

APPENDIX 3b - GEOLOGY, SUBSTRATES & COASTAL GEOMORPHOLOGY

A3b.1 INTRODUCTION

The principal sources of information used in this geology and substrates compilation include, *inter alia*, a number of BGS offshore regional reviews (e.g. Cameron *et al.* 1992, Tappin *et al.* 1994, Gatliff *et al.* 1994) the JNCC, *Coasts and seas of the United Kingdom*, series and a number of technical reports compiled by BGS, commissioned to support the previous offshore SEA programmes. DTI bedform surveys carried out in 2003 as part of the previous SEA programme are also relevant to the current SEA process. More recently, though restricted to English waters, the English Nature, *Marine Natural Areas* reports (Jones *et al.* 2004a-f) briefly describe seabed geology and its evolution. The programme also extends to coastal and terrestrial *Natural Areas* which include coastal geology, geomorphology and habitat. Wider publically available and peer reviewed literature is used and cited where appropriate.

The JNCC UKSeaMap (Connor *et al.* 2006) is also instructive, presenting oceanographic, bedform and ecological features of UK waters as a series of map layers. UKSeaMap shows the geographical distribution of topographic and bed-form features including subtidal sediment banks, shelf mounds and pinnacles, shelf troughs, submarine canyons, deep water and carbonate mounds; in addition to broadscale features such as continental slope, deep ocean rise, pockmark fields, and iceberg ploughmark zones. These were identified on the basis of bathymetry and derived slope data, and data compiled by BGS (shelf troughs, ploughmarks, and pockmarks). Many features are poorly discriminated and the resolution of some of the dataset appears coarser than that provided by previous BGS studies. The sediment classifications used in the JNCC SeaMap are derived from BGS data but the number of sediment types considered is much coarser. The map follows a reduced Folk classification of 4 categories (as opposed to the original 16) in addition to a category for 'rock'. These include; 'mixed sediment', 'mud and sandy mud', 'coarse sediment' and 'sand and muddy sand' which are deemed detailed enough to reflect the substratum types used in habitat classifications (Connor *et al.* 2004).

A number of bathymetric studies of the UKCS have been carried out since 2003 by the MCA as part of the Civil Hydrography Programme, which is still ongoing. Data are viewable via download from the Civil Hydrography Programme Results webpage. Survey locations include the Sound of Harris, South West Approaches, Western Solent, the Dover Strait, and the Thames Estuary. The MESH INTERREG programme has conducted more than 40 surveys in UK waters with the principle aim of mapping seabed habitats. Associated bathymetric and geological reports are of relevance to this section and survey results are available in document and online GIS format via the MESH website. Further surveys have been undertaken in relation to the aggregates industry under the Marine Environment Protection Fund (MEPF), a marine component of the Aggregate Levy Sustainability Fund (ALSF) (e.g. James *et al.* 2007).

A3b.2 UK CONTEXT

Figure A3b.1 and Figure A3b.2 display simplified seabed substrates and notable topographic features for the UK continental shelf respectively. The seabed substrates are derived from BGS DiGMap data (1:625,000) and cover the entirety of the UKCS with the exception of areas in Regional Seas 9, 10 and 11 for which information is currently limited. Features follow those indicated in the JNCC SeaMap (Connor *et al.* 2006), though other notable

features not highlighted in that report are described below. It should be cautioned that the Simplified Seabed Substrates chart is based on widely spaced seabed sampling with interpolation between points.

Figure A3b.1 –Simplified Seabed Substrates

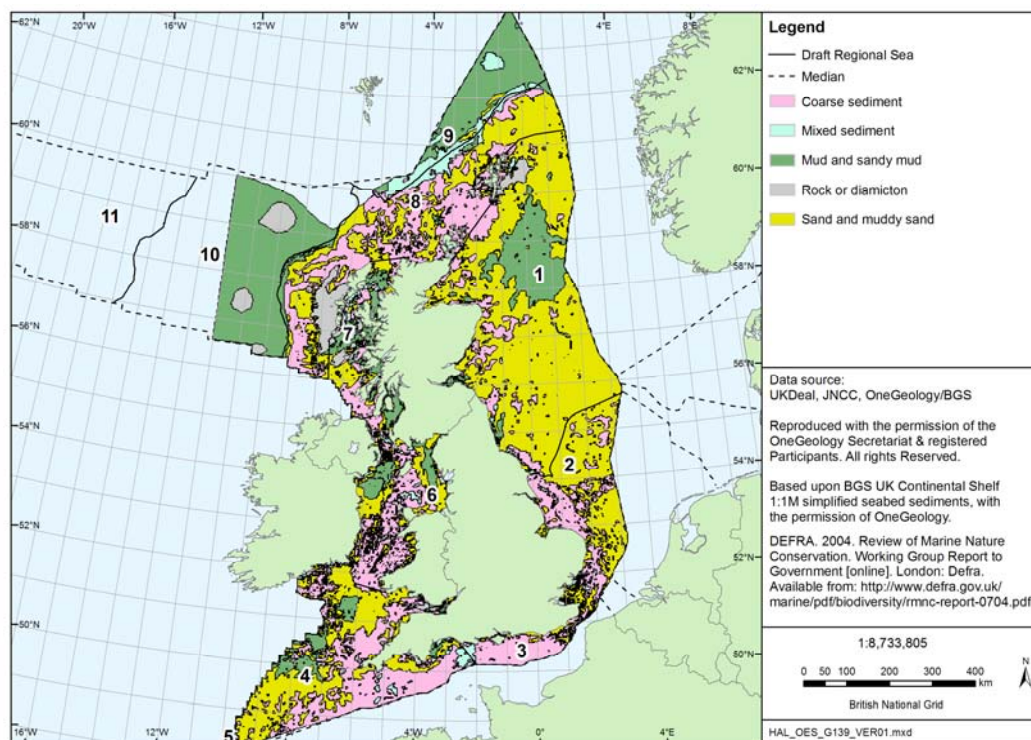
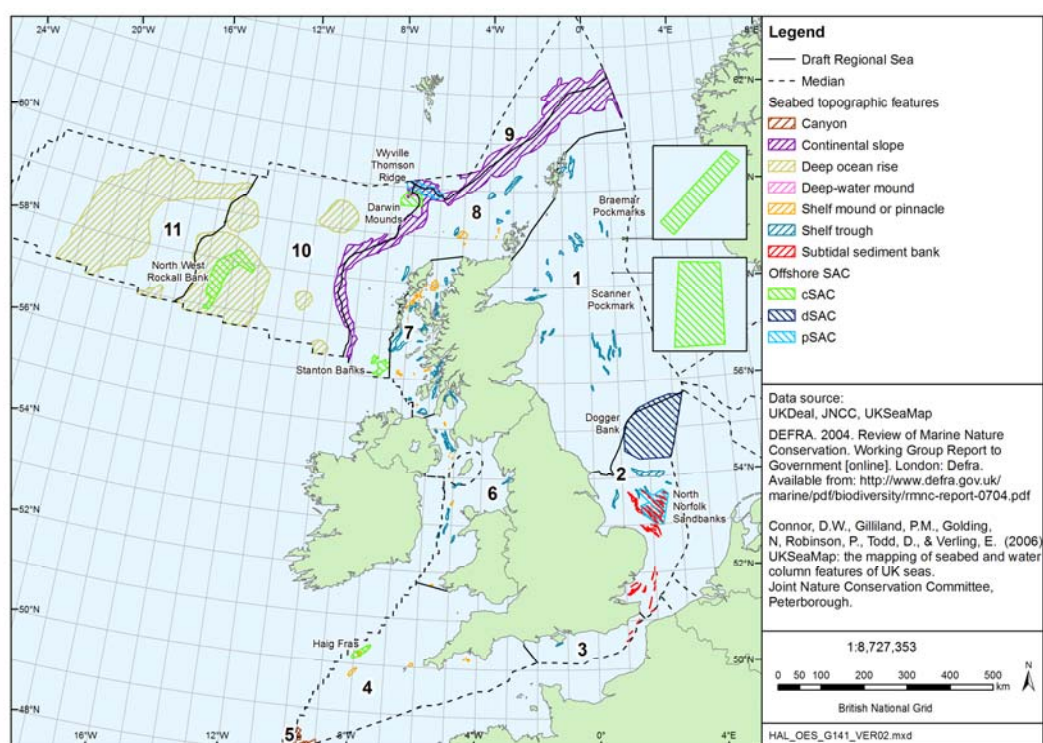


Figure A3b.2 – Seafloor topographic features and offshore designations



These sediments and features provide habitats for numerous species, and are in places being considered for offshore conservation designations (see Appendix 3j) the geological/geomorphological elements of which are discussed below. Physical structures on the seabed are at times formed by marine organisms themselves (biogenic reef); more detail is provided in Appendix 3a.2 but presence (or potential presence) is noted in this section.

The underlying hard geology of the North Sea, eastern Irish Sea and to some extent the English Channel, has given rise to hydrocarbon prospectivity ranging from reserves of primarily oil and condensate in the north (with the exception of Wytch Farm and oil shows in the St. George's Channel) and gas in the south. Many of the North Sea and Irish Sea fields are at a mature stage of development, and so the location and prospectivity of hydrocarbon reserves in these locations are relatively well-known. To the north and west of Shetland, exploration effort has been small relative to the North Sea, though recent discoveries have culminated in the Clair, Schiehallion, Foinaven and Suilven oil fields – the Rosebank oil field, 100 miles north-west of Shetland has had three appraisal wells drilled to date. It is unlikely that any developments will take place north of 62°N until techniques are designed to overcome the barriers to seismic survey imposed by Palaeogene lavas. Areas such as the Celtic Sea, Bristol Channel and Western Approaches have proved to be dry, with a general lack of source rocks, and further south in the English Channel, there has been no offshore development drilling.

A3b.3 REGIONAL SEA 1

The bulk of modern seabed sediments comprise substrates that are more than 10,000 years old and have been reworked from strata by currents generated by tides and waves. The reworked sediments typically form large areas of seabed sand and gravel, and may also form large-scale sandbanks and ridges and smaller sand waves.

A3b.3.1 Pockmarks

In the central and northern North Sea spreads of soft muds are locally characterised by small depressions or 'pockmarks', most of which appear to have been formed at times of fluid/gas escape resulting in fine sediment being vented into suspension which is then redeposited away from the site of emission. The largest areas of pockmarks occur in the Witch Ground Basin. In some cases, where these are associated with modern fluid/gas escape, they may contain distinctive biota of conservation interest (JNCC website e). Pockmarks often support a diverse fauna which includes anemones and squat lobsters, fish using the feature for shelter and chemosynthetic species, which feed on methane and hydrogen sulphide.

A survey programme carried out for SEA 2 in June-July 2001 collected extensive data on pockmarks in the central and northern North Sea including multibeam bathymetry, photography and seabed sampling (DTI 2001).

Within individual areas the pockmark size, density and distribution pattern are not uniform. In the Witch Ground Formation, such variation is caused by the coarseness of the sediments, which fine towards the deeper, central part of the basin. Long (1986) reported that the highest densities ($>30/\text{km}^2$) occur where the seabed sediments are sandy muds, whilst in the pure muds in the centre of the Basin densities are $10\text{-}15/\text{km}^2$. Towards the edges of the Basin, where the Witch Ground Formation sediments are coarser and thinner, pockmarks decrease in size until they are too small to identify acoustically (Judd 2001).

Pockmarks are the only features known to occur in UK offshore waters which may conform to the Habitats & Species Directive Annex 1 habitat, *Submarine structures made by leaking gases*. In the northern North Sea, two examples of this habitat; the Scanner pockmark in Block 15/25 and a series of pockmarks near the Braemar oil field (Block 16/03) have been identified as Group 1 sites (i.e. the presence of Annex 1 habitat has been confirmed; sufficient biological information is available, and sites of this character do not occur in territorial waters) (Johnston *et al.* 2003). These two areas of pockmarks are currently being considered as candidate marine special areas of conservation (cSAC). Johnston *et al.* (2002) identified potential areas to the east of Shetland and an extensive area centred on the Fladen and Witch Grounds which, based on BGS seabed sediment maps, may contain the Annex 1 habitat.

A3b.3.2 Sandbanks and sandwaves

The Sandy Riddle is a large carbonate gravel and sandbank set at the east end of the Pentland Firth (Figure A3b.3). The area is characterised by high current velocities generated from tidal streams which have profoundly affected the regional distribution and composition of seabed sediments. Sediment transport and the resulting geomorphology of the Sandy Riddle are determined by the complex pattern of eddies generated over the area under the influence of tidal and wave-induced currents. Maximum east-travelling surface tidal streams of 5.3m/s are recorded on the west margin of the Pentland Skerries, at which time a strong tidal eddy extends some 3.2km to the south east. Near-bed spring tide currents are more than 2.75m/s near the head of the Sandy Riddle and decrease rapidly to around 0.875m/s further to the south-east (Holmes *et al.* 2004). Though mentioned in minutes of the third meeting of the Marine Natura 2000 project group in 2003 as part of a survey under the heading, 'Selection of offshore SACs for Annex 1 habitat interest features' (JNCC 2003), the Sandy Riddle has not been selected for either of the two possible Annex 1 habitats, *Sandbanks which are slightly covered by sea water all the time*, or *Reefs* for which it may qualify.

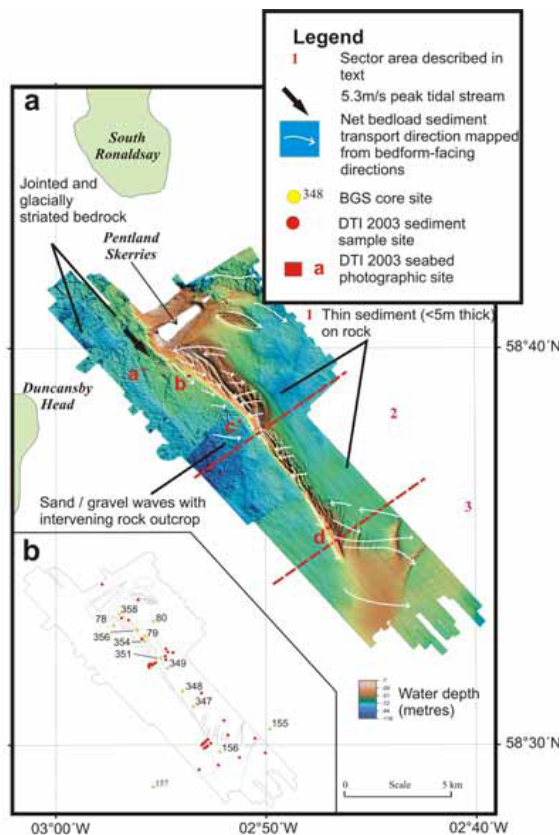
To the north and west of the Sandy Riddle, areas with the strongest tides are swept clean of sediments, exposing bedrock. Cobbles and boulders are also largely swept clean of sandy sediments except in the spaces between the rocks. In this sediment-starved environment the surfaces of the pebbles and cobbles are characterised by abundant attached biota. In areas of weaker currents the seabed is still characterised by cobbles and pebbles but also by mobile bedforms with coarse-grained sands. The mobile sands are thick enough to migrate as sediment waves over the seabed and periodically bury the underlying pavement of cobbles and pebbles. This process appears to prevent the establishment of abundant permanently attached biota found on the pebbles and cobbles in areas of weaker current. Sand and gravel carbonates accumulate in areas of weak or convergent currents. Other sandbanks in Regional Sea 1 include those located within the Moray Firth SAC as a qualifying Annex 1 habitat.

Sandwaves are smaller features, more widely distributed throughout the central North Sea, and unlike sandbanks these are flow-transverse bedforms (Cameron *et al.* 1992). To the south of Fair Isle a very large-scale sediment wave appears to be prograding towards shallower water. It is disconnected from the shallower bedrock adjacent to Fair Isle and appears to be part of a large shoal area in the east lee of the island.

The 2003 DTI survey indicated that low sediment waves were present on the northern flanks of the Smith Bank, with crests of 0.5-1.5m and wavelengths of 50m, showing migration to the south-west, consistent with the dominant mean peak-spring near-bed tidal regime (Holmes *et al.* 2004). The same DTI survey revealed details of sediment waves surrounding Fair Isle,

with a large-scale wave or bank to the east, and a smaller one to the west, with waves migrating in the north over the latter, western bank. Sandwaves appear more abundantly offshore along the Scottish east coast from Fraserburgh to the Firth of Forth. The largest areas are to the south and east of the Aberdeen Bank in water depths of c. 80m, where waves 8m in height and with wavelengths of 160-270m are present (Gatliff *et al.* 1994). Their size is somewhat large for the prevailing oceanic conditions, and these waves may only be active during storms (Owens 1981). Further offshore, hydraulic conditions are not favourable for the generation of such features (Gatliff *et al.* 1994).

Figure A3b.3 – Sandy Riddle: net sediment transport. a. sector areas and summary interpretation b. seabed sample and core sites



A3b.3.3 Tidal sand ridges

The East Bank Ridges are a group of sub-parallel ridges aligned north-east to south-west in relatively deep water to the north west of the Dogger Bank. The banks are up to 50km in length, 3-4km wide and range in height between 10 and 30m (Gatliff *et al.* 1994). These banks were believed by Stride *et al.* (1982) to be features which initially formed early in the Holocene transgression but which are now in water depths too great and with tidal currents too weak for their active maintenance. They were therefore considered to be 'moribund'. They are composed of very fine to fine sand (Davis & Balson 1992) which contrasts with the fine to coarse sand composition of other sandbanks in shallower water further to the south. Their surfaces are smooth and lack the cover of mobile sandwaves seen on other sandbanks in the area.

A3b.3.4 Iceberg ploughmarks

Partially infilled iceberg ploughmarks occur to the north of Regional Sea 1 (and in Regional Sea 8) and were generated by grounding of floating ice on the edge of the continental shelf during the late Pleistocene (Johnson *et al.* 1993). Their morphology ranges from straight to sinuous and overlapping, spreading for hundreds of metres with a width of c. 20m and depth of c. 2m, flanked by ridges of gravelly material.

A3b.3.5 Reefs

Potential reef areas described as *rocky marine habitats or biological concretions that arise from the seabed* occur at a number of locations in Regional Sea 1. To the north of Shetland stony reefs occur to the far north west of the Regional Sea. Though not designated (with the exception of reef habitat at Mousa), these areas may contain the Annex 1 *reefs* habitat which results from animal and plant community development on rock or stable cobbles and boulders, or biogenic structures. Their distribution is partly controlled by underlying geology in addition to depth, oceanographic characteristics, and distance from the coast.

Pobie Bank is located 25-30km east of Shetland, is approximately 70km long and up to 20km wide elongated in a northeast to southwest trend. The bank rises from c. 110m below sea level to less than 80m water depth along its crest. The area was identified by the JNCC (using BGS substrate maps) as containing potential Annex 1 *reef* habitat and has been classified in Group 2 indicating that more information is required before the site can be properly assessed (Johnston *et al.* 2003).

Swath bathymetry collected as part of the previous SEA 5 survey programme indicated a bank crest with features interpreted as bedrock outcrops. Seabed sediments comprised sand and gravelly sand with patches of sandy gravel located on the northern and eastern margins of the bank and slightly gravelly muddy sand on the southern and western margins and southern bank crest. Overall, the patterns of sediment distribution indicate the impact of winnowing by higher energy near-bed currents on the north and east flanks. These patterns are consistent with the predictions for the mean peak spring-tide near-bed currents in stormy conditions and peak near-bed orbital currents having the greatest impact on the northern flanks in stormy conditions (Holmes *et al.* 2004).

A3b.3.6 Seabed substrates

Hard substrates which are resistant to reworking are of both conservation and operational interest as they form areas of stable seabed for biota and may present problems for seabed site developments. The three main types of natural hard substrate occurring at or near the seabed in the study area comprise unconsolidated gravel spreads, hard cohesive sediments which were formed during glaciations, and rock outcrops. All three commonly occur together in the nearshore western margins of the North Sea. The distribution patterns of rock, gravel spreads and the hard cohesive gravelly Quaternary sediments are quite well known and have been mapped by regional surveys.

Outcrops of bedrock are largely restricted to the near coast, revealed mainly along the Scottish coast in the Pentland Firth, Fraserburgh area, around Brora and Helmsdale in the Moray Firth, and in the outer Firth of Forth.

Gravel spreads mostly occur in the nearshore area from Shetland in the north to Flamborough Head in the south, interrupted by a dominance of sand to sandy mud in the Moray Firth and along much of the coast from north of Aberdeen to just south of Hartlepool.

Granular to pebble size classes of gravel are probably mobile during peak tidal currents and storm waves but are virtually static in areas below wave-base (Pantin 1991). In the Moray Firth, there is a large area (greater than 100km²) of gravel off the mouth of the River Spey at Lossiemouth which fines eastwards; smaller patches are also present along the northwest coast of the firth (Andrews *et al.* 1990).

Gravelly sand and sandy gravel occur extensively to the north of Shetland, on the Orkney-Shetland Platform, and on upstanding areas to the east of Shetland; isolated patches are found on Bressay Bank and Halibut Bank. The DTI 2003 survey found sediments around Fair Isle comprised typically coarse to very coarse calcareous sand and gravel with a mean gravel content of approximately 40%. The gravel content of sediments collected from the Sandy Riddle commonly exceed 50%, and comprise broken as well as whole shells (Black 2004). Sandy gravel also occurs on Smith Bank where the gravel is predominantly biogenic. A tongue of well sorted sandy gravel extends northeast from Rattray Head and further south, gravelly sediments are restricted mainly to offshore banks, notably the Marr and Aberdeen Banks (Gatliff *et al.* 1994).

Sand and slightly gravelly sand covers much of the bed of the central to northern North Sea and occurs within a wide range of water depths from the shallow coastal zone to 110m in the north and to below 120m in isolated deeps in the south and west (Andrews *et al.* 1990). Sand deposits in the northern North Sea exhibit significant regional variations in grain size, sorting and carbonate content. These reflect the spectrum of environments, from relatively high energy around Orkney and Shetland where there are sources of carbonate material to low energy further offshore where there is relatively little sediment input. To the east of Shetland, a sand zone 40-60km wide occurs in water depths ranging from 100m to over 120m. The sand is mainly fine grained and well sorted, becoming moderately sorted northwards (Johnson *et al.* 1993). A broad, irregular swath of sand extends from 50km east of Fair Isle to 50km east of Peterhead. Further south in the Moray Firth, the sand has a much lower carbonate content (<20%) and is moderately well sorted.

In the outer Moray Firth and greater central North Sea lie fine-grained sediments which have their primary distribution within the Fladen and Witch Grounds. These sediments are typical of water depths greater than 120m and may therefore occur in other isolated deeps closer to shore (Andrews *et al.* 1990) – this area has been part of a survey for the previous offshore SEA programme (SEA 2).

A3b.3.7 Coastal Geomorphology

The complex coastline of Shetland is formed from a variety of metamorphic, igneous and sedimentary rock types. Extensive stretches of exposed cliffs and rocky shorelines characterise the outer coast with long, narrow inlets known locally as voes extending for several kilometres inland (Stoker *et al.* 1993). Soft shorelines (sand spits, tombolos and bars) are rare and largely restricted to sheltered areas. In some of these, small lagoons have been impounded behind shingle or gravel sand bars providing habitats including salt marsh.

Old Red Sandstone cliffs of Devonian age predominate along the Caithness and outer Moray Firth coast. These cliffs are exposed to the full force of winter storms, allowing few opportunities for accretionary habitats such as sand dunes to develop, except in sheltered bays. Inner regions of the Moray Firth are less exposed, although tidal and storm effects have created extensive sand and shingle formations on either side of the Firth. The sheltered inlets of the firths (Dornoch, Cromarty and the Inner Moray Firth and Beaully Firth)

represent much lower energy environments in which intertidal mudflats and saltmarshes have developed (Doody 1996).

At Peterhead, sandy beach is replaced by a rocky platform and red granite cliffs. The cliffs continue to the Sands of Forvie, a large area of sand dunes at the mouth of the Ythan Estuary. Dune-backed sandy beaches characterise the coast to Aberdeen and thereafter, rugged cliffs give way to the sandy shores and dunes of the outer Firth of Tay and the low-lying rock platforms of Fife (Scott Wilson Resource Consultants 1997).

The Firths of Tay and Forth are major features, formed during the inundation of the land by the sea at the end of the last glaciation. Much of the shoreline is composed of exposed rock platforms with deposits of glacial drift. There are large areas of sand dunes on the outer coast, including the Fife promontory with sheltered inlets holding extensive mud and sand flats. South of the Firth of Forth, cliffs reappear, rising to 152m at St. Abb's Head (Scott Wilson Resource Consultants 1997).

The English section of the coastline is generally composed of (with some local variations) Carboniferous material from its northern point to Newcastle, with Permian rocks dominating the coast to the south until just north of Hartlepool, before moving into Jurassic limestones and clays until around Filey where Cretaceous chalks, clays and sand take over to the south of Flamborough Head (May & Hansom 2003). These younger rocks are relatively weak compared with the Scottish coast and are therefore more susceptible to erosion and coastal retreat (Clayton & Shammon 1998). The most recent coastal descriptions for the area are those of the Natural England *Natural Areas* reports; a synthesis of the coastal character based on these reports is provided below.

Sandstone cliffs and rocky offshore platforms characterise the far north of the English coast. Hard rock cliffs continue south to Beadwell where sandy cliffs backed by low cliffs or dunes dominate. Limestone caves are a feature to the south of Howick and Craston. Sandy bays backed by glacial till make up much of the coast to the south of the Tyne, interspersed by rocky cliffs and platforms. Druridge Bay to the north of the Tyne supports extensive sandy beaches and dunes. Between Tynemouth and Lynemouth cliffs there is the most complete set of Westphalian rocks in the region, which includes coal seams of historical economic importance. Quaternary deposits which include peat are visible at Hauxley and further north, between Boulmer and Howick, Carboniferous limestones form low cliffs and platforms. Sandstone cliffs are a feature of the coast north of Berwick upon Tweed.

Between the Tyne and the Tees several geological features are of note, particularly sequences from the Upper Carboniferous, Marine Permian, Lower Jurassic and Quaternary, many of which are associated with SSSI sites such as at Wear River Bank, Trow Point to Whitburn Steel and Seaham Harbour. Associated with these sequences are geomorphological landforms including wave-cut platforms, caves, arches and stacks, some sandy bays and sand dunes. The underlying geology promotes calcareous and limestone grassland cliff-top vegetation and though severely depleted by reclamation for industry, saltmarsh areas support substantial bird life which is recognised in Special Protection Area (SPA) and Ramsar designations for some locations (e.g. Lindisfarne, the Northumbria Coast).

Further south Lower Jurassic rock rich in ammonites and historically important for iron extraction is found from Saltburn-on-Sea. From Whitby to Scarborough Middle Jurassic sandstones and shales dominate, moving into Upper Jurassic ironstone, limestone and clay towards Filey. Lower Cretaceous clays and Upper Cretaceous chalk from Speeton to Flamborough Head are overlain by Pleistocene deposits which include glacial tills. The

chalk forms eroded wave-cut platforms forming sub-littoral reefs extending up to 6km offshore.

A3b.3.8 Regional Sea 2

Surficial sediments consist largely of material greater than 10,000 years old, reworked by tides and waves into various bedforms. Coastline erosion has provided substantial inputs of sediment, particularly sand, to the North Sea throughout the Holocene (e.g. from the Holderness coast) in addition to large inputs of material from the Humber, Thames, Rhine and Scheldt estuaries (Cameron *et al.* 1992). Sediments reworked during the Holocene typically form large areas of seabed sand and gravel. Such sediments also form large-scale sandbanks and ridges and smaller sandwaves. Several coastal sediment cells (and sub-cells) have been identified by Wallingford (1997) which indicate the net direction of sediment movement in the littoral zone of the UK, though these cells provide a limited explanation of coastal processes where there is a heavy estuarine or offshore influence and where there are strong geological controls (Cooper & Pontee 2006).

A3b.3.9 Sandbanks and sandwaves

Both active sandbanks maintained by the modern tidal current regime, and inactive sandbanks formed at periods of lower sea level, are found in the southern North Sea (Belderson 1986, Cameron *et al.* 1992, Collins *et al.* 1995). A number of sandbanks in coastal and estuarine areas of Regional Sea 2 are included in SAC designations; for example, the Wash, North Norfolk Coast, Essex and Humber Estuaries (JNCC 2007e). Beyond the 12nm limit, the Norfolk Banks are currently being considered as a possible offshore SAC, conforming to the Annex 1 habitat, *Sandbanks which are slightly covered by sea water all of the time*. Five major groups of sandbanks are represented in Regional Sea 2:

- The East Bank Ridges are a group of sub-parallel ridges in relatively deep water to the north west of the Dogger Bank. These banks are considered to be inactive and are composed of very fine to fine sand which contrasts with the fine to coarse sand composition of other banks in shallower water within the area. Their surface is smooth and lacks the cover of mobile sandwaves seen on other sandbanks in the area.
- The Sand Hills are a group of parallel ridges to the south west of the Dogger Bank. Some of these banks are seen to be covered by sandwaves so may in part be presently active.
- The Norfolk Banks are the best known group of sandbanks and lie off the coast of north east Norfolk. These can be subdivided into a nearshore parabolic group with sandwaves on their flanks, and a linear, comparatively stable offshore group of probably older derivation (Cameron *et al.* 1992).
- The Wash contains extensive intertidal flats around its margins and a number of large sandbanks within it. These banks are aligned parallel to the sides of the embayment and to the dominant tidal current directions in and out of the embayment. Most of these banks are partially exposed at low tide.
- The sandbanks or sandwaves in the Thames Estuary area form a complex array aligned approximately parallel to the coast, most of the intervening sea-floor being covered by winnowed 'lag' deposits. In the mouth of the estuary, large sandbanks are exposed at low tide, separated by narrow scoured channels. Narrower, linear banks oriented approximately north-south occur in deeper water north of the Dover Straits.

Connor *et al.* (2006) recently published seabed bathymetry data for the North Sea based on Digital Elevation Model (DEM) interpretation. Areas of 'subtidal sandbanks' were identified off the SE coast of England ranging from the Thames estuary in the south to just north of the Wash, which approximately coincide with the sandbanks of the Thames estuary and the Norfolk Banks. Linear sandbanks in the southern North Sea have been studied since the early days of hydrographic surveying, with significant early echosounder observations made by Van Veen (1935, 1936). Detailed investigations commenced in connection with offshore oil and gas exploration and production activities in the late 1960s and early 1970s (Caston 1969, 1972). To support the SEA process, sandbanks within the southern North Sea were investigated by a survey programme, commissioned by the DTI in June-July 2001. This included high-resolution multibeam bathymetry, photography of sediment features, and epifauna and seabed sampling.

Models for sandbank development include spiral water circulation with convergence over the crestline (Houbolt 1968, Caston 1972); lateral migration; and stratigraphic evolution associated with submergence of coastal sand bodies. Detailed hydrography and sediment transport have been studied on Leman and Well Banks (Caston & Stride 1970, Caston 1972) and Broken Bank (Collins *et al.* 1995). From analysis of historic bathymetric charts, Caston (1972) found that some of the more offshore Norfolk Banks had elongated towards the northwest, the direction of net regional sand transport. The evidence for bank migration perpendicular to their long axis is, however, more equivocal. These offshore banks are markedly asymmetrical in cross-section with their steeper flanks oriented towards the north east suggestive of migration in that direction. It has been suggested (Caston 1972) that opposing movement of sand streams may magnify localised irregularities into a complex "S" shaped bank surrounding a pair of ebb and flow channels (as in banks of the Haisborough Tail – Winterton Ridge system), with subsequent erosion of the bank apices leaving a line of *en echelon* banks. The internal structure within some of the offshore banks is evidence of north eastward migration although it is uncertain whether migration still occurs at the present time.

Understanding of past and potential future movement of sandbanks has been important to several of the wind farm developers in this region. For example, Greater Gabbard Offshore Winds Ltd commissioned several coastal process and geological studies (ABPmer 2005, & 2006, Poulton *et al.* 2005, Kenyon 2005) of the Inner Gabbard and Galloper sandbanks in the outer Thames Estuary which were brought together in the project Environment Statement (GGOWL 2005). This work showed that these banks were in very dynamic areas of sand transport. Kenyon (2005) noted that the area around these banks has the highest suspended sediment load in the southern North Sea) and could be expected to extend to the south by up to 10s of metres per year with a smaller extension to the north at the same time and a general westerly progression laterally of the order of up to a few metres per year.

Sandwaves are smaller features, more widely distributed throughout the southern North Sea and unlike sandbanks, these are flow-transverse bedforms (Cameron *et al.* 1992). This morphological feature occurs extensively offshore and intertidally throughout the southern North Sea area from north of the Dover Straits to south west of the Dogger Bank in water depths of between 18 and 60m, limited at shallower depths due to storm-wave action.

The Dogger Bank is a relict landform of lacustrine clays generated during the last glacial recession which began c. 18,000 years BP, differing from the characteristic boulder clays of this part of the southern North Sea (Jones *et al.* 2004c). The up to 42m thick deposit would have constituted an island as sea levels rose, being inundated by water 10,000-7,500 years BP (Lambeck 1995) and evidence of former coastal environments around the bank come in the form of saltmarsh peat beds and clays containing intertidal molluscs (Balson *et al.* 2002). Water depths in the region of the bank vary from 15 to 30m (Jones *et al.* 2004c), and the

convergence of Atlantic water and residual flows from the English Channel is influenced by its form (Jones *et al.* 2004c). Holocene sands and modern sandwaves with a depth of 1-5m (Fitch *et al.* 2005) overly earlier glaciogenic deposits (Cameron *et al.* 1992) and the extensive fluvial network which followed glacial retreat (Fitch *et al.* 2005). The covering of sandy sediments in shallower (<20m depth) areas to the south west and its associated benthic fauna (e.g. *Echinocardium cordatum*, *Fabulina fabula*, *Lanice conchilega*, *Owenia fusiformis*) falls within the Annex 1 classification, *Sandbanks which are slightly covered by seawater all of the time* (Johnston *et al.* 2002). In addition, superficial mounds of gravel with particle sizes likely to be less than 64mm diameter could fall within the Annex 1 *reef* habitat (Johnston *et al.* 2002). Areas of the Dogger Bank are therefore being considered as draft offshore SACs (Johnston & Turnbull 2007).

A3b.3.10 Seabed substrates

Hard substrates which are resistant to reworking are of both conservation and operational interest as they form areas of stable seabed for biota and may present problems for seabed site developments. The three main types of hard substrate occurring at or near seabed comprise unconsolidated gravel spreads, hard cohesive sediments which were formed during the glaciations, and rock outcrops. All three commonly occur together in the nearshore western margins of the North Sea. The distribution patterns of rock, gravel spreads and the hard cohesive gravelly Quaternary sediments are quite well known and have been mapped by regional surveys.

Bedrock is rarely exposed on the sea floor, being covered in Pleistocene and Holocene sediments, but where exposures exist, these are usually chalk (Jones *et al.* 2004c). Chalk bedrock is the dominant characteristic of the coast around Flamborough Head, and at Thanet in Kent. The exposure at Flamborough Head represents nearly 9% of Europe's coastal chalk and is the most northerly outcrop of coastal chalk in the British Isles. The area is also exceptional in the distance that the chalk is found offshore, at least 3-4km from the headland.

South of the Humber, isolated outcrops of hard substrate are formed mainly of glacial tills. However, isolated stretches of chalk bedrock also extend into the sublittoral at various locations in North Norfolk, mainly between Sheringham and West Runton but also at East Runton and Cromer, representing the only appreciable area of natural hard substrate on the coast of East Anglia. Rocks of Carboniferous age which include coal measures are found north of the North Norfolk coast and form the main source of natural gas in the area (Jones *et al.* 2004c).

The pattern of sediments reworked during the Pleistocene and later is a key control on the distribution of benthic habitats, reducing or removing the influence of the underlying geology on these habitats (Jones *et al.* 2004c). Unconsolidated sediment distribution in the southern North Sea is complex, and reflects both sediment sources and ongoing redistribution by hydrographic processes. Surficial sediments in the coastal area are largely gravelly sands and sandy gravel, extending from Flamborough Head to the outer Thames Estuary and further south, with a large area of sandy gravel off the coast of the Humber and the Wash. To the west in the areas of the Dogger Bank, Norfolk Banks and Southern Bight sand is the dominant surface sediments, with muddy sands restricted to the outer silver pit and near coast of estuarine areas.

Between Flamborough Head and Norfolk, seabed sediment distribution is complex with Holocene sediments generally forming a veneer less than 1m thick. The sand-rich sediments comprising the Norfolk Banks attain a maximum thickness of about 40m, but the

intervening gravelly sand substrate remains thin. Extensive sheets of gravel and sandy gravel occur off the coasts of Lincolnshire. The gravels off the Humber estuary have a varied composition: Carboniferous sandstone and limestones are particularly common, but chalk, Jurassic mudstone, flint and igneous and metamorphic rock types are also found. The gravels are believed to be derived by marine winnowing of glacial moraines and outwash fans deposited during the Devensian glaciation.

Seabed sediments in the southern North Sea are mostly relict, with the distribution of gravelly sediments reflecting glacial, fluvial and coastal processes which have now ceased (Cameron *et al.* 1992). Carbonate gravels, which occur in the east part of the region, were probably reworked from Pliocene Crag deposits similar to those that outcrop onshore in north-east Essex and Suffolk. The carbonate content of seabed sediments is generally low in the area (<10%), probably due to a high glacial source for sediments (Pantin 1991, referenced in Cameron *et al.* 1992); carbonate contributions being modern, reworked early Holocene sediments and older carbonate rich formations (Cameron *et al.* 1992). In the Thames Estuary the seabed sediments were derived by the erosion of beach gravels and fluvial terrace deposits (which mark the ancient courses of the Rivers Thames and Medway) or else from the erosion of underlying Tertiary deposits. There is great lithological variation in these gravels, but flint dominates, and quartz and quartzite are locally common in the north (Cameron *et al.* 1992).

A3b.3.11 Coastal Geomorphology

The geomorphology of the English coastline which meets the southern North Sea varies from exposed, heavily faulted 'soft' chalk cliffs and glacial till/diamict cliffs undergoing retreat, to saltmarsh, small areas of dune systems and sand and shingle beaches and spits. The relatively young rocks of the south east coast are weak compared with those in the north and Scottish coast and are therefore more susceptible to erosion and coastal retreat (Clayton & Shamoon 1998).

At the most northerly point of the SEA area, the chalk cliffs of Flamborough Head are capped with glacial till material and have the most diverse array of active erosional landforms of any chalk coastline in England (May 2003a), though wave diffraction in the intertidal zone in the area prevents extensive erosion like that seen in the Holderness coast to the south. The glacial diamict which forms the coast of Holderness is eroding at rates from 1 to 2.5m year⁻¹ (Furness 1985) with an average of 1.6m year⁻¹ (EH 2008), equivalent to c. 1440kt year⁻¹ (Hardisty 2001) providing substantial inputs of sediment which are moved south by massive longshore transport (May 2003b, EH 2008), with some of the material contributing to the extensive Spurn Head shingle spit at the entrance to the Humber Estuary and much of the material contributing to sediment input to the Humber Estuary itself (Long *et al.* 1998), the North Lincolnshire Coast and the Wash (EH 2008). This process has been ongoing since sea level reached its present elevation at c. 6000 BP (EH 2008). Extensive erosion is also a feature of the Suffolk coast around Covehithe with rates of retreat estimated at between 4.25m and 6m year⁻¹. South of the Humber, erosion and accretion are features of the coastline, with erosion being more recently controlled by coastal defence structures (EH 2008).

Sand and shingle spits are a common feature of the coast in Regional Sea 2, occurring at Spurn Head, Gibraltar Point, Scolt Head Island and Blakeney Point on the North Norfolk coast and Benacre Ness, Winterton Ness, Orfordness, St. Osyth and Dengie on the Suffolk coastline.

Active saltmarsh is a feature which covers extensive areas of the coastline in Regional Sea 2. This includes the northern Humber Estuary, much of the Lincolnshire coast, the area of the Wash, sections of the North Norfolk coast and the Greater Thames Estuary.

A3b.3.12 Reefs

The area of the Wash is well known for accumulations of *Sabellaria spinulosa*, a polychaete worm that constructs tubes of sand grains which, if present in sufficient numbers can coalesce into substantial seabed structures. Biogenic reef such as this can meet criteria for Habitats Directive Annex 1 reef habitat. Biogenic reef is known from other areas in SEA 2 including the Thames estuary. Further detail is provided in Appendix A3a.2.

A3b.4 REGIONAL SEA 3

The bathymetry of the area is extensively controlled by a planation surface of Neogene age which slopes away from the coast at an orientation of south-south-east at 1°, where it is interrupted at a maximum distance of 20km from the coast by the more recent palaeo-valley system (Hamblin *et al.* 1992). Depths rarely exceed 60m, with isolated deeps of 80-100m. The area has many palaeo-channels of extinct rivers which dominated the English Channel region during glacial low-stands of the Pleistocene period. Some of these channels (excluding the Northern Palaeovalley and Lobourg Channel which are now infilled with sediments (Jones *et al.* 2004f), are remnants of the former extension of the Seine, Somme, Solent and Arun rivers, and by the mid-Pleistocene with the opening of the Straits of Dover, the Rhine, Meuse and Thames (Evans 1990, Gibbard & Lautridou 2003, Lericolais *et al.* 2003, Reynaud *et al.* 2003). Quaternary deposits dominate the seafloor and are shaped by modern oceanic processes into bedforms including sandbanks and sandwaves.

A3b.4.1 Substrates

The substrates of the English Channel consist principally of a thin (generally 0-5m, though often only up to 0.5m), coarse lag deposit which is relatively immobile (indicated by encrusted barnacles, serpulids and bryozoa) in modern oceanic conditions (Hamblin *et al.* 1992, BGS 1996b). Less coarse sediments occur to the west and east of this deposit where it is overlain by deeper (5-10m) sands and gravelly sands which have developed into large, mobile sandbanks. Mobile substrates of Holocene age show a tendency to fine towards the coast, with very fine material (phi value of up to 4) present to the east and west of the Isle of Wight, off Selsey Bill, Beachy Head and the Dungeness foreland. Holocene and modern sediment supply is largely derived from coastal erosion, with riverine inputs having declined from terrestrial sources since the early Holocene due to reduced subaerial weathering and the development of depositional estuaries (Hamblin *et al.* 1992).

A3b.4.2 Sandbanks and sandwaves

Tidal sand ridges are the largest mobile bedform in the English Channel and are present south-west of the Dover Strait resulting from the strong tidal current regime in this area. These are up to 18km long, 5-20m thick and are overlain by sandwaves and mega ripples which are asymmetric and orientated normal to the current (Hamblin *et al.* 1992). Sandwaves studied in the Dover Straits are covered in megaripples which reach a vertical elevation of 2m and a wavelength of 10 to 20m, smaller ripples (20cm) with 2m wavelengths are observed on the lee of sandwaves, all orientated at 20° anti-clockwise to the sandwave crest orientation (Idier 2002). Idier (2002) proposes that short term sandwave variation is

the result of megaripple movements which can reach 1mh^{-1} and generate avalanches of material when their slopes reach 34° .

Large sand and gravel waves (approximately 2km long, 0.25 to 2m high, 5 to 18m wavelengths) are found in the West Solent, with asymmetry indicating movement in different directions at either side of the channel (Hamblin *et al.* 1992). Smaller, irregular individual sandwaves are located within the Eastern Solent.

A3b.4.3 Reefs

Reef areas are limited in Regional Sea 3, and no offshore SAC designations are present, nor have any been proposed for this category of habitat. The only such habitat recognized is that of the *South Wight Maritime SAC*, where reefs are recorded as an Annex 1 habitat in combination with *Vegetated Sea Cliffs of the Atlantic and Baltic Coasts* and *Submerged or Partially Submerged Sea Caves*. The reefs present here are comprised of a variety of chalk, limestone and sandstone, the chalk representing more than 5% of Europe's chalk reef exposures.

The eastern English Channel basin is regarded as a potential area of stony reef habitat (Johnston *et al.* 2002) extending over 142km^2 . This consists of the immobile Quaternary lag deposit discussed above, overlain by patchy sands. The Median Deep, as the location of marine aggregates Area 461, also includes material which may form part of a reef habitat, though it is unlikely to fall within the Habitats Directive Annex 1 definition.

A3b.4.4 Coastal geomorphology

The coastal geomorphology of the southern coast of England from Portland Bill to Dover is primarily cliffed, dominated by chalk exposures from the western extent of the Regional Sea to Poole Bay, moving into Tertiary sandstones in the lee of the Isle of Wight until east of Selsey Bill. The southern coast of the Isle of Wight is faced by chalk (primarily), limestone, clay and sandstone of Cretaceous and Jurassic age (BGS 1996b), forming the distinctive needles landform to the south-west. The southern coast of the Isle of Wight is flanked by narrow flint and chalk beaches supplied with material from ongoing coastal erosion.

The coast from Selsey Bill to Dover is dominated by chalk cliffs with the exception of the Dungeness foreland, a large sand and gravel barrier consisting of several hundred storm beaches, dating to at least c. 4000 years BP¹ (Long *et al.* 2006). Sediment supply to this barrier comes partly from offshore and longshore movements of material much of which is derived from soft chalk cliffs to the west (Selsey Bill-Dungeness sediment cell), but also through internal reworking of material (Long *et al.* 2006). Other shingle beach structures fringe the coastline at Weymouth, Lymington, Hurst Castle; and on the Isle of Wight, Newton and the shingle spit system of The Duver, at St. Helen's (BGS 1996b).

Chichester, Langstone and Portsmouth have the largest intertidal areas on the south coast with substantial areas of saltmarsh present. Other areas such as Poole Harbour, Christchurch Harbour and numerous sites on the coasts of the Isle of Wight and the UK mainland fringing the Solent also have saltmarsh. These areas are generally less than 120 years in age and are found in harbours, embayments and small estuaries where they are often grazed (Hill 1996). These areas are often of importance for waders and waterfowl, particularly where large areas of sand and mudflat are exposed at low tide, and attain SPA designations as a result, such as at Poole, Chichester and Langstone Harbours. Like many

¹ This figure has been calibrated to take into account variations in atmospheric ^{14}C .

intertidal areas in the UK, these are subject to 'coastal squeeze' which threatens the future viability of these habitats.

A3b.5 REGIONAL SEAS 4&5

The seabed of the area of the western English Channel, like that further east, is significantly controlled by Eocene and Oligocene planation resulting in the levelling of the inner shelf. The shelf is largely featureless with the exception of some outcrops of igneous rocks where sand ridges and waves have developed (Jones *et al.* 2004b), and in the mid-shelf to the east of the south-west peninsula, Haig Fras crops out to just 38m below the seabed, from surrounding depths of 100-110m (Figure A3b.2).

Water depths on the continental shelf gradually deepen away from the coast in a south-westerly direction to between 140 and 180m at the shelf break. Isolated deeps occur towards the shelf edge, and the varying topography here is partly controlled by major tidal sand ridges (discussed below). The Celtic Deep is a seabed depression at the south-eastern end of St. George's Channel which reaches a maximum depth of 127m, with an average depth of around 110m, and is overlain by significant thicknesses (in places up to 400m) of Quaternary material (Tappin *et al.* 1994). To the east of Regional Sea 4 between 4°W and 2°W, the Hurd Deep is an isolated channel reaching 172m depth, constituting part of the palaeovalley complex of the English Channel, thought to have been cut out in the mid-Pleistocene during a catastrophic flooding event which resulted from the breach of the Weald-Artois Anticline at the Dover Straits (Gibbard 1995).

In addition to this deep, palaeo-processes associated with the now extinct Channel River (see Regional Sea 3 above) generated a significant depositional sedimentary environment to the west of the English Channel, responsible for the Celtic Sea sandbanks and deep-sea fans at the shelf break and slope (Lericolais *et al.* 2003). The Channel River may have reached the shelf break in certain low stands (the most recent of which was the late glacial period within the Devensian) where the sea-level was reduced to below the -100m isobath (Lericolais *et al.* 2003). Erosional forces associated with multiple marine transgressions in the Pleistocene have also influenced the Quaternary sediment profile of the area, though this area would have been free from direct glacial reworking throughout the Pleistocene. A recent survey of the Explorer and Dangaard Canyons on the shelf slope revealed a number of features associated with slope failure (e.g. slumps, slide and slump scars) and dendritic patterns also derived from such sediment failures, but also due to fluvial processes dating back to the Pleistocene period (Davies *et al.* 2008). Erosional features at canyon margins highlight the presence of deep-sea currents transporting suspended material, and the proximity of canyon heads to sandwave fields on the continental shelf and in the Celtic Sea provides a conduit for sediment transport to the shelf slope (Davies *et al.* 2008).

A3b.5.1 Substrates

Sediments deposited in the Western Approaches during previous interglacials when sea-levels were analogous to modern times would have been extensively eroded during subsequent low-stands and marine transgressions. Such Pleistocene sediments are only preserved in the west where the outer shelf was not as exposed (Jones *et al.* 2004b). Quaternary deposits as a whole are sparse and decline in thickness to the east. The Melville Formation – a deposit of Pleistocene material similar in composition to lodgement till, deposited by drifting ice – is located primarily in the middle and outer shelf. This formation is overlain by poorly sorted sand and shelly gravel and at the coast, coarse sand a few tens of centimetres thick which contains some ice-rafted erratics up to 0.5m in diameter (Evans 1990). Partly overlying this layer, sediments deposited following the wave erosion of

the Devensian-Flandrian transgression (Late glacial-early Holocene) are present and are mobilised at their surface by modern bottom currents (Evans 1990).

The seabed sediments of the region primarily consist of deposits derived from either former terrestrial sediments and/or biogenic accumulations. Modern input of material from the coastal margins is extremely small but results from coastal erosion and riverine sources (Reynaud *et al.* 2003). Almost all marine deposits in the channel can be connected with temperate conditions with the exception of ice-rafted clasts (Bates *et al.* 2003). The substrates to the east of the western channel are defined by an area of high tidal current velocities leaving almost no sandy cover (Reynaud *et al.* 2003) with gravel and sandy gravel dominating the seabed, particularly away from the coast. Sediments in the Western Approaches vary from biogenic sand, to gravelly sand, whereas to the north-west, in the Celtic Bank area, mud and sandy mud are present which may be glacially derived.

A3b.5.2 Sandbanks and sandwaves

Sandwaves cover the western English Channel, passing into ribbons where tidal stresses are greater, leaving bare rock or reef environments at the coast. Rippled sand sheets are present in the Western Approaches and Celtic Sea (Evans 1990). Reynaud *et al.* (1999a) provide a summary detailing various previous interpretations of the genesis of the Celtic Sea sand banks which include both erosional (e.g. Berné *et al.* 1998) and depositional beginnings (Reynaud *et al.* 1999b).

Larger tidal sand ridges (up to 200km long and 60m high) occur close to the shelf break, orientated normal to it in a north-easterly direction (Evans 1990, Dyer & Huntley 1999). The surfaces of these ridges are covered in sandwaves which continue to be modified, though the larger features themselves are moribund, relicts from the Devensian low-stand. Investigations of the Kaiser Bank flanks in the outer shelf of the Western Approaches revealed a tide-dominated regime promoting dune and ripple formation and, at depths of less than 145m, wave generated ribbons (Reynaud *et al.* 1999a).

Maerl beds are a feature of coastal parts of Regional Sea 4 and consist of free-living Corallinaceae. These are categorised within the Annex 1 SAC habitat, *Sandbanks which are slightly covered by sea water all of the time*, and are a feature of the Fal and Helford (Cornwall) SAC designation, which hosts the largest maerl bed in England and Wales at 150ha (Jones *et al.* 2004a). Two species of maerl in the SAC are included in the UKBAP (*Phymatolithon calcareum* and *Lithothamnion corallioides*). Areas of dead maerl have historically been subject to licensed extraction, recently excluded on conservation grounds.

A3b.5.3 Reefs

There are several marine SACs within the 12nm limit which include reefs as a primary criteria for site selection (Isles of Scilly, Plymouth Sound and Estuaries, Lundy), and a few others where reefs are a secondary feature (Fal and Helford, Severn Estuary). Outside the 12nm limit, areas of bare rock are present which may be suitable reef habitats.

The area of Haig Fras has been identified as a candidate offshore SAC, and is the only area of rocky reef in the Celtic Sea. Haig Fras is a shoal of three resistant granitic bodies at a distance of c. 150km north-west of Lands End (Evans 1990). The uppermost exposed bedrock pinnacle measures less than 1km across, with the overall exposure being c. 15 by 45km (Rees 2000), covering a total area of c. 35,650ha (flat mapped), putting the reef into grade C for area (0-2% of total rocky reef resource), though for representativeness and structure the site is considered as grade A (JNCC 2008d). The areal extent being

considered for designation covers a total of 75,744ha (JNCC 2008d). Ecological information relating to this site is provided in Section A3a.2.5.2. In addition to Haig Fras, the presence of the Annex 1 species, *Lophelia pertusa*, is probable on the shelf break to the west as this species has been discovered in analogous conditions elsewhere in the west and east of UK waters (Johnson *et al.* 2002).

The South West Approaches have been identified as an Area of Search for the Annex 1 reefs habitat. The recent MESH survey of the area set out with the prediction that canyons located within the South West Approaches on the shelf margin and continental slope may contain bedrock and biogenic reefs formed by cold water corals (Davies *et al.* 2008). The substrata and biological characteristics of two of these canyons (Explorer and Dangaard Canyon) were studied, revealing the presence of Annex 1 biogenic reef (*Lophelia pertusa* reef) and bedrock reef, though no stony reef.

A3b.5.4 Coastal geomorphology

The geological characteristics of the western peninsula produce a coastline which is more resistant to erosion than the soft chalk and Tertiary cliffs further east (Clayton & Shamoon 1998, also see Regional Sea 3). The Scilly Isles are made up of an igneous, granitic shoal (Evans 1990), with 5 inhabited isles and numerous others which are not inhabited. Some of the larger islands have been formed as a result of being linked by tombolos or low terraces (Mitchell & Orme 1967 in May 2003d) and constitute the largest British group of tied islands (May 2003d). Sandy beaches of till and weathered granite are present throughout the islands.

Devon and Cornwall are mostly backed by steep cliffs rising to 100m which are best developed on the northern coast of the peninsula (exemplified at Tintagel and Harland Quay), being more broken on the south coast by rias where the sea penetrates inland along mature valleys (Evans 1990). A number of features including dune systems, sand spits and shingle beaches are present. Sandy beach and dune systems are present along the Bristol Channel coast, for instance at Carmarthen and Oxwich Bay, and further south on the south-west peninsula at Upton and Gwithian Towans, where there is a sandy dune shore which gives way to an exhumed cliff line to the north (May 2003c). Further north at Braunton Burrows there is another example of an extensive dune system (6km in length) at the mouth of the Taw-Torridge estuary which accompanies a sand spit. The other significant sand spit feature on the English coast of Regional Sea 4 is at Dawlish Warren on the Exe Estuary.

Shingle coastal structures are abundant on the southern coast, the largest being the barrier/tombolo of Chesil Beach, which extends southward to connect the mainland to Portland Island. The barrier beach is backed by cliffs to the west and the large lagoon of The Fleet further east. The genesis of the feature probably extends back to late glacial times when sea-level was much lower than at present, perhaps formed from eroded offshore and riverine gravels maintained by longshore sediment supply from west Dorset (May 2003b). The site is included in the Dorset and East Devon World Heritage Site designation of 2001. Other significant shingle structures include the gravel beaches at Loe Bar, Slapton Sands and Westward Ho! The two former sites, like Chesil Beach, are backed by lagoons and cliffs, Slapton Sands having an excellent example of a cobble spit. At Slapton Sands, the present gravel beach once extended south to Hallsands, an area which has suffered erosion of its shingle beach and the exhumation of former cliffs, as well as the loss of the village of Hallsands itself to erosion in 1917 (May 2003b).

Residing on the southern Welsh coast, Carmarthen Bay may have the most varied assemblage of coastal features anywhere in the British Isles, and has been relatively

undisturbed by anthropogenic activities (May 2003e). Sitting at the mouth of the Taf, Twyi and Gwendraeth estuaries, the site includes major dunes, sand spits, barrier beaches, hard- and soft-rock cliffs, rias, raised beaches, intertidal sandflats and saltmarshes. Further to the west, past St. Govan's Head is an active cliff coastline of Carboniferous limestone which has formed a complex of geo, stack, cave and arch, that is retreating into an area of karstic landscape (May 2003a).

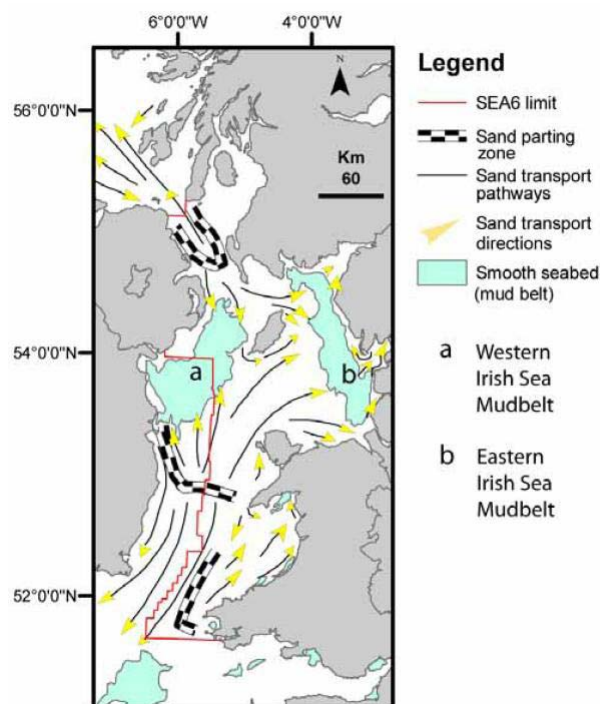
A3b.6 REGIONAL SEA 6

Regional Sea 6 has a complex sea-bed topography with many static, relict, bedforms indicative of glacial and peri-glacial activity (e.g. *rôche moutonnées*, pingos). The wider bathymetry of the area varies from shallow near-shore to deeper waters in the Firth of Clyde (80m). A prominent north-south trough extends from the North Channel (120m), reaching 275m depth in the Beaufort's Dyke passing the Manx Depression, St George's Channel (120m), and towards the Celtic Deep. The areas of Cardigan Bay and Caernarfon Bay are relatively shallow with depths typically ranging between 40 and 80m. Some of the areas described below fall within categories outlined by the JNCC as being suitable offshore Annex 1 SAC habitats (e.g. *sandbanks which are slightly covered by sea water all the time, submarine structures made by leaking gases and reefs*). At the time of writing, there are no offshore (outside 12nm) designations in Regional Sea 6.

A3b.6.1 Sandbanks and sandwaves

Substantial fields of sandwaves and sand ripple bedforms are present in Regional Sea 6, primarily south of 53°N, particularly between the Republic of Ireland and Welsh coasts. These are poorly discriminated by Connor *et al.* (2006) and it is recommended that the BGS regional reviews (Fyfe *et al.* 1993, Tappin *et al.* 1994, Jackson *et al.* 1995) and the sediment transport technical report (Kenyon & Cooper 2005) for the previous SEA 6 programme be consulted. A sandbank to the east of the Isle of Man was studied in a 2004 MESH survey (though this largely centred on the assessment of benthic communities). Sand dominated bedforms range from tidal-parallel sand ribbons to larger transverse barchan-type sand waves and extensive sand patches with smaller sandwaves. These waves occur to the west of St. George's Channel, in the Nymph Bank and to the west of Cardigan Bay, broadly coinciding with sandy seabed substrates. Mobile sandbanks and waves tend to form in areas of moderate shear stress. Sand ribbon features are often found downstream of small obstacles in relatively high shear stress conditions, and are therefore highly mobile (Holmes & Tappin 2005). Tidal stresses are moderate to strong (Connor *et al.* 2006) to the north and south of the Isle of Man, where sand ribbons are most abundant. Smaller linear sand streaks supplemented by linear sand ribbons occur across St. George's Channel and the Cardigan Bay area following a tide-parallel pattern, coinciding with sandy gravel deposits. Analysis of mobile and static bedforms has enabled the prediction of sediment transport pathways (Holmes & Tappin 2005) which are indicated in Figure A3b.4.

Figure A3b.4 – Net sand transport pathways and directions



Source: Holmes & Tappin (2005)

The abundance of sandwaves in the area has resulted in the Annex 1 habitat type, *sandbanks which are slightly covered by sea water all the time*, being used as a qualifying feature for a number of SAC selections, for instance at Menai Strait and Conwy Bay/Y Fenai a Bae Conwy, Cardigan Bay, Morcambe Bay, Murlough (Co. Down) and Pembrokeshire Marine/Sir Benfro Forol.

A number of sandwaves and sandbanks were described for the previous 2004 DTI survey of the Irish Sea. Examples of small to very large sandwaves, sand patches and a sand sheet were recorded in Liverpool Bay using side-scan sonar and multibeam techniques. Using multibeam techniques, the Ballacash Bank was also surveyed. This is an active banner bank lying to the east of the Isle of Man, maintained by sand convergence. In the long term, banner banks to the east of the Isle of Man leak sand to the shelf and are therefore temporary features (Holmes & Tappin 2005).

A3b.6.2 Reefs

A number of reefs were described in the 2004 DTI survey of the SEA 6 area and a number of locations in Regional Sea 6 have reefs as a qualifying feature in their designation as an SAC, for instance Pembrokeshire Marine/Sir Benfro Forol, Llyn Peninsula and the Sarnau/Pen Llyn a'r Sarnau, Strangford Lough (Co. Down) and Menai Strait and Conwy Bay/Y Fenai a Bae Conwy.

Holden's reef lies in the near-shore area of Cardigan Bay off Barmouth and is an area of rocky reef, colonised by a variety of benthic fauna. These reefs were proved to be more extensive than previously thought (Judd 2005) and consist of Methane-Derived Authigenic Carbonate (MDAC) and can be categorised as, *submarine structures made by leaking gas*. The area of 'Texel 11' in the central Irish Sea also revealed a distribution of MDAC sediments which may cover more than 500,000m².

Pisces reef is a 1.4km outcrop of rock lying in an area of soft mud to the west of the Isle of Man, rising to about 60m above the seabed and conforms to the habitats directive definition for reefs. Soft sediments infill hollows in the rock structure.

Potential areas of biogenic reef have been identified off north-west Anglesey through surveys undertaken specifically by Rees (2005) for SEA 6. These areas of horse mussel *Modiolus modiolus* reef are discussed further in Section A3a.2.

A3b.6.3 Pockmarks

As part of the previous SEA 6 programme, Judd (2005) examined the distribution and extent of submarine structures made by leaking gas (which may include pockmarks) relevant to the Habitats Directive. A few pockmark fields were identified in the muddy sediments to the west of St. George's Channel in the north-west Irish Sea, just south of 54°N in an area of high carbonate content. Other areas containing shallow gas identified by acoustic turbidity have no surface pockmark expressions.

A3b.6.4 Glacigenic bedforms

Glacially influenced relict bedforms occur extensively throughout Regional Sea 6. Rôche Moutonnées occur between the eastern Irish coast and the Isle of Man; these are subglacial bedforms which are orientated to the south in the direction of ice flow. To the west of Anglesey and north to the Isle of Man, polygonal textured bedforms originally described by Wigfield (1987) are derived by periglacial ice-wedging, generating features ranging from 15-80m in diameter. Former pingos are also a feature of the area, generated in permafrost conditions when an ice wedge pushes sediment up from the surface to create a dome, which eventually collapses to leave a ridge representing the former dome edge – the diameter of domes can vary from 10-500m in diameter (Holmes & Tappin 2005).

A3b.6.5 Substrates

In the eastern Irish Sea there is a general transition south-east and east of the Isle of Man, towards the western English coast, from coarser-grained gravel and sand to mud (the Eastern Irish Sea Mud Belt) Belderson (1964). To the east and south of Arran, muddy sediments range down to around 55°N in the Firth of Clyde. These muddy areas coincide with areas of weak bed stress, representing depositional environments. These areas were identified by Judd (2005) as potentially providing Holocene-based sources of methane – a key gas involved in the creation of MDAC habitats (though acoustic turbidity did not indicate gas in muddy areas).

Thin sandy, gravelly sediments generally less than 0.3m thick overly a layer of gravelly lag deposits comprising sandy, shelly and poorly sorted gravel, which makes up the floors of the St. George's Channel and North Channel (Jackson *et al.* 1995), the sand only thickening in areas of raised bedforms. Sand thickness increases towards the area of extensive mud to the west and east, varying in thickness from 0.5 to 40m, with surface variations accounted for by the development of sand waves and tidal sand ridges (Jackson *et al.* 1995).

The carbonate content of sediments is nearly 0% in the nearshore of Liverpool Bay, to the east of the Isle of Man, St. George's Channel and Cardigan Bay. Higher (10-25%) carbonate content occurs in sediments in the south-eastern lee of the Isle of Man, to the north and west of Anglesey and the Llyn peninsula and south to Pembrokeshire.

A3b.6.6 Coastal geomorphology

The coast of south-west Wales is characterised by a series of cliffs and small sandy bays. North of Aberystwyth, Cardigan Bay supports a sequence of estuaries and sand dunes. Further north the Llyn Peninsula and Anglesey have rockier coastlines though Anglesey also supports several sand dune systems (DEFRA 2000).

From Liverpool Bay to the Solway Firth the majority of the land is low-lying and includes a number of important estuaries containing areas of saltmarsh, sand or mud flats and sand dunes. Of the 14 major estuaries in this region, all except one are larger than 5,000ha, including Morecambe Bay which is the second largest area of intertidal mud and sand in the UK after the Wash. Much of the estuarine coast in the middle of the region has been highly developed with major industrial and port facilities on the River Mersey and on the Wirral, and to a lesser extent on the River Dee (DEFRA 2000). To the north, rocky shores dominate the coast running from the Solway Firth to the Mull of Galloway. The east and south-west coasts of the Isle of Man also consist of rocky shores with sandy beaches in the exposed north-west (DEFRA 2000).

The coast of Northern Ireland is extremely varied, incorporating high cliffs, extensive sand dunes, mudflats and rocky shores. The principal features are the three sea loughs (Larne, Strangford and Carlingford) which are characterised by fine sand and muddy sediments. Along much of the rest of the coast, sandy beaches and shingle are interspersed along rocky shores with rock outcrops and low cliffs more extensive towards the border with the Republic of Ireland (DEFRA 2000).

A3b.7 REGIONAL SEA 7

Regional Sea 7 has a complex sea-bed topography varying from shallow coastal areas to isolated deeps of 200 or 300m (e.g. the Inner Sound between Raasay and the mainland), resulting from past glacial processes acting on rocks of differing strengths (Fyfe *et al.* 1993).

A3b.7.1 Sandbanks and sandwaves

Sandwaves, sand ribbons and sand ripples are all features of Regional Sea 7 and are consistent with tidal and residual currents which play a major part in the net transport of sand along the shelf, though features larger than sand ripples are largely absent from the Hebrides shelf due to a lack of modern inorganic sediment input (Holmes *et al.* 2006). Sand waves occur off the north east coast of Lewis in shell sands, in the Malin Sea, Inner Hebrides, south of Mull and the Firth of Clyde (Fyfe *et al.* 1993). Off the Northern Irish coast sandwaves reach a maximum height of 30m with a morphology suggesting eastwards migration. Smaller sand ripples occur between rock outcrops in the shell sand of the Stanton Banks and in gravelly and sandy sediments in the Passage of Oronsay and the north end of the Sound of Islay. Sand ribbons predominate in the north and between Islay and Malin Head, and the North Channel.

A3b.7.2 Reefs

To the west and south of the Outer Hebrides, there is a substantial area considered to be potential rocky reef owing to the seabed substrate there, which is primarily rock outcrop of Lewisian gneiss. There are nine other areas within Regional Sea 7 where reefs constitute an Annex 1 habitat in a designated SAC (e.g. Firth of Lorn, Loch Creran, Lochs Duich, Long

and Alsh Reefs, Rathlin Island), or where the Annex 1 habitat is a qualifying feature, but not a primary reason for SAC site selection (e.g. Loch Laxford, Loch nam Madadh, Sunart, Treshnish Isles). See Appendix 3j for more information on relevant conservation designations. In addition to these sites, zones where high carbonate input is associated with submarine bedrock outcrop might be regarded as fringing reefs (Holmes *et al.* 2006).

A3b.7.3 Glacigenic bedforms

The cyclic expansion of glaciers during the Pleistocene has led to erosion and sediment deposition of glaciogenic material offshore. For instance, buried submarine moraines on the outer shelf mark the limit of the last glacial maximum in the area, in addition to relict, static bedforms such as drumlins and iceberg scour. Erosion has featured heavily, generating glaciogenic troughs in weaker rocks, and islands, pinnacles and rock platforms on the Hebrides shelf which generally consists of more resistant igneous and/or metamorphic bedrock (Holmes *et al.* 2006).

A3b.7.4 Substrates

Mud and sandy mud dominate the Little Minch and the Sea of the Hebrides with sandy material comprising much of the surficial sediments to the north in the Minch and south in the Malin Sea around Stanton Banks and Blackstones Bank (Figure A3b.2). Sediment sorting generally increases from Skye (unsorted) north towards the Butt of Lewis and Cape Wrath; the well-sorted material being lithic sand less than 10cm thick probably of periglacial origin (Bishop & Jones 1979). The biogenic fraction of sands in the area varies widely from c. 5% in The Minch, 35% between Lough Foyle and Benbane Head, up to 55% to the south-east of Islay (Fyfe *et al.* 1993).

Coarse sediment (sandy gravel, gravel) is more abundant further south, e.g. to the west of Islay and the North Channel, due to strong currents. Further north, offshore gravelly sediments often reflect onshore geology, with clasts of Lewisian material making up assemblages off the Outer Hebrides, and Mesozoic Permo-Triassic and Jurassic material being found around Skye and Raasay.

The largest rock outcrop in the area is in the North Channel, with other areas including the Stanton Banks, Blackstones Bank, Hawes Bank and platforms which extend from Canna, Tiree, south-west Mull and Islay (Fyfe *et al.* 1993).

A3b.7.5 Coastal Geomorphology

The Regional Sea 7 coast consists largely of cliff and sand dune environments interspersed with small areas of shingle beach. The region has c. 29% of the British hard cliff coastline and therefore represents a significant resource (Barne *et al.* 1997c, f). Lewisian gneiss dominates the eastern coast of the Outer Hebrides with near-vertical cliffs (Dargie 1997), the west having more prolific sand dune formations partly due to the islands' west-east upward tilt, particularly in the south (BGS & Threadgould 1997). Elsewhere the coastal geology is more varied, with notable outcrops of Tertiary volcanics on Rum, Eigg, Skye and Mull, and Torridonian sandstones and Lewisian gneiss making up much of the mainland coast. Further south on Mull, igneous rocks dominate north of the Great Glen Fault, while further south Dalradian rocks make up much of the coastal geology. In addition to cliffs notable features include caves (e.g. Fingal's Cave, Staffa), raised beaches and fossil cliffs (e.g. Jura). These cliffs provide a substantial habitat resource for bird fauna recognised by a number of SPA designations in the area (e.g. Rum, Ardmeanach, Rinns of Islay).

Although numerous dune or machair sites occur in the area, almost all are of a small size and no large systems like those seen on the western coast of the Outer Hebrides occur on the western mainland. Tiree contains the largest dune system within the Inner Hebrides at 785ha, and is recognised as an SAC on account of its mobile and fixed dune, and machair which encompasses 24% of the island. The eastern coast of the Outer Hebrides largely lacks dune coverage (apart from in the far north and south) due to the dominance of cliff habitat discussed above. Many of the island dune systems are recognised in SSSI or ESA designations whereas the mainland types are more typically part of a wider National Scenic Area (NSA). Dune systems provide habitat for a significant floral resource (Dargie 1993 – cited in Dargie 1997). Wildfowl and wader populations are also of importance in relation to machair systems, though these are largely restricted to the western coast of the Outer Hebrides.

A3b.8 REGIONAL SEA 8

There is little modern sediment input to the continental shelf of Regional Sea 8 and the modern seabed environment now largely reflects the effects of reworking by near-bottom currents on the topography and sediments that originated during the former glaciations. The effects of glacial erosion are evident on the outer continental shelf and upper slope but there are also bedforms generated from sediment deposition as the ice sheets advanced and retreated. Inner shelf and nearshore sediments include a substantial component of carbonate fragments derived from benthic fauna during the Holocene. The most recent bathymetric survey relevant to Regional Sea 8 was conducted by the MCA Civil Hydrography Programme in 2005-2006, detailing the area from Cape Wrath to Solan Bank, and Solan Bank to the Fair Isle Channel.

A3b.8.1 Pockmarks

Pockmarks appear to be rare in Regional Sea 8. A small area of apparently relict and extinct pockmarks appear to the north east of Rona, and the genesis of some similar features may result from other processes (e.g. plough marking, slope instability) (Stoker *et al.* 1993).

A3b.8.2 Sandbanks and sandwaves

Sandbanks occur to the north of Orkney reaching 30m in height and 10km in length. What proportion of Holocene and glaciogenic material these banks contain is uncertain (Stoker *et al.* 1993). Sandbanks in the vicinity of Sanday are included in an SAC designation – though not as a primary reason for site selection – under the Annex 1 habitat, *sandbanks which are covered by sea water all the time*.

Tidal sand banks, tidal sand ridges and fields of migrating sandy bedforms typically form in water depths ranging from 20-100m or more and in areas that are prone to the strongest wave and tide generated near-bottom currents. Sandwaves occur along the northern Scottish mainland, to the south west of Orkney and north between the Northern Isles in the middle and inner shelf, often asymmetric indicating the net direction of sediment transport (Stoker *et al.* 1993). These bedforms and adjacent nearshore seabed areas locally consist of more than 60% shell fragments that have been derived from prolific benthic biota during the Holocene.

A3b.8.3 Iceberg ploughmarks

Partially infilled iceberg ploughmarks occur in Regional Sea 8 to the west and north of Shetland at water depths of 200-450m (Masson 2001). These were generated by grounding of floating ice on the edge of the continental shelf during the late Pleistocene (Johnson *et al.* 1993, Stoker *et al.* 1993). These striating features extend for many kilometres in an overlapping path with a width of c. 20m and depth of c. 2m, flanked by ridges of gravelly material generating highly varied bed topography. This area coincides with the potential Annex 1 habitat; *rocky reefs*. Ploughmarks were observed in areas including Rosemary Bank, the Wyville Thomson Ridge and in water depths of less than 500m in the Faroe Shetland Channel in the 2007 SEA 7 survey (Stewart & Davies 2007).

A3b.8.4 Reefs

Potential Annex 1 habitat reefs described as, *rocky marine habitats or biological concretions that arise from the seabed*, occur to the west of Shetland and the Outer Hebrides, and stony areas occur to the north and west of Regional Sea 8. Though not designated, these areas may contain the Annex 1 *reefs* habitat which results from animal and plant community development on rock or stable cobbles and boulders, or biogenic structures. Their distribution is partly controlled by underlying geology in addition to depth, oceanographic conditions and distance from the coast.

The Stanton Banks, Darwin Mounds and Wyville Thomson Ridge candidate and possible offshore SACs have been selected for consideration partly due to the presence of the Annex 1 *reef* habitat. The Stanton Banks consist of bedrock mounds supporting communities typical of moderately exposed/circalittoral bedrock reef. Primarily in Regional Sea 8, but also with elements in Regional Seas 9 and 10, the Wyville Thomson Ridge forms part of the Greenland Scotland Ridge that extends from East Greenland to Scotland, forming a narrow north-westerly trending topographic barrier between the Faroe Shetland Channel and the Rockall Trough. Both basaltic bedrock and extensive pebbles and cobble are present on the Wyville Thomson Ridge, and the area surveyed as part of the 2006 SEA 7 survey (Stewart & Davies 2007) identified biogenic material indicative of an extensive, but now dead, coral reef. This material is redistributed in the area by strong currents. The ridge also has iceberg ploughmarks which occur in more widely in Regional Seas 8 and 9.

A3b.8.5 Seabed substrates

There is a great deal of spatial variation in sediment grain size. Sand and gravel tend to be shelf deposits, whereas muds are in deep-water slopes. Carbonate rich material is likely to be associated with gravels and bedrock in the inner and middle shelf and towards coastal areas. Sediments in the region are mostly of glaciogenic origin, having been reworked in the late glacial or Holocene periods.

Outcrops of submarine rock consist of strong sedimentary material of more than 210Ma age and extremely strong crystalline metamorphic rock of more than 545Ma age. Coastal and mid-shelf areas underlain by these crystalline rocks have resisted repeated glacial erosion and are now mostly swept clean of mobile sediments by very strong near-bottom currents. A significant outcrop of rock is located to the west of the Outer Hebrides consisting of the dominant Lewisian gneiss base geology of the wider Foreland Province which also makes up The Flannan Ridge and Islands, North Rona and Sula Sgeir. On the Hebrides Shelf, St. Kilda is also a feature of bedrock outcrop, though in this case it is of Tertiary igneous intrusive derivation (Stoker *et al.* 1993).

In many shelf locations, but particularly on topographic highs, gravel fields form lag deposits that are exposed or covered by thin mobile seabed sediments for example, extensive fields of seabed gravel occur on regional features such as the Otter, Papa, Stormy and Solan Banks situated to the north and west of Orkney. In contrast, ridges of lag gravel also occur on gravel berms formed by the seabed ploughing processes associated with iceberg scour. Coarse sediments (gravelly sand and sandy gravel) form a large part of the surficial, unconsolidated Holocene substrates in the Regional Sea 8 area.

Inner shelf and nearshore areas of seabed rock and gravel support a diverse and prolific calcareous biota which contributes significantly to the proportion of calcium carbonate in nearshore sediments. These sediments represent major high-latitude centres of modern carbonate production (Farrow *et al.* 1984) consisting of bivalve and echinoid fragments, serpulid tubes, barnacle plates and bryozoans, the proportions and ages of which vary with location – ages of dated material varies from greater than 8000 BP to 3000 BP (Stoker *et al.* 1993) and contributions presumably continue in the modern environment. Fragments of the cold-water coral *Lophelia pertusa* have been found on positions of elevated seabed on moraines and rockhead to the north-west of Shetland.

West of Shetland, large areas of shelf are characterised by longitudinal sand patches overlying a gravel substrate. Individual sand patches are usually strongly elongate, typically a few tens to two hundred metres wide by hundreds of metres to several km long. The predominant trend of the elongate patches is north-east to east-north-east. On the basis of sidescan sonar data, sand cover varies from <5% to >95%, but is typically in the 10-60% range (Masson 2003).

A baseline video survey of the Clair field in 2000 indicated that the seabed was tide scoured and varied from sand, through mixed sand, gravel and pebble, to cobble and boulder pavement. Topographic highs had a greater proportion of cobbles and boulders, although such rocks were ubiquitous over the survey area. The sediment pattern accorded with the BGS description of the area given by Stoker *et al.* (1993), with sediments arranged linearly, parallel to the tidal stream axis, with ribbons of sand alternating with coarser material. Over much of the area the layer of sand was thin and only partially covered the hard clay beneath (Hartley Anderson 2000, ERTSL 2001).

The carbonate component of the sand fraction of sediment in the area is made up of biogenic deposits broken down by hydraulic action and bio-erosion. The result is carbonate contents of generally 25-50%, rising to 100% between Orkney and Shetland. Carbonate content is tending to rise as inputs from local epifauna and infauna continue (Farrow *et al.* 1984).

Muddy sediments are rare on the shelf with the exceptions of sheltered sea lochs and certain mid-shelf enclosed basins. Muddy sand is not abundant and is found locally to the north west of Orkney (incorporating a pockmark field) and more extensively to the north-west of the Outer Hebrides. At other sites, thick sequences of sub-seabed mud occur under superficial sands and gravelly sands.

A3b.8.6 Coastal Geomorphology

The Orkney Islands are generally low-lying with gentle slopes and rounded topography. Spectacular cliff and rock formations characterise much of the western coastline with eastern coasts displaying predominantly rocky shorelines interspersed with sandy and shingle beaches and sand dunes. The islands are mostly composed of Devonian sedimentary rocks (410-360Ma), predominantly Middle and Upper Old Red Sandstone (Barne *et al.* 1997e).

High exposed cliffs formed from a variety of metamorphic, sedimentary and igneous rocks dominate much of the north coast of Scotland. Lewisian gneiss typically forms rounded and hummocky slopes, although in the vicinity of Cape Wrath it forms steep cliffs (Steers 1973). In Caithness, Old Red Sandstone forms high cliffs with stacks and geos, whereas the more intricate and indented coastline between Strathy Point and Loch Eriboll is largely formed of Moine rocks (Stoker *et al.* 1993). Loch Eriboll is one of three large sea lochs which cut into the western part of the coast in alignment with geological formations. Prominent headlands provide shelter for a number of beach and dune systems (Barne *et al.* 1996b).

The coast of the Outer Hebrides is composed of Lewisian gneiss, with many sea lochs of late Devensian origin and low cliffs commonly incised into the overlying glacial drift (BGS & Threadgould 1997). The west coast of the southern isles of North Uist, Benbecula and South Uist tend to be lower than in the east due to tilting, possibly associated with movement along the Minch fault in the Tertiary (BGS & Threadgould 1997). The west coasts of these islands also feature extensive beaches, machair, sand flats and dunes, the morphology of which is greatly controlled by the prevailing wind.

A3b.9 REGIONAL SEA 9

The bulk of modern seabed sediments comprise substrates that are more than 10,000 years old and have been reworked from strata by currents generated by tides and waves.

A3b.9.1 Seabed features

Some features characteristic of more southerly regions are missing from Regional Sea 9 (e.g. reef and pockmark features) which is most likely an outcome of substrate types, bed topography and bathymetry. Consideration is being given to a number of potential areas in close proximity to Regional Sea 9 for the Annex 1 *reef* habitat which largely encompasses the area of iceberg ploughmarks immediately to the south in Regional Sea 8 (discussed above).

A3b.9.2 Seabed substrates

Sediments in the region are mostly of glaciogenic origin having been reworked in the late glacial or Holocene periods. There is little modern sediment input to the continental shelf and Faroe-Shetland Channel. The amount of biogenic carbonate is low compared with mid-shelf and coastal areas to the south, with most of the area having 0-20% by weight, presumably as habitat for carbonate forming fauna reduces. Higher carbonate concentrations (20-40%) are more likely to occur in muddy sediments for this area.

JNCC SeaMap and the BGS work included in Stoker *et al.* (1993) do not indicate any rock outcrops in the area, though data coverage for some of the region to the north east is incomplete. Any outcrops may consist of igneous and sedimentary Tertiary deposits.

North of the shelf break the seabed substratum grades from sand and gravelly sand into gravelly mud, sandy mud and in some cases mud. Mud is centred on the continental slope and tends to increase with depth, generally overlying late Pleistocene to early Holocene muds where accumulation has probably continued throughout the Holocene due to a reduced current compared with the surrounding shelf (Stoker *et al.* 1993, also see Connor *et al.* 2006).

A veneer of sand or muddy sand covers much of the Faroe Bank Channel floor, deposited by bottom currents during the Holocene. However, much coarser sediments occur along the northern edge of the floor and grain-size generally increases towards and onto the lower slope of the Faroe platform. Deep cold water flow between the Norwegian Sea and the North Atlantic passes through the Faroe Bank Channel and Faroe-Shetland Channel generating strong bottom currents capable of eroding and transporting sediments up to gravel size, evidenced by bedform features including scours, furrows and barchan-type dunes detectable in side-scan sonar and high-resolution seismic profiles (Bulat & Long 2001, Masson *et al.* 2004). The floor of much of the Faroe-Shetland Channel is characterised by relatively featureless mud and muddy sand with some gravel. The boundary between muddy sand and mud at the seafloor gradually moves deeper in the basin as it becomes narrower towards the south, reflecting the increasing importance of bottom currents.

A surface veneer of mud covers the floor of the Norwegian Basin below 1000m depth and glaciogenic debris flow sediments of the North Sea Fan underlie much of the area. A field of mud diapirs, the earliest of which are probably of early Pliocene age (5Ma), resulting from the upward migration of fluid/mud to the surface occur in Quadrant 217 of the southern Norwegian Basin (the Pilot Whale diapirs). No evidence for fluid escape (or possible associated biological communities) has yet been found but there remains the possibility that localised areas of fluid escape may be active in the area. Holmes *et al.* (2003) conducted a study of the evolution of the Pilot Whale diapirs, concluding that modern activity and fluid escape is most likely to occur where diapirs are underlain by shallow acoustic scatter.

A3b.10 REGIONAL SEAS 10 & 11

Current knowledge of seabed sediments only allows for a description of those deposits out to 14°W, i.e. those in Regional Sea 10, though features have been described for the Hatton Bank area further west. The current array of sediments on the shelf of Regional Sea 10 are the result of reworking of glaciogenic sediments by submarine processes which have created a seabed armour in areas winnowed by strong bottom-currents (DTI 2007). A number of areas within Regional Seas 10 and 11 were surveyed as part of SEA 7 (Hatton Bank, Rosemary Bank, Anton Dohrn Seamount). The results of this survey are presented in Stewart & Davies (2007) and are synthesised in the sections which follow.

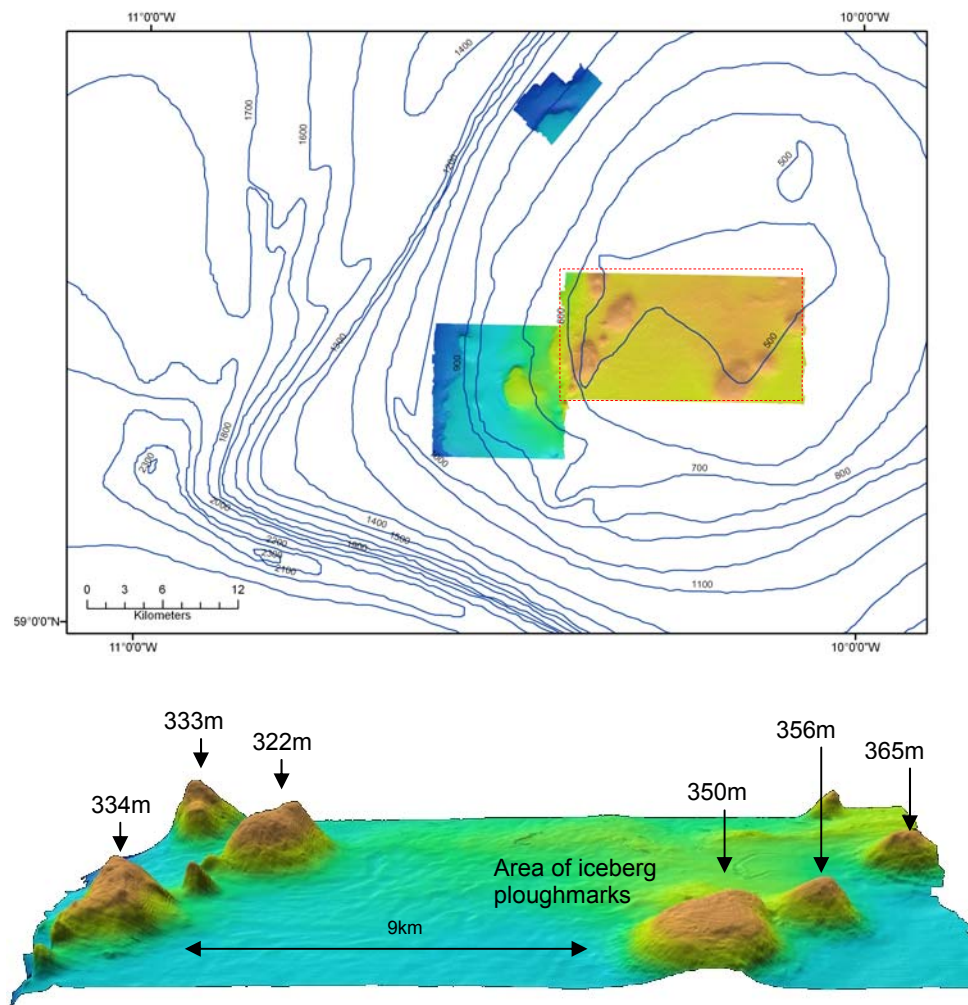
A3b.10.1 Seabed features and substrates

There are two notable areas in Regional Sea 10 which contain the Annex 1 *reef* habitat, The Darwin Mounds and North West Rockall Bank. The former is a candidate SAC located in the north of the Rockall Trough at a depth of c. 1000m, around 160km northwest of Cape Wrath, covering an area of 137,726ha. The features of interest are sandy mounds formed by seabed expulsion, capped with the cold water coral *Lophelia pertusa* (JNCC 2008c). Each mound, of which there are hundreds, is approximately 100m in diameter and 5m in height. Unlike other reef areas, this population of *L. pertusa* is notable in that it colonises sandy rather than hard rock or gravel substrata. The North West Rockall Bank is located between 13 and 15°W and covers an area 488,569ha. This area is currently a draft SAC being considered under the Annex 1 *reefs* habitat.

Most of the seabed sediments in Regional Seas 10 and 11 are muds or sandy muds only interrupted at Rosemary Bank and the Anton Dohrn Seamount. One of the largest inputs of modern material to the shelf is from sources of biogenic carbonate, and the carbonate concentration of shelf muds is typically between 40 and 60%, increasing to 40-80% on and around Rockall Bank.

Rosemary Bank is a seamount 305km west of Cape Wrath with a diameter of 75km. The mound is thought to consist of basalt with localised phono-tephrite lavas and potassium rich tuffs (Stoker 1995) and extends from the seafloor to within 500m of the surface. The bank is of volcanic origin (70Ma) and has large pinnacles of later origin on its surface, extending to a maximum of 180m above the surrounding seafloor (Figure A3b.5). Medium to coarse-grained sediments which include gravel and cobbles, and boulders in areas of iceberg ploughmarks cover the bank. Bedrock outcrops have also been observed.

Figure A3b.5 – The location of multibeam surveys conducted on Rosemary Bank in 2006



Source: Stewart & Davies (2007)

Note: The red dashed boundary indicates the location of the accompanying perspective multibeam survey image

The Anton Dohrn Seamount lies in the centre of the Rockall Trough, extending 1,500-1,600m above the seabed. Sandy sediments surround this feature, extending into shallower water to the west, whereas the feature itself has a covering of gravelly and muddy coarse sands to gravels and broken shell fragments. As the shelf floor rises towards the Rockall Bank and George Bligh Bank, the sediments become coarser, consisting principally of gravelly sandy mud, gravelly sand and gravel. The George Bligh Bank lies to the north and west of the Anton Dohrn Seamount, and has coral on its northern flank and iceberg

ploughmarks on its surface. Its eastern flank is covered in coarse sands, gravels and boulders, and to the south there is evidence of scour from strong current flows (DTI 2007).

The Hatton Bank area in Regional Sea 11 has been subject to survey in 2005 and 2006. The area is covered by Palaeogene lavas with the exception of a few areas which are suggested to be Upper Palaeozoic-Mesozoic sedimentary strata (Hitchen 2004). The central Hatton Bank was found to host diverse reef communities where strong currents are a key influence. Clean and often rippled sands were observed on top of colonised scarp slopes and washed gravel lag deposits were observed at their bases (DTI 2007). Several areas to the south of the Hatton Bank area surveyed in 2006 revealed superficial sediment primarily consisting of coarse sand and gravel, the latter of which often contained biogenic material derived locally from reefs (Stewart & Davies 2007). Pinnacles represent bedrock outcrops and in turn a reef bearing substrate which included the cold water coral *Lophelia pertusa*.

The only feature in Regional Sea 11 which reaches the water surface is Rockall, a small intrusion of granite which is notable for its unusual mineralogy. The small islet was probably formed during late Tertiary igneous activity. The seabed around Rockall is considered of conservation importance due to the presence of cold water corals (JNCC 2007e).

A3b.11 HYDROCARBON PROSPECTIVITY

The location and prospectivity of hydrocarbon reserves in the North Sea (Regional Seas 1 and 2) are relatively well-known given the maturity of exploration and development of this province. In a single North Sea case (Ekofisk, in the Norwegian sector), the extraction of oil and gas has led to production-related seabed subsidence; this process appears to be restricted to a single type of chalk reservoir and (to date) does not appear to have had detectable environmental impact.

Oil and gas production in Regional Sea 3 has been centred on the offshore extension of the Wessex Basin, the largest oil field discovery being Wytch Farm in Poole Bay to the west of the Isle of Wight – this field has no offshore surface infrastructure and is produced onshore. A gas discovery is also located a few kilometres to the south of this field. Bridport Sands and the more productive Sherwood Sandstone Group are the two main prospective reservoirs in the area (Hamblin *et al.* 1992). No offshore development drilling has taken place in the English Channel.

The Celtic Sea and Bristol Channel Basins have proved to be dry with a general absence of organic source rocks (all wells drilled in the area have been either suspended or abandoned). The most promising were the Sherwood Sandstone dominated groups which were observed to be over 50m thick in Well 93/6-1 from the South Celtic Sea basin (Tappin *et al.* 1994). Further North, the St George's Channel has shown oil though economic accumulations are yet to be proven (Tappin *et al.* 1994). Permo-Triassic salt may have provided a suitable reservoir cap in the area and prospects similar to the oil and gas fields of the east Irish Sea are possible at depth (Tappin *et al.* 1994).

No economically exploitable hydrocarbon stores have been discovered to date in the Western Approaches and western English Channel. Jurassic and Cretaceous rocks are the most likely sources for hydrocarbon deposits, though these formations were either never deposited in the west, or have been depleted by late Jurassic to early Cretaceous erosion, with thick sections only being found in the southern part of the Western Approaches Trough in the Brittany Basin (Evans 1990). Deformation may have resulted in the possible breaching of structural traps in these formations, reducing their prospectivity (Ruffell 1995).

The East Irish Sea basin is a mature production area, with the Morecambe gas field being discovered in the mid-1970s, and later discoveries at the Hamilton, Douglas and Lennox fields. Discoveries in Regional Sea 6 have primarily been gas, located in the Cardigan Bay and East Irish Sea Basin, the latter area also having oil discoveries in the Douglas and Lennox fields. Production started in this location in 1985 following the completion of the 34km Morecambe to Barrow-in-Furness pipeline.

Future petroleum discoveries may be centred on the Carboniferous basinal mudstones and coal measures (oil- and gas-prone respectively) in the Solway Basins (Holmes & Tappin 2005). There are multiple potential source rocks in this area, though the most likely hydrocarbon source rocks are early Jurassic marine mudstones (Lias Group). These are fully mature for oil generation in the west of the UK sector, and are mature for gas generation nearby in the Irish sector. Gas-prone Westphalian pre-rift coal measures may also be present at depth locally. Criteria suitable for oil and gas reclamation (reservoirs with viable seals and structural traps) is observed in basins from Larne-Lough Neagh, Solway, Peel, Kish Bank and Central Irish Sea basins, though recovery has been hampered by poor source rock preservation, locally poor seal integrity and unfavourable timing of hydrocarbon migration and trap formation (Naylor & Shannon 1999).

Unlike the North Sea, Regional Seas 7, 10 and 11 have experienced little interest in oil and gas prospecting. Areas beyond 200nm of the mainland are under negotiation for licensing rights, so only Regional Seas 7 and 10 have short-term prospects for licensing in the north west. A single gas discovery (Benbecula) was made by Well 154/1-1 in the north east Rockall Basin (Regional Sea 10) from Palaeocene basin-floor sands (DTI 2006). This well has subsequently been released, though it proves that there are locally workable petroleum systems. It remains to be proven whether there is a viable system for the Hatton Bank to the west (DTI 2006). In Regional Sea 7, Permo-Triassic and Mesozoic half-graben basins have been considered as potential sources of hydrocarbons. Carboniferous rocks are considered more promising than Jurassic as the latter may be insufficiently mature (Fyfe *et al.* 1993). In the Malin Sea, North Channel and Irish Sea, the Triassic Sherwood Sandstone Group is considered to hold potential hydrocarbon resources (Holmes *et al.* 2006). The highest likelihood of recovery is where Carboniferous rocks are overlain by Permo-Triassic material (e.g. south of Arran), though no successful prospecting or development of this resource has been carried out to date (Holmes *et al.* 2006) – see Table A3b.1 below.

Table A3b.1 – Prospectivity and exploration activity in Regional Seas 7, 10 & 11

Region	Prospectivity	Exploration activity
The Minch, Sea of Hebrides	Potential reservoir rocks include Permo-Triassic sandstones. Source rocks are unproven (Carboniferous) or thought to be immature (Jurassic).	Three wells drilled but no licenses retained.
Malin Sea, North Channel	Carboniferous rocks buried beneath Permo-Triassic rocks.	One former license area was awarded in the North Channel but abandoned without drilling.
Rockall Basin & Bank	Most prospective area in Regional Sea 10. Prone to geohazards from submarine landslides.	Irish Dooish gas condensate discovery and the Benbecula gas discovering prove a working petroleum system in the south Rockall Basin.

Region	Prospectivity	Exploration activity
Hatton Basin	Potential source rocks include Carboniferous, Jurassic and Cretaceous but their presence below the volcanic layer of the Hatton Basin is speculative.	Single occurrence of natural oil slick in the northern part of the Hatton Basin reported by Hitchen (2004).

Relative to other areas of UK continental shelf, exploration effort to the north and west of Shetland has been small. Drilling in the region began in 1972 but activity since has continued at a low level compared to the North Sea due to a combination of factors including the deep water, complex geology, lack of offshore infrastructure, and short summer weather window (Hitchen *et al.* 2003). There has been some success with the discoveries of the Schiehallion and Foinaven fields which have reserves of 250 and 500 million barrels of 24-27° API oil, and the Clair field which has an estimated 3-5 billion barrels. The area to the west of Shetland has potential hydrocarbon source rocks (Scotchman *et al.* 1998). Several oil discovery wells are located to the south of the Foinaven and Schiehallion fields between blocks 204/30 and 205/26. In addition to these discoveries, the Rosebank oil field (Block 213/27) has had three appraisal wells drilled to date. This field lies at a depth of 1,100m of water, approximately 100 miles north-west of Shetland. No oil reserves have been located north of 62°N and this is unlikely until techniques are designed to improve seismic resolution beneath Palaeogene lavas (Stoker *et al.* 1993, Hitchen *et al.* 2003). Several wells have been drilled to the west of the Hebrides, and although hydrocarbon shows have been found (particularly gas) there has been no field or infrastructure development to date.

A3b.12 SEISMICITY

The regional distribution patterns of earthquakes occurring under the North Sea are related to deep geological structure. Expectations of earthquakes with magnitude of 4 or higher may require special structural design and are therefore also of environmental concern. In the North Sea as a whole the expected frequency of occurrence for a magnitude 4 natural seismic event is approximately every 2 years and a magnitude 5 natural seismic event every 14 years.

The English Channel is subject to moderate seismic activity with few large (>5.5ML) events, though historic records indicate such sizeable movements (Lagarde *et al.* 2003). 233 events have taken place between 1962 and 2000 following pre-existing fault lines, and from this (brief) dataset it can be calculated that an earthquake of 5.2ML or greater may be expected once in 100 years. Over a longer period, though relying more heavily on observational reports than instrumental records, a number of earthquakes ranging from 4.0-4.9ML have been reported in the English Channel between 1700 and 1993, with particular foci in the central channel to the south of the Isle of Wight and in the Straits of Dover (Musson & Winter 1997).

Earthquakes which have taken place in Regional Sea 6 have been largely coastal attaining a maximum magnitude of 5.0-5.9ML, with smaller earthquakes occurring off the Isle of Man (<3.0ML) and south eastern Irish coast (3.0-3.9ML) Musson (1994). A substantial cluster of events are centred on the area around Anglesey and Lley Peninsula, with a few scattered large events indicated near Whitehaven, off Barrow-in-Furness and Pembrokeshire (5.0-5.9ML). The earthquake hazard maps produced by Musson & Winter (1997) indicate that much of Regional Sea 6 has a 90%, 50 year return interval for an event of 5.0-6.0EMS (i.e. a return interval of 475 years).

Five earthquakes of magnitude 4.0ML have been recorded in the nearshore of Regional Sea 7 since 1970, though none are recorded for the Outer Hebrides shelf and areas further west.

Earthquakes of magnitudes less than 4.0 ML have been recorded 2-3 times per year in the nearshore since 1970, and these may pose risks for local geomorphological stability in bedrock or unconsolidated sediments. More work is required to fully classify the seismic risk for the nearshore in this region (Holmes *et al.* 2006).

To the west in the area of Outer Hebrides, five events of 4.0 or greater have occurred since 1970. Smaller events of < 4.0 have been recorded 2-3 times a year since 1970 and are restricted to the nearshore (Holmes *et al.* 2006). The northern and easterly area of Regional Sea 8 has a much lower incidence of seismic events on record, with a total of 25 known, the largest of which was 3.1 ML (Hitchen *et al.* 2003). The recording of earthquake events in the region is poor and so, therefore, is the understanding of their historical frequency. Instrumentation prior to 1970 was not focussed on collecting local data and therefore our understanding relies mainly on post-1970 data augmented with documentary evidence. It is debatable that any extrapolation can be made from a 30-year dataset though for the UK such estimates have proved reasonable reliable (with the exception of SW Wales) (Hitchen *et al.* 2003).

Seismic activity is largely absent in the west of Regional Sea 9. Any events that may have occurred are unlikely to have been recorded since a magnitude 5.5 ML earthquake to the north of the area would be felt weakly on Shetland and Faroes and imperceptibly elsewhere (Hitchen *et al.* 2003). A number of earthquakes have been recorded in the north east of Regional Sea 9 towards the Møre Basin-Viking Graben active area, the largest of which was magnitude 3.1 ML, though the epicentre of this event is poorly constrained. Slope instabilities due to earthquake motion have been recorded to the north west of Shetland (Jackson *et al.* 2004), like those of much more northerly areas (Leynaud & Meinert 2003). The seismicity of the area is generally low and therefore the seismic hazard is also low though the possibility of an unusually large earthquake occurring at the passive margin of the modern continental shelf, running SW-NE, is unknown (Hitchen *et al.* 2003).

A3b.13 MASS MOVEMENTS

Submarine mass movements pose geohazards for offshore developers. Landslides and debris flows are relatively few on the UK continental shelf, though the eastern margin of Rockall Bank has evidence of landslides on its mid-lower slope and the Faroe-Shetland Channel displays seabed features including landslides and debris flows (Long *et al.* 2004).

The recent geological history of Europe's continental shelf regions has been important in determining the current sediment supply and characteristics of mass wasting features, resulting in mega-scale slides in the previously glaciated area to the north of 52°N, with smaller, large-scale debris flows in the non-glaciated but glacially-influenced margin further south (Leynaud *et al.* in press). The AFEN (off north-west Shetland) and Donegal (to the north of Northern Ireland) submarine mass movements both took place on the UK continental margin during the Holocene (Long *et al.* 2003, Holmes *et al.* 2003, cited in Leynaud *et al.* in press), with the area around the Peach slide (to the north and west of Northern Ireland) which dates to the Pleistocene, receiving two recent seismic events suggesting a possible long-term history of movement in the area. Documented large-scale submarine mass movements are relatively few on the UK continental margin, though mega-scale slides (e.g. the Storegga Slide of the mid-Norwegian margin) probably had far reaching consequences for coastal settlements in the Norwegian and North Sea (e.g. eastern Scotland; Dawson *et al.* 1988) during the early Holocene (dating to ca. 7900 cal. yr. BP).

A3b.14 ENVIRONMENTAL ISSUES

A3b.14.1 Extraction and other issues

Aggregate extraction can alter the topography of the seabed through the removal of substrata and generate sediment plumes which might in turn influence primary production and/or lead to smothering of benthic habitats. The redistributed material may also be more readily resuspended in the water column by natural forces (Jones *et al.* 2004c). It has been also been noted that dredging can reduce the yield of certain areas for fisheries and contribute to species decline (Cooper 2005). Aggregate extraction is a major industry in south east England with areas between the Humber and the Wash, off the Suffolk coast and in the outer Thames Estuary all licensed for extraction. Aggregate extraction takes place in Regional Sea 3 to the south-east and south-west of the Isle of Wight, in the Owers region and also in the wider east English Channel. The principle target for extraction is the Quaternary gravel and sand lag deposit which covers much of the central and eastern English Channel, but only where it exceeds 0.5m thickness, which mainly coincides with the palaeo-valley network (Hamblin *et al.* 1992). As discussed above, the maerl beds of the Fal Estuary have been open to extraction in the past. Only dead maerl was licensed for extraction (from within the Carrick Roads area) amounting to c. 30,000 tonnes per annum, the area dredged avoided the live maerl of the St Mawes Bank (UKBAP 1999). The extracted material was destined for animal food additives, water filtration and to a large extent agricultural soil conditioner as a replacement for lime (Jones *et al.* 2004a). This dredging activity was under review in the cSAC designation stage of Fal Estuary due to the ability of even dead maerl to support a diverse assemblage of species (Jones *et al.* 2004a). DEFRA proposed in early 2008 that the outer SAC area should be closed to scallop dredging and other bottom trawl activity to protect marine fauna under obligations set out in the EU habitats directive (DEFRA 2008), the result of which has been The Fal & Helford Designated Area (Fishing Restrictions) Order 2008.

There are three primary extraction areas in Regional Sea 6, one located 30km offshore from Barrow-in-Furness and another 25km offshore from Liverpool and a newly licensed site (Area 457) some 27km off the coast of North Wales. There are currently no licensed areas for aggregate extraction in the waters of Regional Sea 7 (Crown Estate website) outside of navigational dredging in ports and harbours, so these impacts are of limited concern.

Besides sediment contamination impacts on the geology and substrates, impacts from oil and gas related activities are likely to be associated with sediment plumes and redistribution of sediments associated with seabed activities including pipe and cable lay and the placement of platforms (Jones *et al.* 2004c), though this impact is restricted to the period of construction activity and impact on ecosystems, of cable lay in particular, are thought to be limited (Groot 1996). Similarly, cable lay is an inherent activity associated with offshore renewable energy generation, and wind turbine placement, decommissioning and to some extent operation, has implications for substrates and their associated habitats. Coastal as well as offshore geological features (and associated habitats) can also be affected by the installation of cables where these are brought ashore. Where or historically contaminated sediments are disturbed there is also potential for mobilisation of contaminants that would otherwise be isolated from circulation in marine ecosystems. It is worth noting, however, that monitoring of sediment mobilisation during cable laying and turbine foundation installations has, to date, demonstrated only low levels of sediments to be mobilised (e.g. SeaScape Energy 2008)

A3b.14.2 Sea level change

Sea-level change may have some influence on the coastal geomorphology. Continued rising sea-levels, which may be exacerbated by climate change combined with isostatic readjustment, could influence the dynamics of sediment transport at the coast (EH 2008). Sediment supply to the Humber and Wash from the Holderness coast is vital to maintain intertidal flats (EH 2008) and therefore any anthropogenic interference, which might include coastal defence, may have wider reaching effects for geomorphology, habitat and associated ecological diversity. Embankments and estuary walls associated with land-claim in the Wash, along the Suffolk coast and Greater Thames Estuary areas, already hamper landward migration of saltmarshes, a natural process following sea-level rise which can result in the eventual loss of some intertidal areas ('coastal squeeze'). Erosion of soft cliff materials which include chalk and glacial till/diamict materials are a feature of the coast at Flamborough head and further south on the Norfolk and Suffolk coasts. Erosional activity in which coastal retreat is at a scale of c. 1m year⁻¹ or more, poses problems for existing and possible future infrastructure which includes any intended landfall sites for cabling or pipelines. Though the imposition of coastal defences may be advantageous to the immediate coastline, sedimentary coastlines in the longshore direction are likely to be affected. It is likely that coastal defences have reduced the production of sediment at eroding coasts and the transfer of sediment by longshore drift as sediment is caught up in groynes, which in some cases have aided the offshore movement of material which is then lost from the coastal system (May & Hansom 1993). In the area of the Broads erosion of dune ridges to the north has led to the emplacement of a concrete sea wall which itself has led to erosion of beach areas. Increased storminess associated with the current predicted climatic trajectory compounds this issue, which may result in enhanced coastal erosion and flooding on the south coast.

Scotland has coastal defences in many inhabited areas, but these tend to be small scale. The softer coasts of the Moray Firth are the most protected (Fowler 1996). On Shetland there is concern over erosion at Sumburgh Head and Hermaness. Most defences on the islands are small scale and protect residential land holdings from erosion (Fowler & Everett 1997a). Coastal erosion is not a significant issue in Regional Sea 7 as much of the coast is comprised of rocks which are very resistant to denudation (Clayton & Shamoon 1998) and is generally undeveloped and with a low population density.

A3b.14.3 Aquifers

There is a potential local risk of groundwater contamination if developments are superimposed on areas with aquifers and if normal aquifer measures are not followed. There is a negligible risk of contamination of onshore supplies of freshwater from the mature areas of the oil and gas development provinces in the central and northern North Sea. Overall, the risk of onshore aquifer contamination decreases with increasing distance from the offshore to developments.

A3b.14.4 Existing contamination

14.4.1 Overall consideration

This section describes the current environmental baseline for contamination, drawing on the reviews of existing chemical contamination commissioned for previous DECC SEAs and a wide variety of other sources including the OSPAR Quality Status Report (OSPAR 2000b) and Assessment and Monitoring Series reports (e.g. OSPAR 2007a); reports from UK Oil and Gas including the review of seabed monitoring studies (UKOOA 2001); CEFAS Aquatic

Environmental Monitoring Reports; the Environment Agency's water quality, sediment and shellfish monitoring; and the review of the state of Scotland's seas by Baxter *et al.* (2008).

Contamination of the marine environment is associated principally with industrial development, with major sources comprising terrestrial emissions and discharges (transported to the marine environment via rivers and the atmospheric); shipping; military activities, and offshore industries including oil and gas production (OSPAR 2000b). Work by Stagg (1998) highlights the fact that monitoring and assessment of marine contamination in the OSPAR area (which includes the UKCS) integrates both direct measurement of contaminants in water, sediments and biota but also physiological effects displayed by biota throughout the region. Physiological effects monitoring includes methods such as bioassays, biomarkers and community and population responses. A biological effect monitoring programme has been put in place for specific contaminants, including polyaromatic hydrocarbons (PAHs), heavy metals and tributyltin (TBT). For example, the presence of PAH metabolites in bile, EROD induction in liver and the presence of DNA adducts are diagnostic of PAH exposure. For metals, metallothionein is indicative of exposure to copper, cadmium, zinc and lead. For TBT the occurrence of imposex or intersex is used.

Contamination levels for nutrients, metals, persistent contaminants, polycyclic aromatic hydrocarbons and radioactivity in the water column and sediments are summarised below.

Regional Seas 1 & 2

About 80% of marine pollution comes from a variety of land-based activities (DEFRA 2002). Most pollutants enter the North Sea through direct discharges of effluents or land run-off (mainly via rivers). The highest concentrations of contaminants, and hence the greatest effects, are therefore often in inshore areas (Jones *et al.* 2004c). Water samples with the highest levels of chemical contamination are found at inshore estuary and coastal sites subject to high industrial usage (Table A3b.2). Data from water column monitoring show that mussels and fish are exposed to hydrocarbons from produced water and that the levels decrease with increasing distance to the discharge points. Biomarkers also show the same gradient from the discharge point, but it is still uncertain how the specific biomarkers affect the individual fish, the populations or the ecosystems. Research work is needed to find a better link between biomarkers and ecological risk (OSPAR 2007a). Spatial patterns in water quality, including dissolved oxygen, nutrients, metal and organic contaminants have been described from NMP data (MPMMG 1998), which includes estuarine and offshore sampling locations within the North Sea area.

Table A3b.2 – Summary of contaminant levels typically found in surface waters of the North Sea

Location	THC (µg/l)	PAH (µg/l)	PCB (ng/l)	Ni (µg/l)	Cu (µg/l)	Zn (µg/l)	Cd (ng/l)	Hg (ng/l)
Estuaries	12-152	>1	302	-	-	-	-	-
Coast	2	0.02-0.1	1-104	0.2-0.92	0.3-0.7	0.5-2.2	10-32	0.25-41
Offshore	0.5-0.72	Below det.	-	0.2-0.6	0.3-0.6	0.5-1.4	10-51	1.6-69

Sources: Law and Hudson (1986), OSPAR (2000b), Law *et al.* (1994), SOAEFD (1996)

Reported discharges from the east coast of the UK (which will be dominated by discharges from the major estuary systems and industrial areas of the North Sea area) are given, as a proportion of total discharges to the greater North Sea in table A3b.3.

Table A3b.3 - Summary of riverine inputs and direct discharges from the UK east coast to the North Sea, as a percentage of North Sea totals

	Cd	Hg	Cu	Pb	Zn	g-HCH	PCBs	NH4-N	N03-N	PO4-P	Total N	Total P	SPM
Upper estimate UK E coast %	30.0	30.6	21.5	31.9	17.3	13.1	31.3	7.3	21.0	30.3	17.4	19.6	9.4

Source United Kingdom SEA 3

These data suggest that riverine and direct inputs are substantial sources of contaminants to the North Sea.

The major estuaries in Regional Seas 1 and 2 are the Firth of Forth, the Humber, the Tyne, the Tees and the Thames. SEPA measures the concentrations of a range of contaminants in larger rivers in Scotland (Baxter *et al.* 2008) and the Environment Agency monitors water quality along the English rivers. The estuary water quality classification scheme was developed during the 1970s, with consistent results available since 1985. The scheme provides a broad indication of water, biological and aesthetic quality - mainly related to sewage pollution. The quality of the Forth estuary is significantly affected by historically polluted sediments and continues to be impacted by sewage discharges, and diffuse run-off from urban and agricultural areas (Baxter *et al.* 2008). The estuaries of Yorkshire and the Humber remained at similar quality between 1985 and 1995. Over the decade the length of estuary classed as "good" quality has remained at 49.5km, the length classed as "fair" was 51.4km, and 18.1km was classed as "poor". There are no estuaries classed as "bad".

The Humber estuary is affected by flows from many different rivers including the Aire, Ouse, Don and Trent. The large number of releases carried by the rivers into the estuary are difficult to target for improving overall water quality and concentrations of a number of contaminants remain above those set as indicative of background or likely to be associated with biological effects. The whole of the Esk estuary, on the coast at Whitby, is classified as "good" quality. River quality in the Anglian Region is also improving, in 2000 in the East of England 92% of river lengths were fair to good chemical quality, an improvement over the past five years as in 1995, 88% were fair to good quality. The quality of water in river estuaries within the Thames area is consistently (97%) good or fair. However, there are still significant intermittent water quality problems particularly at times of low flow during the summer months.

Regional Sea 3

Regional Sea 3 comprises the eastern English Channel where the transition occurs between Atlantic and North Sea influences (Jones *et al.* 2004f). Little of the coastline can be described as undeveloped and there are major conurbations at Hastings, Eastbourne, Brighton, and Bournemouth and major ports at Portsmouth and particularly Southampton. Industry is primarily centred around two port areas with refineries at Fawley on Southampton Water (DEFRA 2005b). Medium sized rivers enter the area at Portsmouth/Havant and Southampton. The area is also one of the busiest in the world in terms of shipping with movements both in east-west and west-east directions and across the Channel. There are no major river systems draining industrial areas on the scale of those found in other Regional Seas so the main contaminant sources are likely to be direct discharges from shipping and other point sources, e.g. sewage.

Regional Seas 4 & 5

There is significant urban development around Torbay and Plymouth on the south coast and at Bristol, Cardiff and Swansea along the Bristol Channel. The main industrial development

is at Bristol and along the south Wales coast. The biggest single river is the Severn, which enters the top end of the Bristol Channel; other land run-off from within the Region enters via a number of rivers along the south-west peninsula and south Wales coast. The Severn Estuary/Bristol Channel contributes significantly to the contamination load of the area. The majority of the industrial and domestic centres along with the associated discharges into Regional Sea 4 originate here. The River Severn and its tributaries drain a large land mass and any related runoff into the Region with the Severn Estuary receiving an average freshwater flow of approximately 25 million m³/day of which around 1 million m³/day comes from sewage and industrial discharges (Apte *et al.* 1990). There are a wide range of direct discharges into the Severn Estuary including urban wastewater, industrial and power station discharges and a small number of discharges containing radioactive substances. Various diffuse inputs occur, principally from agriculture, but also from ships (Houghton 2008). Aerial inputs of some contaminants can be significant, particularly in the vicinity of smelting activities around Severnside (Vale & Harrison 1994). Natural erosion and leaching of exposed coal bearing strata and oil bearing shale also contribute to PAH contamination in the estuary and Bristol Channel (Langston *et al.* 2003).

Regional Sea 6

A large proportion of the land on the coastal area of the Irish Sea is used for agricultural purposes and the industry that does exist is concentrated in distinct areas. The major industrial locations within the Region are found in Merseyside and Lancashire. Small areas of industrial development are found in Cumbria and on Deeside in Clwyd. On the western side of the Irish Sea the main industrial areas include Belfast and Dublin. All of these industrial areas contribute to the contaminant input to the Irish Sea (Kenny *et al.* 2005). The Sellafield nuclear processing site is located on the coast of the Irish Sea in Cumbria and is the source of low level radioactive contamination that can be detected (at varying levels) throughout the majority of the UKCS

Outside the influence of oil and gas exploration and development, contaminants are evident entering the Region through riverine discharge and physical dumping of wastes. Studies that have measured the contribution of riverine inputs of metals to the Irish Sea compared to direct discharges show that riverine inputs contribute >80% of most metal concentrations measured. An exception to this is mercury, where direct discharge and river inputs were approximately equal (OSPAR 2004c). Time series of average concentrations of mercury in fish flesh from Liverpool and Morecambe Bays between 1983 and 1996 indicate a sustained decline in contaminant burdens over time following reductions from chlor-alkali plants in north-west England (Matthiessen and Law 2002).

The Clyde also discharges into Regional Sea 6 and has a historic heavy contamination load mostly associated with sediment bound heavy metals, sewage discharges and sludge dumping. Removal of this contaminated sediment has occurred by natural scouring or dredging of the shipping channel but this has translocated the problem elsewhere. It is not surprising therefore, that there is a noticeable increase in contamination in the area used for dumping dredge spoil at the head of the Firth of Clyde close to the mouth of the Holy Loch (Baxter *et al.* 2008). Contaminant levels within the Clyde are monitored by SEPA (Baxter *et al.* 2008).

Regional Sea 7

There are relatively few studies of contamination available for Regional Sea 7. Most of the studies that have been carried out are concentrated in the coastal zone (particularly around the Firth of Clyde to the south of the Region) or are related to fish farming. This reflects the

generally expected lack of contamination in an area where there is little industrial or urban development.

Regional Seas 8 & 9

Deep-water marine environments have relatively low contaminant burdens in comparison to coastal waters and especially industrialised estuaries. Regional Seas 8 and 9 are remote from areas of major industrial activity and therefore includes some of the least polluted habitats in the UK. However, there are local sources of contaminants, in particular hydrocarbons. Long-range transport of persistent contaminants has probably resulted in detectable pollution throughout the Regions. In comparison to coastal environments and estuaries, relatively few data for contaminant concentrations and effects are available for offshore Regional Seas 8 and 9. Much of the available data stems from localised surveys in relation to oil and gas developments in previously licensed blocks and from coordinated wide-area surveys conducted in 1996 and 1998 by the Atlantic Frontier Environmental Network (AFEN). The AFEN also commissioned “fingerprint” analysis of oil residues sampled from Shetland and Orkney coastlines, with the aim of identifying the source of beached oil and tars. Additional sampling and analysis was commissioned by the DTI (now DECC) for the Strategic Environmental Assessment 4 (SEA 4) area in 2002.

Regional Sea 9 has no coast and the coastal landmass of Regional Sea 8 is not heavily populated. Population density is estimated at 4-19 persons/km² throughout a generally rural Region with a number of relatively small settlements. As a result coastal derived contaminant inputs are expected to be low, table A3b.4 describes direct and riverine inputs to Regional Sea 8 in 2004.

Table A3b.4 – Direct and riverine inputs to the Regional Sea 8 in 2004

	Cadmium (t)	Mercury (t)	Copper (t)	Lead (t)	Zinc (t)	g-HCH (kg)	PCB (kg)
Sewage effluents	0.02-0.07	0-0.02	5.7-5.9	0.6-0.7	21.4-21.5	11.7-13.2	0
Industrial effluents	0-0.01	0	0.33-0.34	0.11-0.18	2.54	0.02-0.03	0
Riverine inputs	0.36-1.43	0.09-0.43	79.94-80.88	26.09-27.66	137.11-143.11	3.94-24.17	0-6.67
Total	0.38-1.5	0.09-0.5	86-87	27-29	161-167	15.7-37	0-6.8

Source: OSPAR (2006a)

In general, direct and riverine inputs to Regional Sea 8 are lower than to other sea areas around the UK due to the remote and oceanic nature of the waters. Of those contaminants for which data is available it is clear that riverine inputs dominate.

Regional Seas 10 & 11

Regional Seas 10 and 11 consist of offshore deep water environments with no coastal areas and therefore no direct river based inputs. The deep water areas are regarded as pristine and few measurements of hazardous substances have been made. Those that have are summarised below and support the assessment that Regional Seas 10 and 11 are generally uncontaminated by anthropogenic inputs. The most comprehensive published dataset for the Regions is that of Stevenson *et al.* (1995), which is based on sea bed sediment samples collected by BGS between 1977 and 1986.

14.4.2 Nutrients

OSPAR has proposed common assessment procedures to guide decisions on whether measures are required in any given area to control nutrient release. These set normal and elevated levels for dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) and a guideline that states chlorophyll concentrations should be no more than 50% higher than historical offshore background for the area concerned. Nutrient concentrations vary seasonally owing to variability in dilutions flows from rivers, seasonal variability in the growth of phytoplankton and rates of remineralisation. The common assessment procedures criteria recognise that Regional differences arise naturally and higher levels are set for the Irish Sea than the English Channel or North Sea for example. In general nutrient enrichment is likely to have little or no impact on offshore aquatic environments due to the influence of a number of physical, chemical and biotic factors (Scott *et al.* 1999), including the deep water, current circulation and tidal nature of the majority of the offshore UKCS make it unlikely that sufficient nutrient concentrations could be built up in any one place to cause eutrophication.

Areas containing high quantities of decaying organic matter from point discharges of sewage and industrial effluents, and from diffuse sources such as agricultural run-off are often associated with low dissolved oxygen levels. In common with most land-based sources of pollution, the effects from these inputs are more noticeable in estuaries and near-shore areas and are unlikely to be detected in offshore locations. Where eutrophic conditions prevail in inshore areas oxygen levels can be substantially depleted due to an increased biochemical oxygen demand (BOD). Adequate dissolved oxygen concentrations are essential in estuaries for maintenance of ecosystem function. The only statutory standards for dissolved oxygen in saline waters relate to areas designated under the EC Shellfish Growing Waters Directive (79/323/EEC). This Directive specifies a mandatory standard for shellfish waters of 70% saturation as an average value, and no individual value can be lower than 60% saturation. Reductions in point sources of organic matter are being addressed through the implementation of the Urban Waste Water Treatment Directive (91/271/EEC). The implementation of the Nitrates Directive (91/676/EC) will also provide some controls on nitrate from diffuse agricultural sources. This Directive requires Member States to designate Nitrate Vulnerable Zones (NVZs) and to produce action programmes to reduce nitrate run-off from agricultural areas.

14.4.3 Metals

Metals, including barium, cadmium, copper, iron, lead, mercury, nickel and zinc, are naturally present in seawater and marine sediments, in a range of forms and concentrations. In excessive concentrations, metals can exhibit toxicity and result in significant environmental effects; with cadmium, lead and mercury generally regarded as the elements of greatest concern (OSPAR 2000d).

Some metals are extremely particle-reactive, tending to be adsorbed onto suspended particles, with a consequent reduction in the dissolved phase concentration. The concentrations of trace metals, like other contaminants, tend to be much higher in estuarine sediments than in offshore sediments. In addition, sediment characteristics play a significant role in the preferential accumulation of metals. A great quantity of metals are retained in the fine grained estuarine sediments which act as a sink for contaminants, with this effect decreasing offshore (Lee & Cundy 2001). Chelation by dissolved organic compounds is also a significant factor. A significant proportion of these metals are also likely to end up being redistributed in sea shelf sediments (Ridgeway & Shimmield 2002), and therefore provide a key source of offshore metal contaminants in the North Sea.

Generally metal concentrations in estuaries are higher than at intermediate and offshore sites. This is interpreted as a direct consequence of the proximity of estuarine sites to inputs. Within estuaries there was also a general tendency for metal concentrations to decrease with increasing salinity. Where information is available, concentrations tended to be higher in those estuaries that receive inputs from industrial and/or domestic sources.

14.4.4 Persistent contaminants

Persistent contaminants include chlorinated hydrocarbons such as polychlorinated biphenyls (PCBs), chlorofluorocarbons (CFCs), polychlorinated dioxins and dibenzofurans (PCDD/Fs) and organochlorine pesticides; brominated flame retardants; octylphenol and nonylphenol ethoxylates. Polychlorinated biphenyls (PCBs) were historically used extensively in a wide range of industrial and domestic applications. OSPAR set the EAC range for the sum of these as 1-10µg/kg dry wt in sediments.

Data on chlorinated biphenyls in sediments generally show the same distribution as observed for metals in sediments, with higher concentrations tending to be found in areas where fine-grained sediments are deposited, such as in estuaries, fjords and certain coastal areas. Concentrations in the open sea are generally less than 1µg/kg (OSPAR 2000d). Concentrations are usually expressed in terms of 7 selected CB compounds and the EAC range set by OSPAR was 1-10µg/kg dry wt in sediments and 1-10µg/kg wet wt in whole fish and in mussels of 0.37 to 1.7µg/kg wet wt.

The NMP organic determinands were 11 individual polychlorinated biphenyl congeners, dieldrin, aldrin and endrin, three DDT group compounds (pp-DDT, pp-TDE and pp-DDE) and hexachlorobenzene (HCB). Organic contaminants are lipophilic and therefore have low water solubilities. They preferentially adsorb onto sediments particularly where these are fine grained and/or contain a high proportion of organic carbon. Concentrations would, therefore, be expected to be inherently higher in areas with fine-grained organic-rich sediments than in areas dominated by coarse sandy sediments.

γ-HCH (lindane) is an organochlorine insecticide and was commonly used in agriculture and as a timber preservative until 2002 when its use in the EU was banned.

As a result of their wide use, perfluorinated organic acids (including perfluorooctane sulphonate, PFOS) are widely distributed in the environment on a global scale, and time-trend studies have shown increasing concentrations in wildlife (Giesy & Kannan 2001; Houde *et al.* 2006). Little information is available on toxic effects, though within the OSPAR Hazardous Substances Strategy, PFOS and its salts are listed as chemicals for priority action (OSPAR 2007a). Marine mammals, as top predators, can accumulate high concentrations of persistent and bioaccumulative organic contaminants, and so can act as effective sentinel organisms for monitoring purposes (CEFAS 2008).

Tributyl tin (TBT) is widely used as an anti-fouling agent in paint for ships. Its use has been banned for vessels under 25m in length since 1987, after it was shown to be having a harmful effect on molluscs. However, it is still commonly used on larger vessels. The current Environmental Quality Standard for TBT in sea water is 2µg/l (Cole *et al.* 1999). An indirect physiological measurement of endocrine disruptor contamination is imposex (the development of male sexual organs in female whelks and periwinkles) which is a very sensitive indicator of TBT exposure (CEFAS 2007a). In severe cases, this can lead to significant population damage as a result of sterility and reproductive failure

14.4.5 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are ubiquitous environmental contaminants. Although they can be formed naturally (e.g. in forest fires), their predominant source is anthropogenic emissions, and the highest concentrations of PAH are generally found around urban centres. Their widespread occurrence results largely from formation and release during the incomplete combustion of coal, oil, petrol and wood, but they are also components of petroleum and its products. PAH reach the marine environment via sewage discharges, surface run-off, industrial discharges, oil spillages and deposition from the atmosphere. The lower molecular weight PAH can be acutely toxic to aquatic organisms, but the major concern is that some PAH form carcinogenically-active metabolites (benzo[a]pyrene is the prime example) and PAH concentrations in sediments have been linked with liver neoplasms and other abnormalities in bottom-dwelling fish. Elevated PAH concentrations may therefore present a risk to aquatic organisms and potentially also to human consumers of fish and shellfish. EAC have been set by OSPAR for 8 individual PAH in sediments. All 8 compounds are included in the 10 PAH routinely measured under the National Marine Monitoring Programme (NMMP). The sum of the upper EACs is roughly equivalent to 10,000µg/kg for the ten PAH compounds.

14.4.6 Radioactivity

Inputs of natural radionuclides to the UKCS are mainly from phosphate fertiliser production but mining, ore processing, burning coal, oil and natural gas also contribute. Artificial radionuclides in the southern North Sea have been attributed to the nuclear fuel reprocessing plants at Sellafield and Cap de la Hague. The presence of radionuclides such as ⁹⁰Technetium and ¹³⁷Caesium from the Sellafield plant is clearly detectable and serves as a tracer demonstrating transport from the Irish Sea through the North Channel and via the Scottish Coastal Current into the North Sea and thence towards the Arctic. The background due to weapons testing fallout etc. is regarded as about 2mBq/kg.

In the central and northern North Sea the offshore oil and gas industry may discharge mineral scale that has built up on equipment as a by-product of production. This scale can be classed as naturally occurring radioactive material (NORM) and is generally cleaned from equipment and discharged directly to sea. The quantities and activity of the discharged scale is such that it is readily dispersed and generally undetectable in the sediments and water column around offshore installations. Some equipment cannot be cleaned offshore and is returned to shore for cleaning. The scale removed on shore may be discharged to the near shore environment. Radioactive contamination has been found in sediments around the scale discharge point within Aberdeen harbour and the surrounding beaches. As a result of a recent hearing between SEPA and the discharging company, near shore discharges of LSA material in the Aberdeen area are to cease no later than December 2011.

14.4.7 Sources of contamination from the oil and gas industry

Produced water

Produced water is derived from formation water in oil/gas reservoirs and from seawater injected to maintain reservoir pressure and enhance extraction efficiency. Produced water may have a complex composition, encompassing dispersed oil, metals and organic compounds including dissolved hydrocarbons, organic acids and phenols. Produced water composition varies between specific installations, and generally differs considerably between oil and gas reservoirs. Trends in produced water discharges have been assessed by Oil and Gas UK and oil concentrations have decreased despite large increases in water production

since the mid 90s, due to technical developments including improved separation and re-injection (Table A3b.5).

Table A3b.5 – Oil discharged with produced water 1996-2006

Year	# Installations permitted to discharge oil	Total water discharged (million tonnes)	Total oil discharged (tonnes)	Average oil in water content (mg/l)
1992	43	135	4850	36
1993	46	148	4232	28
1994	52	147	4418	30
1995	55	192	5855	30
1996	60	210	5706	27
1997	64	234	5767	25
1998	64	253	5692	22
1999	73	261	5641	22
2000	68	263	5747	22
2001	74	260	5690	22
2002	74	273	5720	21
2003	85	267	5293	20
2004	114	258	5278	20
2005	108	235	4968	21
2006	100	219	4356	20

Source: DECC oil and gas website

In general over the OSPAR area produced water trends are as follows (OSPAR 2005a):

- The total quantity of dispersed oil (aliphatic oil) discharged to the sea (from produced water, displacement water and accidental spillage) continued to decrease and was 8913 tonnes in 2005 compared to 9341 tonnes in 2003.
- The total amount of produced water and displacement water discharged daily shows an increase over the period 2001-2005. The quality of the water discharged has remained more or less stable over recent years. The annual average dispersed oil content in produced water in 2005 was 20.3mg/l,
- Since 2001 use and discharge of chemicals have been regulated by OSPAR. The total quantity of chemicals used offshore in 2005 was 776,819 tonnes. Only 5 % of the chemicals used contained either substances on the OSPAR List of Chemicals for Priority Action (LCPA) or substances which are candidates for substitution.
- The total quantity of chemicals discharged into the sea in 2005 was roughly 247,000 tonnes, almost 87% of which are chemicals on the OSPAR list of substances/preparations used and discharged offshore which are considered to pose little or no risk to the environment (PLONOR).

Chemicals are used during the production of oil and gas (demulsifiers, dehydrators, etc). Chemicals which are partly or completely water soluble will partition into the water phase of the oil and water mixture. Reported use and discharge quantities of production chemicals from 2003-2006 are tabulated below:

Table A3b.6 – Annual values (in tonnes) of chemicals used and discharged

Year	Chemical use (t)	Chemical discharge (t)
2003	84,213	43,601
2004	86,722	41,491
2005	90,271	48,123
2006	20,171	11,600

Source: Environmental Emissions Monitoring Scheme (2001-2006)

Although the selection of production chemicals for use offshore is regulated under the Harmonised Mandatory Control System for the Use and Reduction of the Discharge of Offshore Chemicals, which encourages the avoidance of toxic and bio-accumulating chemicals, specific concerns remain associated with the use of many chemicals that have been identified as candidates for substitution by OSPAR (CEFAS 2001). These materials are generally of low toxicity, but may be persistent in the environment due to their inert nature. Producers and users of such chemicals must be shown to be actively pursuing replacement programmes to insure chemicals designated as candidates for substitution are replaced by none substitution chemicals.

There is an OSPAR presumption against the discharge to sea of persistent synthetic materials, largely on a precautionary basis, since although the materials may not exhibit toxicity, the long term fate and effects cannot be judged (in the past PCBs and halocarbons were viewed as inert and non toxic).

Drilling

Metals in cuttings discharges are derived mainly from rock formation minerals, and from mud additives (principally barite and bentonite). The mud component of current discharges of cuttings to the UKCS is comprised exclusively of water-based mud (WBM), which generally results in wide dispersion of discharged cuttings in comparison to previous discharges of oil based mud (OBM), and little accumulation of contaminants in sediments and biota (Cranmer 1988, Neff *et al.* 1989, Hyland *et al.* 1994, Daan & Mulder 1996, Hartley Anderson 2005). Organic-phase drilling fluid (OPF), using biodegradable synthetic base fluids, may also be used under some circumstances (e.g. in highly deviated or unstable well sections), but will be contained and returned to shore for treatment, re-use and/or disposal.

There are a number of historic cuttings piles drilled with OBM in the central and northern North Sea. Such piles are contaminated with hydrocarbons and other compounds (Kjeilen-Eilertsen *et al.* 2004). Hydrocarbons are the main contaminants of cuttings drilled with OBM and cuttings piles, with maximum concentrations of total hydrocarbons recorded in excess of 200,000µg/g. A variety of PAHs may also be present. Studies have reported a wide range of metal concentrations. The highest average concentration for depths of 1-10cm for eleven sampled piles was 8µg/g copper, 33µg/g mercury, 173µg/g lead and 40,000µg/g iron. For barium, which is a major component of drilling muds, the highest average concentration was 86,000µg/g (see Law & Fileman 1985; Davies *et al.* 1989; Breuer *et al.* 2004). Results from a range of regional and site specific surveys have shown progressive declines in contamination and ecological effects since the cessation of OBM drilling discharges (e.g. Carroll *et al.* 2000, Hartley Anderson 2003, Webster *et al.* 2007).

14.4.8 Spills

An annual review of reported oil and chemical spills in UK waters – covering both vessels and offshore installations – is made on behalf of the Maritime and Coastguard Agency by the

Advisory Committee on Protection of the Sea (e.g. ACOPS 2007). These reviews split the UK Pollution Control Zone into 11 areas, and 559 separate discharges from vessels and offshore oil and gas installations were identified in the survey area during 2006, with small increase of 2% over the previous year's total. For the sixth successive year another reduction was apparent in the total number of reported vessel-sourced discharges, which numbered 149 during 2006. Excluding permitted produced water discharges, the reported total of 275 accidental oil discharges attributed to offshore oil & gas installations during 2006 was slightly below the corresponding mean annual total of 280 oil discharges between 2000 and 2006. In contrast, the marked increase in the total number of discharges of substances other than mineral oils reported by offshore oil & gas installations since 2003 follows a change in reporting requirements for discharges of this nature.