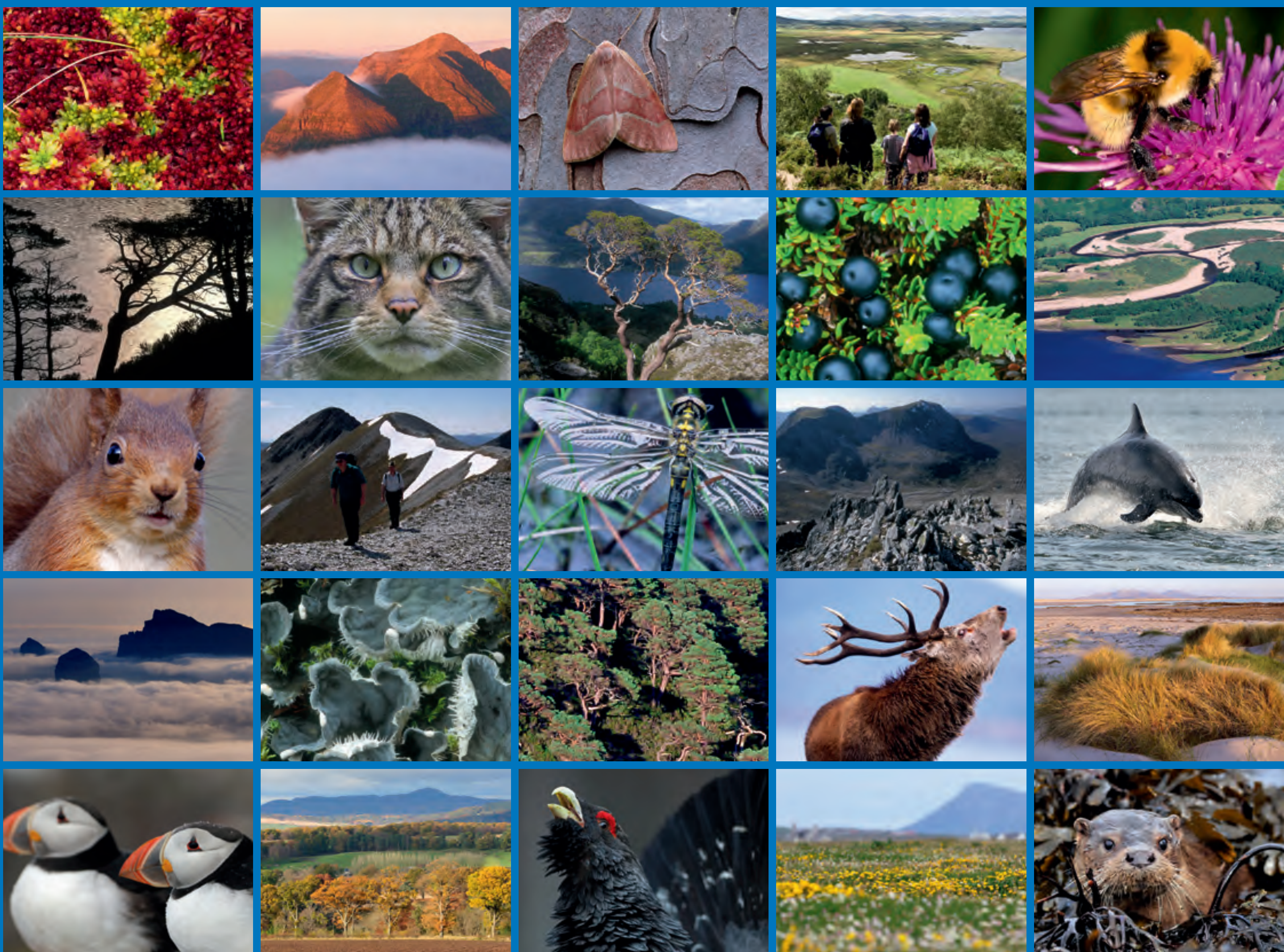
Scottish Natural Heritage
Commissioned Report No. 633

The selection of Nature Conservation Marine Protected Areas (MPAs) in Scotland - assessment of geodiversity interests



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COMMISSIONED REPORT

Summary

The selection of Nature Conservation Marine Protected Areas (MPAs) in Scotland - assessment of geodiversity interests

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Background

In comparison with the terrestrial environment, the conservation of geodiversity (the variety of geological and geomorphological features and processes) in the marine environment has been largely overlooked, despite a great wealth of accumulated information and clear links between many terrestrial and marine features. Legislation introduced through the Marine (Scotland) Act 2010 and the UK Marine and Coastal Access Act 2009 includes provisions for marine geoconservation in waters adjacent to Scotland (Marine Scotland, 2011a & b).

This report: (i) reviews the statutory context for marine geoconservation in Scotland and the assessment methodology used to identify and prioritise key geodiversity areas on the seabed; (ii) evaluates the nature and significance of Scotland's marine geodiversity; (iii) outlines the wider values of marine geodiversity and the main threats from human activities; (iv) assesses the extent to which possible Nature Conservation MPAs and MPA search locations, together with existing marine protected areas, incorporate geodiversity interests; and (v) evaluates the progress of marine geoconservation in Scotland's seas.

Main findings

The geodiversity of Scotland's seas has national and international scientific importance for the assemblage of features representing the geological evolution of the North-west European continental margin. These features are derived from Palaeogene volcanism and rifting, post-rifting evolution (through uplift/exhumation and subsidence/burial) of Cenozoic structural blocks, glaciation and contemporary marine geomorphological processes. Fluctuations in sea level have also allowed a range of marine, coastal and subaerial processes to operate over the shelf at different times, resulting in a geomorphological and landscape continuity from the highest mountains to the deep ocean floor. The geodiversity of this total landscape has a significant bearing on scientific questions of international relevance relating notably to the evolution of 'passive' continental margins (margins not associated with plate tectonic activity), the dynamics of marine-based ice sheets and their coupling with climate and ocean circulation patterns, and contemporary marine processes. Scotland's marine geodiversity is also a significant asset for the ecosystem services it delivers, including underpinning seabed habitats and their diversity of associated marine life, influencing the location of fisheries activity and providing the basis for offshore energy development (oil, gas and renewables).

As part of the wider characterisation of Scotland's seas, Brooks *et al*. (2013) provided an assessment of Scotland's marine geodiversity. This is the first time that marine geodiversity interests have been audited systematically at a national level in Scotland, and indeed elsewhere. They developed criteria and a methodology in line with the scientific framework

of the Geological Conservation Review, which provides the rationale and methods for selecting terrestrial geological and geomorphological Sites of Special Scientific Interest (SSSIs) above low-water. Using an expert judgement approach, they identified eight categories (thematic 'blocks' - the geodiversity equivalent of the MPA search features for biodiversity) of nationally and internationally important geodiversity interests to represent the geological and geomorphological processes that have had a key influence on the evolution and present-day morphology of the Scottish seabed.

The present report provides the scientific background and justification for these eight categories, within which, Brooks *et al*. (2013) prioritised 35 key 'geodiversity areas' on the seabed in terms of their scientific value. Many of these have multiple component interests that range from large-scale landforms (e.g. submarine landslides and trenches) to small-scale dynamic features (e.g. sand waves). It is likely that additional key areas may be identified as further survey information becomes available. The geodiversity audit is being used to advise Scottish Government and others on marine conservation and development, including international commitments to create a network of marine protected areas (MPAs). Scottish Natural Heritage (SNH) and the Joint Nature Conservation Committee (JNCC) identified 33 possible Nature Conservation MPAs and 4 MPA search locations that could contribute to the MPA network in Scotland's seas (SNH and JNCC, 2012). Examples of most, if not all, of the geodiversity component interests or parts of them, present in Scottish waters are included within the proposed network.

In total, 15 of the 35 key geodiversity areas are significantly incorporated (>75% by area) within the possible MPAs/MPA search locations and existing protected areas. The presence of geodiversity features provides significant scientific justification for the selection of 24 of the 37 possible MPAs/MPA search locations. Of the 8 geodiversity categories, the individual interests of 5 (Marine Geomorphology of the Scottish Deep Ocean Seabed; Seabed Fluid and Gas Seep; Cenozoic Structures of the Atlantic Margin; Coastal Geomorphology of Scotland; and, Biogenic Structures of the Scottish Seabed) could be very well represented by the evolving MPA network in Scotland's seas. In the 3 other cases (Quaternary of Scotland; Submarine Mass Movement; and Marine Geomorphology of the Scottish Shelf Seabed), there are some significant key area omissions or partial inclusions. Overall therefore, and bearing in mind the supporting role accorded to geodiversity in the MPA Selection Guidelines (Marine Scotland, 2011b), the MPA process has the potential to significantly progress geoconservation in Scottish waters.

As next steps, the sensitivities and management requirements need to be identified for the range of geodiversity features and their component interests in each of the key areas (and at a finer individual possible MPA resolution) in order to: (a) inform the management of geodiversity interests included within the MPA network; and (b) help prioritise any future actions in relation to omissions (including an assessment of the extent to which wider marine planning might address such gaps in coverage).

The approach to geoconservation that is emerging in the marine environment in Scotland is a pragmatic one that involves aligning geodiversity conservation with biodiversity conservation through integrated management where the respective interests overlap spatially or functionally, and elsewhere for any stand-alone measures for geodiversity to be based on evidence of the sensitivity and vulnerability of the interests.

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Table of Contents **Page**

List of Tables **Page**

List of Figures **Page**

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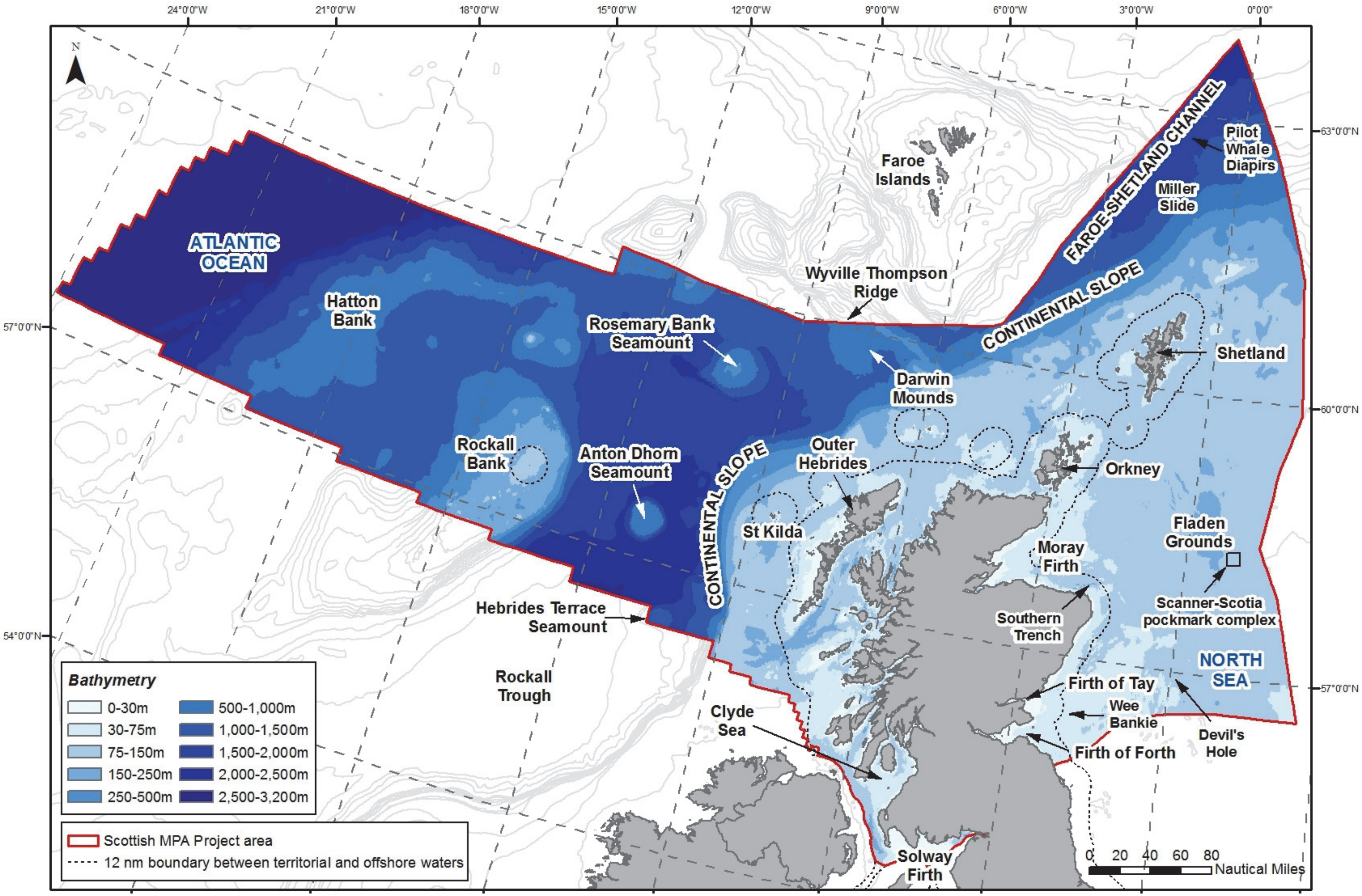
1. INTRODUCTION

For a country of its size, Scotland has an exceptional geodiversity, extending from the tops of the highest mountains to the edge of the continental shelf. Although the coastline is a dynamic and striking physical boundary between the terrestrial and marine environments, there is a natural continuity of geological formations and geomorphological features and processes across this boundary. Indeed, a significant part of the geological record lies offshore as documented, for example, in the BGS UK Offshore Regional Reports (e.g. Stoker *et al*., 1993; Hitchen *et al*., 2013) and other publications (e.g. Bell and Williamson, 2002; Emeleus and Bell, 2005). This is clearly demonstrated in the case of Quaternary landforms and deposits produced by successive advances of the British-Irish Ice Sheet. As global sea levels periodically fell by 120 m or more below their present levels (Rohling *et al*., 2009), ice sheets extended offshore to the edge of the continental shelf to the west and north of Scotland and across the floor of the North Sea before retreating back on land as the climate ameliorated and sea level rose. Consequently, the greater part of the footprint of the last British-Irish Ice Sheet and its earlier counterparts lies offshore (Bradwell *et al*., 2008a).

Until the recent development of underwater survey techniques such as multibeam swath bathymetry, and the acquisition and interpretation of high-resolution seismic and sonar data, much of the detailed geomorphological evidence had gone largely unrecorded, although the Quaternary stratigraphic record in the sub-seafloor sediments was better documented through coring and geophysical methods (Holmes, 1997). Similarly, understanding the complex evolution of the North-west European continental margin since the magmatism and rifting that led to the separation of Europe and North America in the early Eocene is fundamentally dependent on integrating onshore and offshore evidence (Hall and Bishop, 2002; Stoker *et al*., 2005, 2010; Holford *et al*., 2010). Such understanding has delivered critical insights into vital Earth system events and processes of global significance, including the links between plate tectonics, seabed topography, ocean circulation, climate change, glaciation and ice-sheet dynamics, submarine landslides, sea-level change and contemporary marine processes.

The submarine landscape and its characteristic physical features (Figure 1) are an integral part of Scotland's geodiversity and geoheritage, reflecting the geological, glacial and marine processes that have shaped our land mass over an extended period of geological time (Gordon, 2010). The seabed landforms are as impressive as any on land and represent an asset of national and international importance. Particular highlights include steep volcanic seamounts (e.g. Anton Dohrn), remarkable deep trenches extending for tens of kilometres (e.g. the Southern Trench and Devil's Hole), extensive underwater moraines formed by the Last British-Irish Ice Sheet (e.g. the Wee Bankie), vast submarine landslides (e.g. Miller Slide), giant depressions on the sea floor (e.g. Scanner-Scotia-Challenger Pockmark complex) and mud volcanoes (e.g. the Pilot Whale Diapirs). Moreover, they are a significant asset not only for their scientific value, but also for their role in providing a diversity of seabed habitats for marine life and the basis for offshore energy development (oil, gas and renewables) and fisheries. However, from a geoconservation viewpoint, there has been no systematic assessment of the importance of marine geodiversity, either in the UK or elsewhere, comparable to the Geological Conservation Review (GCR) completed for the terrestrial geology and geomorphology of Great Britain (Ellis, 2011).

While much of the focus on protected areas conservation policy and action in the UK and elsewhere has been on the terrestrial environment, including the coast (Evans, 1997; Marren, 2002), the EC Habitats and Birds Directives, the OSPAR Convention and the Marine Strategy Framework Directive have directed attention more recently towards the marine environment. In turn, these international measures have been transposed into UK domestic legislation through the Conservation (Natural Habitats, &c.) Regulations 1994, the UK Marine and Coastal Access Act 2009 and the Marine (Scotland) Act 2010.



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. NOT TO BE USED FOR NAVIGATION. Marine geodiversity assessment ©SNH & JNCC. 03.12.13. All rights reserved.

Figure 1 *Extent of Scotland's seas, showing bathymetry and locations of major physiographical features*

Although primarily addressing the requirements of biodiversity, these acts also include provisions for marine geoconservation (Marine Scotland, 2011a & b; Burek *et al*., 2012). In Scotland, this includes the identification of Nature Conservation Marine Protected Areas (MPAs) that incorporate geodiversity interests, particularly where evidence suggests these have functional links with biodiversity interests. As a contribution to the MPA process, this report:

- outlines the statutory context for marine geoconservation in Scotland;
- reviews the assessment methodology used to assess key areas of scientific importance for geodiversity in Scottish waters;
- evaluates the nature and significance of Scotland's marine geodiversity, including its wider values, and the main threats from human activities;
- assesses the contribution of geodiversity to the proposed new Nature Conservation MPAs (including MPA search locations) and the extent to which these, together with existing marine protected areas, incorporate geodiversity interests; and
- evaluates the progress of marine geoconservation in Scotland's seas.

Where appropriate, the report draws on the outputs of four supporting studies (Brooks *et al*., 2009, 2013, *in prep*.; Brooks, 2013).

2. LEGISLATION AND POLICY CONTEXT

Marine site protection until recently has focused on species and habitats of European importance which are listed in the relevant annexes of the EC Birds and Habitats Directives. Under the Nature Conservation (Scotland) Act 2004, Scottish Natural Heritage (SNH) also has powers to notify parts of the intertidal area and adjacent coastal land as Sites of Special Scientific Interest (SSSIs) to protect important biodiversity and geodiversity features. Marine conservation and the development of strategic planning for Scotland's seas is now a key priority as set out in the Marine (Scotland) Act 2010 which applies to the area inside 12 nautical miles. This provides the legal mechanism to help ensure "a clean, healthy, safe, productive and biologically diverse marine and coastal environment, managed to meet the long term needs of both nature and people, by putting in place a new system for improved management and protection of the marine and coastal environment" (Marine Scotland, 2011a). It introduces a duty to protect and enhance the marine environment and includes measures to streamline licensing for developments in sectors such as marine renewables. Measures for marine planning and conservation allow for conservation of features of geological or geomorphological interest through the designation of Nature Conservation MPAs.

The UK Marine and Coastal Access Act 2009 includes equivalent provisions for Scottish Ministers to designate MPAs for biodiversity and geodiversity features in offshore waters adjacent to Scotland. These provisions will enable Scottish Ministers to fulfill international commitments under the OSPAR Convention to establish an ecologically coherent network of well-managed MPAs within Scottish territorial and offshore waters (Figure 1) as part of a wider network of such areas across the North-east Atlantic. The MPA network in Scotland's seas will comprise existing MPAs (primarily European Marine Sites designated under the EU Habitats and Birds Directives, as well as those subject to other types of area-based management, including marine components of SSSIs and Ramsar sites) and MPAs designated under the new legislation. In terms of geodiversity, Nature Conservation MPAs are considered appropriate (Marine Scotland, 2011b) for contributing to the protection of:

- areas of nationally and/or internationally important geological or geomorphological features;

- areas of exceptional and/or threatened geological or geomorphological features; and/or
- areas of geological or geomorphological features representative of key aspects of the marine geodiversity of UK waters.

The selection process for new MPAs involves five stages including as a first step, the identification of key biodiversity and geodiversity interests through a robust scientific framework with supporting justification (for further details see Marine Scotland, 2011b). For geodiversity features, the guideline specifications were developed to include analogous ‘criteria’ to those of the GCR (Ellis, 2011), but were incorporated in a single unified system with the biodiversity guidelines to ensure a holistic, ecosystem-based approach (Marine Scotland, 2011b).

It should be noted, however, that priority for the selection of Nature Conservation MPAs is given to biodiversity locations, with geodiversity providing a supporting role. Because of this prioritisation, and because a key element of the supporting role centres on the linkages between the distribution of Scottish geodiversity and biodiversity interests, for the most part this assessment has focused on geological and geomorphological interests found at the seabed. In addition, such interests are likely to be more vulnerable to human impacts than those located under the seafloor. The characterisation and assessment of key geodiversity areas has helped to inform the Nature Conservation MPA selection process by highlighting the conservation importance of the geodiversity interests and their geographic distributions.

3. ASSESSMENT FRAMEWORK FOR IDENTIFYING KEY AREAS FOR MARINE GEODIVERSITY

Nationally and internationally important sites for geodiversity in the terrestrial environment have been identified through the scientific framework of the GCR (Ellis, 2011). The sites selected, through a process of expert review, make a special contribution to the understanding and appreciation of Britain’s geoheritage as a consequence of their 'international importance' or inclusion of 'exceptional features', or they are 'representative of fundamental features, events and processes in the geological history of Britain'.

Attempts have also been made to apply aspects of this methodology to assess geological and geomorphological features located in the marine environment through pilot studies at both regional (Furze and Roberts, 2004) and national (UK) (Brooks *et al*., 2009) levels. These involved applications of scoring schemes to individual features based on the assessment of importance and vulnerability. Feature importance was assessed using exceptionality, proportional importance and rarity. Unlike the GCR, such an approach is based on an assessment of individual features, or groups of features *per se*, rather than on a robust scientific framework supported by a scientifically argued and justified evidence base. The GCR, however, is based on identifying networks of key sites within thematic geoscience topics, known as GCR 'blocks' (e.g. British Tertiary Volcanic Province (Emeleus and Gyopari, 1992), Quaternary of Scotland (Gordon and Sutherland, 1993), Mass Movement (Cooper, 2007)) and the key themes of interest within these blocks (e.g. the range of mass movement processes or the characteristics of the Last British-Irish Ice Sheet), and then identifying the most important sites that represent the relevant stratigraphy, range of landforms, processes, environmental history and key events. It starts from a systematic evaluation and prioritisation on scientific grounds of the key interests, supported by a body of substantive evidence. By contrast, in a numerical scheme a submarine mass movement site such as the Afen Slide may score highly on exceptionality or proportionality, but it is critical to know the underlying scientific reasoning - why is it exceptional in terms of submarine slides, how does it compare with all the other mass movement features of its type, to what extent is it representative of submarine mass movements and how does its scientific importance contribute to a national network of submarine mass movement features?

In the present study, therefore, we followed an approach analogous to the terrestrial GCR using expert review of the scientific evidence rather than a numerical scoring system. However, to be wholly consistent with the Scottish MPA Selection Guidelines, this resulted in some differences (see Table A1, Appendix 1). The stage 1 guidelines encompass the presence not only of key features, but also features considered to be under threat as well as areas of the seabed considered to be critical to the overall functioning of the marine ecosystem (see Marine Scotland, 2011b and Table A1). One of the most important departures between the GCR framework and Scottish MPA Selection Guidelines concerns the manner in which the 'rarity' of a geodiversity interest is taken into consideration. Within the Scottish MPA Selection Guidelines, feature rarity by itself is of no significance because rarity in the marine environment is often an artefact of under-recording. This contrasts with the terrestrial environment in which, primarily as a result of the ease with which the landscape can be accessed and mapped, considerably more is known about the spatial distribution of geological and geomorphological features.

A significant consideration in geoconservation assessment is that scientific importance is often determined not simply by the presence or absence of a particular interest, but rather the assemblage of interests and the interpretation(s) placed upon them. For example, an assemblage of landforms (e.g. lineations, moraines and a trough mouth fan) indicating the presence of a fast-flowing palaeo-ice stream will generally be more important than individual landforms, for example in revealing the dynamics of the last British-Irish Ice Sheet. Similarly, a well-dated moraine or assemblage of moraines indicating a particular event, such as the limits of the last British-Irish Ice Sheet on the continental edge west of Shetland and the Outer Hebrides or a significant retreat phase, will have greater significance than other undated or unattributed features.

The starting point of this study was a categorisation of the thematic topic 'blocks' that incorporate the range of marine geodiversity interests on the Scottish seabed. The large-scale physiography of the Scottish seabed comprises: the continental shelf; continental slope; deep-ocean basin; and deep-ocean bathymetric rises. At a more local scale, wide variations in seabed topography and sediments are influenced by the structure and composition of the underlying bedrock, the configurations and properties of features originating at former terrestrial and submarine ice-sheet margins and beds, submarine mass movements, carbonate biological sedimentary input, and past and present near-bed currents (Holmes *et al*., 2004; Brooks *et al*., 2013). However, this variety of features and processes can be broadly categorised into eight main geological topics or thematic 'blocks' (Table 1).

Together, these represent the geological and geomorphological processes that have shaped the evolution and present geomorphology of the Scottish seabed and continue to modify it. Like the blocks of the terrestrial GCR, they include interests and areas of national and international importance; form an integral part of Scotland's geoheritage, and in many cases support important biodiversity interests. Two of the blocks, Quaternary of Scotland and Coastal Geomorphology of Scotland, correspond with terrestrial GCR blocks, reflecting common processes that have shaped both the terrestrial landscape and the seabed. However, other geodiversity interests on the Scottish seabed have formed through processes that are unique to the marine environment. The eight thematic blocks represent the MPA search features for geodiversity described as being developed in the MPA Selection Guidelines (see p. 21 of Marine Scotland, 2011b) and they incorporate the three specified criteria - nationally and / or internationally important features, exceptional and/or threatened features and features representative of key aspects of the marine geodiversity of UK waters (Marine Scotland, 2011b).

Table 1 *Thematic blocks representing the key geodiversity interests of the Scottish seabed and their scientific importance (MPA geodiversity search feature equivalents)*

Thematic block	Interests of scientific importance
The Quaternary of Scotland	A range of landforms and deposits associated with the last and earlier British-Irish Ice Sheets, important for: • understanding the dynamics of palaeo-ice streams and marine-based ice sheets and the links to climate forcing and sea level; • insights into the coupling of ice sheet dynamics, ocean processes, climate, the rheology of the upper mantle, glacio-isostatic adjustment and relative sea-level change; • geomorphological and sedimentary records that augment the terrestrial evidence for the later stages of deglaciation of the last BIS and the subsequent re-expansion of glaciers in the north and west Highlands during the Loch Lomond Stade; • the length and continuity of palaeoenvironmental archives that elucidate regional-scale changes in palaeoceanography and climate variations, fluctuations in the timing and extent of the last BIS and changing sedimentation patterns and processes.
Submarine Mass Movement	Submarine slides of different ages and morphology, important for understanding: • the geological evolution and processes that have shaped the continental slope; • geohazards associated with the thick sediment accumulations on the continental slope.
Marine Geomorphology of the Scottish Deep Ocean Seabed	Contourites, sediment drifts and erosional features associated with deep-ocean currents, important for understanding: • past and present processes associated with ocean currents; • links between sedimentation patterns, palaeoceanographic changes and past climate change.
Seabed Fluid and Gas Seep	Pockmarks and sand volcanoes, important for understanding: • syn-/post- depositional processes associated with thick sediment accumulations on the seafloor; • bedforms associated with gas seepage from the seafloor.
Cenozoic Structures of the Atlantic Margin	Large structural blocks (seamounts) and mud diapirs, important for understanding: • the history and dynamic evolution of a ‘passive’ continental margin, part of the North Atlantic Volcanic Province; • sub-surface fluid migration pathways.
Marine Geomorphology of the Scottish Shelf Seabed	Internationally important examples of non-tropical shelf carbonate systems and bedforms, including horse mussel reefs and banks of coralline algal gravels (maerl) important for: • sources of sediment for machair systems; • understanding shelf processes and relationships between currents and bedform development.
Coastal Geomorphology of Scotland	Submerged coastal landforms, important for: • recording past changes in sea level; • understanding processes of shore platform formation.
Biogenic Structures of the Scottish Seabed	Biogenic sediment mounds and cold-water corals, important for understanding: • the formation and evolution of cold-water coral growth and carbonate mound development.

4. THE NATURE AND SCIENTIFIC IMPORTANCE OF SCOTLAND'S MARINE GEODIVERSITY

Many of the Scottish rocks and landforms described in the terrestrial environment have, over the past 200 years or so, provided fundamental insights into important Earth processes, including past climate change and sea-level fluctuations. Increasingly, as outlined below, Scottish marine geodiversity interests at the seabed are providing similarly critical understanding of Earth system processes in each of the eight thematic blocks (Table 1). These focus principally on features at the seabed, but where appropriate other related key aspects are highlighted.

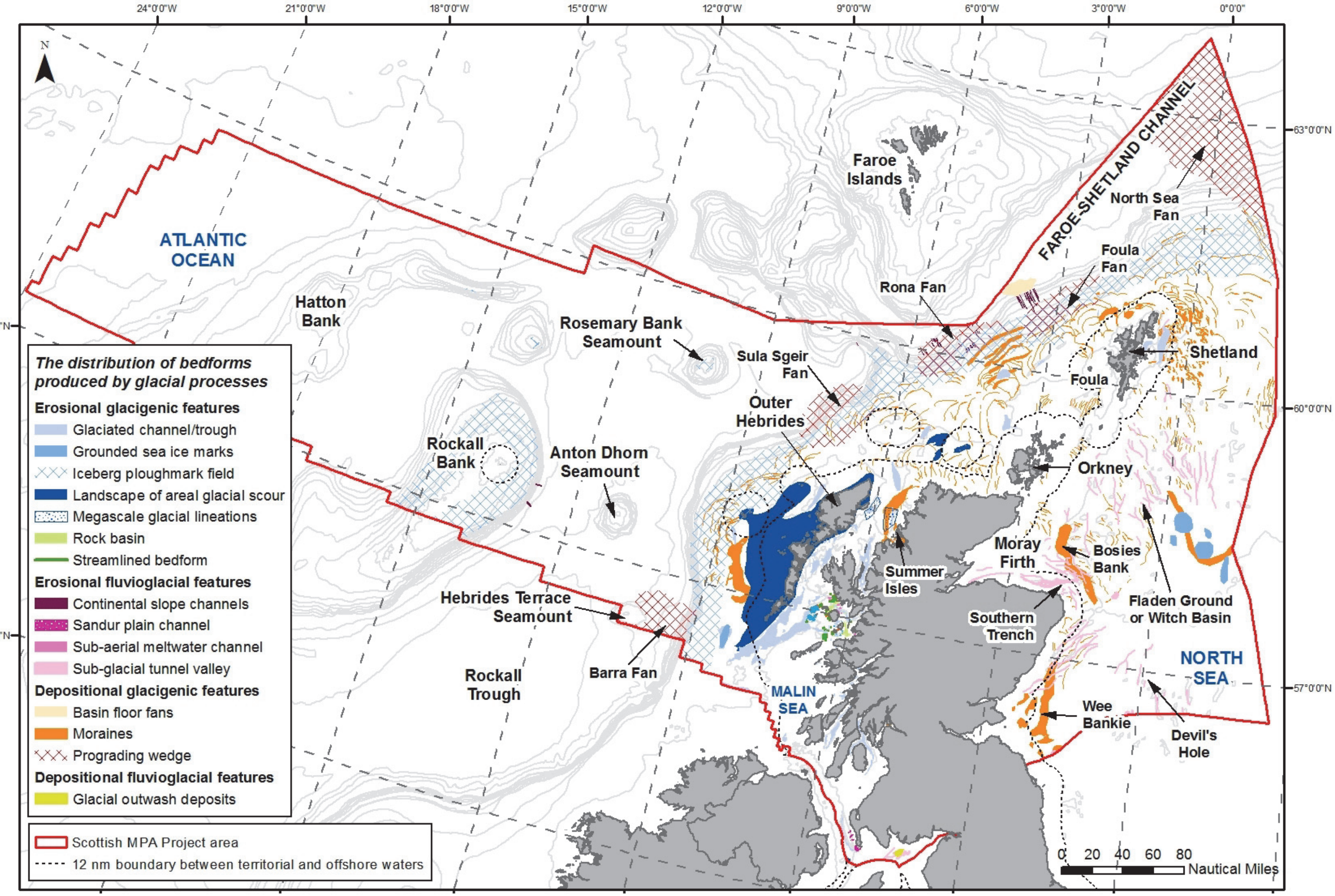
4.1 The Quaternary of Scotland

During the Quaternary (the last 2.6 million years), thick ice sheets accumulated over Scotland on at least five separate occasions (Holmes, 1997; Merritt *et al*., 2003; Thierens *et al*., 2012). These ice sheets have had a huge influence on the morphology and appearance of the present Scottish seabed, producing a range of landforms and deposits (Figures 2 and 3).

During the last (Late Devensian) glaciation between c. 30,000 and 25,000 years ago, and during earlier glaciations (Holmes, 1997; Lee *et al*., 2012), the Scottish ice sheet formed part of a larger British-Irish Ice Sheet extending to the shelf edge (Stoker *et al*., 1993; Bradwell *et al*., 2008a). Fast-flowing ice streams within the ice sheet incised deep channels across the shelf to the west and north-west of Scotland and produced streamlined bedforms (Stoker and Bradwell, 2005; Bradwell *et al*., 2007; Bradwell *et al*., 2008b; Dunlop *et al*., 2010; Howe *et al*., 2012). The presence of palaeo-ice streams and associated bedforms and channels has also been documented in the Moray Firth (Finlayson *et al*., 2008), eastern Scotland (Golledge and Stoker, 2006) and the Witch Basin (Graham *et al*., 2007).

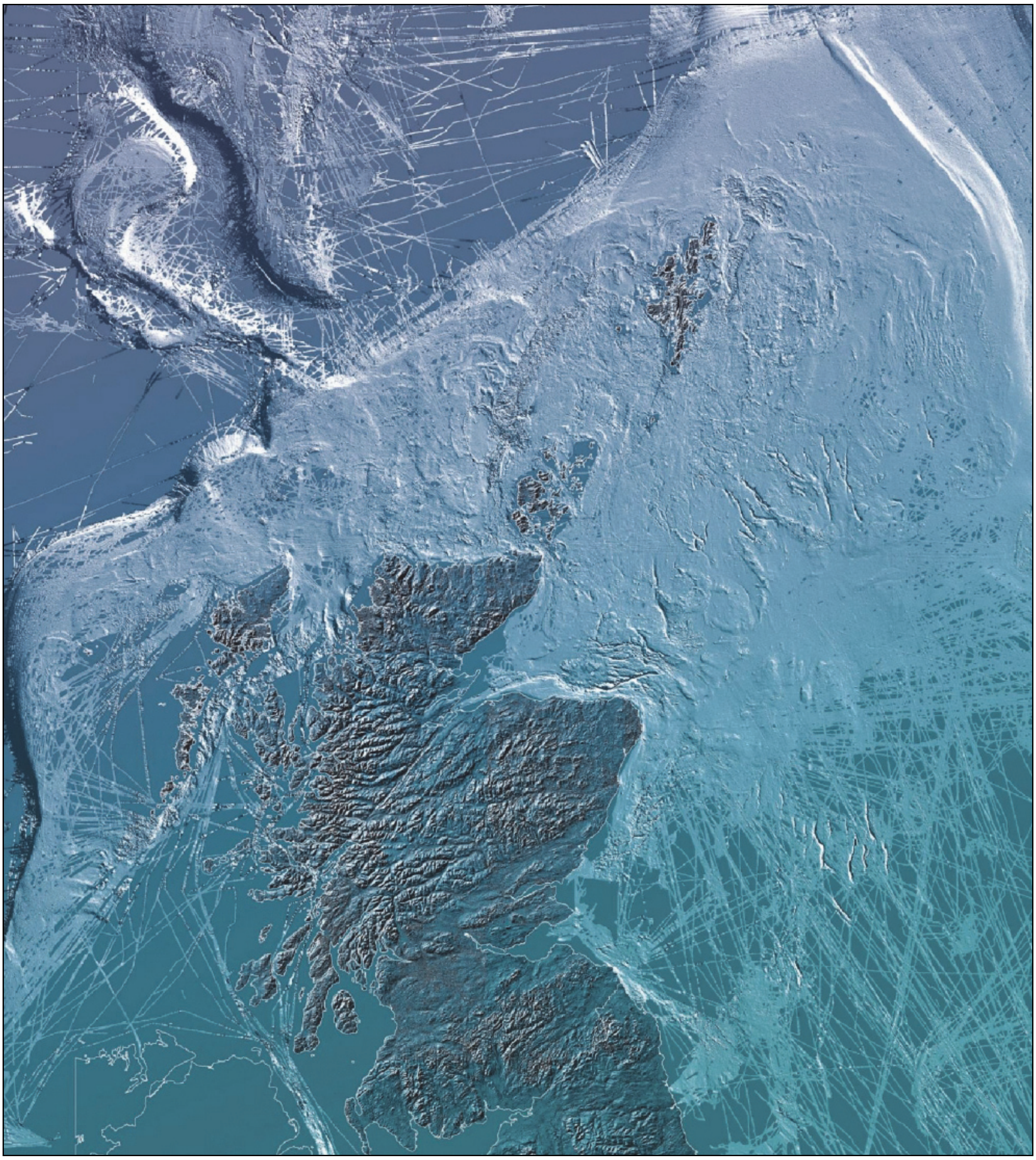
The shelf troughs almost all terminate with extensive prograding wedges that form trough mouth fans spanning the shelf-slope-basin floor region (Figure 2) (Stoker, 1995; Dahlgren *et al*., 2005). The material comprising these fans is mainly sticky mud transported down slope as narrow, slow-moving debris flows. Great numbers of flows are stacked on top of each other forming the Barra and Sula Sgeir fans to the north-west of Scotland and the Rona, Foula and North Sea Fans to the north and north-east. All of these large fans, and adjacent shelf slopes, contain records of sedimentation stretching back many hundreds of thousands of years and thus represent extremely valuable archives of information on the Quaternary glacial history of this region (Stoker *et al*., 1994; Scourse *et al*., 2009; Hibbert *et al*., 2010).

Sonar, seismic and swath bathymetry data have revealed the extensive occurrence of moraine ridges recording the limits and pattern of decay of the British-Irish Ice Sheet, both north and west of Scotland and in the North Sea basin (Figures 2 and 3) (Stoker and Holmes, 1991; Bradwell *et al*., 2008a; Graham *et al*., 2009; Clark *et al*., 2012). At the outer shelf edge, moraines commonly occur as large arcuate ridges, 2-10 km wide and several 10s of kilometres long (Stoker *et al*., 1993; Bradwell *et al*., 2008a). These forms differ greatly from the much smaller 'De Geer' moraines deposited in shallow water settings within the fjordic environment of the Summer Isles (Stoker *et al*., 2009). In the North Sea, Wee Bankie and Bosies Bank are large offshore moraine complexes that have played a central role in the debate regarding the offshore extent of ice in the North Sea basin during the last glacial period. Until recently, they were regarded as end moraines, marking the maximum easterly extent of the British-Irish Ice Sheet (Sutherland, 1984a; Bowen *et al*., 2002). However, the discovery of glacial features in the central North Sea to the east of the moraines (Graham *et al*., 2007, 2010; Sejrup *et al*., 2009) indicates that Bosies Bank and Wee Bankie formed after the Last Glacial Maximum, either as part of the dynamic retreat, or during a readvance, of the British-Irish Ice Sheet.



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. Geodiversity data from the GeMS database; in part from Defra MB0102 ©Crown copyright. 091113. All rights reserved.

Figure 2 *The distribution of bedforms produced by glacial processes - the Quaternary of Scotland*



Source: Onshore topography from NEXTMap Britain © Intermap Technologies; offshore imagery from a database compiled by Olex AS. Image compiled by BGS

Figure 3 *Scotland's combined terrestrial and marine landscape. Prominent offshore features include moraines north and west of Scotland and tunnel valleys in the North Sea*

To the east of Scotland, groups of sub-glacial tunnel valleys form spectacular trenches several hundreds of metres deep (Figures 2 and 3) (Bradwell *et al*., 2008a; Stewart *et al*., 2013). Features such as the Southern Trench, the Devil's Hole and Fladen Deeps (Figure 4) are thought to have been cut by highly pressurised water flowing beneath the ice.

These valleys form part of a much wider network of similar trenches mapped across the North Sea basin (Van der Vegt *et al*., 2012). They are scientifically important for interpreting past changes in the extent and geometry of British-Irish Ice Sheets (Bradwell *et al*., 2008a) and their patterns of retreat (Stewart *et al*., 2013); different generations of tunnel valleys also indicate multiple glacial cycles (Stewart and Lonergan, 2011) and changes in the dynamics of the British-Irish and Scandinavian Ice Sheets between different glaciations (Stewart *et al*., 2013). It is also now clear that tunnel valleys play a central role in meltwater drainage beneath ice sheets (Lonergan *et al*., 2006), and studies of these landforms may help provide better-informed models of the response of modern ice sheets to likely future climate change.

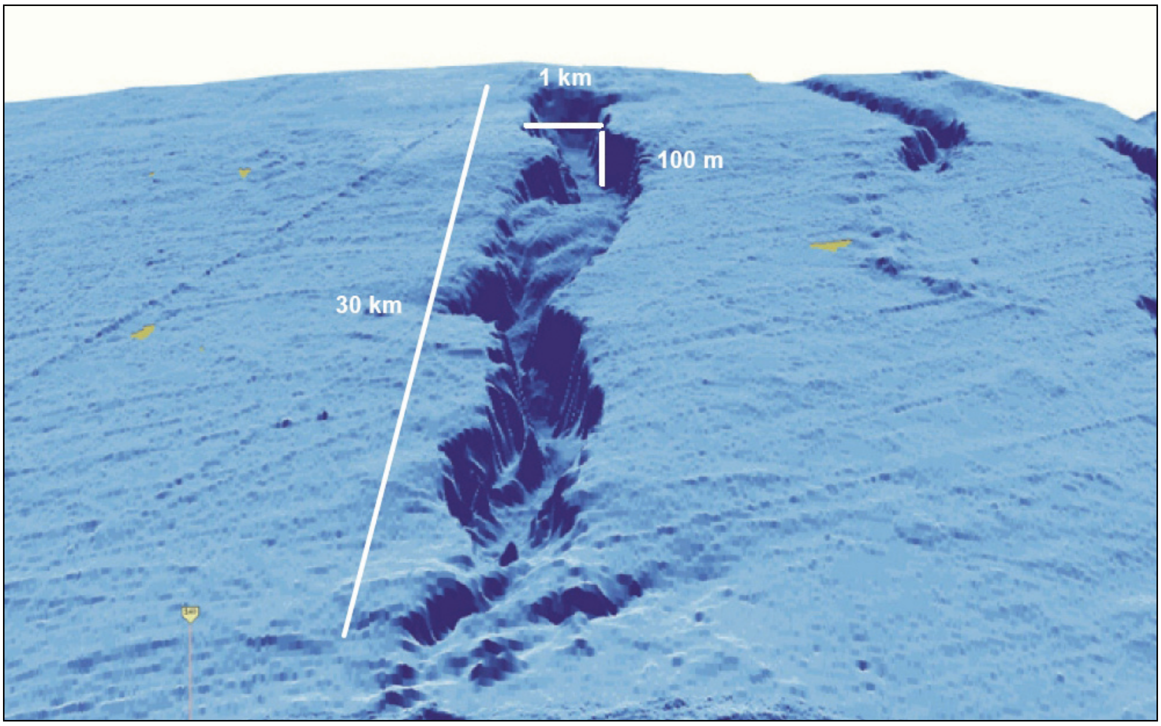


Figure 4 *OLEX oblique 3D imagery of a tunnel valley in the Fladen Deeps complex (5x vertical exaggeration). Image provided by BGS*

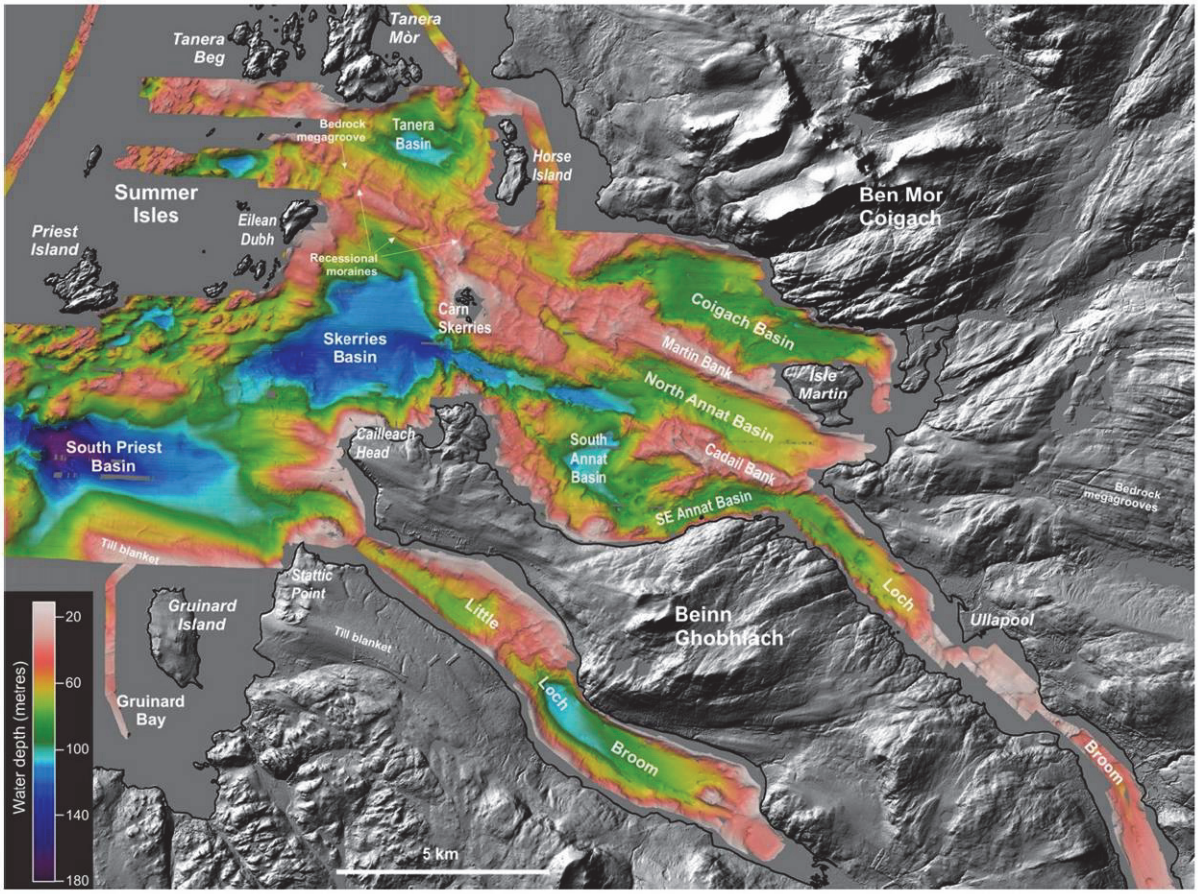
A number of other features are characteristic of the Scottish seabed. The calving fronts of the fast-flowing ice streams that extended across the shelf would have been a productive source of large icebergs. With keels several hundreds of metres below the surface, they ground shallow furrows (iceberg ploughmark fields) into the seafloor sediments, especially on the outer shelf and upper slope down to about 500 m water depth (Figure 2) (Belderson *et al*., 1973). Proglacial features, including sub-aerial meltwater channels and glacial outwash deposits, formed beyond the melting ice sheet margins. West of the Outer Hebrides, landscapes of areal scouring formed by extensive subglacial abrasion extend over the large area of Precambrian outcrop (Kenyon and Pelton, 1979) (Figure 2).

The glacial landform and sedimentary record represented by these features is important for understanding the dynamics of marine-based ice sheets under changing climates and the linkages between ocean circulation and climate change. Because of its extreme maritime location the British-Irish Ice Sheet is considered to have been particularly sensitive to climate changes (Hibbert *et al*., 2010; Thierens *et al*., 2012). Although important, the terrestrial evidence for the last British-Irish Ice Sheet represents only a small, and often discontinuous, part of the ice sheet footprint. The British-Irish Ice Sheet was largely marine-based, so that much of the evidence is offshore in the form of geomorphology (Sejrup *et al*., 2005; Bradwell *et al*., 2008a) and dateable sedimentary records (Peters *et al*., 2008; Scourse *et al*., 2009; Graham *et al*., 2010; Hibbert *et al*., 2010). The importance of this area is underlined by Sejrup *et al*. (2009) who considered that the North Sea region “most likely possesses the best dated marine-based Late Pleistocene ice sheet in the world”.

As noted above, the Scottish seabed contains an abundance of bedforms associated with marine-based ice sheets characterised by the presence of very fast moving ice streams. There are still significant gaps in understanding the dynamics of ice streams that terminate in marine settings, yet they are critical to the behaviour and functioning of contemporary ice sheets, such as those in Greenland and Antarctica (Stoker and Bradwell, 2005). Future research on palaeo-ice stream activity on the Scottish shelf has the potential to play a key role in addressing this knowledge deficit, with findings directly informing predictive modelling of the likely responses of marine-based ice sheets to future climate forcing (Clark *et al.*, 2012). However, to understand the dynamics and behaviour of the British-Irish Ice Sheet, including their links to climate, it is necessary to look at the whole assemblage of evidence, recognising the continuity between the terrestrial and offshore components (Bradwell *et al.*, 2008a; Clark *et al.*, 2012). The last decade has seen significant progress in understanding the dynamics of the British-Irish Ice Sheet as a result of the availability of offshore data, combined with advances in mapping and robust dating of onshore and offshore evidence and whole ice sheet modelling (Evans *et al.*, 2005b; Boulton and Hagdorn, 2006; Bradwell *et al.*, 2008a; Hubbard *et al.*, 2009; Chiverrell and Thomas, 2010; Clark *et al.*, 2012). Offshore evidence has also been vital for interpreting the deglacial history and behaviour of different sectors of the British-Irish Ice Sheet (Scourse *et al.*, 2009) and hence understanding ice-sheet dynamics and links to climate forcing and other factors such as sea level and calving (Bradwell *et al.*, 2008a). In turn, this is enabling insights into wider Earth system processes and the coupling of ice sheet dynamics, ocean processes, climate, the rheology of the upper mantle, glacio-isostatic adjustment and relative sea-level change (Milne *et al.*, 2006). Such understanding is not merely of academic interest but is of critical importance in informing assessments of the future response of ice sheets to likely 21st century climate warming, sea-level rise and possible changes in ocean circulation (Ó Cofaigh, 2012). For example, the British-Irish Ice Sheet may be an analogue for the marine-based West Antarctic Ice Sheet, the future stability of which is a key concern in a warmer world (Vaughan and Arthern, 2007; Lenton *et al.*, 2008), and help to provide empirical evidence to test numerical models of dynamic, fast-flowing ice sheets (Boulton and Hagdorn, 2006; Hubbard *et al.*, 2009).

At a more local level, the west coast fjords of Scotland also hold important geomorphological and sedimentary records that augment the terrestrial evidence for the later stages of deglaciation of the last British-Irish Ice Sheet and the subsequent re-expansion of glaciers in the north and west Highlands during the Loch Lomond Stade (Figure 5) (Stoker *et al.*, 2009; McIntyre and Howe, 2010).

Offshore sedimentary deposits contain palaeoenvironmental archives that have a length and continuity unavailable in terrestrial records. The North-east Atlantic occupies a critical position within the global ocean circulation system and lay close to the position of the oceanic polar front during the last glaciation (Knutz *et al.*, 2007). Studies of past regional-scale changes in ocean circulation from the sedimentary records in this region, notably from cores in the trough-mouth Barra Fan, Rosemary Bank and Rockall Trough, have played an important part in elucidating the links with the wider global climate system and have the potential to greatly improve our understanding of future changes. For example, they have revealed repeated marine-terminating and shelf-edge glaciations (Stoker *et al.*, 1994; Thierens *et al.*, 2012), regional-scale changes in palaeoceanography and climate variations at the sub-Milankovitch (millennial) scale (Howe *et al.*, 1998; Knutz *et al.*, 2001, 2007; Kroon *et al.*, 1997; 2000; Austin and Kroon 2001; Wilson and Austin, 2002; Dickson *et al.*, 2008; McIntyre and Howe, 2009; Hall *et al.*, 2011; Austin *et al.*, 2012; Small *et al.*, 2013), complex spatial and temporal variations in the advance and retreat of the last British-Irish Ice Sheet at millennial timescales linked to latitudinal variations in the North Atlantic Polar front (Knutz *et al.*, 2001, 2002, 2007; Wilson and Austin, 2002; Wilson *et al.*, 2002; Peters *et al.*, 2008; Scourse *et al.*, 2009; Hibbert *et al.*, 2010) and changing sedimentation patterns and processes (Kroon *et al.*, 2000; Knutz *et al.*, 2002).

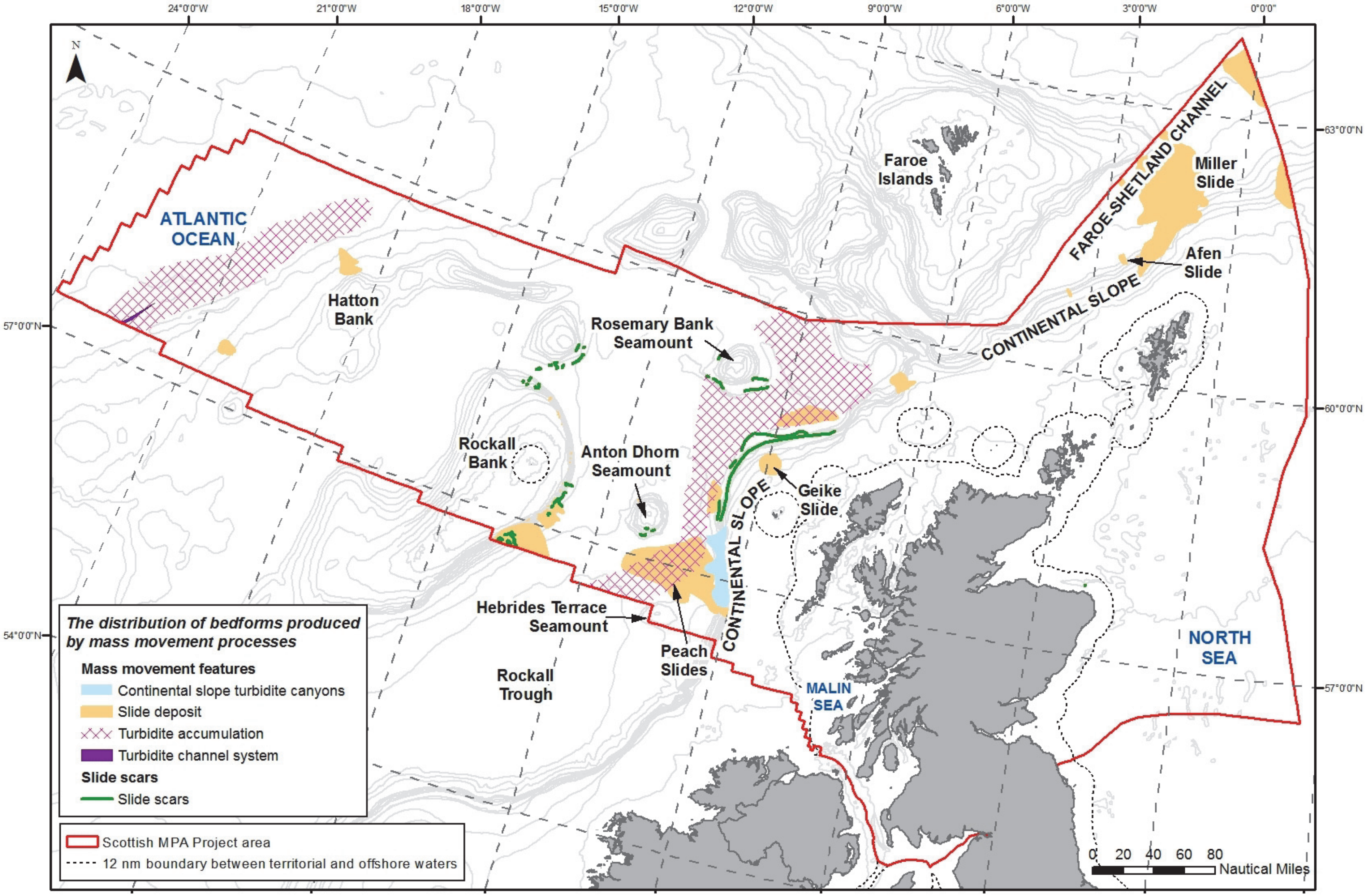


Source: Stoker *et al*. (2009). Reproduced with the permission of the British Geological Survey ©NERC. All rights reserved

Figure 5 *Integrated swath bathymetric image and NextMap digital terrain model of the Summer Isles region, Loch Broom and Little Loch Broom on the north-west coast of Scotland showing moraines and other landforms on the seabed*

4.2 Submarine Mass Movement

Submarine mass movement interests principally include those associated with submarine slides and turbidity currents. Large submarine slides covering many tens of km^2 are a characteristic feature of the continental slope surrounding Scotland's northern and western margins (Figure 6) (Evans *et al*., 2005a). They vary in terms of both age and expression: most of the older (pre-Holocene) slide deposits have been partially or completely buried within the sedimentary column, whilst other (predominantly Holocene age) slides have retained clear seabed expression. Larger slides (such as the Miller Slide) have lateral extents of over 50 km, whilst smaller slides (like the Afen Slide) are only a few kilometres wide. Where there has been a movement on a basal failure surface with little internal deformation except along a series of internal fault planes, the resultant morphology at the seafloor is usually a relatively steep slide scar or several slide scars at the head of the slide. Slide deposits can consist of accumulations of coherent blocks, some of which can be very large, mixed with debris flow deposits and with turbidites. Well-studied examples include the Peach and Geikie Slides (to the west of Scotland and the Hebridean continental slope) and the (palaeo) Afen and Miller Slides (to the north of Scotland on the Scottish side of the Faroe-Shetland Channel continental slope) (Figure 6), which mainly occurred during periods of rapid Quaternary sea-level rise (Leynaud *et al*., 2009). Numerous smaller slides, which occurred over the past 11,000 years or so, have been identified in the sea lochs of western Scotland (Stoker *et al*., 2006).



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. Geodiversity data from the GeMS database; in part from Defra MB0102 ©Crown copyright. 091113. All rights reserved.

Figure 6 *The distribution of bedforms produced by submarine mass movement processes*

Knowing the locations and dynamics of these slides is not only of scientific value, but also has practical relevance: for example, the Storegga Slide off western Norway caused a large tsunami that swept the seaboard of eastern Scotland c.8,100 cal. yr B.P. (Dawson *et al*., 2011), reaching onshore heights in Shetland at least 20 m above the sea level of that time (Bondevik *et al*., 2003; Smith *et al*., 2004). Understanding the dynamics of these ancient slides is very important as it enables the identification of those slope areas which could experience future slide events, potentially putting marine infrastructure and adjacent coastlines at risk. The Scottish seabed represents a key area for research into this type of geohazard.

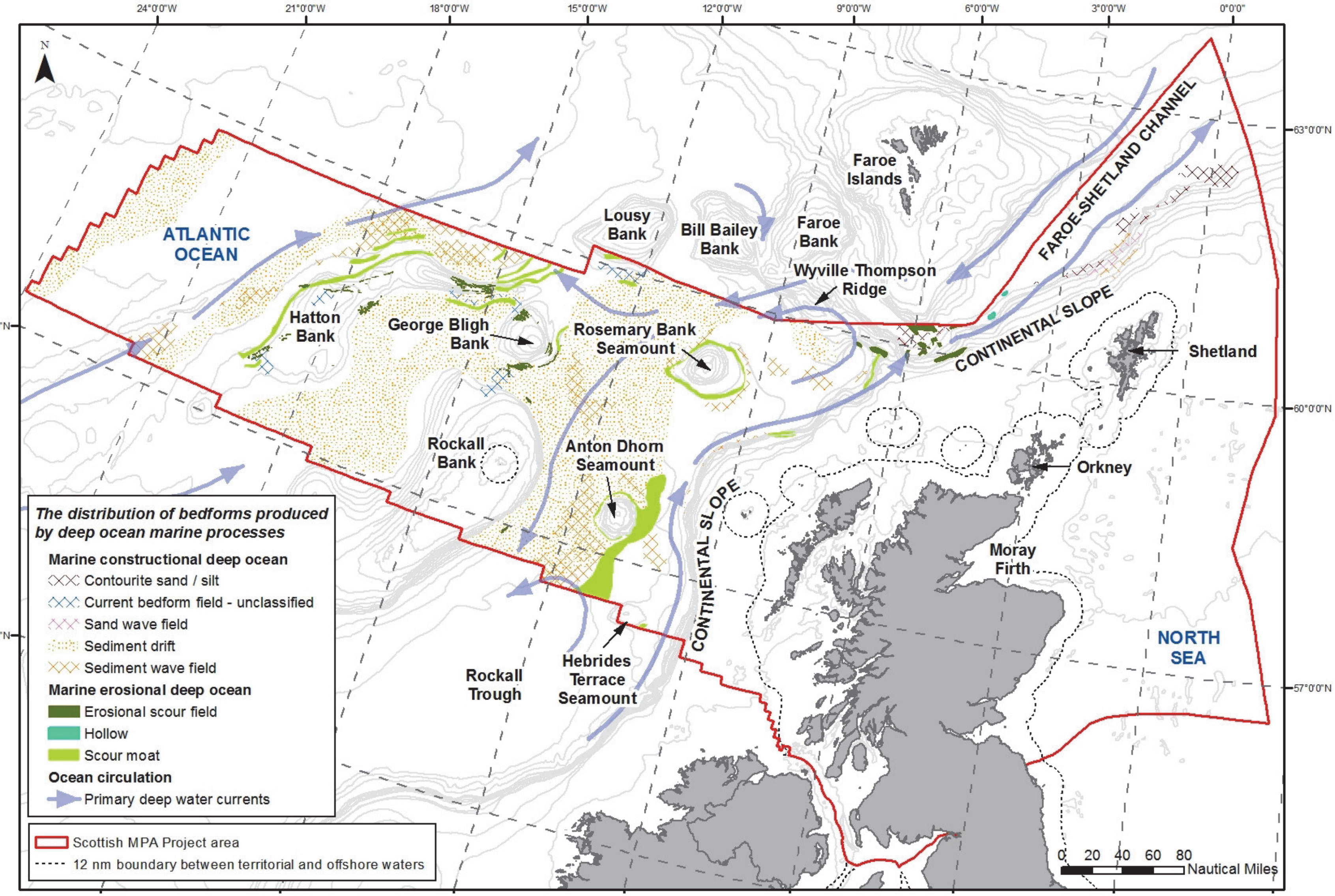
Turbidity currents are the main cause of erosion at the axis of continental slope turbidite canyons, examples of which are found on the Hebridean continental slope margin to the south-west of Scotland's seas. Turbidite accumulations occur mainly beyond the foot of the continental slope and especially at the mouths of slope canyons. Together with contourites, they comprise mostly the land-derived sediment that makes up the continental rises (Figure 6). The most extensive turbidite accumulations in Scottish waters are on the floor of the Rockall Trough west of the Malin Sea and west of Hatton Bank where they are sourced from southern Iceland (Elliott and Parson, 2008). The turbidite systems were for the most part active at times of low sea level when large quantities of sediment were transported near to the shelf edge by rivers.

4.3 Marine Geomorphology of the Scottish Deep Ocean Seabed

Oceanic contour-following currents dominate the sedimentation at certain depths. The North Atlantic Current flows north along the upper slope west and north of Scotland at depths shallower than about 500 m and occasionally spills onto the continental shelf. The Norwegian Sea water flows south through the Faroe-Shetland and Faroe Bank Channels. Some spills across the Wyville-Thomson Ridge and then flows clockwise around Bill Bailey Bank. Both of these currents are strong enough to form sand waves (Figure 7).

Scour moats and erosional scour fields occur where water flows are relatively higher due to restriction by geologically determined topography. The scour moats around igneous blocks north of Hatton Bank to the far west of Scotland are 50 - 200 m deep (MacLachlan *et al*., 2008), whilst well-developed moats occur at the base of a number of Scottish deep ocean rises including Anton Dohrn Seamount, and Rockall, George Bligh and Rosemary Banks. Deep-sea furrows near Lousy Bank are up to 150 m deep.

Sediment drifts (Figure 7) comprise extensive accumulations of muds and silts deposited and moulded by deep-sea currents. The surfaces of the sediment drifts are in many places moulded into large sediment waves (Hohbein and Cartwright, 2006). Along the West Shetland Margin, these contourite deposits form a complex of sandy bedforms that are unique in UK waters and have provided one of the first detailed studies of this scientifically important sedimentary facies (Masson, 2001). The surface sands are assumed to be of Holocene age, whilst the underlying muddy drift was deposited during the Pliocene to Early-Mid Pleistocene. The sandy contourites are a rare phenomenon known from few other places than the Faroe-Shetland Channel and its extension to the west (Akhmetzhanov *et al*., 2007). The muddy drifts, an important part of the architecture of much of the world's continental slopes and rises, are particularly well mapped here by oil industry seismic surveys. Analyses of some of these surveys are starting to reveal the history of currents flowing through this gateway between the Arctic and Atlantic basins, a key location for understanding past climate changes and linkages with ocean circulation (Rasmussen *et al.*, 2002).



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. Geodiversity data from the GeMS database; in part from Defra MB0102 ©Crown copyright. 091113. All rights reserved.

Figure 7 *The distribution of bedforms produced by deep ocean marine processes*

4.4 Seabed Fluid and Gas Seep

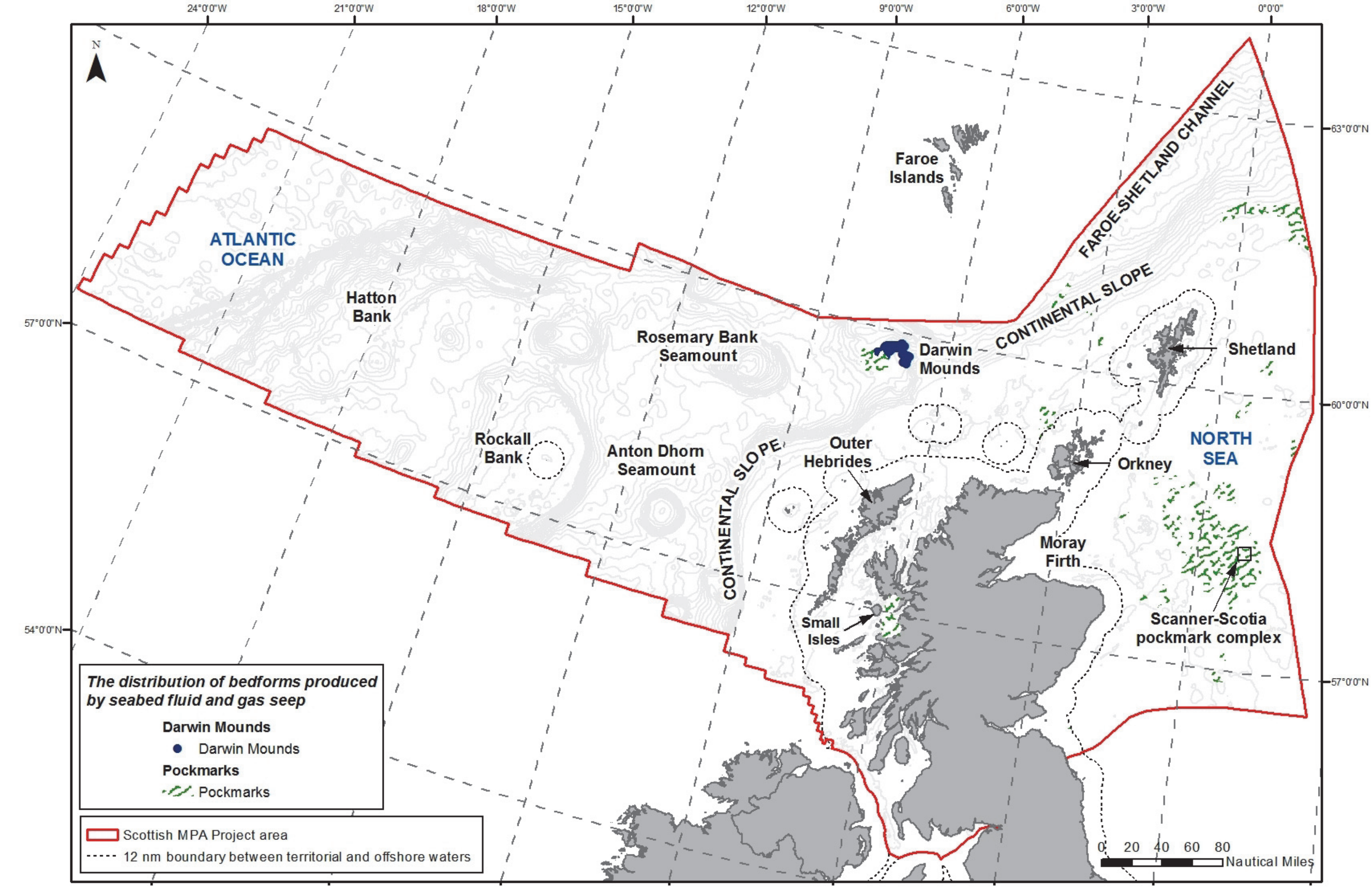
Fluid flow at the seabed can be through thick sediments from deep-seated sources. Where the flows of water and gases reach the seabed, pockmarks (Judd and Hovland, 2007) are a characteristic feature of much of the east and north of Scotland (Figure 8) and some, such as the Scanner Pockmark in the northern North Sea, are considered to be still active (Joint Nature Conservation Committee, 2008). For the most part, these features form shallow seabed depressions, typically several tens of metres in diameter and a few metres deep. However, 'giant' examples collectively form the Scanner-Scotia-Challenger pockmark complex in the North Sea.

Well-sorted sands that are overlain by less porous sediments are subject to sudden expulsion of the sand-water mixture as 'sand volcanoes'. This can result from shaking by earthquakes or the sudden loading by rapid deposition of sediment. The Darwin Mounds, north-west of Scotland, represent very unusual examples of this type of fluid-seep bedform and these small (≤5 m high) mound-tail features have not yet been described from elsewhere (Masson *et al*., 2003).

4.5 Cenozoic Structures of the Atlantic Margin

Cenozoic structures include a range of features formed during the last 65 Ma since the opening of the North Atlantic Ocean (Figure 9). They primarily include large structural blocks of Palaeogene igneous rocks left upstanding due to subsequent differential erosion of weaker surrounding sediments. Such large, deep-ocean bathymetric rises are characteristic of the deep waters to the far west of Scotland. Erosion of the uplifted flanks of the continent was accompanied by the deposition of large amounts of sediment into the gradually cooling and deepening oceanic basin. During the early rifting, large amounts of lava poured out along deep-seated fissures. A number of shallow igneous blocks located oceanwards of western Scotland range in size from isolated volcanic seamounts, such as the Rosemary Bank Seamount and the Anton Dohrn Seamount, up to the Wyville-Thomson Ridge and the Rockall Bank. They have a high proportion of igneous rocks with extensive areas of sub-aerial basalts (Edwards, 2002). Small volcanic parasitic cones occur on some of these seamounts and banks (e.g. Jacobs, 2006; Stewart *et al*., 2009).

Dating evidence from Anton Dohrn has played a scientifically important role in advancing understanding of the volcanic history of the North Atlantic Volcanic Province (O'Connor *et al*., 2000). It demonstrates that the continental rifting that formed the North Atlantic volcanic province began in the Late Cretaceous (c.70 Ma), earlier than previously thought. Along with Rosemary Bank and the Hebrides Terrace Seamount, Anton Dohrn is one of the few accessible remnants of such early mantle plume activity. In addition, the region has provided a range of sedimentary and geophysical evidence that reveals the dynamic evolution of a supposed 'passive' continental margin in response to changes in upper mantle convective flow (Praeg *et al*., 2005; Stoker *et al*., 2005, 2010; Holford *et al*., 2009, 2010). In turn, the associated tectonic movements have driven responses in erosion, sedimentation and deep-ocean circulation and provided the topographic conditions to support glaciation. Such tectonic processes may be characteristic of the development of 'passive' continental margins elsewhere and help to inform interpretation of their evolution (Stoker *et al*., 2005).



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. Geodiversity data from the GeMS database; in part from Defra MB0102 ©Crown copyright. 091113. All rights reserved.

Figure 8 *The distribution of bedforms produced by seabed fluid and gas seep*

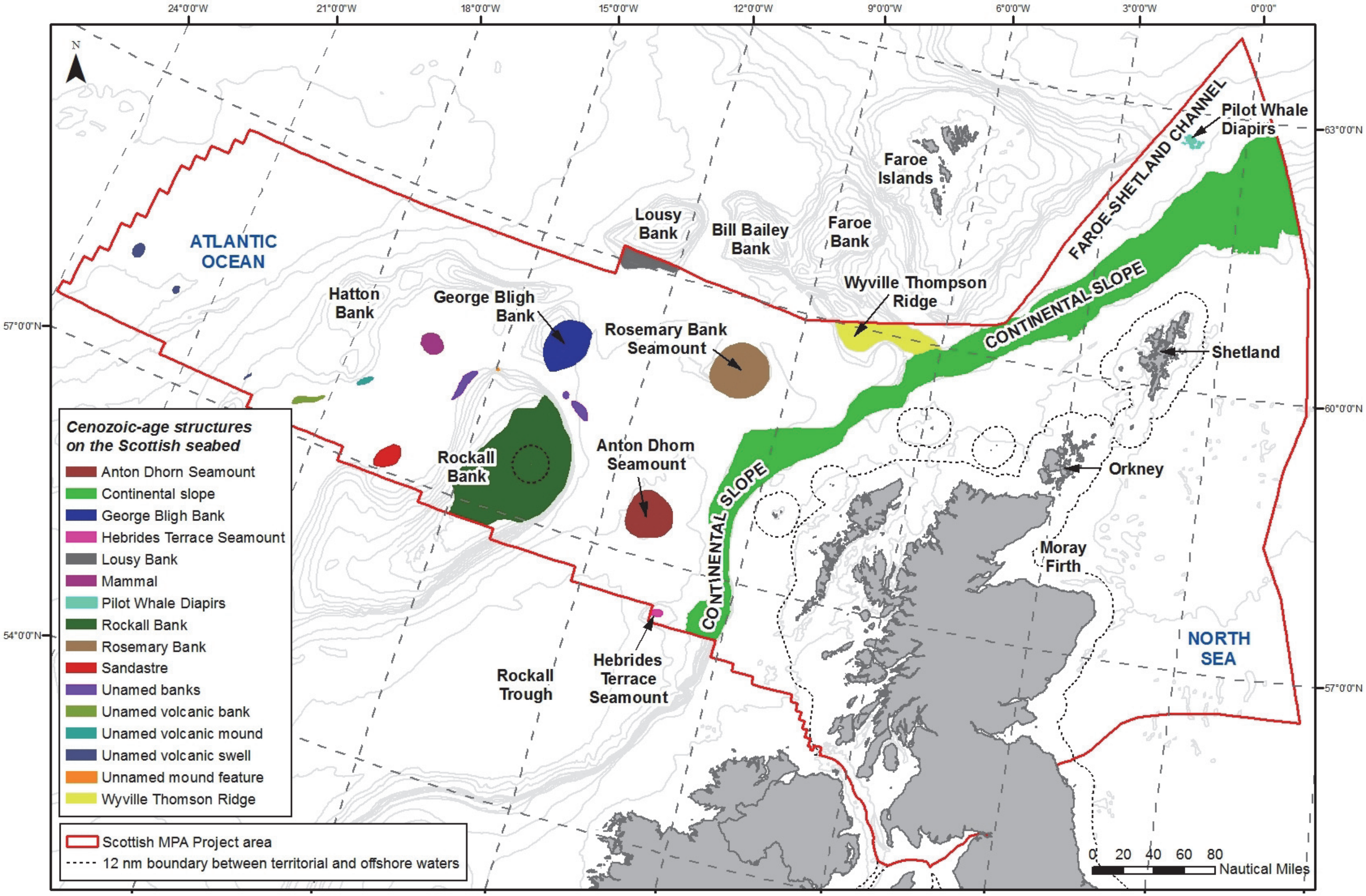


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Figure 9 *The distribution of Cenozoic-age structures on the Scottish seabed*

Also included within this block are mud diapirs produced by the upward movement of relatively fluid mud that is deeply buried by less fluid sediments. The mud contains rock clasts torn from the sides of the pipe, up which it moves. Although mud diapirs are relatively common globally, the only known examples in UK waters (with a seafloor expression) are the Pilot Whale Diapirs at the north end of the Faroe-Shetland Channel (Figure 10) (Holmes *et al*., 2003). The formation of these deep-water (c. 1,500 m) sediment mounds, measuring 2-3 km across and rising to more than 70 m above the surrounding sea floor, is related to overpressure of mobile sediments by the thick glacigenic sediment accumulation of the North Sea Fan and/or lateral tectonic compression (Ritchie *et al*., 2011) and can help to elucidate sub-surface fluid migration pathways within the Faroe-Shetland Channel (Ritchie *et al*., 2008).

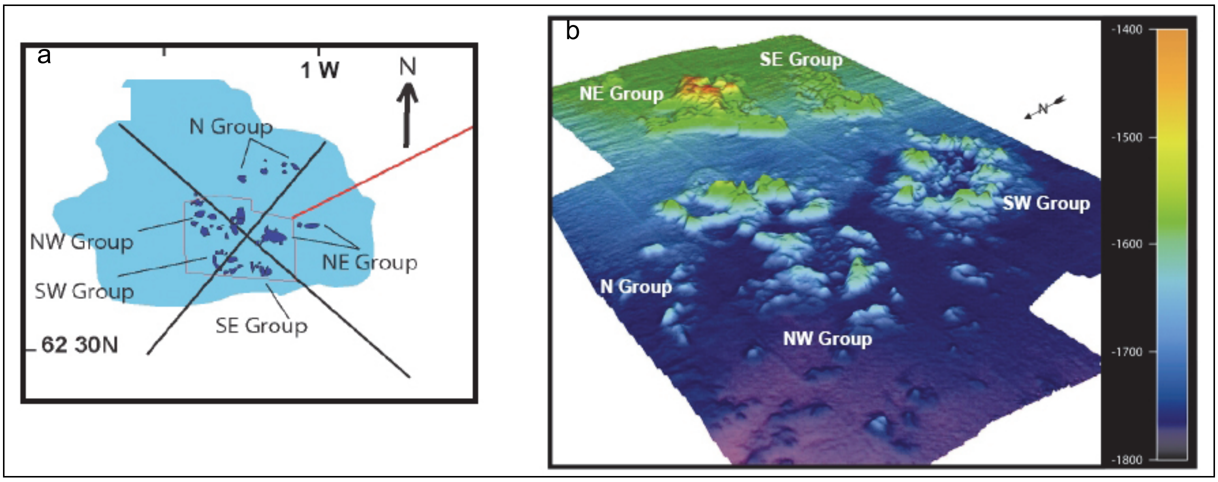

Figure 10 *The Pilot Whale Diapirs. (a) Location; (b) perspective shaded seabed topography of the five diapir groups shown in (a), generated from multibeam survey data*

These features represent the southernmost grouping of a series of replicate features that extend down the Norwegian margin, across the Vøring Plateau and Møre Basin (Hjelstuen *et al*., 1997). These mounds are formed from sediment that has been transferred to the seabed from rocks and sediments more than 24 Ma old. Mud volcanism, subsurface injection of soft sediment and diapirism are all likely to have been involved in the development of the Pilot Whale Diapirs, although their initial development is likely to have been triggered by growth of the Pilot Whale Anticline from early Pliocene times onwards (Ritchie *et al*., 2008).

4.6 Marine Geomorphology of the Scottish Shelf Seabed

Modern marine currents are partly reworking the complex seafloor morphology constructed by all of the processes outlined previously. The currents have been eroding some of the relict features and burying others as they form a new basal bed on much of the continental shelf and on parts of the deeper seabed where the currents are strong. Some marine process features are themselves relict from times of lower sea level, such as some deep offshore tidal banks, but the majority of marine process features are formed by present day currents (Belderson *et al*., 1982). The most significant types of current sweeping the shelf seafloor are tidal currents, storm surge currents and currents induced by storm waves.

The seafloor can be divided into zones where there are characteristic bedforms controlled by peak current speed. The classic zonal sequence down the velocity gradient (Belderson *et al*., 1982) is from scoured rock floors where the peak current is greater than about 1.5 ms^{-1}, to gravel wave fields and gravel furrow fields, to sand ribbon fields and, where sand is plentiful and tidal currents dominant, groups of open shelf tidal sand banks, to large sand wave fields, to fields of small sand waves, to fields of rippled sand to thin patches of sand where the current speed is less than about 0.4 ms^{-1}. Many of the above features occur within the Fair Isle Channel and to the North of Scotland. However, because the influence of currents and waves on the Scottish seabed can vary considerably over short distances, many areas of Scotland's seas display a variety of different current and wave-induced bedforms (Figure 11). There are a few bedforms that are considered characteristic of certain current types. Tidal sand banks, such as the spectacular Sandy Riddle Bank located to the East of Scotland in territorial waters, and symmetrical sand waves are only found in areas of tidal dominance. By contrast, sharp-edged sand patches are only found in areas of storm wave dominance, as are small symmetrical gravel waves.

Storm-surge currents dominate much of the middle shelf west and north of Scotland and cause eastward transport of sand through the Fair Isle Strait. Storm waves dominate areas where the directional currents (tidal, surge and oceanic) are too weak to move sand on their own. The two bedforms characteristic of storm waves are small symmetrical gravel waves and sharp-edged sand patches. Both of these bedforms occur at depths as great as 120 m. They are found, for instance, west of Scotland, north-west of Scotland in the coastal waters around Sula Sgeir, south-west of Scotland, off the coast of Islay, and in the Moray Firth, (Kenyon and Cooper, 2005). In shallower water depths, less than about 20 m, which includes the tops of sand banks, tidal flats and the ramp offshore of exposed coasts, storm waves have a higher effectiveness as agents of sediment transport especially when combined with directional currents (McCave, 1971).

The shelf areas off the Inner and Outer Hebrides and Northern Isles represent internationally important examples of non-tropical shelf carbonate systems (Scoffin, 1988; Light and Wilson, 1998). In these areas, sands and gravels have very high carbonate content (up to 99%). It is likely that storms continue to drive part of this clastic carbonate ashore, supplying the carbonate sands of the important coastal dune and machair systems (Brooks *et al*., 2013), although the supply may be declining (Hansom and Angus, 2001). The onshore geomorphology of the machair supports highly biodiverse grassland vegetation that is recognised to be of outstanding natural heritage importance (Angus, 1994). The areas offshore of the machair are the past and present sources of the carbonate and, as such, are considered to be critical to the functioning of the wider marine and coastal ecosystem (Hansom, 2003a). The processes of breakdown and transport of clastic carbonate are complex and little known, but a requirement for machair formation seems to be a wide extent of rocky seafloor, together with an inner shelf ramp of shell sands and gravels where the tidal currents are relatively weak but the wave-induced currents are especially strong to allow onshore transport (Brooks *et al*., 2013).

4.7 The Coastal Geomorphology of Scotland

The coastal geomorphology Scotland is an existing GCR category that incorporates a variety of coastal settings ranging from hard rock, high-energy coastlines to low-energy salt marsh and machair systems (May and Hansom, 2003). The machair systems are well developed within the Northern Isles and the Inner and Outer Hebrides. The carbonate sands which support these systems are derived from adjacent offshore settings, driven shoreward through the combined action of tides and waves (Section 4.6).

Other soft coastal GCR sites also have past and present dynamic links with nearshore sediment sources and transport processes. However, in the absence of detailed process studies it has so far proved too difficult to extend their boundaries offshore in a robust and meaningful way, and they are currently demarcated only down to Mean High Water Springs (MHWS).

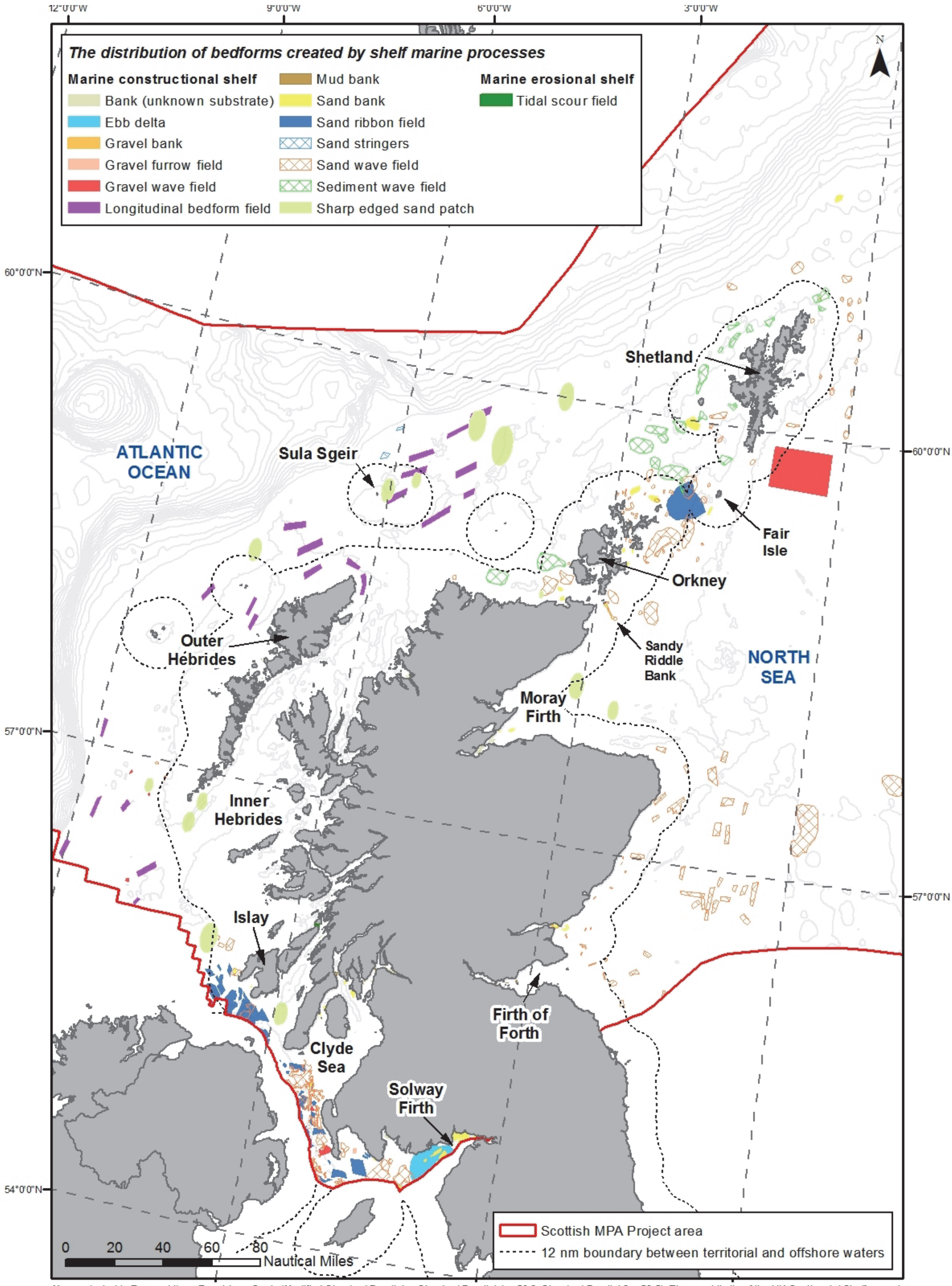

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Figure 11 *The distribution of bedforms produced by shelf marine processes - Marine Geomorphology of the Scottish Shelf Seabed*

As a result of rising sea levels during lateglacial and postglacial times, many landforms of coastal origin, such as cliffs, caves and erosional platforms, are now found submerged offshore (Figure 12). Particularly outstanding examples occur off St Kilda and Sula Sgeir to the west of Scotland in territorial waters and are thought to have formed during episodes of lower sea level which occurred during Quaternary glaciations (Sutherland, 1984b, 1987; Hansom, 2003b). Submerged peat and the tree stumps of former forests also provide clear evidence of rising sea level, e.g. on Sanday and South Ronaldsay in Orkney (Rennie, 2006), with many other examples occuring in the Hebrides and Shetland (Hoppe, 1965; Von Weymarn, 1974; Dawson *et al*., 2001). These submarine landforms provide valuable records of Quaternary sea-level change and coastal evolution.

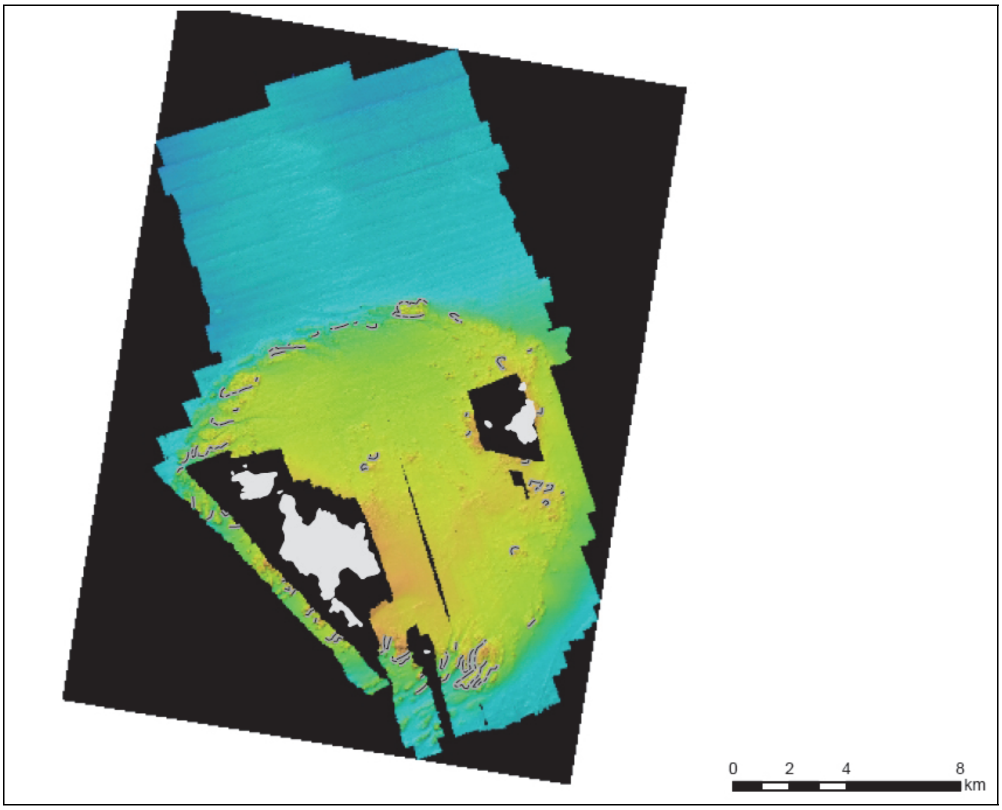

Figure 12 *Swath bathymetry around St Kilda with submerged cliffs marked [seabed imagery from Scottish Natural Heritage - image provided by BGS]*

4.8 Biogenic Structures of the Scottish Seabed

Biogenic structures on the seabed (see Figure 13 for distribution) are those created by marine animals and plants - potentially comprising the organism itself, such as beds of maerl or horse mussels, or arising from an organism's activities or effects. Biogenic sediment mounds are elevated features composed of the skeletal remnants of scleractinian cold-water corals (mainly *Lophelia pertusa* and *Madrepora oculata*) and a veneer of sands, muds and silts. The largest are the giant carbonate mounds, for example on the margins of the Rockall Trough and Plateau (Mienis *et al*., 2007; Roberts *et al*., 2008), that can be over 300 m high. Their location depends on the relatively strong currents that sweep the upper part of the slope in this region, providing a food supply for the cold water coral *L. pertusa*. Although *Lophelia* is the main reef-forming coral in the North-east Atlantic, it rarely forms reef complexes in territorial waters. Mingulay Reef, at the entrance to the Sea of the Hebrides, is unique in that it is the only known extant area with extensive cold-water coral reefs within UK territorial waters. *Lophelia* reefs have been present here for many thousands of years, possibly since the early postglacial period around 11,000 years ago (Davies *et al*., 2009).

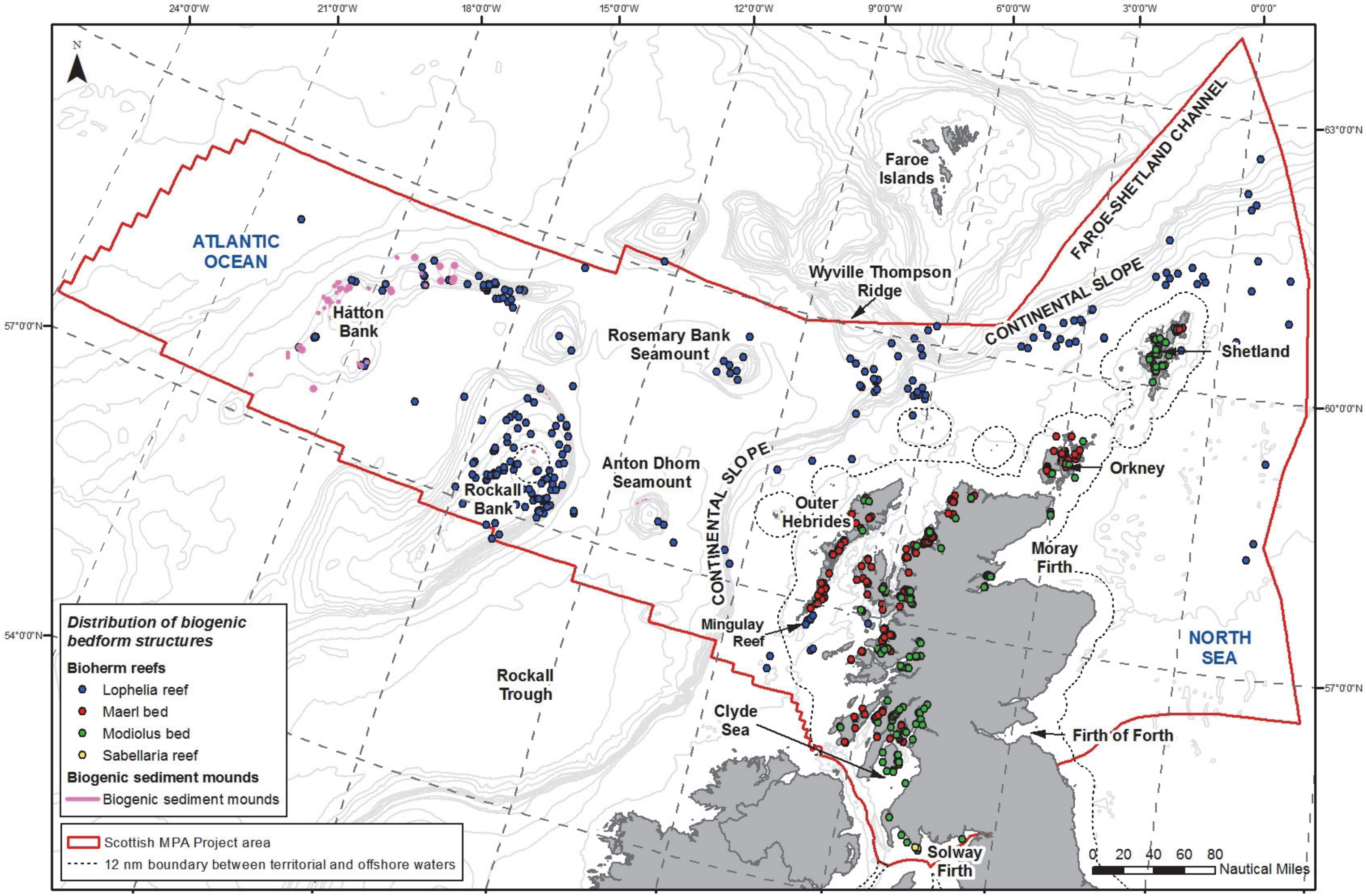

Figure 13 *The distribution of biogenic bedform structures. The locations of biogenic reefs are included since over time, these organisms may accumulate to form reefs which are solid, massive structures with a geomorphic expression*

The horse mussel *Modiolus modiolus* can occur in dense beds (Holt *et al*., 1998) in water depths of between 5 - 250 m. The structurally complex, raised biogenic habitat supports high levels of associated biodiversity, with the habitat often moulded by strong currents into low, wavy bedforms. Extensive beds of maerl, a free-living red seaweed with a hard chalky skeleton, are also widely distributed along the west coast, the Outer Hebrides and the Northern Isles. This biogenic habitat is restricted to shallow tide-swept sandy sea beds where sunlight can penetrate, up to around 20 m depth. Reefs of the polychaete worm *Sabellaria* spp. are also mainly found in shallow waters, and although rare in Scottish waters, are known to occur in the north Irish Sea Basin close to the Galloway coast in the Solway Firth (Figure 13).

4.9 Summary of geoheritage value

Overall, although individual features such as glacial bedforms, submarine slides and sites with long sedimentary records, *inter alia*, occur elsewhere on the North-west European margins (Nielsen *et al*., 2005), the marine geodiversity of Scottish waters is outstanding for the assemblage of features present. It is the particular combination of Palaeogene volcanism and rifting, Cenozoic structural blocks, post-rifting evolution (uplift/exhumation and subsidence/burial), glaciation, high benthic carbonate production and contemporary marine geomorphological processes that give the region its distinguishing characteristics. Sea level has also fluctuated, so that a range of marine, coastal and subaerial processes has operated over the shelf at different times. A critical theme that emerges is the landscape and process continuity from the highest mountains to the deep ocean floor (Figure 3). From a scientific viewpoint, to understand the long-term geological and landscape evolution of Scotland, the evidence must be considered as an integrated whole (e.g. Hall and Bishop, 2002; Stoker *et al*., 2005, 2010; Bradwell *et al*., 2008a; Holford *et al*., 2010), with a significant component occurring offshore. To put this into context, the area covered by the Scottish MPA Project is ~608,000 km^2 from MHWS out to the limit of the claimed UK Continental Shelf. This is over 7.5 times the size of Scotland's land area (an estimated 80,060 km^2 - Baxter *et al*., 2011). For a country of Scotland's size, the geodiversity of this total landscape is quite exceptional and, as outlined above, has a significant bearing on scientific questions of international significance relating notably to the evolution of 'passive' continental margins and the dynamics of marine-based ice sheets and their coupling with climate and ocean circulation patterns.

5. KEY GEODIVERSITY AREAS IN SCOTTISH WATERS

The methodology outlined in Section 3 was used in a desk-based study to identify key Scottish marine geodiversity areas (Brooks *et al*., 2013). A provisional list of key geodiversity areas was initially compiled using expert judgement and existing published information from a GIS database of previously identified geological and geomorphological seabed features (Brooks *et al*., 2009), as well as unpublished information. This was then tested and refined at a workshop attended by invited Earth scientists with expertise and knowledge of the marine geology and geomorphology of the Scottish seabed, including Quaternary glacial geomorphology; coastal geomorphology and shallow marine seabed processes; slope instability and associated submarine mass movement processes and deep-offshore seabed processes. Following the workshop, the list of key geodiversity areas was revised in the light of the recommendations of the expert group, re-circulated for further comment, and then finalised. There was a general consensus on both the category blocks and the key geodiversity areas. Together these areas represent a coherent national network of marine geodiversity interests at the time of writing. Note, however, that intertidal and nearshore extensions to existing Coastal Geomorphology GCR sites were not considered in the assessment because of a lack of information on the extent of physical processes that would enable the system boundaries to be defined.

Thirty-five key geodiversity areas were identified as being of national or international importance (Table 2 and Figure 14). These are grouped according to their main subject block (see Brooks *et al*., 2013 for further details including descriptions of each of the key geodiversity areas). Many of the key areas contain additional supporting interests spanning multiple blocks and these additional blocks are acknowledged in Table A2 (Appendix 2), although the focus of information presented is on the principal interest.

Table 2 *List of 35 key geodiversity areas in Scottish waters categorised by thematic block*

Thematic block	Key geodiversity area name	Ref. no
The Quaternary of Scotland [11]*	Summer Isles to Sula Sgeir Fan	1a & b
	The Small Isles	2
	Loch Linnhe and Loch Etive	3
	West Shetland Margin Palaeo-depositional System	4
	The Southern Trench	5
	Devil's Hole	6
	Fladen Deeps	7
	Wee Bankie	8
	Bosies Bank	9
	North Sea Fan (Scottish sector)	10
	The Barra Fan	11
Submarine Mass Movement [4]	Geikie Slide	12
	The Afen Slide and Palaeo-Afen Slide	13
	The Peach Slide Complex	14
	Miller Slide	15
Marine Geomorphology of the Scottish Deep Ocean Seabed [5]	West Shetland Margin Contourite Deposits	16a - c
	Central Hatton Bank (and adjacent basin floor)	17
	Rosemary Bank Seamount (and adjacent basin floor)	18
	North-East Rockall Bank (and adjacent basin floor)	19
	George Bligh Bank (and adjacent basin floor)	20
Seabed Fluid and Gas Seep [2]	Darwin Mounds	21
	Scanner - Scotia - Challenger Pockmark Complex	22a & b
Cenozoic Structures of the Atlantic Margin [2]	Anton Dohrn Seamount (and adjacent basin floor)	23
	The Pilot Whale Diapirs	24
Marine Geomorphology of the Scottish Shelf Seabed [6]	Sandy Riddle Bank (south-east of Pentland Skerries)	25
	Fair Isles Strait Marine Process Bedforms	26
	Outer Hebrides Carbonate Production Area	27
	Inner Hebrides Carbonate Production Area	28
	Orkney Carbonate Production Area	29
	Shetland Carbonate Production Area	30
Coastal Geomorphology of Scotland [2]	St Kilda Archipelago Submerged Landforms	31
	Sula Sgeir Submerged Platforms	32
Biogenic Structures of the Scottish Seabed [3]	Rockall Bank Biogenic Sediment Mounds	33
	Hatton Bank Carbonate Mounds	34
	Mingulay Reef	35

*The number of key areas in each block is given in brackets

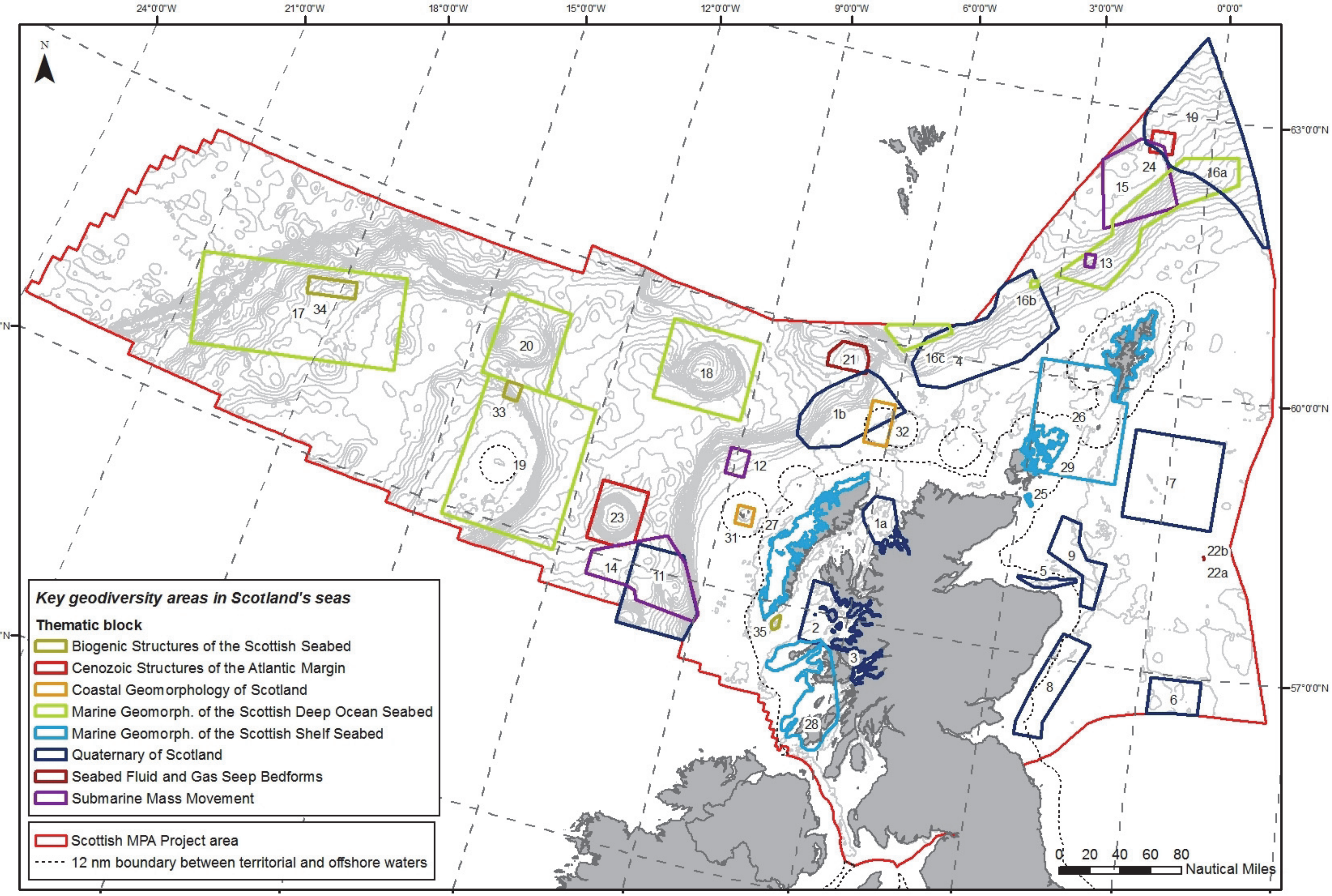

Figure 14 *Key geodiversity areas identified on the Scottish seabed (see Table 2 for area names and thematic blocks and Table A2, Appendix 2 for additional information) (from Brooks* et al.*, 2013)*

The largest number of areas (11) falls within the Quaternary of Scotland thematic block. This reflects the diversity of features representing Scotland's glacial legacy as well as the relatively strong focus on Quaternary interests in the study of seabed landforms and deposits. In some cases, the prime interest lies in individual landforms (e.g. the Scanner and Scotia Pockmarks), but in others it is not simply the presence of particular landforms but rather the assemblage of landforms, their context and the interpretations placed upon them (e.g. the palaeo-ice stream landform assemblage represented by the Summer Isles to Sula Sgeir Fan key geodiversity area).

The boundaries around each key area were drawn to capture the main landforms/assemblages of landforms for which the area was identified. The accuracy with which this has been achieved is variable and constrained by the extent of existing surveys. In a number of cases, this is a key information gap. Most of the boundaries are rectilinear, reflecting guidance that they should be drawn as simply as possible whilst encompassing a viable amount of the geodiversity interests to be represented. Supporting statements include scientific assessments and literature reviews (Brooks *et al*., 2013). The focus on the MPA process and context, and the emphasis on seabed features means that not all locations with interests of high scientific importance are included (e.g. those with sub-seabed sedimentary sequences and bedrock features). There has also been considerable seabed mapping over the last few years, especially associated with offshore renewable developments. As this information becomes available to the academic community, together with the results of future seabed mapping, it is probable that additional geodiversity areas of high scientific importance will be identified under the assessment methodology developed here. Also, additional areas with important biodiversity support functions may emerge in due course.

It is also important to note that the key geodiversity areas identified within each subject block sometimes comprise several 'sub-areas'. This arises where the various interests within the key geodiversity area are separated by very large distances (e.g. the contourite deposits along the West Shetland Margin which occur as groupings several tens of kilometres apart).

Most of the key geodiversity areas meet guideline 1a (see Table A1, Appendix A) of the MPA Selection Guidelines (Marine Scotland, 2011b). None are presently considered to be under specific threat (guideline 1b, Table A1). A few (the carbonate production areas) have wider functional significance, particularly in the context of coastal machair habitats (guideline 1c, Table A1).

6. THE WIDER VALUE OF SCOTLAND'S MARINE GEODIVERSITY

As in the terrestrial environment (Gordon and Barron, 2013), Scotland's marine geodiversity is important not only for its inherent scientific value, but also for the wider ecosystem services it provides (see Appendix 3 for details). Geological and geomorphological processes have shaped the large-scale physiography of the Scottish seabed, so that the special character and natural diversity of Scotland's seas have been influenced to a large degree by the interaction of the geological evolution and geographical location in relation to major ocean currents. The cumulative effects of the tectonic evolution of the continental margin during the Cenozoic, processes of pre-glacial erosion and deposition, multiple glaciations and sea-level change contribute significantly to the diversity of the physiography, and hence marine habitats, at different scales, namely:

- the large-scale physiography - continental shelf, slope, deep ocean, deep-ocean rises - which influences hydrographic environments and processes;

- the regional-scale physiography comprising shelf features (islands, sheltered fjord coasts, bays, banks, mounds) and deep-ocean features (basins, troughs, sediment plains, seamounts, banks) which influences more local habitat opportunities and diversity.

Scotland's seas represent a huge environmental, economic and recreational resource, essentially underpinned by geodiversity. In particular, there are clear relationships between marine geodiversity and ecosystem support, healthy diverse seas, offshore development (oil, gas and renewables) and fisheries (Baxter *et al*., 2011), as well as a range of other regulating, supporting, provisioning and cultural services (Table A3, Appendix 3). As yet there has been no systematic assessment of the role of geodiversity in supporting marine life and providing a diversity of wildlife habitats.

7. PRESSURES ON SCOTLAND'S MARINE GEODIVERSITY

Human activities and development in the marine environment have the potential to impact upon both geomorphological and geological features at the seabed (Brooks *et al*., 2009; Defra, 2010; Baxter *et al*., 2011; Brooks, 2013). Such activities include; fishing, aggregate extraction, hydrocarbon exploration, renewable energy developments, cables and pipelines, navigational dredging, dredge waste disposal and military activity (Table 3). The principal potential impacts from these activities (Table 3) may be categorised into five generic types, similar to those affecting terrestrial geodiversity interests (Gordon and Barron, 2011):

- physical damage or loss through removal of material from the seabed, disturbance to the seabed or installation of infrastructure;
- loss of visibility (e.g. through burial);
- fragmentation of the interest and loss of relationships between interest features;
- disruption of natural processes (e.g. sediment cycling); and
- loss of natural state through stabilisation of active landforms (e.g. through coastal defences).

Given the dynamic nature of the marine environment, all of these activities have the ability to cause both near- and far-field effects through the interruption of existing sediment transport pathways and hydrodynamic processes. Furthermore, any disturbance of soft sediments on the seabed will also give rise to the suspension of fine particles in the water column, potentially altering local-regional sedimentation patterns. The potential impacts of marine activities on the seabed are discussed in more detail in 'Charting Progress II: Productive Seas Report' (Defra, 2010). The planned nearshore expansion of marine renewable energy arrays in Scottish waters is a relatively new pressure, with uncertain impacts on marine geomorphological processes.

Building on the study of Brooks *et al*. (2009), Brooks (2013) developed a generic sensitivity assessment of the main categories of geodiversity interest to different activities in Scotland's seas. A feature that is said to be sensitive is one that is readily adversely affected by external factors (pressures) arising from human activities, and is expected to recover only over a very long time period, or not at all. The generic sensitivity assessment for different categories of geodiversity interests takes into account sediment type or geology (resistance) and the ability of these interests to recover from degradation (resilience) (Brooks, 2013). Features comprising soft, unconsolidated material (e.g. sand waves) are likely to be far more susceptible to a pressure than features comprised of compacted, hard material (e.g. glacial moraines) or cut into bedrock (e.g. glacial troughs). Features with low resistance and low resilience are likely to be highly sensitive and vice-versa. For example, as a general rule, large-scale erosional glacigenic features are likely to have low sensitivity, and relict sediment bedforms a comparatively higher sensitivity. Active sediment bed forms such as sand banks and sand waves have a high resilience score since they are (potentially) able to recover quickly from impact.

Table 3 *Principal activities giving rise to pressures on geodiversity interests (adapted from Brooks, 2013)*

Activities giving rise to potential pressures	Potential pressures
Energy production and associated infrastructure (e.g. offshore oil and gas, wind farms, wave and tidal turbines)	Physical change to landforms/processes Physical removal (extraction of substratum) Seabed surface scour/penetration Sub-seabed surface scour/penetration Water flow (tidal current) changes - local Wave exposure changes - local
Extraction of non-living resources (e.g. capital/ maintenance dredging, sand and gravel, and oil and gas)	Physical change to landforms/processes Physical removal (extraction of substratum) Siltation rate changes (high) Sub-seabed surface scour/penetration Wave exposure changes - local
Extraction of living resources (e.g. harvesting seaweed, fishing)	Seabed surface scour/penetration Sub-seabed surface scour/penetration Water flow (tidal current) changes - local
Food production (aquaculture - fin fish and shellfish)	Physical change to landforms/processes
Non-energy infrastructure (cables and pipelines; ports, marinas, leisure facilities; coastal defence and land claim)	Physical change to landforms/processes Physical removal (extraction of substratum) Seabed surface scour/penetration Sub-seabed surface scour/penetration Water flow (tidal current) changes - local Wave exposure changes - local
Military activities (e.g. seabed activity)	Physical change to landforms/processes Physical removal (extraction of substratum) Siltation rate changes (high) Seabed surface scour/penetration Sub-seabed surface scour/penetration
Shipping (anchor use & propeller scour)	Seabed surface scour/penetration Sub-seabed surface scour/penetration
Waste disposal (sewerage, munitions, navigational dredging and quarrying)	Physical change to landforms/processes Siltation rate changes (high)

Note: physical change to landforms/processes includes permanent change from one marine habitat type to another through a change in substrate (e.g. from sediment to solid substrate, including artificial through the use of concrete mattresses, rock dumping etc.).

The sensitivity assessment of individual geodiversity feature component interests (summarised in Table A4, Appendix 4) is indicative only, but shows that just under half of the geodiversity feature component interests of the geodiversity key areas have a low generic sensitivity to the pressures arising from current human activities. This is because although most of the feature components are relict (thereby having either low or no resilience), many have high resistance to pressures since they are typically composed of hard geology which has a low susceptibility to modification. Conversely, just over half are potentially sensitive to one or more pressures.

Further analysis is required for any downscaled application at a site-specific level both to define the relative sensitivity of individual sites and their constituent components and to assess their vulnerability (which requires a consideration of both sensitivity and exposure to particular activities) to a given pressure in order to help inform the development and prioritisation of site-specific management options for geodiversity features within possible Nature Conservation MPAs/MPA search locations. Consideration of the sensitivities of the particular combinations of features and component interests present and also the impacts of fragmentation of the interests and loss of relationships is crucial at a site-specific level. It is also important that the actual magnitude, spatial extent and precise location of any identified pressures are taken into account.

8. ASSESSMENT OF THE SCOTTISH MPA PROCESS AND EXISTING MARINE PROTECTED AREAS AS A MECHANISM FOR MARINE GEOCONSERVATION

In total, 33 possible Nature Conservation MPAs and 4 MPA search locations (see Appendix 5 for details) have been identified that could contribute to the MPA network in Scotland's seas (SNH and JNCC, 2012)[1]. Examples of most, if not all, of the individual geodiversity interests, or parts of them, present in Scottish waters are included within the possible MPAs/MPA search locations and/or existing protected areas (see Table A6, Appendix 6). However, as noted above, in assessing the MPA process as a mechanism for marine geoconservation, it is important to bear in mind that it is the assemblages of interests present and the interpretations placed upon them that, to a significant degree, determines the national and international scientific importance of the key geodiversity areas in Scottish waters, not simply the representation of individual features.

The following five possible MPAs/MPA search locations fully enclose six discrete key geodiversity areas: South-east Fladen, North-east Faroe Shetland Channel, Rosemary Bank Seamount, Geikie Slide and Hebridean Slope, and the Southern Trench.

Furthermore, the North-east Faroe Shetland Channel (with the Faroe-Shetland sponge belt) and the Small Isles possible MPAs encompass at least 75% by area of an additional two key geodiversity areas; while four others (Firth of Forth Banks Complex, The Barra Fan and Hebrides Terrace Seamount, Loch Creran and Loch Sunart to the Sound of Jura) collectively provide more partial overlaps (25-75%) with three other key geodiversity areas. Although the North-west sea lochs and Summer Isles includes <25% of the Summer Isles part of the Summer Isles to Sula Sgeir Fan key geodiversity area, it does contain a particularly important part of this area. The Eye Peninsula to Butt of Lewis MPA search location also includes important features (mega-scale glacial lineations) that are part of this same key geodiversity area. In the case of all these possible Nature Conservation MPAs, the presence of the geodiversity features provides significant additional scientific justification for their selection.

Existing protected areas (SACs, SPAs and areas with existing fisheries restrictions in place) incorporate all, or a significant (>75%) part of, an additional seven key geodiversity areas (Table A6).

In terms of coverage of geodiversity features within the possible Nature Conservation MPAs/MPA search locations and existing protected areas, the breakdown by key thematic block is summarised overleaf and illustrated in Figure 15.

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[1] The 33 possible Nature Conservation MPAs were subject to a 16-week formal consultation over the summer 2013 and a final decision from the Scottish Government on the progression of these proposals is expected in early 2014. A decision on whether to consult on the remaining four MPA search locations is also expected at this time.

8.1 Quaternary of Scotland

Quaternary of Scotland feature interests are represented in several possible MPAs/MPA search locations (Table A6), notably in the North-east Faroe Shetland Channel (North Sea Fan), the Southern Trench (the Southern Trench), Small Isles (Small Isles), Firth of Forth Banks Complex (Wee Bankie), Loch Creran and Loch Sunart to the Sound of Jura (Loch Linnhe and Loch Etive), and The Barra Fan and Hebrides Terrace Seamount (the Barra Fan). Together, these areas incorporate key elements of the footprint of the last British-Irish Ice Sheet and its associated landforms and deposits, including ice stream lineations, ice sheet limit moraines, trough-mouth fans, recessional moraines, iceberg ploughmarks, debris flow deposits and channels, and tunnel valleys. Notwithstanding this correspondence, however, there are some notable gaps (e.g. Devil's Hole) or examples of partial coverage where the landform assemblages in 9 of the 11 geodiversity key areas are intersected by the boundaries of the possible MPAs/MPA search locations or of existing protected areas (Figure 15). Consequently, integral parts of the key geodiversity interests are excluded.

8.2 Submarine Mass Movement

Submarine Mass Movement feature interests are represented in the North-east Faroe Shetland Channel possible MPA (Miller Slide) and Geikie Slide and Hebridean Slope (Geikie Slide) possible MPA (Table A6). However, the Geikie Slide and Hebridean Slope possible MPA is a science-based alternative currently being considered alongside South-west Sula Sgeir and Hebridean Slope possible MPA and may not be progressed if the alternatives are accepted. Should it be excluded, the Geikie Slide geodiversity feature would not be represented. A small part of the Peach Slides Complex lies within The Barra Fan and Hebrides Terrace Seamount possible MPA. The Afen and Palaeo-Afen Slides are not included within any possible MPAs/MPA search locations or existing protected areas.

8.3 Marine Geomorphology of the Scottish Deep Ocean Seabed

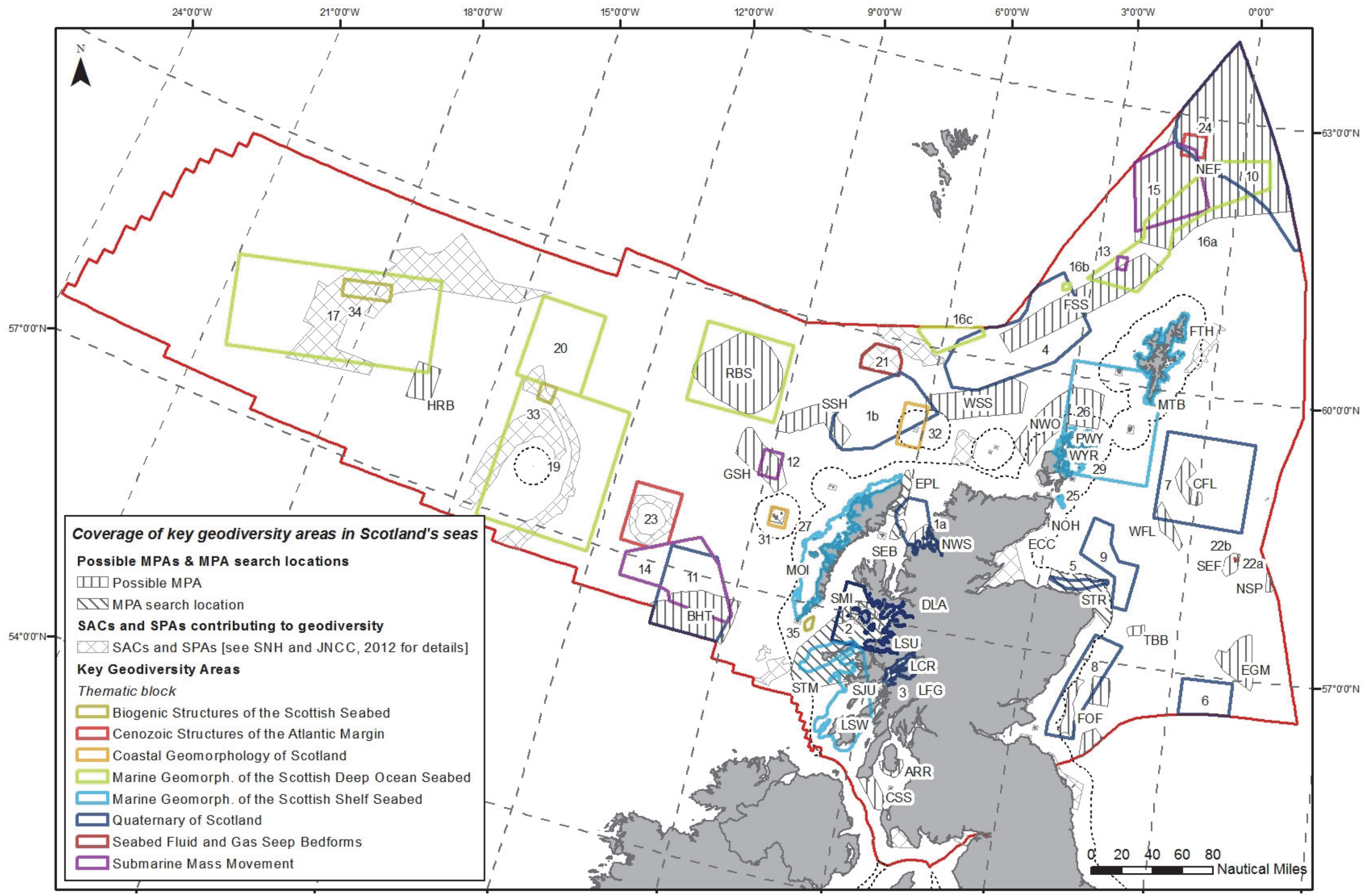
Marine Geomorphology of the Scottish Deep Ocean Seabed feature interests are represented in several possible MPAs (Table A6) - the Rosemary Bank Seamount (Rosemary Bank) and the Faroe-Shetland sponge belt/Faroe-Shetland Channel (West Shetland Margin Contourite Deposits) - and existing protected areas - North-west Rockall Bank cSAC and East Rockall Bank cSAC (North-East Rockall Bank and adjacent sea floor) and Hatton Bank cSAC (Central Hatton Bank and adjacent basin floor). The only key geodiversity area not covered is George Bligh Bank.

8.4 Seabed Fluid and Gas Seep

Seabed Fluid and Gas Seep interest features are fully covered by the South-east Fladen possible MPA (Scanner-Scotia-Challenger Pockmark Complex) and Darwin Mounds SAC (Darwin Mounds) (Table A6). However, South-east Fladen is a science-based alternative currently being considered alongside Central and Western Fladen possible MPAs and may not progress. Should this be the final conclusion, 50% of the Scanner-Scotia-Challenger Pockmark Complex would still be considered adequately protected by the Scanner Pockmark SAC.

8.5 Cenozoic Structures of the Atlantic Margin

Cenozoic Structures of the Atlantic Margin feature interests are fully covered by the North-east Faroe-Shetland Channel possible MPA (Pilot Whale Diapirs) and to a significant extent in the Anton Dohrn Seamount cSAC (Anton Dohrn Seamount and adjacent basin) (Table A6).



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. Geodiversity data from the GeMS database; in part from Defra MB0102 ©Crown copyright. 091113. All rights reserved.

Figure 15 *Coverage of key geodiversity areas within possible Nature Conservation MPAs/MPA search locations and existing protected areas*

Key geodiversity areas are numbered (see Table 2 for details). Possible MPAs/MPA search locations labelled by three-letter code (see Table A5 for details). Existing protected areas (SACs and SPAs) are shown but not labelled (see SNH and JNCC, 2012 for details). Other area-based measures are not mapped.

8.6 Marine Geomorphology of the Scottish Shelf Seabed

Marine Geomorphology of the Scottish Shelf Seabed feature interests are not well represented (Table A6). The Sandy Riddle key geodiversity area is excluded and the dynamic landforms and processes in the Fair Isle Strait Marine Process Bedforms key area are poorly represented in the MPA proposals and existing protected areas. The important and extensive shelf carbonate production areas of Shetland, Orkney and the Outer Hebrides are also not represented to any significant extent within the possible MPAs/MPA search locations and existing protected areas.

8.7 Coastal Geomorphology of Scotland

Coastal Geomorphology of Scotland feature interests are represented in existing protected areas in the St Kilda World Heritage Site and SAC (St Kilda Archipelago Submerged Landforms), but the North Rona and Sula Sgeir SPA includes only a small part of the Sula Sgeir Submerged Platforms (Table A6).

8.8 Biogenic Structures of the Scottish Seabed

Biogenic Structures of the Scottish Seabed feature interests are mainly covered by existing protected areas: Hatton Bank cSAC entirely contains Hatton Bank Carbonate Mounds, and East Mingulay cSAC entirely contains the Mingulay Reef key geodiversity area (Table A6). The East Rockall Bank cSAC covers a significant part of the Rockall Bank Biogenic Sediment Mounds. The management in place at these locations is considered to afford adequate protection for the geodiversity interests present.

9. CONCLUSIONS

Scotland's seas contain geodiversity features of national and international scientific importance for a range of interests representing the evolution of the North-west European continental margin, the dynamics of marine-based ice sheets and their coupling with climate and ocean circulation patterns, and past and present marine processes. These geodiversity interests are also a significant asset for their role in providing ecosystem services, including seabed habitats for marine life and the basis for offshore energy development (oil, gas and renewables) and fisheries.

As part of a wider study of the characterisation of Scotland's territorial and offshore waters, 35 key areas have been selected to represent eight categories of nationally and internationally important geodiversity interests at the seabed surface. Many of these areas have multiple interests. It is likely that additional key areas may be identified as further survey information becomes available. This is the first time that marine geodiversity interests have been audited systematically at a national level in Scotland, and indeed elsewhere. Together with detailed information on marine wildlife and habitats, the geodiversity audit has contributed to a national overview of the marine environment. The information has been used to advise Scottish Government and others on marine conservation and development, including international commitments to create a network of marine protected areas (SNH and JNCC, 2012).

Of the eight geodiversity categories (thematic blocks), the interests of five could be very well represented by the evolving MPA network. In the three other cases, Quaternary of Scotland, Submarine Mass Movement and Marine Geomorphology of the Scottish Shelf Seabed, the coverage is more limited. In total, 15 of the 35 key geodiversity areas are significantly incorporated (>75% by area) within the possible Nature Conservation MPAs/MPA search locations and existing protected areas and a further 4 overlap by between 25-75% by area. Overall therefore, and bearing in mind the supporting role accorded to geodiversity in the

Scottish MPA Selection Guidelines, the process has the potential to significantly advance geoconservation in Scottish waters (see below). This is notwithstanding that there are still options around which possible Nature Conservation MPAs/MPA search locations go forward, resulting in some uncertainty over the final representation of key geodiversity interests. The MPA process has also been moderately successful in developing an integrated approach, since the presence of key geodiversity features provides significant additional scientific justification for the selection of 24 of the 37 possible Nature Conservation MPA/MPA search locations (SNH and JNCC, 2012).

The extent to which the MPA process has actually been successful in meeting the needs of geoconservation in terms of affording protection to these interests still remains to be fully determined since the inclusion of all or part of a geodiversity feature within the possible MPAs/MPA search locations or existing protected areas does not automatically provide protection. Ultimately, the real measure of success, or otherwise, will depend on how well the management delivers for geoconservation and how the requirements of those features or parts of features not included within protected areas are addressed under marine planning. Further work to define the presence and distribution of finer-scale geodiversity interests within a number of the possible MPAs and to determine the sensitivities of the geo-features to pressures associated with activities to which they are exposed is required to help inform this process.

The geodiversity interests in the key areas range from large-scale landforms (e.g. submarine landslides and trenches) to small-scale dynamic features (e.g. sand waves). Consequently, and as shown by the generic sensitivity assessment, they will have a range of sensitivities to different pressures and hence different conservation/management requirements. The next step is to apply sensitivity assessment at a finer resolution, and in particular to identify the sensitivities, vulnerabilities and management requirements for the range of component interests in each of the possible MPAs/MPA search locations and existing protected areas. This approach should also encompass the full scope of the key geodiversity areas (including those, or parts thereof, that lie outwith the proposed MPA network). The area-specific assessments are required in order to:

a. inform the management of geodiversity interests included in the MPA network (including existing protected areas) (e.g. determine whether they require specific protection, and if so, whether or not that protection is adequately delivered through existing site-specific management measures); and
b. help prioritise any future action in relation to addressing the gaps in coverage of the geodiversity key areas.

The assessments should determine suitable conservation strategies in the context of Marine Scotland's 'three-pillar' approach to effective marine conservation in Scotland. As set out in '*A Strategy for Marine Nature Conservation in Scotland's Seas*' (Marine Scotland, 2011a), conservation measures may include wider seas policies (e.g. marine planning) in addition to the proposed targeted site-based protection.

Given the importance of the Shelf Carbonate Production Areas as a source of shell sand for the internationally important coastal machair habitats and their limited representation within the possible Nature Conservation MPAs/MPA search locations and existing protected areas, research is required to identify any particularly critical areas within the present extensive boundaries of the geodiversity key areas that require protection and management.

A related issue that also merits attention is the possible extension of some existing terrestrial Coastal Geomorphology GCR sites into the intertidal and nearshore marine areas. Some of the key beach, dune, machair and saltmarsh sites are part of wider geomorphological systems and their dynamics and future evolution, as well as the condition of their associated habitats, depend on connectivity with sediment sources and uninterrupted sediment supply and pathways outside the existing terrestrial site boundaries. Information is required on the extent of these wider connections, pathways and physical processes to enable the whole system boundaries to be defined.

From a geoconservation perspective, the approach that is being adopted in the marine environment is a pragmatic one. Given the real practical difficulties in managing and monitoring most key areas because of their remoteness and location on the seabed, but also recognising the benefits in developing an ecosystem approach, it makes sound sense to align geodiversity conservation with biodiversity conservation through integrated management as far as possible where the respective interests overlap spatially or functionally, and elsewhere for stand-alone measures for geodiversity to be prioritised on evidence of the sensitivity and vulnerability of the interests. This approach differs from that in the terrestrial environment where there is a justifiable presumption that all key geodiversity sites require stand-alone designation to ensure their protection. What this means as a general rule, and in the absence so far of site-specific sensitivity and vulnerability assessments for the key geodiversity areas identified, is that management measures for habitats and species requirements should probably also deliver adequate protection for most of the geodiversity interests, so that additional management constraints may not be necessary. However, it is crucial that the values and requirements of the geodiversity interests are fully and explicitly considered in the conservation management.

A more integrated approach will require better understanding of the functional links between the geodiversity backdrop and associated biodiversity. However, these remain to be analysed at a site-specific scale. The potential application of the Norwegian ‘nature areas’ mapping type of approach in the marine environment (Dolan *et al*., 2009; Thorsnes *et al*., 2009) could offer promising new insights into the functional links between marine geodiversity and biodiversity and provide a basis for informing future marine planning.

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APPENDIX 1: EXCERPT FROM THE MPA SELECTION GUIDELINES (MARINE SCOTLAND, 2011B)

Table A1 *Stage 1 guidelines for the identification of search locations containing MPA search features with particular reference to geodiversity (from Marine Scotland, 2011b)*

Guideline	Relationship to GCR criteria
Guideline 1a Presence of key features The area contains features considered to be of conservation value at a national or international level. This is likely to comprise principally: • features for which Scotland is considered to be a stronghold; • features considered to be of exceptional scientific importance; and/or • features which are characteristic of Scotland's marine environment. For geodiversity, areas should make a direct contribution to the principal networks of marine geodiversity interests (e.g. Quaternary ice sheet and environmental history).	• broadly analogous to GCR sites of 'international importance'; • same as GCR 'exceptional features', but with the key difference that rarity by itself does not make the feature in question exceptional; • same as GCR sites that are representative of an Earth science feature event or process which is fundamental to Scotland's Earth history.
Guideline 1b Presence of features considered to be under threat and / or subject to rapid decline Geodiversity features considered to be threatened will principally include the following categories: • active marine landforms and the geomorphological processes that maintain them; • relict geological and geomorphological features (principally Quaternary landforms and sediments); • seaward extensions of existing terrestrial features of national importance (principally for coastal geomorphology), where the site integrity is dependent on the uninterrupted operation of near-shore processes.	Not a GCR site selection criterion

Guideline	Relationship to GCR criteria
Guideline 1c Functional significance for the overall health and diversity of Scottish seas The area does not necessarily contain key and/or threatened/ declining features, but provides ecological resources or geomorphological processes considered to be critical to the functioning of wider marine ecosystems, e.g. places for feeding, breeding, resting, nurseries, juveniles and/or spawning, or sediment supply.	Not a GCR site selection criterion

APPENDIX 2: AN OVERVIEW OF THE KEY GEODIVERSITY AREAS AND COMPONENT INTERESTS IDENTIFIED IN SCOTTISH WATERS

Table A2 *Summary of key geodiversity areas in Scottish waters (from Brooks* et al.*, 2013)*

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
Block 1: Quaternary of Scotland					
1. Summer Isles to Sula Sgeir Fan (represented by 2 sub-areas)	Region III - Celtic Seas Region V - Wider Atlantic	None	Glaciated channel/ troughs Moraines Mega-scale glacial lineations Prograding wedge Iceberg ploughmarks Ice-proximal and ice-contact facies Sub-glacial tills Ice-distal and glacimarine facies Slide deposits Pockmarks	1a Stronghold/ international Exceptional scientific importance Characteristic/ representative	This area is a classic glacial landscape formed by repeated glaciation over at least the last 0.5 million years. It forms part of an integrated landform assemblage associated with fast-flowing ice streams extending from the NW Scottish Highlands to the Sula Sgeir trough-mouth fan on the continental slope. The outstanding range of glacial interests, coupled with the exceptional detail of the landform and sedimentary record, means this area should be regarded as internationally important. It is also scientifically important for understanding Quaternary ice sheet dynamics, the deglaciation of the last British-Irish Ice Sheet, Lateglacial climate change, and the style and rates of fjord sedimentation. It contains numerous representative examples of different glacial moraine types including ‘terminal moraines’ on the outer shelf edge, ‘recessional push moraines’ and ‘De Geer moraines’, as well as mega-scale glacial lineations.
2. Small Isles	Region III - Celtic Seas	None	Glaciated channel/ troughs Moraines Pockmarks Glacial lineations Streamlined bedforms (possible) Tunnel valleys Meltwater channels Rock basins	1a Exceptional scientific importance	This area is scientifically important because it contains key information about the extent and deglacial history of the last British-Irish Ice Sheet, and particularly the role played by ice streams in ice-sheet demise. A large assemblage of bedforms are present in this region including moraines, glaciated troughs, meltwater channels and glacial lineations, the latter being diagnostic of streaming ice-sheet flow in this region.
3. Loch Linnhe and Loch Etive	Region III - Celtic Seas	None	Glaciated channel/ troughs Moraines Extensive glacimarine deposits Debris flows Deltaic sediments	1a Exceptional scientific importance Characteristic/ representative	This area is scientifically important for sedimentary sequences and bedforms that reveal the depositional history of Scotland’s fjords during the deglaciation of the last British-Irish Ice Sheet. It is also a critical area for furthering scientific understanding of the Loch Lomond Readvance.

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
4. West Shetland Margin Palaeo-Depositional System	Region I - Arctic Waters Region II - Greater North Sea Region III - Celtic Seas Region V - Wider Atlantic	Submarine Mass Movement	Continental slope channels Moraines Prograding wedge Iceberg ploughmarks Slide deposits Basin floor fans	1a Characteristic/ representative	This area includes a series of inter-linked, glacigenic landforms reflecting the influence of glacial activity and ice-marginal processes on the outer shelf and slope, indicating that the last British-Irish Ice Sheet terminated at the shelf edge. The landforms comprise: 1) large, curvilinear, arcuate moraines that are representative of the 'terminal' moraine systems characteristic of Scotland's outer shelf seabed; 2) stacked glacigenic, debris-flow deposits that form the glacially fed Rona and Foula prograding wedges; 3) a group of open, straight channels running down to the floor of the Faroe-Shetland Channel. The channels lie downslope of coalescing debris-flow deposits and end at a number of fan-shaped sediment accumulations. Probably they form part of a palaeo-depositional system that was active during the last glacial period. Two additional areas of shorter, less well-defined downslope channels have been mapped to the west, along the Faroe-Shetland margin. These channels also probably form part of a similar palaeo-depositional system although they have now been largely infilled. Together, these three groups of channels are representative of a distal, non-ice-contact glacial process transferring material from a former ice margin to a basinal depocentre.
5. The Southern Trench	Region II - Greater North Sea	None	Tunnel valleys(?); and/or Glaciated channel/ troughs (?); and/or Glacial lake outburst flood scour feature (?) Slide scars	1a Exceptional scientific importance Characteristic/ representative	Large-scale seabed incisions are a characteristic feature of the shelf seabed off east and north-east Scotland. The Southern Trench is one of the largest and best examples. The exact origin of the trench (along with other large-scale incisions in this region) remains contentious, although detailed morphological analyses reveal that it formed from at least two erosional events operating in different directions. These events may have been driven by different processes of fluvial and/or ice-marginal erosion (e.g. by movement of a fast stream of glacier ice, sub-ice water or possibly the catastrophic release of meltwater). The trench system is scientifically important for furthering understanding of ice sheet drainage.

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
6. Devil's Hole and 7. Fladen Deeps	Region II - Greater North Sea	None	Tunnel valleys	1a Exceptional scientific importance Characteristic/ representative	Both Devil's Hole Deeps and Fladen Deeps are a series of large-scale, bathymetric depressions incised into the seabed off eastern Scotland. In places, these deeps, or 'tunnel valleys', are up to 150 m in relief, 4 km wide and 40 km long and are likely to have formed by pressurised melt-water flowing beneath an ice sheet. They are a characteristic feature of Scotland's marine environment and are especially ubiquitous off Scotland's east and north-east coast, in the North Sea Basin. They are scientifically important since they hold potentially valuable information regarding past changes in the extent and geometry of the last British-Irish Ice Sheet and the nature of meltwater drainage beneath ice sheets.
8. Wee Bankie and 9. Bosies Bank	Region II - Greater North Sea	None	Moraines	1a Exceptional scientific importance	Wee Bankie and Bosies Bank are interpreted as marking an ice limit during the retreat of the last British-Irish Ice Sheet after the Last Glacial Maximum. These moraines have played a central role in debate regarding the offshore extent of Late Devensian ice in the North Sea basin and remain scientifically important for understanding the deglacial history of the last British-Irish Ice Sheet.
10. North Sea Fan (Scottish sector)	Region I - Arctic Waters Region II - Greater North Sea	Submarine Mass Movement	Prograding wedge Slide deposits	1a Exceptional scientific importance	The North Sea Fan is a large example of a trough-mouth fan system, located to the north-east of Shetland in the northern North Sea Basin. The Fan occupies a position astride the outer shelf, slope and deep-sea basin floor and is one of the largest such features identified on the north-east Atlantic margin. It is scientifically important since it holds a detailed archive of information on the Quaternary glacial history of the British-Irish and Fennoscandian ice sheets extending back to at least 1.1 million years ago.
11. The Barra Fan	Region V - Wider Atlantic	Marine Geomorphology of the Scottish Deep Ocean Seabed Submarine Mass Movement Cenozoic Structures of the Atlantic Margin	Prograding wedge Iceberg ploughmarks Scour moat Sediment wave field Slide deposits Continental slope turbidite canyons Turbidite accumulation Seamount	1a Exceptional scientific importance Characteristic/ representative	The Barra Fan is a large prograding wedge of Neogene to Quaternary age that has built out into the deep-water basin of the Rockall Trough. Together with the Donegal Fan (which is generally considered to be part of the same fan complex), it covers an area of c. 6300 km^2 and is locally in excess of 660 m thick. The morphology and sedimentary sequences of the Barra fan are scientifically important for understanding regional-scale palaeoceanographic changes, as well as fluctuations in the timing and extent of the last (and earlier) British-Irish Ice Sheet(s). Within this area there are a number of other geodiversity interests representative of the region, including the Hebrides Terrace Seamount, large-scale slides, other smaller mass movement features and bedforms formed by the action of deep-ocean currents.

<table>
<tr><th colspan="2">Area</th><th>OSPAR region(s)</th><th>Presence of additional qualifying marine geodiversity features</th><th>Relevant geodiversity interests</th><th>Guideline(s) / criteria</th><th>Summary of supporting justification*</th></tr>
<tr><td colspan="7">Block 2: Submarine Mass Movement</td></tr>
<tr><td rowspan="4">Scottish Continental Slope Slide Complexes</td><td>12. Geikie Slide</td><td>Region V - Wider Atlantic</td><td rowspan="4">Quaternary of Scotland</td><td rowspan="4">Slide deposits
Slide scars
Prograding wedge</td><td rowspan="4">1a
Characteristic/ representative</td><td rowspan="4">Large-scale slides are a characteristic feature along the Scottish continental slope. These slides vary in terms of both age and morphology: most of the older (pre-Holocene) slide deposits have been partially or completely buried within the sedimentary column, whilst other (predominantly Holocene age) slides have retained clear seabed expression. Larger slides (e.g. the Miller Slide) may have lateral extents of over 50 km, whilst smaller slides (e.g. the Afen Slide) may be only a few kilometres wide. The five examples selected are broadly representative of the range of large-scale slides found in Scottish offshore waters.</td></tr>
<tr><td>13. Afen slide and Palaeo-Afen slide</td><td>Region II - Greater North Sea</td></tr>
<tr><td>14. The Peach slide</td><td>Region V - Wider Atlantic</td></tr>
<tr><td>15. Miller Slide</td><td>Region I - Arctic Waters

Region II - Greater North Sea</td></tr>
<tr><td colspan="7">Block 3: Marine Geomorphology of the Scottish Deep Ocean Seabed</td></tr>
<tr><td colspan="2">16a-c. West Shetland Margin Contourite Deposits</td><td>Region I - Arctic Waters

Region II - Greater North Sea

Region V - Wider Atlantic</td><td>None</td><td>Contourite sand/ silt</td><td>1a
Exceptional scientific importance</td><td>The contourite deposits west of Shetland together include a complex of sandy bedforms that are unique in UK waters. They have been the focus of detailed scientific studies and have a critical role in understanding Neogene to Holocene palaeoceanography and associated climate changes.</td></tr>
<tr><td colspan="2">17. Central Hatton Bank (and adjacent basin floor)</td><td>Region V - Wider Atlantic</td><td>Biogenic Structures of the Scottish Seabed</td><td>Sediment drift
Sediment wave field
Slide deposits
Scour moat
Current bedform field
Erosional scour field
Bioherm reefs (inc. carbonate mounds)
Biogenic sediment mounds
Large bank
Polygonal faulting (Hatton Rockall Basin)</td><td>1a
Exceptional scientific importance
Characteristic/ representative</td><td>The Hatton Bank, part of the Rockall-Hatton Plateau, is shaped mainly by contour-following oceanic currents rather than the downslope processes and terrigenous sediment input that shape the margins of continental shelves bordering land masses. As well as a variety of representative sea-bed types related to the deep-water currents, it has a cluster of large coral carbonate mounds.</td></tr>
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Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
18. Rosemary Bank Seamount (and adjacent basin floor)	Region V - Wider Atlantic	Cenozoic Structures of the Atlantic Margin	Seamount (Palaeogene igneous centre) Parasitic cones Scour moat Iceberg ploughmarks Sediment wave field Turbidite accumulations Bioherm reefs Slide scars	1a Exceptional scientific importance	Rosemary Bank Seamount is a volcanic remnant characteristic of the macro-scale physiography of the Far West Scotland MPA region. Geological investigations into the origins of the seamount have been instrumental in furthering scientific understanding of the volcanic history of the North Atlantic Volcanic Province. Dating evidence from the seamount indicates that continental rifting began in the Late Cretaceous, earlier than previously thought. Along with Anton Dohrn and the Hebrides Terrace Seamount, Rosemary Bank Seamount is one of the few accessible remnants of such early activity. It forms a large obstacle to the flow of deep-ocean currents. These currents have produced a drift-moat complex surrounding the entire seamount that reveals variations in the action of strong bottom currents over the last few million years. The Rosemary Bank Seamount (and the adjacent basin floor) contains a number of representative examples of geomorphological features formed by a range of (primarily relict) geological and geomorphological processes.
19. North-East Rockall Bank (and adjacent basin floor)	Region V - Wider Atlantic	Cenozoic Structures of the Atlantic Margin Biogenic Structures of the Scottish Seabed Quaternary of Scotland	Scour moats Erosional scour fields Sediment drifts Sediment wave field Bioherm reefs Biogenic sediment mounds Parasitic cones Iceberg ploughmarks Slide scars Slide deposits Small scale ridges Large bank (Palaeogene igneous centre)	1a Characteristic/ representative	The North-East Rockall Bank and adjacent basin floor contains a number of geodiversity interests that occur widely in Scottish offshore waters and are commonly associated with deep-ocean rise settings. Many of these interests (such as scour moats, erosional scour fields, downslope canyons, biogenic sediment mounds and parasitic cones) are representative examples of their types. The north-east Atlantic occupies a critical position within the global ocean circulation system and investigations of the sedimentary record from the Feni Drift on the western margin of the Rockall Trough have a key role in understanding past changes in ocean circulation and their links with the wider global climate system.
20. George Bligh Bank (and adjacent basin floor)	Region V - Wider Atlantic	Cenozoic Structures of the Atlantic Margin	Scour moats Erosional scour fields Sediment drifts Bioherm reefs Parasitic cones(?) Iceberg ploughmarks Slide scars Large bank (Palaeogene igneous centre)	1a Exceptional scientific importance Characteristic/ representative	George Bligh Bank is a large deep-ocean rise, located at the northern end of the Rockall Trough. The Bank, as well as the adjacent basin floor, contains representative examples of bedforms produced by deep-ocean currents. Other interests are also represented, including iceberg ploughmarks, (likely) carbonate-mounds and slide scars. Analysis of sediment cores has revealed important information about the influence of North Atlantic Deep Water flow extending back to Eocene times.

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
Block 4: Seabed Fluid and Gas Seep					
21. Darwin Mounds	Region V - Wider Atlantic	Marine Geomorphology of the Scottish Deep Ocean Seabed Biogenic Structures of the Scottish Seabed	Fluid/gas seep structures Bioherm reefs	1a Exceptional scientific importance	Darwin Mounds are coral-topped mounds comprised mostly of sand and interpreted as 'sand volcanoes'. Individual mounds are up to 75 m wide and 5 m high and are morphologically unique in UK waters. These mounds probably represent an unusual example of bedforms produced by fluid expulsion from the seabed. (The Darwin Mounds were under threat from commercial demersal trawling until the imposition of a European Commission ban which came into force in 2003).
22a & b. Scanner - Scotia - Challenger Pockmark Complex	Region II - Greater North Sea	None	Pockmarks	1a Exceptional scientific importance	The Scanner - Scotia - Challenger Pockmark complex represents an exceptional example of pockmark bedforms produced by methane seepage. These pockmarks are considerably greater in size than other pockmarks within the North Sea region, and they have been termed 'giant' pockmarks. Although well known for their biodiversity, the size of these features also makes them both exceptional and scientifically important from a geodiversity perspective.
Block 5: Cenozoic Structures of the Atlantic Margin					
23. Anton Dohrn Seamount (and adjacent basin floor)	Region V - Wider Atlantic	Marine Geomorphology of the Scottish Deep Ocean Seabed	Scour moats Sediment drifts Sediment wave field Bioherm reefs Biogenic sediment mounds Parasitic cones Slide scars Cliff Slide deposit Seamount (Palaeogene igneous centre)	1a Exceptional scientific importance Characteristic/ representative	Anton Dohrn seamount is a former volcano of Palaeogene age, situated in the Rockall Trough, adjacent to the Hebridean slope. Large Palaeogene deep-ocean bathymetric rises such as this are a characteristic feature of the Far West of Scotland MPA region and Anton Dohrn is included as a best representative example of a seamount because of the quality of data and range of features present. The slopes of the seamount are relatively steep and are surrounded by a moat-like depression. Recent high resolution seabed surveys have enabled the identification of a variety of geodiversity interests on the summit and flanks of the seamount, including volcanic parasitic cones, radial ridges of igneous origin, biogenic sediment mounds, erosional scour moats and evidence of mass failure events. Dating evidence from Anton Dohrn has also played a scientifically important role in advancing understanding of the volcanic history of the North Atlantic Volcanic Province, indicating that continental rifting began about 70 million years ago in the Late Cretaceous, earlier than previously thought, and may have been episodic for some time afterwards. Along with Rosemary Bank and the Hebrides Terrace Seamount, Anton Dohrn is one of the few accessible remnants of such early volcanic activity.

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
24. The Pilot Whale Diapirs	Region I - Arctic Waters	Seabed Fluid and Gas Seep	Mud diapirs Prograding Wedge (North Sea Fan) Slide deposits (Miller Slide)	1a Exceptional scientific importance	The Pilot Whale Diapirs are a series of deep-water, diapiric sediment mounds that measure 2-3 km across and rise to more than 70 m above the surrounding sea floor. These mounds are formed from sediment that has penetrated up to the seabed from strata more than 24 million years old. They are the only known diapirs found in UK waters that breach the seabed surface and are scientifically important for understanding sub-surface fluid migration pathways in the Faroe-Shetland Channel.
Block 6: Marine Geomorphology of the Scottish Shelf Seabed					
25. Sandy Riddle Bank (South-East of Pentland Skerries)	Region II - Greater North Sea	None	Sand bank Sand wave fields Gravel wave field (Focus of biological production of calcium carbonate)	1a Stronghold/ international Exceptional scientific importance	The Sandy Riddle Bank is an exceptional example of a large banner bank system whose morphology is influenced by the interaction of very strong tidal streams. The outstanding nature of this bedform means this area may be considered internationally important. Associated with the bank are a complex series of bedforms including very large mobile sediment waves that comprise shelly carbonate gravel. The Bank contains one of the thickest deposits of shell-derived carbonate known from any shelf sea, and this and nearby banks have been described as 'carbonate factories'. The area in the neighbourhood of the Bank is also scientifically important for understanding shelf bedform systems.
26. Fair Isle Strait Marine Process Bedforms	Region II - Greater North Sea	None	Sand bank Sand wave fields Sand ribbon fields Sediment wave fields	1a Exceptional scientific importance	The Fair Isle Strait between Orkney and Shetland is scientifically important for the study of marine shelf processes and the relationship between currents, bed sediments and bedforms. A number of marine process bedforms have been mapped including sand (banner) banks, sand waves and sand ribbons. There is a sequence of zones that are symmetrically arranged on either side of the Strait. These zones correspond to the increasing current speed caused by the restricted flow, with rock floors and sand ribbons associated with the strongest currents, then sand wave fields and patches of thin sand on the outer shelf, and sheets of fine sand in the northern North Sea. Bedload transport is into the North Sea, caused by the superimposition of the eastward flowing Fair Isle Current and eastward flowing storm surge currents on the near equal ebb and flood tidal currents. Small sand banks are found tied to the eastern sides of some islands.

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<tr><th colspan="2">Area</th><th>OSPAR region(s)</th><th>Presence of additional qualifying marine geodiversity features</th><th>Relevant geodiversity interests</th><th>Guideline(s) / criteria</th><th>Summary of supporting justification*</th></tr>
<tr><td rowspan="4">Scottish Continental Shelf Carbonate Production Areas</td><td>27.Outer Hebrides Carbonate Production Area</td><td>Region III - Celtic Seas</td><td rowspan="4">Coastal Geomorphology of Scotland</td><td rowspan="4">Focus of biological production of calcium carbonate</td><td rowspan="4">1a
Stronghold/ international

1c
Critical to the functioning of the wider marine and coastal ecosystem</td><td rowspan="4">The shelves west and north of Scotland are an internationally important example of a non-tropical shelf carbonate system. Sands and gravels have a very high carbonate content (99% content of broken shells has been reported for the sands forming fields of sand waves). Ditrupa-rich sediments dominate the outer shelf and mollusc-rich, skeletally diverse carbonates dominate the inner shelf. Large molluscs, Modiolus and Glycymeris, dominate in some very strong current areas such as the Fair Isle Strait. Locally, in shallow locations swept by moderate currents, there are banks of coralline algal gravels (maerl). Following early Holocene sea-level rise, the sediment supply changed from mainly terrigenous quartz clastics to mainly clastic carbonates. There is some evidence that storms continue to drive part of this clastic carbonate ashore and supply the carbonate sands of the machair of the Inner Hebrides, the western Outer Hebrides, Orkney and Shetland. The machair supports specific grassland vegetation with a near unique ecosystem of international natural heritage importance. The areas offshore of the machair are important as the past and present source of carbonate supply and as such, these areas are considered to be critical to the functioning of the wider marine and coastal ecosystem.</td></tr>
<tr><td>28. Inner Hebrides Carbonate Production Area</td><td>Region III - Celtic Seas</td></tr>
<tr><td>29. Orkney Carbonate Production Area</td><td>Region II - Greater North Sea</td></tr>
<tr><td>30. Shetland Carbonate Production Area</td><td>Region II - Greater North Sea</td></tr>
<tr><td colspan="7">Block 7: Coastal Geomorphology of Scotland</td></tr>
<tr><td colspan="2">31. St Kilda Archipelago</td><td>Region III - Celtic Seas</td><td>Quaternary of Scotland</td><td>Submerged clifflines/ Emerged clifflines
Submerged caves
Submerged erosion platforms</td><td>1a
Stronghold/ international
Exceptional scientific importance</td><td>The seabed around the St Kilda archipelago contains an exceptional suite of submerged coastal landforms including clifflines and shore platforms that formed during episodes of lower sea level. They are important for understanding the Quaternary sea-level history of this region. The outstanding nature of the landforms means this area may be considered internationally important.</td></tr>
<tr><td colspan="2">32. Sula Sgeir Submerged Platforms</td><td>Region III - Celtic Seas

Region V - Wider Atlantic</td><td>Quaternary of Scotland</td><td>Submerged erosion platforms</td><td>1a
Exceptional scientific importance</td><td>To the west of Sula Sgeir, two major submerged erosion platforms occur at depths of c.-155m and c.-125m. They are thought to have formed from extensive marine erosion when sea level was lower. These platforms provide a record of Pliocene and Quaternary sea-level change and coastal evolution in this region.</td></tr>
</table>

Area	OSPAR region(s)	Presence of additional qualifying marine geodiversity features	Relevant geodiversity interests	Guideline(s) / criteria	Summary of supporting justification*
Block 8: Biogenic Structures of the Scottish Seabed					
33. Rockall Bank Biogenic Sediment Mounds	Region V - Wider Atlantic	None	Bioherm reefs Biogenic sediment mounds	1a Characteristic/ representative	Biogenic sediment mounds are characteristic of many of the deep-ocean rises in Scottish waters. Numerous examples have been mapped on Rockall Bank, and a subset from the northern flank of the bank is included as representative of their type.
34. Hatton Bank Carbonate Mounds	Region V - Wider Atlantic	None	Bioherm reefs Biogenic sediment mounds	1a Exceptional scientific importance	Hatton Bank is the location of large coral carbonate mounds which are several tens of metres high. They are the first examples to be reported in UK waters. Although widely distributed along the eastern margin of the North Atlantic, large coral carbonate mounds are rare in a global context.
35. Mingulay Reef	Region III - Celtic Seas	None	Bioherm reefs	1a Exceptional scientific importance 1b Presence of features considered to be under threat or subject to rapid decline	The Mingulay Reef contains several biogenic reefs formed by the cold-water coral, *Lophelia pertusa*. Surface samples of coral rubble date from around 4000 radiocarbon years ago, although growth is likely to have begun at the end of the last glaciation around 11,500 years ago. There are no other documented locations of such an abundance of *L. pertusa* growth in UK inshore waters and the Mingulay Reef is a unique example of this kind of cold-water coral habitat within the UK.

* See Brooks *et al*. (2013) for detailed descriptions of the key geodiversity areas

APPENDIX 3: A SUMMARY OF THE ECOSYSTEM SERVICES PROVIDED BY SCOTLAND'S MARINE GEODIVERSITY

Table A3 *Ecosystem services provided by Scotland's marine geodiversity*

Ecosystem service[1]	Service detail
Regulating	
Ocean circulation	Submarine topography regulates ocean circulation and dynamic processes.
Natural hazard regulation	The presence of beaches and saltmarshes at the coast provides natural forms of coast defence, helping to reduce damage caused by waves and storms.
Supporting	
Habitat provision	Submarine landforms, processes and substrate properties support a diverse range of habitats and species.
Burial and storage	Includes waste dumps on the seafloor (e.g. Beaufort's Dyke), oil & gas reservoirs, and carbon capture and storage.
Natural harbours and seaways	Geological and geomorphological features provide seaways (straits), natural harbours and sheltered inlets.
Provisioning	
Food	Geodiversity provides habitats for economic species. Many of our key fishing grounds are associated with important geodiversity features (e.g. Wee Bankie, Rockall and the Southern Trench).
Fuel	Supply of essential non-renewable (oil, gas and coal).
Minerals	Economic benefits through supply of essential non-renewable non-energy minerals (e.g. construction aggregates).
Renewable energy	Geology, topography and natural processes help to provide renewable forms of energy (wind, wave and tidal power), as well as a platform for their development.
Ornamental products	Includes shells.
Cultural	
Educational values	Geodiversity features and processes provide the basis for both formal and informal education for people of all ages and across a wide range of disciplines.
Cultural heritage values	Geodiversity has a profound influence on coastal and seascape character, and on patterns of human habitation and way of life in Scotland since the Mesolithic (e.g. machair and crofting).
Artistic inspiration	The hugely varied character of our coastal landscapes and seascapes is a strong influence on art, literature and poetry.
Recreation and ecotourism	Geodiversity provides a great variety of coastal scenery and beaches for recreation, as well as opportunities for recreational diving and the range of habits and species of interest.
Scientific knowledge	Knowledge of how the Earth's systems work underpins understanding of ecosystems and provides a long-term perspective on their status, trends, rates of change and future trajectories. Records of past climate and environmental changes preserved in the sedimentary archives in Scottish Waters are crucial to understanding the past and informing future climate scenarios. The landforms and deposits on the Scottish shelf are particularly important for understanding the dynamics of marine-based ice sheets, which is relevant to assessing the future response of the West Antarctic Ice Sheet to global warming.

[1] Adapted from the Millennium Ecosystem Assessment (2005) - www.millenniumassessment.org

APPENDIX 4: GENERIC ASSESSMENT OF THE POTENTIAL SENSITIVITY OF THE PRINCIPAL COMPONENT INTERESTS OF THE GEODIVERSITY FEATURES

Table A4 *Generic assessment of the potential sensitivity of the principal component interests of the geodiversity features (adapted from Brooks, 2013)*

Feature	Component interest	Potential sensitivity to principal pressures
Quaternary of Scotland	Continental slope channels	Medium to physical extraction, since potential to cause partial disruption to the component's surface or stratigraphy.
	Glaciated channel/trough	Low to all, since it is a rock feature.
	Iceberg ploughmark field	High to physical extraction; Medium to sub-surface scour.
	Landscape of areal glacial scour	Low to all, since it is a rock feature.
	Mega-scale glacial lineations	High to physical extraction; Medium to sub-surface scour and water flow changes.
	Moraines	High to physical extraction; Medium to sub-surface scour and water flow changes.
	Prograding wedge	Low to all since large-scale component.
	Sub-glacial tunnel valley	Low since large-scale feature and resistant geology.
Submarine Mass Movement	Continental slope turbidite canyons	Medium to physical extraction since potential to cause partial disruption to the component's surface or stratigraphy.
	Slide deposit	High to physical extraction; Medium to sub-surface scour, Medium to water flow changes.
	Slide scars	Low to all.
Marine Geomorphology of the Scottish Deep Ocean Seabed	Contourite sand/silt	High to physical extraction.
	Sand wave field	Medium to physical extraction: dynamic feature with potential to recover.
	Scour moat	Low to all.
	Sediment drift	Low to all.
	Sediment wave field	Medium to sub-surface scour.
	Polygonal faults	Low to all.
Seabed Fluid and Gas Seep	Pockmarks	Medium to water flow (tidal current) changes.
Cenozoic Structures of the Atlantic Margin	Continental slope	Low to all.
	Hebrides Terrace Seamount	Low to all.
	Mud diapirs	Low to all.
	Rosemary Bank Seamount	Low to all.
Marine Geomorphology of the Scottish Shelf Seabed	Bank (unknown substrate)	High to water flow (tidal current) changes.
	Longitudinal bedform field	High to water flow (tidal current) changes; High to physical extraction.
	Sand bank	High to water flow (tidal current) changes; High to physical extraction.
	Sand ribbon field	High to water flow (tidal current) changes; High to physical extraction.
	Sand wave field	High to water flow (tidal current) changes; High to physical extraction.
	Sediment wave field	High to water flow (tidal current) changes; High to physical extraction.

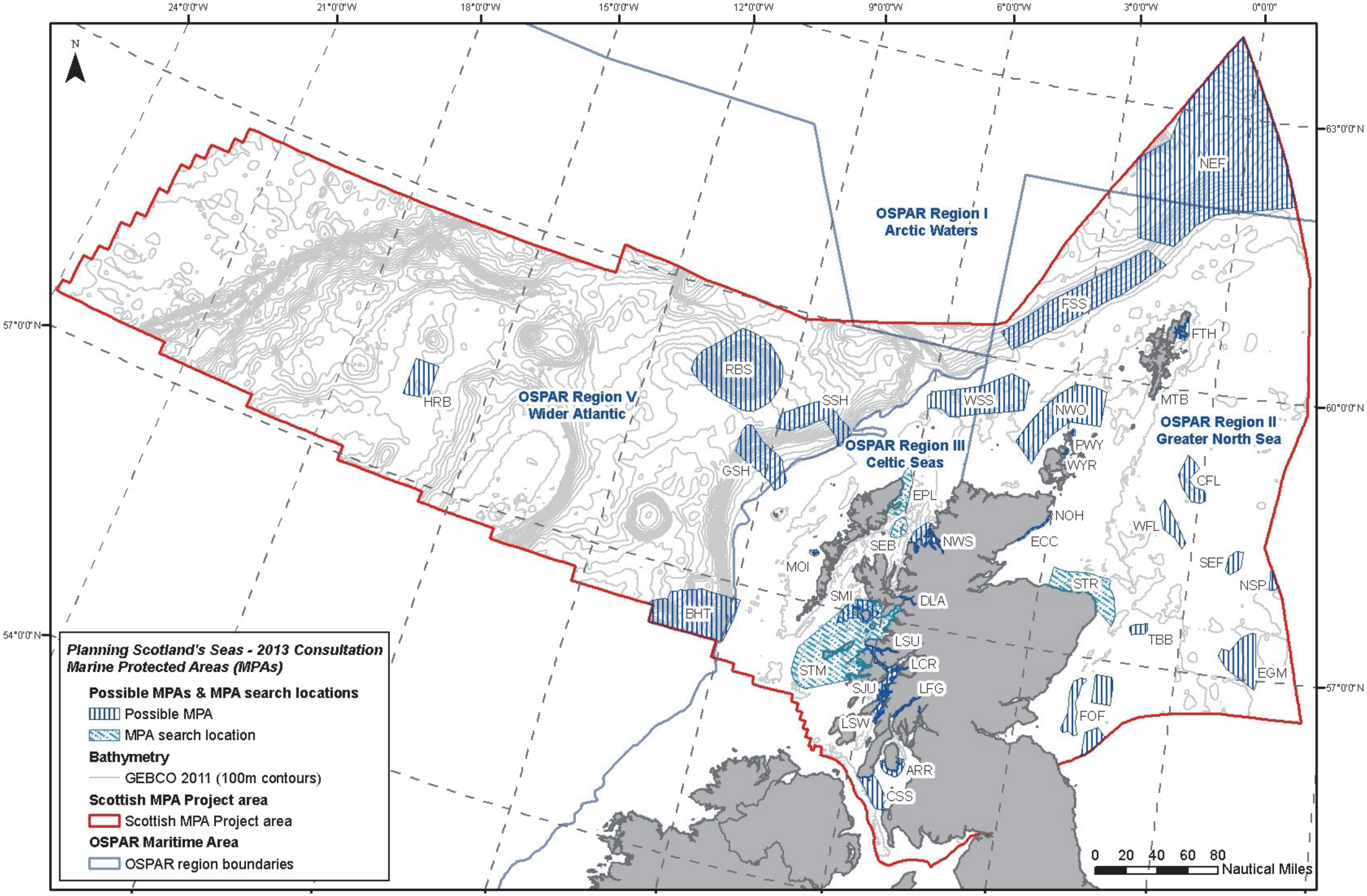
Feature	Component interest	Potential sensitivity to principal pressures
Coastal Geomorphology of Scotland	Carbonate sand deposits	High to physical extraction; high to water flow (tidal current) changes.
	Submerged platforms, cliffs and caves	Low to all.
	Submerged peat	High to physical extraction, seabed surface scour/penetration, sub-seabed surface scour/penetration, water flow (tidal current) changes, wave exposure changes and siltation rate changes.
Biogenic Structures of the Scottish Seabed	Carbonate mounds and reefs	High to physical extraction, seabed surface scour/penetration, sub-seabed surface scour/penetration, water flow (tidal current) changes, wave exposure changes and siltation rate changes.

APPENDIX 5: POSSIBLE NATURE CONSERVATION MPAS AND MPA SEARCH LOCATIONS IN SCOTTISH WATERS

Table A5 *Possible Nature Conservation MPAs and MPA search locations in Scottish waters (MPA search locations are marked with an asterisk)*

OSPAR Region(s)	Possible MPAs/MPA search location*	Code
I, II & V	Faroe-Shetland sponge belt	FSS
I & II	North-east Faroe Shetland Channel	NEF
II	Central Fladen	CFL
	East Caithness Cliffs	ECC
	East of Gannet and Montrose Fields	EGM
	Fetlar to Haroldswick	FTH
	Firth of Forth Banks Complex	FOF
	Mousa to Boddam	MTB
	North-west Orkney	NWO
	Norwegian boundary sediment plain	NSP
	Noss Head	NOH
	Papa Westray	PWY
	South-east Fladen	SEF
	Southern Trench*	STR
	Turbot Bank	TBB
	Western Fladen	WFL
II	Wyre and Rousay Sounds	WYR
II & III	West Shetland Shelf	WSS
III	Clyde Sea Sill	CSS
	Eye Peninsula to Butt of Lewis*	EPL
	Loch Creran	LCR
	Lochs Duich, Long and Alsh	DLA
	Loch Sunart	LSU
	Loch Sunart to the Sound of Jura	SJU
	Loch Sween	LSW
	Monach Isles	MOI
	North-west sea lochs and Summer Isles	NWS
	Shiant East Bank*	SEB
	Skye to Mull*	STM
	Small Isles	SMI
	South Arran	ARR
	Upper Loch Fyne and Loch Goil	LFG
III & V	Geike Slide and Hebridean Slope	GSH
	South-west Sula Sgeir and Hebridean Slope	SSH
	The Barra Fan and Hebrides Terrace Seamount	BHT
V	Hatton-Rockall Basin	HRB
	Rosemary Bank Seamount	RBS

Figure A1 *Possible Nature Conservation MPAs and MPA search locations in Scotland's seas (refer to Table A5 for details)*



Map projected in Europe Albers Equal Area Conic (Modified Standard Parallels - Standard Parallel 1 = 50.2; Standard Parallel 2 = 58.5). The exact limits of the UK Continental Shelf are set out in orders made under section 1(7) of the Continental Shelf Act 1964 (©Crown Copyright). Coastline ©Crown copyright and database right [2013]. All rights reserved. Ordnance Survey Licence number 100017908. Bathymetry ©GEBCO. NOT TO BE USED FOR NAVIGATION. MPA network ©SNH, JNCC and Marine Scotland. 03.07.13. All rights reserved.

APPENDIX 6: SUMMARY OF OVERLAPS OF KEY GEODIVERSITY AREAS WITH POSSIBLE NATURE CONSERVATION MPAS/MPA SEARCH LOCATIONS AND EXISTING MEASURES

Table A6 *Summary of overlaps of key geodiversity areas with possible Nature Conservation MPAs/MPA search locations and existing measures (SACs, SPAs and other area-based measures)*

Geo Area #	*Key Geodiversity Area*	*Proportion of geodiversity areas within possible MPAs/MPA search locations* (100%, >75%, 75-25%, <25%, 0%)	*Proportion of geodiversity areas within existing measures (SACs, SPAs, Fisheries Areas)* *(100%, >75%, 75-25%, <25%, 0%)*	*Features within key areas should become a protected feature of possible MPAs/MPA search locations*	*Scale of coverage of existing measures warrants further assessment of protection afforded*	*Key areas & component features adequately covered in MPAs and existing measures*
The Quaternary of Scotland						
1a	Summer Isles	<25% (North-west sea lochs and Summer Isles, Shiant East Bank, Eye Peninsula to Butt of Lewis)	<25% (Priest Island SPA)	Y	Y	N
1b	Sula Sgeir Fan	<25% (South-west Sula Sgeir and Hebridean Slope, West Shetland Shelf)	<25% (Edge of Scottish continental shelf blue ling protection area Fisheries Area)	-	Y	N
2	Small Isles	>75% (Skye to Mull, Small Isles, Loch Sunart, Loch Sunart to the Sound of Jura)	<25% (Canna and Sanday SPA, Rum SPA, Lochs Duich, Long and Alsh SAC, Sound of Arisaig SAC, Sunart SAC)	Y	Y	Further assessment of sensitivity required
3	Loch Linnhe and Loch Etive	25-75% (Loch Sunart to the Sound of Jura, Loch Creran)	<25% (Eileanan agus Sgeiran Lios mor SAC, Loch Creran SAC, Firth of Lorn SAC)	Y	Y	N
4	West Shetland Margin Palaeo-depositional System	<25% (Faroe-Shetland Sponge Belt)	0%	Y	-	N
5	The Southern Trench	100% (The Southern Trench)	25% - 75% (East Coast of Scotland sandeel closure Fisheries Area)	Y	-	Y
6	Devil's Hole	0%	0%	-	-	N
7	Fladen Deeps	<25% (Central Fladen, Western Fladen)	0%	Y	-	N
8	Wee Bankie	25-75% (Firth of Forth Banks Complex)	100% (East Coast of Scotland sandeel closure Fisheries Area)	Y	-	Y

Geo Area #	*Key Geodiversity Area*	***Proportion of geodiversity areas within possible MPAs/MPA search locations*** (100%, >75%, 75-25%, <25%, 0%)	***Proportion of geodiversity areas within existing measures (SACs, SPAs, Fisheries Areas)*** *(100%, >75%, 75-25%, <25%, 0%)*	***Features within key areas should become a protected feature of possible MPAs/MPA search locations***	***Scale of coverage of existing measures warrants further assessment of protection afforded***	***Key areas & component features adequately covered in MPAs and existing measures***
9	Bosies Bank	0%	25% - 75% (East Coast of Scotland sandeel closure Fisheries Area)	-	-	N
10	North Sea Fan (Scottish sector)	>75% (North-east Faroe-Shetland Channel)	0%	Y	-	N[2]
11	The Barra Fan	25-75% (The Barra Fan and Hebrides Terrace Seamount)	0%	Y	-	N
Submarine Mass Movement						
12	Geikie Slide	100% (Geikie Slide and Hebridean Slope)	0%	Y	-	Y
13	The Afen Slide and Palaeo-Afen Slide	0%	0%	-	-	N
14	The Peach Slide Complex	<25% (The Barra Fan and Hebrides Terrace Seamount)	0%	Y	-	N
15	Miller Slide	100% (North-east Faroe-Shetland Channel)	0%	Y	-	Y
Marine Geomorphology of the Scottish Deep Ocean Seabed						
16a	West Shetland Margin Contourite Deposits	>75% (Faroe-Shetland Sponge Belt, North-east Faroe-Shetland Channel)	0%	Y	-	Further assessment of sensitivity required
16b - c	West Shetland Margin Contourite Deposits	0%	0%	-	-	N
17	Central Hatton Bank (and adjacent basin floor)	<25% (Insignificant overlap in Hatton-Rockall Basin)	25 - 75% (Hatton Bank cSAC and Fisheries Area)	-	Y	N

2 Much of the North Sea Fan extends beyond UK waters; of the area within UK waters >75% is contained within the North-east Faroe-Shetland Channel possible Nature Conservation MPA

Geo Area #	*Key Geodiversity Area*	***Proportion of geodiversity areas within possible MPAs/MPA search locations*** (100%, >75%, 75-25%, <25%, 0%)	***Proportion of geodiversity areas within existing measures (SACs, SPAs, Fisheries Areas)*** *(100%, >75%, 75-25%, <25%, 0%)*	***Features within key areas should become a protected feature of possible MPAs/MPA search locations***	***Scale of coverage of existing measures warrants further assessment of protection afforded***	***Key areas & component features adequately covered in MPAs and existing measures***
18	Rosemary Bank Seamount (and adjacent basin floor)	100% (Rosemary Bank Seamount)	>75% (Edge of Rosemary Bank blue ling protection Fisheries Area)	Y	-	Y
19	North-East Rockall Bank (and adjacent basin floor)	0%	25 - 75% (NW Rockall Bank SAC, East Rockall Bank cSAC, North West Rockall Fisheries Area)	-	Y	N
20	George Bligh Bank (and adjacent basin floor)	0%	0%	-	-	N
Seabed Fluid and Gas Seep						
21	Darwin Mounds	0%	100% (Darwin Mounds SAC and Fisheries Area)	-	Y	Y
22a & b	Scanner - Scotia - Challenger Pockmark Complex	100% (South-east Fladen)	25 - 75% (Scanner Pockmark SAC)	Y	Y	Y
Cenozoic Structures of the Atlantic Margin						
23	Anton Dohrn Seamount (and adjacent basin floor)	0%	>75% (Anton Dohrn Seamount cSAC)	-	Y	Y
24	The Pilot Whale Diapirs	100% (North-east Faroe-Shetland Channel)	0%	Y	-	Y
Marine Geomorphology of the Scottish Shelf Seabed						
25	Sandy Riddle Bank (south-east of Pentland Skerries)	0%	0%	-	-	N
26	Fair Isle Strait Marine Process Bedforms	<25% (North-west Orkney, Papa Westray, Wyre and Rousay Sounds)	<25% (Foula SPA, Fair Isle SPA, East Coast of Sanday SAC, Calf of Eday SPA, Faray and Holm of Faray SAC, Rousay SPA, West Westray SPA)	Y	Y	N

Geo Area #	*Key Geodiversity Area*	***Proportion of geodiversity areas within possible MPAs/MPA search locations*** (100%, >75%, 75-25%, <25%, 0%)	***Proportion of geodiversity areas within existing measures (SACs, SPAs, Fisheries Areas)*** *(100%, >75%, 75-25%, <25%, 0%)*	***Features within key areas should become a protected feature of possible MPAs/MPA search locations***	***Scale of coverage of existing measures warrants further assessment of protection afforded***	***Key areas & component features adequately covered in MPAs and existing measures***
27	Outer Hebrides Carbonate Production Area	<25% (Monach Islands)	<25% (Loch Roag Lagoons SAC, North Uist Machair and Islands SPA, Monach Islands SAC, South Uist Machair SAC, Mingulay and Berneray SPA)	Y	Y	N
28	Inner Hebrides Carbonate Production Area	<25% (Skye to Mull)	<25% (Rinns of Islay SPA, North Colonsay and Western Cliffs SPA)	Y	Y	N
29	Orkney Carbonate Production Area	<25% (Papa Westray, Wyre and Rousay Sounds)	<25% (East Coast of Sanday SAC, Calf of Eday SPA, Faray and Holm of Faray SAC, Rousay SPA, West Westray SPA)	Y	Y	N
30	Shetland Carbonate Production Area	<25% (Fetlar to Haroldswick, Mousa to Boddam)	<25% (Mousa SAC, Papa Stour SAC, Sullom Voe SAC, The Vadills SAC, Yell Sound Coast SAC, Hermaness, Saxa Vord and Valla Field SPA, Ramna Stacks and Gruney SPA, Otterswick and Graveland SPA, Fetlar SPA, Ronas Hill - North Roe and Tingon SPA, Papa Stour SPA, Noss SPA, Fetlar SPA, Hermaness, Saxa Vord and Valla Field SPA, Mousa SPA, Sumburgh Head SPA)	Y	Y	N
Coastal Geomorphology of Scotland						
31	St Kilda Archipelago Submerged Landforms	0%	100% (St Kilda SAC & SPA)	-	Y	Y
32	Sula Sgeir Submerged Platforms	0%	<25% (North Rona and Sula Sgeir SPA)	-	Y	N
Biogenic Structures of the Scottish Seabed						
33	Rockall Bank Biogenic Sediment Mounds	0%	>75% (East Rockall Bank cSAC)	-	Y	Y
34	Hatton Bank Carbonate Mounds	0%	100% (Hatton Bank cSAC and Fisheries Area)	-	Y	Y

Geo Area #	*Key Geodiversity Area*	***Proportion of geodiversity areas within possible MPAs/MPA search locations*** (100%, >75%, 75-25%, <25%, 0%)	***Proportion of geodiversity areas within existing measures (SACs, SPAs, Fisheries Areas)*** *(100%, >75%, 75-25%, <25%, 0%)*	***Features within key areas should become a protected feature of possible MPAs/MPA search locations***	***Scale of coverage of existing measures warrants further assessment of protection afforded***	***Key areas & component features adequately covered in MPAs and existing measures***
35	Mingulay Reef	0%	100% (East Mingulay cSAC)	-	Y	Y

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