Natural Area: M18. Lands End to Minehead	**Geological Significance:** Outstanding **(provisional)**

General geological/Geomorphological character: The Land's End Marine Natural Area contains the greatest number (68) of GCR SILs (single interest localities) of all the MNAs. The coastline is generally rocky in character, with coves and headlands, many of which reach great heights. The solid rocks of the area are almost wholly of Upper Palaeozoic age (400 to 230 Ma). These are mainly folded and faulted slates and sandstones of Devonian and Carboniferous age, with some igneous rocks (mainly granite and basalt).

Onshore Geology / Geomorphology:The rocky coastline provides many sections through complexly deformed Palaeozoic slates and sandstones. These were once sands and muds at the bottom of a marine gulf in Devonian and Carboniferous times. Throughout this period, the gulf narrowed as the continental area at the southern margin of the sea drifted north towards the landmass covering central and north Britain. During the closure, volcanoes became active within the gulf, intruding small igneous bodies into the sediments. Eventually, the two continents collided and the sea bottom sediments and rocks were squeezed and crumpled up to form a land area in which the rock layers were complexly folded and faulted. The collision (known as the Variscan Orogeny) caused rock deep in the Earth to melt and rise up through the deformed rocks, some of which reached the surface as lava. Rock which solidified below-surface formed the granite in the southwest of the MNA. The hot granites heated up groundwaters, which leached out minerals from the granite and sedimentary rocks, concentrating them in mineral-rich brines. These percolated through faults and breaks in the rocks and on cooling, precipitated out tin, copper and lead minerals. The area underlain by the granites has been a land area of considerable relief since the Variscan orogeny. The land area was not glaciated during the last ice ages, but was a periglacial tundra above sea level. Some evidence suggests however that at its maximum extent, the ice covered the Celtic Sea and abutted the north peninsular coast. Deposits of 'head' (slope-slide gravels formed by freeze-thaw action) were created widely during glacial periods. The coastline has moved during eustatic sea-level changes. Raised beaches mark previous inter-glacial periods when the sea-level was higher, and submerged coastlines and drowned mature valleys formed during glacial periods of lower sea level.

Offshore Geology / Geomorphology: Variscan rocks extend offshore to form the bedrock of most of the MNA out to 20 km offshore. The seabed in the outer part of the Bristol Channel is underlain by younger Lower Jurassic mudstones of the Bristol Channel Basin and Oligocene clays of the Stanley Bank Basin deep grabens (fault bounded basins). Lundy is of particular interest because it is the southernmost outcrop of Tertiary (58-60 Ma) igneous rocks. This granite is part of a larger subsurface basic igneous body. Apart from rocky areas around Cape Cornwall and the Camel Estuary, most of the seabed has a covering of Quaternary sediment, primarily sand and gravel. Muddier sediments are found in the Bristol Channel and Barnstaple Bay. Most of the bedforms are modern, mostly sand patches with some areas of sand ridges off the northern parts of the MNA.

Geomorphological Evolution and Processes: Land's End to Hartland Point is a rugged undeveloped, cliffed coastline with stretches of sand beaches separated by rocky foreshores. Many of the beaches are backed by dune systems and are prone to erosion. This part of the coastline is exposed to Atlantic swell and the active beach zone extends to a considerable depth. Waves cause strong seasonal onshore/offshore movements of sediment. From Land's End to Trevose Head there is no evidence of any significant northward drift ie. no areas of accretion linked to littoral transport. Further north to Hartland Point there is a low northward drift, although little interaction between stretches of cliffed coast which separate the major sand beaches. Upton to Gwithian Towans , Cornwall is a 1km stretch of coastline containing an assemblage of dunes in the south which are progressively replaced northwards by rockcliffs, caves, stacks and arches overlain by blown sand and dunes. These erosional features have been exposed as formerly much larger dunes have eroded. Remnants of former dunes are also preserved on stacks. Tintagel cliffs lie on the north Cornish coast near the village of Tintagel and comprises a 10km section of cliffs, caves, arches and stacks. Cliffs and Platforms are cut in Lower Carboniferous and Upper Devonian rocks. The coastal frontage displays slope-over-wall forms, some bevelled and some forming hog's-backs. Normal faults have had considerable influence on cliff forms. South of Tintagel island, some short stretches of cliffline are true fault-line cliffs. North of the island, the coastline is more complex, with many inlets and headlands. Erosion along normal faults, less resistant beds and joint planes has produced an intricate set of bays, headlands, stacks, blowholes and caves. Marsland to Clovelly coast includes the geomorphologically important site of Hartland's Quay which contains examples of hog's back cliffs and shore platforms. Also found at this site are former river valley's which have been truncated by retreat of the cliff-line, so that their floors now lie well above present sea-level. unlike similarly truncated streams on the Isle of Wight, those in Hartland Quay area have been unable to erode valleys to sea-level and so reach the shore via waterfalls.

North of Hartland Point to Morte Point lies a complex of coastal and estuarine features including, the pebble ridge of Westward Ho! enclosing saltmarsh, and the massive sand dune system of Braunton Burrows which encloses saltmarsh on the estuaries north shore. Braunton Burrows stretches for some 5km and is one of the three largest dune systems on the west coast of Britain and one of the least affected by underlying geology and afforestation. In the central area, where the dune structure is best developed, the Burrows consist of three ridges, separated by slacks. The ridges lie parallel to the shore and to each other, with an overall width of about 1.3km. (The highest dune up to 30m high). Barnstaple Bay forms a distinct cell, but the smaller bays of Croyde and Morte, which are separated by large promontories can also be considered as independant units. There is low eastward drift from Hartlands Point to Westward Ho! with little nett drift occurring elsewhere in this section. Sand circulation in the mouth of the Taw-Torridge estuary is very complex and not well understood. The island of Lundy [MNR] outcrops approximately 28km off Morte Point. East of Mort Point a 'hard' coastline of sandstone and shale cliffs back shingle beaches strewn with boulders to Minehead. Low, strongly unidirectional, eastward drift of sand and shingle extends to Minehead and beyond.

Key geological features:

- Devonian sediments and associated fossil fauna, deformed by the Variscan Orogeny.
- Igneous rocks, particularly around Lands End.
- Minerals sites, particularly related to the granites.
- Coastal erosion features - arches, stacks, hanging valleys etc.

Number of GCR sites:

Variscan Structures of SW England: 17 Marine Devonian: 13 Igneous Rocks of SW England: 11
Mineralogy of SW England: 8 Pleistocene/Quaternary of SW England: 8
Coastal Geomorphology of England: 5 Silurian - Devonian Chordata: 2 Caves: 1
Dinantian of S. England/Wales: 1 Namurian: 1 Non-marine Devonian: 1

Geological/geomorphological SSSI coverage: There are 32 coastal (P)SSSIs in the MNA containing 68 GCR SILs representing 11 different GCR networks. These are predominantly related to the solid geology and the story of the ancient marine gulf which closed during the Variscan Orogeny, and related evidence of the accompanying mountain building episode. An example of the marine sediments laid down in the Devonian is at Harbour Cove SSSI, while similarly aged sediments at Bedruthan Steps contain an important early fossil fish fauna. The igneous rocks of the basin and the Variscan deformation of the igneous and sedimentary rocks is at Tintagel Cliffs SSSI. The granites of the Cornubian batholith are shown for example at Carrick Du to Clodgy Point GCR site, whilst the related mineralisation can be seen e.g. at Botallack Mine to Wheal Owles GCR site. The Periglacial environment during the glacial stages of the Ice Ages are represented for example by the Valley of the Rocks GCR site. Braunton Burrows SSSI is one of the largest dune systems in Britain and also one of the best known. It's diversity of form and relief and cartographic records has made it a significant site for geomorphological research. Napp's Cave SSSI, Devon has an entrance in an old quarry. The cave is of prime importance for the aragonite crystals whose size and abundance make them unique to Britain. Crystals up to 70mm in length occur in radiating clusters and those in the inner chambers are in a perfect state of preservation.

Key geological management issues:

- Maintain Natural Processes.
- Maintain integrity of landforms eg. Dune ridges.
- Clearance of mineral spoil tips with their rare minerals and habitats as derelict land.
- Offshore mineral dredging for tin and sand/gravel with alterations to bedforms and seabed.
- Mineral collecting, and resultant damage to / pollution of the marine environment.

Key geological objectives:

1. **Maintain and where possible enhance the natural processes** and existing geological and geomorphological features through a) the inclusion of coastal defence and flood defence schemes within estuarine and shoreline management plans and b) placeing restrictions on other potentially damaging activities such as dredging, afforestation etc.

2. **Maintain integrity of dune systems and other landforms:** any operation which causes or leads to modification of the landforms should be opposed eg. military manoeuvers, sand extraction, recreational activities.

3. **Encourage initiatives** aimed at the joint management and promotion of the MNA's geological and biological resources eg. in offshore areas such as Lundy Island MNR.

Useful guides/references:

EVANS, C.D.R. (1990): The geology of the western English Channel and its western approaches. BGS UK Offshore Regional Report.

FLOYD, P.A., EXLEY, C.S. & STYLES, M.T. (1993): Igneous Rocks of Southwest England JNCC GCR Series Volume 5; Chapman & Hall, London.

STEERS, J.A. (1964): The Coastline of England and Wales (2nd Edition) Cambridge University Press.

TAPPIN, D. R., CHADWICK, R. A., JACKSON, A.A., WINGFIELD, R.T.R. & SMITH, N.J.P. (1994) The geology of Cardigan Bay and the Bristol Channel. BGS UK Offshore Regional Report.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- Ayres Point to Carrick Du
- Bedruthan Steps and Park Head
- Boscastle to Widemouth
- Boscawen
- Bude Coast
- Cameron Quarry
- Cligga Head
- Godrevy Head to St. Agnes
- Gwithian to Mexico Towans
- Harbour Cove
- Penhale Dunes
- Pentire Peninsula
- Rock Dunes
- St. Agnes Beacon Pits
- Stepper Point
- Tintagel Cliffs
- Treberthick Point
- Trevaunance Cove
- Trevone Bay
- Trevose Head and Constantine Bay
- Barricane Beach
- Braunton Burrows
- Fremington Quay Cliffs
- Hele and Sandy Bays
- Marsland to Clovelly Coast
- Mill Rock
- Napp's Cave
- Northam Burrows
- Saunton to Baggy Point
- Watersmeet
- WestExmoor Coast and Woods
- Westward Ho! Cliffs
- Glenthorne

Maritime Natural Area: M19. Minehead to Brean Down	**Geological Significance:** Considerable **(provisional)**

General geological /geomorphological character: The Minehead to Brean Down Maritime Natural Area forms the southern cliffed coastline of the Bristol Channel.

Geological History: The solid geology of the Maritime Natural Area is dominated by rocks of Triassic and Jurassic age. The Triassic rocks, formed around 240 Ma, were deposited in an arid environment and consist primarily of Keuper Marls (now known as the Mercia Mudstone Group). The Mercia Mudstones are silty clays variously interpreted as the product of deposition in ephemeral lakes, in an inland sea or saline lake. These marls are overlain by marine rocks of the Lower Jurassic Lias Group (208-187 Ma).

Quaternary History: Southern parts of the Maritime Natural Area are dominated by a sequence of Quaternary deposits consisting of alluvium, peats and marine clays. The origins of these deposits is the changing sea levels and climate over the last 2 million years. Marine clays formed at times of relatively high sea level such as interglacials, and peats formed at times of relatively low sea level. The area was also affected by the Anglian glaciation (around 300,000 years BP) when a large ice sheet advanced into the area from the Irish Sea basin. This deposited layers of glacial sands, clays and gravels across the area and also impounded a large glacial lake which is associated with lacustrine clays. At times of cold climate when precipitation was not sufficient to support ice sheets, the area was affected by periglacial processes, and layers of head (such as that exposed in the cliffs at Brean Down) formed due to frost weathering.

Geomorphological Evolution and Processes: The southern coastline of the Bristol Channel is characterised by cliffs rising to a maximum of 84 metres AOD, and fronted by a well-developed series of inter-tidal platforms varying in width from 120 metres to over 500 metres. The platforms are partially covered by shingle, sand and mud and, reflect in detail the variable resistance to erosion of the Mercia Mudstones, Penarth Group and Lower Lias bedrock. A key feature of the platforms is their development in a macro-tidal environment and their different exposure from narrower platforms in similar rocks, on the northern side of the Bristol Channel. Near -vertical cliffs rising eastwards to Blue Anchor Point give way to higher cliffs which are affected greatly by many small landslips. They fall steadily towards sea-level at Watchet, beyond this to Brean Down is low-lying land. A hanging valley has been truncated at ST057434, and is left hanging about 25 metres above the base of the cliffline. Differential erosion is a dominant factor when considering the coastlines general form and detailed features and parts of the platform warrant the description of "washboard-relief" (this refers to the micro-relief created due to the process of marine planatation cutting across the outcrop). The alignment of this coastline has little relationship to the direction of wave attack from the Atlantic. There is a low, strong unidirectional, eastward drift (of both sand and shingle), extending to Bridgwater Bay where mud accretion occurs. Storm surges at high spring tides can produce over-topping at Minehead, Watchet and Brean, as well as low-lying coast east of Hinkley Point. The coastal regime in Bridgwater Bay itself is affected by tidal currents. The upper beach however is dominated by wave action and windblown sand is also an important factor on west-facing beaches from Burnham-on-Sea.

Key geological/geomorphological features:

- Coastal exposures of Rhaetian and Hettangian-Pliensbachian rocks.
- The dominance of differential erosion producing the general form of the coastline.
- Well-developed inter-tidal platforms up to 500 metres in width in places and examples of "washboard relief".

Number of GCR sites:

Rhaetian: 2 Hettangian- Pliensbachian: 1 Coastal Geomorphology of England: 1
Pleistocene/ Quaternary of Somerset: 2 Pleistocene Vertebrata: 1

Geological/geomorphological SSSI coverage: There are 2 coastal (P)SSSIs in this Maritime Natural Area containing 7 GCR SILs representing 5 different GCR networks. Apart from its considerable geological importance (for Lower Lias strata), Blue Anchor to Lilstock Coast SSSI is important geomorphologically for its examples of variations in the micro-relief of shore platforms, developed in a macro-tidal environment. In particular it has one of the best examples of "washboard" relief on the British coast.

Key geological/geomorphological management issues:

- Management of the Palaeontological resource
- Minimise interruption to sediment movement along the coast in such places as the west-facing beaches from Burnham-on-Sea, that rely on wind blown sand.

Key geological/geomorphological objectives:

1. **Maintain natural marine and littoral processes** through a) the erection of coast protection works, including cliff or landslip drainage or stabilisation measures must refer to Shoreline Management Plans.

2. **Maintain integrity of Geological resource** by examining restrictions on mineral extraction .

3. **Encourage responsible fossil collecting.**

Useful guides/references:

WHITTAKER, A. & GREEN, G.W. 1983: Geology of the country around Weston-super-Mare. Memoir for sheet 279 with parts of 263 and 295, New Series, Institute of Geological Sciences, NERC.

TAPPIN, D.R. *et al.* 1994: The geology of Cardigan Bay and the Bristol Channel. British Geological Survey, United Kingdom Offshore Regional Report. London. HMSO.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- Blue Anchor to Lilstock Coast
- Brean Down

Maritime Natural Area: M20 Brean Down to Southern Welsh Border	**Geological Significance:** Notable (provisional)

General geological /geomorphological character: The Brean Down to Southern Welsh Border Maritime Natural Area constitutes the north-facing coastline of the Severn Estuary. Geological exposures in the cliffs of the area show the limestones of the Carboniferous, formed in shallow tropical seas with abundant life now preserved as fossils, through the barren red beds of the Triassic when a desert covered the area, through to the marine limestones and shales of the Jurassic.

Geological History: The solid geology of the Natural Area is dominated by rocks of Jurassic, Triassic and Carboniferous age. The oldest of these rocks are those of the Devonian Old Red Sandstone, which are poorly exposed other than around the Portishead area. They consist of quartz-rich non-marine sandstones, often containing the remains of fossil fish. The Lower Carboniferous rocks (Dinantian, 350-333million years ago) are predominantly limestones which form easterly trending ridges across the area. They are truncated at the coast around Spring Cove. Around Middle Hope, the limestones display evidence of volcanic activity in the form of layers of vocanic lava and tuffs. The Triassic rocks, formed around 240 million years ago, were deposited in an arid environment and consist primarily of Keuper Marls (now known as the Mercia Mudstone Group). The Keuper Marl is a silty clay variously interpreted as the product of deposition in ephemeral lakes, in an inland sea or saline lake. Above the Mercia Mudstones is the Penarth Group ("Rhaetic"), consisting of limestones and mudstones. The Triassic rocks are overlain by marine rocks of Jurassic age (208-187 million years ago) belonging to the Lias Group.

Quaternary History: Southern parts of the Natural Area are dominated by a sequence of Quaternary deposits consisting of alluvium, peats and marine clays. The origins of these deposits is the changing sea levels and climate over the last 2 million years. Marine clays formed at times of relatively high sea level such as interglacials and peats formed at times of relatively low sea level. The area was also affected by the Anglian glaciation (around 300,000 years before present) when a large ice sheet advanced into the area fro the Irish Sea basin. This deposited layers of glacial sands, clays and gravels across the area and also impounded a large glacial lake which is associated with lacustrine clays. At times of cold climate when precipitation was not sufficient to support ice sheets the area was affected by periglacial processes, and layers of head (such as that exposed in the cliffs at Brean Down) formed due to frost weathering.

Geomorphological Evolution and Processes: Most of this coastline lies below the high water of springtides and is therefore very vulnerable to flooding. Mud flats and salt marshes front an alluvial backshore with some higher ground of easily eroded sandstone and limestone between Clevedon and Portishead and again at Aust (Severn Bridge). The headlands at Brean, Weston and Sandbay make the intervening bays independant units and wind blown sand is an important factor on west-facing beaches to the northend of Sandbay. There is no appreciable drift along this stretch of coastline but the Severn Estuary is subject to a great tidal range and also to fairly strong currents. Tidal currents dominate movements in the estuary but appear to have little coastal impact. The tidal currents carry a high percentage of fine sediment in suspension, with much of the sedimentation taking place in Bridgwater Bay. Wave heights are relatively modest, being generated within the estuary and have very little penetration of Atlantic swell. However high tide levels combined with surges leads to flooding of surrounding low-lying land.

Key geological features:

- Coastal geological exposures of Devonian, Triassic and Jurassic rocks and fossils
- Morphology of the Severn Estuary, including large tidal range

Number of GCR sites:

Dinantian of South England and Wales: 2 Permian-Carboniferous Igneous: 1 Non-marine Devonian: 1
Pleistocene/Quaternary of Somerset: 1 Mineralogy of the Mendips: 1 Westphalian: 1
Silurian-Devonian Chordata: 1 Varsican Structures of South Wales and Mendips: 1 Rhaetian: 1
Paleoentomology: 1 Permian-Triassic: 1 Permian-Triassic Reptilia: 1

Geological/geomorphological SSSI coverage: There are 5 coastal (P)SSSIs in the Maritime Natural Area, covering 13 GCR SILs representing 12 different GCR networks and showing the geological diversity of the area. Portishead Pier to Black Nore SSSI shows exposures of the Carboniferous sandstones (Westphalian) and of the important non-marine Devonian rocks. The Old Red Sandstone at this site is noted for the remains of fossil fish, and the rocks are also strongly folded by the Variscan Earth movements. Aust Cliff SSSI is an important stratigraphical site, showing the sequence of Triassic rocks from Mercia Mudstones through to the Penarth Group. Spring Cove Cliffs SSSI shows the Lower Carboniferous (Dinantian) limestones and the lavas and tuffs which were erupted into them during deposition.

Key geological management issues:

- Threats to coastal geological sites from coast protection works and/or cliff drainage schemes
- Management of the palaeontological resource and need to ensure responsible fossil collecting from sensitive or vulnerable coastal sites.

Key geological objectives:

1. Maintain marine and littoral processes by a) ensuring that all coast protection works are part of an agreed Shoreline Management Plan

2. Maintain and enhance Palaeolontological resource by a) Ensuring responsible fossil collecting at sensitive or vulnerable sites and through b) on-site interpretation.

Useful guides/references:

MACFADYEN, W.A. 1970. Geological Highlights of the West Country. London, Butterworths.

WHITTAKER, A. AND GREEN, G.W. 1983. Geology of the country around Weston-super-Mere. Memoir of the Geological Survey of Great Britain. Sheet 279.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- Spring Cove Cliffs
- Middle Hope
- Clevedon Shore
- Portishead Pier to Black Nore
- Aust Cliff

Natural Area: M21. Northern Welsh Border to Rossall Point, Fleetwood	**Geological Significance:** Notable **(provisional)**

General geological character: The Northern Welsh Border to Rossall Point, Fleetwood Maritime Natural Area is a low lying coastal zone much developed by man containing the two major estuaries of the Dee and the Mersey.

Geological History: The underlying solid geology of the Maritime Natural Area is dominated by rocks of Triassic age (around 240 million years old), although these are generally masked by overlying deposits of Quaternary age (the last 2 million years: see below). The Triassic Period was dominated by continental deposition in an arid desert-like climate. It comprises two Groups; 1. the Sherwood Sandstone Group (including the Kinnerton Sandstone, Chester Pebble Beds and Wilmslow Sandstone Formations) which was dominantly fluvial (braided river) in origin and 2. the Mercia Mudstone Group (including the Tarporley Siltstone Formation) which is interpreted as becoming increasing intertidal in influence. Elsewhere Sherwood Sandstone rocks have yielded ealry reptile remains (skeletal and trace fossil), and recent footprint dicoveries at Hilbre Island confirm the potential these rocks have for such finds. No younger Mesozoic or Tertiary rocks are known and it is likely that the area was a positive feature during the succeeding period.

Quaternary History: The Triassic sequence underwent extreme denudation during the Quaternary when the area was glaciated an unknown number of times by ice sheets advancing southwards down the Irish Sea. Much of the low lying area is covered in glacial clays, sands and gravels (known collectively as "boulder clay") with erratics clearly originating from the Lake District and the Southern Uplands. Following the last glaciation rivers such as the Dee and the Mersey have adjusted their courses in response to fluctuating sea levels. Changes in sea level are also recorded in the sequence of marine clays and terrestrial peats found along the low-lyimg coast, for example at Lytham.

Geomorphological Evolution and Processes: Within this Natural Area are two major estuaries: The Dee and The Mersey. The Dee Estuary is macrotidal and lies between the Wirral Peninsula and the North Wales coast. It is a funnel-shaped feature, formed during the last glaciation. Approximately 80% of the estuary is composed of intertidal sand and mud flats, and extensive saltmarshes have developed at the head and on the English side of the estuary where low energy conditions allow the deposition of fine grained sediment. The Dee has asymmetric diurnal tides, the flood tide rising faster than the ebb falls. Tidally induced currents are primarily responsible for sediment entrainment and transport in the estuary. It ap[pears that the estuary is approaching a dynamic equilibrium or has a sediment surplus, since the saltmarsh area on the English side continues to accrete seaward. The Mersey Estuary is again a macro tidal estuary located on the border of the undulating Lancashire Lowlands and the relatively flat Cheshire plain. Extensive saltmarshes, sand and mudflats comprise 62% of the entire area of the estuary. Ther Mersey estuary experiences a large tidal range. Shelter provided by the Isle Of Man means that the wave conditions experienced in the outer estuary are mainly fetch limited. A positive sediment budget (i.e. higher levels of sediment coming into the estuarine environment than being lost from the system) and the relatively sheltered nature of the inner estuary has allowed salt marshes to adjust to a slowly rising relative sea level.

Although much of the shoreline is undergoing erosion there are relatively stable bar features in the intertidal zone. The series of intertidal ridges and runnels run obliquely away from the shore to the north, and are generally more pronounced in the summer months than in the winter when the foreshore adopts a more planar characteristic. The dunes and foreshore at Ainsdale form part of a larger dune barrier complex which extends from Crosby to Southport. The complex forms a natural barrier which prevents marine flooding of low-lying agricultural land in West Lancashire and north Merseyside.

Key geological/geomorphological features:

- Quaternary sediments with records of recent sea level changes.
- Two large estuarine environments: The Dee and The Mersey.
- The large dune barrier comples extending from Crosby to Southport (including Ainsdale).

Number of GCR sites:

Permian-Triassic: 1 Holocene sea level: 1 Coastal Geomorphology of England: 1
Pleistocene/Quaternary of the Pennines and Adjacent Areas: 1

Geological/geomorphological SSSI coverage: There are 4 coastal (P)SSSIs in the MNA containing 4 GCR SILs representing 4 different GCR networks. The Dungeon SSSI shows a section through the Tarporley Siltstone Formation of the Mercia Mudstone Group, and its faulted contact with the Wilmslow Sandstone Formation. At Dee Cliffs SSSI the nature of the Quaternary glacial deposits are shown, including well-known glacial depositional and deformational structures.Further north on the coast the (P)SSSI coverage includes one site with a Holocene sea-level change record, Lytham Coastal Changes SSSI, where terrestrial peats and marine silts provide details of sea level change over the last 10,000 years. Finally, Ainsdale Sand Dunes SSSI is an important site for coastal geomorphology with regard to the large sand dunes and multiple sand bars that occur on the foreshore.

Key geological management issues:

- Coastal defence schemes pose a threat to the sites by (i) affecting sediment transport, (ii) fixing the coastline and causing "coastal squeeze", and (iii) affecting sensitive geological exposures.
- Need to promote effective dune management.
- Threat to limited geological resource by inappropriate development.

Key geological objectives:

1. Maintain the integrity of geological and geomorphological features by a) ensuring all remaining sites are adequately documented and, if appropriate, protected as RIGS.

2. Maintain marine and littoral processes by ensuring coastal defence proposals are part of an agreed Shoreline Management Plan.

3. Utilise the area as an educational resource: Gain a deeper understanding of such coastal sedimentary systems as Ainsdale, to aid prediction of likely effects of a sea-level rise.

Useful guides/references:

EDWARDS, W & TROTTER, F.M. 1954: The Pennines and adjacent areas, British Regional Geology, Institute of Geological Sciences. HMSO.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- The Dungeon
- Dee Cliffs
- Ainsdale Sand Dunes
- Lytham Coastal Changes

Natural Area: **M22. Rossall Point, Fleetwood to Walney Island (mid point)**	**Geological Significance:** Some **(provisional)**

General geological character: The Rossall Point, Fleetwood to Walney Island Maritime Natural Area is generally a low lying coastal zone with a large estuary area. Much of the solid geology is concealed by glacial clays, sands and gravels ('Boulder Clay'). This underlying geology comprises a sequence of Carboniferous limestones and sandstones (c. 350-320 Ma) overlain by Triassic (c. 240 Ma) red beds belonging to the Sherwood Sandstone Group (St Bees Sandstone) and the Mercia Mudstone Group. The Carboniferous Period was initially marine depositing the limestones which today dominate the Furness Headland and the northern part of Morecambe Bay. Towards the end of the Carboniferous extensive deltas encroached the area depositing sandstones such as the Millstone Grit. The Triassic is dominated by continental red beds, the Sherwood Sandstone Group being largely fluvial in origin, the Mercia Mudstone Group being more typically estuarine to lagoonal. Salt deposits in the Mercia Mudstone Group, the result of evaporation in the arid Triassic climate, are found under Walney Island and at one time formed the basis of a small salt industry. Post Triassic folding and faulting affects the sequence on both sides of Morecambe Bay, in particular, the Haverigg Fault which can be traced across the mouth of the Bay. During the Pleistocene the area was glaciated during the late Devensian leaving a thick boulder clay cover particularly on Walney Island. Remaining evidence of earlier glaciations is scant but the area was certainly glaciated on more than one occasion. Raised bogs on Morecambe Bay estuaries provide evidence of fluctuating sea levels since the last glaciation.

Geomorphological Evolution and processes: This Maritime Natural Area covers a large estuary area encompassing Morecambe Bay. Morecambe Bay has vast expanses of inter-tidal sand flats, with areas of saltmarsh at the head of the Bay, and in the Lune Estuary there are extensive mudflats as well as saltmarsh. The Bay acts as a sediment sink for sands and silts, but the low-lying land bordering it is still prone to flooding. The western margin of the Bay has low clay cliffs separated by stretches of low-lying land. Erosion of glacial material there, forms mounds of pebbles, called scars, on the upper foreshore. There is a moderate northerly littoral drift between Sunderland Point and Heysham. Elsewhere the drift is low and generally insignificant. Movement on intertidal banks is dominated by tidal currents although waves do have some effect, penetrating via a deep water channel called Lune Deep into Morecombe Bay. Surges significantly increase the flood risk, particularly associated with very strong westerly or south-westerly winds. Walney Island, lies north of Morecambe Bay and is about eight miles in length. It is narrow and extends both northwards and southwards by a series of recurved shingle ridges. Walney Island acts as a breakwater for Barrow-in-Furness. The seaward side of the island is comparatively straight and simple in outline but the landward side is diversified by numerous bays and marshes. Erosion is high on this western side. High wave and tidal energies are responsible for the erosion and redistribution of till sands and gravels and the movement on-shore, of large quantities of fluvio-glacial origin sand from the off-shore zone of Morecambe Bay and adjacent parts of the Irish Sea. Considerable longshore drift is created by refraction of waves from the south-east and north-east by the shallow zones around south and north Walney. This has led to development of the distal spit features.

Key geological/geomorphological features:

- South Walney represents one of the distal features of a barrier island.
- The presence of scars on many of the western upper foreshores: cretaed by the erosion of glacial material forming mounds of pebbles.
- Carboniferous limestones and sandstones
- Triassic red beds
- Post Triassic faulting
- Late Devensian boulder clays

Number of GCR sites:

Pollen Stratigraphy of England: 1 Coastal Geomorphology of England: 1

Geological/geomorphological SSSI coverage: There are 2 coastal (P)SSSIs in the Maritime Natural Area containing 2 GCR SILs representing 2 different GCR networks. The site coverage includes a single coastal landform, Walney Island and also Hawes water notified for Pollen Stratigraphy of England. The sites at Walney Island are important in their own right for the study of geomorphological process and forms and for comparison with other barrier island type features. South Walney's geomorphological boundary is limited to the beach and foreshore extending from Hilock Whins to the spit end at South End Haws.

Key geological/geomorphological management issues:

- Coastal defence and other man-made operations damaging coastal processes such as the cliff section directly to the north of the south Walney boundary, which is currently providing a source of material for the accreting bar now developing on south Walney.
- Minimise human effects on delicate coastal systems.

Key geological/geomorphological objectives:

1. Maintain marine and littoral processes through a) consulting Shoreline Mangement Plans for applications to defend areas, immediately adjacent to SSSI sites in particular

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2. Maintain integrity of geological and geomorphological sites by a) any proposal for a landfill site should not be allowed and b) no new sea defence structures should be permitted within the SSSI's.

Useful guides/references:

EDWARDS, W. & TROTTER, F.M. 1954: The Pennines and adjacent area, British Regional Geology, Institute of Geological Sciences. HMSO.

ROSE, W.C.C. & DUNHAM, K.C., 1977: Geology and hematite deposits of South Cumbria. Memoir of the Geological Survey of Great Britain, England and Wales (Sheets 58 and 48)

TAYLOR B.J.*et al*, 1971: Northern England, British Regional Geology, Institute of Geological Sciences. HMSO.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- South Walney & Piel Channel Flats
- Hawes Water

Natural Area: M23. Walney Island (Midpoint) to Maryport	Geological Significance: Some (provisional)

General Geological Character : The Walney Island (midpoint) to Maryport Maritime Natural Area comprises the flat west Cumbrian coastal strip between the Solway Firth and Morecambe Bay. Apart from the rocky cliffs around Whitehaven and St. Bees, the coast is flat-lying, with little or no bedrock exposed.

Onshore Geology: The rocks range from Ordovician to Triassic in age (480-200 million years ago), although the Ordovician rocks only reach the coast in the Esk and Duddon estuaries, which cut back into the uplands behind the coastal plain. Glacial and recent drift deposits dominate the coastal and offshore geology.

The Ordovician and Silurian rocks of the Lake District form a core around which younger Carboniferous to Triassic age rocks are draped. The Lake District rocks - slates, limestones, sandstones, granites and volcanic lavas and ashes were formed in and around an ancient volcanic Island Arc, rather like present day Japan. On top of these ancient rocks lie Carboniferous rocks which show how the environment changed from a tropical coral sea covering the old arc, to coastal rivers and coal swamps as the land rose once more above the sea. Limestones formed in the tropical sea form bedrock around the Duddon Estuary, but underlie much of the area below the surface. Sandstones and coals of the Late Carboniferous swamps are exposed occasionally along the coast between Maryport and St. Bees Head. Spoil tips from working the coal also form characteristic features on this coastal stretch. From Saltom Bay around St. Bees Head, the rocks are a sequence showing the changes from swampy river conditions through an inland salt sea (Magnesian Limestone and shales) to a desert (red St. Bees Sandstone). South of this headland, there are no solid rock outcrops, but the area is underlain by Triassic sandstones and mudstones. The coast north of St. Bees Head is mainly coated by Pleistocene ('Ice Age') tills which underlie most of the beach deposits. The drift deposits are coarse and pebbly north of Workington, with raised beaches and fossil dune systems in parts. Between Workington and Whitehaven, these form low cliffs. Low glacial till cliffs are cut by river mouths at the Esk estuary and the Duddon, with their sandy spits and banks (eg. Sandscale). The Duddon estuary is formed in a down-faulted block in the solid rock, partly filled by glacial deposits.

Offshore Geology: The offshore solid geology of the area is relatively simple. Most of the MNA is underlain by Permian and Triassic mudstones and sandstones. Exceptions are two areas of older Carboniferous rocks (coal measure sandstones between Maryport and Workington, and limestones at the mouth of the Duddon Estuary) and Silurian slates beneath the inner Duddon Estuary. The recent and unconsolidated sediments are primarily muds and sands. These lie on top of deep glacial-till filled channels formed by ice scouring. Between Workington and Barrow, the sea bed sediment is predominantly muddy, but close inshore, between Seascale and Barrow, and in a small patch off Whitehaven, recent sandy sediments predominate.

Geomorphological Evolution and processes: The foreshore south of Maryport to St. Bees Head is characterised by boulders, often of considerable size and wieght, with limited sand and shingle which typifies the coastline updrift from Maryport. The beaches rest on boulder clay, with occasional outcrops of solid rock, for example the reefs of St. Bees sandstone. From Maryport to Whitehaven the coast is heavily industrialised, with coal mines occuring close to or on the coast. Slag and shale from the collieries and steel works has previously been dumped on the shore, forming cliffs and reclaimed beaches at Whitehaven, Workington and Maryport. These are now eroding following industrial decline in this area. St. Bees Head forms the only hard cliff coastline in the area; rocky cliffs reaching 100m in height, with a wave-cut platform below. The cliffs of St. Bees Head mark an important divide in the direction of coastal drift. A moderate northward wave induced littoral transport to the north, and a weak southern littoral drift just south of Bees Head with variability in direction further along the coast. South of St. Bees Head wide sandy beaches are backed in places by pebble storm ridges (Walney Island, between Whitbeck and Ravenglass and intermittently between Seascale and St. Bees), and low clay cliffs. For several miles down to Drigg the coast is almost straight and without pronounced features. Cliffs are low and cut into glacial material. The whole coastline from St. Bees Head to Walney Island is a relatively open stretch of 'soft' coastline with a number of rivers and estuaries. These estuaries are sinks for sediment, with tidal currents aiding, the transport of material into the estuary mouths and the process of infilling. This is particularly well illustrated at Ravenglass and the confluence of the rivers Irt, Mite and Esk. The soft glacial cliffs and the more recent deposits of sand and shingle are subject to long term erosion by wave action. Wind action is also important, controlling the development of dune systems eg. Haverigg Point and Ravenglass, and Drigg and Eskmeals spit are mostly

covered by dunes as well. On Drigg the dunes reach a width of about ½ mile. Walney Island was formed from a glacial till bank which has been modified by longshore drift to a barrier island, with shingle beaches and spits on the outside and marshy bays and tombolo on the inner side.Natural erosion at North Walney is quite serious. It is in the form of blowouts. The prevailing wind erodes a depression through the dunes and continues to sweep out a channel, completely denuding the sand of vegetation, endangering the island from fragmentation.

Key geological features:

- Cliff exposures of Carboniferous and Permian sediments around St. Bees Head.
- Estuarine geomorphological features and the processes which form them (eg. Duddon Estuary).
- Raised beaches and other static features as evidence of coastal geomorphological changes.
- Glacial deposits and landforms including those modified by coastal processes (Walney Island).

Number of GCR sites:
Permian - Triassic: 2 Pleistocene / Quaternary of Cumbria: 2 Coastal Geomorphology of England: 1
Westphalian: 1

Geological/geomorphological SSSI coverage: There are 3 coastal (P)SSSIs in the Maritime Natural Area containing 6 GCR SILs representing 4 different GCR networks. The St. Bees Head site includes the coastal exposures around the rocky headland which forms the westernmost part of the site. The rocks here are of stratigraphical importance for their Carboniferous and Permian rocks which illustrate the changing environments of between 300 and 250 million years ago. In addition, glacial sediments from the last Ice Age around 15-10000 years ago provide important evidence of the conditions which existed at the start of the recent warm period in the Earth's history. The Duddon Estuary site contains the northern half of the Walney Island GCR site, and is of great importance as an offshore island barrier which originated as glacial sediment.

Key Geological/Geomorphological management issues:

- Use of Estuary and Shoreline Management Plans to support the conservation of contiued natural processes, eg. against 'coastal squeeze' or waste disposal.
- Restrictions on dredging of seabed gravel resources.

Key geological objectives:

1. **Maintain and where possible enhance the existing geological and geomorphological features** and natural processes, including use of estuary and shoreline management plans for the coastal zone.

2. **Encourage initiatives** aimed at the joint management of the MNA's geological and biological resources.

3. **Maintain and enhance dune systems** by a) re-seeding bare ground with marram grass (*Ammophilia arenaria*) and b) constructing chestnut fences across blow-through to encourage sand accumulation.

Useful guides/references:

EASTWOOD, T., HOLLINGWORTH, S.E. & SMITH, B. 1931: The Geology of the Whitehaven and Workington area. Memoir of the Geological Survey of Great Britain.

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- St. Bees Head
- Duddon Estuary
- Annaside

Natural Area: M24. Maryport to Western Scottish Border	Geological Significance: Some (provisional)

General geological/geomorphological character: The Maryport to Western Scottish Border Maritime Natural Area comprises the southern side of the Solway Firth, one of the largest estuaries in the country. The onshore area comprises mainly soft low raised-beach cliffs, sand dunes and beaches, with sandbanks and marshes. Little solid rock is exposed except in the south of the area. In the north of the area, the Solway Firth is fed by four main estuaries, the Eden, Esk, Wampool and Waver. Between these, the coastline is primarily low saltmarsh, formed in the last 10,000 years.

Geological History: To the south of the Waver estuary, the coast is dominated by sand and shingle beaches, with fossil 'raised beaches' parallel to and behind the current shoreline. Rocky coasts are limited to foreshore exposures of Triassic 'red-bed' sandstones (230-220 Ma) in the area around Maryport. Triassic rocks also lie beneath the entire onshore coastal area but are usually covered by the peat, till and sand.Quaternary and recent deposits dominate the area within 1 mile inland of the coast, with glacial tills controlling the gently rolling landscape. Offshore, the solid bedrock geology is Triassic sandstone under much of the Solway Firth. Tills drape over much of the seabed, infilling submarine topography scoured during the ice ages. The seabed sediments on top of the tills are primarily sands and muddy sands with a prominent gravel ridge running offshore from south of Silloth out of the Natural Area.

Geomorphological Evolution and Processes: The coastline north of Maryport Harbour is low-lying with predominantly sandy foreshores. Sand dunes extend from Maryport north to Silloth, giving way to saltmarshes in the Solway Firth. Slag and shale from collieries and steelworks have previously been dumped on the shore, forming cliffs and reclaimed beaches at Maryport and to the south. These are now eroding following industrial decline in this area and sand banks and mudflats are often veneered with coal dust north of Allonby.

The predominant southwesterly fetch results in a strongly unidirectional, moderate northward wave induced littoral transport with consequent downdrift effects, which are most apparent to the north of harbour mouths e.g. Maryport and Silloth. North of Silloth the drift reduces rapidly. The Firth is a sink for sediments and has also trapped substantial quantites of coal particles from the polluted beaches in the south. Large scale sediment movement due to tidal current action gives rise to changes in the patterns of siltation/erosion in this area. The geomorphology of the saltmarshes is outstanding and covers a range of landform features including: well developed dendritic creek systems, four types of saltpan, a cliff some 2 - 3m high on the marsh edge in the southeastern part of Rockcliffe and also marsh terraces formed by creek migration and isostatic uplift. [steps between terraces vary from 60 - 120cm].

Key geological /geomorphological features:

- Estuarine saltmarsh formations and the processes which form them.
- Raised beaches and evidence of changes in coastal morphology from beaches and spits.
- Glacial deposits and landforms.

Number of GCR sites: Saltmarsh Morphology: 1

Geological/geomorphological SSSI coverage: There is 1 coastal (P)SSSI in the Maritime Natural Area containing 1 GCR SIL. The saltmarsh morphology site (Upper Solway) covers the features of one of the best developed Holocene estuarine marshes in Britain. The site lies on both sides of the Solway, and management is shared with Scotland.

Key geological management issues:

- Allow natural processes to continue to evolve the intertidal area in as near-natural manner as possible.
- Restrict dredging of seabed gravel resources and access channels and destruction of geomorphological features.
- Promotion of the links between geomorphological sites and biological & environmental aspects.

Key geological objectives:

1. Maintain and where possible enhance the existing geomorphological features, including use of estuarine and shoreline management plans for the coastal zone.

2. Encourage initiatives aimed at the joint management of the MNA's geological and biological resources.

3. Use of Estuary management plans to support the conservation of continued natural processes in the saltmarshes, e.g. against coastal squeeze through a) discouragment of uncoordinated and poorly constructed 'do it yourself' embankments.

4. Examine closely and minimise actions that are likely to disturb natural processes, for example dredging to maintain access channels (eg. to Annan).

Useful guides/references:

ALLEN, J. R. L. 1992: Saltmarshes - Morphodynamics, conservation and engineering significance. Cambridge University Press.

JONES. R. L. & KEEN, D.H. 1993: Pleistocene Environments in the British Isles. Chapman & Hall,

Earth science coastal (P)SSSIs in the Maritime Natural Area:

- Upper Solway Flats and Marshes