundary of the Leckenby Formation is defined by a sharp downward change from mudstones or sandstones of the Seeley and Corallian formations respectively. There is a corresponding decrease in gamma values and increase in velocity.

Lower boundary
The lower boundary of the Leckenby Formation is placed at the base of a thin limestone unit (Cornbrash equivalent) which forms a prominent gamma ray and velocity spike in most sections (e.g. 47/15a-3, 48/1 Ib-4, p. 113; 48/17b-3, p.91). In a few well sections the basal spike is less well defined on the gamma-ray response (e.g. 47/14a-2, p.113; 47/9a-7, p.99). In well 42/28-1 (p.91) this discrete basal limestone unit is not developed, and the boundary is picked on a lithological change from marine sandstones to variegated mudstones, corresponding to a downward increase in gamma values and decrease in velocity.

Distribution and thickness
The Leckenby Formation is a thin (up to 15m in thickness) but persistent unit recognizable throughout the Southern North Sea area.

Regional correlation
The Leckenby Formation passes westwards into the Kellaways Beds and Cornbrash units of eastern England. To the east the formation is absent over the Cleaver Bank High but in the West Netherlands Basin is coeval with part of the Brabant Formation (NAM & RGD 1980).

Genetic interpretation
The sandstones mudstones and limestones of the Leckenby Formation were deposited in a shallow-marine shelf setting.

Biostratigraphic characterization
No detailed information is available on the microfaunas and microfloras of the Leckenby Formation.

Age
Callovian.

References
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STRANGWAYS FORMATION (new)

The term Strangways Formation is introduced in this report for a heterogeneous unit of paralic to marine sandstones, mudstones and limestones, lying between the paralic sediments of the Hudleston Formation above and of the Wroot Formation below.

Type section
47/3b-4: 979-1117m (3212-3664ft)

Reference wells
42/24-1: 328-369m (1076-1211ft)
47/10-1: 1538.5-1671 (5047-5482ft)
48/3-3: 995-1137m (3264-3730ft)

Name. After the eminent geologist C.E. Fox-Strangways (1844-1910) who carried out extensive studies of the Jurassic of the UK.
Lithology
The Strangways Formation consists dominantly of sandstones with interbedded siltstones, mudstones and occasional limestones. The sandstones are pale grey to white poorly to well-cemented, very fine to medium grained, occasionally glauconitic and carbonaceous. The interbedded mudstones are pale green-grey, dark grey or variegated. Thin, grey or buff to cream, micritic, oolitic or bioclastic limestones may also occur (e.g. 42/24-1, 47/29a-1, 48/3-3).

Upper boundary
The top of the Strangways Formation is normally defined by a sharp downward change from variegated mudstones to sandstones or siltstones with interbedded mudstones. This lithological change corresponds to a downward decrease in gamma values commonly accompanied by an increase in velocity.

Lower boundary
The base of the Strangways Formation is marked by a change from sandstone to the dominantly mudstone lithologies of the underlying Wroot Formation. This lithological change corresponds to a downward increase in gamma values and decrease in velocity.

Distribution and thickness
The Strangways Formation is very variable in thickness, reaching its greatest development (c.150m) along the Dowsing Fault Zone or in rim-synclinal developments. In more structurally stable settings the unit may be only thinly developed (42/24-1).

Regional correlation
The Strangways Formation passes laterally, into the varied marine and paralic successions of the Scarborough and Cloughton formations (Yorkshire: Hemingway & Knox 1973) and of the Redbourne Group (Lincolnshire: Lincolnshire Limestone Formation, Gaunt et al. 1992). In the West Netherlands Basin correlative strata form part of the interbedded sandstones and mudstones of the Brabant Formation (NAM & RGD 1980). The formation is absent over the Mid-North Sea High and is coeval, at least in part, with the Pentland Formation and Brent Group successions of the Central and Northern North Sea (Richards et al. 1993).

Genetic interpretation
The Strangways Formation consists largely of fluviodeltaic sandstones and mudstone with the interbedded limestones representing periodic marine incursions into the general fluviodeltaic setting of the basin.

Biostratigraphic characterization
The Strangways Formation yields marine microplankton in variable proportions. The Nannoceratopsis gracilis biomarker occurs close to the top of the formation. The microfaunal Praeschuleridea decorata and Ammodiscus yonnabensis biomarkers are situated in the lower Bajocian part of the formation.

Age
Bajocian to ?Bathonian.

References
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STRANGWAYS FORMATION

STRANGWAYS FORMATION

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STRANGWAYS FORMATION

 Lies with this text above.

LITHOLOGY

Siltstone
Sandstone
Mudstone
Limestone

0 100 m

100 km

DISTRIBUTION MAP

STRANGWAYS FORMATION

STRANGWAYS FORMATION

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CERDIC FORMATION

LECKENBY FORMATION

LEOWES FORMATION

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47 / 3b-4

47 / 10-1

48 / 3-3

42 / 24-1

C. hyalina
H. pokrovkaensis

K. sermoisensis
L. spinosa / M. prima

V. subvitreus
A. yonsnabensis
P. decorata
N. gracilis

Parvocysta spp.

Micropneumatocythere / Glyptocythere spp.

Agglutinating foraminifera

Key biomarkers

Phillips Member

WEST SOLE GROUP

EARLY JURASS.

LIAS

MID-JURASSIC

PHILLIPS MEMBER

HUDLESTON FORMATION

STRANGWAYS FORMATION

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The term Wroot Formation is introduced in this report for a heterogeneous unit of paralic to marine sandstones, siltstones and mudstones lying between the marine to paralic sediments of the Strangways Formation above, and the fully marine sandstones, siltstones or mudstones of the Cerdic Formation (Lias Group) below.

**Type section**
47/3b-4: 1117-1213.5m (3664-3981ft)

**Reference wells**
42/24-1: 369-437m (1211-1434ft)
47/10-1: 1671.5-1747m (5484-5731ft)
48/3-3: 1137-1248m (3730-4094ft)

**Name.** After the amateur geologist H.E. Wroot (1890-1939) who in association with P.F. Kendall carried out extensive studies of the Jurassic rocks of Yorkshire.
Lithology
The Wroot Formation consists of mudstones with interbedded siltstones and sandstones. The mudstones and siltstones are pale grey to grey-green or purple, waxy and poorly to non-calcareous and carbonaceous. The interbedded sandstones are very fine to fine grained, pale grey to white, poorly cemented and carbonaceous.

Upper boundary
The top of the Wroot Formation is normally defined by a downward change from sandstones or siltstones with interbedded mudstones and limestones to variegated siltstone and mudstone lithologies. This lithological change corresponds to a downward increase in gamma-ray values and decrease in velocity.

Lower boundary
The base of the Wroot Formation is marked by a change from sandstone and siltstone lithologies to the harder, grey, marine siltstones, sandstones or mudstones of the underlying Cerdic Formation. This lithological change corresponds to a downward increase in gamma-ray values and in velocity. The boundary between the Wroot Formation and underlying Lias Group is a major erosive break over much of the outcrop, with the upper part of the Lias Group often missing.

Distribution and thickness
The Wroot Formation is very variable in thickness, ranging up to about 95m along the Dowsing Fault Zone (47/3b-4) and rim-synclinal structures (48/3-3). Over structurally stable areas the formation may be thin or absent.

Regional correlation
The Wroot Formation passes laterally into the varied marine and paralic successions of the onshore Saltwick and Dogger formations (Ravenscar Group, Hemingway & Knox 1973) in Yorkshire and of the Redborne Group (Grantham and Northampton Sand formations, Gaunt et al. 1992) in Lincolnshire. In the West Netherlands Basin coeval strata probably form part of the Brahan Formation (NAM/RGD 1980). The formation is absent over the Mid-North Sea High and is coeval, at least in part, with the Pentland Formation and Brent Group successions of the Central and Northern North Sea (Richards et al. 1993).

Genetic interpretation
The dominantly paralic sediments of the Wroot Formation consist largely of interbedded fluviodeltic sandstones, siltstones and mudstone. The presence of marine palynomorphs suggests that occasional marine incursions took place across the delta plain.

Biostratigraphic characterization
Agglutinated foraminifera are present in the formation.

Age
Aalenian to Bajocian.

References
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The Lias Group was established by Rhys (1974, p.6) for the succession lying between the top of the Penarth Group (formally Winterton Formation of Rhys 1974; see Johnson et al. 1994) below and the West Sole Group above. Rhys made no formal attempt to subdivide the group except to comment that a unit, probably equivalent to the Marlstone Rock Bed facies (now termed the Marlstone Rock Formation, Brandon et al. 1990) was present in the offshore area. In the present revision the Lias Group is divided, in descending order into four formations, Cerdic, Ida, Offa, and Penda.

The Lias Group is dominated by dark grey to grey, shallow marine mudstone and argillaceous limestone lithologies. There is considerable variability in their carbonate content producing rhythmic cyclicity to the log responses within the sequence. Where complete the upper part of the group includes a sandstone sequence (Phillips Member) of Late Toarcian age. A thin interval (Ida Formation, Late Pliensbachian) which includes sandstone and ironstone (the latter occasionally oolitic) lithologies is widely developed and provides the best marker unit within the group.

The lithologies present and their corresponding patterns of log response suggest three major fining/shallowing-upwards cycles are present within the Lias Group. The first cycle is contained within the Penda Formation with a relatively expanded shallow-water phase of limestone development; the second cycle encompasses the Offa and Ida formations, with the Ida Formation representing a condensed shallow-phase. The third cycle is often truncated by pre-Aalenian erosion prior to West Sole Group sedimentation, but when complete comprises the Cerdic Formation, with the sandstones and siltstones of the Phillips Member forming the final shallow-water phase.

The upper boundary of the group is marked by a downward transition from the paralic sandstone and mudstone lithologies of the West Sole Group into marine sandstones or mudstones. The Lias Group is erosively truncated over large areas of the basin and a variety of younger formations overlie the group (e.g. 49/16-8, p. 155). The lower boundary of the group is characterized by a change from hard, thinly interbedded argillaceous limestones and mudstones to black organic-rich mudstones which mark the top of the underlying Penarth Group (see Johnson et al. 1994).

The group reaches a maximum thickness of 820m in the UK sector with the Sole Pit Basin but, in general, thins to less than 300m over much of the basin (Lott 1992; e.g. Lias Group Correlation Panel 5, p.153). The group has the most extensive outcrop remnant of all the Jurassic units in the UK sector of the Southern North Sea Basin and is known to extend beyond the Cleaver Bank High into the Dutch sector, where it is included within the Altena Group (NAM & RGD 1980; Cope et al. 1992). Northwards the Lias Group thins against the Mid-North Sea High and southwards against the Anglo-Brabant Massif. In the Central Graben area only limited occurrences of Lower Jurassic sediments have been proved but further north in the Viking Graben coeval sediments of a similar mudstone-dominated facies are assigned to the Dunlin Group (Richards et al. 1993).

### Name

The name is an extension of the usage of the term Lias from the onshore UK area and is believed to derive from the Greek word 'Lea' meaning flat stone (see Arkell 1933, p.12).

### Constituent formations

- **CERDIC FORMATION**
  - p.125
- **IDA FORMATION**
  - p.131
- **OFFA FORMATION**
  - p.135
- **PENDA FORMATION**
  - p.139

### Age

Hettangian to Toarcian.

### References

- **Arkell, W.J.** 1933. The Jurassic System in Great Britain. Oxford University Press.
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The term Cerdic Formation is proposed here for a unit of marine mudstones and sandstones, that lie between the paralic sediments of the overlying Wroth Formation and the heterogeneous unit of siltstones, sandy and occasionally oolitic and ferruginous limestones of the underlying Ida Formation. The Cerdic Formation is the topmost unit of the Lias Group.

**Name.** After the last British King of Elmet in the 7th century.

**Type section**
42/29-1: 878-997m (2880-3270ft)

**UK reference sections**
47/29a-1: 559-590m (1834-1937ft)
48/1b-4: 1116.5-1221m (3863-4006ft)
49/12a-7: 1699-1804m (5574-5919ft)
Lithology
The Cerdic Formation consists dominantly of dark grey marine mudstones, with sporadic thin argillaceous limestone developments passing upwards, where the sequence is most complete, into fine sandstones at the top of the unit.

Upper boundary
The top of the Cerdic Formation is erosional in all sections. In most wells the top of the formation is marked by a downward change from coarse clastics to mudstone lithologies. This corresponds to a sharp downward increase in gamma values and decrease in velocity response. In the most complete sections, however, an upper sandstone / siltstone member of the unit is preserved at the top of the Cerdic Formation (e.g. 42/29-1, p. 127). In such sections, the top of the formation is defined by a downward change from paralic sandstones to shallow marine sandstones / siltstones. The corresponding change in gamma and velocity responses is less marked (e.g. 48/18c-5, Panel 5, p. 153).

Lower boundary
The base of the Cerdic Formation is marked by a downward change from mudstones to silty, sandy and occasionally ferruginous and oolitic limestone lithologies of the underlying Ida Formation. This change corresponds to a marked downward increase in velocity and decrease in gamma.

Distribution and thickness
The Cerdic Formation is widely distributed throughout the area of Lias Group subcrop but shows considerable variations in thickness because of subsequent pre-Aalenian erosion. The formation has a proved thickness of c. 120m in well 42/29-1.

Regional correlation
The Cerdic Formation correlates with the Whitby Mudstone and Blea Wyke Sandstone formations (Ivimey-Cook & Powell 1991) of the Cleveland Basin. In the East Midlands onshore area equivalents are mostly lacking because most of the Toarcian succession has been removed by pre-Aalenian erosion (Cope et al. 1980). To the east the formation equates with the lower part of the Werkendam Shale Formation (NAM & RGD 1980).

Genetic interpretation
The mudstones of the formation are considered to have been deposited as marine hemipelagic sediments following a slight deepening of the basin. The sandstones are the end-member of a marine shallowing-upward cycle.

Biostratigraphic characterization
The top of the formation, and the top of the Toarcian, is characterized by the Verneullinoides subvitreus biomarker. Two further biomarkers occur, the Kinkelinella sermoisensis biomarker in the middle part of the formation and the Marginulina prima biomarker just above the base (within the falciferum Zone). The Cerdic Formation yields abundant palynomorph associations dominated by gymnospermous pollen. Dinoflagellate cysts are present throughout; these are typically dominated by Nannoceratopsis gracilis. The Luehddea spinosa biomarker is present within the formation.

Age
Toarcian.

References
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The term Phillips Member is proposed here for grey siltstones and fine sandstones which are developed at the top of the Cerdic Formation in some wells.

**Name.** After the eminent Victorian geologist John Phillips (1800–1874).

**Type section**
47/3b-4: 1213.5–1254.5 m (3961–4116 ft)

**Reference section**
48/3-3: 1248–1306 m (4094–4284 ft)

**Lithology**
The Phillips Member comprises interbedded grey, calcareous, muddy, marine siltstones and fine sandstones.

**Upper boundary**
The top of the member is defined by a downward change from the medium to coarse paralic sandstones of the Wroot Formation to fine, muddy siltstones and sandstones. There is a corresponding downward increase in gamma values. The Phillips Member displays a generally higher and more consistently high velocity in the member.

**Lower boundary**
The base of the Phillips Member is marked by a downward change from sandstones and siltstones to dark grey mudstones. There is a corresponding increase in gamma values and decrease in velocity.

**Distribution and thickness**
The Phillips Member has a restricted distribution and is present only in those areas of the basin where the Lias Group is most thickly developed, e.g. rim synclinal structures and along the Dowsing Fault Zone (Panel 5, p. 153). Over much of the basin the upper part of the Lias Group was extensively eroded prior to the deposition of the succeeding West Sole Group sediments and therefore the original extent of the Phillips Member is difficult to ascertain. The maximum proved thickness for the member is c.60 m.

**Regional correlation**
The Phillips Member is equivalent in part at least to the late Toarcian Blea Wyke Sandstone Formation of the Cleveland Basin (Knox 1984). Elsewhere in onshore eastern England, late Toarcian sediments are generally absent either through non-deposition or pre-Aalenian erosion.

**Genetic interpretation**
The Phillips Member sandstones and siltstones were deposited as shallow marine sheet sands. They form the end member of a major shallowing-upward cycle of marine sedimentation and mark the end of the marine mudstone-dominated deposition of the Lias Group.

**Biostratigraphic characterization**
No information.

**Age**
Late Toarcian.

**References**
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IDA FORMATION
(new)

The term Ida Formation is proposed here for an interval dominated by grey to brown, ferruginous, siltstones and sandy, occasionally oolitic and ferruginous limestones which forms a prominent marker horizon throughout the UK and adjacent sectors of the North Sea. The formation lies between marine mudstones of the Cerdic and Offa formations.

Name.  After the 6th century king of Bernicia.

Type section
47/29a-1: 590-607m (1937-1991ft)

UK reference sections
42/24-1: 541-559m (1775-1834ft)
48/18c-5: 1030-1066m (3379-3498ft)
53/1-3: 912.5-929m (2994-3048ft)
Lithology
The Ida Formation consists of thinly interbedded, brown to grey, siltstones, fine sandstones and argillaceous limestones which are occasionally oolitic (chamositic) and carbonaceous.

Upper boundary
The top of the formation is marked by a downward change from the mudstones of the Cerdic Formation above to harder sandy and calcareous lithologies typical of the Ida Formation below. There is a corresponding sharp downward increase in velocity and decrease in gamma values.

Lower boundary
The base of the Ida Formation is placed at the abrupt downward transition from sandy and calcareous lithologies to mudstones of the underlying Offa Formation. The boundary is shown in some wells by a marked decrease in velocity and increase in gamma values (e.g. 53/1-3, p. 133), but in others the change in gamma response is less marked (e.g. 47/29a-1, 48/18c-5, p. 133).

Distribution and thickness
The Ida Formation is thin but widespread marker throughout the Southern North Sea Jurassic subcrop area, rarely reaching more than 30m in thickness.

Regional correlation
The Ida Formation is in large part the equivalent of the Marlstone Rock Formation (East Midlands; Brandon et al. 1990) and the coeval Stathes and Cleveland Ironstone formations of the Cleveland Basin (Powell 1984; Ivimey-Cook & Powell 1991). To the east, in the Dutch sector a unit of similar lithology and log character, with sandy beds and oolitic grains, is recognized within the upper part of the Aalburg Shale Formation at a similar stratigraphic level (NAM & RGD 1980, p.34).

Genetic interpretation
Upward change from mudstones to the sandy Ida Formation indicates shallowing of the marine inner shelf environments, which characterize the other formations of the Lias Group, allowing the influx of siliciclastic detritus across the basin (e.g. Cope et al. 1992). Shallow marine ferruginous, oolitic carbonate shoals developed locally.

Age
Mid to Late Pliensbachian.

Biostratigraphic characterization
The Ogmoconcha/Ogmoconchella biomarker is situated immediately below the upper boundary of the formation in the highest Pliensbachian. The Ida Formation typically yields similar palynofloras to the overlying Cerdic Formation.

References.
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OFFA FORMATION
(new)

The term Offa Formation is proposed here for an interval dominated by dark grey, thinly bedded marine mudstones with subordinate interbedded, moderately thick beds of argillaceous limestone.

Name. After the 8th-9th century king of Mercia.

Type section
47/14a-9: 1108-1169m (3635-3836ft)

Reference sections
42/24-1: 559-753m (1834-2470ft)
48/3 1b-4: 1242.5-1412.5m (4076-4634ft)
49/12a-7: 1837-1899m (6027-6230ft)
Lithology
The Offa Formation comprises a rhythmically interbedded sequence of dark grey mudstones with moderately thick beds of argillaceous limestone. Thin ferruginous developments have been described within this unit over the East Midlands Shelf.

Upper boundary
The top of the Offa Formation is marked by an abrupt downward change from hard, silty and sandy limestone lithologies of the overlying Ida Formation to mudstones. There is a corresponding marked decrease in velocity and gradual increase gamma-ray values in some wells (e.g. 53/1-3, p.153). In other wells the gamma change is less marked (e.g. 49/12a-7, p.157).

Lower boundary
The base of the Offa Formation is characterized by a sharp change from dark grey mudstones to the paler, harder, argillaceous limestones of the underlying Penda Formation. There is a corresponding marked increase in velocity accompanied in many sections by a slight decrease in gamma values.

Distribution and thickness
The Offa Formation is well developed throughout the Lias Group subcrop. The formation reaches up to c. 190m in thickness (e.g. 42/24-1).

Regional correlation
The Offa Formation is, in part at least, equivalent to the Brant Mudstone Formation (Brandon et al. 1990) of the East Midlands and the Ironstone and Pyritous Shale units of the Cleveland Basin (Powell 1984; Ivimey-Cook & Powell 1991). Included within this formation are beds equivalent to the Pecten Ironstone Member (Gaunt et al. 1980) and the Gryphaea Bed (Sumbler 1993), which are often marked by a low gamma/high velocity interval (e.g. 47/29a-1, Panel 5, p.153)

Genetic interpretation
This argillaceous limestone-dominated formation was deposited in a shallow-marine, inner-shelf setting (e.g. Cope et al. 1992). The lower part of the formation has a higher proportion of low-velocity mudstones which probably represent a slight deepening of the basin relative to the underlying Penda Formation sediments.

Biostratigraphic characterization
The top is marked by the presence of the Dentalina matutina biomarker, which onshore equates with the top of the marginatus Zone. Intraformational biomarkers are recognized by the FDO of Wichmanella seminora, Vaginulina denticulatavarinata (a good marker for the top of the davoei Zone), Gammacythere ubiquita and Lingulina tenera subprismatica (in the basal davoei Zone onshore). The Offa Formation is largely characterized by miospores, principally pollen genera such as Classopolis. Dinoflagellate cysts are absent.

Age
Upper Sinemurian to Lower Pliensbachian.

References


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PENDA FORMATION
(new)

The term Penda Formation is proposed here for the basal unit of the Lias
Group which comprises an interval dominated by dark grey, thinly bedded,
argillaceous limestones with subordinate mudstones. The Penda Formation
underlies the mudstones of the Offa Formation and overlies mudstones of the
Triassic Penarth Group.

Name. After the 7th century king of Mercia.

Type section
47/29a-l: 667-767m (2254-2517ft)

Reference sections
42/29-1: 1096-1266.5m (3595-4155ft)
48/1 b-4: 1412.5-1672m (4634-5486ft)
49/12a-7: 1899-2052m (6230-6731ft)
Lithology
The Penda Formation consists of thinly interbedded, dark grey, hard, argillaceous limestones, and dark grey calcareous mudstones. The limestones characteristically show a spiky, high velocity log response (e.g. 48/18c-5 Lias Group Panel 5, p. 153). A number of minor sedimentary cycles, from carbonate-poor to carbonate-rich beds, can be distinguished within the formation on the basis of the changing velocity response (e.g. 42/29-1).

Upper boundary
The top of the Penda Formation is marked by the downward passage from limestone- poor mudstones of the overlying Offa Formation to the limestone-dominated lithologies of the Penda Formation. This corresponds to a sharp downward increase in the velocity response.

Lower boundary
The lower boundary is marked by the sharp transition from the carbonate dominated lithologies of the Penda Formation to the organic-rich mudstones of the underlying Penarth Group. This lithological change corresponds to a marked downward decrease in velocity and increase in gamma-ray values.

Lithological subdivision
The formation may be divided into three informal subdivisions (P1-P3) which can be recognized throughout the basin (e.g. 48/46-4, Panel 5, p. 153).

P1. The unit comprises thinly interbedded, hard, argillaceous limestones which immediately overlie low velocity mudstones of the Penarth Group. The limestones are dark grey, occasionally brown, hard, finely crystalline and argillaceous and are interbedded with thin, dark grey, mudstones. The unit is occasionally silty or sandy, with traces of glauconite.

By comparison with the onshore sequence this unit probably includes to the Jurassic/Triassic system boundary interval.

P2. This unit comprises thinly interbedded dark grey to brown mudstones, with sporadic, harder, argillaceous limestones. The unit shows a characteristically low velocity compared with the underlying and overlying subdivisions.

P3. This unit represents the bulk of the formation and comprises the main argillaceous limestone development and is characterized by lower gamma values and a more consistently high velocity.

Distribution and thickness
The Penda Formation is well developed throughout the Lias Group subcrop. The formation is the thickest recognized within the Lias Group reaching up to 250m.

Regional correlation
The Penda Formation is probably equivalent to the Scunthorpe Mudstone Formation (Brandon et al. 1990) in the East Midlands and the informal Calcareous and Siliceous Shales units of the Redcar Mudstone Formation in the Cleveland Basin (Powell 1984; Ivimey-Cook & Powell 1991).

The P1 unit is probably equivalent to the unit commonly known as the Hydraulic Limestones (e.g. Kent 1980) now named the Barnstone Member by Brandon et al. (1990).

The P2 unit is probably equivalent to the Barnby Member of Brandon et al. (1990).

Genetic interpretation
This argillaceous limestone dominated formation was deposited in a shallow-marine, inner-shelf setting (e.g. Cope et al. 1992). The limestone developments in general are considered to comprise both primary depositional and diagenetically developed types or may be formed by a combination of both these processes.

Biostratigraphic characterization
The Dentalina matutina acme biomarker is situated at or near the top of the formation and marks the varicostatum Zone. The following microfossil biomarkers are located within the P1 unit: Dentalina matutina acme, Kinkelinneria triebeli, Ogmococha hagena (a marker for the turneri Zone onshore), Lenticulina semireticulata (which has its FDO at the top of the turneri Zone basin wide), Ogmococha aspinata, Involutina liassica acme (marking the top of the bucklandi Zone) and Reinholdella planiconvexa acme. The last named biomarker is also situated in the upper part of the P2 unit. The Lingulina tenera colemani acme biomarker is located in P1 at the top of the planorbis Zone. In terms of the palynoflora, the Liasidium variabile biomarker marks the top of the Penda Formation and the microflora in the remainder of the formation is dominated by miozoans.

Age
Latest Triassic to Sinemurian.

References
CORRELATION PANELS
(HUMBER/WEST SOLE/LIAS GROUPS)
### Southern North Sea

<table>
<thead>
<tr>
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**Diagram:**
- **Humber Group**
- **West Sole Group**
- **Lias Group**

**Formations:**
- Penarth Group
- Penda Formation
- Seeley Formation
- Woodward Formation
- Coralian Formation
- Kimmeridge Clay Formation
- Valhall Formation
- Spilsby Sandstone Formation
- West Sole Group
- Lias Group

**Time Periods:**
- Early Jurassic
- Late Jurassic
- Triassic

**Member:**
- LECKENBY FORMATION
- KIMMERIDGE CLAY FORMATION
- WOODWARD FORMATION
- CALLOVIAN
- BATHONIAN
- BAJOICAN
- AALENIAN
- VOLTGANIAN
- RYAZANIAN
- VALANGINIAN

**Location:**
- 100 km
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CORRELATION PANEL 2

HUMBER GROUP

Nettleton Bottom

LITHOLOGY

Mudstone
Sandstone
Limestone
Limestone, oolitic

KIMBERIDGE CLAY FORMATION
WOODHALL FORMATION
SKEELER FORMATION
CORALLIAN FORMATION

100 km

Nettleton Bottom
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LIAS GROUP

CORRELATION PANEL 5

47 / 29a-1

42 / 29-1

48 / 18c-5

49 / 12a-7

53 / 1-3

LITHOLOGY

Mudstone

Sandstone

Limestone / Mudstone interbedded

Limestone, sandy

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EARLY JURASSIC

200 km

40 0 120GR 140 DT

49 / 12a-7

40 0 150GR 190 DT 40

49 / 12a-7

0 100GR 140 DT

48 / 18c-5

0 150GR 190 DT 40

47 / 29a-1

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CORRELATION PANEL 5

EARLY JURASSIC

Phillips Member

CERDIC FORMATION

PENDA FORMATION

IDA FORMATION

TRITON FORMATION

WROOT FM.

VALHALL FORMATION

PENARTH GROUP

PENARTH GROUP

LIAS GROUP

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APPENDICES
APPENDICES 1-3

Paleogene, Cretaceous and Jurassic biostratigraphic markers

The following appendices identify and describe Southern North Sea Paleogene, Cretaceous and Jurassic key biostratigraphic markers. The order of presentation of these microfossil-based schemes is from the youngest system to the oldest, with the taxonomic groups within each section, i.e. calcareous nannoplankton, dinoflagellate cysts, radiolaria, foraminifera and ostracods following convention. Many of the biostratigraphic schemes used at present, although loosely correlated to one another, often lack an unequivocal link to a standard biozonation or other chronostratigraphic scheme. This contribution attempts to establish the relative stratigraphic order of the biomarkers as a guide to the Southern North Sea succession.

Identification of regionally consistent biostratigraphic markers for the Southern North Sea succession is hampered by a scarcity of high-quality data. For this reason, most of the biomarkers presented in this study are based on the key biomarkers identified for the Central North Sea, selected on the basis of their being widely and consistently used (see Harland et al. in Knox & Holloway 1992, pp.A1-A5; Wilkinson et al. in Johnson et al. 1993, pp.A1-A5; Riding et al. in Richards et al. 1993, pp.A1-A5). Most of these markers are known to occur in the onshore English sections, and are therefore presumed to extend throughout the Southern North Sea Basin. A few biomarkers of restricted Southern North Sea application are also included.

All of the biomarkers are either first downhole occurrences (FDOs) or first downhole acme occurrences (FDAOs). Many of the FDOs and FDAOs of the key biomarkers have never been fully defined; in some instances one specimen of the nominate species may be sufficient to recognize an FDO, in others a consistent downhole presence is necessary. Undoubtedly, different criteria have operated at different times. Similarly, the definition of acme occurrences may also be problematic. However, a revision and formal definition of the biomarkers is outside the scope of this study.
CALCAREOUS NANNOFOSILS

1) Reticulofenestra umbilica
Definition. The FDO of Reticulofenestra umbilica (Levin) Martinii & Ritzkovski.
Age. Early Oligocene.

2) Reticulofenestra reticulata
Definition. The FDO of Reticulofenestra reticulata (Gartner & Smith) Roth & Thierstein.
Age. Late Eocene.

3) Discocysta distinctus
Definition. The FDO of Discocysta distinctus (Bramlette & Sullivan) Locker.
Age. Mid Eocene.

4) Rhabdosphaera gladius
Definition. The FDO of Rhabdosphaera gladius Locker.
Age. Mid Eocene.

5) Trilobatus orthoystus
Definition. The FDO of Trilobatus orthoystus Shamrai.
Age. Early Eocene.

6) Pontosphaera exilis
Definition. The FDO of Pontosphaera exilis (Bramlette & Sullivan) Romein.
Age. Early Eocene.

7) Hornbrosokina edwardsii
Definition: The FDO of Hornbrosokina edwardsii Perch-Nielsen.
Age. Early Paleocene.

DINOFLAGELLATE CYSTS

1) Choroteridium lobospinosum
Definition. The FDO of Choroteridium lobospinosum (Gocht in Weiler) Gocht.
Age. Late Oligocene.
Remarks. The FDO of the eponymous species together with Membranophoridium aspinatum (Tiemann) Gocht marks the top of the Oligocene (Costa & Manum 1988).

2) Arosephaeridium dityospilosus
Definition. The FDO of Arosephaeridium dityospilosus (Klumpp) Eaton.
Age. Late Eocene.
Remarks. This biomarker is a useful guide to the top of the Upper Eocene. Other dinoflagellate cyst tops reported to be coincident (Costa & Manum 1988) include Heterosphaeracysta leptaleae Eaton, Phthanoberidium echinatum Eaton and Thalassaphora fenestrata Lienig et al.

3) Eatonocystra aurulce
Definition. The FDO of consistent Eatonocystra aurulce (Morgenroth) Stover & Evitt (Heilmann-Clausen 1985) and members of the Apectodinium homomorph plexus (Harland 1979).

5) Leiosphere influx
Definition. A downhole influx of large leiospheres and prasinophycean algae, including Pseudopectenella and Tasmanites.
Age. Early Eocene.
Remarks. This biomarker is included amongst the dinoflagellate cyst biomarkers for convenience. Undoubtedly, it serves to distinguish a change in the environment of deposition and is unlikely to be applicable outside the North Sea Basin.

APPENDIX 1
Paleogene key biostratigraphic markers
by R. Harland, I.P. Wilkinson and N.M. Hine

1) Cibicides truncaniscus
Definition. The FDO of Cibicides truncaniscus (Guembel).
Age. Late Eocene.
Remarks. The FDO of Vagnulinopsis decoratus is an alternative biomarker, although the FDO of its consistent occurrence is a little below the top of the Mid Eocene.

2) Planulina costata
Definition. The FDO of Planulina costata (Hantken).
Age. Late Eocene.

3) Neospinoides karsteni
Definition. The FDO of Neospinoides karsteni (Reuss).
Age. Mid Eocene.

7) Planulina burlingtonensis tenedani
Definition. The FDO of Planulina burlingtonensis tenedani Kaasschieter.
Age. Early Mid Eocene.
Remarks. The nominate species, together with Cibicides wenti Howe, forms a characteristic assemblage in lower sublittoral facies (Leinsh & Sissingh 1983).

8) Gaudryina miliaris
Definition. The FDO of Gaudryina miliaris Meinl.
Age. Early Eocene.

9) Steinsieina beccariiformis acme
Definition. The FDO of substantial numbers of Steinsieina beccariiformis (White).
Age. Late Paleocene.
Remarks. A marked increase in diversity and abundance of calcareous benthonics is recognized at this biomarker (King 1989). The accompanying FDOS of Cibicides velasconis (Cushman) and C. dayi (White) are characteristic only in bathyal areas.

b) Planktonic microfossils
1) Globigerinatheka index
Definition. The FDO of Globigerinatheka index (Finlay).
Age. Late Eocene.
Remarks. The FDO of the nominate species, near the top of the Eocene, is characteristic of the Southern North Sea. The FDO of the rare Subbotina inornata (Guembel) is approximately at the same level.

2) Pseudoagnostina micra
Definition. The FDO of Pseudoagnostina micra (Cole), together with the FDO of persistent Pseudoagnostina spp.
Age. Mid Eocene.
Remarks. Although P. micra has been recorded from the early Oligocene in some onshore sequences, it is generally absent in younger strata offshore.

3) Cenosphera sp.
Definition. The FDO of large, spherical and frequently pyritized specimens of Cenosphera sp. (sensu King 1983).
Age. Mid Eocene.
Remarks. This biomarker is accompanied by a reduction in the proportions of planktonic and benthonic foraminifera.

4) Subbotina ex gr. linaperta acme
Definition. The FDO of Subbotina ex gr. linaperta Finlay together with the reappearance of common planktonics including Globigerina patagonica Todd & Kniker, Globorotalia ex gr. pontcarmarae Subbotina and Pseudohastigerina wilcoxi (Cushman & Ponton).
Age. Early Eocene.
Remarks. Abundant large spherical radiolaria also occur in association with this biomarker.
5) **Coscinodiscus spp. acme**
Definition. The FDAO of abundant *Coscinodiscus* sp. 1 and sp. 2 (sensu King 1983).
Age. Early Eocene.
Remarks. This biomarker is also accompanied by the disappearance of abundant planktonic and calcareous benthonic foraminifera.

6) **Cenosphaera lenticularis**
Definition. The FDO of common to abundant *Cenosphaera lenticularis* (Grzybowski).
Age. Late Paleocene.
Remarks. The large nominate radiolarian has been referred to as cf. *Cenodiscus* and 'Cenosphaera' before Jones (1988) assigned it to *Cenosphaera lenticularis*, despite preservation problems rendering identification difficult. Planktonic foraminifera are absent.

7) **Globorotalia pseudobulloides**
Definition. Reappearance of abundant planktonic foraminifera, including *Globorotalia pseudobulloides* (Plummer).
Age. Late Paleocene.
Remarks. This biomarker occurs somewhat above the base of the late Paleocene and includes *Globorotalia chapmani* Parr, *G. compressa* (Plummer), *Subbotina triloculinoides* (Plummer) and *Globigerina* spp. as characteristic elements.

8) **Globigerina trivialis/Globorotalia cf. compressa**
Definition. The FDO of *Globigerina trivialis* Subbotina and *Globorotalia cf. compressa* (sensu Blow 1979).
Age. Early Eocene.

9) **Globoconusa daubjergensis**
Definition. The FDO of *Globoconusa daubjergensis* (Bromman).
Age. Earliest Paleocene.
Remarks. Although populations are often low in diversity and/or poorly preserved, this biomarker, when recognisable, is useful (Crittenden 1982; Stewart 1987). The FDOs of *Globigerina sulphurea* Blow and *G. truncatulinoides* sensu Blow (1979) also occur at this level.

10) **Bathysiphon spp.**
Definition. A downhole influx of an abundant, low-diversity fauna of agglutinating taxa and the FDO of *Spiroplectammina spectabilis* (Grzybowski).
Age. Late Paleocene.
Remarks. The fauna is characterized by abundant *Bathysiphon* species, together with less common *Glomospira* spp., *Haplophragmoides* spp., *Recurvoides* spp. and rare specimens of *Spiroplectammina spectabilis*.

4) **Spiroplectammina spectabilis acme**
Definition. A downhole influx of high-diversity agglutinating fauna, including an acme of *Spiroplectammina spectabilis* (Grzybowski) and the FDO of *Trochammina rathenmurrayae* Cushman & Renz.
Age. Late Paleocene.
Remarks. The biomarker is characterized by the introduction of *Buzasina cf. pacifica* (Krasheninnokov), *Karrierella conversa* (Grzybowski), *Pracystammina cf. globigeriniformis* (Krasheninnokov) (=Cv. stammma sp. A of King 1989), *Rectophragmium sp.* A of King 1989 (=R. pauperata of Gradstein et al., 1988) and *Rzehakina epigona* (Rzehak).
Figure A1. Palaeogene key biomarkers for the UK Southern North Sea.
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APPENDIX 2
Cretaceous biostratigraphic markers by L.P. Wilkinson, J.B. Riding and N.M. Hine

DINOFLAGELLATE CYSTS

1) Lithosphaeridium siphonophorum
   Definition. The FDO of Lithosphaeridium siphonophorum (Cookson & Eisenack) Davey & Williams. Age. Early Hauterivian. Remarks. Although its occurrence has been reported from the late Hauterivian (Aurisano 1989), it has not been reported from the early/mid Barremian boundary (Harding 1990; Mutterlose 1991).

2) Bolivinoides multiformis
   Definition. The FDO of Bolivinoides multiformis (Grzybowski) and the nominate species. Age. Late Valanginian (top part of the Kienevianian) Davey.

3) Gavelinella acuta
   Definition. The FDO of Gavelinella acuta (Bolin) and the nominate species. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

4) Epelidosphaeridia spinosa
   Definition. The FDO of Epelidosphaeridia spinosa (Davey) Davey. Age. Late Valanginian (top part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

5) Tenuioniscus acuminatus
   Definition. The FDO of Tenuioniscus acuminatus (Bolin) and the nominate species. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

6) Palaeohystrichophora infusorioides
   Definition. The FDO of Palaeohystrichophora infusorioides (Deflandre & Cookson) Davey & Verdier. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

7) Nematosphaeropsis venter
   Definition. The FDO of Nematosphaeropsis venter (Deflandre) Deflandre & Cookson. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

8) Infusoria infusoria
   Definition. The FDO of Infusoria infusoria (Deflandre) Deflandre & Cookson. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

9) Rotosphaeropsis thula
   Definition. The FDO of Rotosphaeropsis thula (Davey) Riding & Davey. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

10) R. szajnochae
    Definition. The FDO of Rotosphaeropsis szajnochae (Davey) Riding & Davey. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

11) Stensioeina granulata incondita
    Definition. The FDO of Stensioeina granulata incondita (Vasilenko) and the nominate species. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

12) Cretaceous biostratigraphic markers
    Definition. The FDO of Cretaceous biostratigraphic markers. Age. Cretaceous (latest Barremian to early Aptian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

FORAMINIFERA

1) Pseudostelatula elegans
   Definition. The FDO of Pseudostelatula elegans (Riezek) and Rugoglophiarella sp. Age. Maastrichtian. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

2) Gavelinella spp.
   Definition. The FDO of Gavelinella spp. Age. Maastrichtian. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

3) Palaeohystrichophora infusorioides
   Definition. The FDO of Palaeohystrichophora infusorioides (Deflandre & Cookson) Davey & Verdier. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

4) Nematosphaeropsis venter
   Definition. The FDO of Nematosphaeropsis venter (Deflandre & Cookson) Davey & Verdier. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

5) Rotosphaeropsis thula
   Definition. The FDO of Rotosphaeropsis thula (Davey) Riding & Davey. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

6) Stensioeina granulata incondita
    Definition. The FDO of Stensioeina granulata incondita (Vasilenko) and the nominate species. Age. Early Barremian (late part of the Bajocianian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.

7) Cretaceous biostratigraphic markers
    Definition. The FDO of Cretaceous biostratigraphic markers. Age. Cretaceous (latest Barremian to early Aptian) Davey. Remarks. The taxon occurs throughout the Albian and is a reliable marker for the Albian-Cenomanian boundary.
8) Conosphera sp.
Definition. The FDO of Conosphera sp.
Age. Late Cretaceous (Campanian Zone).
Remarks. The planktonic foraminifers of this species are associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

9) Protocythere dubia
Definition. The FDO of Protocythere dubia Koch. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

10) Bolivinoides aureus
Definition. The FDO of Bolivinoides aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

11) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

12) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

13) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

14) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

15) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

16) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

17) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.

18) Bolivinoides cf. aureus
Definition. The FDO of Bolivinoides cf. aureus Cushman. Age. Early Cenomanian (Coniacian Zone).
Remarks. The nominate species is widely distributed, becoming rarer to the south. Remarks. The FDO of the nominate species is associated with the top of the Early Turonian to early Cenomanian (Tappan). The FDOs of other species, such as Uvigerina lactea, are more useful in this interval. The nominate species is widely distributed, becoming rarer to the south.
Figure A2. Cretaceous key biomarkers for the UK Southern North Sea.
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APPENDIX 3

Jurassic biostatigraphic markers

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

DINOFLAGELATE CYSTS

1) Glossodinium dimorphum
Definition. The FDO of Glossodinium dimorphum loamides et al.
Age. Mid Volgian (anguiformis Zone).
Remarks. Other species with coeval FDOs are Dichodgodonovaulus, pannea (Norris) Sarjeant and Senoniasphaera (Gismite & Sarjeant) Lentin & Williams.

2) Cybrioperidinium longicorne
Definition. The FDAO of Cybrioperidinium longicorne (Downie) Lentin & Williams.
Age. Early Volgian (hudslestoni Zone).
Remarks. An acme occurrence of Oligoasteridium patatum Riding & Thomas is an alternative marker. The FDOs of Oligoasteridium patatum and Pteroschiasma pannonicus Davey & Williams mark the early/mid Volgian part of the Oxfordian (Riding & Thomas 1988).

3) Endocentrum luridum
Definition. The FDO of Endocentrum luridum (Deflandre) Gocht.
Age. Latest Kimmeridgian (autissiodorensis Zone).
Remarks. The FDO of Glossodinium dimorphum (Deflandre) Norris & Sarjeant is an alternative datum this biomarker (Harker et al. 1987; Riding & Thomas 1992).

4) Scinodinium crystallinum
Definition. The FDAO of Scinodinium crystallinum (Deflandre) Klement.
Age. Earliest Kimmeridgian (baylei Zone).
Remarks. The FDOs of Chlathrococenosites asapha (Drugg) Stover & Helby, Nanocapretopsis pelletsii Deflandre and Strinodinium orbiis Drugg can be used as alternative markers (see Riding & Thomas 1988, 1992).

5) Scinodinium crystallinum
Definition. The FDAO of Scinodinium crystallinum (Deflandre) Klement.
Age. Latest Oxfordian (rosenkrantzi Zone).
Remarks. Scinodinium crystallinum occurs in relatively small proportions in the earliest Kimmeridgian, but in the Oxfordian it is common to abundant (Riding 1984; Riding & Thomas 1992). The FDAO of the species may be used to define the Kimmeridgian/Oxfordian boundary, although when palynomorph recovery is poor, it may be difficult to differentiate the FDAO from the FDAO.

6) Rigaudella aemula
Definition. The FDO of Rigaudella aemula (Deflandre) Below.
Age. Mid Oxfordian (tenausseratum Zone).
Remarks. Three species with coeval FDOs are Chrytrioechria cerastes Davey, Gonyaulacysta jurassica subsp. aucta Sarjeant var. longicornis (Deflandre) Sarjeant and Trichodiadum scarborghusi (Sarjeant) Williams et al. (often quoted as Acanthaulax senta Drugg), see Riding & Thomas (1992).

7) Wanaea spp.
Definition. The FDAO of Wanaea spp.
Age. Early Oxfordian (cordatum Zone).
Remarks. The three species of Wanaea found in Europe are W. digitata Cookson & Eissnack, W. fimbrina Sarjeant and W. hysanota Woodall. Other markers for the early Oxfordian are the FDOs of Cricostoma dietlini Wolfard & Van Erve, Energyia acollaris (Dodekova) Sarjeant, Gonyaulacysta centronica Riding, Limnodinium abditatum (Drugg) Riding and Tubulibellula dentata Raynaud (Riding & Thomas 1992).

8) Nanocapretopsis gracilis
Definition. The FDO of consistent Nanocapretopsis gracilis Alberri.
Age. Early Bajocian (thumbrisetum Zone).
Remarks. An alternative biomarker is the FDO of Mancordium semianulatum Morgenroth (see Riding 1984).

9) Luehndea spinosa
Definition. The FDAO of Luehndea spinosa Morgantho.
Age. Early Toarcian (tenuiserratum Zone).
Remarks. The early Toarcian is characterized by the FDAO of small sphaeromorph auriarchids, probably referable to Halaphepraenopsia laeviuscula Madler (Riding 1987).

10) Liasium variabile
Definition. The FDAO of Liasium variabile Drug.
Age. Late Sinemurian (varicosstatum Zone).

RADIALARIA

Radiolaria, although not reported in published form from the UK North Western Sea, have considerable biostatigraphical potential in this area (see Dyer & Copestake 1989; Partington et al. 1993).

1) Trilococospa sp. 1 / Trilococospa sp. 2
Age. Late Ryazanian (stemonophasal Zone).
Remarks. This biomarker occurs a little below the top of the Kimmeridge Clay.

2) Praceocorynomomya sp. 2 acme
Age. Mid Volgian (lumplughii Zone).
Remarks. The first FDAO of Conesphaera sp. 1 of Dyer & Copestake (1989) and Stichocapsa devorata Rust are also characteristic of this bioevent, together with the FDOs of Orbiculariforma mclaughlini Pessagno and Parvicecula jurassica Pessagno.

3) Praceocorynomomya sp. 1 acme
Age. Late Volgian (early primitivus Zone).

4) Parvicecula sp. 1 acme
Age. Mid Volgian (anguiformis Zone).
Remarks. Species of Parvicecula become common at this biomarker, including the FDAO of Parvicecula jurassica.

5) Conocisca sp. 1 acme
Age. Mid Volgian (fitzoni Zone).
Remarks. An acme of Conocisca sp. 1 and Conesphaera sp. 1 of Dyer & Copestake (1989) in the lower part of the Middle Volgian is indicated by Partington et al. (1993).

6) Orbiculariforma loireyiensis
Definition. The FDAO of Orbiculariforma loireyiensis Pessagno (Early Volgian (hudslestoni Zone)).
Remarks. Although Pessagno (1977) and Pessagno et al. (1984) record Orbiculariforma loireyiensis from the Tibetan and Berrussian, its local FDAO, in the North Sea Basin, is characteristic of the early Volgian. A marked increase in diversity takes place at this biomarker and the FDAO of Spongodiscus sp. 3 of Dyer & Copestake (1989) and the influx of consistent Orbiculariforma mclaughlini Pessagno also occur.

7) Praceocorynomomya hexagona acme
Definition. The FDAO of Praceocorynomomya hexagona (Rust). Age. Early Volgian (early scitulus-elegans Zone).
Remarks. An influx of Conesphaera sp. 1 and sp. 2 of Dyer & Copestake (1989) takes place at this biomarker.

8) Pyritised radiolaria
Definition. The FDAO of common pyritized radiolaria, particularly Parvicecula spp.
Age. Kimmeridgian (autissiodorensis Zone).
Remarks. Rabbesella perforata Hinde is often common or abundant at this biomarker; an influx of Conesphaera sp. 2 of Dyer & Copestake (1989) also occurs.

9) Liasium sp. 1
Age. Early Kimmeridgian (early martialis Zone).
Remarks. An influx of Praeconocaryomma hexagona, Parvicecula blowi Pessagno and Parvicecula jurassica Pessagno also occurs at this biomarker.

10) Absence of abundant in situ radiolaria
Definition. In situ radiolaria are very rare. Age. Early Kimmeridgian (baylei Zone).
Remarks. Jurassic sediments below the basal Kimmeridgian have not been examined for radiolaria due to their rarity.

FORAMINIFERA

1) Lenticulina ectypa
Definition. The FDAO of Lenticulina ectypa (Loeblich & Tappan) and Eponina zelligera (Reuss).
Age. Late to mid Oxfordian.

2) Halophragmatus pokrovkaensis
Remarks. The FDO of Lenticulina tricarinella (Reuss) occurs at this biomarker.

3) Ammodiscus yonissnabensis
Remarks. The FDO of the nominate species may be younger in the Southern North Sea than in the Central and Northern North Sea. Onshore, in Yorkshire, its extinction occurs within the early laeviuscula Zone (Nagy et al. 1983).

4) Sparse, small agglutinated foraminifera
Definition. The FDAO of sparse, low-diversity faunas dominated by small agglutinated representatives of the Textulariina. Age. Early Aalenian.

5) Verneuilinoides subtrivius
Remarks. The FDO of the nominate species probably occurs at the Aalenian/Toarcian boundary.

6) Marginulina prima
Definition. The FDAO of Marginulina prima d'Orbigny and Saracenaria sublaevius (Franke).
Age. Earliest Teucarian/earliest falceratum to latest tenusconsulatum Zones).
Remarks. This biomarker is accompanied by a downhole increase in foraminiferal diversity and, in some sections, 'floods' of Reinehodella madayi (Ten Dam).
8) Vaginalinopsis denticulataturcica
Definition. The FDO of Vaginalinopsis denticulataturcica (Franke). Age. Early Pliensbachian (davoei Zone).
Remarks. The accompanying fauna includes the FDO of common Lingulina tenora tenuissimata (Norvang).
9) Lingulina tenora tenuissimata
Definition. The FDO of Lingulina tenora tenuissimata (Franke). Age. Earliest Early Pliensbachian (lamoei Zone).
Remarks. The FDO of common Lingulina tenora tenuissimata (Norvang) also occurs at this biomarker.
10) Dentalina matutina acme
Definition. The FDAO of Dentalina matutina d'Obrigryn. Age. Late Sinemurian (racicostatum Zone).
Remarks. Trochammina cf. grziy Tappan (= Trochammina nana forma a of Bartenstein & Brand 1957; = Trochammina sp. 1 of Copestake & Johnson 1989) is also a useful indicator of this biomarker. The FDO of common Asstacolus speciosus (Terquem) coincides with this biomarker in some sections.
11) Lenticulina semiventiculata
Definition. The FDO of Lenticulina semiventiculata Fuchs and/or Reinholdella margarita (Terquem). Age. Early Sinemurian (basal obovnau or latest turnus Zones).
Remarks. In the Southern North Sea, the FDO of R. margarita lies close to the early/late Sinemurian junction (Copestake & Johnson, 1989). It occurs with common Vaginalina listi (Bormann) and Dentalina matutina. Below this biomarker there is a gradual downhole reduction in faunal richness.
12) Involutina laissaica acme
Definition. The FDAO of Involutina laissaica (Jones). Age. Earliest Early Pliensbachian (bucklandi Zone).
Remarks. Although long ranging, I. laissaica occurs in abundance in the Southern North Sea and onshore at approximately the bucklandi/semitesticostum boundary.
13) Lingulina tenora substrata
Definition. The FDO of Lingulina tenora substrata (Norvang). Age. Late Hettangian (angulata Zone).
Remarks. The nominate species has its FDO at or immediately below the Hettangian/Sinemurian boundary.
14) Reinholdella planconvexa
Definition. The FDAO of Reinholdella planconvexa (Fuchs). Age. Hettangian (laissaica Zone).
Remarks. The range of abundant R. planconvexa is restricted to the laissaica Zone.
15) Lingulina tenora colinotii
Definition. The FDAO of Lingulina tenora colinotii (Terquem). Age. Hettangian (planorbis Zone).

OSTRACODS
1) Galliaucytheridea compresca
Definition. The FDO of Galliaucytheridea compresca Christensen & Kilenyi. Age. Mid Volgian (angliqueformis Zone).
Remarks. In the Dutch Central Graben G. compresca and G. spinosa Kilenyi occur together (Herngreen & Wong 1989). However, in Britain, these two species are mutually exclusive (Kilenyi 1969; Christensen & Kilenyi 1970). Whereas this biomarker has not yet been recorded in the UK Sector of the Southern North Sea, it can be recognized in adjacent areas.
2) Galliaucytheridea polita
Definition. The FDO of Galliaucytheridea polita Kilenyi. Age. Mid Volgian (fittoni Zone).
Remarks. A rare species that has been recorded from Dorset (where it is a zonal index) and the Southern North Sea, including the Dutch sector (Herngreen & Wong 1989).
3) Galliaucytheridea spinosa
Definition. The FDOs of Galliaucytheridea spinosa, Schuleridea moderata Christensen & Kilenyi and Mandelstamia (Neromandelstamia) tumida Christensen & Kilenyi. Age. Mid Volgian (earliest rotunda Zone).
Remarks. The nominate species is not always common; S. moderata and M. (K.) tumida may be more numerous.
4) Eucytheropteron aquitanum
Definition. The FDO of Eucytheropteron aquitanum (Donze). Age. Early Volgian (earliest batonii Zone).
Remarks. The FDO of Macrodetinita (Polydentinita) woonensis Wilkinson and the FDO of consistent Paranoocythere (Unicosta) pusculata (Kilenyi) are coincident with the biomarker in some sections.
5) Galliaucytheridea elongata
Remarks. The FDOs of Macrodetinita (Polydentinita) steighausi (Klingler), Schuleridea triebeli (Steighaus) and Paranoocythere (Unicosta) extendae Bussiurini coincide with this biomarker. The FDO of Exophtalmoocythere hejraeggerensis Steighaus occurs at or near the biomarker, but the taxon is generally rare.
6) Galliaucytheridea manedstami kilenyi
7) Galliaucytheridea dorostoris/Micromocythere edmundi
Definition. The FDO of both Galliaucytheridea kivinosa Christensen & Kilenyi and Micromocythere edmundi Wilkinson. Age. Kimmeridgian (early mutabilis Zone).
8) Galliaucytheridea dissimilis
Remarks. The FDO of the nominate species in the Southern North Sea is often accompanied by increased diversity. This biomarker is apparently present in the Dutch Central Graben (Herngreen & Wong 1989).
9) Macrodetinita pulchra gallica
Definition. The FDO of Macrodetinita pulchra gallica Glashoff. Age. Early Kimmeridgian (earliest bayiei Zone).
Remarks. The nominate species may be accompanied by the FDO of Erignaea elanowae Wilkinson, which occurs in abundance close to the lower stage boundary in some areas of the Southern North Sea.
10) Galliaucytheridea punctata acme / Vernoniella sequana
Definition. The FDAO of Galliaucytheridea punctata Kilenyi together with the FDO of Vernoniella sequana Oertli. Age. Latest Oxfordian (rosenkrantzii Zone).
11) Galliaucytheridea "praedissimilis"
Definition. The FDO of several informally named species of Galliaucytheridea including G. "praedissimilis" Herngreen & Wong. Age. Early Oxfordian (cordatum Zone).
Remarks. The nominate species is accompanied by the FDO of G. "praepostsinuata" and G. "incurvata" of Herngreen & Wong (1989) and Herngreen et al. (1991).
12) Micropneumatocythere/Glyptocythere spp.
Definition. The FDO of the genera Micropneumatocythere and Glyptocythere. Age. Late Bathonian (discus Zone).
Remarks. In some sections, the FDO of Mid Jurassic freshwater ostracods occur at this biomarker.
13) Praeschuleridea decorata
Definition. The FDO of Praeschuleridea decorata Bate. Age. Early Bajocian (serviaevola Zone).
14) Kinkelinella sermoisensis
Remarks. The FDO of Kinkelinella intregida Bate & Coleman is at this biomarker.
15) Omoconchus/Omoconchella spp.
Definition. The FDO of Omoconchus/Omoconchella spp. Age. Late Pliensbachian (spinatum Zone).
16) Wichmannella semiora
Definition. The FDO of Wichmannella semiora Lord. Age. Late Pliensbachian (marginatus Zone).
17) Gammacuycythere abiquita
18) Kinkelinella triebeli
Definition. The FDO of Kinkelinella triebeli (Klingler & Neuweiler). Age. Late Sinemurian (obtusum Zone).
19) Omoconchus hagenowi
Definition. The FDO of Omoconchus hagenowi Drexler. Age. Early Sinemurian (turned Zone).
20) Omoconchella aspinita
Definition. The FDO of Omoconchella aspinita (Drexler). Age. Early Sinemurian (semitesticostum Zone).
Figure A3. Jurassic and earliest Cretaceous biomarkers for the UK Southern North Sea.

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<th>CHRONOSTRATIGRAPHY</th>
<th>STANDARD BOREAL (AMMONITE) ZONES</th>
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Biomarkers - Assumed to be present by extrapolation from Central North Sea and Dutch Southern North Sea but not proved in UK Southern North Sea.
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