SCOTTISH EXECUTIVE

FABER MAUNSELL | AECOM

METOC

Note: This document is only a section of the Final Environmental Report

Scottish Marine Renewables SEA

Environmental Report Section C SEA Assessment: Chapter C2: Geology, Seabed Sediments and Sediment Transport

Scottish Executive

March 2007

Table of Contents

Glossary & Abbreviations

BGS	British Geological Survey
Biogenic Material	Sediment, principally Calcium Carbonate, created by the break-up of hard shelled marine organisms. Shallow nearshore and coastal areas are now major high-latitude centres of modern shallow-water carbonate accumulation (Farrow et al, 1984). (SEA5 Seabed and superficial geology processes).
Drift Geology	Also see Pleistocene. Rocks that were laid down during the last 1.8 Ma.
Drumlin	Glacial deposits that are aligned with their long axis parallel to the direction of the ice flow during the time of their formation.
Geological Period	A defined measure of time within the geological record during which rocks of a particular type were formed.
Glaciogenic material	Material deposited during the last glaciation which is reworked by current coastal processes. By far the greatest source of sediment within the study area has been derived from glaciogenic sources, deposited both inland and on the adjacent shelf by either glaciers or glacial meltwater.
Holocene	A period after the retreat of the ice and the dominance of modern homo-sapiens. The Holocene is the geological current period.
Igneous	Literally “rocks formed by fire” – igneous rocks are formed through the release of material from within the Earth by heat.
ka	Abbreviation for thousands of years before present
Lewisian Gneiss	Metamorphic rocks that represent some of the oldest rocks in Europe and the world.
Ma	Abbreviation for millions of years before present
Metamorphic	Literally “change of form”, rocks that have been exposed to changes to temperature and/or pressure which has changed its structure and properties through exposure to high temperatures and/or pressures.
Metasediments	A sedimentary rock that has been subject to metamorphism.
Moine Supergroup	Rocks formed by marine sediments that were deposited from approximately 1000 to 870 Ma, and subsequently metamorphosed during closure of the Iapetus Ocean, an ocean that existed some 600 to 400 million years ago
Pleistocene	Period during which there were successive periods of ice advance and retreat. This period started approx 1.8 Ma and the retreat of the last sheet in the British Isles was 10,000 years BP, after which time the Holocene
Sedimentary	Rocks formed within a water environment – either through the action of water breaking down and removing existing material, or the formation of material within water (such as calcium carbonate from shells of marine organisms).
Solid Geology	Defined by the BGS as rocks that were laid down before the start of the Pleistocene (cv) ice age, and therefore are older than 1.8 Ma
Syncline	Broad basin formed by folding of rocks into which other material is deposited.
Terrigenous material	Sediment supplied from rivers or the breakdown of coastal rock. Lack of major river sediment input and resistance of most of the shorelines to erosion, has resulted in only minor input to coastal areas over the last 10,000 years
Torridonian sandstones	Sandstones deposited during the Pre Cambrian period, the sandstones that were subject to metamorphism became the Moine Supergroup.

C2 Geology, Seabed Sediments and Sediment Transport

C2.1 Introduction

In order to carry out the assessment of marine renewables on geology and sedimentary processes a baseline description will be made.

The baseline description describes the geology and sediment transport processes that operate within the area. These provide the framework around which the coastal and marine geomorphological features of the area are created.

There are many locations in Scotland where the geology or geomorphology of an area is of significant conservation value. The distribution and conservation protection given to these sites is summarised.

The installation of the renewable devices will have some impact on the geology and geomorphology of the area. The criteria against which the impacts can be assessed and the effects that installing renewable energy devices will have on this baseline are discussed.

Finally recommendations to mitigate against the effects or to identify where additional information is needed to ensure that the effects can be monitored are given.

Figures C2.1-C.3c accompany this chapter.

C2.2 Background

Geology encompasses all of the materials found within or on the Earth's surface, from the most ancient rocks that show evidence of the evolution of the planet, to the sand ripples created by the outgoing tide.

Geological descriptions broadly separate rocks and sediments into 'solid' and 'drift' deposits. These divisions are based upon the ages of the material with reference to the start of the last ice age, the Pleistocene, which started some 1.8 Ma ago.

'Solid' geology is material that is older than 1.8 Ma and comprises the landscape which the ice sheets encroached 1.8 Ma ago.

'*Drift'* material is younger than 1.8 Ma and is grouped into *Pleistocene*, material deposited by the actions of the ice sheet, and the *Holocene*, representing the time since the final retreat of the ice some 10,000 years ago to the present day – the present day seabed sediments were deposited since the retreat of the ice sheets.

C2.2.1 Scotland's Terrestrial Geological Heritage

The natural heritage of Scotland both offshore and onshore owes much to the rocks, fossils and landforms which make up its geological and geomorphological foundations or 'Earth heritage'. Additionally geological and geomorphological characteristics exert a strong influence on the natural systems and biodiversity of Scotland. Furthermore it influences sea use, industry and infrastructure and the economic and cultural development of Scotland.

Scotland and the west coast in particular, contain an exceptional diversity of Earth heritage. Within this part of Scotland rocks from almost all periods of geological time are represented, from some of the oldest rocks in Europe – the Lewisian gneiss, to the most recent – the glacial derived material and landforms created after the latest ice age. These recent landforms continue to evolve post glaciation, by the action of ocean currents, tides and rivers which continue to drive coastal and sediment processes.

Conservation of Scotland's Earth heritage is therefore intrinsic to conserving Scotland's varied character and natural heritage (Scottish Geology, 2007) (SNH, 2007).

C2.2.2 Scotland's Marine Geological Heritage

The offshore geology and geomorphology of Scotland, in common with other countries, is less well understood than on land. This is due to the logistical difficulties and high costs of acquiring data in the marine environment when compared to land. Available data sources are either, very regional in nature such as the BGS offshore 1:250 000 scale or site specific and therefore detail is limited in spatial extent.

However, the marine geology of the SEA area has the potential for significant diversity with environments ranging from low energy sheltered deep water lochs to high energy straits such as the Pentland Firth which has some of the strongest currents in the British Isles.

Earth heritage sites are, at present, limited in extent to the low water mark, so this level of protection does not extend to the marine environment. However, there is a growing interest in the development of offshore geological conservation, which may result in the provision for designating offshore geological conservation sites as part of the Marine Bill.

C2.3 Baseline Environment

C2.3.1 Introduction

The information for following sections has been derived largely from the JNCC coastal directories series, 1997, the website on Scottish Geology (www.scottishgeology.com) maintained by the Hunterian Museum, and the Strategic Environmental Assessment reports for Oil and Gas SEA area 4, 5 and 7 undertaken for the DTI. The baseline environment section describes the following aspects of the study area, as appropriate:

- solid geology
- seabed sediments
- likely sediment pathways and areas of erosion and accretion
- offshore and coastal geomorphology
- sedimentary structures
- earth heritage conservation sites

C2.3.2 Data Sources

The data used to compile this section has drawn heavily on the Oil and Gas SEAs which cover the study area (SEA4, SEA5 and SEA7). In addition, the primary, publicly available data source for assessing the distribution and marine geological mapping is the British Geological Survey's 1:250 000 offshore series. These maps differentiate between the two types of seabed sediments and deposits:

- "Quaternary Geology" Series: this maps the distribution of Pleistocene material from the 1.8 ma to about 11500 years BP, which is derived from the actions of glaciers. This comprises of material that, whilst generally being 'unconsolidated', may comprise of some semi-cemented (lithified) soils, or very stiff and hard clays. This data is not yet available in digital form.
- "Seabed Sediments" Series: these map the size distribution of unconsolidated sediments found directly on the seabed surface. This is the only data type available in digital format, and the distribution of seabed surface sediments within the study area is shown in Figure C2.1.

C2.3.3 Coastal and Marine Geology of the Study Area

C2.3.3.1 Background

The geology of this part of Scotland is very complex, and the description below can only provide an indication of the rocks that are found.

The older (Pre-Cambrian) rocks present along the NW coast and the Western Isles characterise a landscape that has been very resistant to erosion and, by the action of ice, caused the coastline of today.

Offshore there is a variable cover of glacial deposits and seabed sediments. The driver behind the mobility of seabed sediments into bedforms and the distribution of the material is discussed further in the next section.

The geological time eras represented in Scotland's geology are outlined below. The names of geological periods are given in italics and the ages given reflect those provided by the International Commission on Stratigraphy.

- The *Precambrian* is the oldest era from about 4.6 billion years ago to 540 million years ago (Ma) and the study area contains rocks which are thought to be in excess of 3 billion years old representing not only the oldest rocks in the UK but also some of the oldest rocks in the world.
- The *Palaeozoic* is from about 540 – 250 Ma; the *Mesozoic* is from about 250 – 65 Ma.
- The *Cenozoic* from about 65 Ma to the present day
- The *Quaternary* period extends from 1.8 Ma BP to the present day. The Quaternary is divided into the Pleistocene (1.8Ma to 10ka BP) and Holocene (the last 10,000 years).

C2.3.3.2 North Channel

The coastal geology of the North Channel area is predominantly comprised of Ordovician/Silurian sedimentary rocks with some younger Permian/Triassic rocks within Loch Ryan and Luce Bay.

Offshore there is very limited sediment within the North Channel due to the high current speeds and extensive areas of bedrock occur between the Rhinns of Galloway and Northern Ireland. Within sheltered waters such as to the east of this area north of the Isle of Man and Wigtown Bay sediment cover increases.

There are features of geological significance. Terrestrial geomorphology within the area has been identified as "notable for its glacial deposits, particularly drumlins, and for its coastal landforms, particularly saltmarshes, sandflats and mudflats" (Scottish Geology, 2007).

C2.3.3.3 Argyll and Bute

Within this area there is a notable difference between the coastline of the Midland Valley – defined by the Southern Uplands and Highland Boundary faults / Isle of Arran and the rest of the coastline.

The Midland Valley / Arran comprise of Devonian/Carboniferous limestones, and sandstones which have been eroded to form a gently rounded coast. The rest of this area is dominated by the much older Dalradian rocks. These are highly resistant and this has resulted in the deeply incised coastline as shown within the areas of Islay, Jura and the Mull of Kintyre.

There are igneous rocks both onshore and offshore including the Blackstones Bank (about 30 km south-west of Mull) which is associated with the exposed onshore Tertiary igneous centres Arran, Mull and Skye.

Glacial landforms are well preserved both on land and at the coast, in addition there are active river landforms (Scottish Geology 2007).

Offshore, the surface geology has variable thicknesses of material. There is limited sediment cover where currents are high, such as between some of the islands. In some of the sheltered and deep lochs there are thick sequences, which include the finer muds which settle out within low energy water environments.

C2.3.3.4 Western and Inner Isles

This area includes some of the most complex geology within the UK and contains some of the oldest, and the youngest formed rocks.

The oldest rocks are represented by or in four main PreCambrian groups: the Lewisian Gneiss (3000 Ma old) Torridonian Sandstone, Moine Metasediments (1000 Ma old) and Dalradian metasediments

Within the area of the Western Isles, the Lewisian gneiss (the oldest rocks in the UK at 3000 Ma) form, virtually exclusively, the geology of the islands of Outer Hebrides (Lewis, N. & S. Uist, Benbecula) and down to Coll and Tiree.

Along the mainland coast, the Torridonian sandstones and their associated metamorphic Moine rocks, 1000 Ma old form much of the coastal geology with areas of Lewisian gneiss occurring inland and along the coast between Skye and the mainland at Kyle Rhea.

The more recent Tertiary volcanic activity is responsible for the creation of Mull, Muck, Eigg and much of Skye. This also accounts for the rugged sea floor in the area with many subsurface pinnacles. These igneous outcrops are absent from the Minch which has a smoother sea floor.

The seabed geology is variable with exposed rock creating the pinnacles around the Tertiary aged volcanics, whilst sediment cover is generally thin and patchy.

C2.3.3.5 North Coast and Northern Isles

Along much of the coastline of north-west Scotland the four main Precambrian rock groups (Lewisian, Torridonian, Moine and Dalradian) are present. Further north, around the Sutherland coast, Moine and Lewisian metamorphic rocks crop out on the seafloor.

The Orkney Islands and offshore sediments are underlain by the Shetland Platform, which is composed largely of Devonian sandstones, rich in fish fossils. Offshore, most solid geology is covered by sediments. Rock outcrops on the seabed, such as those to the south of Orkney, are found where tidal currents, such as those found in the Pentland Firth, have removed material.

Permian and Triassic rocks outcrop on the seabed in the West Fair Isle Basin and in the West Orkney Basin Complex. Offshore the Shetland Islands Precambrian metamorphic rocks are dominant. However, younger sedimentary rocks such as Devonian and Permo-Triassic sandstones and shales overlie the metamorphic rocks further offshore to the east and south.

Between Orkney and Shetland the sediments are dominated by coarser gravel fractions due to the actions of currents that have removed the finer fractions. Sediment cover is patchy.

C2.3.4 Sediment Transport

C2.3.4.1 Background

This section, on sediment transport, provides a description of the sedimentary process acting upon the present day shoreline.

Materials for marine sediments are principally derived from three sources:

- Glacial - representing the largest source of sediment, deposited both inland and on the adjacent shelf by the action of glaciers, either directly or by glacial meltwater.
- Terrigenous - sediments from land brought into the marine environment by rivers and estuaries.
- Biogenic - material created by hard bodied marine organisms

The Glossary provides further explanation about each of these sediment sources.

Across the study area seabed sediments vary from mainly gravel spreads, in the exposed nearshore and relatively shallow water areas, to predominantly sandy and muddy sediments on the open continental shelf further offshore. Sheltered bays and estuaries (firths) contain large areas of muddy sediments in locations sheltered from tidal and wave currents and sand sheets. They also contain sandbanks in exposed nearshore and tidally-constricted locations that are characterised by relatively high rates of sediment supply or sediment re-circulation.

The distribution of seabed sediment types within the study area is shown in Figure C2.1

The present day sedimentary environment now largely reflects the effects of reworking by near-bottom currents on the topography and the sediments that originated during the glaciations. The drivers for sediment transport are primarily marine currents which are created by:

- Action of the tide – the study area has some of the highest tidal currents velocities within the British Isles. Notable areas include:
    - The North Channel across to Jura - approximately the median line between Scottish and Northern Irish waters
    - Headland of Cape Wraith
    - Straits between islands, and islands and mainland (Mull – Kintyre; Mull – Tyree; Tiree - Coll; Skye – Lewis; North to South Uist.
    - Shetland-Caithness
- Action of wind on the sea: the predominant westerly winds travel over an extensive 'fetch' (the distance of open sea between two coastlines). The action of the wind creates waves and thus orbital currents which, depending upon water depth, may reach the seabed.
- Non-tidal ocean circulation currents which generally run parallel to the coast. Post-glacial sea-level rise was associated with the opening of gateways for movement of NE Atlantic water into the North Sea around the coastal boundaries across the Orkney and Shetland Islands (Figure C2.2).

The net transport of sediments, driven by the above currents within the study area is illustrated below. These generalised directions are based upon the net sediment transport pathways shown in the geology reports for SEA 4, 5 and 7.

C2.3.4.2 Major Sediment Pathways

North Channel

The orientation of the coastline relative to the prevailing winds and the varied tidal regime of the northern Irish Sea results in complex sediment circulation along the coasts of the southern end of the study area in the North Channel. Prevailing westerly winds create tidal currents and waves which move sediment into the Solway Firth, although transport rates are low north of Silloth. Along the north coast of the Solway Firth, sediment transport is to the east. Further along the coast at Wigtown Bay the infill of sand here and the presence of sand dunes at the head of Luce Bay indicate that sediment transport is northwards into these bays, being driven dominantly by wave rather than tidal transport.

Overall, the Solway Firth acts as a sediment sink, although it contains areas of both erosion and accretion. Longshore drift of sediment enters the estuary, and therefore accretion is probably generally greater than erosion. Wigtown Bay and Kirkcudbright Bay are almost infilled with sediment, but Luce Bay, to the west, remains open, although the northern shores of the bay are backed by extensive sand dunes.

To the west of the Mull of Galloway in the North Channel there is no detectable net drift direction except at Ballantrae, where drift is to the south. Side-scan profiles led Caston (1976) to propose a divergence of net transport directions for sandy sediment within the North Channel, to the north-west in the northern part of the channel and to the south-east in the southern part.

Whilst the volume of erosion is probably lower than accretion, locally it may be significant. For example around Luce Bay, local erosion of the narrow raised beach threatens roads, and defences have been constructed in places. The dunes in the bay are suffering continual erosion and there is localised erosion in Loch Ryan and on the western coastline of The Rhinns.

Argyll and Bute

In the north-west of this region, the complex form of the coastline in relation to the prevailing winds, and thus the wave climate, results in a highly variable sediment transport regime. This restricts littoral transport to specific bays, between which there is little or no interchange of material. Tidal currents are in general, weak and net sediment transport offshore is at large northwards, as determined by residual currents.

Within the Firth of Clyde there is no obvious indication of longshore drift. Along the east coast of the Firth of Clyde, between the rocky headlands at the Heads of Ayr, Troon and Saltcoats, the curve of the long sandy beaches at Ayr, onshore transport of sediment may occur but rates are low. Beaches in the area are often thin with an underlying rock platform and there is severe erosion between Troon and Saltcoats in Irvine Bay

In the Inner Firth of Clyde tidal streams are weak, and due to the more sheltered conditions and restricted wave 'fetch' (extent of open water upwind), wave action is also reduced. There is possibly a low rate of northward drift along both sides of the Firth of Clyde. At Inverkip in the inner Firth of Clyde severe erosion is being controlled by coast protection measures.

Between the Isle of Arran and the Mull of Kintyre there is little evidence of any net movement. Erosion and accretion are minimal. Sand and shingle beaches lie within small bays and there is a continuous shingle fringe along the edges of most of the sea lochs, with large inter-tidal sand and gravel deposits at the loch heads.

Between the Mull of Kintyre and Ardnamurchan Point the western coasts are fully exposed to the Atlantic wave action although many beaches are protected by offshore islands and their locations at heads of lochs. Erosion and accretion in this stretch of the coast is not substantial, except during storms that blow up along the lochs. Sandy beaches make up about 6% of the western open coasts of Argyll, typically as small pocket beaches. Sediment accumulations are most extensive where islands protect the shoreline from wave attack. Sandy and gravely accumulations commonly form at the heads of sea lochs and consist of both marine and alluvial sediments.

Outer, Western and Inner Isles

Within this area there is little input of terrigenous sediment from rivers and coastal erosion is slow in comparison with rates elsewhere in Great Britain. The bulk of beach sediment is derived offshore, being moved onshore by wave-generated currents.

The irregular form and aspect of the coastline in relation to the prevailing winds creates a variable wave climate within these areas. There is a net northerly sediment transport direction, driven by current transporting bedload sediment northwards along the Hebrides Slope and Outer Hebrides Shelf.

For the inner islands there can be limited littoral transport to individual sheltered bays, between which there is little or no interchange of material.

Along the west coast of the Western Isles much of the beach sediment is formed of shell fragments produced on the shallow shelving rocky platform offshore. Tidal currents are generally weak and net sediment transport offshore is generally northwards, determined by residual currents.

On the north-east coast of Lewis, cliffs composed of Triassic conglomerates and sandstones are more easily eroded than the Lewisian Gneiss that makes up much of the islands and provide some onshore sediment input. Along most of the east coast of the Western Isles the coastline is rocky with many cliffs and sea lochs.

Much of the west coast between Ardnamurchan Point and Cape Wrath is sheltered from the Atlantic swell by the Western Isles and beaches occur along this section of coast. Wind and wave erosion does, however, occur in many places between Rubha Reidh and Cape Wrath. Littoral drift here is strongly influenced by the orientation of the coastline but is generally low.

North Coast and Pentland Firth

In this region there is little evidence of littoral drift or sediment accretion. The coastline is predominantly rocky and resistant to erosion from the small river catchments within the area. Beaches are typically small along this stretch of coastline with a few larger inter-tidal sand flats that have generally formed of offshore glacial deposits. Beach and cliff erosion is minor, as is longshore drift.

The Northern Isles

The coasts of Orkney and Shetland are very complex, with numerous enclosed and deeply indented bays that interact little with each other. Between the Pentland Firth and south of the Orkney Isles the coastline is predominantly rocky and exposed to harsh wave conditions. Sediment transport is from east to west with sand accreting on the eastern side of the Churchill Barriers which connect the islands of South Ronaldsay, Burray, Glimps Holm and Lamb Holm to Mainland. Wave processes dominate littoral transport. The extremely high flood and ebb currents that occur in most of the straits between the islands decrease inshore. It is unlikely that tidal currents in this region have any direct effect on moving beach material. However, the strength of the peak flow currents can give rise to significant movement of material on the sea bed. Long-term coastal and cliff erosion is occurring on most beaches.

Scapa Flow in the middle of the Orkney Isles has a much less severe wave climate. Although current speeds are high in the straits between the islands and off rocky headlands, they are much lower in the indented bays and hence have little impact on beaches. The Churchill Barriers have blocked off potential sediment transport into the Scapa Flow which formerly could have reached the beaches within Scapa Flow. Overall there is little beach erosion and only very slight accretion at the western end of the beach at Scapa.

The north-east coast of Mainland and Shapinsay has numerous large indented beaches. Although relatively sheltered, wave action is a dominant factor in the movement of beach material. Littoral drift is low. However strong tidal action is responsible for moving sediment in an easterly direction. There is little significant erosion in this region with minor accretion.

Within the northern islands of Orkney the littoral processes are wave dominated, dependent on the orientation of the beaches and the amount of shelter provided by other islands. There is unlikely to be any significant net longshore drift or interchange of beach sediments. Equally, although tidal currents are very strong, they are generally unlikely to directly affect beach areas. However, within parts of the Orkney archipelago, tidal currents are sufficiently powerful to affect the sediment transport routes controlling coastal evolution. There is little long-term erosion or accretion is this region. Many beach systems are broadly in equilibrium with their wave climate, with most changes within bay head beaches, probably associated with coastal retreat associated with sea level rise.

The coasts of the Shetland Isles are rocky and natural with few developed areas. Deep water extends close to the shoreline, and a severe wave climate exposes the coastline to high energy conditions. Sediment transport is therefore governed by wave action. Beach material and sediment from eroding cliffs can be readily moved under destructive wave conditions, and as the offshore seabed is steep, this material is lost as a source of future natural beach nourishment. Erosion occurs along much of the relatively soft beach frontage, with varying degrees of cliff erosion depending on the rock type. There is little significant accretion.

C2.3.5 Geomorphology

C2.3.5.1 Coastal Geomorphology

Scotland's present day coastal geomorphology reflects the interaction between sea-level change, land uplift as a result of isostatic readjustment, resistance of coastline rocks and unconsolidated sediments to erosion and the sediment supply to the coast since the end of the last glaciation (Smith, 1997 in SEA 5).

Whilst sea levels around the world are rising today, for the last 6,000 years much of the Scottish coastline has continued to slowly rise out of the sea after the release of the weight of the ice sheet. Uplift has been greatest where the ice was thickest, around the Western Highlands, and least in areas closer to the margins of the ancient ice sheet, such as the Western Isles, Orkney and Shetland. Where sea-level rise has outpaced uplift of the land, as in Orkney, Shetland and the Western Isles, submerging of the landscape continues (SNH, 2006).

Raised beaches created by changes in sea level represent significant features in understanding the geology of the last 1.8Ma and the coastal processes of the time.

C2.3.5.2 Seabed Geomorphology

Much of the offshore morphology of the seabed in northwest Scotland owes its present day form to the actions of past glaciations.

The bathymetry around the coast of Scotland has been greatly influenced by geological processes and in particular the actions of the last ice age. About 20,000 years ago an ice sheet up to 1.5 km thick blanketed Scotland. Sea levels were around 140 m lower than they are today and the edge of the Atlantic Ocean lay many kilometres west of the Hebrides.

When the ice melted between 15,000 and 10,000 years ago Scotland's coastline began to take on its present form. Glaciers retreated and left behind a barren landscape, carved out by the scouring actions of massive ice sheets and glacial meltwater. The melting ice resulted in isostatic readjustment and sea levels rose dramatically with seas flooding the ice-scoured landscape. Groups of islands such as Orkney and Shetland were created and the lower lying river channels and glacial valleys were submerged to form many of the firths found in Scotland today.

The present seabed morphology is a consequence of the landscape left behind from the retreat of the glaciers – since there is a limited supply of new material; the bedforms found on the seabed surface are primarily due to the reworking of glacial deposits and the seabed sediments through the action of marine currents.

The classification of marine geomorphologic features is based upon that given within SEA 4.

Immobile Bedforms

Pockmarks are created by gas escaping, originating from the release of shallow gas or fluids. This occurs at the sediment/water interface due to the weight of sediments versus the upwards pressure of escaping gas/fluids, and pockmarks are therefore only formed only in fine grained sediments. Pockmarks have been identified a marine Potential Annex I Habitat (PAIH) as they are geological features which potentially support important marine biological communities.

Moraine glaciogenic features are characterised by their large size and distinctive seabed topography. By resistance to modern erosion they commonly form sea bed banks consisting of an over-consolidated (hard) sediment substrate if exposed at seabed. They include former terrestrial and submarine moraines and the enclosed basins formed at former lowland or tidewater ice-sheet margins.

Iceberg ploughmarks – these were created as icebergs detached from the ice sheet and scraped along the seabed. Their importance lies in the role of creating variable seabed topography with a wide range of sediment types. However as they generally only occur in water depths of greater than 120 m, their distribution within the study area is likely to be limited.

Enclosed basins originated by erosion into the continental shelf seabed. They have greater than 100m incised depths (all are partly filled), 2km or more width and they may be up to 50km or more in length (Wingfield, 1990). When the positions of the enclosed basins have been compiled with those of the moraines, they have been used as a basis for an interpretation of the regional extents of the former terrestrial and submarine ice sheet margins (e.g. Ehlers and Wingfield, 1991). These features are significant as they form isolated environments and, in areas of modern low near-bed currents, they are sediment sinks for fine-grained sediments that have settled out of suspension. In areas of strong near-bed currents they are sinks for bedload sediments that have spilled over the basin edges from the surrounding continental shelf.

Mobile Bedforms

Mobile sedimentary bedforms such as ripples and sandbanks are created within a dynamic environment, so do not represent a feature of lasting significance – it is the process that is significant. However, these features may represent PAIH habitats if formed by material that is predominantly sandy sediment in less than 20m water depth.

C2.3.5.3 Geological Conservation

For a feature to be defined as being of geological importance or conservation value there needs to be a definition as to what constitutes such criteria. The issue of where sites of geological / conservation importance are found and defined is addressed in the Section below.

The Annex I habitats directive focuses on specific habitats – these are determined both by defined biological species and the required geological conditions to support these species. There is, therefore an element to geological conservation of features through the implementation of this directive. Examples include sandbanks and pockmarks. The potential significance of impacts of renewable developments on PAIH's is addressed in Chapter C5: Protected Sites and Species.

From a solely geological perspective, there are two forms of geological conservation within Great Britain, the non statutory geological review (GCR) sites and the statutory designation of Sites of Special Scientific Interest (SSSIs).

The Geological Conservation Review (GCR) managed by JNCC, principally aims *"to provide a public record of the features of interest and importance at localities already notified or being considered for notification as 'Sites of Special Scientific Interest' (SSSIs). The selected GCR sites therefore form the basis of statutory geological and geomorphological site conservation in Britain."* (JNCC Geological Conservation Review (JNCC, 2007).

Many of the GCR sites correspond to the standard divisions of geological time or to major events within those periods. They can be grouped into seven broad selection categories:

- Stratigraphy
- Palaeontology
- Quaternary geology
- Geomorphology: the landforms and processes which form the current landscape
- Igneous petrology
- Structural and metamorphic geology
- Mineralogy

The distribution of coastal GCR sites and SSSI sites designated for their geological or geological and biological importance is shown in Figure C2.3

Any proposed development in an area designated as a GCR or SSSI for its geological or geomorphological features must consider whether it is likely to cause deterioration of the geological feature of interest at the site.

Offshore sites with a geological value are not defined within this existing framework of GCR or SSSI sites. Therefore whilst a marine site may have conservation value through the implementation of the Habitats Directive, it is not possible to define a marine site as being of geological conservation value based on its geological attributes alone.

C2.4 Potential Effects

The potential for interaction of renewable devices offshore with the geological and broader geomorphological environment is generally low, being confined to small areas where devices are piled into, or moored on, the seabed, and the export cables to shore.

Of greater concern is the potential interaction of marine renewable devices with the hydrodynamic regime, which may in turn affect the sediment dynamics and thus sediment movements and coastal processes.

Specific potential effects on geology and the sedimentary environment are listed below. The effects are assessed purely in terms of the physical geological environment. The associated potential effects on marine wildlife (benthic ecology, fish and shellfish, birds and marine mammals) are not included here but are addressed in the relevant ecology chapters (C6, C7, C8 and C9 respectively).

C2.4.1 Installation Effects

Increase in suspended sediment caused by release of sediment into the water column during installation / decommissioning of devices and their associated export cables. These effects will generally be limited in duration and extent, especially given the high energy environments where marine and tidal devices will be sited, and the dynamic nature of the marine environment, causing continual changes in suspended sediment load.

Change in Seabed Morphology caused by piling of seabed fixed devices into the seabed, or the physical disturbance during export cable installation. This impact has the potential to affect sedimentary structures and bedforms, solid geology or geomorphological features. Currently, only shoreline devices and export cables have the potential to affect designated GCR or SSSI sites, as no marine sites have been designated.

Buried power export cables are installed only within only the top couple of metres of unconsolidated sediments or (partially) consolidated glacial drift material. Burial material is mobile or subject to dynamic environment and erosion from currents.

C2.4.2 Operation Effects

Change in sediment processes: Modifications to sediment transport pathways in the immediate vicinity of operating devices, and sediment accretion or erosion (scour) of sediment at the site, could occur during operation. This impact could occur both as a result of the physical presence of devices on the seabed acting as a barrier or diversion to sediment transport during device operation, or as a result of localised hydrodynamic changes associated with wave or tidal energy removal by the operating device. High confidence estimates, based on expert knowledge, can be given for the extent of effects on sediment processes of up to 50 m from devices (see Chapter C3). This impact is therefore localised to the vicinity of the device array, but will be effective for the operational life of the device.

Change in coastal processes: Coastal processes and sediment supply and dynamics may be affected as a result of changes to hydrodynamic processes and sediment transport regimes. This effect is considered more likely for devices in sites at or close to the coast. This may be difficult to quantify for wave and tidal devices, bearing in mind the complex hydrodynamic environment and the limited baseline data from which to define change.

The potential effects are summarised in Table C2.1.

Table C2. 1: Summary of the Potential Effects on Geology

Effect	Development Phase	Direct/Indirect	Duration	Extent
Increase in suspended sediment	CD CC	Direct	Temporary	Negligible
Change in seabed morphology	CD CC	Direct	Long term (device life)	Within array area Wave: 0.24 – 2 km^2 Tidal: 0.36 – 4 km^2 Cable route
Change in sediment processes	OD	Direct	Long term (device life)	50m
Change in coastal processes	OD	Indirect	Long term (device life)	Unknown and variable

CD = Construction/decommissioning impact – devices
CC = Construction/decommissioning impact - cables
OD = Operation impact – devices
OC = Operation impact – cables

C2.5 Sensitivity of Receptors

Receptors from the perspective of geology and seabed process are difficult to define. Within other aspects of a strategic environmental assessment receptors can be well defined as biological organisms or specific habitats. An example when considering receptors and the impacts upon them is given as *"establishment and maintenance of each identified receptor and the identification of sensitivities to changes in wave/tidal energies, where possible by reference to thresholds beyond which impacts on habitats/populations will be significant."* (Welsh Assembly Government, 2004)

For the purposes of the SEA, geological receptors are defined as:

- Water quality;
- Seabed morphological features which are protected as GCR, SSSI and PAIH sites;
- Sediment transport pathways;
- Coastal Processes.

However, it is not possible to define sensitivity for geological receptors in the same way as has been done for some of the other sections of the SEA. The concept of receptors being habitats or populations also implies a location at which conditions are either found or not found, and whether a population will increase or decrease as a consequence of the offshore renewable development. Where the habitats/species are limited in extent or rare then any changes to them is more significant than a localised change on a common or widely distributed habitat/species.

Difficulties also occur when extending the concept of mapping the sensitivity of receptors to the marine geological environment. These owe primarily to:

- defining the scale of processes;
- defining the marine extent of terrestrial sensitive/protected sites which may be effected by change;
- difficulty in measuring a baseline from which changes may be perceived and quantified.

The scale on which a receptor is defined is fundamental in assessing whether the receptor is sensitive to one of the key effects given in the previous section. For example, changes in sediment erosion, transport and deposition because of modification in the hydrodynamic regime within a sea loch. Whilst there may be removal of sand from a beach, which is locally significant, the sediment budget may be redistributed within the loch so at a broader scale there has been no overall net change. At the scale of the beach the receptor has been sensitive to the development, but at the scale of the loch there is a little or no sensitivity.

Although there are numerous sites of geological conservation, they are defined from a terrestrial perspective and their offshore level of protection is defined by the Low Water Mark. Therefore there is essentially no defined marine component to such sites or a means by which their offshore extent can be defined without site specific information. This also makes assessing the importance of marine geological features difficult - there is no framework around which their importance can be assessed from a geological perspective. Current UK effort to define the hydromorphological status of estuarine and transitional (estuarine) waters within the Water Framework Directive may clarify some aspects of this problem in future.

C2.6 Potential Significance of Effects

C2.6.1 Assessment Criteria

The assessment of effect significance has been undertaken based on the criteria below. These have been developed specifically for the SEA, and take into account the information available to inform the assessment of significance.

Due to the strategic nature of this assessment, it has not been possible to quantify magnitude of effects. Potential effects of offshore renewables can be identified and their significance on geological features and processes can be qualitatively described. However, the quantification of changes and mapping of significance cannot readily be transferred to the marine geological and sedimentary environment without the level of detail on a regional level to support this.

Table C2.2: Significance Assessment Criteria - Geology, Seabed Sediments and Sediment Transport

Significance Level	Determining criteria
Major	Impact on the structure/integrity of an SSSI where geology or geomorphology is a cited feature, or a Geological Conservation Review (GCR) site. Long term impact on the sediment regime which may have significant adverse affects on erosion or accretion – above those created by extreme storm events.
Moderate	Impact on the structure/integrity of the total geological/geomorphological feature identified as a potential Annex I habitat for its geological features.
Minor	Impact on the structure/integrity of an area where the geology is known to contain no valuable features or important sediment transport pathways.
Negligible/No Impact	No measurable direct or indirect impacts that would compromise the integrity of the geology of the study area. No measurable impacts on the sediment regime that would result in adverse affects on erosion or accretion.

An assessment of the significance of the potential effects identified in above is given below in Table C2.3.

C2.6.2 Results of Significance Assessment

In general, marine renewable energy devices have the potential to create effects of major significance where coastal processes or important sediment transport pathways are affected by the renewable development.

It should be noted that that the assessment of significance has been undertaken at a strategic level, and uses the precautionary principle by assuming maximum effects.

C2.6.2.1 Installation Effects

Increase in suspended sediment: This will generally be limited in duration and extent, especially given the high energy environments where marine and tidal devices will be sited, and the dynamic nature of the marine environment, causing continual changes in suspended sediment load. It is therefore estimated that the significance of physical impacts of suspended sediment will be negligible.

Change in Seabed Morphology: Should cable installation be undertaken at a shore landing, which is a site of conservation value, this would be an effect of potentially major significance, depending on the nature of the site geology. Major effects are likely to occur where the installation methodology directly affects the nature of the site – for example pinning of cable/rock cutting on a geologically sensitive outcrop or earth works across landscape features of conservation value. Use of appropriate mitigation such as avoiding protected areas, or areas where rock cutting or cable pinning would be required could be expected to reduce residual effects to minor.

Where the cable can be installed beneath the mobile sediment layer then potential effects are likely to be minor and temporary.

C2.6.2.2 Operation Effects

Change in sediment processes: High confidence estimates, based on expert knowledge, can be given for the extent of impacts on sediment processes of up to 50 m from devices (see Section C3). This impact is therefore localised to the vicinity of the device array, but will be effective for the operational life of the device. It is therefore considered to be an impact of potentially moderate significance. Project specific modelling studies, associated with site specific survey data as appropriate and careful siting of devices can be expected to reduce the residual effects associated with changes in sediment processes to minor.

Change in coastal processes: Should changes in coastal sediment processes result in changes to rates of erosion or accretion at the coast this would be a potentially major impact. As for sediment processes impacts, project specific modelling studies, associated with site specific survey data as appropriate and careful siting of devices could be expected to reduce the residual effects associated with changes in coastal processes to minor.

Table C2.3: Potential Significance of Effects - Geology, Seabed Sediments and Sediment Transport

Potential Effect	Device Characteristic	Development Phase	Receptor	Potential Significance of Effect	Likely Impact Extent	Source	Confidence	Figure Number
Increase in suspended sediment	All wave and tidal	CD CC	Water quality	Negligible	Negligible	Estimate based on expert knowledge	High	Not mapped
Change in seabed morphology	Piled devices	CD CC	Seabed morphological features (GCR, SSSI and PAIH sites)	Major	Within array area Wave: 0.24 – 2 km^2 Tidal: 0.36 – 4 km^2 Cable route (unknown)	Discussions with developers	High	Not mapped
Change in sediment processes	All devices on the seabed and shoreline	OD	Sediment transport pathways	Moderate	50m	Estimate based on expert knowledge	Low	Not mapped
Change in coastal processes	All devices on the seabed and shoreline	OD	Coastal processes	Major	Unknown	Estimate based on expert knowledge	Low	Not mapped

C2.7 Likelihood of Occurrence

The most significant potential effects are likely to be those related to changes in the hydrodynamic and sediment transport patterns, and the consequences of these on changes to coastal processes.

There is potential for marine renewables to have effects of major significance on coastal processes and sediment dynamics, due to the changes in the sediment distribution, and energy that drives the coastal process system.

The difficulty facing both; i) assessment of likelihood and, ii) significance of any impacts, is the lack of available information from which baseline conditions can be determined.

While there is the potential for changes in the energy environment (and thus coastal processes) due to the siting of devices, attributing any changes as consequence of a causal effect of device placement is the most difficult to achieve. This is because such changes are dependent on the detailed pre-understanding of sediment dynamics associated with a specific development, and a more detailed understanding of the magnitude of expected wave and tidal energy impacts.

C2.8 Mitigation Measures

Where potentially significant effects have been identified for a specific receptor, the following mitigation measures are appropriate for reducing or mitigating impacts.

Table C2.4: Mitigation Measures - Geology, Seabed Sediments and Sediment Transport

Potential Effect	Development Phase	Mitigation Measures
Increase in suspended sediment	CD CC	Suspended sediment dispersion modelling at the project stage
Change in seabed morphology	CD CC	Avoidance of installation of devices in coastal GCR and SSSI sites.
Change in sediment processes	OD	Avoidance of placement of devices in areas where sediment transport pathways are modelled as highly sensitive to change.
Change in coastal processes	OD	Avoidance of placement of devices within zones where coastal processes are modelled as highly sensitive to change

CD = Construction/decommissioning impact – devices
CC = Construction/decommissioning impact - cables
OD = Operation impact – devices
OC = Operation impact – cables

C2.9 Confidence and Knowledge Gaps

C2.9.1 Baseline Data

C2.9.1.1 Regional Data Sources

There are important considerations to be taken into account, when looking at data sources such as the 1:250 000 series as a reference for the impacts of device placement on seabed geology and processes.

Aside from the size fraction of sediments, the Seabed Sediment maps do not all show a consistent level of interpretation. For example, whilst some sheets may also show the thickness of seabed sediments, others may show very generalised information, or none at all. Therefore, common data sets do not exist for the entire study area.

Non site-specific data sources such as the Offshore Series of maps can provide a broad overview of expected ground conditions but their validity in deriving conclusive statements about broader geological site conditions is limited.

C2.9.1.2 Scale of Features

Certain features of geological significance may only be identifiable on a detailed scale. Features such as pockmarks only range in size from 50-200m (SEA4). These require site-specific mapping programs to confidently identify their size and distribution.

Where the significance of changes to coastal processes, or cumulative impacts, are to be assessed the location of other features that may be impacted by the development(s) would also need to be identified. This requires additional marine surveys, undertaken at a project specific level.

C2.9.1.3 Offshore Geological Conservation

Both GCR and SSSI sites are restricted to the land, extending only to the low water mark. Whilst there is growing interest in the conservation of geology and geomorphology below the low water mark and JNCC has commissioned a study into this, there are no present marine designations. It is likely that most marine designations would be extensions of existing coastal sites. Of particular interest are the sites selected for their geomorphological value (personal communication, Neil Ellis, 2006).

Table C2.6 below summarises the current data gaps which will require further research / investigation in order to assign greater confidence to the assessment of potential effect significance.

C2.9.2 Potential Effects

The current state of knowledge to support assessment and monitoring of impacts is low. This is due to the limitations in coverage and resolution of marine geological data, and to the lack of operating devices from which to record impacts. Key data sources are of only a general level of detail, mainly because of the high costs of acquiring marine geological data. Site-specific data will be obtained as a requirement for site planning and construction but this creates "islands" of good quality information. There is the need to consider both effects outside of the site and cumulative effects which require these islands to be joined by data of comparable quality.

Computer modelling may be able to address some of the issues regarding changes in energy levels and sedimentary processes due to installation of individual devices, but this may become difficult in the case of non-linear combination of individual effects into cumulative effects. There may be a requirement for additional modelling, informed by the results of field survey – and subsequent refinement of model results once data from demonstration projects are made available.

Sensitive offshore features (pockmarks, glaciogenic features) may be impacted by the installation of a device, or the consequences of its installation. However, since the locations of these are not shown within offshore digital data sets (seabed sediments data simply indicate grain sizes) there is no adequate way to represent it on a map.

Table C2.5: Data Gaps - Geology, Seabed Sediments and Sediment Transport

Identified Data Gap	Potential to Fill the Data Gap
Highly limited data to enable an understanding of the potential geographic footprint of change.	▪ Modelling predicted change, with field survey where feasible, to increase understanding of the potential geographic extent of change. ▪ The spatial extent to which consideration needs to be given drives all programmes of marine data acquisition beyond those survey requirements that exist to support site selection and installation.
Only very general and regional information exists regarding knowledge of offshore geology and sedimentary environment – geological features that form PAIH sites may not be represented at the level of data available.	▪ Project specific marine geophysical and sampling programme ▪ For a development, a site survey will be undertaken for site planning and construction purposes. ▪ This knowledge needs to be extended outside of site boundaries to consider broader coastal process / cumulative effects and identification of significant features.
Offshore SSSIs or other possible sites of geological conservation value are not designated.	▪ Definitions of sites to include marine component – either supported by survey data, or buffered distance ▪ Effects on sites of geological importance are currently limited to terrestrial geology.
Creation of baseline information on sediment transport pathways and sediment transfer volumes.	▪ Hydrodynamic modelling supplemented with third party/survey obtained information on sediment grain sizes and density. Some work is done within regional SEA reports, but this needs further refinement in order to use to establish baseline conditions.

Identified Data Gap	Potential to Fill the Data Gap
Limited comprehension of "baseline". A "baseline" within a dynamic system is not a fixed condition or rigid threshold but should itself capture something of the variability of the system to enable natural changes to be attributed to anthropogenic change.	▪ Fundamental research is needed on ways in which the specification of a baseline may be attempted with some site-specific case studies. The definition needs to capture the inherent variability of dynamic systems.
Changes to the sediment transport, water circulation and coastal processes through removal of energy due to tidal / wave systems.	▪ Computer modelling based upon unit design. ▪ Tidal / wave devices will by definition only be located in high energy areas. On a proportional basis these are the least sensitive to changes in small changes. Proximity of sheltered lower energy environments presents opportunity for a more significant impact as these are more sensitive to smaller changes in the energy environment.
Certainty in the prediction of potential changes to coastal processes through a modification of sediment transport pathways	▪ Collection of baseline data and subsequent monitoring data to confirm prediction regarding potential changes in coastal processes. ▪ Changes at specific site can be monitored through repeat surveys. Extending understanding to cumulative effects presents difficulties if there is no information between sites.

C2.9.3 Recommendations for Site Specific Survey and Monitoring

C2.9.3.1 Pre-installation Survey

There may be a requirement to undertake modelling and monitoring of sites before construction goes ahead in order that natural variability in the sediment transport regime can be separated out from variations that are a consequence of construction.

The effective monitoring of change from a baseline needs similar definitions of the baseline and of the state of the (possibly) changed system. A baseline within a dynamic system cannot be one of fixed condition or rigid threshold. It should parameterize the "fixed" and variable parts of the system. Similarly, the monitoring should provide for recognition of changes to the "fixed" and variable parts. If this is not done, changes are likely to be incorrectly attributed to anthropogenic change.

Changes in sedimentary processes can be assessed through the use of repeat surveys, such as multi-beam bathymetry and/or sidescan sonar. Such surveys would enable variations in sediment distribution and water depth to be determined – thus changes in sediment deposition or erosion can be mapped or quantified. Important considerations for the effectiveness of these surveys are data standards and frequency of repeat measurements. Both these key issues – temporal accuracy and precision of measurements - can be defined by statutory bodies.

The scope of repeat survey work also needs to be the defined. Important factors driving scope are the duration for which repeat measurements are required, and the size of the area over which survey work is undertaken.

- Duration of measurements need to be defined as the costs for this work may effect the economic viability of a site, especially if surveys are to be undertaken for the operational life. Existing third party data sources should be assessed to see if these are able to provide an effective baseline data set.
- The spatial extent of repeat surveys is required as this determines the volume of survey work and thus costs. Due to cumulative effects of additional sites, the aerial extents for repeat survey extents may therefore change.

Guidance from the statutory bodies would be required to provide developers with clear guidelines on methodologies regarding survey scope and frequency in order to determine cumulative effects.

C2.9.3.2 Post-installation Modelling

A 'sphere of influence' for each development could be determined by the statutory body and this would include the spatial extent for which survey and monitoring are required. Policy on the consequences of changing this area due to cumulative effects of later development would need to be defined.

There is also a requirement to delineate marine areas of geological sensitivity rather than having a system limited to the low water mark. Where developments are planned close to geologically sensitive sites, it should be up to the developer to show that such sites do not occur within the sphere of influence of the planned development.

It is considered likely that monitoring of demonstration projects may be required for at least 5 years and that 2 years monitoring post removal is needed.

C2.10 Residual Significance of Effects

Because of the variability in geological setting and energy environments, and their sensitivity to changes through the placement of renewable energy devices, it is not possible to generalize the assessment of effects within specific areas such as been undertaken in other chapters. Conditions that are sensitive to change are localised and are not easily delineated from existing data sources.

The issue of defining the scale for consideration creates additional problems in describing impacts across defined areas. For example the placement of a device in the high energy environment of the North Channel may have a negligible effect on the energy environment, and thus coastal processes, around the site. Table C2.6, below, summarises the potential effect, significance and confidence of the key possible effects identified in the preceding sections.

Table C2.6: Potential and Residual Significance of Effects - Geology, Seabed Sediments and Sediment Transport

Potential Effect	Device Characteristic	Development Phase	Receptor	Potential Significance of Effects	Industry Good Practice Mitigation	Likelihood of Occurrence	Residual Significance of Effects	Confidence
Increase in suspended sediment	All wave and tidal	CD CC	Water quality	Negligible	Suspended sediment dispersion modelling at the project stage	High	Negligible	High
Change in seabed morphology	Piled devices	CD CC	Seabed morphological features (GCR, SSSI and PAIH sites)	Major	Avoidance of installation of devices in coastal GCR and SSSI sites	Low	Minor	High
Change in sediment processes	All devices on the seabed and shoreline	OD	Sediment transport pathways	Moderate	Avoidance of placement of devices in areas where the sediment regime is highly sensitive to change	High	Minor	Low
Change in coastal processes	All devices on the seabed and shoreline	OD	Coastal processes	Major	Avoidance of placement of devices within zones where coastal processes are highly sensitive to change	High	Minor	Low

CD = Construction/decommissioning impact – devices
CC = Construction/decommissioning impact – cables
OD = Operation impact – devices
OC = Operation impact – cables

References

British Geological Survey, 2005. Seabed surface sediments GIS data, purchased October 2005.

Ehlers, J., Wingfield, R., The extension of the late Weichselian/late Devensian ice sheets in the North Sea basin, JQS. Journal of Quaternary Science, vol.6, no.4, pp.313-326, 1991

Hitchen, K., Holmes, R., Musson, R.M.W., Cooper, R.M., & Jones, S.M., 2003. DTI Strategic Environmental Assessment Area 4 (SEA4): Sub seabed Geology. British Geological Survey Commercial Report CR/03/080.

Holmes, R., & Tappin, D. R., 2005. DTI Strategic Environmental Assessment Area 6, Irish Sea, seabed and surficial geology and processes. British Geological Survey Commissioned Report CR/05/057

Holmes, R., Cooper, R.M., & Jones, S.M., 2003. DTI Strategic Environmental Assessment Area 4 (SEA4): Continental shelf seabed geology and processes. British Geological Survey Commercial Report CR/03/081.

Holmes, R., Et. al., 2004. DTI Strategic Environmental Assessment Area 5 (SEA5): Seabed and superficial geology and processes. Geological Survey Commercial Report CR/03/081.

Joint Nature Conservation Committee, 2007. Geological Conservation Review website http://www.jncc.gov.uk/page-2947 [website accessed 12th February 2007]

Scottish Natural Heritage, 2007. Website accessed 31st January 2007. http://www.snh.org.uk/scottish/ns-un-aa.asp

ScottishGeology.com, 2007. Website accessed 31st January 2007. Resource on regional geology and mapping http://www.scottishgeology.com/

Smith, D.E.,1997. Sea-level change in Scotland during the Devensian and Holocene. *Reflections on the ice age in Scotland.* Gordon, J.E. Glasgow, Scottish Association of Geography Teachers and Scottish Natural Heritage.

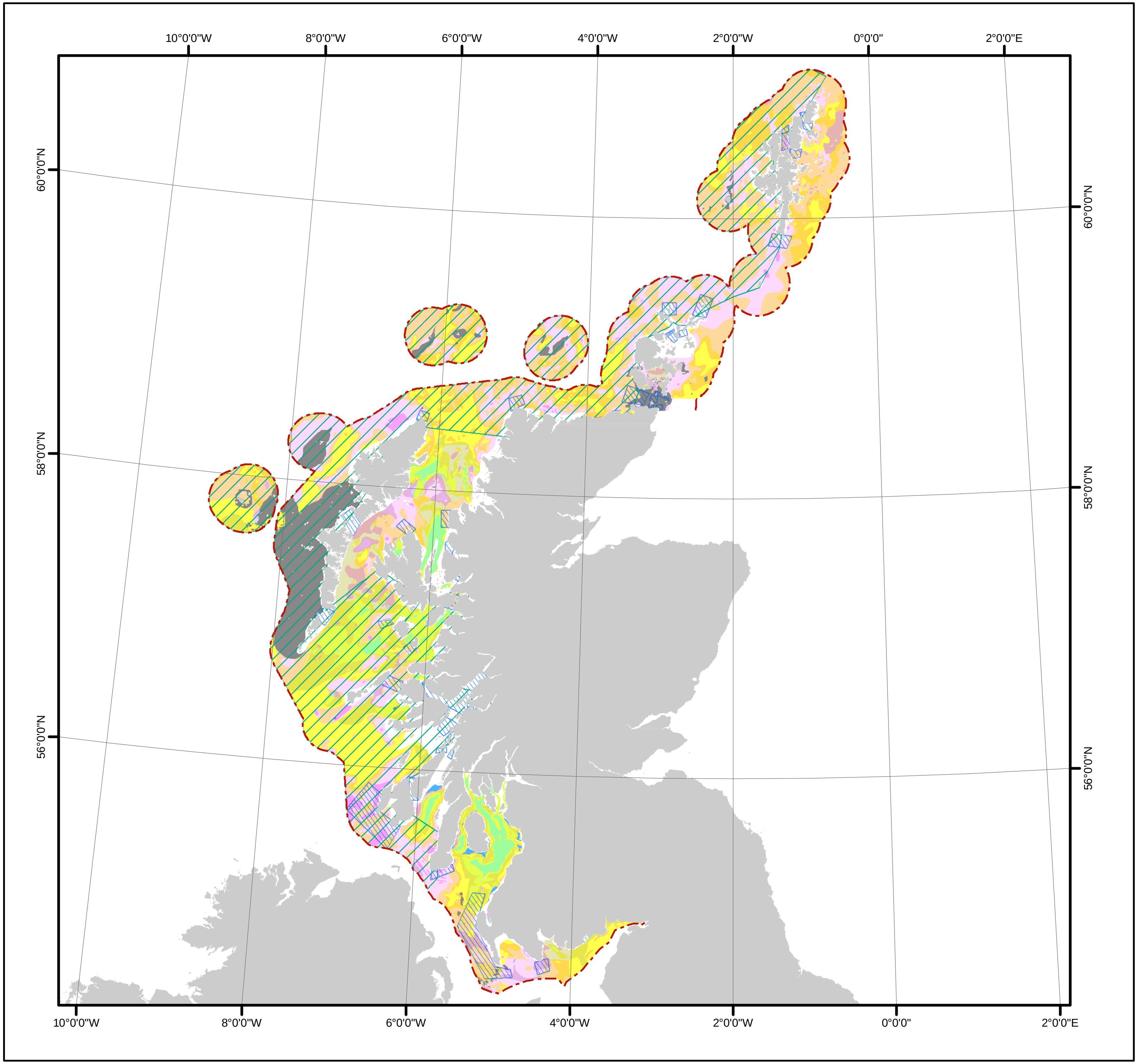
Welsh Assembly Government 2004 / Llywodraeth Cynulliad Cymru, 2004, “The potential nature conservation impacts of energy extraction by marine renewable developments”.

Wingfield, R., The origin of major incisions within the Pleistocene deposits of the North Sea, Marine Geology, vol.91, no.1-2, pp.31-52, Jan 1990

Figures

Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure C2.1: Seabed surface geology



Legend

Potential development area

- Tidal resource
- Wave resource

- Land
- 12 Nautical mile limit (study area only)

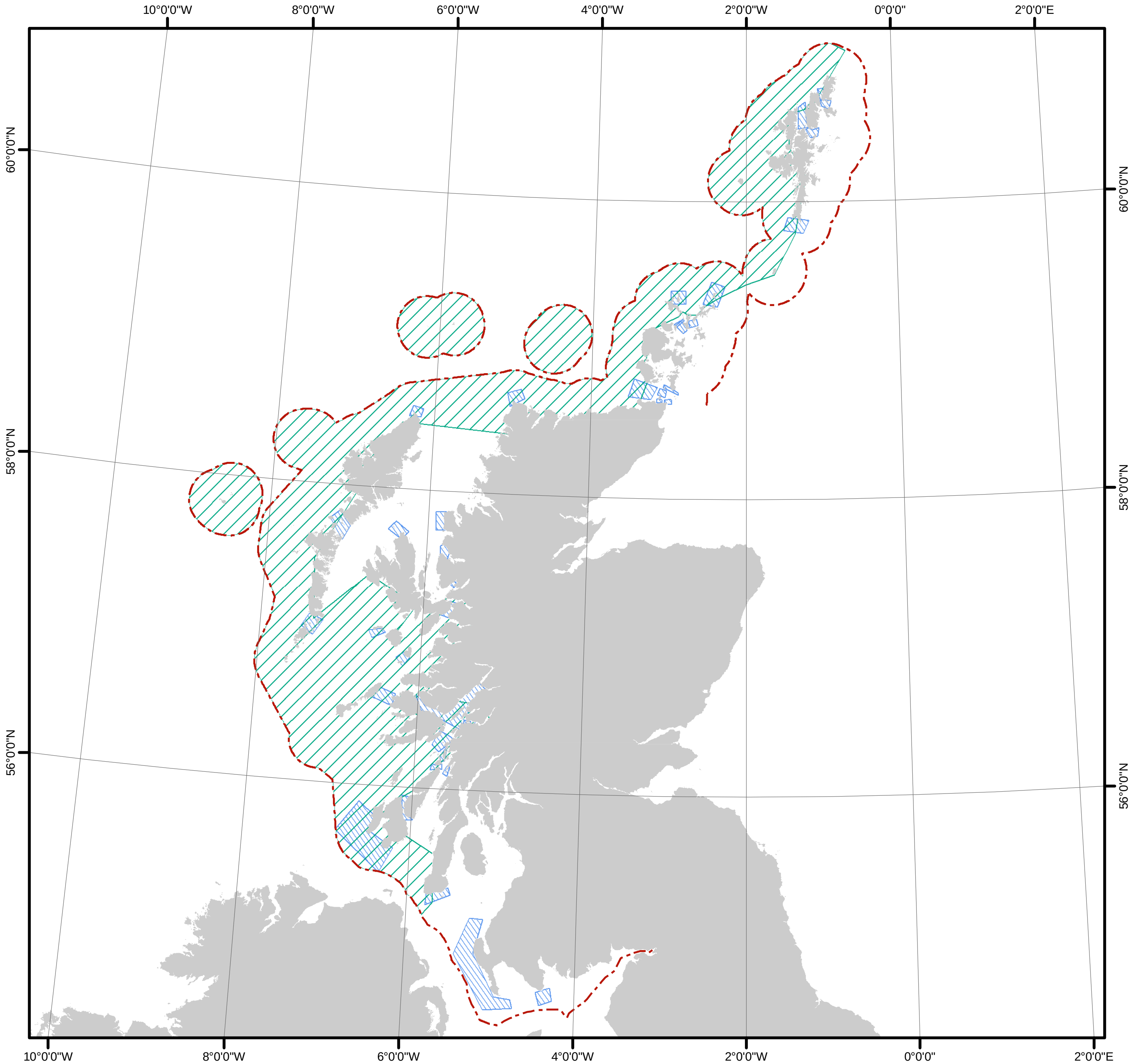
- Mussel deposit
- Gravelly muddy sand
- Gravel, mud and silt
- Gravel
- Gravelly mud
- Gravelly sand
- Muddy gravel
- Muddy sandy gravel
- Mud
- Muddy sand
- Sandy gravel
- Sandy mud
- Slightly gravelly muddy sand
- Slightly gravelly mud
- Slightly gravelly sand
- Slightly gravelly sandy mud
- Sand
- Diamicton
- Rock or Diamicton
- Rock and sediment
- Undifferentiated solid rock
- Clay and sand

Date	12th February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	British Geological Survey, 2005	
File Reference	P736\GIS\Mxd\SEA\Baseline maps	
Checked	SH	GIS Specialist
	FLB	Project Manager

SCOTTISH EXECUTIVE FABER MAUNSELL | AECOM METOC

Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure C2.2: Sediment transport pathways



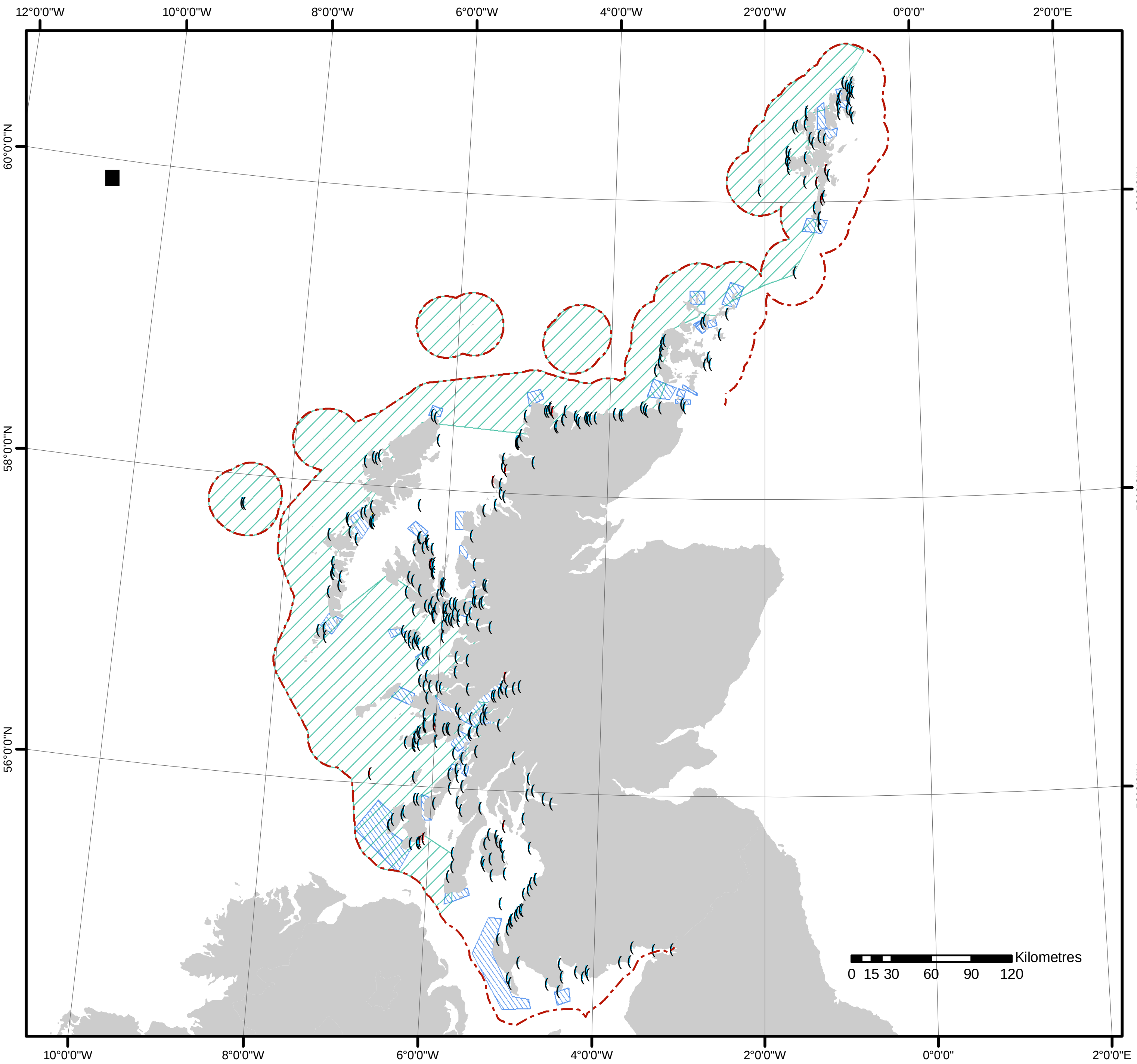
Legend

Potential development area

- Tidal resource
- Wave resource
- sediment transport pathway
- Land
- 12 Nautical mile limit (study area only)

Date	12th February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	DTI Oil and Gas SEA 4, 5 and 7	
File Reference	P736\GIS\Mxd\SEA\Baseline maps	
Checked	SH	GIS Specialist
	FLB	Project Manager

SCOTTISH EXECUTIVE FABER MAUNSELL | AECOM METOC



Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure C2.3a: Distribution of geological review sites (GCRs) in the study area

Legend

12 Nautical mile limit (study area only)

Geological Review Sites (GCRs)

- Confirmed
- Proposed
- Under Review

Potential development area

- Tidal resource
- Wave resource

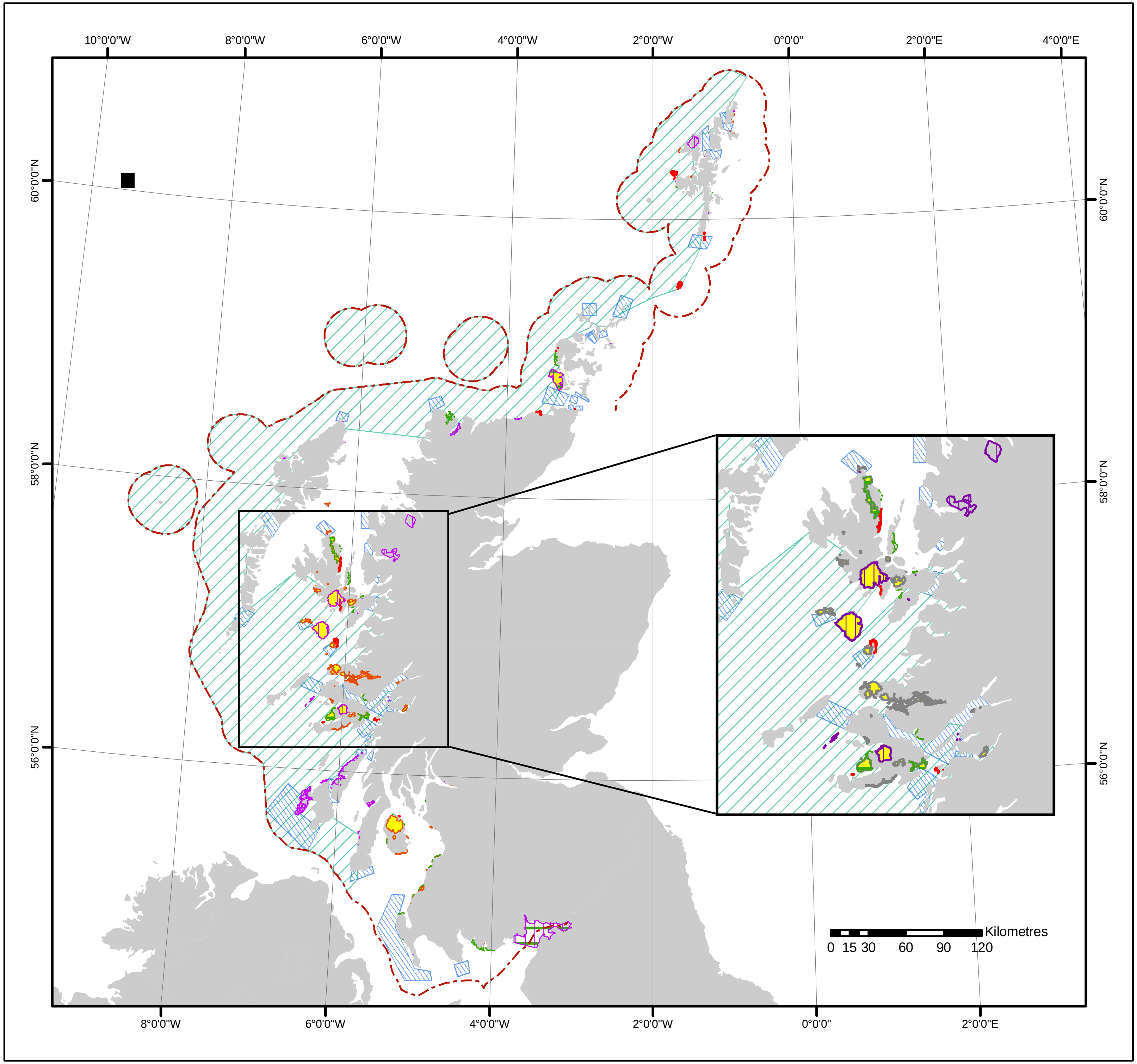
Date	15 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SNH	
File Reference	P736\GIS\MXD\SEA\Baseline maps \C2_3a_geoconservation.mxd	
Checked	JH	GIS Specialist
	FLB	Project Manager

FABER MAUNSELL | AECOM

METOC

Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure C2.3b: Distribution of geological SSSI sites in the study area



Legend

- 12 Nautical mile limit (study area only)
- SSSI (Palaeontology)
- SSSI (Igneous petrology)
- SSSI (Quaternary and geomorphology)
- SSSI (Stratigraphy)

Potential development area

- Tidal resource
- Wave resource

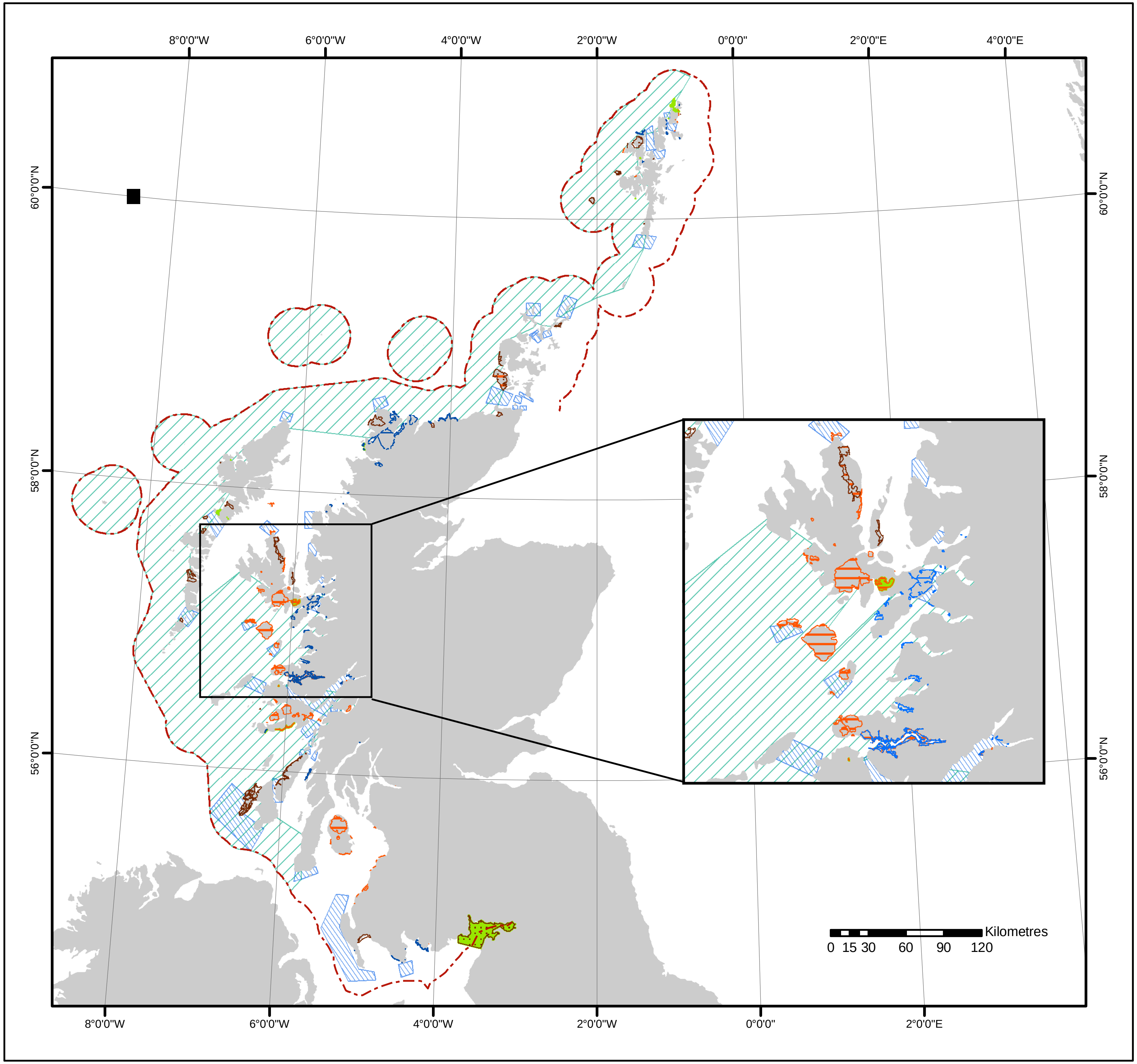
Date	15 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SNH	
File Reference	P736\GIS\MXD\SEA\Baseline maps \C2_3b_geconservation.mxd	
Checked	JH	GIS Specialist
	FLB	Project Manager

FABER MAUNSELL | AECOM

METOC

Scottish Executive Marine Renewables Strategic Environmental Assessment

Figure C2.3c: Distribution of geological SSSI sites in the study area



Legend

- 12 Nautical mile limit (study area only)
- SSSI (Structural and metamorphic)
- SSSI (Igneous petrology)
- SSSI (Mineralogy)
- SSSI (Geomorphology)

Potential development area

- Tidal resource
- Wave resource

Date	15 February 2007	
Projection	Transverse Mercator	
Spheroid	Airy	
Datum	OSGB36	
Data Source	SNH	
File Reference	P736\GIS\MXD\SEA\Baseline maps \C2_3c_geoconservation.mxd	
Checked	JH	GIS Specialist
	FLB	Project Manager

FABER MAUNSELL | AECOM

METOC