



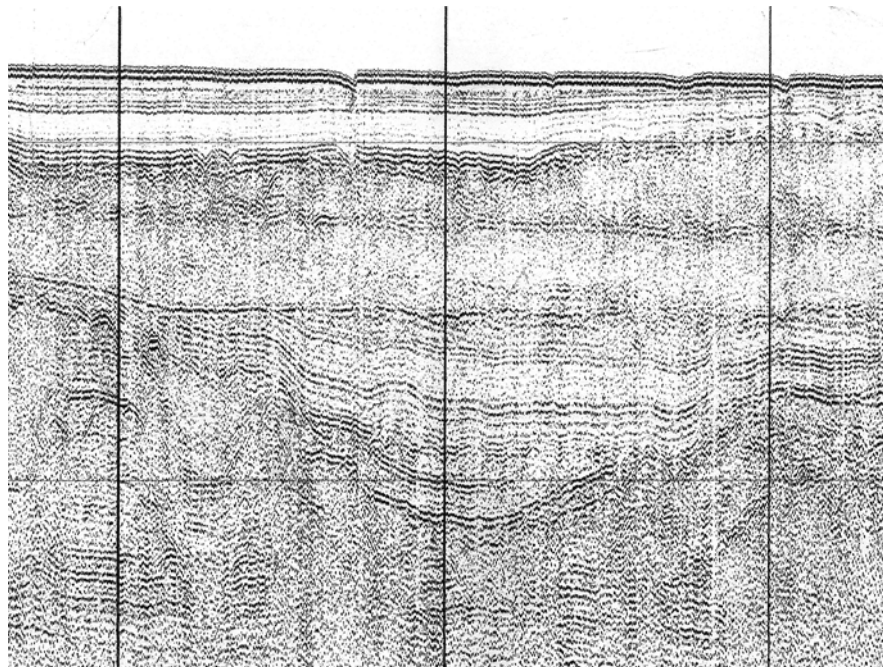
**British
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NATURAL ENVIRONMENT RESEARCH COUNCIL

An overview of the lithostratigraphical framework for the Quaternary deposits on the United Kingdom continental shelf

Marine Geoscience Programme

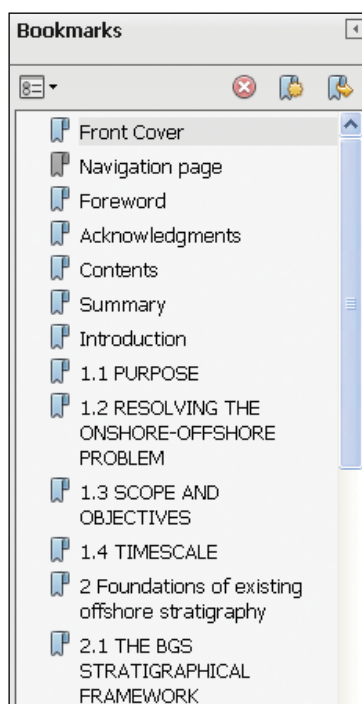
Research Report RR/11/03



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BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCE PROGRAMME

RESEARCH REPORT RR/11/03

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Front cover

Seismic cross section of the Witch Ground Basin, central North Sea (BGS 81/04-11); showing flat-lying marine sediments of the Zulu Group incised and overlain by stacked glacial deposits of the Reaper Glacigenic Group.

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An overview of the lithostratigraphical framework for the Quaternary deposits on the United Kingdom continental shelf

M S Stoker, P S Balson, D Long and D R Tappin

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Foreword

This report is the result of a study by the British Geological Survey to rationalise the Quaternary stratigraphy of the United Kingdom continental shelf (UKCS). The report presents a new, unified, lithostratigraphical framework that is applicable to the entire UKCS. Whereas formations represent the principal mapping units, it is the delineation and definition of a series of groups in this report that provide the basis for regional correlation. This hierarchy provides a first-order correlation with the Quaternary deposits of onshore Great Britain, which is a crucial step towards a better understanding of landscape evolution in Britain and Ireland, and the North Sea region in general. Understanding the ground conditions remains paramount to the development and safety of other sectors of the offshore industry, and it is intended that this stratigraphical scheme will have use in a variety of applications. Thus, the aim of this work is to produce a stratigraphical nomenclature that will have the widest acceptance within the scientific community and industry.

John Ludden
Executive Director
British Geological Survey

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- M S Stoker: Summary and chapters 1–3, 5 and 6;
Atlantic margin scheme in Chapter 4;
Appendices 1 and 2; overall report
compilation
- P S Balson: Southern North Sea scheme in Chapter 4
- D Long: Central and Northern North Sea scheme
in Chapter 4
- D R Tappin: English Channel–South-west Approaches
and Celtic Sea–Irish Sea schemes in
Chapter 4

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Summary

This stratigraphical framework report presents a lithostratigraphical scheme for the Quaternary succession on the United Kingdom continental shelf (UKCS). The emphasis has been placed on the delineation and definition of a series of lithostratigraphical groups that provide the basis for first-order correlation between Quaternary deposits, both offshore and onshore. The proposed scheme is based on information derived from the extensive marine dataset acquired by the British Geological Survey (BGS) since the late 1960s, and published as a series of offshore maps and regional reports.

The first part of the report (Chapter 1) introduces the project and in particular focuses upon the fundamental differences between onshore and offshore stratigraphical approaches. Resolving this problem is fundamental to creating a unified stratigraphical scheme that is applicable to both domains. The timescale that we use defines the base of the Quaternary System/Period and the Pleistocene Series/Epoch at 2.58 Ma, as formally ratified by the International Union of Geological Sciences (IUGS) (Gibbard et al., 2010).

This is followed in Chapter 2 by a brief description of the methodology that underpins the existing offshore stratigraphy. Although this scheme has been constructed largely on the basis of seismic stratigraphy, information on the nature and age of the stratigraphical units is provided by a wealth of borehole and short core data. Consequently, the offshore scheme is best described as a hybrid of seismic, litho- and biostratigraphy.

Chapter 3 outlines the principles behind the new proposed lithostratigraphical scheme. Although the scheme is not wholly lithostratigraphical in nature, the hierarchy of lithostratigraphical nomenclature is adopted as the most practical terminology for describing a succession that is mappable at several levels, is divided by distinctive regional bounding surfaces, and displays significant lithological variation. By adopting a lithostratigraphical nomenclature

we retain consistency with a recently published BGS onshore lithostratigraphical framework, thereby promoting an integrated land–sea approach to Quaternary correlation.

A brief description of the new lithostratigraphical scheme is presented in Chapter 4, with emphasis at the group level. We define twelve groups from the Atlantic margin, North Sea and Celtic Sea–Irish Sea region that represent regional subdivision into predominantly non-glacial Lower–Middle Pleistocene, and glacially-dominated Middle Pleistocene–Holocene units. The proposed defining formations from each group are presented in a series of accompanying tables. Some of the larger estuaries (e.g. Moray Firth) and the English Channel–South-west Approaches region remain undivided at the present time.

A comparison of the UKCS lithostratigraphical scheme with those in adjacent international sectors is presented in Chapter 5, with specific focus on the Dutch and Norwegian sectors. A major concern across the international boundaries is that the lithostratigraphical hierarchy of equivalent units varies between countries.

Chapter 6 presents some recommendations for further work in order that the stratigraphical scheme be fully utilised by the scientific community and industry. This includes: 1) complete revision, update and population of the offshore entries in the BGS Stratigraphical Lexicon of Named Rock Units; 2) the production of a full framework report that details all aspects of the offshore Quaternary succession (groups, formations, members, etc); 3) a review of areas where the Quaternary stratigraphy is ambiguous or poorly defined; 4) the development of a single onshore–offshore classification scheme that can be captured seamlessly within the BGS Geological Spatial Database (GSD); and 5) the development of a unified North-west European Quaternary stratigraphical scheme. It is concluded that tasks 1 and 4 are essential corporate issues that underpin the entire BGS superficial deposits framework.

1 Introduction

1.1 PURPOSE

The purpose of this report is to set down a provisional basis for a standard lithostratigraphical framework and nomenclature for Quaternary deposits of the United Kingdom (UK) continental shelf. Existing seismic-stratigraphical work offshore the UK (Chapter 2) has identified a series of units that are bounded by unconformity surfaces or their correlative conformities that are commonly of regional extent. Extensive borehole data have provided lithological, bio- and magnetostratigraphical information that helps to define the attributes of these units, which are thus not defined solely on the nature of their bounding surfaces nor their acoustic character. Although the proposed scheme is not wholly lithostratigraphical in nature, the hierarchy of lithostratigraphical nomenclature is adopted as the most practicable terminology for describing a succession that is mappable at several levels, is divided by distinctive regional bounding surfaces, and displays significant lithological variation. It also retains consistency with the recently published Quaternary onshore lithostratigraphical framework (McMillan et al., 2005, 2011), thereby promoting an integrated land-to-sea approach to understanding the Quaternary evolution of the UK landmass and its adjacent continental shelf.

The lithostratigraphical nomenclature is based on international guidelines as published by the International Union of Geosciences (Murphy and Salvador, 1999; Salvador, 1994) and the Stratigraphy Commission of the Geological Society of London (Rawson et al., 2002). The report demonstrates how the lithostratigraphical scheme has been applied to the Quaternary deposits around the UK (Chapter 3). It will especially highlight two scales of mappable unit: relatively localised units are defined by formations, whereas the stratigraphy on the largest spatial and temporal scale, for example, basin infill or margin-wide sediment wedges, is defined at group level. An overview of the new lithostratigraphical nomenclature describes the groups with examples of their defining formations (Chapter 4).

The area addressed by this scheme includes the Atlantic margin off north-west Britain, the North Sea Basin, the English Channel and south-west approaches, and the Celtic Sea–Irish Sea region. This domain extends from the coastline onto the continental shelf as far as the median line that separates the UK and adjacent territories. This area is commonly defined as the UK continental shelf (UKCS). Along the Atlantic margin, the scheme extends beyond the shelf-edge onto the adjacent continental slope and into the deep-water basins (Figure 1). Information used in this report is derived from the extensive regional marine dataset acquired by the BGS since the late 1960s, and published in the 1:250 000 series Quaternary maps and the UK Offshore Regional Reports (Appendix 1).

1.2 RESOLVING THE ONSHORE–OFFSHORE PROBLEM

Stratigraphical schemes for Quaternary sediments onshore Great Britain have traditionally been separated from

those established offshore. This is unsurprising given the different methodologies and techniques employed onshore and offshore. Moreover, the difference in the scale of mapping is considerable; for example, onshore terrains mapped generally at 1:10 000 scale contrast markedly with basin-wide continuity of offshore sequences mapped at 1:250 000 scale. Whereas lithogenetic units defined by lithology, morphology and genesis underpin the onshore stratigraphical framework, acoustic methods of remote sensing form the basis of mapping offshore deposits. Despite these differences, an increased understanding of the dynamics of the British–Irish ice-sheet and its control on the spatial distribution of sediment packages has led to increasing awareness that it is possible to consider onshore–offshore correlation at some level determined by a comparable mappable unit.

Onshore, a lithostratigraphical scheme has recently been developed for Neogene and Quaternary deposits (McMillan, 2005; McMillan and Hamblin, 2000; McMillan et al., 2005, 2011) in a bid to correlate what has traditionally been the poorly exposed and fragmented, predominantly terrestrial record of superficial sediments throughout Great Britain (Bowen, 1999; Mitchell et al., 1973). Although many of these terrestrial deposits have commonly been assigned formation status, on the basis of being a mappable unit, the proliferation of localised formations and constituent members has hindered regional correlation by being ‘not amenable to systematic and widespread mapping away from their stratotypes’ (Bowen, 1999). This problem has been addressed by McMillan et al. (2005, 2011) and McMillan (2005) who have employed a ‘top-down’ approach that retains the use of formation as the basic mappable unit, but links them to a series of lithologically-, geographically- and provenance-defined groups and subgroups. Otherwise unassigned lithogenetically-defined units are also captured within this scheme at the group and subgroup level, which therefore gives a regional mapping structure for all onshore superficial deposits.

Offshore, a regional Plio-Pleistocene stratigraphical framework became established by the early 1990s as part of the BGS 1:250 000 scale mapping programme of the UKCS. This stratigraphical framework is constructed primarily on the basis of seismic stratigraphy. In contrast to the onshore, the UKCS and adjacent deep-water areas have been depocentres for Upper Neogene and Quaternary sediments. Through repeated cycles of erosion and deposition, Quaternary sediments in excess of 800 m thick have accumulated in the North Sea and along the Atlantic margin. Despite local complexity in sedimentary architecture, a shelf-wide series of units has been mapped and mostly designated with informal formation or sequence status. In the North Sea and along the Atlantic margin, regional mapping has shown that the component seismic sequences that comprise the Quaternary succession can be broadly divided into two, separated by a widespread Mid Pleistocene glacial erosion surface that has been dated on the Hebrides Slope at about 0.44 Ma (Stoker et al., 1994) (Figure 2). The units above this erosion surface were largely deposited by continental-scale glaciations (Cameron et al., 1987; Sejrup et al., 2005; Stoker et al., 1994).

Biostratigraphical and palaeomagnetic data supplemented by various dating techniques (see section 2.1) have provided information that has enabled these units to be placed within a chronostratigraphical context.

Recent reconstructions of the northern sector of the British ice-sheet (e.g. Bradwell et al., 2008a, b; Graham et al., 2007), and its interaction with the Fennoscandian ice sheet, have unequivocally confirmed the shelf-wide extent of the ice cover across the UKCS at times of glacial maximum. Thus, glacial and glaciofluvial facies, which dominate the current onshore areas, also occur on the UKCS. Although coastal and marine deposits are most prevalent in the current offshore area, isostatic rebound and uplift of certain parts of the UK landmass has preserved such deposits locally around the periphery of the mainland. Geomorphological continuity of glacial landforms, such as moraines and megascale lineations, across the present-day coastline has also been demonstrated (Bradwell et al. 2008a, b; Stoker and Bradwell, 2005). Thus, a morpho-litho-genetic linkage between present-day onshore and offshore units, implicit in such a reconstruction, should be utilised as much as possible in any future offshore classification and correlation.

1.3 SCOPE AND OBJECTIVES

This report is intended to advise on the formulation of a hierarchical scheme for the classification of Quaternary sediments on the UKCS and in the surrounding deep-water basins. Specifically, we focus on the following:

- a brief description of the methodology that underpins the existing offshore stratigraphy
- the principles behind the new proposed lithostratigraphical scheme
- a brief description of the new lithostratigraphical scheme at group level.

The proposed scheme is intended to be comparable to that recently erected for onshore Great Britain (McMillan et al., 2005, 2011), in order to facilitate integrated onshore–offshore correlation. It is hoped that a more expanded lithostratigraphical framework, detailing all of the current offshore units, will be developed as a result of this preliminary revision.

1.4 TIMESCALE

The timescale used in this study is that recently ratified by the Executive Committee of the IUGS, which defines

the base of the Quaternary at 2.58 Ma (Gibbard et al., 2010). This places the Gelasian Stage (formerly a Late Pliocene stage) within the Early Pleistocene (Figure 3). The implications of this change for the offshore record are summarised below.

1.4.1 North Sea

In the North Sea Basin, the Pliocene–Pleistocene boundary has traditionally been placed at the beginning of the Praetiglian Stage (Figure 4), which marks the onset of climatic deterioration within Dutch sequences (Gibbard et al., 1991; Zagwijn, 1989). Although a date of about 2.3 Ma was commonly cited for this change, the base of the Praetiglian Stage has more recently been revised to about 2.6 Ma (Gibbard et al., 2004; Rio et al., 1998).

In the central North Sea, the Pliocene–Pleistocene boundary is biostratigraphically defined in commercial wells by the last common occurrence of the foraminifera *Cibicides grossa* Ten Dam and Reinold (cf. Knudsen and Asbjörndóttir, 1991). On seismic profiles, this may correspond to a ‘crenulate reflector’ (Holmes, 1977) that is possibly linked to a widespread erosional event (Gatliff et al., 1994). In the southern North Sea, the Pliocene–Pleistocene boundary corresponds to an angular unconformity that is traceable across the basin (Balson and Cameron, 1985; Figure 2c), and is exposed in East Anglia as a marine planation surface (West, 1980).

1.4.2 Atlantic margin

The formally defined Pliocene–Pleistocene boundary at about 1.6 Ma (Aguirre and Pasini, 1985) has commonly been used on the Atlantic margin, though there are indications of enhanced climatic deterioration since about 2.5 Ma, with the onset of ice rafting west of Britain (Shackleton et al., 1984; Stoker et al., 1993, 1994). On this basis, the large, shelf-margin, prograding sediment wedges have previously been assigned a Plio-Pleistocene age, dating from the late Early Pliocene (about 4 Ma), though the bulk of the sediment forming the wedges is younger than about 2.5 Ma (Stoker, 2002; Stoker et al., 2005). Under the revised scheme, the prograding sediment wedges are predominantly of Quaternary age, though their instigation might still extend into the Early Pliocene.

2 Foundations of existing offshore stratigraphy

2.1 THE BGS STRATIGRAPHICAL FRAMEWORK

The BGS offshore regional reconnaissance mapping programme has resulted in total coverage of the UKCS at a scale of 1:250 000, illustrating the Quaternary geology. The maps and accompanying offshore regional reports (Appendix 1) describe the characteristics of the component stratigraphical units as defined in the mid 1990s. A summary of the offshore scheme, excluding the Hebrides region, was presented in an informal lithostratigraphical framework by Cameron and Holmes (1999) as part of the Geological Society Special Report on Quaternary deposits in the British Isles (Bowen, 1999).

The regional mapping proved that the Quaternary succession locally exceeds 800 m in thickness along the axis of the North Sea Basin, and within the slope apron of the Atlantic continental margin (Cameron et al., 1987; Caston, 1977; Holmes et al., 1993). In these areas, a record of Early Pleistocene to Holocene sedimentation is preserved (Cameron et al., 1987; Stoker et al., 1983, 1994). Over most of the UKCS, however, the Quaternary succession is generally less than 200 m thick and consists mostly of sediments of Mid Pleistocene and younger age that rest unconformably on pre-Neogene strata. Around the UK coastline, and up to 100 km offshore, Quaternary deposits are mostly less than 50 m thick and are locally represented only as a veneer on bedrock (e.g. north and west of Scotland, English Channel), indicative of the predominantly erosional nature of the coastal and inner shelf regions.

Over ninety stratigraphical units, equivalent to formation rank, have thus far been identified by BGS mapping of the Quaternary succession on the UKCS (Appendix 2). This subdivision has been achieved by the detailed interpretation of grids of high-resolution seismic profiles (totalling some 200 000 line kilometres) from which a seismic stratigraphy was erected, employing techniques outlined by Mitchum et al. (1977) and Vail (1987). Individual seismic-stratigraphical units were defined on the basis of reflection termination patterns (e.g. onlap, downlap, truncation) together with reflection configuration (e.g. stratified, chaotic) and external geometry. The interpretation was supplemented by lithological data from thousands of shallow (<6 m) cores, and over 550 boreholes that were continuously cored for up to 235 m below the sea bed.

Most short cores did not penetrate sediments older than late Devensian; in contrast, the boreholes were generally sited to investigate and test the deeper levels of the Quaternary succession. In combination, the shallow and deeper core database provides lithological information for the entire Pleistocene to Holocene stratigraphical range. Consequently, for most of the UKCS a lithostratigraphical terminology was applied to the seismic stratigraphical units, predominantly at formation level but with component members where applicable. However, application of this nomenclature remains largely informal with only about 50 per cent of the stratigraphical units currently logged within the BGS Lexicon, and even these entries are currently classified only with a 'partial entry' status. Although these entries currently have a Lex Code (Lexicon Code), on inspection of the full record it is clear that the entries

are incomplete, and in places the reference information is incorrect. In contrast, most of the Quaternary succession on the Atlantic margin — the Hebrides and West Shetland regions — remains wholly informal. With the exception of a few units defined in the Sea of the Hebrides area, this succession was divided using the term 'sequence' (but not to be confused with sequence stratigraphy) as the main mappable unit, albeit essentially equivalent in status to the formation as defined on other parts of the UKCS. To further complicate matters, the terms 'supersequence' and 'subsequence' were used on several of the 1:250 000 scale maps, though these were largely discarded in a general overview of the Atlantic margin succession (Stoker et al., 1993). The sequence nomenclature has not been submitted to the BGS Lexicon.

The boundaries of many of the seismic-stratigraphical units have been mapped for hundreds of kilometres. Across most of the UKCS, the boundaries separating Middle and Upper Pleistocene units are unconformities formed largely by glacial processes. These include distinctive and highly irregular channelised boundaries, that represent tunnel valley systems formed by subglacial drainage (Loneragan et al., 2006; Praeg, 2003). In the southern North Sea, boundaries between Lower Pleistocene formations that comprise the (Miocene to Mid Pleistocene) Eridanos fluviodeltaic system are sequence boundaries, in that they represent intervals of hiatus during which there was significant basinward shift of coastal onlap (Cameron et al., 1993; Overeem et al., 2001).

Information on the age of the stratigraphical units has been mainly based on biostratigraphy, with specific focus on dinoflagellate cysts, benthonic and planktonic foraminifera and calcareous nannoplankton. These data have also aided analyses of climatic and oceanographical change during the Quaternary interval. Additional age data have also been derived from magnetic polarity studies, amino-acid geochronology (D-¹¹e/L-¹¹e), U-series or radiocarbon dating, or by tephrochronology. Results of the biostratigraphy confirm that Middle and Upper Pleistocene sediments were mainly deposited under arctic conditions, the culmination of a gradual climatic deterioration through the Early Pleistocene, since about 2.48 Ma (the onset of ice-rafting off north-west Britain: Shackleton et al., 1984; Stoker et al., 1994). Middle and Upper Pleistocene interglacial deposits are poorly preserved offshore, with rare occurrences patchily preserved beyond the limits of subsequent ice-sheets, or as thin layers within the composite fill of tunnel valleys eroded during the previous glaciation (Long and Stoker, 1986).

Direct correlation between the terrestrial and continental shelf record of glaciation with that of the deep-ocean oxygen isotope sequence has traditionally been difficult, due largely to the inherent problem of dating continental successions that are repeatedly subject to glacial erosion and fluctuating sea levels. However, a recent study by Toucanne et al. (2009) of a sediment core from the Bay of Biscay has linked sediment discharge from the Fleuve Manche palaeoriver, which drained the West European Atlantic margin through the English Channel, to the expansion and recession of the European ice-sheets. This study has demonstrated, for the first time, a direct correlation between

the European chronostratigraphical record and the marine isotope stratigraphy for the last 1.2 Ma. On this basis, it is now possible to begin to link, with increasing confidence, the well-dated parts of the offshore stratigraphy of the UKCS with the Marine Isotope Stages (MIS), though it is stressed that in poorly dated units such correlation remains broad and largely inferred, albeit constrained within the overall scheme.

2.2 THE UKOOA LITHOSTRATIGRAPHY

The United Kingdom Offshore Operators Association (UKOOA) has published a series of Cenozoic lithostratigraphical atlases for the North Sea Basin (Knox and Holloway, 1992; Lott and Knox, 1994), which built upon a preliminary scheme developed by Deegan and Scull (1977). In these schemes, all Quaternary deposits are incorporated within a single lithostratigraphical unit known as the Nordland Group. By definition, this group incorporates all sediments deposited between the Mid Miocene and Holocene. This rather broad assignment of the bulk of the Neogene–Quaternary record to a single group largely reflects the lack of detailed analysis of this part of the stratigraphical record by the hydrocarbon industry.

This group nomenclature was subsequently applied to the West Shetland margin (Knox et al., 1997), albeit more as a chronostratigraphical rather than a lithostratigraphical assignment.

Stoker (1999) divided the Nordland Group on the West Shetland margin into three informal units: upper, middle and lower Nordland units. The middle and upper units were correlated with Pliocene–Middle Pleistocene and Middle Pleistocene–Holocene sequences, respectively, which are separated by a shelf-wide glacial unconformity. These units and their component sequences comprise the prograding sediment wedge on the West Shetland margin.

Recent work in the Rockall–Hebrides region led Stoker et al. (2007) to propose that the status of the Neogene–Quaternary succession along the Atlantic margin be revised, with the development of a new lithostratigraphical scheme for the upper Cenozoic succession to replace the somewhat generalised UKOOA framework. Stoker et al. (2007) proposed a new group nomenclature for the Cenozoic of the Rockall–Hebrides region, which included the prograding sediment wedge on the Hebrides margin being assigned to a single lithostratigraphical group (the Eilean Siar Group). This study proposes further revision and refinement to this scheme that takes into account the significant lithological change across the Mid Pleistocene glacial unconformity.

3 Principles and definitions

3.1 THE LITHOSTRATIGRAPHICAL NOMENCLATURE AND ITS APPLICATION

The hierarchy of internationally accepted lithostratigraphical units referred to in this report is set out by Salvador (1994), and summarised by Murphy and Salvador (1999) and Rawson et al. (2002). The unit terms (sections 3.1.2–3.1.7) are described in order of rank. Comparison with the recently established framework for onshore Quaternary deposits in Great Britain (McMillan et al., 2005, 2011) is made where appropriate.

3.1.1 Naming of lithostratigraphical units

To ensure continuity, it is intended to retain the existing descriptive component of the offshore nomenclature whenever possible, albeit combined with the appropriate lithostratigraphical unit term (e.g. formation, member). Geographical terms based both on area and bathymetric feature have been used as much as possible on the UKCS, though large areas of flat-lying shelf are commonly devoid of such markers. Consequently, other features such as Scottish clan names, Scottish female names and the names of survey vessels used by the BGS have also become a part of the existing nomenclature. In terms of new and ongoing work, including group definition in this report, and work in the coastal zone (e.g. the Scottish fjords), it is recommended that geographical or other locally relevant epithets be used wherever possible. In coastal regions, where onshore–offshore continuity can be demonstrated, a single name should be applied to the unit, e.g. Loch Broom Till Formation in the Summer Isles region (Stoker et al., 2009).

During the production of this report, it has become apparent that several Quaternary formations have the same name as existing UKOOA lithostratigraphical units that have been established for Mesozoic and older rocks (cf. Tables 1–9). In these cases, the Quaternary nomenclature will be revised accordingly during formalisation of the lithostratigraphical scheme.

3.1.2 Supergroup

3.1.2.1 DEFINITION

A supergroup may be used for several associated groups or for associated formations and groups with significant lithological properties in common (Salvador, 1994).

3.1.2.2 APPLICATION

It has been proposed that the onshore Quaternary and Neogene natural superficial deposits comprise a single supergroup — the Great Britain Superficial Deposits Supergroup (McMillan et al., 2005, 2011; Figure 4). No equivalent unit is considered at this time for the offshore succession.

3.1.3 Group

3.1.3.1 DEFINITION

A group is the formal lithostratigraphical unit next in rank above a formation, and is applied to a sequence of contiguous formations with significant and diagnostic lithological properties in common (Salvador, 1994).

3.1.3.2 APPLICATION

It is proposed to establish groups of Quaternary formations on the UKCS that reflect the widespread and significant change from Early to early Mid Pleistocene (pre-Anglian) fluvial, deltaic and shallow marine facies, with restricted glaciation, to Mid to Late Pleistocene (Anglian and younger) continental-scale glaciation that covered much of the continental shelf. Glacigenic facies dominate the Middle–Upper Pleistocene section, with subordinate, interbedded, marine interglacial deposits. On seismic reflection profiles, deltaic and glacial deposits commonly display distinctive geometries and internal reflector patterns, which may constitute a form of unity for sediment bodies with similar gross depositional characteristics. To highlight this distinction, at the group level, the proposed Quaternary lithostratigraphical framework utilises a genetic epithet (e.g. deltaic, glacigenic) albeit recognising that genesis is inferred away from borehole locations. This follows a protocol established for the onshore Quaternary groups (McMillan et al., 2005, 2011).

On this basis, the defining formations can be classified within twelve major groups (Figure 4). These groups represent the major mappable units at the basin or shelf scale. Group boundaries are defined on the basis of several criteria, including: 1) physical separation; 2) lateral lithological gradation; and, 3) source region. It should be noted that in the border region between the southern and central North Sea, stratigraphical relationships between the Lower Pleistocene deltaic (south) and prodeltaic (central) deposits, and the continuity of the Middle–Upper Pleistocene glacigenic deposits across the Dogger Bank remain to be fully defined; thus at the present time, the existing nomenclature is retained in separate groups. In the northern North Sea–West Shetland region, several formations extend laterally between groups. The onshore glacigenic scheme is divided into pre-Ipswichian (Albion Group) and Ipswichian and later (Caledonia Group) groups (Figure 4). Whilst it is not considered possible at present to apply a similar subdivision regionally for the offshore region, it should be considered during any future detailed work.

3.1.4 Subgroup

3.1.4.1 DEFINITION

Although not in the formal hierarchy, there may be certain instances when a group may be divided into subgroups (Salvador, 1994; Rawson et al., 2002).

3.1.4.2 APPLICATION

The onshore Quaternary succession includes a series of catchment and glacigenic subgroups that enable better definition of lithological characteristics and geographical extent of component formations (McMillan et al., 2005, 2011). This domainal approach provides a means of defining the provenance of major river systems or ice streams. The validity of this application offshore remains to be assessed, in that farther away from the source region of the river or glacier the more the likelihood of increased mixing between different systems. For example, discrete valley glaciers

close to source are likely to lose their individual signature once they merge with other glaciers on the continental shelf to form larger ice-sheets. Nevertheless, it may be possible to extend some of the onshore glacial subgroups relating to an identified ice stream into the coastal/inner shelf region. This concept remains to be discussed and assessed as the offshore framework develops.

3.1.5 Formation

3.1.5.1 DEFINITION

The formation is the primary unit of lithostratigraphy, and is generally regarded as the smallest mappable unit (Rawson et al., 2002; Salvador, 1994). It has lithological characteristics that distinguish it from adjacent formations, and is defined by a type section or a type area, which includes a recognisable top and base to the section.

3.1.5.2 APPLICATION

In common with the onshore Quaternary succession, the formation forms the basic building block of the offshore scheme for both nonglacigenic and glacial deposits. Over ninety stratigraphical units equivalent to formation status have previously been defined for the UKCS on the basis of the above definition. This includes those units on the Atlantic margin that were informally termed sequences. On seismic profiles, many of these units are mappable over tens to hundreds of square kilometres. This level of stratigraphical subdivision is the basis for onshore–offshore correlation.

3.1.6 Member

3.1.6.1 DEFINITION

A member is the formal lithostratigraphical unit next in rank below a formation, and is always part of a formation (Salvador, 1994). However, formations are not necessarily divided wholly or partially into members (Rawson et al., 2002).

3.1.6.2 APPLICATION

Members have been defined in the offshore UKCS on the basis of seismic character as well as lithological distinction. They generally have relatively local expression.

3.1.7 Bed

3.1.7.1 DEFINITION

A bed is the smallest formal unit in the lithostratigraphical hierarchy (Salvador, 1994). Bed names and status are commonly applied to distinctive units that may be thin and reflect some specific geochronological or lithological significance.

3.1.7.2 APPLICATION

The term bed was originally applied in an informal sense to seismic-stratigraphical units in the Forth Approaches area during early attempts to develop an offshore stratigraphy (Holmes, 1977; Thomson and Eden, 1977). However, the rank of these units was subsequently raised to formation status (Stoker et al., 1985a). The correct usage of this term may be more applicable to distinctive occurrences of cobble and boulder layers in units such as the Jura Formation in the Firth of Lorne (Davies et al., 1984).

3.2 THE SEA-BED SEDIMENT LAYER

On the UKCS, the modern sea-bed sediment layer is generally defined as the unconsolidated surficial sediments that cover the sea floor below mean low water mark (MLWM). Generally described as the ‘mobile layer’, its nature, distribution and thickness vary on the basis of bathymetry, tidal currents and storm surges (Owens, 1981; Pantin, 1991). The derivation of the sediment includes coastal and marine erosion as well as fluvial and estuarine input. On some areas of the UKCS, such as the Hebrides and West Shetland shelves and in the English Channel, the sea bed is commonly marked by a lag gravel or sandy veneer. In contrast, parts of the central and southern North Sea include carbonate mud and bedform-moulded sand deposits, a few metres to a few tens of metres thick. On the BGS 1:250 000 series sea-bed sediment maps, the lithology of the sea-bed deposits is based on the Folk (1954) classification, which divides the sediments on the basis of their mud, sand and gravel proportions.

To a large extent, the resultant lithological variation is a culmination of processes that began during deglaciation, continued through the early Holocene transgression, and in places continue to be modified at the present day, though there are areas of the UKCS that have been mostly starved of sediment since the early Holocene. Consequently, the incorporation of the sea-bed sediment layer into the offshore Quaternary framework has been inconsistent in terms of its hierarchical placement, and largely dependent upon its visibility. For example, in the southern North Sea, where significant bedforms are developed, the sea-bed deposits are included within Holocene formations (Cameron et al., 1992). In contrast, in the central North Sea, they are included as members within late Devensian–Holocene formations, whilst in other areas they remain as undivided Holocene deposits.

It should be noted that coastal zone deposits — above MLWM — have not generally been included on the sea-bed sediment maps or within the offshore Quaternary framework. However, there is no reason why land–sea integration of coastal and marine deposits cannot be incorporated into the new scheme.

4 Proposed lithostratigraphical framework

4.1 INTRODUCTION

This chapter outlines the proposed offshore Quaternary lithostratigraphical framework. It distinguishes twelve broad categories at group level (Tables 1–9), ten of which are new. These are listed below on the basis of geographical location; however, the English Channel and its south-west approaches remain unassigned at this level at present.

- Atlantic margin
 - Hebrides Margin and West Shetland Margin groups (mainly Early to Mid Pleistocene (pre-Anglian) shelf-margin progradation; may include Pliocene strata in basal section).
 - Eilean Siar and Hjaltland glacigenic groups (mainly glacigenic deposits; Anglian to Holocene).
- Central and northern North Sea
 - Zulu Group (Early to Mid Pleistocene; pre-Anglian).
 - Reaper Glacigenic Group (mainly glacigenic deposits; Anglian to Holocene).
- Southern North Sea
 - Crag, Southern North Sea Deltaic and Dunwich groups (fluvial, paralic, deltaic and shallow marine deposits, Early to Mid Pleistocene; pre-Anglian).
 - California Glacigenic Group (mainly glacigenic deposits, but with interbedded marine interglacial units; Anglian to Holocene).
- English Channel–south-west approaches (not divided)
- Celtic Sea–Irish Sea
 - Demetae Group (?Mid Pleistocene; pre-Anglian).
 - Brython Glacigenic Group (mainly glacigenic deposits; ?Anglian to Holocene).

The component formations that currently comprise these groups, and their position within the proposed framework, are shown in Tables 1–9. These units have been defined in a range of scientific publications, including published BGS maps and regional reports (Appendices 1 and 2), and Bowen (1999).

The various groups are summarised in the following sections, which are ordered according to geographical region, and bear reference to some of the constituent formations. Their correlation to the onshore groups is illustrated in Figure 4. There is currently a dispute on the timing of onset of widespread onshore UK glaciation, with Cromerian (Hamblin et al., 2005) and Anglian (Preece et al., 2009) stage assignments both proposed. It has recently been demonstrated that mean sediment accumulation rates associated with fluvial discharge from the West European Atlantic margin were at a maximum during the Elsterian/Anglian (MIS 12) glaciation, which has led Toucanne et al. (2009) to conclude that this interval represents the first time that British and European ice-sheets were confluent covering the North Sea Basin. This is consistent with biostratigraphical data from the Hebrides Slope off north-west Britain which also implied an Anglian instigation of shelf-wide glaciation (Stoker et al., 1994).

4.2 ATLANTIC MARGIN

4.2.1 Hebrides Margin Group

The Hebrides Margin Group (Table 1) is established for discrete shelf-margin to deep-water deposits preserved along the eastern flank of the Rockall Basin (Figure 5). On the upper Hebrides Slope, the magneto- and biostratigraphical record in BGS borehole 88/7,7A indicated that the bulk of the prograding shelf-margin succession is probably no older than about 3.15 Ma, and largely of Early to early Mid Pleistocene (≥ 0.44 Ma) age (Stoker et al., 1994). Early Pliocene foraminifera occur in a lag deposit at the base of the shelf-margin succession. In the Rockall Basin, Site 981 of the Ocean Drilling Program (ODP) penetrated the seismically correlative basal surface of the Hebrides Margin Group and proved an intra-Early Pliocene age (about 4 Ma) for the boundary in deep water (Stoker et al., 2001; Stoker, 2002).

At the present time, the group is defined with reference to a single constituent formation, the Lower MacLeod Formation, which consists of debris flow diamictites and interbedded sands and muddy sands on the slope apron, passing into finer-grained contourite and turbidite facies in the Rockall Basin (Stoker et al., 1993, 2005). Whereas the Lower MacLeod Formation is generally regarded to have formed prior to expansive shelf-edge glaciation, the Hebrides Slope deposits preserve a record of ice-rafting dating back to 2.48 Ma (Stoker et al., 1994).

4.2.2 West Shetland Margin Group

The West Shetland Margin Group (Table 1) is established for shelf-margin to deep-water deposits preserved along the eastern margin of the Faroe–Shetland Basin (Figure 5). This nomenclature replaces the previous terminology — the Middle Nordland unit (Stoker, 1999; see section 2.2) — applied to this succession. On the outer part of the West Shetland Shelf, BGS borehole 77/9 proved Lower Pliocene sediments in the basal part of the shelf-margin succession (Stoker, 2002). However, as with the Hebrides Margin Group the bulk of the succession is no older than Late Pliocene, and largely Early to Mid Pleistocene (Stoker, 1999).

The group is defined with reference to three constituent formations: the Faroe–Shetland Channel, Sinclair and Lower Morrison¹ (Table 1). The Faroe–Shetland Channel Formation is currently undivided and spans the Pliocene — Quaternary boundary. The upper part (Anglian and younger) of this formation is included within the overlying Hjaltland Group. The Faroe–Shetland Formation is dominated by deep-water contourite and turbidite facies (Akhurst, 1991; Akhurst et al., 2002; Stoker et al., 1993). The Sinclair Formation consists of deltaic/shallow marine deposits, whereas prodeltaic and mass-flow deposits characterise the Lower Morrison Formation (Cockcroft, 1987; Stoker et al., 1993).

¹ A revised terminology for the Lower Morrison and Faroe–Shetland Channel formations is under consideration.

4.2.3 Eilean Siar Glacigenic Group

The Eilean Siar Glacigenic Group is established for all glacigenic formations preserved on the Hebrides Shelf, including the inner Hebridean region (Figure 6). The name is derived from the Gaelic for Western Isles. The Eilean Siar Group is derived exclusively from western and north-western Scotland. Glacigenic deposits comprise the bulk of the group which, at present, consists of 33 formations² (Table 2).

The base of the Eilean Siar Glacigenic Group is marked by the Mid Pleistocene Glacial Unconformity (Figure 2), which was initiated during the Anglian glaciation (marine isotope stage (MIS) 12, about 0.44 Ma (Stoker et al., 1994), and has been subsequently modified during successive glacial cycles on the Hebrides Shelf. On the upper Hebrides Slope, this unconformity broadly correlates with the marine nannofossil NN19 biozone, which can be traced into the deep-water deposits of the Rockall Basin (STRATAGEM Partners, 2003; Stoker, in press).

On the Hebrides Shelf, the Eilean Siar Glacigenic Group is dominated by diamicton deposits constructed by a variety of ice-contact and ice-marginal processes (Stoker et al., 1993; Stoker, in press). For example, the sea-bed expression of the late Devensian MacDonald and Conan formations (Table 2) retains a significant mounded morphology related to the deposition of submarine morainal banks, including at the shelf edge. In older, buried formations, such as the Banks and Conchar formations, any diagnostic landform morphology has been eroded during the subsequent glaciation(s), resulting in a sheet-like geometry to these units. The thickest glacigenic sequences on the Hebrides Shelf are generally preserved as stacked assemblages of diamicton within glacially-eroded troughs that represent palaeo-ice streams linking north-west Scotland to the Hebrides Slope. For example, in ascending stratigraphical order, the Shona, Flora, Elspeth, Aisla and Jean formations represent repeated occupation, erosion and deposition within The Minch palaeo-ice stream that operated during the Anglian and younger glaciations (Stoker and Bradwell, 2005). This palaeo-ice stream extended to the shelf-edge and delivered glacial material directly onto the Hebrides Slope as trough-mouth fans, e.g. the Sula Sgeir Fan. Muddy mass-flow diamictons dominate the glacially influenced slope apron on these fans, which is mostly assigned to the Upper MacLeod Formation. The latter extends into the Rockall Basin where it passes into finer-grained contourite and turbidite facies.

4.2.4 Hjaltland Glacigenic Group

The Hjaltland Glacigenic Group is established for all glacigenic formations in the West Shetland region (Figure 6). The name is derived from the Old Norse for Shetland. This nomenclature replaces the previous terminology — the Upper Nordland unit (Stoker, 1999; see Section 2.2) — applied to this succession. Glacigenic deposits comprise the bulk of the group, which consists of 11 formations (Table 3) that represent mixed derivation from northern Scotland, Shetland, Orkney and the northern North Sea. The base of the Hjaltland Glacigenic Group is marked by the Mid Pleistocene Glacial Unconformity.

In common with the Eilean Siar Glacigenic Group in the Hebridean region, the Hjaltland Glacigenic Group is similarly dominated by diamicton deposits, with the

submarine morainal banks of the late Devensian Otter Bank Formation especially well preserved on the West Shetland Shelf (Bradwell et al., 2008a; Stoker and Holmes, 1991; Stoker et al., 1993). Buried glacigenic sequences include the pre-Devensian Mariner and Ferder formations, which although defined in the northern North Sea have been extended widely within the West Shetland area, and consequently are included in the Hjaltland Glacigenic Group as well as the Reaper Glacigenic Group (see Section 4.3.2). On the West Shetland Slope, trough-mouth fan deposits are preserved within the Rona and Foula prograding sediment wedges, and are largely assigned to the Upper Morrison Formation³. On the mid to lower slope, the debris flow dominated fans interdigitate with basinal contourite and turbidite facies of the Faroe–Shetland Channel Formation (Akhurst, 1991; Akhurst et al., 2002; Stoker et al., 1993).

4.3 CENTRAL AND NORTHERN NORTH SEA

4.3.1 Zulu Group

The Zulu Group is established for a thick sequence of pro-deltaic to shallow-marine sediments in the central and northern North Sea (Figure 5). The name is taken from a type of drifter fishing boat common to eastern Scotland and the Northern Isles during the 19th and early 20th centuries. There is no evidence for the presence of the Zulu Group in the Moray Firth (west of 2°W) (Andrews et al., 1990). This apparent absence may be due to extensive subsequent glacial activity, but as some Pliocene sediment has survived in this area there is a possibility that deposits of the Zulu Group are present in small pockets. The age assignment of this succession is based largely on a combination of palaeomagnetic and biostratigraphical data (Gatliff et al., 1994; Johnson et al., 1993; Stoker et al., 1985a, b). East of Shetland, BGS boreholes 81/16 and 81/18 proved earliest Pleistocene sediments that, in 81/18, overlie Pliocene deposits (Johnson et al., 1993; Long et al., 1988). Along its southern margin, the Zulu Group passes laterally and transitionally into the deltaic- and fluvial-dominated Southern North Sea Deltaic and Dunwich groups, respectively (Figure 5).

At the present time, the Zulu Group is defined with reference to two constituent formations (Table 4): the Shackleton Formation, which occurs to the east and north of Shetland, and the Aberdeen Ground Formation that is present east of mainland Scotland. Both formations have been extensively eroded and dissected prior to the deposition of the overlying glacigenic sediments of the Reaper Glacigenic Group (section 4.3.2), manifest as a characteristic and diagnostic irregular surface that is easily recognised on seismic reflection profiles (Figure 2). Despite this, some ambiguity remains in locally distinguishing between the Shackleton Formation and the overlying glacigenic Mariner Formation to the north-east of Shetland, where the nature of the upper bounding surface is less distinct. In BGS borehole 78/9, for example, the Mariner Formation is reported to have an upper part consisting of clay-dominated glaciomarine sediment, and a lower unit of silty sand containing a warmer-water microfauna and the Brunhes–Matuyama palaeomagnetic boundary (Skinner and Gregory, 1983). The latter is generally found within the Aberdeen Ground and Shackleton formations (Stoker et al., 1983). Thus, it may be that the lower part of the Mariner

² Constituent formations still being established for coastal fjord region of north-west Scotland

³ A revised terminology for the Upper Morrison Formation is being considered

Formation requires reassignment, locally, to the Shackleton Formation.

The base of the Aberdeen Ground Formation has been linked with a distinctive acoustic reflector in the central North Sea (Holmes, 1977) referred to as the 'crenulate reflector', and considered to be close in age to the base of the Quaternary. Several recent studies have indicated that this surface displays evidence for iceberg ploughmarks. There is also evidence for iceberg scoured surfaces at several levels within the Aberdeen Ground Formation, which implies a glacial influence in the area prior to Mid Pleistocene shelf-wide glaciation (Graham, 2007). This is consistent with observations from the upper part of the Aberdeen Ground Formation which preserves lithological evidence for limited ice advance offshore eastern Scotland possibly during the early 'Cromerian' Stage (Stoker and Bent, 1985).

4.3.2 Reaper Glacigenic Group

The Reaper Glacigenic Group is established for all glacigenic formations of the central and northern North Sea region (Figure 6). The name is taken from the Fifie sailing herring drifter, Reaper FR 958, which spent the early part of the 20th century fishing the waters around Shetland. Glacigenic deposits comprise the bulk of the Reaper Glacigenic Group which, at present, consists of 21 formations (Table 5). There is a change in the nomenclature between the northern and central North Sea which reflects the development of separate seismic stratigraphies east of Shetland and east of mainland Scotland. Whilst this is in part a consequence of the mapping history of the region, it might also reflect genuine differences across the region due to the interaction of ice derived from the north-east Scottish mainland and Scandinavia. Consequently, the extent of this group is defined on the basis of its mixed British-Fennoscandian glacial derivation, and the predominantly north to north-westerly flowing ice streams. The succession in the Moray Firth remains largely undivided at the present time.

The base of the Reaper Glacigenic Group is marked by the highly irregular erosion surface cut into the top of the underlying Zulu Group (Figure 2). Biostratigraphical data imply an Anglian age for the timing of incision (Stoker et al., 1985a, b). In general terms, the Reaper Glacigenic Group succession is preserved as a stacked association of glacial packages that have been eroded episodically by frequent phases of tunnel valley incision, which themselves have been largely backfilled by sub- and proglacial facies (Cameron et al., 1987; Carr et al., 2006; Gatliff et al., 1994; Johnson et al., 1993; Lonergan et al., 2006). The survival of some valleys as open features during the present-day interglacial period implies that a similar scenario might have occurred in the past, and that older interglacial deposits may be preserved within currently buried valleys (Feyling-Hansen, 1980; Knudsen and Sejrup, 1993; Stoker et al., 1985b).

Significant moraine ridges built during the last glacial maximum and subsequent deglaciation are preserved at the present-day sea bed in association with several units, including the Wee Bankie, Tampen and Coal Pit formations. In addition, moraines are commonly linked with the Otter Bank Formation, which, although defined on the Atlantic margin as part of the Hjaltland Glacigenic Group (see Section 4.2.4), does extend into the northern North Sea, immediately east of Shetland. Older, largely buried glacial packages include the Mariner, Ferder, Cape Shore, Sperus, Ling Bank and Fisher formations, which commonly display a highly variable internal reflection configuration

that ranges from layered and flat-lying to highly chaotic and disturbed. Tunnel-valley erosion and deposition is particularly associated with the Mariner, Ling Bank and Coal Pit formations, as well as most recently with the Forth Formation. Late- to post-glacial glaciomarine and marine sediments are associated with units such as the Witch Ground and Flags formations, with shoreface and intertidal facies recorded in the Forth and Viking Bank formations.

4.4 SOUTHERN NORTH SEA

4.4.1 Crag Group

The Crag Group has been defined in eastern England as a suite of shallow-water marine and estuarine sands, gravels, silts and clays deposited on the south-west flank of the North Sea Basin (cf. McMillan et al., 2005, and references therein). The sands are characteristically dark green from glauconite, but weather to orange or reddish brown where exposed to air. The gravels in the lower part of the group are almost entirely of flint except at the base of the Red Crag Formation where phosphatic mudstone pebbles predominate. Gravels higher in the Group include up to 10 per cent of quartzite from the Midlands, igneous rocks from Wales, and chert from the Upper Greensand of south-eastern England.

The only offshore formation assigned to the Crag Group is the Red Crag Formation (Figure 5; Table 6) which is correlated with the onshore formation of the same name. The Red Crag Formation is a high-energy shallow-marine glauconitic deposit, and therefore lithologically similar to its onshore counterpart. The Red Crag Formation might range in age from Late Pliocene to Early Pleistocene, dated to 3.2–2.4 Ma, based on the presence of the planktonic foraminiferid *Neogloboquadrina atlantica* (Berggren) (Funnell, 1988). It rests with marked unconformity on Palaeogene or Neogene formations and is unconformably overlain by deposits of the Southern North Sea Deltaic Group, though it may be, at least in part, correlated to the Westkapelle Ground Formation of the Southern North Sea Deltaic Group (Cameron et al., 1992).

4.4.2 Southern North Sea Deltaic Group

The term Southern North Sea Deltaic Group is proposed for a thick succession of marine deltaic formations, including delta front and prodelta deposits, formed by sediments derived from south eastern England and the Netherlands that are preserved in the Southern North Sea. To the north, these deposits pass transitionally into the more basal Zulu Group (Figure 5). Initially these deltas prograded into the North Sea from Britain in the west and from the European mainland in the east, until eventually the two deltas coalesced and progradation became generally northward. Deltaic deposition in the southern North Sea area might have commenced in the Pre-Ludhamian. During the Ludhamian–Pastonian interval, influx from the European mainland eventually overwhelmed the British supply and the European delta overstepped the British delta and caused the shallowing of the Southern Bight waters by extending the delta plain of the Netherlands. The coalescence of the two delta fronts occurred in earliest Beestonian (Eburonian) times, when the direction of advance swung northwards (Cameron et al., 1992). The whole of the group is of Early Pleistocene age. The base of the Southern North Sea Deltaic Group lies at the Gauss/Matuyama magnetic polarity reversal and the top is close to the Matuyama/Brunhes reversal.

The Southern North Sea Deltaic Group is defined with reference to nine constituent formations: the Westkapelle Ground, Crane, Smith's Knoll, Ijmuiden Ground, Winterton Shoal, Markham's Hole, Outer Silver Pit, Aurora and Batavier formations (Table 6). All of these, with the exception of the Crane Formation, were deposited in prodelta or delta front environments. These formations succeed each other northwards as the delta prograded into the basin. The Crane Formation was deposited seaward of the delta front and is gradually overstepped by the prograding delta deposits. The base of the Southern North Sea Deltaic Group mostly overlies the Red Crag Formation, though the latter may be partly correlated with the Westkapelle Ground Formation; the top deltaic group is diachronous with the Yarmouth Roads Formation, which is here assigned to the Dunwich Group (Cameron et al., 1992).

4.4.3 Dunwich Group

The Dunwich Group has been defined in eastern England as fluvial gravels with subsidiary clays and silts (cf. McMillan et al., 2005 and references therein). The group comprises the interpreted fluvial terrace sequences of those rivers that were either destroyed by or, in the case of the Proto-Thames, significantly modified by the overriding ice sheets that deposited the California Glacigenic Group (see section 4.4.4). The pebble contents of these various gravels can be used to demonstrate the denudation history of the source areas of the sediments. Offshore (Figure 5), delta plain sediments were deposited by the rivers as they flowed northwards across the deposits of the Southern North Sea Deltaic Group, and are envisaged to pass laterally into the upper part of the Zulu Group.

The only offshore formation to be assigned to the Dunwich Group is the Yarmouth Roads Formation (Table 6) which has been correlated in part with the Sudbury Formation of the Kesgrave Catchment Subgroup in East Anglia. The base is highly diachronous being oldest (Beestonian/Waalian) in the south, and becoming less easily definable towards the centre of the basin, where it is locally coeval with the fully marine formations of the Southern North Sea Deltaic Group. The formation was deposited prior to the Anglian (MIS 12) (Cameron and Holmes, 1999) and is unconformably overlain by the California Glacigenic Group.

4.4.4 California Glacigenic Group

The California Glacigenic Group is established for all glacigenic formations in the southern North Sea region (Figure 6). The name is derived from the California 1:250 000-scale BGS offshore map area. The group consists of 16 formations (Table 7); although these are predominantly of glacigenic derivation, the occurrence of several interbedded marine interglacial units, of regional extent, contrasts with the laterally equivalent Reaper Glacigenic Group to the north. There is a change in the nomenclature between the central and southern North Sea, in part a consequence of the mapping history of the region, but it might also reflect genuine differences across the region due to the interaction of ice derived from the UK mainland with that derived from Scandinavia and mainland Europe. Ice streams sourced from south-east Scotland and north-east England, with southerly flow lines, interacted with ice derived from the Netherlands and Denmark to control the southern sector of the North Sea ice-sheet. Consequently, the northern boundary of this group, separating it from the Reaper Glacigenic Group, is defined by a combination of

ice-flow separation, ice-sheet derivation and the northern limit of extensive interdigitating interglacial units. Despite these criteria, the accurate location of the boundary remains ambiguous, and it is likely that formations in this transitional zone may interdigitate between groups.

The base of the California Glacigenic Group is marked by the Swarte Bank Formation, which may be discontinuous and infills a fan-like array of palaeovalleys up to 12 km wide and 450 m deep that are incised into the Early to Mid Pleistocene deltaic and fluvial formations (Southern North Sea Deltaic Group and Dunwich Group) and pre-Pleistocene strata, especially off East Anglia. The valleys are believed to have been incised by subglacial processes during a major ice advance into the southern North Sea area during Anglian times. The infilling of the valleys commenced with stiff glacial diamictons and glaciofluvial sand, overlain by glaciolacustrine muds and culminating with marine interglacial sediments of the Sand Hole and Egmond Ground formations (see below). The age of the infilling deposits therefore spans late Anglian to earliest Hoxnian.

The Cleaver Bank and Tea Kettle Hole formations occur close to the centre of the southern North Sea. They are both of Wolstonian age and have an eastern (Fennoscandian) provenance. The Cleaver Bank Formation is a partly marine proglacial diamicton with clasts derived from the east and an arctic dinoflagellate assemblage (Cameron et al., 1992), but also includes glaciolacustrine and glaciofluvial facies. It passes eastwards into a subglacial till which extends westwards into the southern North Sea from the Netherlands (Joon et al., 1990). The Tea Kettle Hole Formation is broadly contemporaneous with the Cleaver Bank Formation, and consists of discontinuous deposits of periglacial aeolian sands. These units are overlain by the interglacial Eem Formation (see below).

The youngest suite of glacigenic units consists of seven formations: the Well Ground, Bolders Bank, Dogger Bank, Botney Cut, Twente, Sunderland Ground and Hirundo formations, which are all Devensian. Periglacial, fluvial deposits comprise the Well Ground Formation. The Bolders Bank Formation is a widespread deposit of diamicton believed to have been deposited by a lobe of ice which moved down the east coast of England. The Bolders Bank Formation interfingers with proglacial waterlain sediments of the Dogger Bank Formation. Subglacial valleys were incised into older Pleistocene sediments and have partially been infilled by the diamictons of the Botney Cut Formation. The Twente Formation represents periglacial wind-blown sands deposited near the ice margin. Late-stage infilling of troughs as the ice retreated westwards occurred with the glaciolacustrine to glaciomarine sediments of the Sunderland Ground and Hirundo formations.

Marine interglacial units are represented by six constituent formations: the Sand Hole and Egmond Ground formations are Hoxnian; the Eem and Brown Bank formations are Ipswichian to Early Devensian; and the Elbow and Southern Bight formations are Holocene. The Sand Hole Formation is confined to an area around the modern Inner Silver Pit. In contrast, the Egmond Ground Formation occurs widely and may infill the uppermost portions of Anglian subglacial valleys overlying the Swarte Bank or earlier deltaic formations such as those of the Dunwich Group. A stratigraphical break due to the fall in sea level during Wolstonian times separates these formations from those of the next marine incursion during Ipswichian times. The Eem Formation rests unconformably on the Egmond Ground Formation and is overlain by a marginal marine deposit, the Brown Bank Formation, which may have been deposited as sea levels fell during Early Devensian times

equivalent to MIS 4 (Cameron and Holmes, 1999). A further stratigraphical break separates these formations from the deposits of the postglacial return of marine conditions into the southern North Sea. The Elbow Formation was deposited in shallow water intertidal or coastal environments and commonly includes a freshwater basal peat which, depending on location, may be latest Devensian in age. As fully open marine conditions became established the Elbow Formation was overlain unconformably by the deposits of the Southern Bight Formation, which contains a number of diachronous members. These members include transgressive deposits that formed around 8000 BP and the modern mobile marine sediments, such as those found within sandwaves or sandbanks in the southern North Sea.

4.5 ENGLISH CHANNEL–SOUTH-WEST APPROACHES

Quaternary deposits of the English Channel have not, to date, been formally subdivided by the BGS. Sediments older than the Holocene transgression are confined to the complex system of palaeovalleys that extends from the Dover Strait to the Hurd Deep, and to isolated valleys farther west which comprise the Fleuve Manche palaeoriver, and which have not been sampled. The origin of the valleys is a subject of controversy with both fluvial (Gibbard, 1988; Hamblin et al., 1992; Toucanne et al., 2009) and catastrophic ice-dammed lake discharge (Gupta et al., 2007; Smith, 1985) cited as possible mechanisms. Outside of the palaeovalleys, Quaternary deposits are mainly less than a few metres thick; however within palaeovalleys, such as the Hurd Deep, they attain significant thicknesses of up to 180 m.

By way of contrast, the Quaternary succession in the south-western approaches has been divided into two formations and two informal sea-bed units (Evans, 1990), although the bulk of the Pleistocene record is missing (Table 8). The oldest sediments are those of the Little Sole Formation, the uppermost beds of which are confined to the outer continental shelf and contain an Early Pleistocene foraminiferal assemblage (Curry et al., 1965; Evans and Hughes, 1984). These assemblages are similar to those described from the St Erth Beds of Cornwall, which are dated at 1.9 to 2.1 Ma (Jenkins et al., 1986). Seismically, the unit forms a blanket-like unit about 50 m thick, with chaotic, discontinuous reflectors.

The Melville Formation is preserved as a series of ridges up to 60 m high on the outer shelf (Pantin and Evans, 1984). Resting on the flanks of the ridges are sediment lenses of glacial aspect, which have yielded an arctic molluscan fauna (Scourse et al., 1990). Devensian deposits have been traced south-westward from the north Celtic Sea, and subglacial till deposited from grounded ice has now been proved from the Scilly Isles (Scourse et al., 1990; Scourse and Furze, 2001). Moreover, proglacial marine sediments have been traced to the shelf edge and ice-rafted glacial erratics and isolated mounds of glaciomarine sediment have been sampled at a number of sites. As there is no evidence of any pre-Devensian glacial sediment in the area, the formation of the sand ridges thus appears to be coeval with Late Devensian glaciation (Evans, 1990; Scourse and Furze, 2001; Scourse et al., 2009).

The two youngest deposits are of Late Devensian to Holocene age, with the oldest, Layer A, a lag deposit formed during the transgression following Devensian ice retreat. Layer B is a fully marine mobile sediment covering much of the sea bed. Over large parts of the area, Holocene sediment rests directly on pre-Quaternary bedrock.

4.6 CELTIC SEA–IRISH SEA

4.6.1 Demetae Group

The Demetae Group (Table 9) is established for a succession of sediments that are preserved in shallow basins and channels beneath the present-day deep-water troughs in the St George's Channel–North Celtic Sea region (Hession, 1988; Jackson et al., 1995; Tappin et al., 1994) (Figure 5). The name is taken from the Brythonic-speaking Celtic people of Iron Age Britain who inhabited south-west Wales. The base of the group rests with marked unconformity on pre-Quaternary strata.

At present, the Demetae Group is defined with reference to a single constituent formation, the Bardsley Loom Formation, which includes both terrestrial and marine sediments of pre-Anglian, possibly Cromerian, age. Its seismic character suggests a fluvial or shallow marine origin (there is no evidence of glacial diamicts), an interpretation supported by the only samples in BGS borehole 89/10 in the Celtic Deep, which included clay, sand, gravel and peat layers (Tappin et al., 1994). The formation was also possibly sampled in the Mochras Borehole as a series of varved clays with a cool-temperate microbiota.

4.6.2 Brython Glacigenic Group

The Brython Glacigenic Group is established for all glacigenic formations in the St George's Channel–Irish Sea region (Figure 6). The name is taken from the Welsh language with reference to the indigenous Celtic inhabitants of most of pre-Roman Britain. Glacigenic deposits comprise the bulk of the group, which, at present, consists of five formations (Hession, 1988; Jackson et al., 1995; Tappin et al., 1994) (Table 9). The deposits of these units were derived from ice streams sourced in south-west Scotland, north-west England, Wales and Ireland, and merged in the present offshore region to form the Irish Sea ice stream (Roberts et al., 2007).

The base of the Brython Glacigenic Group truncates the Demetae Group, and elsewhere rests with marked unconformity on rocks of Oligocene, Early Jurassic and Precambrian age. In places, the unconformity surface is highly irregular reflecting multiple stages of valley incision that occurred during the development of the Caernarfon Bay, Cardigan Bay and Western Irish Sea formations. In common with the North Sea region, these incisions are envisaged to have been formed by glacial activity instigated during the Anglian (Wingfield, 1990). A number of the incisions retain a modern-day bathymetric expression, including the Celtic Deep and St George's Channel troughs (Jackson et al., 1995; Tappin et al., 1994).

Subglacial and proglacial sediments are interpreted to comprise the bulk of the Caernarfon Bay, Cardigan Bay and Western Irish Sea formations. The St George's Channel Formation is interbedded between the Caernarfon Bay and Cardigan Bay formations, and has previously been assigned an interglacial status (Hession, 1988; Jasin, 1976). Whereas the bulk of the microbiota is predominantly of a boreal and cold-water character, a sample of a rich warm-temperate foraminiferal assemblage of Hoxnian affinity has been recorded from this unit (C. Dickson, unpublished data, in Bowen, 1999), which may thus straddle the Hoxnian–Wolstonian stages. The uppermost Surface Sands Formation represents the latest Quaternary sequence across the region, and includes the products of Holocene and modern-day processes.

5 Correlation with adjacent offshore stratigraphical schemes

This chapter presents a comparison between the UKCS and two adjacent offshore sectors — The Netherlands and Norway — where the establishment of Quaternary stratigraphical frameworks has been similarly addressed, albeit to varying degrees. Tables 10 and 11 show our current understanding of the correlation between stratigraphical units straddling the median line in the southern North Sea (mainly Dutch sector), and the northern North Sea (Norway)/north-west European Atlantic margin, respectively. In the North Sea, the BGS has published 1:250 000-scale Quaternary maps in partnership with the Rijks Geologische Dienst (The Netherlands) and the Institutt For Kontinentalsokkelundersøkelser (IKU) (Norway). Additional collaboration in the southern North Sea was undertaken with the Danmarks Geologiske Undersøgelse (Denmark), the Niedersächsisches Landesamt für Bodenforschung (Germany), and the Belgische Geologische Dienst (Belgium) where their median lines were crossed (cf. Appendix 1; Figure A1.1). The southern North Sea lithostratigraphical scheme developed between the UK and Dutch sectors was applied to the Danish, German and Belgian sectors.

Since the completion of the joint southern North Sea maps, the Upper Cenozoic stratigraphical scheme has been revised and refined in the Dutch sector (Rijsdijk et al., 2005). The current scheme shown in Table 10 is based on elements of lithostratigraphy, seismic stratigraphy and allostratigraphy. From the present correlation between the two sectors, a number of key points are noted:

- Changes to nomenclature and status of some of the units. Some of the Middle–Upper Pleistocene glacial formations in the UKCS have been downgraded to member status in the Dutch sector. However, most of the Lower–Middle Pleistocene deltaic formation names have been retained.
- The Dutch formations have been incorporated into one supergroup: the Upper Noordzee Supergroup.

- In the Dutch sector, the delatic succession has been divided into subgroups 5.1 and 4.1, as well as synthems 5 and 4, which are broadly equivalent to the Southern North Sea Deltaic and Dunwich groups in the UK sector.
- The glacial formations in the Dutch sector have been grouped into a further three synthems, 1, 2 and 3; tentatively assigned ages of Elsterian–Saalian, Eemian–Weichselian, and Holocene, respectively. No equivalent regional subdivision has been undertaken in the UKCS.

In the Norwegian sector, there are some major differences between the stratigraphical frameworks developed for the North Sea and the Atlantic margin. In the northern North Sea, joint mapping between the BGS and IKU resulted in consistency in nomenclature of formations across the median line, as well as the recognition of units specific to each sector (Table 11). Although published in 1984, the BGS/IKU nomenclature has not been universally used. Despite this high-resolution framework, the Quaternary succession in this area remains as part of the Nordland Group — an undifferentiated Mid Miocene to Quaternary unit (Isaksen and Tonstad, 1989) — within the current NORLEX (Norwegian Offshore Stratigraphical lexicon) scheme (www.nhm.uio.no/norlex/). In contrast, the framework developed for the mid Norwegian continental margin has assigned the entire Late Pliocene to Quaternary prograding sediment wedge to a single formation: the Naust Formation (Dalland et al., 1988). This has been divided into a number of sequences, in ascending stratigraphical order: W, U, S, R and O (Berg et al., 2005). In comparison to the Atlantic margin off north-west Britain, the Naust sequences W, U and S correlate with the West Shetland Margin and Hebrides Margin groups, whereas Naust sequences R and O correlate with the Hjaltdland Glacial and Eilean Siar Glacial groups (Table 11).

6 Conclusions and recommendations for further work

At present, 99 units of formation rank have been defined for the offshore Quaternary succession (Appendix 2). Despite local complexity, a basic two-fold division of the Quaternary succession can be applied across much of the UKCS: 1) Lower to Middle Pleistocene (pre-Anglian), predominantly non-glacial sediments; and, 2) Middle Pleistocene (Anglian) to Holocene glacially-dominated sediments. In order to facilitate better correlation between the offshore formations, we have established twelve lithostratigraphical groups that regionally define this subdivision. Lower to Middle Pleistocene sediments comprise the Hebrides Margin, West Shetland Margin, Zulu, Crag, Southern North Sea, Dunwich and Demetae groups, though the age range of the Atlantic margin units (and the Crag Group) extends back into the Pliocene. The Eilean Siar, Hjalmland, Reaper, California and Brython glacigenic groups comprise the Middle Pleistocene–Holocene succession. These two sets of groups are separated by a regional unconformity that is commonly highly irregular; an expression of the onset of shelf-wide glacial activity during and since the Anglian.

This lithostratigraphical scheme provides the framework for improved future Quaternary mapping and correlation both offshore and onshore. However, as the report has highlighted, there are a number of key issues that need to be addressed before this scheme can be fully utilised, namely:

- Only about 50 per cent of the offshore formations are currently included within the BGS Lexicon, and all are classified as partial entries.
- The Lexicon descriptions may contain incorrect reference information.
- In a number of areas, it is clear that the Quaternary succession remains poorly defined (e.g. the English Channel and its south-western approaches), whereas in other areas, where the stratigraphy is locally complex (e.g. the Celtic Sea–Irish Sea region, and the transition zone between the southern and central North Sea), there is a need for better definition and integration of existing units.
- An improved land–sea integration of coastal and marine deposits is imperative. This includes the

estuaries and fjords, as well as the more continuous areas of unbroken coastline. Issues, such as the onset of widespread Mid Pleistocene glaciation, for which different dates have been published for the onshore and offshore records, cannot be resolved until a single, unified, stratigraphical framework has been established.

- The production of an offshore stratigraphical correlation chart.

In order to address these issues, we recommend the following scope for further work:

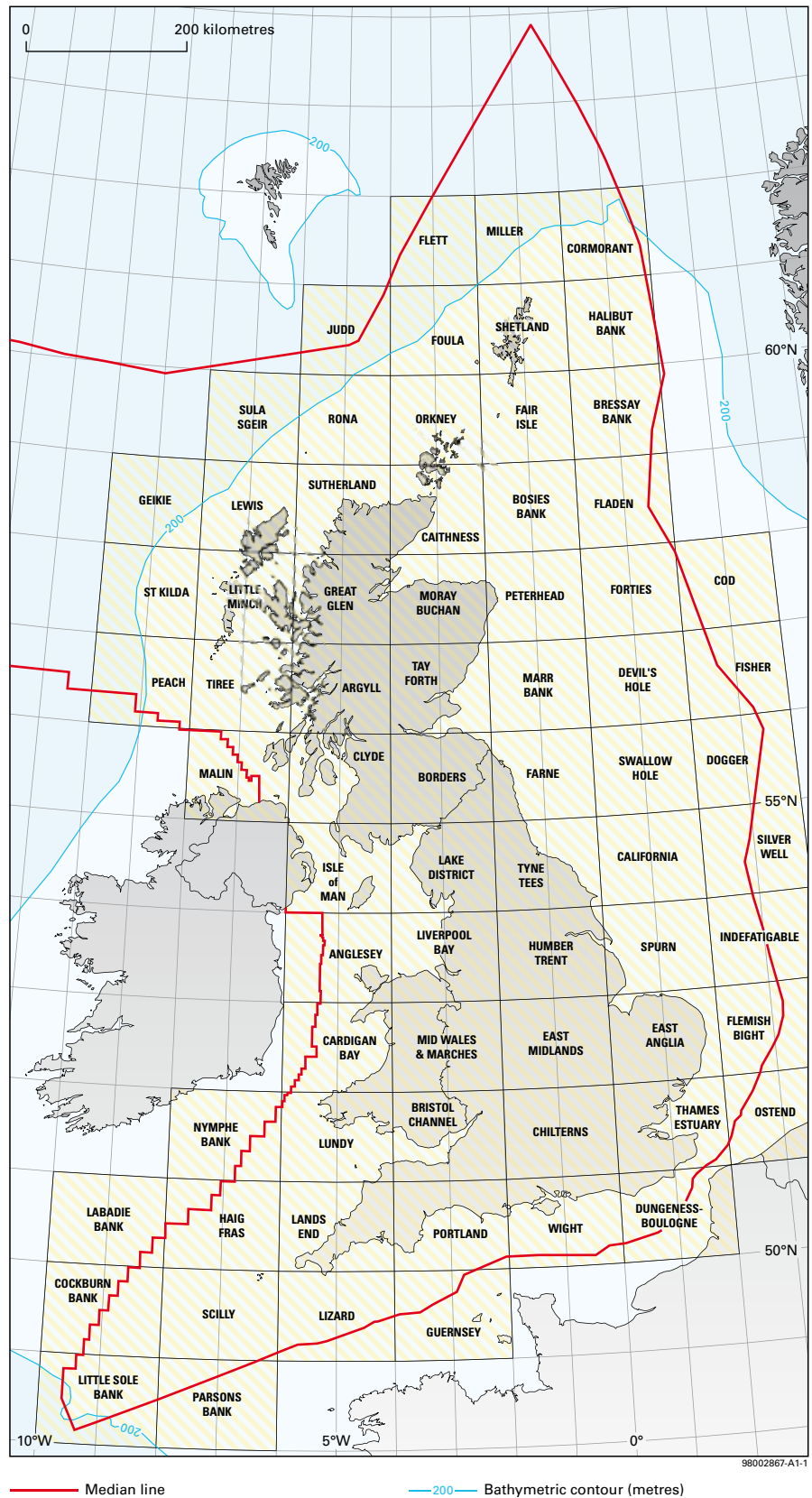
1. A complete revision, update and population of the offshore component of the BGS Lexicon.
2. The production of a detailed framework report that defines all aspects of the stratigraphy, e.g. groups, formations, members, etc.
3. Undertaking a review of areas (both coastal and offshore) where the existing stratigraphy remains poorly defined or ambiguous, or poorly integrated.
4. The integration and correlation of onshore and offshore stratigraphical units must use a common nomenclature so that both domains are captured seamlessly in the BGS Geological Spatial Database (GSD). For example, the onshore glacigenic scheme is currently divided into the Albion (pre-Ipswichian) and Caledonian (Ipswichian and younger) glacigenic groups, and their subgroups (McMillan et al., 2005, 2011), whereas it is not considered possible at present to apply a similar subdivision regionally for the offshore region. This kind of issue requires further discussion.
5. The integration and unification of a north-west European Quaternary stratigraphical scheme. At the very least, the hierarchy of the stratigraphical units should be consistent across international boundaries.

Tasks 1 and 4 are considered especially critical as they are corporate issues that essentially underpin the entire BGS superficial deposits framework.

Appendix 1 Published offshore Quaternary database

This appendix highlights the regional extent of the offshore Quaternary database captured on the 1:250 000 scale map series (Figure A1.1) and in the offshore regional reports, including the Faroe–Shetland Basin and soon-to-be-published Rockall Basin reports (Figure A1.2). This database underpins the regional stratigraphical framework presented in this report.

Figure A1.1 Published 1:250 000 scale geological map sheets (yellow). BGS/International collaboration on maps along the median line include: Cormorant (BGS/IKU); Dogger (BGS/RGD/DGU/NLFB); Silver Well, Indefatigable and Flemish Bight (BGS/RGD); Ostend (BGS/RGD/BGD). Abbreviations: BGD, Belgische Geologische Dienst (Belgium); DGU, Danmarks Geologiske Undersøgelse (Denmark); IKU, Institutt For Kontinentalsokkelundersøkelser (Norway); NLfB, Niedersächsisches Landesamt für Bodenforschung (Germany); RGD, Rijks Geologische Dienst (The Netherlands).



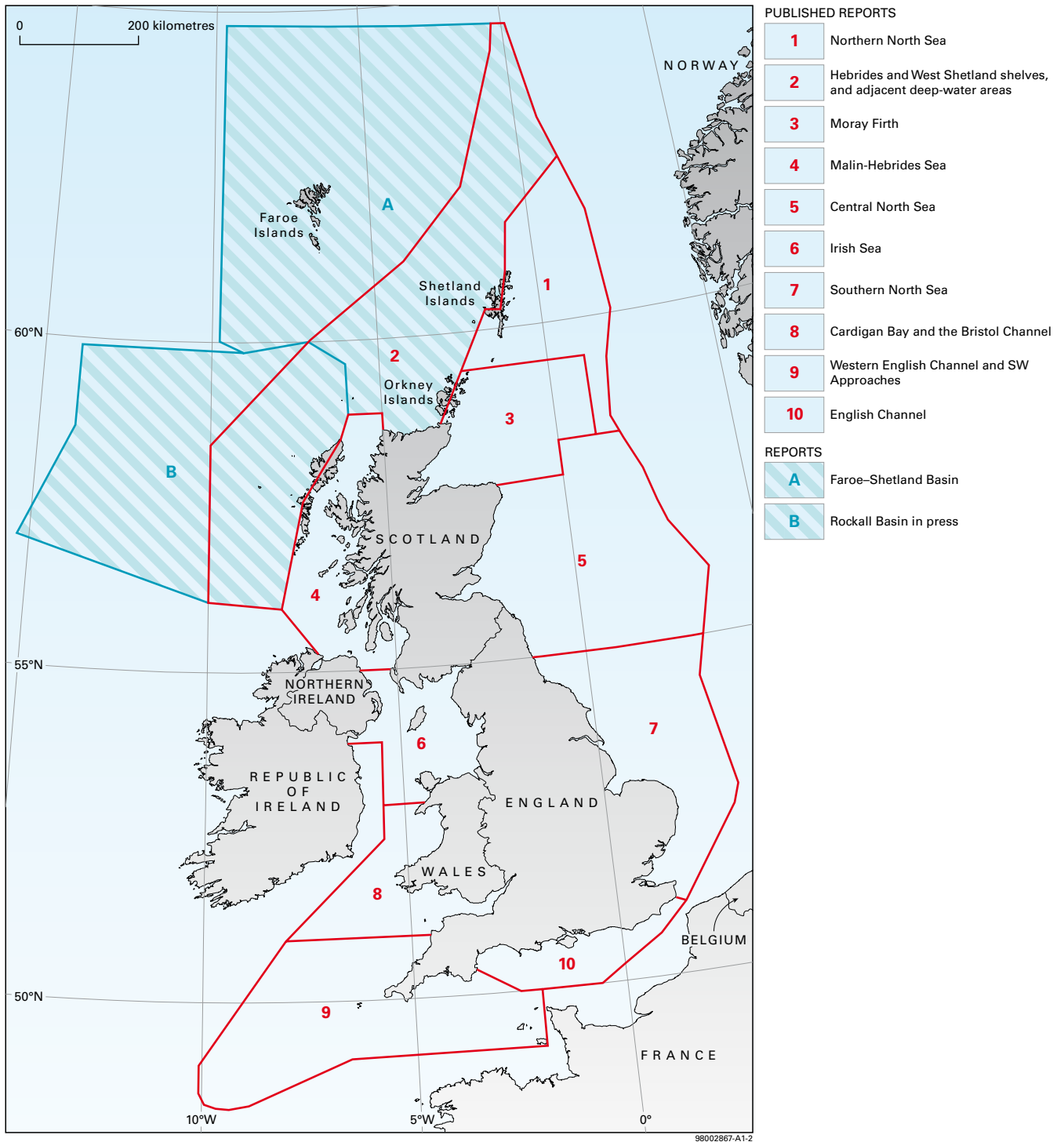


Figure A1.2 United Kingdom Offshore Regional Reports. The Hebrides–West Shetland area has undergone major revision during the construction of the Faroe–Shetland Basin and Rockall Basin reports.

Appendix 2 Existing nomenclature

The existing offshore stratigraphical units and terminology (of formation rank) as depicted on 1:250 000 scale maps and accompanying regional reports is listed below in alphabetical order, together with their group assignation (shown in brackets) based on this work:

1. ABERDEEN GROUND FORMATION (ZG)
2. AISLA SEQUENCE (ESG)
3. ANNIE SEQUENCE (ESG)
4. AURORA FORMATION (SNSG)
5. BANKS SEQUENCE (ESG)
6. BARDSLEY LOOM FORMATION (DG)
7. BARRA FORMATION (ESG)
8. BATAVIER FORMATION (SNSG)
9. BLYTH BANK FORMATION (Dutch sector)
10. BOTNEY CUT FORMATION (CALG)
11. BRIELE GROUND FORMATION (Dutch sector)
12. BROWN BANK FORMATION (CALG)
13. BUITENBANKEN FORMATION (Dutch sector)
14. CAERNARFON BAY FORMATION (BG)
15. CANNA FORMATION (ESG)
16. CAOILTE SEQUENCE (ESG)
17. CAPE SHORE FORMATION (RG)
18. CARDIGAN BAY FORMATION (BG)
19. CATRIONA SEQUENCE (ESG)
20. COAL PIT FORMATION (RG)
21. CONAN SEQUENCE (ESG)
22. CONCHAR SEQUENCE (ESG)
23. CRANE FORMATION (SNSG)
24. EEM FORMATION (CALG)
25. EGMOND GROUND FORMATION (CALG)
26. ELBOW FORMATION (CALG)
27. ELSPETH SEQUENCE (ESG)
28. FAROE-SHETLAND CHANNEL SEQUENCE (WSMG/HG)
29. FERDER FORMATION (HG/RG)
30. FIONA SEQUENCE (ESG)
31. FIONN SEQUENCE (ESG)
32. FISHER FORMATION (RG)
33. FLAGS FORMATION (RG)
34. FLORA SEQUENCE (ESG)
35. FORTH FORMATION (RG)
36. GWAELO SEQUENCE (ESG)
37. HEBRIDES FORMATION (ESG)
38. HIRUNDO FORMATION (CALG)
39. IJMUIDEN GROUND FORMATION (SNSG)
40. JEAN SEQUENCE (ESG)
41. JURA FORMATION (ESG)
42. KIRSTY SEQUENCE (ESG)
43. KLEPPE SENIOR FORMATION (RG)
44. KREFTENHEYE FORMATION (Dutch sector)
45. LING BANK FORMATION (RG)
46. LITTLE SOLE FORMATION (Unass)
47. LOWER MACLEOD SEQUENCE (HMG)
48. MACAULAY SEQUENCE (ESG/HG)
49. MACDONALD SEQUENCE (ESG)
50. MACIVER SEQUENCE (ESG)
51. MACKAY SEQUENCE (ESG)
52. MALIN FORMATION (ESG)
53. MARINER FORMATION (HG/RG)
54. MARKHAMS HOLE FORMATION (SNSG)
55. MARR BANK FORMATION (RG)
56. MELVILLE FORMATION (Unass)
57. MINCH FORMATION (ESG)
58. MOIRA SEQUENCE (ESG)
59. MORAG SEQUENCE (ESG)
60. MORRISON 1 SEQUENCE (WSMG)
61. MORRISON 2 SEQUENCE (HG)
62. MURRAY SEQUENCE (HG)
63. NORWEGIAN TRENCH FORMATION (RG)
64. OISEIN SEQUENCE (ESG)
65. OTTER BANK SEQUENCE (HG/RG)
66. OUTER SILVER PIT FORMATION (SNSG)
67. PLATEAU EDGE FORMATION (RG)
68. RED CRAG FORMATION (CRAG)
69. RONA SEQUENCE (HG)
70. SHACKLETON FORMATION (ZG)
71. SHEENA SEQUENCE (ESG)
72. SHONA SEQUENCE (ESG)
73. SINCLAIR SEQUENCE (WSMG)
74. SKERRY SEQUENCE (HG)
75. SKERRYVORE FORMATION (ESG)
76. SMITH'S KNOLL FORMATION (SNSG)
77. SOUTHERN BIGHT FORMATION (CALG)
78. SPERUS FORMATION (RG)
79. ST ABBS FORMATION (RG)
80. ST GEORGES CHANNEL FORMATION (BG)
81. STANTON FORMATION (ESG)
82. STORMY BANK SEQUENCE (HG/RG)
83. SUNDERLAND GROUND FORMATION (CALG)
84. SURFACE SANDS FORMATION (BG)
85. SWATCHWAY FORMATION (RG)
86. TAMPEN FORMATION (RG)
87. TEA KETTLE HOLE FORMATION (CALG)
88. TWENTE FORMATION (CALG)
89. UNDIFFERENTIATED UPPER PLEISTOCENE SEQUENCE (HG)

90. UPPER MACLEOD SEQUENCE (ESG)
91. VIKING BANK FORMATION (RG)
92. WEE BANKIE FORMATION (RG)
93. WELL GROUND FORMATION (CALG)
94. WESTERN IRISH SEA FORMATION (BG)
95. WESTKAPELLE GROUND FORMATION (SNSG)
96. WINTERTON SHOAL FORMATION (SNSG)
97. WITCH GROUND FORMATION (RG)
98. WYVILLE THOMSON RIDGE SEQUENCE (ESG)
99. YARMOUTH ROADS FORMATION (DUNG)

ABBREVIATIONS:

BG	Brython Glacigenic Group
DG	Demetae Group
CALG	California Glacigenic Group
CRAG	Crag Group
ESG	Eilean Siar Glacigenic Group
DUNG	Dunwich Group
HMG	Hebrides Margin Group
HG	Hjaltland Glacigenic Group
RG	Reaper Glacigenic Group
SNSG	Southern North Sea Deltaic Group
WSMG	West Shetland Margin Group
ZG	Zulu Group
Unass	Unassigned

Appendix 3 BGS Information sources

British Geological Survey maps and boreholes relevant to this work are listed below. Enquiries concerning geological data should be addressed to the Manager, National Geological Records Centre, Keyworth, NG12 5GG.

Maps

1:250 000

Sula Sgeir: Quaternary Geology, 1990
St Kilda: Quaternary Geology, 1992
Peach: Quaternary Geology, 1992
Judd: Quaternary Geology, 1990
Rona: Quaternary Geology, 1990
Foula: Quaternary Geology, 1991
Flett: Quaternary Geology, 1991
Miller: Quaternary Geology, 1991
Lewis: Quaternary Geology, 1989
Sutherland: Sea Bed Sediments and Quaternary Geology, 1989
Tiree: Quaternary Geology, 1987
Little Minch, including part of Great Glen: Sea Bed Sediments and Quaternary Geology, 1988
Geikie: Quaternary Geology, 1989
Cormorant: Quaternary Geology, 1986
Halibut Bank: Quaternary Geology, 1988
Bressay Bank: Quaternary Geology, 1990
Flemish Bight: Quaternary Geology, 1984

Boreholes

Borehole 88/7,7A: 58° 38.70'N, 08° 30.76'W; 140 km west of the Butt of Lewis
Borehole 77/9: 59° 57.75'N, 03° 45.50'W; 95 km WSW of Foula
Borehole 81/16 : 60° 26.81'N, 00° 29.96'E; 96 km ENE of Lerwick (Shetland)
Borehole 81/18: 60° 05.99'N, 01° 28.74'E; 147 km east of Lerwick (Shetland)
Borehole 78/9: 61° 30.65'N, 00° 49.78'E; 104 km NNE of Muckle Flugga (Shetland)
Borehole 89/10: 51° 22.31'N, 06° 17.59'W; 91 km SW of St David's Head (SW Wales)

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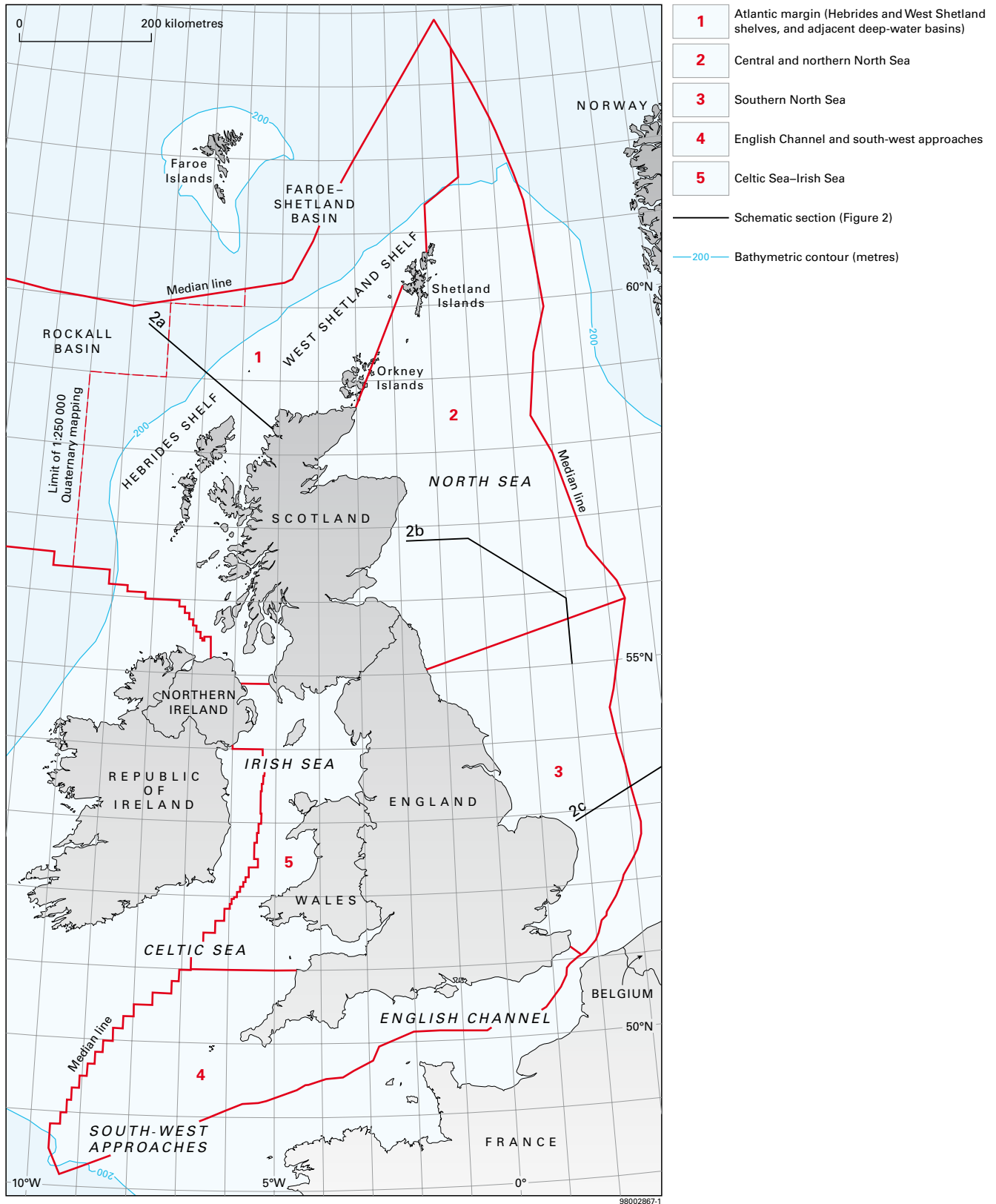


Figure 1 Outline of study area with delineation of geographical regions referred to in the text: 1, Atlantic margin (Hebrides and West Shetland shelves and adjacent deep-water basins); 2, central and northern North Sea; 3, southern North Sea; 4, English Channel and south-west approaches; 5, Celtic Sea and Irish Sea. Locations of schematic sections (red lines) in Figure 2 also shown, together with 200 m bathymetric contour (blue lines).

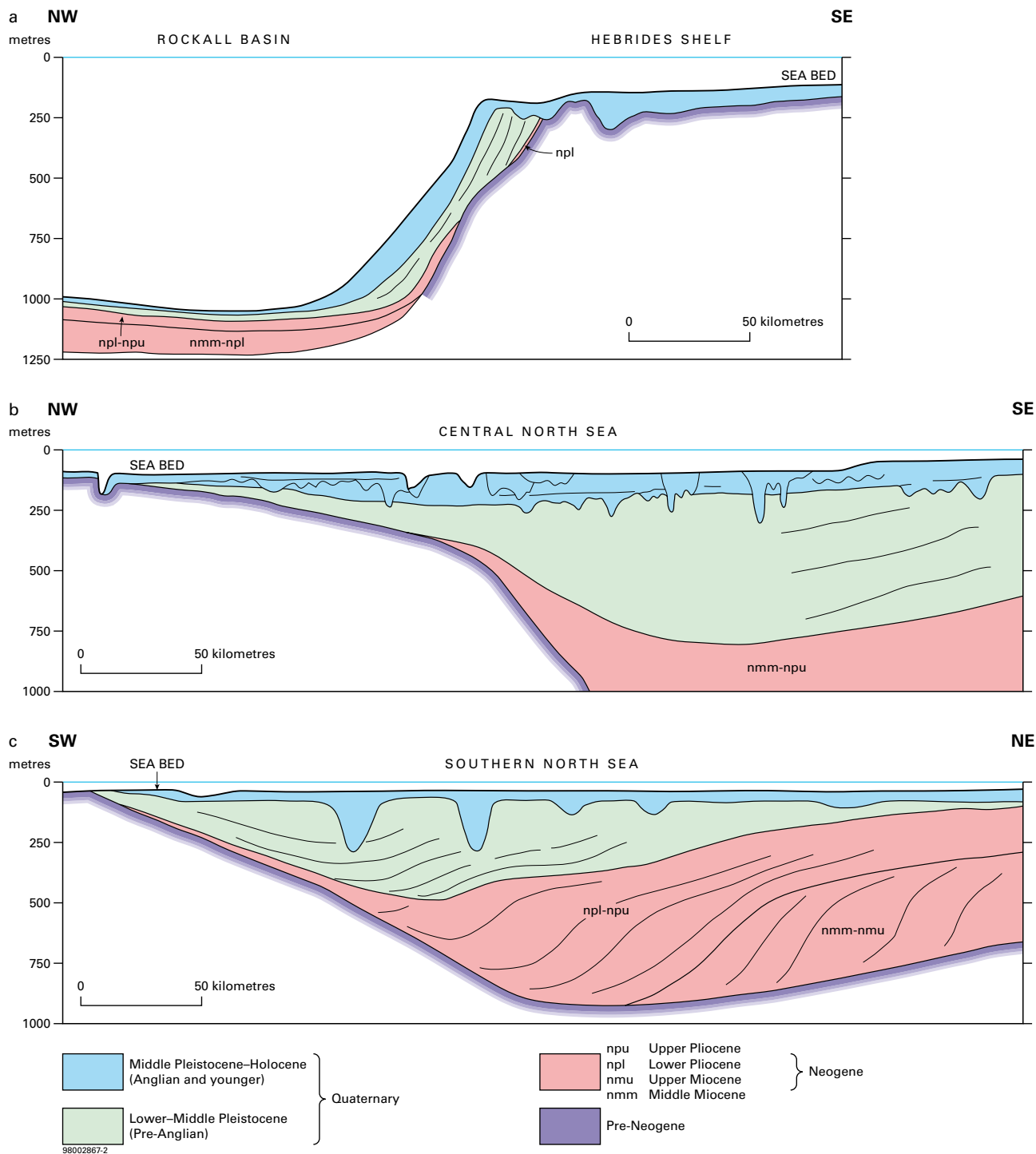


Figure 2 Schematic sections showing regional subdivision of the offshore Neogene and Quaternary succession on the Atlantic margin and in the North Sea, with Lower-Middle Pleistocene (pre-Anglian) and Middle Pleistocene-Holocene sequences separated by a regional glacial unconformity. Sections modified after: (a) Stoker and Bradwell (2005); (b) Holmes et al. (1993); (c) Cameron et al. (1993). Sections located in Figure 1.

ERA	PERIOD	EPOCH and SUBEPOCH	STAGE	Age (Ma)	
CENOZOIC	QUATERNARY	HOLOCENE		0	
		PLEISTOCENE	LATE	TARANTIAN	0.0015
			MID	IONIAN	0.126
			EARLY	CALABRIAN	0.781
				GELASIAN	1.806
	NEOGENE	PLIOCENE	LATE	PIACENZIAN	2.588
			EARLY	ZANCLEAN	3.6
		MIOCENE		5.3	
					23

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Figure 3 Timescale and status of the Quaternary used in this study, based on Gradstein et al. (2004) and Gibbard et al. (2010). The stratigraphical intervals are not scaled to geological time.

SERIES	SUBSERIES	STAGE	British Quaternary Stage (onshore) (Gordon and Sutherland, 1993; Mitchell et al., 1973; West, 1961, 1980; Zalesiewicz et al., 1991; Gibbard et al., 2004)	NW European Quaternary Stage (Gibbard et al., 1991, 2004; Funnell, 1996; Lister, 1998, 2000; Zagwijn, 1992)	MIS	ONSHORE QUATERNARY (McMillan et al., 2005, 2011)			OFFSHORE QUATERNARY (This report)					
						Glacigenic deposits	Non-glacigenic deposits	Glacigenic deposits	Atlantic Margin Hebrides	West Shetland	Central & northern North Sea	Southern North Sea	English Channel & SW Approaches	Celtic Sea-Irish Sea
HOLOCENE 11.5 ka						GREAT BRITAIN SUPERFICIAL DEPOSITS SUPERGROUP								
PLEISTOCENE	UPPER	TARANTIAN	DEVENSIAN	WEICHSELIAN	1-2	CALEDONIA GLACIGENIC GROUP	ALBION GLACIGENIC GROUP	(UNASSIGNED AT PRESENT TIME)						
					3	BRITISH COASTAL DEPOSITS GROUP	CRAIG GROUP	DUNWICH GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP			
	4	BRITANNIA CATCHMENTS GROUP	DUNWICH GROUP											
	MIDDLE	IONIAN	CROMERIAN	CROMERIAN COMPLEX	13-21	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					5a-5d	BRITANNIA CATCHMENTS GROUP	DUNWICH GROUP							
	LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	22-64	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP
						5e	IPSWICHIAN	EEMIAN						
	MIDDLE	IONIAN	CROMERIAN	CROMERIAN COMPLEX	CROMERIAN COMPLEX	6-10	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP
						11	WOLSTONIAN	SAALIAN						
	LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	12	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP
						13-21	ANGLIAN	ELSTERIAN						
	LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	22-64	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP
						13-21	CROMERIAN	CROMERIAN COMPLEX						
	LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP
13-21						BEESTONIAN	BAVELIAN	MENAPIAN	WAALIAN					
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	PRE-PASTONIAN	TIGLIAN C4c							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	BAVENTIAN	TIGLIAN C1-4b							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	BRAMERTONIAN	TIGLIAN B							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	THURNIAN	TIGLIAN A							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	LUDHAMIAN	PRAETIGLIAN							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	PRE-LUDHAMIAN	REUVERIAN C							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	REUVERIAN C	REUVERIAN C							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	REUVERIAN C	REUVERIAN C							
LOWER	CALABRIAN	PASTONIAN	PASTONIAN	TIGLIAN C5-6	65-95	RESIDUAL DEPOSITS GROUP	DUNWICH GROUP	CRAIG GROUP	WEST SHETLAND MARGIN GROUP	HEBRIDES MARGIN GROUP	ZULU GROUP	SOUTHERN NORTH SEA DELTAIC GROUP	CRAIG GROUP	
					65-95	REUVERIAN C	REUVERIAN C							

Figure 4 Summary of the Quaternary lithostratigraphical framework for the UKCS with relationships of groups to Quaternary stages, suggested correlation with Marine Isotope Stages (MIS), and correlation with onshore framework (see text for details). Quaternary chronostratigraphy and correlation of MIS is compiled from Gibbard et al. (2004, 2009) and Gradstein et al. (2004). Abbreviations: ka = 1000 calibrated radiocarbon years; Ma = 10 years.

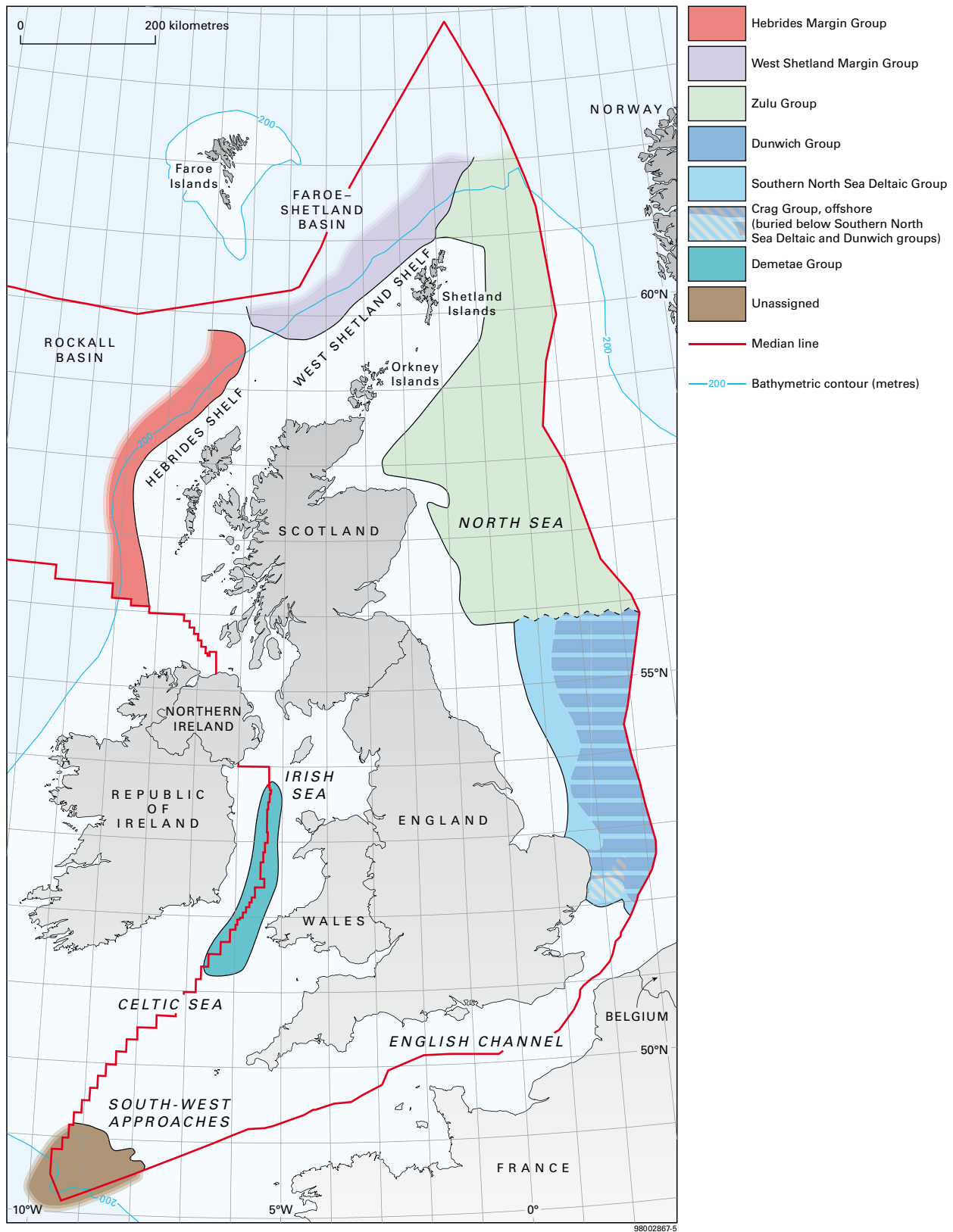


Figure 5 Schematic distribution of Lower–Middle Pleistocene (pre-Anglian) groups on the UK continental shelf, predominantly buried beneath younger glacial groups.

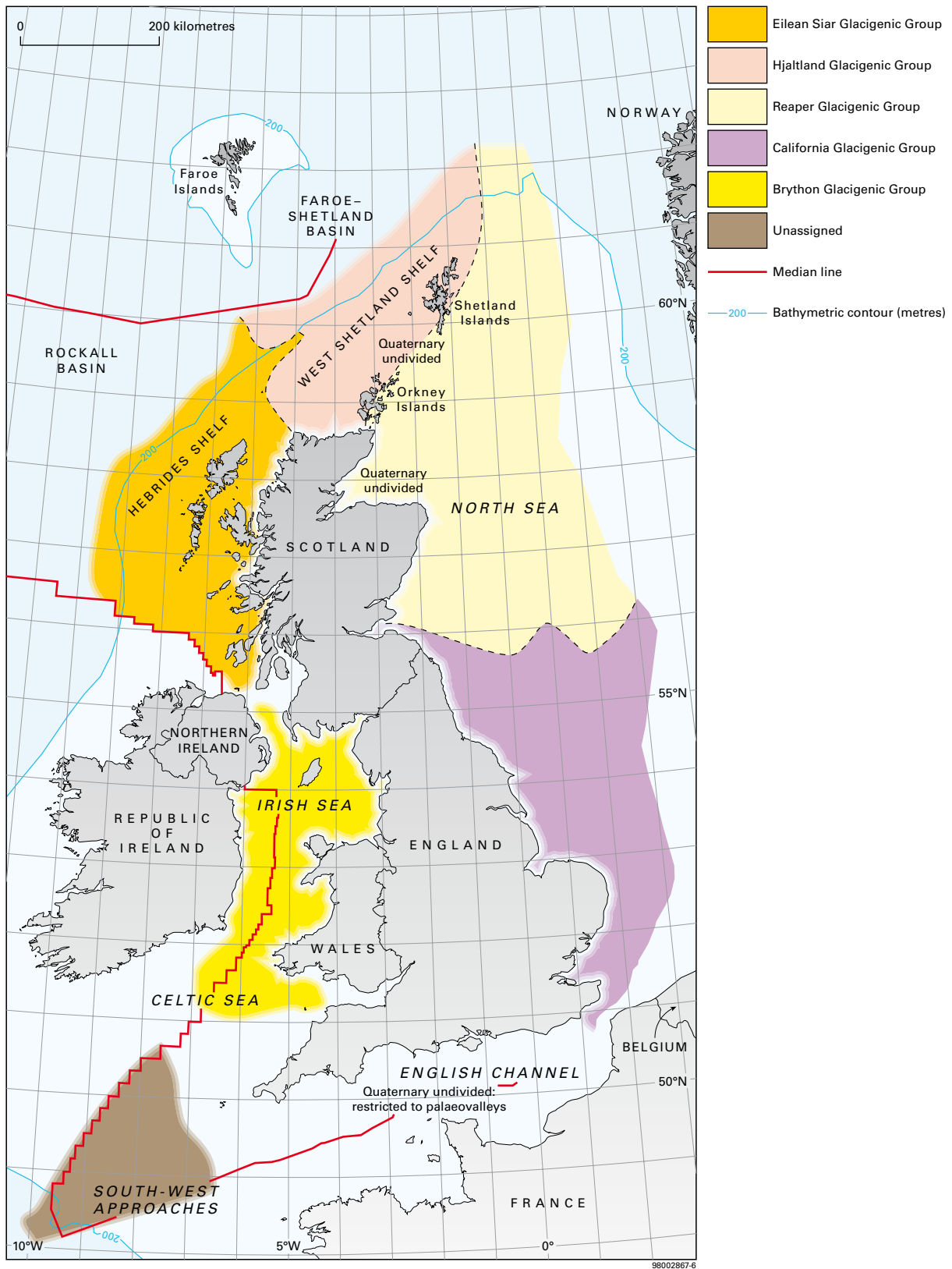


Figure 6 Schematic distribution of Middle Pleistocene–Holocene glacial groups on the UK continental shelf.

Table 1 Proposed formations of the Hebrides Margin Group and West Shetland Margin Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only. MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
HEBRIDES MARGIN GROUP	Lower ¹ MacLeod Formation		?13–Gi16?	Informally defined as MacLeod subsequence A on Sula Sgeir (1990) Quaternary map. Revised term of Lower MacLeod sequence established on St Kilda (1992) and Peach (1992) Quaternary maps. Regional summary in Stoker et al. (1993).	
WEST SHETLAND MARGIN GROUP	Lower ¹ Morrison Formation		?13–62?	Informally defined as Morrison sequence package 1 and Morrison subsequence 1 on, respectively, Judd (1990) and Rona (1990) Quaternary maps. Largely undivided on Foula (1991), Flett (1991) and Miller (1991) maps. Regional summary in Stoker et al. (1993).	Holmes, p.134–136: undivided Morrison Formation
	Sinclair Formation		?63–Gi16?	Informally defined as Sinclair sequence on Judd (1990), Rona (1990) and Foula (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	Holmes, p.134
	Faroe–Shetland Channel Formation ^{2*}		?13–Gi16?	Informally defined as Faroe–Shetland Channel sequence on Judd (1990), Foula (1991), Flett (1991) and Miller (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	

Notes:

¹ Possibly drop ‘Lower’ prefix, and change name of ‘Upper’ component bearing same name.

² Currently spans entire Quaternary. Division into separate formations for the West Shetland Margin Group and Hjaltland Glacigenic Group to be considered.

* Also forms part of the Hjaltland Glacigenic Group.

Table 2 Proposed formations of the Eilean Siar Glacigenic Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.

MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
EILEAN SIAR GLACIGENIC GROUP	MacAulay Formation [†]		1–3?	Informally defined as MacAulay sequence on Sula Sgeir (1990), Rona (1990), Judd (1990) and Foula (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	
	Gwaelo Formation		1–3?	Informally defined as Gwaelo subsequence on Peach (1992) Quaternary map. Redefined as Gwaelo sequence in regional summary by Stoker et al. (1993).	
	Fionn Formation		1–2	Informally defined as Fionn subsequence on Peach (1992) and St Kilda (1992) Quaternary maps. Redefined as Fionn sequence in regional summary by Stoker et al. (1993).	
	Catriona Formation		1–2	Informally defined as Catriona sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993) and Stoker et al. (1993).	
	Annie Formation		1–2	Informally defined as Annie sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993) and Stoker et al. (1993).	
	Jura Formation	JUR	1–2	Defined by Davies et al. (1984). Occurs on Tiree (1987) and Little Minch (1988) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Oisean Formation		2	Informally defined as Oisean subsequence on Peach (1992) and St Kilda (1992) Quaternary maps. Redefined as Oisean sequence in regional summary by Stoker et al. (1993).	
	Caoilte Formation		2–3	Informally defined as Caoilte subsequence on St Kilda (1992) Quaternary map. Redefined as Caoilte sequence in regional summary by Stoker et al. (1993).	
	Conan Formation		2–3	Informally defined as Conan subsequence on Peach (1992) and St Kilda (1992) Quaternary maps. Divided into units A and B on St Kilda map. Redefined as Conan sequence in regional summary by Stoker et al. (1993).	
	Sheena Formation		2–3	Informally defined as Sheena sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Morag Formation		2–3	Informally defined as Morag sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Fiona Formation		2–3	Informally defined as Fiona sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Barra Formation	BARA	2–3	Defined by Davies et al. (1984). Occurs on Tiree (1987) and Little Minch (1988) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Hebrides Formation	HEBR	2–3	Defined by Davies et al. (1984). Occurs on Tiree (1987) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Minch Formation	MIN	2–3	Defined and established by Boulton et al. (1981) and Davies et al. (1984). Occurs on Tiree (1987) and Little Minch (1988) Quaternary maps. Regional summary in Fyfe et al. (1993).	
MacIver Formation		4?	Informally defined as MacIver sequence on Lewis (1989) and Sula Sgeir (1990) Quaternary maps. Regional summary by Stoker et al. (1993).		

Table 2 *Continued.*

EILEAN SIAR GLACIGENIC GROUP (continued)	Mackay Formation		4?	Informally defined as Mackay sequence on Sula Sgeir (1990) and Rona (1990) Quaternary maps. Regional summary by Stoker et al. (1993).	
	Jean Formation		4?	Informally defined as Jean sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Stanton Formation	STAN	4?	Defined by Davies et al. (1984). Occurs on Tiree (1987) and Little Minch (1988) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	MacDonald Formation		?4–6?	Informally defined as MacDonald sequence on Geikie (1989), Lewis (1989), Sula Sgeir (1990) and Rona (1990) Quaternary maps. Regional summary by Stoker et al. (1993).	
	Wyville-Thomson Ridge Formation		?4–6?	Informally defined as Wyville Thomson Ridge sequence on Sula Sgeir (1990) Quaternary map. Regional summary in Stoker et al. (1993).	
	Conchar Formation		?4–12?	Informally defined as Conchar subsequence on St Kilda (1992) and Peach (1992) Quaternary maps. Redefined as Banks sequence in regional summary by Stoker et al. (1993).	
	Banks Formation ¹		?4–12?	Informally defined as Banks subsequence on Peach (1992) Quaternary map. Redefined as Banks sequence in regional summary by Stoker et al. (1993).	
	Canna Formation	CANA	?6–12?	Defined by Davies et al. (1984). Occurs on Tiree (1987) and Little Minch (1988) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Malin Formation	MALN	?6–12?	Defined by Davies et al. (1984). Occurs on Tiree (1987) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Skerryvore Formation	SKV	?6–12?	Defined by Davies et al. (1984). Occurs on Tiree (1987) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Aisla Formation		?6–12?	Informally defined as Aisla sequence on Lewis (1989) and Sutherland (1989) Quaternary maps. Regional summary in Fyfe et al. (1993).	
	Elsbeth Formation		?6–12?	Informally defined as Elsbeth sequence on Lewis (1989) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Flora Formation ²		?6–12?	Informally defined as Flora sequence on Lewis (1989) Quaternary map. Regional summary in Stoker et al. (1993).	
	Moira Formation		?6–12?	Informally defined as Moira sequence on Lewis (1989) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Shona Formation		?6–12?	Informally defined as Shona sequence on Lewis (1989) Quaternary map. Regional summary in Fyfe et al. (1993).	
	Kirsty Formation		?6–12?	Informally defined as Kirsty sequence on Lewis (1989) Quaternary map. Regional summary in Fyfe et al. (1993).	
Upper MacLeod Formation ³		1–12?	Informally defined as MacLeod subsequence B on Sula Sgeir (1990) Quaternary map. Redefined as Upper MacLeod sequence on St Kilda (1992) and Peach (1992) Quaternary maps. Regional summary in Stoker et al. (1993).		

Notes:

¹ Name to be revised. Duplication with Late Triassic–Early Jurassic Banks Group.

² Name to be revised. Duplication with Carboniferous Flora Sandstone.

³ Possibly change name, to differentiate from Lower MacLeod Formation.

* Also forms part of the Hjaltland Glacigenic Group.

Table 3 Proposed formations of the Hjaltland Glacigenic Group.

Lex code = Codes from the BGS Lexicon of named rock units (where assigned). Most of the assigned codes represent partial entries only.

MIS = Marine Isotope Stage (inferred correlation)

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
HJALTLAND GLACIGENIC GROUP	Stormy Bank Formation [*]		1–2	Informally defined as Stormy Bank sequence on Rona (1990), Foula (1991) and Miller (1991) Quaternary maps. Regional summary in Stoker et al. (1993). See also Johnson et al. (1993).	Holmes, p.136; (see also p.133).
	MacAulay Formation ⁺		1–3?	Informally defined as MacAulay sequence on Sula Sgeir (1990), Rona (1990), Judd (1990) and Foula (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	
	Otter Bank Formation ^{1*}		2–3?	Informally defined as Otter Bank sequence on Judd (1990), Rona (1990), Foula (1991) and Miller (1991) Quaternary maps. Regional summary by Stoker et al. (1993).	Holmes, p.136; (see also p.133)
	Skerry Formation		3?	Informally defined as Skerry sequence on Rona (1990) Quaternary map. Regional summary in Stoker et al. (1993).	Holmes, p.136
	Undifferentiated Upper Pleistocene Formation ²		2–3?	Informally defined as Undifferentiated Upper Pleistocene sequence on Miller (1991) Quaternary map. Regional summary in Stoker et al. (1993).	Holmes, p.136
	Murray Formation		4–6?	Informally defined as Murray sequence on Judd (1990), Rona (1990) and Foula (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	Holmes, p.136
	Rona Formation ³		4–6?	Informally defined as Rona sequence on Rona (1999) Quaternary map. Regional summary in Stoker et al. (1993).	Holmes, p.136
	Ferder Formation [*]	FD	4–6?	Initially used on Cormorant (1986) and Halibut Bank (1988) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993) and Stoker et al. (1993).	Holmes, p.136
	Mariner Formation [*]	MRN	?8–12? or 19?	Initially used on Cormorant (1986) and Halibut Bank (1988) Quaternary maps and defined by Rise et al., 1984. Regional summary in Johnson et al. (1993) and Stoker et al. (1993).	Holmes, p.131 and 136
	Upper Morrison Formation ⁴		1–12?	Informally defined as Morrison sequence package 2 and Morrison subsequence 2 on, respectively, Judd (1990) and Rona (1990) Quaternary maps. Largely undivided on Foula (1991), Flett (1991) and Miller (1991) maps. Regional summary in Stoker et al. (1993).	Holmes, p.134–136: undivided Morrison Formation
	Faroe-Shetland Channel Formation ^{5#}		1–12?	Informally defined as Faroe-Shetland Channel sequence on Judd (1990), Foula (1991), Flett (1991) and Miller (1991) Quaternary maps. Regional summary in Stoker et al. (1993).	

Notes:

¹ Name to be revised. Duplication with Permo-Triassic Otter Bank Formation.

² Change name?

³ Name to be revised. Duplication with Jurassic Rona Formation.

⁴ Change name, to differentiate from (Lower) Morrison Formation?

⁵ Currently spans entire Quaternary. Division into separate formations for the West Shetland Margin Group and Hjaltland Glacigenic Group to be considered.

^{*} Also forms part of the Reaper Glacigenic Group.

⁺ Also forms part of the Eilean Siar Glacigenic Group.

[#] Also forms part of the West Shetland Margin Group.

Table 4 Proposed formations of the Zulu Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.

MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
ZULU GROUP	Aberdeen Ground Formation	ANG	13–100	Originally defined as the Aberdeen Ground Beds by Holmes (1977), and Aberdeen Ground Formation by Stoker et al. (1985a). Regional summary in Gatliff et al. (1994).	Holmes, p.128
	Shackleton Formation	SHN	?13–62?	Initially used on Cormorant (1986) and Halibut Bank (1988) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.131 and 134

Table 5 Proposed formations of the Reaper Glacigenic Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.
 MIS = Marine Isotope Stage (inferred correlation)

GROUP	Examples of defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
REAPER GLACIGENIC GROUP	Kleppe Senior Formation	KSE	1–2	Initially used on the Cormorant (1986) Quaternary map and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.134
	Stormy Bank Formation*		1–2	Informally defined as Stormy Bank sequence on Rona (1990), Foula (1991) and Miller (1991) Quaternary maps. Regional summary in Stoker et al. (1993). See also Johnson et al. (1993).	Holmes, p.136; (see also p.133).
	Viking Bank Formation		1–2	Initially used on the Halibut Bank (1988) and Bressay Bank (1990) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.134
	Flags Formation	FLG	1–2	Initially used on the Halibut Bank (1988) and Bressay Bank (1990) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.133
	Forth Formation	FH	1–2	Originally defined as the Forth Beds by Thomson and Eden (1977), and the Forth Formation by Stoker et al. (1985a). Regional summary in Gatliff et al. (1994).	Holmes, p.130–131
	Witch Ground Formation	WGD	1–2	Originally defined as the Witch Ground Beds by Holmes (1977) and Witch Ground Formation by Stoker et al (1985a).	Holmes, p.131
	Plateau Edge Formation	PE	2	Initially used on the Cormorant (1986) Quaternary map and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.133
	Norwegian Trench Formation	NT	2	Initially used on the Cormorant (1986) Quaternary map and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.134
	Tampen Formation	TAM	2	Initially used on the Cormorant (1986) Quaternary map and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.133
	Sperus Formation	SPE	2	Initially used on the Cormorant (1986) Quaternary map and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.133
	Otter Bank Formation*		2–3?	Informally defined as Otter Bank sequence on Judd (1990), Rona (1990), Foula (1991) and Miller (1991) Quaternary maps. Regional summary by Stoker et al. (1993).	Holmes, p.136; (see also p.133)
	St Abbs Formation	SBB	2	Originally defined as the St Abbs Beds by Thomson and Eden (1977) and the St Abbs Formation by Stoker et al. (1985a). Regional summary in Gatliff et al. (1994).	Holmes, p.130
	Swatchway Formation	SWAT	2–3	Originally defined as the Swatchway Beds by Holmes (1977) and Swatchway Formation by Stoker et al. (1985a).	Holmes, p.130
	Marr Bank Formation	MAR	2	Originally defined as the Marr Bank Beds by Thomson and Eden (1977) and the Marr Bank Formation by Stoker et al. (1985a).	Holmes, p.130
	Wee Bankie Formation	WBA	2	Originally defined as the Wee Bankie Beds by Thomson and Eden (1977) and the Wee Bankie Formation by Stoker et al. (1985a).	Holmes, p.130
	Cape Shore Formation	CSO	2–3	Initially used on the Cormorant (1986), Halibut Bank (1988) and Bressay Bank (1990) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993).	Holmes, p.133
	Ferder Formation*	FD	4–6	Initially used on Cormorant (1986) and Halibut Bank (1988) Quaternary maps and defined by Rise et al. (1984). Regional summary in Johnson et al. (1993) and Stoker et al. (1993).	Holmes, p.131–133
	Coal Pit Formation	COP	3–6	Originally defined as the Upper Channel deposits by Holmes (1977) and Coal Pit Formation by Stoker et al (1985a).	Holmes, p.130
	Fisher Formation	FIS	6–10	Originally defined as the Fisher Beds by Holmes (1977) and Fisher Formation by Stoker et al (1985a).	Holmes, p.130
	Ling Bank Formation	LBK	10–12	Originally defined as the Lower Channel deposits by Holmes (1977) and Ling Bank Formation by Stoker et al (1985a).	Holmes, p.128–130
Mariner Formation*	MRN	6–12	Initially used on Cormorant (1986) and Halibut Bank (1988) Quaternary maps and defined by Rise et al., 1984. Regional summary in Johnson et al. (1993) and Stoker et al. (1993).	Holmes, p.131	

Notes:

¹ Name to be revised. Duplication with Permo-Triassic Otter Bank Formation.

* Also forms part of the Hjaltland Glacigenic Group.

Table 6 Proposed formations of the Crag, Southern North Sea Deltaic and Dunwich groups.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.

MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
DUNWICH GROUP	Yarmouth Roads Formation	YM	13–62?	Defined by Cameron et al. (1984). Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.127
SOUTHERN NORTH SEA DELTAIC GROUP	Batavier Formation		21–62?	Regional summary in Gatliff et al. (1994).	Cameron and Holmes, p.127
	Aurora Formation		22–62?	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127
	Outer Silver Pit Formation		22–62?	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127
	Markhams Hole Formation		22–62?	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127
	Winterton Shoal Formation	WN	22–62?	Defined by Cameron et al. (1984). Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127
	Ijmuiden Ground Formation	IJ	63–95?	Defined by Cameron et al. (1984). Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127
	Smith's Knoll Formation	SK	63–95?	Defined by Cameron et al. (1984). Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.127
	Crane Formation		63–95?	Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.127
	Westkapelle Ground Formation	WK	Pre-63–103?	Defined by Cameron et al. (1984). Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.127
CRAG GROUP	Red Crag Formation	RCG		Principal reference: Zalasiewicz et al. (1988). Mapped offshore on Flemish Bight (1984) Quaternary map.	Cameron and Holmes, p.127

Table 7 Proposed formations of the California Glacigenic Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.
MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999
CALIFORNIA GLACIGENIC GROUP	Southern Bight Formation		1		
	Elbow Formation	ELW	1	Principal reference: Oele (1971a).	Cameron and Holmes, p.128
	Hirundo Formation		2	Regional summary in Gatliff et al. (1994).	Cameron and Holmes, p.128
	Sunderland Ground Formation		2	Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.128
	Twente Formation	TN	2	Principal reference: Van Den Toorn (1960). Regional summary in Gatliff et al. (1994).	Cameron and Holmes, p.128
	Botney Cut Formation		2	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Dogger Bank Formation		2–3	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Bolders Bank Formation	BSBK	2–3	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Well Ground Formation		3	Regional summary in Cameron et al. (1992).	
	Brown Bank Formation	BNB	4–5	Principal reference: Oele (1971b). Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.128
	Eem Formation	EE	5	Principal reference: Zagwijn (1961). Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Cleaverbank Formation		6–10	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Tea Kettle Hole Formation		6–10	Regional summary in Cameron et al. (1992).	
	Egmond Ground Formation	EG	11	Principal reference: Cameron et al. (1984). Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.128
	Sand Hole Formation		11	Regional summary in Cameron et al. (1992).	Cameron and Holmes, p.128
Swarte Bank Formation		12	Regional summary in Cameron et al. (1992) and Gatliff et al. (1994).	Cameron and Holmes, p.127–128	

Table 8 Quaternary subdivision in the south-west approaches.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.
 MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999 ¹
UNASSIGNED	Layers A and B ¹		1–2	Informally defined by Pantin and Evans (1984)	Cameron, p.139
	Melville Formation	MELV	2	Informally defined by Pantin and Evans (1984)	Cameron, p.139
UNASSIGNED	Little Sole Formation	LISO	95–58	Informally defined by Evans and Hughes (1984)	Cameron, p.139

Notes:

¹ Name to be revised?

Table 9 Proposed formations of the Demetae Group and Brython Glacigenic Group.

Lex code = Codes from the BGS Lexicon of Named Rock Units (where assigned). Most of the assigned codes represent partial entries only.
 MIS = Marine Isotope Stage (inferred correlation).

GROUP	Proposed defining formations	Lex code	MIS	Status of units	Reference in Bowen, 1999 ¹
BRYTHON GLACIGENIC GROUP	Surface Sands Formation	SURF	1–2	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137
	Western Irish Sea Formation		2–6?	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137
	Cardigan Bay Formation	CBAY	2–6?	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137
	St George's Channel Formation		6–12?	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137
	Caernarfon Bay Formation		6–12?	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137
DEMETAE GROUP	Bardsley Loom Formation		?13–62?	Informally defined by Hession (1988); modified by Wingfield in Tappin et al. (1994)	Cameron, p.137

Note:

During the compilation of this review it was concluded by D R Tappin that the summary presented in Bowen (1999) is demonstrably incorrect; in particular, there is confusion in the description of the formations, and the quoted amino acid dates, which form the basis of the MIS correlation above, are not from this area.

Table 10 Correlation of UK and Dutch stratigraphical units in the southern North Sea. Not all members and beds associated with the Dutch scheme are shown; only those that correlate with a UK unit. Adapted from Cameron et al. (1992) and Rijdsdijk et al. (2005).

UK SECTOR		DUTCH SECTOR			
Southern Bight Formation	California Glacigenic Group	Southern Bight Formation	Synthem 1	UPPER NOORDZEE SUPERGROUP	
		Urania Formation			
Elbow Formation		Naaldwijk Formation Velsen Bed			
Elbow Formation		Nieuwkoop Formation Basal Peat Bed			
Hirundo Formation					
Sunderland Ground Formation					
		Echteld Formation			
Twente Formation Tea Kettle Hole Formation		Boxtel Formation Drachten Member			Synthem 2
Botney Cut Formation Dogger Bank Formation Volans Member Bolders Bank Formation Well Ground Formation		Dogger Bight Formation Botney Cut Member Dogger Bank Member Volans Member Bolders Bank Member Well Ground Member			
Eem Formation Brown Bank Formation		Eem Formation Brown Bank Member			
		Kreftenheye Formation			
Cleaver Bank Formation		Drente Formation Uitdam Member			
Egmond Ground Formation		Egmond Ground Formation	Synthem 3		
Sand Hole Formation					
Swarte Bank Formation		Peelo Formation			
		Urk Formation	Synthem 4		Subgroup 4.1
Yarmouth Roads Formation Alkaid Member		Dunwich Group Formation 4.1.1 Alkaid Member			
Batavier Formation		Southern North Sea Deltaic Group Batavier Formation			
Aurora Formation		Aurora Formation			
Outer Silver Pit Formation		Outer Silver Pit Formation			
Markhams Hole Formation	Markhams Hole Formation	Synthem 5	Subgroup 5.1		
Yarmouth Roads Formation	Dunwich Group Formation 5.1.1				
Winterton Shoal Formation	Southern North Sea Deltaic Group Winterton Shoal Formation				
Ijmuiden Ground Formation	Ijmuiden Ground Formation				
Smith's Knoll Formation	Smith's Knoll Formation				
Crane Formation					
Westkapelle Ground Formation	Westkapelle Ground Formation				
	Brielle Ground Formation				
Red Crag Formation	Crag Group Lillo Formation				

Table 11 Correlation of UK and Norwegian stratigraphical units in the northern North Sea and along the North-west European Atlantic margin. Information derived from Dalland et al. (1988), Isaksen and Tonstad (1989), Rise et al. (1984), Johnson et al. (1993), Berg et al. (2005) and NORLEX (www.nhm.uio.no/norlex/).

NORTHERN NORTH SEA (60° 30'–62° N, 1°–5° E)			NORTH-WEST EUROPEAN ATLANTIC MARGIN					
UK SECTOR		NORWEGIAN SECTOR			UK SECTOR			
Reaper Glacigenic Group	Viking Bank Formation	Viking Bank Formation		Nordland Group (part of)	Naust Formation	Naust sequences R & O	Hjaltland Glacigenic Group	Eilean Siar Glacigenic Group
	Plateau Edge Formation	Plateau Edge Formation						
	Flags Formation							
	Kleppe Senior Formation	Kleppe Senior Formation						
		Langrunna Formation						
		Storegga Formation						
	Norwegian Trench Formation	Norwegian Trench Formation						
Tampen Formation	Tampen Formation							
		Oseberg Trough Formation						
	Sperus Formation	Sperus Formation	Eastern Trench Formation					
	Cape Shore Formation	Cape Shore Formation						
	Ferder Formation	Ferder Formation						
Zulu Group	Mariner Formation	(Absent — probably through glacial erosion in the Norwegian Trench)				Naust sequences W, U & S	West Shetland Margin Group	Hebrides Margin Group
	Shackleton Formation							
		Base Quaternary						
		(Late Pliocene)						