## Tables

**(Table 1.1) Number of items in the computerized bibliography of geomorphology of Britain that are classified as 'Coasts' (total 1400), by year of publication.**

| Year | Items |
|---|---|
| 1830–1859 | 5 |
| 1860–1899 | 15 |
| 1900–1909 | 1 |
| 1910–1919 | 10 |
| 1920–1929 | 24 |
| 1930–1939 | 36 |
| 1940–1949 | 28 |
| 1950–1954 | 68 |
| 1955–1959 | 73 |
| 1960–1964 | 102 |
| 1965–1969 | 86 |
| 1970–1974 | 121 |
| 1975–1979 | 197 |
| 1980–1984 | 229 |
| 1985–1989 | 209 |
| 1990–1994 | 68 |
| 1995–1999 | 102 |

**(Table 1.2) Number of items under selected keywords** (some items appear more than once as several keywords are allocated to each).

| | |
|---|---|
| Beach | 284 |
| Erosion | 267 |
| Sea level | 186 |
| Cliffs | 126 |
| Saltmarsh | 104 |
| Sand dunes | 90 |
| Gravel/Shingle | 86 |
| Littoral/Longshore drift | 79 |
| Coastal protection | 74 |
| Spit | 66 |
| Coastal platform | 42 |
| Accretion | 27 |
| Sediment cell | 3 |

**(Table 1.3) Geographical analysis of the British coastal literature, using selected grid squares only.**

| Grid square | Estimated length of coastline | Number of publications | Coastline length per number of publications |
|---|---|---|---|
| SY (Dorset) | 110 km | 97 | 1.13 km |
| TM (Suffollc/Essex) | 120 km | 95 | 1.26 km |
| SD (Lancashire/S. Cumbria) | 150 km | 82 | 1.83 km |
| SN (Fishguard to Aberdovey) | 95 km | 35 | 2.71 km |
| NJ (south side of Moray Firth) | 100 km | 22 | 4.55 km |
| NZ (Durham/North Yorkshire) | 130 km | 18 | 7.22 km |
| NC (Sutherland) | 150 km | 9 | 16.67 km |

**(Table 1.4) General order of resistance to erosion of British rock types (from Clayton and Shamoon, 1998).**

Very Resistant: Precambrian metamorphosed sediments, Cambrian quartzite and sandstone, Ordovician tuff.
Resistant: Old Red Sandstone, Lower Palaeozoic slates, Palaeozoic basalt and andesite.
High Average: Skiddaw slate, Millstone Grit, Carboniferous limestone, Yoredale series.
Low Average: Palaeozoic shale, Coal Measures, Devonian greywackes, Tertiary basalts.
Weak: Magnesian (Permian) limestone, Jurassic limestone, Hastings Beds, Chalk.
Very Weak: Mesozoic and Cainozoic mudrocks, Thanet sand.

**(Table 1.5) Morphosedimentological classification of the British coast** (based on European Commission (1998 – the CORINE project érosion cotieré).

| Morpho-sedimentological type | Active (km) | Protected* (km) | Total (km) |
|---|---|---|---|
| Hard-rock cliffs | 7990 | 7 | 7997 |
| Soft-rock cliffs | 1401 | 221 | 1622 |
| Shingle beaches | 818 | 225 | 1043 |
| Sand beaches | 1274 | 302 | 1576 |
| Heterogeneous beaches | 415 | 126 | 541 |
| Beaches for which no data available | 59 | 0 | 59 |
| Muddy and estuarine coasts | 999 | 484 | 1483 |
| **Totals** | 12956 | 1365 | 14321 |
| Anthropogenic coasts (including harbours, land-claim) | | | 2096 |
| **Total** | | | 16417 |
| * i.e. modified by coastal defence/protection works. coastal geomorphology unnecessary duplication was avoided. | | | |

**(Table 1.6) Main features of each GCR Site, broadly following the classification of King, 1978, to show where different features are represented.**

**Table 1.6 Column headings**

| | |
|---|---|
| 1. Large-scale structural control | 14. Cliff-foot beaches |
| 2. Small-scale structural control | 15. Dunes, including sandplains |
| 3. Cliff forms and processes | 16. Spits |
| 4. Exhumed forms: cliffs, benches | 17. Barrier beaches |
| 5. Karstic development | 18. Cuspate forelands and nesses |
| 6. Shore platforms — structural control | 19. Tombolos and tied islands |
| 7. Shore platforms — erosional control | 20. Intertidal sediments |
| 8. Beach orientation | 21. Mudtlats, ridge and runnel forms |
| 9. Beach undergoing erosion | 22. Saltmarsh morphology |
| 10. Prograding beach | 23. Machair |
| 11. Beach phases | 24. Coastal valleys |
| 12. Pre-existing clasts | 25. Inlets and submerged coasts |
| 13. Emerged ('raised') beaches | 26. Semi-enclosed bay |

| **Chapter 3 Hard-rock cliffs** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | St Kilda Archipelago | x | x | x | x | | | | | | | | | | | | | | | | | | | | | x | |
| 2 | Villians of Hamnavoc, Shetland | x | x | x | x | | | x | | | | | | | | . | | | | | | | | | | x | |
| 3 | Papa Stour, Shetland | x | x | x | x | | | x | | | | | | | x | | | | | | | | | | | x | |
| 4 | Foula, Shetland | x | x | x | x | | x | x | | | | | | | x | | | | | | | | | | | x | |
| 5 | West Coast of Orkney | x | x | x | x | | x | x | | | | | | | x | | | | | | | | | | | x | |
| 6 | Duncansby to Skirza Head, Caithness | x | x | x | x | | x | x | | | | | | x | x | | | | | | | | | | | x | |
| 7 | Tarbat Ness, Easter Ross | x | | x | x | | | x | | | | | | x | x | | | | | | | | | | | | |
| 8 | Loch Maddy-Sound of Harris coastline | | | x | | | | | | | | | | | | | | | | | | | | | | x | x |
| 9 | Northern Islay, Argyll and Bute | x | | | x | | | x | | | | | | x | x | | | | | | | | | | | | |
| 10 | Butlers of Buchan, Aberdeenshire | | x | x | x | | | x | | | | | | | x | | | | | | | | | | | | |
| 11 | Dunbar, East Lothian | x | x | x | x | | x | x | | | | | | x | x | | | | | | | | | | | | |
| 12 | St Abb's Head, Berwickshire | x | x | x | | | x | x | | | | | | x | x | | | | | | | | | | | | |
| 13 | Tintagel, Cornwall | x | | x | | | x | | | | | | | | x | | | | | | | | | | | | |
| 14 | South Pembroke Cliffs, Pembrokeshire | | x | x | x | x | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | Hartland Quay, Devon | x | x | x | | | x | x | | | | | | | | | | | | | | | | | x | | |
| 16 | Solfach, Pembrokeshire | | | x | | | | x | | | | | | | | | | | | | x | | | | x | x | |

**Chapter 4 Soft-rock cliffs**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | Ladram Bay, Devon | | x | x | | | x | | | | | | | | x | | | | | | | | | | | | |
| 18 | Robin Hood's Bay, Yorkshire | x | x | x | | | x | x | | x | | | | | x | | | | | | | | | | | | |
| 19 | Blue Anchor—Watchet—Lilstock, Somerset | | x | x | | | x | x | | | | | | | | | | | | | | | | | | | |
| 20 | Nash Point, Glamorgan | | x | x | | | x | x | | | | | | | | | | | | | | | | | | | |
| 21 | Lyme Regis to Golden Cap, Dorset | | x | x | | | | | | x | | | x | | x | | | | | | | | | | | | |
| 22 | South-west Isle of Wight | x | x | x | | | x | x | x | x | | | | | x | | | | | x | | | | | x | | |
| 23 | Kingsdown to Dover, Kent | | x | x | | | | x | | x | | | | | x | | | | | | | | | | | | |
| 24 | Beachy Head to Seaford Head, East Sussex | x | x | x | | | x | x | x | x | | | | | x | | | | | | | | | | x | | |
| 25 | Ballard Down, Dorset | x | x | x | | | | x | | | | | | | x | | | | | | | | | | | | |
| 26 | Flamborough Hcad, Yorkhsire | x | x | x | | | x | x | | | | | | | x | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Joss Bay (Forencss Point), Kent | | x | x | | | | x | | | | | | | x | | | | | | | | | | | | |
| 28 | Porth Neigwl, Gwynedd | | | x | | | | | x | x | | | | | x | | | | | | | | | | | | |
| 29 | Holdcmcss, Yorkshire | | x | x | | | | | x | x | | | | | x | | | | | | | | | | | | |

**Chapter 6 Gravel and 'shingle' beaches**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | Westward Ho! Cobble Beach, Devon | | | | | | | | x | x | | | x | | | | x | | | | | | | | | | |
| 31 | Loe Bar, Cornwall | | | x | | | | x | x | x | | | | | x | | x | | | | | | | | | | |
| 32 | Slapton Sands, Devon | | | | | | | | x | x | | | | | x | | x | | | | | | | | | x | |
| 33 | Hallsands, Devon | | x | x | x | | | x | | x | | | | x | | | | | | | | | | | | | |
| 34 | Budleigh Salterton Beach, Devon | | | x | | | | | x | x | x | | x | | | | | | | | | | | | | | |
| 35 | Chesil Beach, Dorset | | | x | | | | x | x | x | | x | x | | | | | | | x | | | | | | | |
| 36 | Porlock, Somerset | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37 | Hurst Castle Spit, Hampshire | | | | | | | | x | x | x | | | | | | x | | | | x | x | x | | | | |
| 38 | Pagham Harbour, West Sussex | | | | | | | x | x | | x | | | | | | x | | | x | | | | | | x | |
| 39 | The Ayres of Swinister, Shetland | | | | | | | | x | | | | | | | | x | x | | x | x | | | | | x | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | Whiteness Head, Moray | | | | | | | | x | x | x | | | x | | x | x | | | | x | | x | | | | |
| 41 | Spey Bay, Moray | | | | | | | | x | x | x | x | x | x | | x | x | | | | x | | x | | | | |
| 42 | The West Coast of Jura, Argyll and Butc | | | x | | | x | x | | | | | x | x | x | | | | | | | | | | | | |
| 43 | Benacre Ness, Suffolk | | | | | | | | x | x | x | x | | | | | | | x | | | | | | | | |
| 44 | Orfordness and Shingle Street, Suffolk | | | | | | | | x | x | x | | | | | | x | | x | | | | | | | | |
| 45 | Rye Harbour, East Sussex | | | | | | | | x | x | x | | | | | x | x | x | | | | | | | | | |
| 46 | Dungeness, Kent | | | | | | | | x | x | x | x | x | | | | x | x | x | | x | | | | | | |

**Chapter 7 Sandy beaches and coastal dunes**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | Marsden Bay, County Durham | | x | x | | | | x | x | | | x | | | x | | | | | | | | | | | | |
| 48 | South Haven Peninsula, Dorset | | | | x | | | | x | x | x | | | | | x | | | | | | | | | | | |
| 49 | Upton and Gwithian Towns, Cornwall | | x | x | x | | | | | x | | | | | x | x | | | | | | | | | | | |
| 50 | Braunton Burrows, Devon | | x | x | x | | | x | x | x | x | | | x | | x | x | | | | x | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Oxwich Bay, Glamorgan | | | | | | | | x | x | x | | | | | x | | | | | | | | | | | |
| 52 | Tywyn Abcrffraw, Anglesey | | | x | | | | | x | x | x | | | | | x | | | | | | | | | | | |
| 53 | Ainsdale, Lancashire | | | | | | | | x | x | x | x | | | | x | | | | | | x | | | | x | |
| 54 | Luce Sands. Dumfries and Galloway | | | | | | | | x | | x | x | | x | | x | | | | | x | x | x | | | | |
| 55 | Sandwood Bay, Sutherland | | | | | | | | x | x | | | | x | | x | | | | | x | | | x | | | |
| 56 | Torrisdale Bay and Invernaver, Sutherland | | | | | | | | x | x | x | | | x | | x | | | | | x | x | x | x | | x | x |
| 57 | Dunnet Bay, Caithness | | | | | | | | x | x | | x | | | | x | | | | | x | | | | | | |
| 58 | Balta Island, Shetland | | | | | | | | | x | | | | | | x | | | | | | | | x | | | |
| 59 | Stratlibeg, Aberdeenshire | | | | | | | | x | x | x | x | | x | | x | | | | | x | | | | | | |
| 60 | Forvic, Aberdeenshire | | | | | | | | x | x | x | | | x | | x | x | | | | x | | | | | | |
| 61 | Barry Links, Angus | | | | | | | | x | x | | x | | x | | x | | | x | | x | | | | | | |
| 62 | Tentsmuir, Fife | | | | | | | | x | x | x | x | | | | x | x | | | | x | x | | | | | |
| | **Chapter 8 Sand spas and tombolos** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 63 | Pwll-ddu, Glamorgan | | | x | | | | | x | | x | | | | | . x | x | | | | | | | | | | |
| 64 | Ynyslas, Ceredigion | | | | | | | | x | x | x | | | | | x | x | | | | x | | x | | | | |
| 65 | East Head, West Sussex | | | | | | | | x | x | x | | | | | x | x | | | | x | | | | | | |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 66 | Spurn Head, Yorkshire | | | | | | | | x | x | x | | | | | x | x | | | | x | | | | | | |
| 67 | Dawlish Warren, Devon | | x | | | | | | x | x | | | | | | x | x | | | | x | | | | | | |
| 68 | Gibraltar Point, Lincolnshire | | | | | | | | x | | x | x | | | | x | x | | | | x | x | x | | | | |
| 69 | Walney Island. Lancashire | | | x | | | | | x | x | x | | | | x | x | x | x | | | | | | | | | |
| 70 | Winterton Ness, Norfolk | | | | | | | | x | x | | | | | | x | | | x | | | | | | | | |
| 71 | Morfa Barka, Merioncth, Gwynedd | | | | | | | | x | x | x | | | | | x | x | | | | x | x | x | | | | |
| 72 | Morfa Dyffryn, Merioneth, Gwynedd | | | | | | | | x | x | x | | x | | | x | x | | x | x | x | | | | | | |
| 73 | St Ninian's Tombolo, Shetland | | | x | | | | | x | | x | | | | | x | | | | x | x | | | x | | x | |
| 74 | Isles of Scilly | | x | x | | | | x | x | x | x | | x | | x | | x | | | x | x | | | | | | |
| 75 | Central Sanday. Orkney | | | | | | | | x | x | x | x | | | | x | x | | | x | x | x | | x | | x | |

**Chapter 9**

**Machair**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 76 | Machir Bay, Islay, Argyll and Bute | | . | . | | | | | x | x | | | | x | | x | | | | | x | | | x | | | |
| 77 | Eoligarry, Barra, Western Isles | | | | | | | | x | x | x | | | | | x | | | | x | x | x | x | x | | x | |
| 78 | Ardivacher to Stoncybridge, South Uist | | | | | | | | x | x | | | | | | x | | | | | x | | | x | | x | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | Homish and Lingay Strands (GCR name: Machairs Robach and Newton), North Uist | | | | | | | | x | x | x | | | | | x | x | | | x | x | x | x | x | | x | |
| 80 | Pabbay, Harris, Western Isles | | | | | | | | | x | x | | | | | x | | | | | x | | | x | | x | |
| 81 | Luskentyre and Corran Scilebost, Harris | | | | | | | | x | x | | | | | | x | x | | x | | x | | x | x | | x | |
| 82 | Mangestra, Lewis, Western Isles | | | | | | | | | x | | | | | | | | | | | x | | | x | | | |
| 83 | Traigh nit Berle, Lewis, Western Isles | | | | | | | | x | x | | | | | | x | | | | | x | | | x | | x | |
| 84 | Balnakeil, Sutherland | | | | | | | | x | x | | | | x | | x | | | | | x | | | x | | x | |

**Chapter 10 Saltmarshes**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 | Culbin, Moray | | | | | | | | x | x | x | x | x | x | | x | x | x | | | x | x | x | | | | |
| 86 | Morrich More, Ross and Cromarty | | | | | | | | x | x | x | x | | x | | x | x | | | | x | x | x | | | | |
| 87 | St Osyth Marsh, Essex | | | | | | | | x | x | x | x | x | | | | x | | | | x | x | x | | | | |
| 88 | Dengic Marsh, Essex | | | | | | | | x | x | x | x | x | | | | x | | | | x | x | x | | | | |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 89 | Keyhaven Marsh, Hurst Castle, Hampshire | | | | | | | | | | | | x | | | | x | | | | x | x | x | | | x | |
| 90 | Solway Firth (north shore), Dumfries and Galloway | | | | | | | | | | | | | x | | | | | | | x | x | x | | | | |
| 91 | Solway Firth: Upper Solway flats and marshes (south shore), Cumbria | | | | | | | | | | | | | x | | | | | | | x | x | x | | | x | |
| 92 | Solway Firth: Crec Estuary (Outer Solway Firth), Dumfries and Galloway | | | | | | | | | | | | | x | | | | | | | x | x | x | | | x | |
| 93 | Loch Gruinart, Islay | | | | | | | | | | x | | | x | | x | | | | | x | x | x | | | | |

**Chapter 11 Coastal assemblages**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Culbin, Moray — see site number 85 | | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Morrich More, Ross and Cromarty — see site number 86 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 94 | Carmarthen Bay (including GCR site Burry Inlet), Carmarthenshire | x | x | x | x | | x | x | x | x | x | x | x | x | | | | | | | x | x | x | | x | x | |
| 95 | Newborough Warren, Anglesey | | x | x | | | | x | x | x | x | x | | | | x | x | | | | x | x | x | | | x | |
| 96 | Morfa Dinlle, Gwynedd | | | x | | | | | x | x | x | | | | | x | x | | | | x | | | | | | |
| 97 | Holy Island (GCR name: Goswick—Holy Island—Budle Bay, Northumberland | x | x | x | x | | x | x | x | x | x | x | | x | x | x | x | x | | | x | x | x | | | | |
| 98 | North Norfolk Coast | | | x | | | | x | x | x | x | x | | | x | x | x | x | | | x | x | x | | | | |
| 99 | The Dorset Coast: Peveril Point to Furzy Cliff | x | x | x | | | x | x | x | x | | | x | | x | | | | | | | | | | | | x |

**(Table 1.7) Coastal Annex I habitats occurring in the UK (from McLeod *et al.*,** 2002.)

| EU code | Habitat name | Lay name | Priority habitat/ UK special species responsibility |
|---|---|---|---|
| 1130 | Estuaries | Estuaries | x |

| | | | | |
|---|---|---|---|---|
| 1140 | Mudflats and sandflats not covered by seawater at low tide | Intertidal mudflats and sandflats | | |
| 1150 | Coastal lagoons | Lagoons | x | x |
| 1160 | Large shallow inlets and bays | Shallow inlets and bays | | x |
| 1170 | Reefs | Reefs | | x |
| 1210 | Annual vegetation of drift lines | Annual vegetation of drift lines | | |
| 1220 | Perennial vegetation of stony banks | Coastal shingle vegetation outside the reach of waves | | x |
| 1230 | Vegetated sea cliffs of the Atlantic and Baltic coasts | Vegetated sea cliffs | | x |
| 1310 | *Salicornia* and other annuals colonizing mud and sand | Glasswort and other annuals colonizing mud and sand | | |
| 1320 | *Spartina* swards (*Spartinion maritimae*) | Cord-grass swards | | |
| 1330 | Atlantic salt meadows (*Glauco- Puccinellietalia maritimae*) | Atlantic salt meadows | | |
| 1420 | Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*) | Mediterranean saltmarsh scrub | | |
| 2110 | Embryonic shifting dunes | Shifting dunes | | |
| 2120 | Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes') | Shifting dunes with marram | | |
| 2130 | Fixed dunes with herbaceous vegetation ('grey dunes') | Dune grassland | x | x |
| 2140 | Decalcified fixed dunes with *Empetrum nigrum* | Lime-deficient dune heathland with crowberry | | |
| 2150 | Atlantic decalcified fixed dunes (*Calluno-Ulicetea*) | Coastal dune heathland | x | |
| 2160 | Dunes with *Hippophae rhamnoides* | Dunes with sea-buckthorn | | |
| 2170 | Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*) | Dunes with creeping willow | | |
| 2190 | Humid dune slacks | Humid dune slacks | | x |
| 21A0 | Machairs | Machair | | x |

| | | | | |
|---|---|---|---|---|
| 2250 | Coastal dunes with *Juniperus* spp. | Dunes with juniper thickets | x | |
| 8330 | Submerged or partially submerged sea caves | Sea caves | | x |

**(Table 2.1) Likely recession rates in different materials (compiled by Carter, 1988, from data in Sunamura, 1983).**

| Lithology | Recession rate (m $a^{-1}$) |
|---|---|
| Granite | $10^{-3}$ |
| Limestone | $10^{-3}$ to $10^{-2}$ |
| Shales and flysch | $1^{0-2}$ |
| Chalk | $10^{-1}$ to 1 |
| Tertiary sedimentary | $10^{-1}$ to 1 |
| Quaternary sedimentary | 1 to 10 |
| Recent volcanic rocks | 10 to $10^{2}$ |

**(Table 2.2) Primary, secondary and tertiary controls on cliff form** (based on May, 1997a).

| **FIRST ORDER** | **SECOND ORDER** | **THIRD ORDER** |
|---|---|---|
| Geological structure and lithology | Weathering and transport slope processes | Coastal land-use Resource extraction |
| Wave climate | Slope hydrology | Coastal management |
| Subaerial climate | Vegetation | |
| Water-level change (sea level and tide) | Cliff-foot erosion | |
| Geomorphology of the hinterland (landforms into which the cliffs are cut) | Cliff-foot sediment accumulation | |
| | Resistance of cliff-foot sediment to attrition and transport | |

**(Table 2.2) Primary, secondary and tertiary controls on cliff form** (based on May, 1997a).

| **FIRST ORDER** | **SECOND ORDER** | **THIRD ORDER** |
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| Geomorphology of the hinterland (landforms into which the cliffs are cut) | Cliff-foot sediment accumulation | |
| | Resistance of cliff-foot sediment to attrition and transport | |

**(Table 2.3) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Vegetated sea cliffs of the Atlantic and Baltic coasts' and/or 'Submerged or partially submerged sea caves' as qualifying European features.** Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, November 2002.)

| **SAC name** | **Local authority** | **Cliff habitat extent (ha)** |
|---|---|---|
| Ardmeanach | Argyll and Bute | 125.9 |
| **Beast Cliff–Whitby (Robin Hood's Bay)** | North Yorkshire | 156.1 |
| **Berwickshire and North Northumberland Coast** | Northumberland; Scottish Borders | † |
| **Buchan Ness to Collieston** | Aberdeenshire | 62.2 |

| | | |
|---|---|---|
| Cape Wrath | Highland | 299.6 |
| **Cardigan Bay/ Bae Ceredigion** | Ceredigion; Penfro/ Pembrokeshire | † |
| **Clogwyni Pen Ll■n/ Seacliffs of Lleyn** | Gwynedd | 65 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 1 |
| **Durham Coast** | Durham | 120.4 |
| East Caithness Cliffs | Highland | 310 |
| Exmoor Heaths | Devon; Somerset | 85.6 |
| Fair Isle | Shetland Islands | 129 |
| **Flamborough Head** | East Riding of Yorkshire; North Yorkshire | 315.6 |
| Glac na Criche | Argyll and Bute | 50 |
| Glannau Ynys Gybi/ Holy Island Coast | Ynys Môn/ Isle of Anglesey | 111.1 |
| Great Orme's Head/ Pen y Gogarth | Conroy | 13.9 |
| Hastings Cliffs | East Sussex | 55.1 |
| **Hoy** | Orkney Islands | 94.9 |
| **Isle of Portland to Studland Cliffs** | Dorset | 579 |
| Isle of Wight Downs | Isle of Wight | 18.4 |
| **Limestone Coast of South West Wales/Arfordir Calchfaen de Orllewin Cymru** | Abertawe/ Swansea; Penfro/ Pembrokeshire | 349.5 |
| Lundy | Devon | † |
| Mousa | Shetland Islands | † |
| Mull of Galloway | Dumfries and Galloway | 137.6 |
| North Rona | Western Isles/ Na h-Eileanan an Iar | 31.4 |
| Overstrand Cliffs | Norfolk | 28 |
| **Papa Stour** | Shetland Islands | † |
| **Pembrokeshire Marine/ Sir Benfro Forol** | Penfro/ Pembrokeshire | † |
| **Pen Ll■n a'r Sarnau/ Lleyn Peninsula and the Sarnau** | Ceredigion; Gwynedd; Powys | † |
| Polruan to Polperro | Cornwall | 192 |
| Rigg-Bile | Highland | 450.8 |
| Rum | Highland | 216.7 |
| **Sidmouth to West Bay** | Devon; Dorset | 807.5 |
| **South Devon Shore Dock** | Devon | 238.7 |
| South Hams | Devon; Torbay | 3.8 |
| **South Wight Maritime** | Isle of Wight | 198.6 |
| **St Abb's Head to Fast Castle** | Scottish Borders | 122.4 |
| **St Albans Head to Durlston Head** | Dorset | 28.7 |
| **St David's/ T■ Ddewi** | Penfro/ Pembrokeshire | 303.9 |
| **St Kilda** | Western Isles / Na h-Eileanan an Iar | 738.8 |
| Strathy Point | Highland | 169.3 |
| **Stromness Heaths and Coast** | Orkney Islands | 63.5 |
| **Thanet Coast** | Kent | † |
| The Lizard | Cornwall | 149.8 |
| **Tintagel–Marsland–Clovelly Coast** | Cornwall; Devon | 1457.9 |
| Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay | Conwy; Gwynedd; Ynys Mon/ Isle of Anglesey | † |

* Possible SAC not yet submitted to EC.

† SAC proposed for sea caves; sea cliffs not a qualifying feature.

Bold type indicates a coastal geomorphological GCR interest within the site.

**(Table 3.1) Hard-rock cliff GCR sites**, including those sites described in other chapters of the present volume that include hard-rock cliffs in the assemblage.

| Site* | Main features | Main geological materials | Tidal range (m) |
|---|---|---|---|
| **St Kilda Archipelago. Western Isles** | Plunging cliffs, submerged caves and platforms; structural controls | Igneous complex of granophyres, basalts and dolerites | 3.0 |
| **Villians of Hamnavoe, Shetland** | Structural controls, wave stripping, cliff-top boulder beaches | Devonian extrusive andesites and ignimbrites | 1.5 |
| **Papa Stour, Shetland** | Diversity of cliff forms, caves, stacks, arches; inherited cliffs | Devonian extrusive rhyolite and ignimbrite | 1.5 |
| **Foula, Shetland** | Higher cliffs, shore platforms, geos; exhumed cliffs stacks and geos | Devonian sandstones and Dalradian metamorphic rocks | 1.5 |
| **West Coast of Orkney** | Structural control of steep over- hanging cliffs; stacks arches; inherited cliffs; young individual features | Devonian Old Red Sandstone | 3.0 |
| **Duncansby to Skirza Head, Caithness** | Geos and stacks, shore platforms, blowhole | Devonian Old Red Sandstone | 3.0 |
| **Tarbat Ness, Easter Ross** | Weathering forms: tafoni and solution pits | Fault-controlled Devonian Old Red Sandstone | 3.2 |
| **Loch Maddy–Sound of Harris coastline** | Drowned surface of glacial erosion; rock basins, skerries and platform | Lewisian gneiss, faulted and crushed zones | 3.5 |
| **Northern Islay, Argyll and Bute** | Emerged shore platform and beach gravels | Precambrian quartzites and tillites; Dalradian Limestone | 2.0 |
| **Bullers of Buchan, Aberdeenshire** | Geos, caves, arches. stacks, platform, blowhole | Granite and dyke intrusions | 3.5 |
| **Dunbar, East Lothian** | Four shore platforms, some of which are glaciated | Devonian Old Red Sandstone, Carboniferous sandstone, igneous intrusions | 4.5 |
| **St Abb's Head, Berwickshire** | Steep cliffs, geos, fault-controlled inlets and headlands | Devonian extrusive felsites, tuffs, and grits; faulting | 4.5 |
| **Tintagel, Cornwall** | Longitudinal coast, structural control caves, arches, slope-over- wall cliff | Upper Devonian slates, siliceous sandstones, pillow lavas, tuffs and phyllites | 6.5 |
| **South Pembroke cliffs** | Structural controls, eroded karstic coast, stack, arch, cave, geo | Carboniferous limestones | 6.0 |
| **Hartland Quay, Devon** | Truncated valleys, waterfalls, slope-over-wall cliffs, shore platforms | Carboniferous interbedded fine-grained sandstones and shales | 6.4 |
| **Solfach, Pembrokeshire** | Ria, infilled ria | Cambrian and Ordovician flags and dolerites | 5.9 |
| Carmarthen Bay, Carmarthenshire | Ria, shore platforms | Old Red Sandstone and Carboniferous limestone | 8.0 |

| | | | |
|---|---|---|---|
| Furzy Cliff—Peveril Point, Dorset | Structural controls, longitudinal coast, slope-over-wall cliffs, truncated valleys | Portlandian and Purbeckian limestones and sandstones | 1.9 |
| Holy Island, Northumberland | Structural controls, shore platforms | Carboniferous sandstones and limestones | 4.1 |
| Upton and Gwithian Towans, Cornwall | Exhumed cliffs and stacks | Devonian slates | 5.8 |
| Hallsands, Devon | Emerged shore platform | Mica-schist and quartz- schist | 4.4 |

*Sites described in the present chapter are in bold typeface

**(Table 3.2). Altitude and orientation of some cliff-top boulder deposits in Shetland (after Hansom *et al.,* in press).**

| **Location** | **Altitude (m)** | **Coastal orientation (degrees)** | **Mean orientation of boulder long axis (degrees)** | **Number of boulders** | **Mean long axis (m)** |
|---|---|---|---|---|---|
| Virda Field, Papa Stour | 35 | 5 | 300 | 15 | 0.7 |
| South Head, Villians of Hamnavoe | 25 | 0 | 315 | 25 | 1.1 |
| Grind of the Navir 1 (beach ridge) | 19 | 0 | 314 | 20 | 1.2 |
| Grind of the Navir 2 (boulder clusters) | 20 | 0 | 290 | 25 | 0.7 |
| Esha Ness | 35 | 20 | 275 | 15 | 1.0 |

**(Table 4.1) The main features of soft-rock cliff coastal geomorphology GCR sites**, including coastal geomorphology GCR sites described in other chapters of the present volume that contain soft-rock cliffs in the assemblage. Sites described in the present chapter are in bold typeface.

| **Site** | **Main features** | **Other features** | **Mean rate of cliff-top retreat (m $a^{-1}$)** | **Tidal range (m)** |
|---|---|---|---|---|
| Budlcigh Salterton | Cliff erosion feeding Budleigh Salterton Pebble Beds into local and regional beaches | Shingle beach (see Chapter 6) | 0.30 | 4.0 |
| Ladram Bay | Cliff—stack—platform development in Triassic sandstone and mudstone | | 0.20 | 3.7 |
| Robin Hood's Bay | Cliffs in till resting on Liassic shales. Till/platform junction | Platform across Liassic shales | 0.03 | 4.8 |
| Blue Anchor–Watchet–Lilstock | Rapid retreat in Liassic shales with very unusual 'washboard' topography in macro-tidal environment | Platform development | Up to 1.20 | 9.4 |
| Nash Point | Rapid cliff retreat in Liassic shales. Cave development | Platform development | 0.2–0.10 | 6.0 |

| | | | | |
|---|---|---|---|---|
| Lyme Regis to Golden Cap | Intensively researched landslide and related beach coast | Major mass-movements | 0.60–0.96 | 3.5 |
| Peveril Point to Furry Cliff | Rapidly eroding cliffs in range of materials from Chalk to Oxford Clay. Longitudinal coast | Semi-enclosed beaches. Submarine rock reefs. Landslides) | 0.00–0.41 | 1.7 (east)–2.0 (west) |
| South-west Isle of Wight | Differential erosion in materials from Chalk to Wealden. Contrasts between relict and modern beaches. Stacks. Chines | Major mass-movements | 0.20–2.10 | 3.3 (east)–2.2 (west) |
| Kingsdown to Dover | Cliff and beach development in high (over 30 m) cliffs. Recent beach depletion | Flow failures | 0.20–0.60 | 5.9 |
| Beachy Head to Seaford | Cliffs of variable height in Upper Chalk. Narrow platforms. Locally limited sediment supply. Recent beach depletion | | 0.40–1.26 | 5.3 . |
| Ballard Down | Classic cave—arch—stack site in Upper Chalk. Transverse coast | Pocket beach formation | 0.01–0.60 | 1.7 |
| Marsden Bay | Cliffs and stacks | Beach phases | | 4.2 |
| Flamborough Head | Highly complex chalk cliffs overlain by Devensian till. Caves and stacks | Extensive platforms | 0.30–0.90 | 4.0 |
| Joss Bay | Cliff and platform development in Upper Chalk | | 0.30 | 4.0 |
| Carmarthen Bay | Both hard-rock cliffs and easily eroded cliffs | Major dunes, sand-spits and barrier beaches, rias, emerged beaches, intertidal sandflats, saltmarsh | | 8.0 |
| North Norfolk Coast | Rapidly eroding cliffs in chalk and till, latter feeding regional sediment budget | Major spits, beaches and saltmarsh (see Chapter 11) | 0.30–0.42 | 4.7 (E)–6.4 (W) |
| Benacre Ness | Rapidly eroding till cliffs resulting from longshore movements of ness and subsequent reduction of natural protection | Shingle ness (see Chapter 6) | 0.42–0.96 | 2.1 |

| | | | | |
|---|---|---|---|---|
| Porth Neigwl | Rapidly retreating glacial drift cliffs, chines, beach cusps | Contemporary beach cementation (see Campbell and Bowen, 1989) | Up to 1.00 | 3.9 |
| Walney Island | Till cliffs, rapid erosion | Barrier islands, recurved spits | | 9.0 |
| Holderness | Rapidly eroding cliffs, mainly in till | Till shore platform, ords, thin beach | Up to 2.22 | 4.0 |

**(Table 4.2) Rates of cliff-top retreat of soft-cliffed coasts** (from various sources).

| **Cliff-top retreat (m $a^{-1}$)** | **Rock type** | **Location** | **Period (years)** |
|---|---|---|---|
| 0.01 | Upper Chalk | North Ballard Down | 100 |
| 0.01 | Upper Chalk | East Ballard Down | 100 |
| 0.03 | Bracklesham Beds | Highcliffe Castle | 92 |
| 0.07 | Upper Chalk | Kingsdown–St Margaret's Bay | 84 |
| 0.07 | Upper Chalk | Thanet | 85 |
| 0.09 | Middle/Lower Chalk | Dover to Folkestone | 90 |
| 0.16 | Upper Chalk | Cuckmere to Seaford | 120 – |
| 0.18 | Chalk | Hambury Tout to White Note | 98 |
| 0.19 | Upper/Middle Chalk | St Margaret's Bay | 84 |
| 0.27 | Hamstead Beds | North-west Isle of Wight | 95 |
| 0.28 | Glacial drift | North Yorkshire | 72 |
| 0.29 | Glacial drift | Holderness | 100 |
| 0.37 | Jurassic clays | Furry Cliff–Shortlake | 98 |
| 0.39 | Kimmeridge clays and shales | Kimmeridge | 100 |
| 0.41 | Upper Chalk | Newhaven–Rottingdean | 89 |
| 0.41 | Wealden | South-west Isle of Wight | 125 |
| 0.41 | Kimmeridge clays | Ringstead | 99 |
| 0.42 | Glacial drift | Weybourne–Cromer | 100 |
| 0.57 | Glacial drift | Gorleston–Corton | 100 |
| 0.57 | Glacial drift | Holderness | 100 |
| 0.58 | Barton Clay | Barton | 62 |
| 0.68 | London Clay | Reculver | 79 |
| 0.83 | Glacial drift | Gratby-Caister | 100 |
| 0.85 | Glacial drift | Holdemess | 100 |
| 0.88 | London Clay, crag and glacial drift | The Naze | 100 |
| 0.96 | London Clay | Northern Isle of Sheppey | 79 |
| 0.96 | Glacial drift | Cromer–Mundesley | 100 |
| 1.05 | Glacial drift | Pakefield–Kessingland | 100 |
| 1.06 | Chalk | Beachy Head | 90 |
| 1.08 | Sandstone | Cliffend | 75 |
| 1.11 | Glacial drift | Holdemess | 100 |
| 1.19 | Hastings Beds sandstones | Ecclesbourne Glen | 75 |
| 1.20 | Glacial drift | Holderness | 100 |
| 1.22 | Chalk | Birling Gap | 120 |
| 1.26 | Chalk | Seaford Head | 120 |
| 1.43 | Hastings Beds clays | Fairlight Glen | 75 |
| 1.75 | Glacial drift | Holderness | 100 |
| 1.96 | Glacial drift | Holderness | 100 |

| | | | |
|---|---|---|---|
| 2.22 | Glacial drift | Holderness | 100 |
| 3.00 | Glacial drift | Covehithe | 100 |

**(Table 4.3) North Yorkshire coast cliff retreat rates in m a$^{-1}$** (based on Agar, 1960).

| | | Cliff top | Cliff foot |
|---|---|---|---|
| Whole coast | | 0.02 | 0.05 |
| Headlands only | | 0.01 | 0.04 |
| Bays only | | 0.04 | 0.07 |
| Robin Hood's Bay | Lower Lias | 0.02 | between 0.07 and 0.16 |
| | Glacial drift | 0.31 | between 0.05 and 0.31 |

**(Table 4.4) Land-loss by natural sections of the Holdemess coast, 1852–1952** (Valentin, 1954, 1971).

| Section | Annual cliff recession (m) | Shore length (m) | Annual land-loss (m$^2$) | Average cliff height (m) | Annual loss in volume (m$^3$) |
|---|---|---|---|---|---|
| A. Sewerby to Earl's Dike | 0.29 | 8100 | 2357 | 11.0 | 25 927 |
| B. Earl's Dike to Hornsea | 1.10 | 13 650 | 15 015 | 11.8 | 177 177 |
| C. Hornsea to Withernsea | 1.12 | 24 250 | 27 160 | 16.2 | 439 992 |
| D. Withernsea to Kilnsea Warren | 1.75 | 15 525 | 27 200 | 13.2 | 359 040 |
| Entire coast (approx.) | 1.20 | 61 500 | 72 000 | 14.0 | 1 000 000 |

**(Table 5.1) Classification of beach structures based on their plan form** (after Pethick, 1984); outline definitions are provided in the glossary of the present volume.

| | |
|---|---|
| Rhythmic beach morphology | Cusps |
| | Crescentic bars |
| | Cell circulation topography |
| Shoreline beaches | Pocket beaches — swash-aligned (Davies, 1980) |
| | Open beaches — drift-aligned (Davies, 1980) |
| | Zeta-form or fish-hook beaches (Sllvester, 1960; Swift, 1976) |
| | Combined swash and drift alignment |
| Detached beaches | Spits |
| | Cuspate forelands, nesses and tombolos |
| | Barrier beaches and islands |

**(Table 6.1) Main features and sediment sources of gravel/shingle beach and ness GCR sites**, including coastal geomorphology GCR sites described in other chapters of the present volume that contain shingle beach/ness structures in the assemblage.

| Site* | Main features | Other geomorphological features | Present day natural sources of sediment | Tidal range (m) |
|---|---|---|---|---|
| Marsden Bay | Beach phases | Cliff, stack | Local cliff erosion — small | 4.2 |
| Furry Cliff to Peveril Point (Dorset Coast) | Shingle pocket beaches | Cliffs/platforms Mass movements | Cliff erosion — small, restricted | 1.7 (E)–2.0 (W) |

| | | | | |
|---|---|---|---|---|
| Nash Point | Cobble and shingle pocket beaches | Platforms, caves | Local cliff/platform erosion — small | 6.0 |
| Kingsdown to Dover | Cliff-foot beach | Cliffs and platforms | Cliff erosion — small | 5.9 |
| Seven Sisters, (Beachy Head to Seaford Head) | Cliff-foot fringing beaches | Cliffs and platforms | Cliff/platform erosion — small | 6.0 |
| South-west Isle of Wight | Cliff-foot beach and feeder cliffs | Cliffs | Chalk and sandstones — small | 3.3 (E)–2.2 (W) |
| Lyme Regis to Golden Cap | Shingle beach sediment supply and budget | Feeder cliffs | Significant inputs of flint/chert | 3.5 |
| Ynyslas | Sand and shingle spit | Dunes | Reworking till — restricted | 4.0 |
| Westward Ho! | Cobble beach and spit | Dunes | Reworking of emerged beach — restricted | 7.9 |
| Loe Bar | Shingle bay-bar | Cliffs, ria | Local cliff erosion — small | 4.7 |
| Slapton Sands and Hallsands | Shingle bay-bar Beach destruction | Emerged beach, relict cliff and platform | Minimal | 4.4 |
| Budleigh Salterton | Shingle beach and spit<br>Major former feeder to south coast beaches | Soft cliffs | Cliff erosion — maintains budget | 4.0 |
| Chesil Beach | Barrier beach Tombolo | | Minimal — local | 2.0 |
| Porlock | Retreating shingle barrier with both swash-aligned and drift-aligned longshore sections | Recent breached tidal inlet allowing active back-barrier saltmarsh development | Minor source of gravel from updrift coastal slides. Main solifluction source of sediment now exhausted until future sea-level rise creates new supply | 9.3 |
| Hurst Castle Spit | Shingle spit and recurves | Saltmarsh | Possible from offshore | 2.2 |
| St Osyth Marsh | Cheniers | Saltmarsh | Localized reworking of gravels and chenier root | 3.8 |
| Dengie Marsh | Cheniers | Saltmarsh | Localized reworking of gravels and chenier root | 3.8 |
| Blakeney Point (North Norfolk Coast) | Major shingle spit | North Norfolk coast assemblage | Cliff erosion — restricted<br>Longshore transport — large | 6.4 (W)–4.7 (E) |
| Scolt Head Island (North Norfolk Coast) | Barrier beach and spits | North Norfolk coast assemblage | Longshore transport — large | 6.5 |
| Pagham Harbour | Double spit development | | Local cliffs — restricted Kelp rafting | 3.4 |
| Ayres of Swinister | Complex of bay bars and spits | | Local tills — small | 1.5 |
| Rye Bay | Spit developments Shingle beach plain | | Reworking proximal<br>end | 5.8 |
| Benacre Ness | Shingle ness | Rapidly retreating cliffs | Longshore — minimal Cliff erosion — maintains input | 2.1 |

| | | | | |
|---|---|---|---|---|
| Whiteness Head | Spit | | Longshore transport — large | 3.5 |
| Spey Bay | Spits, bay bars, emerged gravel ridges | | Longshore — now partially restricted fluvial input | 3.5 |
| West Coast of Jura | Over 11 000 year sequence of emerged gravel ridges | Emerged shore platforms | Local, between headlands | 2.5 |
| Orfordness and Shingle Street | Major shingle ness and spit | | Longshore — restricted by groyne fields | 1.9 (N)–3.4 (S) |
| Dungeness ridges | Major cuspate foreland<br>Relict barrier beach<br>Over 5000 year sequence of beach | | Re-distribution within site | 6.2 |

* Sites described in the present chapter are in bold typeface

**(Table 6.2) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Perennial vegetation of stony banks' and/or Annual vegetation of drift lines' as qualifying European features.** Non-significant occurrences of these habitats on SACS selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Gravel/ shingle habitat extent (ha) |
|---|---|---|
| Bae Cemlyn/ Cemlyn Bay | Ynys Mon/ Isle of Anglesey | 1.3 |
| **Chesil Beach and the Fleet** | Dorset | 96.2 |
| **Culbin Bar** | Highland; Moray | 122.5 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 1 |
| **Dungeness** | East Sussex; Kent | 2266.1 |
| **Isle of Portland to Studland Cliffs** | Dorset | 1.4 |
| **Lower River Spey–Spey Bay** | Moray | 65.2 |
| Minsmere to Walberswick Heaths and Marshes | Suffolk | 8.8 |
| **Morecambe Bay** | Cumbria; Lancashire | 57.5 |
| **North Norfolk Coast** | Norfolk | 98.4 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an lar | 3 |
| **Orfordness-Shingle Street** | Suffolk | 553.3 |
| **Sidmouth to West Bay** | Devon; Dorset | 4.4 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 226.5 |
| **Solway Firth** | Cumbria; Dumfries and Galloway | 8 |
| **South Uist Machair** | Western Isles / Na h-Eileanan an lar | † |

***** Possible SAC not yet submitted to EC

† Feature is minor component of SAC

Bold type indicates a coastal geomorphology GCR interest within the site

**(Table 6.3) Westerly extension of the active gravel beach (West Spey Bay).** (From Gemmell *et al.,* 2001b.)

| Time period | Westerly growth (m) | Growth per annum ($m\ a^{-1}$) |
|---|---|---|
| 1870–1903 | 1360 | 41 |

| | | |
|---|---|---|
| 1903–1967 | 2090 | 33 |
| 1967–1994 | 720 | 27 |
| July 1994–December 1995 | 30 | 20 |
| 1870–1995 | 4200 | 34 |

**(Table 6.4) Development phases at Dungeness. Ridge height data are mainly from Lewis and Balchin (1940).**

| | **Phase** | **Preserved as** | **Shingle ridge height (m OD** |
|---|---|---|---|
| 1 | Low barrier beach associated with Midley Sands, stretching from Fairlight to St Mary's Bay and thence to Hythe. Dating uncertain but placed between 5500 and 4000 years BP by Eddison (1983a) | (i) Broomhill and Sandylands | Max = +1.5 |
| | | (ii) Recurves at St Mary's Bay | Max = +1.0 |
| | | (iii) Low-level shingle at West Hythe | +0.6 to –1.0 |
| 2 | Higher level barrier system, dated *c.* 3000 years BP Overlain in parts by peat dated *c.* 2700 years BP | (i) Shingle ridges at Jury's Gap and the Wicks, and Beach Bank Soil Series west and north of Lydd | Average = +4.11 Max = +5.00 |
| | | (ii) Shingle recurves at Hythe | +2.8 to +3.5 |
| 3 | Slightly higher beaches, younger than peat. Dated *c.* 2000 years BP | (i) Holmstone Beach and its extensions as Beach Bank Soil Series west of Lydd | Average = +4.31 |
| | | (ii) Recurves at Hythe | No published data |
| 4 | (a) Ness development with eastern shore trending south-east—north-west to Lydd | (i) Wickmaryholm eastwards to Muddymore Pit | Average (west of Galloways) = +4.69<br>Average (east of Galloways)<br>=+3.81 |
| | (b) Barrier beach with spit and recurve development to north and south | (i) New Romney | No published data |
| | | (ii) Recurves at Hythe | No published data |
| 5 | (a) Ness development with long NW- trending ridges. Eastern limit dated at about 750 AD. | (i) Areas south and west of Open Pits | Max = +6.28 |
| | | (ii) Beach Bank series in Denge Marsh | |
| | (b) Land-claim | (i) Areas mainly around Lydd within embankments | |
| | | (ii) Open Pits | |
| 6 | Spit extension and recurves | (i) Open Pits | |
| 7 | (a) Ness and beach plain to distal recurves | (i) Denge Beach to Northlade (by *c.* 1250 AD) | +4.5 to +6.0 Average = +5.33 |
| | | (ii) Greatstone Point (by *c.* 1800 AD) | |
| | (b) Dune development | (i) Romney Warren | |
| | | (ii) Camber | |

| | | |
|---|---|---|
| | (c) Spit development | (i) Littlestone Point<br>(ii) Broomhill Farm, Hythe |
| | (d) Land claim | (i) West of Lydd<br>(ii) Caldecot—Belgar area<br>(iii) Romney Hoy |
| | (e) Beach ridges associated with longshore drift | (i) Camber and Rye Harbour |
| | | (ii) Romney Hoy: Littlestone and Greatstone Points<br>(iii) Hythe Ranges |
| 8 | (a) Modern sea-wall construction | (i) Dymchurch Wall is earliest example |
| | (b) Beach-feeding | (i) Broomhill,<br>(ii) Pett<br>(iii) Power Station<br>(iv) St Mary's Bay |

**(Table 7.1) Main features and present-day sediment sources of dune types.** Exemplar sites described in the present chapter are in bold typeface. See also Table 7.2. (Based on Ranwell, 1972.)

| Type | Sediment sources | Geomorphological setting | Wind directions | Exemplar GCR sites |
|---|---|---|---|---|
| **Foreshore dunes** | | | | |
| Spit dunes | Intertidal banks and longshore | On promontories at estuary mouths with near-parallel or radiating ridges and slacks | More common with onshore prevailing and dominant, but not restricted to this | Forvie, Strathbeg, South Haven Penin-sula, Moth Harlech, Holy Island (Goswick and the Snook), Culbin, Morrich More |
| Prograding ness dunes | Accretion at ness, possibly with longshore sediment supply from opposite directions alongshore | On open coast | Prevailing and dominant winds from opposite directions (offshore/ onshore) | Winterton Ness, Barry Links, Tentsmuir |
| Offshore island dunes | Offshore, longshore and intertidal drying banks | Offshore or barrier islands narrow, subject to washover, often display time- series development in main direction of longshore transport | Can occur with both onshore and offshore prevailing winds | Scolt Head Island, Blakeney Point recurves (North Norfolk Coast), Pembrey (Carmarthen Bay), Culbin, Morrich More |
| **Hindshore dunes** | | | | |
| Bay dunes | Restricted in longshore direction | Usually at bay head on indented coasts | Prevailing onshore | Dunnet Bay, Luce Sands, Upton and — Gwithian Towans, Tywyn Aberffraw, Oxwich Bay Sandwood, Balta Island, Torrisdale Bay and Invernaver |

| | | | | |
|---|---|---|---|---|
| Hindshore dune system | Offshore and intertidal | Extensive sandy coasts | Prevailing and dominant winds from the same direction | Braunton Burrows, Newborough Warren, Ainsdale, Holy Island (Ross Links) |
| Hindshore sand plains | Offshore, intertidal and beach | Bay-head and low- lying rocky coasts | High wind-speeds that restrict vertical development | Tywyn Aberffraw |

**(Table 7.2) Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage.** It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in bold typeface.

| **Site** | **Main features** | **Other features** | **Present-day sediment sources** | |
|---|---|---|---|---|
| **Marsden Bay** | Beach phases | Cliffs and stacks | Local cliff erosion — small | 4.2 |
| **South Haven Peninsula** | Shore-parallel dune ridges, originating from the 16th century, slacks, sand-spit | Relict and active cliffs., caves, rock platform | Longshore — restricted Offshore — significant | 1.5 |
| **Upton and Gwithian Towans** | Climbing dunes, exhumed bedrock base | Stacks | Offshore — restricted | 5.8 |
| **Braunton Burrows** | Large dune field, parabolic dunes, slacks | Ridge and runnel | Intertidal and estuarine | 7.3 |
| **Oxwich Bay** | Bay-head beach and dunes | Cliffs and emerged platform | Offshore — limited | 8.2 |
| **Tywyn Aberffraw** | Sand plain, isolated parabolic dunes shore-parallel linear dunes | | Offshore, probably in deficit | 4.7 |
| **Ainsdlale** | Large dune field, slacks, ridge and runnel, long dated history | | Offshore — limited — in deficit | 8.3 |
| **Luce Sands** | Bay-head dunes | Holocene emerged gravel ridges | Onshore and longshore — significant | 5.6 |
| **Sandwood Bay** | Dynamic beach-dune complex, climbing dunes | Gravel-cored bar, blowouts | Offshore and recycled — limited | 4.2 |
| **Dunnet Bay** | Bay-head dunes and sand plain | Blowouts | Offshore — limited | 4.0 |
| **Baba Island** | Climbing dunes | Beach-dune-grassland continuum | Local — limited | 1.9 |
| **Strathbeg** | Shore-parallel dune ridges, large blowouts | Holocene emerged gravel ridges | Longshore — restricted, loch outlet source | 3.3 |
| **Forvie** | Shore-parallel dune ridges, originally moved as waves northwards | | Longshore — cycled from estuary | 3.1 |
| **Barry Links** | Foreland sand plain, linear parabolic dunes | | Estuarine, longshore — limited | 4.4 |
| **Tentsmuir** | Shore-parallel dune ridges-intertidal sands | | Estuarine and longshore — significant | 4.4 |

| | | | | |
|---|---|---|---|---|
| **Torrisdale and Invernaver** | Beach-dune, hill-top dunes, glaciofluvial terraces | Archaeological context | Offshore and fluvial recycled — now limited | 4.0 |
| Morrich More | Shore-parallel beaches and dunes: sandplain | Holocene beaches and cliffs | Offshore — restricted | 4.3 |
| Culbin | Shore-parallel dunes, large dune field now stabilized by forest | Holocene emerged gravel ridges and spits | Longshore -restricted, offshore — limited | 3.6 |
| East Head | Small spit-based dunes | | Intertidal | 3.4 |
| Holy Island | Dune field, spits, barrier beach | Cliffs, Holocene saltmarsh, intertidal mudflats | Longshore, offshore — significant | 4.1 |
| Dawlish Warren | Parallel spit-based linear dunes | Recurved spit | Intertidal and possibly estuarine In deficit | 4.1 |
| North Norfolk Coast | Major mainly linear dunes | Spits, barrier beach | Longshore and offshore | 6A-4.7 |
| Morfa Harlech | Linear shore-parallel dunes | | Longshore — restricted, estuarine | 4.5 |
| Morfa Dyffryn | Linear shore-parallel dunes, blowouts, dunes invading slacks | | Longshore — restricted, offshore | 4.3 |
| Winterton Ness | Linear dunes on cuspate foreland | | Longshore | 2.6 |
| Ynyslas | Spit-based dunes | | Longshore — restricted, estuarine | 4.3 |
| Carmarthen Bay | | | | |
| Pendine | Shore-parallel linear dunes | | Offshore, estuarine to distal end | 8.0 |
| Pembrey | Large dune field, spit-based linear dunes | | Offshore and estuarine | 8.0 |
| Whitford spit | Estuary-mouth spit | | Longshore, drying intertidal | 8.0 |
| Laugharne Burrows | Cliff-top dunes | | Local redistribution, drying intertidal | 8.0 |
| Newborough Warren and Morfa Dinlle | Major dune field, parabolic and linear dunes, spit, tied island and slacks | Saltmarsh | Offshore and estuarine | 4.7 |

**(Table 7.3) Calcium carbonate content of upper beach/foredune in selected coastal geomorphology GCR sites.** Sites described in the present chapter are in bold typeface. (Based in part on Goudie, 1990, and various sources cited by Ritchie and Mather, 1984.)

| **Dune location** | **$CaCO_3$ (%)** | **Median grain size (Phi)** |
|---|---|---|
| Culbin | 0.0 | 2.0 |
| South Haven Peninsula | 0.015 | ? |
| Lossiemouth | 0.26 | 2.0 |
| Tentsmuir | 0.4 | 2.5 |
| Luce Sands | 0.5 | 2.4 |

| | | |
|---|---|---|
| Forvie | 0.55 | 1.9 |
| Buddon Ness (Barry Links) | 1.0 | 2.0 |
| Walney Island | 1.51 | 2.21 |
| Morfa Dyffryn | 3.34 | 2.31 |
| Ainsdale | 3.57 | 2.13 |
| Invernaver | 3.8 | 1.9 |
| Morfa Harlech | 3.96 | 2.13 |
| Newborough Warren | 4.56 | 2.50 |
| Ynyslas | 4.98 | 2.29 |
| Strathbeg | 7.86 | 2.0 |
| Rattray (Strathbeg site) | 9.10 | 1.9 |
| Laugharne (Pendine)* | 11.15 | 2.40 |
| Morrich More | 12.0 | 2.4 |
| Pembrey* | 12.04 | 2.33 |
| Oxwich Bay | 12.45 | 1.93 |
| Tywyn Aberffraw | 13.20 | 2.47 |
| Llangennith* | 15.65 | 1.63 |
| Braunton Burrows | 19.59 | 2.13 |
| Dunnet Bay | 20.4 | 1.7 |
| Dunbar | 20.4 | 1.5 |
| Westward Ho! | 21.79 | 2.45 |
| Machir, Islay | 33.6 | 2.2 |
| Mangersta, Lewis | 38 | 1.4 |
| Luskentyre, Harris | 44 | 2.0 |
| Tràigh na Berie, Lewis | 47 | 2.4 |
| St. Ninian's Tombolo, Shetland | 47.5 | 2.0 |
| Balnakiel | 52.0 | 1.8 |
| Hayle (Upton and Gwithian Towans) | 56.80 | 1.56 |
| Loch Gruinart, Islay | 59.0 | 2.1 |
| Eoligarry, Barra | 80.0 | 2.0 |
| Ardivachar, South Uist | 84.0 | 1.7 |
| Balta Island, Shetland | 95.5 | 1.8 |

*Camarthen Bay

**(Table 7.4) Variations in calcium carbonate content and pH in foredunes and main dunes.** (Based on Salisbury, 1952; and Willis, 1985)

| **Location** | **Calcium carbonate** | **content of dunes** | **pH** | |
|---|---|---|---|---|
| | Foredunes | Main dunes | Foredunes | Main dunes |
| South Haven Peninsula | 0.015 | 0.01 | 7.0 | 3.6 |
| Southport (near Ainsdale) | 6.0 | 0.2 | 8.2 | 5.5 |
| Braunton Burrows | 20.0 | 8.5 | 9.05 | 8.2 |
| Blakeney Point, North Norfolk Coast | 0.6 | 0.02 | 7.3 | 4.2 |

**(Table 7.5) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features.** Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| **SAC name** | **Local authority** | **Dune habitat extent (ha)** |
|---|---|---|
| **Barry Links** | Angus | 447.6 |

| | | |
|---|---|---|
| **Braunton Burrows** | Devon | 767.5 |
| **Carmarthen Bay Dunes/Twyni Bae Caerfyrddin** | Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire | 780.2 |
| Coll Machair | Argyll and Bute | 409.0 |
| **Culbin Bar** | Highland; Moray | 612.9 |
| **Dawlish Warren** | Devon | 28.2 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 4.0 |
| **Dornoch Firth and Morrich More** | Highland | 974.4 |
| **Dorset Heaths (Purbeck and Wareham) and Studland Dunes** | Dorset | 95.9 |
| Drigg Coast | Cumbria | 519.8 |
| Durness | Highland | 386.7 |
| **Humber Estuary*** | City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire | 529.0 |
| **Invernaver** | Highland | 54.2 |
| **Kenfig/ Cynffig** | Pen-y-bont ar Ogwr/ Bridgend | 673.8 |
| **Limestone Coast of South West Wales/ Arfordir Calchfaen de Orllewin Cymru** | Abertawe/ Swansea; Penfro/ Pembrokeshire | 397.1 |
| Monach Islands | Western Isles / Na h-Eileanan an Iar | 215.1 |
| **Morecambe Bay** | Cumbria; Lancashire | 220.5 |
| **Morfa Harlech a Morfa Dyffryn** | Gwynedd | 228.6 |
| **North Norfolk Coast** | Norfolk | 387.3 |
| **North Northumberland Dunes** | Northumberland | 1078.6 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 963.3 |
| **Oldshoremore and Sandwood** | Highland | 165.3 |
| Penhale Dunes | Cornwall | 422.4 |
| **Saltfleetby-Theddlethorpe Dunes and Gibraltar Point** | Lincolnshire | 265.6 |
| **Sands of Forvie** | Aberdeenshire | 469.7 |
| Sandwich Bay | Kent | 258.3 |
| **Sefton Coast** | Sefton | 1072.7 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 113.2 |
| **Solway Firth** | Cumbria; Dumfries and Galloway | 32.6 |
| **South Uist Machair** | Western Isles / Na h-Eileanan an Iar | 545.7 |
| Tiree Machair | Argyll and Bute | 237.4 |
| **Torrs Warren-Luce Sands** | Dumfries and Galloway | 819.5 |
| **Winterton-Horsey Dunes** | Norfolk | 44.7 |
| **Y Twyni o Abermenai i Aberffraw/ Abermenai to Aberffraw Dunes** | Gwynedd; Ynys Mon/ Isle of Anglesey | 672.3 |
| * Possible SAC not yet submitted to EC. | Bold type indicates a coastal GCR interest within the site. | |

**(Table 8.1) The main features of sediment sources and tidal ranges of sand spit GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain important sand spit structures in the assemblage of features**. Many machair sites have small sandspits — see Chapter 9. (Sites described in the present chapter are in bold typeface )

| Site | Main features | Other features | Present-day natural sources of sediment | Tidal range (m) |
|---|---|---|---|---|
| Pwll-ddu | Sand spits | | Local fluvial and shallow nearshore | 8.2 |
| Ynyslas | Sand spit | Dunes | Estuarine, longshore (reduced) | 4.1 |
| East Head | Sand spit, distal dunes | | Restricted alongshore: mainly from offshore banks | 3.4 |
| Spurn Head | Major spit in macro-tidal environment | Dunes | Longshore and offshore | 6.4 |
| Dawlish Warren | Sub-parallel double spit | Dunes | Intertidal banks | 4.1 |
| Gibraltar Point | Series of spits, effects of extreme events | Dunes | Longshore and offshore banks | 7.0 |
| Walney Island | Barrier islands recurved spits | Till cliffs | Cliff erosion | 9.0 |
| Winterton Ness | Linear dunes on cuspate foreland | | Longshore | 2.6 |
| Morfa Harlech | Spits and recurves, ridge and runnel | Dunes | Longshore limited, intertidal estuarine banks | 4.5 |
| Morfa Dyffryn | Tombolo and dunes, sam | Dunes | Longshore limited, offshore possible but unconfirmed | 4.3 |
| St Ninian's Tombolo | Tombolo | Dunes, climbing dunes | Nearshore and some local reworking | 1.1 |
| Isles of Scilly | Tied islands, spits | Emerged beach | Local feeder cliffs and platforms | 5.5 |
| Central Sanday | Tombolos, spits, sandflats, dunes | Gravel ridges, machair, dunes | Local reworking and nearshore machair | 3.0 |
| Eoligarry | Emerged tombolo | Sand dunes and machair, bowthroughs | Local and offshore, biogenic sources from the east | 4.0 |
| Culbin | Bluckie Lock spit | Emerged gravel strand-plain, dunes, saltmarsh | Nearshore and erosional recycling | 3.6 |
| Morrich More | Innis Mhór sand spit | Emerged strandplain, dunes, saltmarsh | Fluvial, glaciogenic and offshore | 4.3 |
| Tentsmuir | Shore-parallel dune ridges, ness | Sand dunes, intertidal sands | Estuarine and longshore, significant | 4.4 |
| Luskentyre–Corran Seilebost | Sand spit | Sand dunes and machair | Nearshore, intertidal to the east | 3.8 |
| Forvie | Shore-parallel dune ridges, spit | Unvegetated and parabolic dunes | Longshore and recycled from estuary | 3.1 |
| Torrisdale Bay | Dune landforms, climbing dunes | Sandspits, intertidal sandflats, saltmarsh | Fluvial and offshore, limited | 4.0 |
| Holy Island | Barrier beaches, spits | Emerged beach, dunes | Longshore and offshore | 4.1 |
| Scolt Head Island, North Norfolk | Barrier beach, recurved spits | Dunes | Longshore and offshore | 5.6 |
| Newborough Warren | Spits, modem and relict | Dunes | Intertidal estuarine banks offshore, local reworking | 4.7 |

| | | | | |
|---|---|---|---|---|
| Carmarthen Bay | Spits | Dunes, cliffs | Fluvial/estuarine, offshore and intertidal banks, local reworking | 8.0 |
| Braunton Burrows | Distal estuarine shore-parallel spit | Dunes | Fluvial/estuarine, offshore and intertidal banks, local reworking | 7.3 |

**(Table 8.2) Area of East Head — historical data from 1846 to 1996**

| **Date** | **Area (ha)** | **Data source** |
|---|---|---|
| 1846 | 8.9 | Tithe map: property 541 |
| 1875 | 5.3 | OS Area 83 |
| 1898 | 6.5 | OS Area 310 |
| 1911 | 2.3 | OS Areas 310 and 310a |
| 1933 | 17.5 | OS Areas 309a, 310 and 310a |
| 1975 | 30.7 | Searle (1975) |
| 1996 | c. 40 | May (1997b) |

**(Table 9.1) Machair GCR sites**

| **Machair site** | **Main features** | **Other features** | **Tidal range (m)** |
|---|---|---|---|
| Machir bay | Beach–dune–machair, high-level machair terraces, emerged beaches | Climbing dunes | 3.0 |
| Eoligarry | Vigorous erosional machair forms large blowouts, tombolo structure | Storm beach, wide intertidal, sheltered beach, archaeological dating | 4.0 |
| Ardivachar–Stoneybridge | Machair type site, high and low machair deflation corridors | Archaeological dating gravel barrier, palaeosols ' | 3.6 |
| Hornish and Lingay Strands | Flat, low-lying machair, water-table effects | Superimposed small dunes, artificial drainage | 3.9 |
| Pabbay | Climbing machair, conical dunes, wet machair | No rabbits | 3.0 |
| Luskentyre–Seilebost | Large beach-dune machair remnant of former larger system, 35m high dunes; growth/decay model site | Spits, blowouts | 3.8 |
| Mangersta | Eroded and deflated formerly extensive machair, advanced stage of erosion | Water table | 3.8 |
| Tràigh na Berie | Large dynamic beach–dune–machair dune cordon intact and well-nourished | Infill of valleys and lochs, no chronic erosion | 3.8 |
| Balnakeil | Dynamic climbing machair and dune blowouts, headland by-passing of sediment | Erosion of frontal edge, sand-fall over cliff | 4.0 |

**(Table 9.2) Candidate Special Areas of Conservation supporting Habitats Directive Annex I habitat 'Machair' as a qualifying European feature.** (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Machair extent (ha) |
|---|---|---|
| Coll Machair | Argyll and Bute | 681 |
| Monach Islands | Western Isles / Na h-Eileanan an Iar | 292 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 1707 |
| **Sheigra–Oldshoremore** | Highland | 222 |
| **South Uist Machair** | Western Isles / Na h-Eileanan an Iar | 1785 |
| Tiree Machair | Argyll and Bute | 510 |

Bold type indicates a coastal GCR interest within the site

**(Table 10.1) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal saltmarsh habitat(s) as qualifying European features.** Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| **SAC name** | **Local authority** | **Saltmarsh extent (ha)** |
|---|---|---|
| **Alde, Ore and Butley Estuaries** | Suffolk | 390 |
| **Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd** | Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire; Penfro/ Pembrokeshire | 2764 |
| **Chesil and the Fleet** | Dorset | 21 |
| **Culbin Bar** | Highland; Moray | 203 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 2431 |
| **Dornoch Firth and Morrich More** | Highland | 539 |
| Drigg Coast | Cumbria | 162 |
| **Essex Estuaries** | Essex | 3770 |
| Fal and Helford | Cornwall | 70 |
| **Glannau Môn (Cors heli)/Anglesey Coast (Saltmarsh)** | Ynys Môn/ Isle of Anglesey | 191 |
| **Humber Estuary*** | City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire | 840 |
| Kenfig/ Cynffig | Pen-y-bont ar Ogwr/ Bridgend | 20 |
| Mòine Mhór | Argyll and Bute | 94 |
| **Morecambe Bay** | Cumbria; Lancashire | 1897 |
| **North Norfolk Coast** | Norfolk | 19 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 82 |
| **Pembrokeshire Marine/ Sir Benfro Forol** | Penfro/ Pembrokeshire | 274 |
| **Pen Ll■n a'r Sarnau/Lleyn Peninsula and the Sarnau** | Ceredigion; Gwynedd; Powys | 748 |
| **Plymouth Sound and Estuaries** | Cornwall; Devon; Plymouth | 192 |
| Severn Estuary/ Môr Hafren* | Bro Morgannwg/Vale of Glamorgan; Caerdydd/ Cardiff; Casnewydd/Newport; City of Bristol; Fynwy/ Monmouthshire; Gloucestershire; North Somerset; Somerset; South Gloucestershire | 656 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 2276 |
| **Solway Firth** | Cumbria; Dumfries and Galloway | 4171 |

| | | |
|---|---|---|
| **The Wash and North Norfolk Coast** | Lincolnshire; Norfolk | 3341 |

* Possible SAC not yet submitted to EC.

Bold type indicates a coastal GCR interest within the site

**(Table 10.2) Characteristic geomorphological features of some of the main Solway Firth saltmarshes.**

| | **Rockcliffe** | **Burgh** | **Moricambe Bay** | **Caerlaverock** | **Cree** |
|---|---|---|---|---|---|
| **Type** | Fringing estuary | Fringing estuary | Fringing estuary, bay | Fringing estuary, transitional | Fringing estuary, bay |
| **Marsh-edge morphology** | Low cliffs and terraces | Low cliffs and terraces, locally ramped | Low cliffs and terraces, locally ramped | Low cliffs and terraces, rarely ramped | Ramped, locally cliffs and terraces |
| **Creek system** | Dendritic | Modified dendritic | Dendritic | Dendritic | Dendritic |
| **Saltpans** | Common | Common | Common | Infrequent | Common |
| **Age of active marsh** | >200 years | Unknown | Unknown | Pre-mid 19th century | Unknown |
| **Mean sediment type** | | | | | |
| **Upper marsh** | Sandy silt | Sand:fine sand /silt: clay | Sand:fine sand/silt: clay | Sand:silt:clay | Fine sand |
| **Marsh edge** | Sandy silt | Sandy silt | Sandy silt | Fine sand | Fine sand |
| **Upper tidal flat silt** | Sand to sandy | Sand to silty sand | Silty sand | Fine sand | Sand and gravel |

**(Table 10.3) Estimated areal accretion in hectares between 1864 and 1946, 1946 and 1973, 1973 and 1993 for selected inner Solway saltmarshes.** (Based on data from Marshall, 1962; Rowe, 1978 and Pye and French, 1993.) All areas in ha. Caerlaverock Marsh is in the Solway Firth (north shore) GCR site.

| Marsh | 1864 | 1946 | 1993 | 1894–1964 | 1946–1973[1] | 1946–1993[2] |
|---|---|---|---|---|---|---|
| Rockcliffe | 664 | 709 | 565 | +45 | +414 | –144 |
| Burgh | 688 | 534 | 524 | –154 | –82 | –10 |
| Skinburness | 445 | 506 | n/a | +61 | +100 | n/a |
| Caerlaverock | 194 | 607 | 563 | +413 | –93 | –44 |

[1] Rowe (1978)

[2] Pye and French (1993)

**(Table 11.1) Main geomorphological features of the 'Coastal Assemblage' GCR sites.**

| **Site** | **Main geomorphological features** | **Tidal range (m)** |
|---|---|---|
| Culbin | Extensive dune system with dunes up to 30m high; parabolic dunes; emerged gravel strandplain and spits; sandy spits; gravel spits; extensive intertidal sandflats and saltmarshes; westerly shift. | 3.6 |
| Morrich More | Emerged sandy coastal strandplain with interdigitated saltmarsh and sandy beaches on either flank; offshore sandy islands and spit; large parabolic dune system; 1 km width intertidal sandflats in Dornoch Firth. | 3.4 |

| | | |
|---|---|---|
| Carmarthen Bay | Major dunes; sand-spits and barrier beaches; hard-rock and easily eroded cliffs; rias; emerged beaches; extensive intertidal sandflats; and saltmarshes. | 8.0 – |
| Newborough Warren and Morfa Din& | Major dunes (linear and parabolic); Holocene dunes; gravel spits; hard-rock and easily eroded cliffs; extensive intertidal sandflats; estuary; saltmarshes. | 4.2 |
| Holy Island | Barrier beaches; spits; emerged beach; longshore and offshore sediment sources (Huddart and Glasser, 2002) | 4.1 |
| North Norfolk Coast | Scolt Head Island, a major barrier island; Blakeney Point, a large shingle spit; intertidal flats; beaches; dunes; saltmarshes; cliffs. One of the few areas on the coastline of England and Wales where saltmarsh morphology, including saltpans, has been examined in detail. | 6.4 (west) to 4.7 (east) |
| The Dorset Coast: Peveril Point to Furry Cliff | Differential erosion to a longitudinal coastline; includes such classic landforms as Lulworth Cove. Hard-rock and soft-rock cliffs; platforms; landslides; pocket beaches; chines; submerged rock barriers. | 1.7 (east) to 2.0 (west) |

**(Table 11.2) CORINE categories, data for the Carmarthen Bay, North Norfolk Coast, Purbeck (Dorset Coast) and Newborough Warren/Morfa Dinlle GCR sites;** measurements are in km.

| | **CORINE categories** | **Carmarthen Bay** | **North Norfolk** | **Purbeck** | **Newborough Warren and Morfa Dinlle** |
|---|---|---|---|---|---|
| (A) | Hard-rock cliffs (with fringing beaches) | 10 | 0 | 7 | 4 |
| (B) | Soft rock cliffs (with fringing beaches) | 1(1) | 2(1) | 21(4) | 1 |
| (C) | Pocket beaches | 1 | 0 | 3 | 0 |
| (D) | Coarse elastic beaches | 2 | 3 | 0 | 1 |
| (E) | Sandy beaches | 9 | 13 | 0 | 5 |
| (G) | Foreshores: fine sediments | 4 | 11 | 11 | 1 |
| (H) | Estuary | 2 | 1 | 1 | 1 |
| (J) | Port/harbour zone | 3 | 0 | 0 | 0 |
| (L) | Embankment | 0 | 1 | 1 | 1 |
| (I) | Mixed beaches | 0 | 2 | 2 | 0 |
| | Mean segment length (km) | 2.25 | 1.47 | 1.42 | 2.30 |
| | Total segments | 32 | 35 | 31 | 14 |

**(Table 11.3) Summary of saltmarsh development in north Norfolk**

| Time | Development |
|---|---|
| 7500 years ago | First signs of marine incursion at c. –7 m OD |
| Until 5500 years ago | Sediments accumulate as sea level rises |
| Between 5500 and 4500 years ago | Peats within saltmarsh muds and silts imply stability or perhaps fall in sea level |
| About 4000 years ago | Barrier features at Scolt Head and Blakeney probably in place (Allison, 1989) |
| About 3000 years ago | Coastline at Holkham is 3km north of its present position |
| About 2000 years ago | Romano-British remains indicate inner marshes at Brancaster and Burnham |
| Last few hundred years | Outer marshes develop at Scolt Head Island, Blakeney and at Warham |
| Since 1900 | Open coast marshes grow rapidly with Spartina colonization between Wells and Stiffkey |
| Since 1950 | New marshes at western Scolt, Thornham, Morston, western Blakeney. Dune ridges transgressing onto marsh at Brancaster |

**(Table 11.4) Rates of cliff-top retreat since c. 1900 on the Dorset Coast.**

| Mean annual rate (m $a^{-1}$) | Rock type | Location of retreat |
|---|---|---|
| 0.01 | Portland Stone | Durlston Head to Winspit |
| 0.18 | Chalk | Hambury Tout to White Nothe |
| 0.22 | Chalk | Worbarrow Bay |
| 0.25 | Purbeck Beds | Durlston Bay |
| 0.37 | Jurassic clays | Furzy Cliff to Shortlake |
| 0.38 | Wealden | Worbarrow Bay |
| 0.39 | Kimmeridge clays and shales | Kimmeridge |
| 0.41 | Kimmeridge clays | Ringstead |
| 0.43 | Kimmeridge clays | Chapman's Pool |
| 0.50 | Wealden | Lulworth Cove |

**Table 1.1** Number of items in the computerized bibliography of geomorphology of Britain that are classified as 'Coasts' (total 1400), by year of publication.

| Year | Items |
|---|---|
| 1830–1859 | 5 |
| 1860–1899 | 15 |
| 1900–1909 | 1 |
| 1910–1919 | 10 |
| 1920–1929 | 24 |
| 1930–1939 | 36 |
| 1940–1949 | 28 |
| 1950–1954 | 68 |
| 1955–1959 | 73 |
| 1960–1964 | 102 |
| 1965–1969 | 86 |
| 1970–1974 | 121 |
| 1975–1979 | 197 |
| 1980–1984 | 229 |
| 1985–1989 | 209 |
| 1990–1994 | 68 |
| 1995–1999 | 102 |

**Table 1.2** Number of items under selected keywords (some items appear more than once as several keywords are allocated to each).

| | |
|---|---|
| Beach | 284 |
| Erosion | 267 |
| Sea level | 186 |
| Cliffs | 126 |
| Saltmarsh | 104 |
| Sand dunes | 90 |
| Gravel/Shingle | 86 |
| Littoral/Longshore drift | 79 |
| Coastal protection | 74 |
| Spit | 66 |
| Coastal platform | 42 |
| Accretion | 27 |
| Sediment cell | 3 |

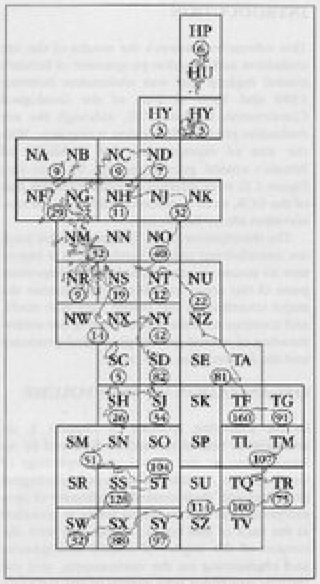


**Figure 1.1** Geographical distribution of UK coastal research, based on a comprehensive computerized bibliography of books and papers on the geomorphology of the British Isles, containing some 9000 entries, compiled by K.M. Clayton. Of the 9000 entries, some 1400 are classified as dealing with coasts. These in turn are indexed under the 100 km squares of the National Grid and the number of published articles is shown (encircled number) for each relevant National Grid square, or combination of National Grid squares. As the map shows, they are strongly biased to the southern half of Britain. Because some articles cover the coast in more than one grid square, the total number of entries on this map is 1671.

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As Figure 1.1 shows, the geographical distribution of published coastal research is very uneven, with a clear bias to the south and east. The largest numbers are for TF (Lincolnshire, The Wash and North Norfolk) and SS (north and southern shores of the Bristol Channel).

Of course the length of coastline within a grid



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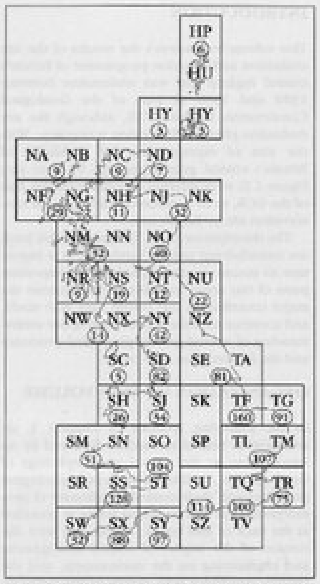


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*(Table 1.2) Number of items under selected keywords (some items appear more than once as several keywords are allocated to each).*

**Table 1.3** Geographical analysis of the British coastal literature, using selected grid squares only.

| Grid square | Estimated length of coastline | Number of publications | Coastline length per number of publications |
|---|---|---|---|
| SY (Dorset) | 110 km | 97 | 1.13 km |
| TM (Suffolk/Essex) | 120 km | 95 | 1.26 km |
| SD (Lancashire/S. Cumbria) | 150 km | 82 | 1.83 km |
| SN (Fishguard to Aberdovey) | 95 km | 35 | 2.71 km |
| NJ (south side of Moray Firth) | 100 km | 22 | 4.55 km |
| NZ (Durham/North Yorkshire) | 130 km | 18 | 7.22 km |
| NC (Sutherland) | 150 km | 9 | 16.67 km |

square varies considerably, but if we take the following examples of grid squares that have a generally linear coast without long indentations, we find the pattern set out in Table 1.3. Clearly in this analysis, such coasts as Dorset, Suffolk/Essex and Lancashire/south Cumbria are among the most studied, whereas Sutherland is among the least. Therefore, Figure 1.1 helps to highlight those areas of the British coast that are better understood geomorphologically, and, perhaps, identifies those areas where further study may help us to gain a more complete understanding of the coastal geomorphology of Britain.

## THE GEOLOGICAL BACKGROUND

*K.M. Clayton*

The pattern of geological outcrops along the British coast (Figure 1.2) has a fundamental control on the nature of the coastline. This is for several reasons, outlined below.

- **Coastal topography**: Underlying geology has influenced the topography of the land, and the detailed outline of the coast in large part reflects the relief of the littoral zone. Rocks that are susceptible to erosion tend to form bays and inlets, whereas erosion-resistant rocks form headlands. Local differences in the level to which outcrops adjacent to the coast have been lowered by subaerial erosion – and the impact of such differences on the coastal form – are seen best along the English Channel coast, such as along the coast of Dorset, or demonstrated in such contrasting situations as Beachy Head and the adjoining Pevensey Levels.
- **Dissection in rocks of different strengths**: Where relatively erosion-resistant rocks have been deeply dissected by erosion, the coastal outline is complex, such as in western Scotland. Where weaker rocks have been dissected, former headlands and bays may have been truncated by marine erosion, such as the Seven Sisters in Sussex.
- **Geological control on cliff profile**: Rocks of all strengths can be cut back by erosion to form cliffs, but weaker rocks generally fail more readily and so form sloping cliffs with angles from 20° to 40°, whereas erosion-resistant rocks are more likely to form near-vertical cliffs, such as at Duncansby, Caithness. In the more resistant rocks, the details of bedding and jointing commonly influence cliff form, both in plan and profile; thus seaward-dipping rocks are likely to suffer slide failure as basal erosion persists, leading to gentler slopes than on horizontal or landward-dipping strata.
- **Lithological control of landsliding**: Where weak rocks underlie stronger ones, landslides are likely to occur; good examples are Folkestone Warren, now largely controlled by drainage and 'toe loading', and Ventnor–Shanklin on the Isle of Wight, where seaward-

Overleaf:
**Figure 1.2** Geological map of Great Britain, also showing the locations of the Coastal Geomorphology GCR Sites. The map shows sedimentary rocks classified according to their age of deposition and igneous rocks according to their mode of origin. The numbers in the key indicate age in millions of years (Ma). (Permit number IPR/26-45C British Geological Survey 



(Table 1.3) Geographical analysis of the British coastal literature, using selected grid squares only.

**Table 1.4** General order of resistance to erosion of British rock types (from Clayton and Shamoon, 1998).

**Very Resistant:** Precambrian metamorphosed sediments, Cambrian quartzite and sandstone, Ordovician tuff.

**Resistant:** Old Red Sandstone, Lower Palaeozoic slates, Palaeozoic basalt and andesite.

**High Average:** Skiddaw slate, Millstone Grit, Carboniferous limestone, Yoredale series.

**Low Average:** Palaeozoic shale, Coal Measures, Devonian greywackes, Tertiary basalts.

**Weak:** Magnesian (Permian) limestone, Jurassic limestone, Hastings Beds, Chalk.

**Very Weak:** Mesozoic and Cainozoic mudrocks, Thanet sand.

northern and western Britain and the younger and weaker rocks found in east and southern England, within each of these zones local contrasts dominate the coastal geomorphology. From Flamborough Head in Yorkshire southwards and westwards to the Exe estuary in Devon, the Chalk and sandstones that form the cuestas of the scarpland and vale landscape also form the major coastal headlands (Flamborough Head, North Foreland in Kent, Beachy Head in Sussex, and the Needles on the Isle of Wight, for example, all on Chalk) and between them on the intervening clays or on till-covered littoral plateaux, wide bays, locally fronted by salt-marshes and sand dunes, alternate with low cliffs cut into the low till-capped plateaux of Holderness, Norfolk and Suffolk.

## Geological influence on sediment supply into the coastal system

A further influence of geology on coastal geomorphology is in the provision of sediment that can be incorporated into beaches. Beaches around Britain vary considerably in their texture (from fine-grained sand to boulders) and in their lithology (from shelly sands to flint cobbles) and reflect the local supply of material of appropriate dimensions. Some coarse sediments are still brought to the coast by rivers, especially in Scotland and Wales, where gradients are steep and coarse-grained material is readily transported by floods. In contrast, very little sediment other than mud (clay and silt) is now brought down the rivers of lowland Britain to the coast. Thus, especially in areas with more gentle inland relief, it is the delivery of sediment from offshore as well as from retreating cliffs that has provided most of the material for the local beaches. Boulders and coarse gravel are derived from erosion of resistant rocks in areas such as Scotland and parts of the Welsh coast, their initial size depending on rock-joint spacing. Locally along the English coast, quartzites are the source of coarse gravel (e.g. at Budleigh Salterton); flints form the commonest pebbles and cobbles on beaches in the south of England.

Many 'shingle' (gravel) beaches (such as Slapton Sands in Devon, Chesil Beach in Dorset and Blakeney Point in Norfolk) have been built from offshore gravels, swept ashore as sea level rose during the Holocene marine transgression, and former sea-floor sediment has contributed to many beaches elsewhere (see Figure 6.2). In places, flints are derived from erosion of the Chalk in which they occur. Indeed, Chalk cliffs are generally associated with flint beaches because eroded Chalk debris is quickly broken down by wave action so that Chalk cobbles form a minor part of the beach material. Most flint in English beaches is secondarily derived from quite a wide range of intermediate sources. These include the Pebble Beds of the Tertiary succession of south-east England, where the 'Pebbles' are either derived directly from local erosion, or through their incorporation into river gravels, such as the sequence of Early Pleistocene river terraces – attributed in part to the River Thames – cropping out in Essex, Suffolk and Norfolk. Thus at Dunwich, the cliff contributes flints from gravels at the top of the exposure that were deposited by the ancient River Thames. In contrast, with no local landward source, the flints that dominate Slapton Sands must have been brought ashore from an offshore source. The former river concerned flowed down the English Channel, no doubt fed by such tributaries as the present-day Seine, Rhine and Thames at a time when much of the present-day area of the North Sea was occupied by an ice sheet.

Farther north in England, while we cannot rule out such offshore sources, a large proportion of the gravel has been eroded from glacial gravels and till cropping out along the coast or



*(Table 1.4) General order of resistance to erosion of British rock types (from Clayton and Shamoon, 1998).*

cussion of managed re-alignment and coastal zone management and Viles and Spencer (1995) discuss coastal problems.

Steers provides descriptive texts on the coastlines of England and Wales (1964a) and Scotland (1973).

## GCR SITE SELECTION GUIDELINES

*V.J. May and N.V. Ellis*

The GCR site-selection exercise for coastal geomorphology followed four categories ('GCR Blocks'), one for each of England, Scotland and Wales and one for 'Saltmarsh Geomorphology'; although three of the 'Blocks' are country based, comparisons were made to ensure that certain types of site occurring in each were not over-represented in a Great Britain-wide context.

Before site assessment and selection began, the first stage in the project was to apply the ethos of the GCR – outlined below – in order to fine-tune GCR selection-criteria. The coastal geomorphological literature was reviewed to identify the most cited sites to assist in the compilation of lists of candidate GCR sites. The GCR site selection work also included a survey of the morphodynamics of the whole coastline, carried out in conjunction with the CORINE coastal erosion project (European Commission, 1998), which provided a means by which to judge the 'representativeness' (see below) of the short-listed sites.

### Broad GCR site selection criteria

The general principles guiding GCR site selection are described in the introductory GCR volume (Ellis *et al.*, 1996), but can be encapsulated in three broad components:

- International geological or geomorphological importance (for example, internationally renowned 'type' sites, but other sites that have informal, but widely held, international recognition are also selected).
- Presence of 'classic' or exceptional features that are scientifically important (for example, 'textbook' examples of particular features or exceptionally unusual or rare types of features are included).
- Presence of representative Earth science features that are essential in comprehensively portraying Britain's Earth history. Thus, a site may be selected for showing the most complete regional representation of phenomena that are otherwise quite widespread.

It should be assumed that an 'internationally' rated site will also be representative of an event or process and may include exceptional features.

In order to ensure true national importance in the selected representative sites, site selection was underpinned by the premise that the *minimum number* of sites should be selected. By choosing only those sites absolutely necessary to represent the most important aspects of Britain's

**Table 1.5** Morphosedimentological classification of the British coast (based on European Commission (1998 – the CORINE project érosion cotière).

| Morpho-sedimentological type | Active (km) | Protected* (km) | Total (km) |
|---|---|---|---|
| Hard-rock cliffs | 7990 | 7 | 7997 |
| Soft-rock cliffs | 1401 | 221 | 1622 |
| Shingle beaches | 818 | 225 | 1043 |
| Sand beaches | 1274 | 302 | 1576 |
| Heterogeneous beaches | 415 | 126 | 541 |
| Beaches for which no data available | 59 | 0 | 59 |
| Muddy and estuarine coasts | 999 | 484 | 1483 |
| Totals | 12956 | 1365 | 14321 |
| Anthropogenic coasts (including harbours, land-claim) | | | 2096 |
| Total | | | 16417 |

* i.e. modified by coastal defence/protection works.



(Table 1.5) Morphosedimentological classification of the British coast (based on European Commission (1998 – the CORINE project érosion cotieré).

*(Table 1.6) Main features of each GCR Site, broadly following the classification of King, 1978, to show where different features are represented.*

designated solely because of their Earth science features have interesting wildlife and habitat features, underlining the inextricable links between 'the environment' and the underlying geology and geomorphology.

It is clear from the discussion in previous sections that the conservation interest of the geomorphological features is likely to be affected by shoreline management activities outside the site itself, especially where the GCR sites lie within larger sediment transport cells. However, since SSSI notification of GCR sites presently extends to mean low-water mark in England and Wales, and mean low-water of spring tides in Scotland, there is no statutory protection of the shallow water sediments that may be the main sediment source for beaches.

### *International measures*

Presently, there is no formal international conservation convention or designation for geological/geomorphological sites below the level of the 'World Heritage Convention' (the 'Convention concerning the Protection of the World Cultural and Natural Heritage'). World Heritage Sites are declared by the United Nations Educational, Scientific and Cultural Organisation (UNESCO). The objective of the World Heritage Convention is the protection of natural and cultural sites of global significance. Many of the British World Heritage sites are 'cultural' in aspect, but the Giant's Causeway in Northern Ireland and the Dorset and East Devon Coast are inscribed because of their importance to the Earth sciences as part of the 'natural heritage' – the Dorset and East Devon site is of particular relevance here insofaras it was the outstanding geology and coastal geomorphology that led to its inscription. The St Kilda World Heritage site certainly has an important geological component contributing to its status.

In contrast to the Earth sciences, there are many other formal international conventions –

**Table 1.7** Coastal Annex I habitats occurring in the UK (from McLeod *et al.*, 2002.)

| EU code | Habitat name | Lay name | Priority habitat/species | UK special responsibility |
|---|---|---|---|---|
| 1130 | Estuaries | Estuaries | | × |
| 1140 | Mudflats and sandflats not covered by seawater at low tide | Intertidal mudflats and sandflats | | |
| 1150 | Coastal lagoons | Lagoons | × | × |
| 1160 | Large shallow inlets and bays | Shallow inlets and bays | | × |
| 1170 | Reefs | Reefs | | × |
| 1210 | Annual vegetation of drift lines | Annual vegetation of drift lines | | |
| 1220 | Perennial vegetation of stony banks | Coastal shingle vegetation outside the reach of waves | | × |
| 1230 | Vegetated sea cliffs of the Atlantic and Baltic coasts | Vegetated sea cliffs | | × |
| 1310 | *Salicornia* and other annuals colonizing mud and sand | Glasswort and other annuals colonizing mud and sand | | |
| 1320 | *Spartina* swards (*Spartinion maritimae*) | Cord-grass swards | | |
| 1330 | Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*) | Atlantic salt meadows | | |
| 1420 | Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*) | Mediterranean saltmarsh scrub | | |
| 2110 | Embryonic shifting dunes | Shifting dunes | | |
| 2120 | Shifting dunes along the shoreline with *Ammophila arenaria* ('white dunes') | Shifting dunes with marram | | |
| 2130 | Fixed dunes with herbaceous vegetation ('grey dunes') | Dune grassland | × | × |
| 2140 | Decalcified fixed dunes with *Empetrum nigrum* | Lime-deficient dune heathland with crowberry | | |
| 2150 | Atlantic decalcified fixed dunes (*Calluno-Ulicetea*) | Coastal dune heathland | × | |
| 2160 | Dunes with *Hippophae rhamnoides* | Dunes with sea-buckthorn | | |
| 2170 | Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*) | Dunes with creeping willow | | |
| 2190 | Humid dune slacks | Humid dune slacks | | × |
| 21A0 | Machairs | Machair | | × |
| 2250 | Coastal dunes with *Juniperus* spp. | Dunes with juniper thickets | × | |
| 8330 | Submerged or partially submerged sea caves | Sea caves | | × |



(Table 1.7) Coastal Annex I habitats occurring in the UK (from McLeod et al., 2002.)

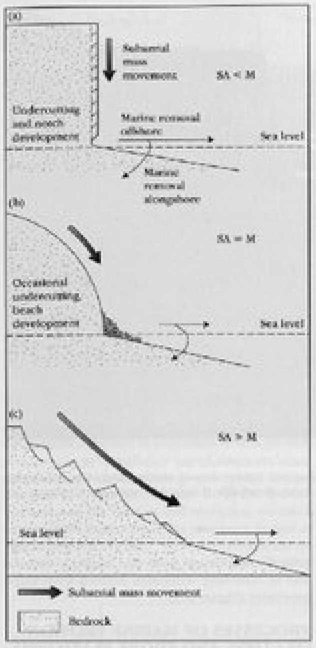


**Figure 2.3** Processes of cliff retreat. SA = subaerial erosion of material, symbolized by the large arrow; M = marine erosion, symbolized by the fine arrows = eroded material is removed offshore and alongshore by marine process. (a) SA<M; here steep cliffs, undercut by marine processes, develop. (b) SA=M; here a balance between the two sets of processes allows small beaches to develop at the toes of sloping cliffs; (c) SA>M; here subaerial mass movements by sliding produce a low stepped profile and marine transport of plentiful debris. On most coastal slopes, the rate of erosion of material falls far short of the ability of waves and tides to remove it, so that the slope angles are maintained (a,b). However, on weaker rocks (c) material is delivered at a rate controlled in large part by the ability of the sea to maintain removal and thus the rate of basal erosion, in which case slope angle will decline until sediment input matches the rate of removal. (After Hansom, 1988.)

**Table 2.1** Likely recession rates in different materials (compiled by Carter, 1988, from data in Sunamura, 1983).

| Lithology | Recession rate (m $a^{-1}$) |
|---|---|
| Granite | $10^{-3}$ |
| Limestone | $10^{-3}$ to $10^{-2}$ |
| Shales and flysch | $10^{-2}$ |
| Chalk | $10^{-2}$ to 1 |
| Tertiary sedimentary | $10^{-1}$ to 1 |
| Quaternary sedimentary | 1 to 10 |
| Recent volcanic rocks | 10 to $10^{2}$ |

retreat: the formation of tension cracks parallel to the erosion surface arises from reductions in confining pressures as surface rock is removed. The 1999 failure of the chalk cliff at Beachy Head is a good example of this process.

Deep-seated mass movements are common in some coastal regions, where geological conditions are suitable, particularly where the compressive strength of the rock is exceeded by the load it must bear. Easily sheared rocks with low bearing strength are particularly susceptible to landslides and, as a result, they are more frequent in soft rocks and less common in resistant rocks (Trenhaile, 1987). However, a relatively common type of landslide in hard rock occurs where the cliff is characterized by seaward-dipping beds or alterations of permeable and impermeable strata, or where massive rocks overlie rocks with low load-bearing strength. In such situations, translational slides and 'dip-slip' slides, where failure occurs along a slope-parallel failure surface or bedding plane, produce large but often shallow features whose failure may often have been triggered by high pore-water pressures following prolonged rainfall. Spectacular examples of such landslides occur in the 30° westward-dipping beds of the Aberystwyth Grits near Aberystwyth, Wales.

Brunsden (1973) and Brunsden and Jones (1976, 1980) showed how complex coastal slopes may develop on coastal landslides. The cliffs of west Dorset are noted for the spectacular landslide systems that truncate NE–SW-trending ridges rising to between 140 and 170 m. The ridges are formed in chert and Upper Greensand overlying unconformably interbedded Lower Jurassic clays, marls, mudstone and thin argillaceous limestones. Large arcuate landslide scars form the upper part of the slope and are sepa-



(Table 2.1) Likely recession rates in different materials (compiled by Carter, 1988, from data in Sunamura, 1983).

**Table 2.2** Primary, secondary and tertiary controls on cliff form (based on May, 1997a).

| FIRST ORDER | SECOND ORDER | THIRD ORDER |
|---|---|---|
| Geological structure and lithology | Weathering and transport slope processes | Coastal land-use |
| Wave climate | Slope hydrology | Resource extraction |
| Subaerial climate | Vegetation | Coastal management |
| Water-level change (sea level and tide) | Cliff-foot erosion | |
| Geomorphology of the hinterland (landforms into which the cliffs are cut) | Cliff-foot sediment accumulation | |
| | Resistance of cliff-foot sediment to attrition and transport | |

have not met with much success. The many combinations of process, lithology and structure and the variety of controls on cliff form in different climatic and sea-level situations make generalization of cliff form inherently difficult. Nevertheless, some types of cliff are more common in particular morphogenetic regions than in others. Steep cliffs are common in the wave-dominated environments of the north and west coast of Great Britain where the accumulation of cliff-foot sediment is restricted by wave-transport. Where wave activity is weaker and subaerial weathering stronger, coastal slopes tend to be gentler and more convex in form.

It is also possible to classify active sea-cliff profiles according to the interaction of process and geology. Emery and Kuhn (1982) propose a matrix of cliff-forms produced as a result of varying bedrock homogeneity and the relative importance of marine and sub-aerial processes (Figure 2.7). However, the shape and gradient of cliffs are also profoundly influenced by dip, strike, lithological variation, and structural weaknesses. Steep cliffs generally develop in rocks that are either vertically or horizontally bedded, whereas intermediate bed angles tend to produce more moderate slopes. Lithology also influences cliff morphology – high cliffs tend to be associated with more resistant rocks such as unbedded, impermeable, crystalline rocks that are highly resistant to wave erosion, whereas sedimentary rocks are more susceptible to wave quarrying, especially where dissolution of the rock cement or exploitation of weaker bedding planes aids disintegration. As a result of this complexity, the available models, although useful simplifications, take limited account of the infinite possibilities of structural variation. The topography of the cliff hinterland adds another dimension (see p. 44).

## Characteristic medium-scale features of cliffs

The rate of mechanical wave erosion is particularly sensitive to variations in rock structure. Small bays, inlets and narrow gorges that develop along joint and fault planes and in the fractured and crushed rock produced by faulting are generally the result of accelerated erosion along these lines of structural weakness. Narrow inlets or geos, caves, arches and stacks are often found in close association with each other on coasts with well-defined and well-spaced planes of weakness. However, these features are less likely to develop in *very* weak rocks or in rocks with a *very* dense joint pattern, since the rock must also be strong enough to produce high, near-vertical slopes or to support the roofs of caves, tunnels and arches. If the joints or planes of weakness are very close together then long, narrow inlets develop such as the geos of northern Scotland. The angle of dip of the plane of weakness affects the occurrence and form of the erosional feature produced. For example, geo-like gorges with vertical sides are common in many horizontally bedded rocks with predominantly vertical joint planes such as occurs around the coast of Hoy in Orkney or at Skirza Head, Caithness (see GCR site report, Chapter 3). In steeply dipping rocks, where the planes of weakness are usually inclined, geos may either fail to develop or will be irregular in shape (Steers, 1962). Although



*(Table 2.2) Primary, secondary and tertiary controls on cliff form (based on May, 1997a).*

**Table 2.3** Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Vegetated sea cliffs of the Atlantic and Baltic coasts' and/or 'Submerged or partially submerged sea caves' as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, November 2002.)

| SAC name | Local authority | Cliff habitat extent (ha) |
|---|---|---|
| Ardmeanach | Argyll and Bute | 125.9 |
| **Beast Cliff–Whitby (Robin Hood's Bay)** | North Yorkshire | 156.1 |
| **Berwickshire and North Northumberland Coast** | Northumberland; Scottish Borders | † |
| **Buchan Ness to Collieston** | Aberdeenshire | 62.2 |
| Cape Wrath | Highland | 299.6 |
| **Cardigan Bay/ Bae Ceredigion** | Ceredigion; Penfro/ Pembrokeshire | † |
| **Clogwyni Pen Llŷn/ Seacliffs of Lleyn** | Gwynedd | 65 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 1 |
| **Durham Coast** | Durham | 120.4 |
| East Caithness Cliffs | Highland | 310 |
| Exmoor Heaths | Devon; Somerset | 85.6 |
| Fair Isle | Shetland Islands | 129 |
| **Flamborough Head** | East Riding of Yorkshire; North Yorkshire | 315.6 |
| Glac na Criche | Argyll and Bute | 50 |
| Glannau Ynys Gybi/ Holy Island Coast | Ynys Môn/ Isle of Anglesey | 111.1 |
| Great Orme's Head/ Pen y Gogarth | Conwy | 15.9 |
| Hastings Cliffs | East Sussex | 55.1 |
| **Hoy** | Orkney Islands | 94.9 |
| **Isle of Portland to Studland Cliffs** | Dorset | 579 |
| Isle of Wight Downs | Isle of Wight | 18.4 |
| **Limestone Coast of South West Wales/ Arfordir Calchfaen de Orllewin Cymru** | Abertawe/ Swansea; Penfro/ Pembrokeshire | 349.5 |
| Lundy | Devon | † |
| Mousa | Shetland Islands | † |
| Mull of Galloway | Dumfries and Galloway | 157.6 |
| North Rona | Western Isles/ Na h-Eileanan an Iar | 31.4 |
| Overstrand Cliffs | Norfolk | 28 |
| **Papa Stour** | Shetland Islands | † |
| **Pembrokeshire Marine/ Sir Benfro Forol** | Penfro/ Pembrokeshire | † |
| **Pen Llŷn a'r Sarnau/ Lleyn Peninsula and the Sarnau** | Ceredigion; Gwynedd; Powys | † |
| Polruan to Polperro | Cornwall | 192 |
| Rigg–Bile | Highland | 450.8 |
| Rum | Highland | 216.7 |
| **Sidmouth to West Bay** | Devon; Dorset | 807.5 |
| **South Devon Shore Dock** | Devon | 258.7 |
| South Hams | Devon; Torbay | 3.8 |
| **South Wight Maritime** | Isle of Wight | 198.6 |
| **St Abb's Head to Fast Castle** | Scottish Borders | 122.4 |
| **St Albans Head to Durlston Head** | Dorset | 28.7 |
| St David's/ Tŷ Ddewi | Penfro/ Pembrokeshire | 303.9 |
| **St Kilda** | Western Isles / Na h-Eileanan an Iar | 758.8 |
| Strathy Point | Highland | 109.3 |
| **Stromness Heaths and Coast** | Orkney Islands | 63.5 |
| **Thanet Coast** | Kent | † |
| The Lizard | Cornwall | 149.8 |
| **Tintagel–Marsland–Clovelly Coast** | Cornwall; Devon | 1457.9 |
| Y Fenai a Bae Conwy/ Menai Strait and Conwy Bay | Conwy; Gwynedd; Ynys Môn/ Isle of Anglesey | † |

* Possible SAC not yet submitted to EC.
† SAC proposed for sea caves; sea cliffs not a qualifying feature.
**Bold type indicates a coastal geomorphological GCR interest within the site.**



*(Table 2.3) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Vegetated sea cliffs of the Atlantic and Baltic coasts' and/or 'Submerged or partially submerged sea caves' as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, November 2002.)*

**Table 3.1** Hard-rock cliff GCR sites, including those sites described in other chapters of the present volume that include hard-rock cliffs in the assemblage.

| Site* | Main features | Main geological materials | Tidal range (m) |
|---|---|---|---|
| **St Kilda Archipelago, Western Isles** | Plunging cliffs, submerged caves and platforms; structural controls | Igneous complex of granophyres, basalts and dolerites | 3.0 |
| **Villians of Hamnavoe, Shetland** | Structural controls, wave stripping, cliff-top boulder beaches | Devonian extrusive andesites and ignimbrites | 1.5 |
| **Papa Stour, Shetland** | Diversity of cliff forms, caves, stacks, arches; inherited cliffs | Devonian extrusive rhyolite and ignimbrite | 1.5 |
| **Foula, Shetland** | Higher cliffs, shore platforms, geos; exhumed cliffs stacks and geos | Devonian sandstones and Dalradian metamorphic rocks | 1.5 |
| **West Coast of Orkney** | Structural control of steep over-hanging cliffs; stacks arches; inherited cliffs; young individual features | Devonian Old Red Sandstone | 3.0 |
| **Duncansby to Skirza Head, Caithness** | Geos and stacks, shore platforms, blowhole | Devonian Old Red Sandstone | 3.0 |
| **Tarbat Ness, Easter Ross** | Weathering forms: tafoni and solution pits | Fault-controlled Devonian Old Red Sandstone | 3.2 |
| **Loch Maddy–Sound of Harris coastline** | Drowned surface of glacial erosion; rock basins, skerries and platform | Lewisian gneiss, faulted and crushed zones | 3.5 |
| **Northern Islay, Argyll and Bute** | Emerged shore platform and beach gravels | Precambrian quartzites and tillites; Dalradian Limestone | 2.0 |
| **Bullers of Buchan, Aberdeenshire** | Geos, caves, arches, stacks, platform, blowhole | Granite and dyke intrusions | 3.5 |
| **Dunbar, East Lothian** | Four shore platforms, some of which are glaciated | Devonian Old Red Sandstone, Carboniferous sandstone, igneous intrusions | 4.5 |
| **St Abb's Head, Berwickshire** | Steep cliffs, geos, fault-controlled inlets and headlands | Devonian extrusive felsites, tuffs, and grits; faulting | 4.5 |
| **Tintagel, Cornwall** | Longitudinal coast, structural control caves, arches, slope-over-wall cliff | Upper Devonian slates, siliceous sandstones, pillow lavas, tuffs and phyllites | 6.5 |
| **South Pembroke cliffs** | Structural controls, eroded karstic coast, stack, arch, cave, geo | Carboniferous limestones | 6.0 |
| **Hartland Quay, Devon** | Truncated valleys, waterfalls, slope-over-wall cliffs, shore platforms | Carboniferous interbedded fine-grained sandstones and shales | 6.4 |
| **Solfach, Pembrokeshire** | Ria, infilled ria | Cambrian and Ordovician flags and dolerites | 5.9 |
| Carmarthen Bay, Carmarthenshire | Ria, shore platforms | Old Red Sandstone and Carboniferous limestone | 8.0 |
| Furzy Cliff–Peveril Point, Dorset | Structural controls, longitudinal coast, slope-over-wall cliffs, truncated valleys | Portlandian and Purbeckian limestones and sandstones | 1.9 |
| Holy Island, Northumberland | Structural controls, shore platforms | Carboniferous sandstones and limestones | 4.1 |
| Upton and Gwithian Towans, Cornwall | Exhumed cliffs and stacks | Devonian slates | 5.8 |
| Hallsands, Devon | Emerged shore platform | Mica-schist and quartz-schist | 4.4 |

*Sites described in the present chapter are in **bold** typeface



(Table 3.1) Hard-rock cliff GCR sites, including those sites described in other chapters of the present volume that include hard-rock cliffs in the assemblage.

| Site | Main features | Other features | Mean rate of cliff-top retreat (m $a^{-1}$) | Tidal range (m) |
|---|---|---|---|---|
| Budleigh Salterton | Cliff erosion feeding Budleigh Salterton Pebble Beds into local and regional beaches | Shingle beach (see Chapter 6) | 0.30 | 4.0 |
| **Ladram Bay** | Cliff–stack–platform development in Triassic sandstone and mudstone | | 0.20 | 3.7 |
| **Robin Hood's Bay** | Cliffs in till resting on Liassic shales. Till/platform junction | Platform across Liassic shales | 0.03 | 4.8 |
| **Blue Anchor–Watchet–Lilstock** | Rapid retreat in Liassic shales with very unusual 'washboard' topography in macro-tidal environment | Platform development | Up to 1.20 | 9.4 |
| **Nash Point** | Rapid cliff retreat in Liassic shales. Cave development | Platform development | 0.2–0.30 | 6.0 |
| **Lyme Regis to Golden Cap** | Intensively researched landslide and related beach coast | Major mass-movements | 0.60–0.96 | 3.5 |
| Peveril Point to Furzy Cliff | Rapidly eroding cliffs in range of materials from Chalk to Oxford Clay. Longitudinal coast | Semi-enclosed beaches. Submarine rock reefs. Landslides) | 0.00–0.41 | 1.7 (east)–2.0 (west) |
| **South-west Isle of Wight** | Differential erosion in materials from Chalk to Wealden. Contrasts between relict and modern beaches. Stacks. Chines | Major mass-movements | 0.20–2.10 | 3.3 (east)–2.2 (west) |
| **Kingsdown to Dover** | Cliff and beach development in high (over 30 m) cliffs. Recent beach depletion | Flow failures | 0.20–0.60 | 5.9 |
| **Beachy Head to Seaford** | Cliffs of variable height in Upper Chalk. Narrow platforms. Locally limited sediment supply. Recent beach depletion | | 0.40–1.26 | 5.3 |
| **Ballard Down** | Classic cave–arch–stack site in Upper Chalk. Transverse coast | Pocket beach formation | 0.01–0.60 | 1.7 |
| Marsden Bay | Cliffs and stacks | Beach phases | | 4.2 |
| **Flamborough Head** | Highly complex chalk cliffs overlain by Devensian till. Caves and stacks | Extensive platforms | 0.30–0.90 | 4.0 |
| **Joss Bay** | Cliff and platform development in Upper Chalk | | 0.30 | 4.0 |
| Carmarthen Bay | Both hard-rock cliffs and easily eroded cliffs | Major dunes, sand-spits and barrier beaches, rias, emerged beaches, intertidal sandflats, saltmarsh | | 8.0 |
| North Norfolk Coast | Rapidly eroding cliffs in chalk and till, latter feeding regional sediment budget | Major spits, beaches and saltmarsh (see Chapter 11) | 0.30–0.42 | 4.7 (E)–6.4 (W) |
| Benacre Ness | Rapidly eroding till cliffs resulting from longshore movements of ness and subsequent reduction of natural protection | Shingle ness (see Chapter 6) | 0.42–0.96 | 2.1 |
| **Porth Neigwl** | Rapidly retreating glacial drift cliffs, chines, beach cusps | Contemporary beach cementation (see Campbell and Bowen, 1989) | Up to 1.00 | 3.9 |
| Walney Island | Till cliffs, rapid erosion | Barrier islands, recurved spits | | 9.0 |
| **Holderness** | Rapidly eroding cliffs, mainly in till | Till shore platform, ords, thin beach | Up to 2.22 | 4.0 |

*(Table 4.1) The main features of soft-rock cliff coastal geomorphology GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain soft-rock cliffs in the assemblage. Sites described in the present chapter are in bold typeface.*

Sand can usually only accumulate in bays, although considerable lengths (as for example the Seven Sisters, Sussex) can be fronted by a rather patchy beach of flint pebbles or cobbles. In addition, the greater coherence of Chalk means that cliff failure is generally by falls (toppling) rather than by rotational slides, although where mudrocks underlie the cliff section, as at Folkestone Warren (Hutchinson *et al.*, 1980), or on the southern coast of the Isle of Wight (Hutchinson *et al.*, 1991), huge rotational slides have occurred, extending from below sea level to the cliff top at 200 m.

There is considerable variety of form within the examples described here (Flamborough Head, Thanet, the Seven Sisters and the folded Chalk of the Dorset coast), yet, despite a number of local studies, no integrated study of our chalk

**Table 4.2** Rates of cliff-top retreat of soft-cliffed coasts (from various sources).

| Cliff-top retreat ($m\ a^{-1}$) | Rock type | Location | Period (years) |
|---|---|---|---|
| 0.01 | Upper Chalk | North Ballard Down | 100 |
| 0.01 | Upper Chalk | East Ballard Down | 100 |
| 0.03 | Bracklesham Beds | Highcliffe Castle | 92 |
| 0.07 | Upper Chalk | Kingsdown–St Margaret's Bay | 84 |
| 0.07 | Upper Chalk | Thanet | 85 |
| 0.09 | Middle/Lower Chalk | Dover to Folkestone | 90 |
| 0.16 | Upper Chalk | Cuckmere to Seaford | 120 |
| 0.18 | Chalk | Hambury Tout to White Nothe | 98 |
| 0.19 | Upper/Middle Chalk | St Margaret's Bay | 84 |
| 0.27 | Hamstead Beds | North-west Isle of Wight | 95 |
| 0.28 | Glacial drift | North Yorkshire | 72 |
| 0.29 | Glacial drift | Holderness | 100 |
| 0.37 | Jurassic clays | Furzy Cliff–Shortlake | 98 |
| 0.39 | Kimmeridge clays and shales | Kimmeridge | 100 |
| 0.41 | Upper Chalk | Newhaven–Rottingdean | 89 |
| 0.41 | Wealden | South-west Isle of Wight | 125 |
| 0.41 | Kimmeridge clays | Ringstead | 99 |
| 0.42 | Glacial drift | Weybourne–Cromer | 100 |
| 0.57 | Glacial drift | Gorleston–Corton | 100 |
| 0.57 | Glacial drift | Holderness | 100 |
| 0.58 | Barton Clay | Barton | 62 |
| 0.68 | London Clay | Reculver | 79 |
| 0.83 | Glacial drift | Grathy–Caister | 100 |
| 0.85 | Glacial drift | Holderness | 100 |
| 0.88 | London Clay, crag and glacial drift | The Naze | 100 |
| 0.96 | London Clay | Northern Isle of Sheppey | 79 |
| 0.96 | Glacial drift | Cromer–Mundesley | 100 |
| 1.05 | Glacial drift | Pakefield–Kessingland | 100 |
| 1.06 | Chalk | Beachy Head | 90 |
| 1.08 | Sandstone | Cliffend | 75 |
| 1.11 | Glacial drift | Holderness | 100 |
| 1.19 | Hastings Beds sandstones | Ecclesbourne Glen | 75 |
| 1.20 | Glacial drift | Holderness | 100 |
| 1.22 | Chalk | Birling Gap | 120 |
| 1.26 | Chalk | Seaford Head | 120 |
| 1.43 | Hastings Beds clays | Fairlight Glen | 75 |
| 1.75 | Glacial drift | Holderness | 100 |
| 1.96 | Glacial drift | Holderness | 100 |
| 2.22 | Glacial drift | Holderness | 100 |
| 3.00 | Glacial drift | Covehithe | 100 |



(Table 4.2) Rates of cliff-top retreat of soft-cliffed coasts (from various sources).

favourable conditions for formation of the present foreshore have existed' (Agar, 1960, p. 422). Extrapolating from the measured rates of retreat, he argued that most of the local erosion has occurred only during the last six centuries. As a result, many profiles, including those of South Cheek, would have been affected by only limited postglacial erosion. Their upper slopes were not regarded by Agar as contemporary forms, but as probably of last interglacial age. Both the discussion following Agar's paper and later comments cast doubts on his interpretation of the coastal features.

Straw and Clayton (1979) consider that if Agar is correct then the present coastline must approximate in location to that of the Ipswichian (Eemian) interglacial. They cite the resistance of the rocks to marine erosion and recognize the difficulty of ascribing the platform solely to late Holocene marine erosion. They thought it inevitable that the platforms must have been prepared during preceding interglacial periods. However, Robinson (1977c) was not convinced by the view that many of the platforms have been reworked and that notches revealed beneath the till show that the platforms are at least Weichselian in age. Robinson counters by arguing that many of the features are recent, some less than 200 years old, and that much of the alleged pre-Weichselian glacial form has been buried by postglacial landslipped material that has then been removed, exhuming the pre-talus surface.

In a wider discussion of shore platforms, Trenhaile (1974b) describes this site as the only location in 225 km of platformed coastline with 'a continuous shore platform extending around a well-defined headland–embayment sequence'. He also records that the platform gradient increases towards the headlands, especially in the north, typically from about 35' to 2.5°. The headland site is more rugged than the Lower Lias shales of the embayment and is also more exposed to greater wave activity. From such evidence here and on other shore platforms around the coastline of England and Wales, Trenhaile (1974b) concludes that the platform gradient is being maintained in dynamic equilibrium. This appears to cast doubt on the claim that many of these platforms, including the platform at this site, have been inherited from previous forms (Trenhaile and Layzell, 1981). However, they argue that the evidence suggesting that shore platforms are partially inherited features is not incompatible with the evidence indicating that they are at or close to a state of dynamic equilibrium with a morphology finely tuned to their present environments. Despite some debate (Carr and Graff, 1982; Trenhaile, 1982), this argument appears to hold good for Robin Hood's Bay – that the platforms are likely to be be reworked earlier platforms, retrimmed by Holocene seas. Unfortunately neither Agar, nor Trenhaile and Layzell, take sufficient note of the role of debris on the platforms either in its erosional, or its protecting and roughening, role.

Robinson (1977a–c) argued that the morphology of the platforms resulted from the presence of sand debris rather than the nature of the rocks forming the platform. The width of the platform is controlled primarily by the protection afforded to the cliffs by the deposits at their foot (Figure 4.7). Where debris is absent, the platform has a low angle of inclination, characteristically about 1°. Robinson calls this the 'plane'. In contrast, where there is a beach, the slope is greater, usually up to 15°. This is the 'ramp'. Trenhaile (1974b) believed that the steeper ramp was produced by harder materials. Robinson identified five erosion processes here:

1. micro-quarrying;
2. the expansion and contraction of clay mineral lattices by hydration and desiccation. He estimated that processes 1 and 2 together low-

**Table 4.3** North Yorkshire coast cliff retreat rates in m $a^{-1}$ (based on Agar, 1960).

| | | Cliff top | Cliff foot |
|---|---|---|---|
| Whole coast | | 0.02 | 0.05 |
| Headlands only | | 0.01 | 0.04 |
| Bays only | | 0.04 | 0.07 |
| Robin Hood's Bay | Lower Lias | 0.02 | between 0.07 and 0.16 |
| | Glacial drift | 0.31 | between 0.05 and 0.31 |



(Table 4.3) North Yorkshire coast cliff retreat rates in m $a^{-1}$ (based on Agar, 1960).

## HOLDERNESS, EAST YORKSHIRE (TA 182 660–TA 142 190)
### POTENTIAL GCR SITE

*K.M. Clayton*

### Introduction

Cliffs cut into weak Quaternary rocks undergoing rapid erosion occur along the North Sea coast of Britain and locally around the Irish Sea. The Holderness Cliffs (see Figure 4.1 for general location) stretch from Bridlington in the north some 60 km to Kilnsea in the south, where the coast continues southwards as a spit to Spurn Head (Figure 4.40). Most of this line of cliffs remains undefended, though walls and groynes have been built along relatively short frontages at Bridlington, Skipsea, Hornsea and Withernsea, and more recently at Mappleton (south of Hornsea) and in front of the gas terminal site at Easington close to Kilnsea. The contemporary rate of erosion increases from north to south; from less than 0.5 m $a^{-1}$ just south of Bridlington to as much as 3 m $a^{-1}$ at Easington. A feature of this coast is the sectors with an unusually low beach profile; these are locally known as 'ords' and over time they migrate southwards down the coast. As the ords pass by, waves are able to erode the cliffs more effectively and the rate of erosion speeds up, to slow down again when a higher and wider beach replaces the ord (Figure 2.1c).


Figure 4.40 Lost villages of the Holderness coast. As the till has been easily eroded for hundreds of years at rates of 2 m $a^{-1}$, there has been substantial loss of agricultural land and villages. (After Hansom, 1988)

### Description

The Holderness cliffs front an undulating till plain deposited during the last (Devensian) glaciation. The cliffs themselves cut through various till facies and related fluvio-glacial gravels. They begin in the north at the exposed Sewerby cliff of Ipswichian age, where the Chalk cliffs of Flamborough Head end, and continue southward for 61.5 km to Kilnsea at the northern end of the Spurn Head spit. The average height is

**Table 4.4** Land-loss by natural sections of the Holderness coast, 1852–1952 (Valentin, 1954, 1971).

| Section | Annual cliff recession (m) | Shore length (m) | Annual land-loss ($m^2$) | Average cliff height (m) | Annual loss in volume ($m^3$) |
|---|---|---|---|---|---|
| A. Sewerby to Earl's Dike | 0.29 | 8100 | 2357 | 11.0 | 25 927 |
| B. Earl's Dike to Hornsea | 1.10 | 13 650 | 15 015 | 11.8 | 177 177 |
| C. Hornsea to Withernsea | 1.12 | 24 250 | 27 160 | 16.2 | 439 992 |
| D. Withernsea to Kilnsea Warren | 1.75 | 15 525 | 27 200 | 13.2 | 359 040 |
| Entire coast (approx.) | 1.20 | 61 500 | 72 000 | 14.0 | 1 000 000 |



*(Table 4.4) Land-loss by natural sections of the Holdemess coast, 1852–1952 (Valentin, 1954, 1971).*

**Table 5.1** Classification of beach structures based on their plan form (after Pethick, 1984); outline definitions are provided in the glossary of the present volume.

| | |
|---|---|
| Rhythmic beach morphology | Cusps |
| | Crescentic bars |
| | Cell circulation topography |
| Shoreline beaches | Pocket beaches – swash-aligned (Davies, 1980) |
| | Open beaches – drift-aligned (Davies, 1980) |
| | Zeta-form or fish-hook beaches (Silvester, 1960; Swift, 1976) |
| | Combined swash and drift alignment |
| Detached beaches | Spits |
| | Cuspate forelands, nesses and tombolos |
| | Barrier beaches and islands |

*(Table 5.1) Classification of beach structures based on their plan form (after Pethick, 1984); outline definitions are provided in the glossary of the present volume.*

| Site* | Main features | Other geomorphological features | Present day natural sources of sediment | Tidal range (m) |
|---|---|---|---|---|
| Marsden Bay | Beach phases | Cliff, stack | Local cliff erosion– small | 4.2 |
| Furzy Cliff to Peveril Point (Dorset Coast) | Shingle pocket beaches | Cliffs/platforms Mass movements | Cliff erosion – small, restricted | 1.7 (E)– 2.0 (W) |
| Nash Point | Cobble and shingle pocket beaches | Platforms, caves | Local cliff/platform erosion – small | 6.0 |
| Kingsdown to Dover | Cliff-foot beach | Cliffs and platforms | Cliff erosion – small | 5.9 |
| Seven Sisters, (Beachy Head to Seaford Head) | Cliff-foot fringing beaches | Cliffs and platforms | Cliff/platform erosion – small | 6.0 |
| South-west Isle of Wight | Cliff-foot beach and feeder cliffs | Cliffs | Chalk and sandstones – small | 3.3 (E)– 2.2 (W) |
| Lyme Regis to Golden Cap | Shingle beach sediment supply and budget | Feeder cliffs | Significant inputs of flint/chert | 3.5 |
| Ynyslas | Sand and shingle spit | Dunes | Reworking till – restricted | 4.0 |
| **Westward Ho!** | Cobble beach and spit | Dunes | Reworking of emerged beach – restricted | 7.9 |
| **Loe Bar** | Shingle bay-bar | Cliffs, ria | Local cliff erosion – small | 4.7 |
| **Slapton Sands and Hallsands** | Shingle bay-bar Beach destruction | Emerged beach, relict cliff and platform | Minimal | 4.4 |
| **Budleigh Salterton** | Shingle beach and spit Major former feeder to south coast beaches | Soft cliffs | Cliff erosion – maintains budget | 4.0 |
| **Chesil Beach** | Barrier beach Tombolo | | Minimal – local | 2.0 |
| **Porlock** | Retreating shingle barrier with both swash-aligned and drift-aligned longshore sections | Recent breached tidal inlet allowing active back-barrier saltmarsh development | Minor source of gravel from updrift coastal slides. Main solifluction source of sediment now exhausted until future sea-level rise creates new supply | 9.3 |
| **Hurst Castle Spit** | Shingle spit and recurves | Saltmarsh | Possible from offshore | 2.2 |
| St Osyth Marsh | Cheniers | Saltmarsh | Localized reworking of gravels and chenier root | 3.8 |
| Dengie Marsh | Cheniers | Saltmarsh | Localized reworking of gravels and chenier root | 3.8 |
| Blakeney Point (North Norfolk Coast) | Major shingle spit | North Norfolk coast assemblage | Cliff erosion – restricted Longshore transport – large | 6.4 (W)– 4.7 (E) |
| Scolt Head Island (North Norfolk Coast) | Barrier beach and spits | North Norfolk coast assemblage | Longshore transport – large | 6.5 |
| **Pagham Harbour** | Double spit development | | Local cliffs – restricted Kelp rafting | 3.4 |
| **Ayres of Swinister** | Complex of bay bars and spits | | Local tills – small | 1.5 |
| **Rye Bay** | Spit developments Shingle beach plain | | Reworking proximal end Longshore – minimal | 5.8 |
| **Benacre Ness** | Shingle ness | Rapidly retreating cliffs | Cliff erosion – maintains input | 2.1 |
| **Whiteness Head** | Spit | | Longshore transport – large | 3.5 |
| **Spey Bay** | Spits, bay bars, emerged gravel ridges | | Longshore – now partially restricted – fluvial input | 3.5 |
| **West Coast of Jura** | Over 11 000 year sequence of emerged gravel ridges | Emerged shore platforms | Local, between headlands | 2.5 |
| **Orfordness and Shingle Street** | Major shingle ness and spit | | Longshore – restricted by groyne fields | 1.9 (N)– 3.4 (S) |
| **Dungeness** | Major cuspate foreland Relict barrier beach Over 5000 year sequence of beach ridges | | Re-distribution within site | 6.2 |

* Sites described in the present chapter are in bold typeface

(Table 6.1) *Main features and sediment sources of gravel/shingle beach and ness GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain shingle beach/ness structures in the assemblage.*

**Table 6.2** Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Perennial vegetation of stony banks' and/or 'Annual vegetation of drift lines' as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Gravel/ shingle habitat extent (ha) |
|---|---|---|
| Bae Cemlyn/ Cemlyn Bay | Ynys Môn/ Isle of Anglesey | 1.5 |
| **Chesil Beach and the Fleet** | Dorset | 96.2 |
| **Culbin Bar** | Highland; Moray | 122.5 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 1 |
| **Dungeness** | East Sussex; Kent | 2266.1 |
| **Isle of Portland to Studland Cliffs** | Dorset | 1.4 |
| **Lower River Spey–Spey Bay** | Moray | 65.2 |
| Minsmere to Walberswick Heaths and Marshes | Suffolk | 8.8 |
| **Morecambe Bay** | Cumbria; Lancashire | 57.5 |
| **North Norfolk Coast** | Norfolk | 98.4 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 3 |
| **Orfordness–Shingle Street** | Suffolk | 555.3 |
| **Sidmouth to West Bay** | Devon; Dorset | 4.4 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 226.5 |
| **Solway Firth** | Cumbria; Dumfries and Galloway | 8 |
| **South Uist Machair** | Western Isles / Na h-Eileanan an Iar | † |

* Possible SAC not yet submitted to EC
† Feature is minor component of SAC
**Bold** type indicates a coastal geomorphology GCR interest within the site

north. This sequence of plant communities is also influenced by natural cycles of degeneration and regeneration of the shrub vegetation that occurs on some of the oldest ridges.

Vegetated stony banks are scarce. There are only a few large sites in Europe, and the UK hosts a significant part of the European resource of this habitat. Although there are only some 4000 ha of stable or semi-stable vegetated gravel/shingle around the whole of the coast of the UK, the habitat is widely distributed and also exhibits a wide range of variation. The selection of sites reflects the UK's special responsibility for conservation of this habitat type and aims to cover the geographical range and variation of the habitat type. All the largest examples with good conservation of structure and function have been selected, together with additional smaller sites to complete the coverage of range. Site selection has also favoured gravel/shingle structures that support vegetation sequences ranging from pioneer communities to heath and scrub. The selected sites represent a substantial proportion of the European resource.

The vegetation that colonizes drift lines of gravel/shingle at or above mean high-water spring tides is dominated by annual plants. The types of deposits involved are generally at the lower end of the clast-size range (2–200 mm diameter), with varying amounts of sand interspersed in the gravel/shingle matrix. These deposits occur as fringing beaches that are subject to periodic displacement or overtopping by high tides and storms. The distinctive vegetation, which may form only sparse cover, is therefore ephemeral and composed of annual or short-lived perennial species. At most sites where it occurs, the habitat is naturally species-poor, and there is a limited range of ecological variation. Many gravel/shingle beaches are too dynamic to sustain drift-line vegetation. Many of the fringing beaches supporting drift-line vegetation are small, and annual vegetation may exist in one location in one year but not another.



*(Table 6.2) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I habitat 'Perennial vegetation of stony banks' and/or Annual vegetation of drift lines' as qualifying European features. Non-significant occurrences of these habitats on SACS selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)*

Table 6.3 Westerly extension of the active gravel beach (West Spey Bay). (From Gemmell *et al.*, 2001b.)

| Time period | Westerly growth (m) | Growth per annum (m $a^{-1}$) |
|---|---|---|
| 1870–1903 | 1360 | 41 |
| 1903–1967 | 2090 | 33 |
| 1967–1994 | 720 | 27 |
| July 1994–December 1995 | 30 | 20 |
| 1870–1995 | 4200 | 34 |

high sand dunes and forest. The full landward extent of ridges is known to be substantial, continuing into the Spynie area to the south of Lossiemouth and as far west as Burghead Bay (Gemmell *et al.*, 2001a,b). Within Spey Bay, the junction between these younger, more recently deposited ridges and the ridges of the emerged gravel strandplain, is marked by a 1–2 m rise in altitude and a distinct break in slope, best seen 2–3 km east of Kingston.

On the seaward face of the gravel beaches, cusp forms of different wavelengths are well developed, the size and spacing of these ephemeral features altering in response to short-term processes that vary with wave and tidal conditions. Beach-face slope angles, the degree of sediment sorting and crest elevations also alter in response to wave and tidal conditions. Sediment sorting is well developed down the beach face, with finer-grained, well-sorted gravel lying in the intertidal zone whereas larger calibre, but more poorly sorted, gravel, occurs at or above high-water mark or in the horns of the cusps. However, there is no obvious alongshore trend in beach sediment size, until the abrupt transition from gravel to sand close to Lossiemouth. The median grain size of the gravel varies from 30 mm to 50 mm along the beach, whereas the sand has a median grain size of 0.22 mm (Gemmell, 2000; Gemmell *et al.*, 2001b).

Along much of its length, the gravel ridge is subject to washover during storms and at several places washover throats occur in the main gravel ridge that allow coarse gravel lobes to accumulate landwards of the main ridge. This roll-over effect is widespread along the coast. Gravel is also being moved westwards under the influence of westerly waves. According to Grove (1955) 'the most recent gravel bank on the west side [of Spey Bay] appears to have grown steadily along the beach towards Lossiemouth over a distance of one and half miles (2.4 km) since 1870' at an average rate of westerly extension comparable with that of the gravel spits that grow across Spey mouth (Grove, 1955). Using map and field evidence the total westerly extension of the gravel beach was 4.2 km between 1870 and 1995, an average annual extension rate of 33.6 m $a^{-1}$ (Gemmell *et al.*, 2001a,b; Table 6.3). Where there was no gravel present in 1903, today there is a 60 m-wide gravel beach, consisting of an active beach ridge of *c.* 4 m OD behind which lie several landward-recurving ridges at about the same altitude.

Changes in the position of mean high-water springs (MHWS) and MLWS at Spey Bay between the first (1870) and the latest current Ordnance Survey (1970) reveal that the eastern side of Spey Bay has been eroded over the intervening 100-year period. This erosional trend declines to the west beyond the Spey delta until it gives way to accretion *c.* 4 km west of the delta (Gemmell *et al.*, 2001a,b). Recession rates since 1975 of 1–1.5 m $a^{-1}$ have been recorded both east and west of the river exit (Riddell and Fuller, 1995). The replacement of sand by gravel, discussed above, is reflected by accretion over the 1870–1970 period in the west of Spey Bay along a 4 km stretch in the vicinity of Boar's Head Rock. Farther west, the sandy beach and dunes at Lossiemouth are wholly erosional over the map period, a trend which continues today (Gemmell *et al.*, 2001a).

At the mouth of the Spey, complex fluvial and coastal processes interact to create a dynamic and highly active system (Figure 6.35). Historical records (Grove, 1955) suggest that:

'the mouth of the Spey alters more rapidly from year to year than almost any other section of the coastline of Britain and ... the position of the mouth of the Spey has fluctuated violently throughout the last two centuries'.

Changes in the position of the river mouth



(Table 6.3) Westerly extension of the active gravel beach (West Spey Bay). (From Gemmell et al., 2001b.)

**Table 6.4** Development phases at Dungeness. Ridge height data are mainly from Lewis and Balchin (1940).

| | Phase | Preserved as | Shingle ridge height (m OD) |
|---|---|---|---|
| 1 | Low barrier beach associated with Midley Sands, stretching from Fairlight to St Mary's Bay and thence to Hythe. Dating uncertain but placed between 5500 and 4000 years BP by Eddison (1983a) | (i) Broomhill and Sandylands | Max = +1.5 |
| | | (ii) Recurves at St Mary's Bay | Max = +1.0 |
| | | (iii) Low-level shingle at West Hythe | +0.6 to −1.0 |
| 2 | Higher level barrier system, dated *c.* 5000 years BP Overlain in parts by peat dated *c.* 2700 years BP | (i) Shingle ridges at Jury's Gap and the Wicks, and Beach Bank Soil Series west and north of Lydd | Average = +4.11<br>Max = +5.00 |
| | | (ii) Shingle recurves at Hythe | +2.8 to +3.5 |
| 3 | Slightly higher beaches, younger than peat. Dated *c.* 2000 years BP | (i) Holmstone Beach and its extensions as Beach Bank Soil Series west of Lydd | Average = +4.51 |
| | | (ii) Recurves at Hythe | No published data |
| 4 | (a) Ness development with eastern shore trending south-east–north-west to Lydd | (i) Wickmaryholm eastwards to Muddymore Pit | Average (west of Galloways) = +4.69<br>Average (east of Galloways) = +3.81 |
| | (b) Barrier beach with spit and recurve development to north and south | (i) New Romney | No published data |
| | | (ii) Recurves at Hythe | No published data |
| 5 | (a) Ness development with long NW-trending ridges. Eastern limit dated at about 750 AD | (i) Areas south and west of Open Pits | Max = +6.28 |
| | | (ii) Beach Bank series in Denge Marsh | |
| | | (i) Areas mainly around Lydd within embankments | |
| | (b) Land-claim | (ii) Open Pits | |
| 6 | Spit extension and recurves | (i) Open Pits | |
| 7 | (a) Ness and beach plain to distal recurves | (i) Denge Beach to Northlade (by *c.* 1250 AD) | +4.5 to +6.0<br>Average = +5.33 |
| | | (ii) Greatstone Point (by c. 1800 AD) | |
| | (b) Dune development | (i) Romney Warren | |
| | | (ii) Camber | |
| | (c) Spit development | (i) Littlestone Point | |
| | | (ii) Broomhill Farm, Hythe | |
| | (d) Land claim | (i) West of Lydd | |
| | | (ii) Caldecot–Belgar area | |
| | | (iii) Romney Hoy | |
| | (e) Beach ridges associated with longshore drift | (i) Camber and Rye Harbour | |
| | | (ii) Romney Hoy: Littlestone and Greatstone Points | |
| | | (iii) Hythe Ranges | |
| 8 | (a) Modern sea-wall construction | (i) Dymchurch Wall is earliest example | |
| | (b) Beach-feeding | (i) Broomhill, | |
| | | (ii) Pett | |
| | | (iii) Power Station | |
| | | (iv) St Mary's Bay | |

The processes of longshore transport at Dungeness have been modified, first by a system of beach replenishment and second by coastal protection structures defending the power station site. The replenishment programme, where shingle near the ness is returned to the western end of the beach near Brommhill, has been operating since the 1950s (Thorn, 1960) and is one of the longest running schemes anywhere. Figure 6.50 offers an interpretation of the probable sediment pathways both now and at earlier stages of beach development. They warrant further investigation to evaluate the effects of wave climate, storm events, different sea levels, and changes in sediment supply.

The preservation of so many beach ridges has tempted a number of writers (Gilbert, 1930; Lewis, 1932; Lewis and Balchin, 1940) to invoke changes in sea level as the cause of their varying height. Surveys of ridge altitudes by Plater and Long (1995) largely confirm the variations in altitude reported by Lewis and Balchin (1940). Plater and Long do not, however, agree with the earlier interpretation. They recognized that the altitude of the ness could be as much as 1.2 m below both the adjacent west–east (proximal) ridges and the south-east–north-west (distal) ridges. The latter also fell towards their north-western ends. Plater and Long (1995) observed an overall rise in ridge-swale altitude of about



*(Table 6.4) Development phases at Dungeness. Ridge height data are mainly from Lewis and Balchin (1940).*

all of the others.

It is evident from the GCR sites described in this chapter (Figure 7.1 and Tables 7.1 and 7.2) that both beach and dune features co-exist and depend upon the availability of sand that may come from the seabed, from fluvial sources and from cliff erosion, depending upon their geomorphological setting. Small sand beaches can develop with very limited sediment supplies. For example, small sand beaches form localized pockets within embayments of the Thanet chalk coast and the indented rocky coasts of south-western Britain and northern and western Scotland. Sand commonly forms a veneer on some shore platforms and displays a range of minor current- and wave-related forms.

In the Chalk, sand derives from attrition of flint and from the release of fossil shell fragments from the chalk itself. Elsewhere, sandstone and soft sediment cliffs provide large quantities of sand to their beaches, which may then be transported alongshore. Erosion of the till coast and shallow seabed off Holderness provides very large volumes of sand and gravel annually that are transported both alongshore to form a large sand spit at Spurn Head and into the North Sea. Along the coast of East Anglia, very large volumes of sand and gravel are derived from erosion of till cliffs, but there are also large volumes in offshore banks that result

**Table 7.1** Main features and present-day sediment sources of dune types. Exemplar sites described in the present chapter are in **bold** typeface. See also Table 7.2. (Based on Ranwell, 1972.)

| **Type** | **Sediment sources** | **Geomorphological setting** | **Wind directions** | **Exemplar GCR sites** |
|---|---|---|---|---|
| **Foreshore dunes** | | | | |
| Spit dunes | Intertidal banks and longshore | On promontories at estuary mouths with near-parallel or radiating ridges and slacks | More common with onshore prevailing and dominant, but not restricted to this | **Forvie, Strathbeg, South Haven Peninsula**, Morfa Harlech, Holy Island (Goswick and the Snook), Culbin, Morrich More |
| Prograding ness dunes | Accretion at ness, possibly with longshore sediment supply from opposite directions alongshore | On open coast | Prevailing and dominant winds from opposite directions (offshore/onshore) | Winterton Ness, **Barry Links, Tentsmuir** |
| Offshore island dunes | Offshore, longshore and intertidal drying banks | Offshore or barrier islands narrow, subject to washover, often display time-series development in main direction of longshore transport | Can occur with both onshore and offshore prevailing winds | Scolt Head Island, Blakeney Point recurves (North Norfolk Coast), Pembrey (Carmarthen Bay), Culbin, Morrich More |
| **Hindshore dunes** | | | | |
| Bay dunes | Restricted in longshore direction | Usually at bay head on indented coasts | Prevailing onshore | **Dunnet Bay, Luce Sands, Upton and - Gwithian Towans, Tywyn Aberffraw, Oxwich Bay Sandwood, Balta Island, Torrisdale Bay and Invernaver** |
| Hindshore dune system | Offshore and intertidal | Extensive sandy coasts | Prevailing and dominant winds from the same direction | **Braunton Burrows, Newborough Warren, Ainsdale**, Holy Island (Ross Links) |
| Hindshore sand plains | Offshore, intertidal and beach | Bay-head and low-lying rocky coasts | High wind-speeds that restrict vertical development | **Tywyn Aberffraw** |



*(Table 7.1) Main features and present-day sediment sources of dune types. Exemplar sites described in the present chapter are in bold typeface. See also Table 7.2. (Based on Ranwell, 1972.)*

**Table 7.2** Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage. It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in **bold** typeface.

| Site | Main features | Other features | Present-day sediment sources | Tidal range (m) |
|---|---|---|---|---|
| **Marsden Bay** | Beach phases | Cliffs and stacks | Local cliff erosion – small | 4.2 |
| **South Haven Peninsula** | Shore-parallel dune ridges, originating from the 16th century, slacks, sand-spit | Relict and active cliffs, caves, rock platform | Longshore – restricted<br>Offshore – significant | 1.5 |
| **Upton and Gwithian Towans** | Climbing dunes, exhumed bedrock base | Stacks | Offshore – restricted | 5.8 |
| **Braunton Burrows** | Large dune field, parabolic dunes, slacks | Ridge and runnel | Intertidal and estuarine | 7.3 |
| **Oxwich Bay** | Bay-head beach and dunes | Cliffs and emerged platform | Offshore – limited | 8.2 |
| **Tywyn Aberffraw** | Sand plain, isolated parabolic dunes shore-parallel linear dunes | | Offshore, probably in deficit | 4.7 |
| **Ainsdale** | Large dune field, slacks, ridge and runnel, long dated history | | Offshore – limited – in deficit | 8.3 |
| **Luce Sands** | Bay-head dunes | Holocene emerged gravel ridges | Onshore and longshore – significant | 5.6 |
| **Sandwood Bay** | Dynamic beach–dune complex, climbing dunes | Gravel-cored bar, blowouts | Offshore and recycled – limited | 4.2 |
| **Dunnet Bay** | Bay-head dunes and sand plain | Blowouts | Offshore – limited | 4.0 |
| **Balta Island** | Climbing dunes | Beach–dune–grassland continuum | Local – limited | 1.9 |
| **Strathbeg** | Shore-parallel dune ridges, large blowouts | Holocene emerged gravel ridges | Longshore – restricted, loch outlet source | 3.3 |
| **Forvie** | Shore-parallel dune ridges, originally moved as waves northwards | | Longshore – cycled from estuary | 3.1 |
| **Barry Links** | Foreland sand plain, linear parabolic dunes | | Estuarine, longshore – limited | 4.4 |
| **Tentsmuir** | Shore-parallel dune ridges–intertidal sands | | Estuarine and longshore – significant | 4.4 |
| **Torrisdale and Invernaver** | Beach–dune, hill-top dunes, glaciofluvial terraces | Archaeological context | Offshore and fluvial recycled – now limited | 4.0 |
| Morrich More | Shore-parallel beaches and dunes: sandplain | Holocene beaches and cliffs | Offshore – restricted | 4.3 |
| Culbin | Shore-parallel dunes, large dune field now stabilized by forest | Holocene emerged gravel ridges and spits | Longshore – restricted, offshore – limited | 3.6 |
| East Head | Small spit-based dunes | | Intertidal | 3.4 |
| Holy Island | Dune field, spits, barrier beach | Cliffs, Holocene saltmarsh, intertidal mudflats | Longshore, offshore – significant | 4.1 |
| Dawlish Warren | Parallel spit-based linear dunes | Recurved spit | Intertidal and possibly estuarine in deficit | 4.1 |
| North Norfolk Coast | Major mainly linear dunes | Spits, barrier beach | Longshore and offshore | 6.4–4.7 |
| Morfa Harlech | Linear shore-parallel dunes | | Longshore – restricted, estuarine | 4.5 |
| Morfa Dyffryn | Linear shore-parallel dunes, blowouts, dunes invading slacks | | Longshore – restricted, offshore | 4.3 |
| Winterton Ness | Linear dunes on cuspate foreland | | Longshore | 2.6 |
| Ynyslas | Spit-based dunes | | Longshore – restricted, estuarine | 4.3 |
| Carmarthen Bay | | | | |
| Pendine | Shore-parallel linear dunes | | Offshore, estuarine to distal end | 8.0 |
| Pembrey | Large dune field, spit-based linear dunes | | Offshore and estuarine | 8.0 |
| Whiteford spit | Estuary-mouth spit | | Longshore, drying intertidal | 8.0 |
| Laugharne Burrows | Cliff-top dunes | | Local redistribution, drying intertidal | 8.0 |
| Newborough Warren and Morfa Dinlle | Major dune field, parabolic and linear dunes, spit, tied island and slacks | Saltmarsh | Offshore and estuarine | 4.7 |



(Table 7.2) Main features, sediment sources, tidal ranges of sandy beach and dune GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain dune features in the assemblage. It should be noted that all of the machair sites in Chapter 9 have dune features (see Table 9.1). Sites described in the present chapter are in bold typeface.

**Table 7.3** Calcium carbonate content of upper beach/foredune in selected coastal geomorphology GCR sites. Sites described in the present chapter are in **bold** typeface. (Based in part on Goudie, 1990, and various sources cited by Ritchie and Mather, 1984.)

| Dune location | $CaCO_3$ (%) | Median grain size (phi) |
|---|---|---|
| Culbin | 0.0 | 2.0 |
| **South Haven Peninsula** | 0.015 | ? |
| Lossiemouth | 0.26 | 2.0 |
| **Tentsmuir** | 0.4 | 2.5 |
| **Luce Sands** | 0.5 | 2.4 |
| **Forvie** | 0.55 | 1.9 |
| Buddon Ness (**Barry Links**) | 1.0 | 2.0 |
| Walney Island | 1.51 | 2.21 |
| Morfa Dyffryn | 3.34 | 2.31 |
| **Ainsdale** | 3.57 | 2.13 |
| **Invernaver** | 3.8 | 1.9 |
| Morfa Harlech | 3.96 | 2.13 |
| Newborough Warren | 4.56 | 2.50 |
| Ynyslas | 4.98 | 2.29 |
| **Strathbeg** | 7.86 | 2.0 |
| Rattray (Strathbeg site) | 9.10 | 1.9 |
| Laugharne (Pendine)* | 11.15 | 2.40 |
| Morrich More | 12.0 | 2.4 |
| Pembrey* | 12.04 | 2.53 |
| **Oxwich Bay** | 12.45 | 1.93 |
| **Tywyn Aberffraw** | 13.20 | 2.37 |
| Llangennith* | 15.65 | 1.63 |
| **Braunton Burrows** | 19.59 | 2.13 |
| **Dunnet Bay** | 20.4 | 1.7 |
| Dunbar | 20.4 | 1.5 |
| Westward Ho! | 21.79 | 2.45 |
| Machir, Islay | 33.6 | 2.2 |
| Mangersta, Lewis | 38 | 1.4 |
| Luskentyre, Harris | 44 | 2.0 |
| Traigh na Berie, Lewis | 47 | 2.4 |
| St. Ninian's Tombolo, Shetland | 47.5 | 2.0 |
| Balnakeil | 52.0 | 1.8 |
| **Hayle (Upton and Gwithian Towans)** | 56.80 | 1.56 |
| Loch Gruinart, Islay | 59.0 | 2.1 |
| Eoligarry, Barra | 80.0 | 2.0 |
| Ardivachar, South Uist | 84.0 | 1.7 |
| **Balta Island, Shetland** | 95.5 | 1.8 |

* Carmarthen Bay

millennia, especially from the evidence of preserved peat associated with dune slacks and larger wetlands that developed shorewards of the coastal beaches. In contrast, other dunes are more recent, for example at South Haven Peninsula the dunes have formed since the 16th century. Some dunes, for example at Culbin, Moray, Newborough Warren on the Isle of Angelsey, and Hayle and Upton and Gwithian Towans, Cornwall, have migrated inland covering buildings and farmland. British dunes tend to be located:

1. in areas of high tidal range,
2. where prevailing winds provide the main means of landward aeolian transport, and
3. in association with estuary mouths dominated by large sandy sediment loads or at the heads of inlets and bays,
4. on north-eastern coasts, where strong winds from the north and east provide the means for landward aeolian transport e.g. the coasts between Aberdeen and Fraserburgh and Northumberland.

Narrow, linear-dune systems occur along eastern coasts that are associated with sandy estuaries or high tidal ranges, but the size of the dunes is generally much less than those of the exposed and windy western coasts, even though the intertidal sandy area may be very extensive.

There are few significant dunes on the eastern coast of England, apart from the dunes around Holy Island, Northumberland, and along the Lincolnshire and north Norfolk coasts. Between the Tees and the Tamar there are 24 dune sites (*c*. 8%) and between the Tamar and the Mull of Galloway 67 dune sites (*c*. 23%). The remaining 204 (*c*. 69%) sites lie along the coast of Scotland and the English coast north of the Tees. The largest area of dunes is in north-west Scotland, particularly in the Outer Hebrides where machair predominates (Ritchie and Mather, 1984; Dargie, 2000; see Chapter 9). Of 43

**Table 7.4** Variations in calcium carbonate content and pH in foredunes and main dunes. (Based on Salisbury, 1952; and Willis, 1985)

| Location | Calcium carbonate content of dunes | | pH | |
|---|---|---|---|---|
| | Foredunes | Main dunes | Foredunes | Main dunes |
| South Haven Peninsula | 0.015 | 0.01 | 7.0 | 3.6 |
| Southport (near Ainsdale) | 6.0 | 0.2 | 8.2 | 5.5 |
| Braunton Burrows | 20.0 | 8.5 | 9.05 | 8.2 |
| Blakeney Point, North Norfolk Coast | 0.6 | 0.02 | 7.3 | 4.2 |



*(Table 7.3) Calcium carbonate content of upper beach/foredune in selected coastal geomorphology GCR sites. Sites described in the present chapter are in bold typeface. (Based in part on Goudie, 1990, and various sources cited by Ritchie and Mather, 1984.)*

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| **Forvie** | 0.55 | 1.9 |
| Buddon Ness (**Barry Links**) | 1.0 | 2.0 |
| Walney Island | 1.51 | 2.21 |
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| Pembrey* | 12.04 | 2.53 |
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| Balnakeil | 52.0 | 1.8 |
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| Eoligarry, Barra | 80.0 | 2.0 |
| Ardivachar, South Uist | 84.0 | 1.7 |
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(Table 7.4) Variations in calcium carbonate content and pH in foredunes and main dunes. (Based on Salisbury, 1952; and Willis, 1985)

## Dunes and sandy beaches as biological SSSIs and Special Areas of Conservation (SACs)

In Chapter 1, it was emphasized that the SSSI site series is constructed both from areas nationally important for wildlife, and GCR sites. An SSSI may be established solely for its geology/geomorphology, or its wildlife/habitat, or it may comprise a 'mosaic' of biological and GCR sites that may be adjacent, partly overlap, or be co-incident. There are a number of sand dune and beach sites that are crucially important to the natural heritage of Britain that are notified as SSSIs primarily for their wildlife value, but implicitly will contain interesting coastal

**Table 7.5** Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Dune habitat extent (ha) |
|---|---|---|
| **Barry Links** | Angus | 447.6 |
| **Braunton Burrows** | Devon | 767.5 |
| **Carmarthen Bay Dunes/Twyni Bae Caerfyrddin** | Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire | 780.2 |
| Coll Machair | Argyll and Bute | 409.0 |
| **Culbin Bar** | Highland; Moray | 612.9 |
| **Dawlish Warren** | Devon | 28.2 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 4.0 |
| **Dornoch Firth and Morrich More** | Highland | 974.4 |
| **Dorset Heaths (Purbeck and Wareham) and Studland Dunes** | Dorset | 95.9 |
| Drigg Coast | Cumbria | 519.8 |
| Durness | Highland | 386.7 |
| **Humber Estuary*** | City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire | 529.0 |
| **Invernaver** | Highland | 54.2 |
| **Kenfig/ Cynffig** | Pen-y-bont ar Ogwr/ Bridgend | 673.8 |
| **Limestone Coast of South West Wales/ Arfordir Calchfaen de Orllewin Cymru** | Abertawe/ Swansea; Penfro/ Pembrokeshire | 397.1 |
| Monach Islands | Western Isles / Na h-Eileanan an Iar | 215.1 |
| Morecambe Bay | Cumbria; Lancashire | 220.5 |
| **Morfa Harlech a Morfa Dyffryn** | Gwynedd | 228.6 |
| **North Norfolk Coast** | Norfolk | 387.3 |
| **North Northumberland Dunes** | Northumberland | 1078.6 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 963.3 |
| **Oldshoremore and Sandwood** | Highland | 165.3 |
| Penhale Dunes | Cornwall | 422.4 |
| **Saltfleetby–Theddlethorpe Dunes and Gibraltar Point** | Lincolnshire | 265.6 |
| **Sands of Forvie** | Aberdeenshire | 469.7 |
| Sandwich Bay | Kent | 258.3 |
| **Sefton Coast** | Sefton | 1072.7 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 113.2 |
| Solway Firth | Cumbria; Dumfries and Galloway | 32.6 |
| South Uist Machair | Western Isles / Na h-Eileanan an Iar | 545.7 |
| Tiree Machair | Argyll and Bute | 257.4 |
| **Torrs Warren–Luce Sands** | Dumfries and Galloway | 819.5 |
| **Winterton–Horsey Dunes** | Norfolk | 44.7 |
| **Y Twyni o Abermenai i Aberffraw/ Abermenai to Aberffraw Dunes** | Gwynedd; Ynys Môn/ Isle of Anglesey | 672.3 |

* Possible SAC not yet submitted to EC.

Bold type indicates a coastal GCR interest within the site.



*(Table 7.5) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal dune habitat(s) (other than machair) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)*

has extended a spit across an estuary. Some sand spits have a distal 'spatulate' form that does not display individual recurve ridges. Typically, these occur where there is a base on which the sand transported to the distal end can accumulate over a wide area. This base may be salt-marsh or mud-flats. Many spits have been built upon gravel ridges, or, in Scotland, emerged beaches as their foundation, and in some cases the presence of morainic gravels provides a basis for the distal parts of these spits (for example Spurn Head, Yorkshire and Whitford Spit,

**Table 8.1** The main features of sediment sources and tidal ranges of sand spit GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain important sand spit structures in the assemblage of features. Many machair sites have small sandspits – see Chapter 9. (Sites described in the present chapter are in **bold** typeface.)

| Site | Main features | Other features | Present-day natural sources of sediment | Tidal range (m) |
|---|---|---|---|---|
| **Pwll-ddu** | Sand spits | | Local fluvial and shallow nearshore | 8.2 |
| **Ynyslas** | Sand spit | Dunes | Estuarine, longshore (reduced) | 4.1 |
| **East Head** | Sand spit, distal dunes | | Restricted alongshore: mainly from offshore banks | 3.4 |
| **Spurn Head** | Major spit in macro-tidal environment | Dunes | Longshore and offshore | 6.4 |
| **Dawlish Warren** | Sub-parallel double spit | Dunes | Intertidal banks | 4.1 |
| **Gibraltar Point** | Series of spits, effects of extreme events | Dunes | Longshore and offshore banks | 7.0 |
| **Walney Island** | Barrier islands recurved spits | Till cliffs | Cliff erosion | 9.0 |
| **Winterton Ness** | Linear dunes on cuspate foreland | | Longshore | 2.6 |
| **Morfa Harlech** | Spits and recurves, ridge and runnel | Dunes | Longshore limited, intertidal estuarine banks | 4.5 |
| **Morfa Dyffryn** | Tombolo and dunes, sarn | Dunes | Longshore limited, offshore possible but unconfirmed | 4.5 |
| **St Ninian's Tombolo** | Tombolo | Dunes, climbing dunes | Nearshore and some local reworking | 1.1 |
| **Isles of Scilly** | Tied islands, spits | Emerged beach | Local feeder cliffs and platforms | 5.5 |
| **Central Sanday** | Tombolos, spits, sandflats, dunes | Gravel ridges, machair, dunes | Local reworking and nearshore machair | 3.0 |
| Eoligarry | Emerged tombolo | sand dunes and machair, bowthroughs | Local and offshore, biogenic sources from the east | 4.0 |
| Culbin | Bluckie Lock spit | Emerged gravel strand-plain, dunes, saltmarsh | Nearshore and erosional recycling | 3.6 |
| Morrich More | Innis Mhor sand spit | Emerged strandplain, dunes, saltmarsh | Fluvial, glaciogenic and offshore | 4.5 |
| Tentsmuir | Shore-parallel dune ridges, ness | Sand dunes, intertidal sands | Estuarine and longshore, significant | 4.4 |
| Luskentyre–Corran Seilebost | Sand spit | Sand dunes and machair | Nearshore, intertidal to the east | 3.8 |
| Forvie | Shore-parallel dune ridges, spit | Unvegetated and parabolic dunes | Longshore and recycled from estuary | 3.1 |
| Torrisdale Bay | Dune landforms, climbing dunes | Sandspits, intertidal sandflats, saltmarsh | Fluvial and offshore, limited | 4.0 |
| Holy Island | Barrier beaches, spits | Emerged beach, dunes | Longshore and offshore | 4.1 |
| Scolt Head Island, North Norfolk | Barrier beach, recurved spits | Dunes | Longshore and offshore | 5.6 |
| Newborough Warren | Spits, modern and relict | Dunes | Intertidal estuarine banks offshore, local reworking | 4.7 |
| Carmarthen Bay | Spits | Dunes, cliffs | Fluvial/estuarine, offshore and intertidal banks, local reworking | 8.0 |
| Braunton Burrows | Distal estuarine shore-parallel spit | Dunes | Fluvial/estuarine, offshore and intertidal banks, local reworking | 7.5 |



(Table 8.1) The main features of sediment sources and tidal ranges of sand spit GCR sites, including coastal geomorphology GCR sites described in other chapters of the present volume that contain important sand spit structures in the assemblage of features. Many machair sites have small sandspits — see Chapter 9. (Sites described in the present chapter are in bold typeface )

**Table 8.2** Area of East Head – historical data from 1846 to 1996

| Date | Area (ha) | Data source |
|---|---|---|
| 1846 | 8.9 | Tithe map: property 541 |
| 1875 | 5.3 | OS Area 83 |
| 1898 | 6.5 | OS Area 310 |
| 1911 | 2.3 | OS Areas 310 and 310a |
| 1933 | 17.5 | OS Areas 309a, 310 and 310a |
| 1975 | 30.7 | Searle (1975) |
| 1996 | *c.* 40 | May (1997b) |

became established once more. Steady erosion reduced the spit to its narrow form, which was breached in 1963. The establishment of groynes to the east may have been an important factor in speeding the onset of breaching. Since 1963, the more stable Type B has been the characteristic form (see Figure 8.6).

## Interpretation

East Head owes some of its present-day form to the coast protection activities that have taken place both within and beyond the boundaries of the site. The National Trust has taken steps to ensure that the dune system is stabilized and that the vegetation, in particular, is not seriously disturbed. After the 1963 breach, brushwood and small scrub windbreaks were constructed to aid sand deposition (Searle, 1975). Harlow (1982) outlined the more substantial coast protection works that have been undertaken to the east of the site, at Medmerry and Bracklesham, and their effects upon sedimentary processes. Both activities have been intended to retain sediment within specific parts of the coastline. Whereas the National Trust action has been concerned with the retention of sand and shingle within the site, the action of coast protection authorities to the east has been designed to prevent (or at least retard) movement of sediment away from other sites towards East Head (Hooke *et al.*, 1996). Shingle has tended to move northwards along the spit at East Head, but has not been replaced by shingle arriving from the east as happened in the past. Harlow (1982) estimated that about 7000 $m^3 a^{-1}$ of shingle was added naturally to the front of East Head between 1975 and 1978.

After 1965, there was a marked increase in sand seaward of the old vegetated ridge of the dunes (Figure 8.6) and there was also considerable intertidal accretion that provided a source of windblown sand for the dunes. Harlow's (1982) sediment budget analysis for this coastline confirmed that this sand supply and the changes in intertidal areas of East Pole, West Pole and The Winner are related.

This site is unusual among small estuary-mouth spits in that it continues to grow even though the main longshore sediment source has been curtailed by extensive groyne-fields. It has been viewed as an erosional site by its managers, although the overall volume of sand and shingle has increased. The reason for this is that much of the sediment added to it has so far accumulated on the intertidal banks at the mouth of Chichester Harbour. Recent changes in the position of the spit have tended to assist progradation by making both wave and wind transport from the intertidal area perpendicular to the shore and dunes.

This site is also important because of the juxtaposition of shingle beach, spit, dunes and saltmarsh. A similar assemblage is found at Gibraltar Point, Lincolnshire, but East Head is smaller and in a different tidal and current environment. It has undergone considerable anthropogenic modification, as measures have been sought to manage and preserve the dune system. The shingle beach processes seem to have been independent of the management activities. The site is an excellent example of beach dynamics in circumstances where, despite interference with longshore transport, the plan-form of the sediment cell is adjusting towards a new dynamic equilibrium with changes in sediment availability and alterations in wave direction. As a result, the shoreline has swung back towards its earlier north-west–south-east alignment. The intertidal area is a mobile sediment store and forms part of a transport system by which sediment crosses the mouth of an estuary (Harlow, 1982). Progradation of the intertidal area provides a source of sediment for the beach and thence the dunes.

At a regional level, the contrast between East Head and the shingle spit at the mouth of Pagham Harbour, West Sussex, is an important one. The Pagham site lacks sand and dunes and has well-developed shingle ridges and fulls. The lack of sand is mainly a result of the limited volume in the intertidal area seaward of the spit. East Head has a shingle base, but its dunes owe their development very largely to the presence of intertidal sources of sand. In addition, East Head is on a windward shore in contrast to the



*(Table 8.2) Area of East Head — historical data from 1846 to 1996*

Historical evidence extends the above pattern of phased instability and stability of the machair into modern times. During the 16th century machair surfaces were stable with well-established agriculture, but the 17th century brought widespread sand-blow on much of the Scottish coast and burial of machair surfaces and buildings in the Outer Hebrides (Ritchie, 1966, 1979a; Lamb, 1991; Angus, 1997). Although probably more stable than it has been in the past, Hebridean machair is still actively forming and the present-day machair surface has probably formed over the same timescale as it has in the past, that is over periods of less than 100 years (Gilbertson *et al.*, 1999). Nevertheless, the present machair system as a whole represents the latest manifestation of a continuum of essentially similar processes operating since at least middle Holocene times.

## The conservation value of machair

The geomorphological significance, and hence the Earth science conservation value, of machair arises from its importance to our understanding of:

1. the processes of machair erosion and accumulation;
2. the interaction of sediment supply and sea-level change;
3. the interaction of sediment, vegetation and land use.

As described above, it is believed that machair grassland has been modified by humans throughout its development. Traditionally, machair supports extensive grazing regimes and unique forms of cultivation that rely on cattle-grazing and low-intensity systems of rotational cropping. This traditional agriculture sustains a rich and varied dune and arable weed flora. Some of the arable weed species are now largely restricted in the UK to these traditionally managed areas. The habitat type also supports large breeding bird populations and is particularly important for waders and corncrake *Crex crex*.

The GCR site selection rationale for machair has been to represent the range and diversity of the geomorphological features (Table 9.1). In the present chapter, sites are arranged in a clockwise order around the coast, starting with the southernmost.

## Machairs as biological SSSIs and Special Areas of Conservation (SACs)

In Chapter 1, it was emphasised that the SSSI site series is constructed both from areas nation-

**Table 9.1** Machair GCR sites

| Machair site | Main features | Other features | Tidal range (m) |
|---|---|---|---|
| Machir bay | Beach–dune–machair, high-level machair terraces, emerged beaches | Climbing dunes | 3.0 |
| Eoligarry | Vigorous erosional machair forms large blowouts, tombolo structure | Storm beach, wide intertidal, sheltered beach, archaeological dating | 4.0 |
| Ardivachar–Stoneybridge | Machair type site, high and low machair deflation corridors | Archaeological dating gravel barrier, palaeosols | 3.6 |
| Hornish and Lingay Strands | Flat, low-lying machair, water-table effects | Superimposed small dunes, artificial drainage | 3.9 |
| Pabbay | Climbing machair, conical dunes, wet machair | No rabbits | 3.0 |
| Luskentyre–Seilebost | Large beach–dune machair remnant of former larger system, 35m high dunes; growth/decay model site | Spits, blowouts | 3.8 |
| Mangersta | Eroded and deflated formerly extensive machair, advanced stage of erosion | Water table | 3.8 |
| Tràigh na Berie | Large dynamic beach–dune–machair dune cordon intact and well-nourished | Infill of valleys and lochs, no chronic erosion | 3.8 |
| Balnakeil | Dynamic climbing machair and dune blowouts, headland by-passing of sediment | Erosion of frontal edge, sand-fall over cliff | 4.0 |



*(Table 9.1) Machair GCR sites*

Table 9.2 Candidate Special Areas of Conservation supporting Habitats Directive Annex I habitat 'Machair' as a qualifying European feature. (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Machair extent (ha) |
|---|---|---|
| Coll Machair | Argyll and Bute | 681 |
| Monach Islands | Western Isles / Na h-Eileanan an Iar | 292 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 1707 |
| **Sheigra–Oldshoremore** | Highland | 222 |
| **South Uist Machair** | Western Isles / Na h-Eileanan an Iar | 1785 |
| Tiree Machair | Argyll and Bute | 510 |

**Bold** type indicates a coastal GCR interest within the site

ally important for wildlife and GCR sites. An SSSI may be established solely for its geology/geomorphology, or its wildlife/habitat, or it may comprise a 'mosaic' of wildlife and GCR sites that may be adjacent, partially overlap, or be co-incident. Therefore, there are some areas of machair that are crucially important to the natural heritage of Britain that have been designated as SSSIs primarily for their wildlife conservation value, but implicitly will contain interesting coastal geomorphology features that are not included independently in the GCR because of the 'minimum number' criterion of the GCR rationale (see Chapter 1). These sites are are not described in the present geomorphologically focused volume.

In addition to being protected through the SSSI system for its national importance, machair is a 'Habitats Directive' Annex I habitat, eligible for selection as Special Areas of Conservation, (see Chapter 1). Furthermore, many machairs are of international ornithological importance, primarily for breeding waders, and for this reason may be designated Special Protection Areas under the 'Birds Directive'.

Because machair is a habitat unique to the north and west of Scotland and western Ireland, the UK has a special responsibility for machair, and has recently established a UK Machair Habitat Action Plan (Angus and Dargie, 2002)

### *Machair SAC site selection rationale*

Site selection has taken account of the wide range of variation in physical type shown by Scottish machairs and has also been influenced by the UK's special responsibility for machair conservation. The largest sites have been selected, as these demonstrate the best structure and function and include the most diverse examples of transitions to other habitats. Sites have been selected from across the range of machair in the Outer and Inner Hebrides and on the Scottish mainland.

Table 9.2 lists machair SACs, and indicates which of these sites are also important (at least in part) as part of the GCR and are described in the present chapter.

## MACHIR BAY, ISLAY, ARGYLL AND BUTE (NR 210 630)

### Introduction

Machir Bay is a highly dynamic beach–dune–machair assemblage located on the exposed Atlantic coast of Islay (see Figure 9.1 for general location and Figure 9.5). The wide, high-energy beach is backed by a complex sequence of dune forms including low embryo dunes, an active foredune ridge, multi-ridged mature dunes, re-depositional sandhills and an extensive machair surface. The machair plain is of exceptional geomorphological interest as it drapes a number of topographical features including a series of high-level marine terraces, glacial deposits, talus slopes, and rock plateaux. Many streams drain through the dune and machair providing a strong hydrological control on morphology. Although several descriptions exist of the beach–dune–machair morphology of Machir Bay (Ritchie and Crofts, 1974; MacTaggart, 1996), greater interest has been shown in the emerged beaches, glacial terraces and relict clifflines that the machair partially obscures (Dawson, 1983; Dawson *et al.*, 1997).

**Figure 9.5** Geomorphology of Machir Bay, Islay, showing a mix of machair types including substantial terraces at the rear of the system covered by high machair. (After Ritchie and Crofts, 1974.)



(Table 9.2) Candidate Special Areas of Conservation supporting Habitats Directive Annex I habitat 'Machair' as a qualifying European feature. (Source: JNCC International Designations Database, July 2002.)

**Table 10.1** Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal saltmarsh habitat(s) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)

| SAC name | Local authority | Saltmarsh extent (ha) |
|---|---|---|
| **Alde, Ore and Butley Estuaries** | Suffolk | 390 |
| **Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd** | Abertawe/ Swansea; Caerfyrddin/ Carmarthenshire; Penfro/ Pembrokeshire | 2764 |
| **Chesil and the Fleet** | Dorset | 21 |
| **Culbin Bar** | Highland; Moray | 205 |
| Dee Estuary/ Aber Dyfrdwy* | Cheshire; Fflint/ Flintshire; Wirral | 2431 |
| **Dornoch Firth and Morrich More** | Highland | 539 |
| Drigg Coast | Cumbria | 162 |
| **Essex Estuaries** | Essex | 3770 |
| Fal and Helford | Cornwall | 70 |
| **Glannau Môn (Cors heli)/ Anglesey Coast (Saltmarsh)** | Ynys Môn/ Isle of Anglesey | 191 |
| **Humber Estuary*** | City of Kingston upon Hull; East Riding of Yorkshire; Lincolnshire; North East Lincolnshire; North Lincolnshire | 840 |
| Kenfig/ Cynffig | Pen-y-bont ar Ogwr/ Bridgend | 20 |
| Mòine Mhór | Argyll and Bute | 94 |
| **Morecambe Bay** | Cumbria; Lancashire | 1897 |
| **North Norfolk Coast** | Norfolk | 19 |
| **North Uist Machair** | Western Isles / Na h-Eileanan an Iar | 82 |
| **Pembrokeshire Marine/ Sir Benfro Forol** | Penfro/ Pembrokeshire | 274 |
| **Pen Llŷn a'r Sarnau/ Lleyn Peninsula and the Sarnau** | Ceredigion; Gwynedd; Powys | 748 |
| **Plymouth Sound and Estuaries** | Cornwall; Devon; Plymouth | 192 |
| Severn Estuary/ Môr Hafren* | Bro Morgannwg/ Vale of Glamorgan; Caerdydd/ Cardiff; Casnewydd/ Newport; City of Bristol; Fynwy/ Monmouthshire; Gloucestershire; North Somerset; Somerset; South Gloucestershire | 656 |
| **Solent Maritime** | City of Portsmouth; City of Southampton; Hampshire; Isle of Wight; West Sussex | 2276 |
| **Solway Firth** | Cumbria; Dumfries and Galloway | 4171 |
| **The Wash and North Norfolk Coast** | Lincolnshire; Norfolk | 3341 |

* Possible SAC not yet submitted to EC.
Bold type indicates a coastal GCR interest within the site

geomorphology, or its wildlife/habitat, or it may comprise a 'mosaic' of biological and GCR sites that may be adjacent, partially overlap, or be co-incident. Therefore there are a number of coastal SSSIs that are primarily selected for their wildlife conservation value, but implicitly will contain interesting coastal geomorphology features that are not included independently in the GCR because of the 'minimum number' criterion of the GCR rationale (see Chapter 1; Sherwood *et al.*, 2000). Therefore there are some areas of saltmarsh that are crucially important to the natural heritage of Britain are not described in the present geomorphologically



*(Table 10.1) Candidate and possible Special Areas of Conservation in Great Britain supporting Habitats Directive Annex I coastal saltmarsh habitat(s) as qualifying European features. Non-significant occurrences of these habitats on SACs selected for other features are not included. (Source: JNCC International Designations Database, July 2002.)*

gether with similarities, warrant their treatment within a combined section. The saltmarshes are, in the main, of the estuarine fringing type, being developed along the shores of the main Firth and its tributaries, although showing varying degrees of transition into open coast marsh at Caerlaverock on the Scottish shore. In addition, the saltmarsh at Moricambe Bay on the English shore shows many of the characteristics of a more enclosed embayment marsh (Table 10.2). The following text therefore describes the general topographic and hydrodynamic situation of the sites, and then seeks to describe and interpret the south shore group, the north shore group, and the Cree saltmarshes in turn.

The Solway Firth reaches almost 60 km wide between Burrow Head on the Scottish coast and St Bees Head on the English coast and extends over 130 km eastwards to the exits of the rivers Esk and Eden. With the exception of the Cree saltmarshes, the Solway saltmarshes are all located within the inner (eastern) Firth (Figure 10.12). The Firth is macrotidal; mean tidal range at Silloth on the Cumbrian coast reaches 8.4 m at springs and 4.8 m at neaps. On the northern coast the mean tidal range at Heston Islet in Auchencairn Bay is 7.4 m at springs and 3.9 m at neaps (Pye and French, 1993). The tidal streams generated can be significant especially at the mouths of tributary streams, at headlands and promontories and within channels between sandbanks. For example, the tidal stream in and out of the River Cree reaches 2.5 m $s^{-1}$ at springs and similar velocities occur offshore of Southerness Point (Ramsay and Brampton, 2000f). The general situation is that the ebb tide runs for longer and flows at lower velocities than the flood tide. The extensive area of sandbanks retards the flood peak at successive locations upstream and contributes to a marked tidal asymmetry. This differential tidal flow accentuates the net deposition of sediment within the estuary as slower ebb currents are less able to transport sediment than the stronger flood (Comber *et al*., 1994).

The Solway Firth is exposed to waves from the south-west, although fetch lengths are rarely more than 250 km. As a result, most waves reach the shore as wind-waves generated in the Irish Sea or the Firth itself, or as refracted Atlantic swell (Ramsay and Brampton, 2000f). The net effect of what amounts to a unidirectional wave climate is that the Solway Firth, and in particular the inner Firth, is a sediment trap with sediment accreting on the extensive intertidal sandbanks. Thus there is a net build-up of sediment within the Solway, with little sediment escaping seawards (Perkins and Williams, 1966). One result of the predominantly eastward movement of sediment is that the Solway Firth saltmarshes are dominated by sandy sediments that are mainly marine in provenance.

**Table 10.2** Characteristic geomorphological features of some of the main Solway Firth saltmarshes.

| | **Rockcliffe** | **Burgh** | **Moricambe Bay** | **Caerlaverock** | **Cree** |
|---|---|---|---|---|---|
| **Type** | Fringing estuary | Fringing estuary | Fringing estuary, bay | Fringing estuary, transitional | Fringing estuary, bay |
| **Marsh-edge morphology** | Low cliffs and terraces | Low cliffs and terraces, locally ramped | Low cliffs and terraces, locally ramped | Low cliffs and terraces, rarely ramped | Ramped, locally cliffs and terraces |
| **Creek system** | Dendritic | Modified dendritic | Dendritic | Dendritic | Dendritic |
| **Saltpans** | Common | Common | Common | Infrequent | Common |
| **Age of active marsh** | >200 years | Unknown | Unknown | Pre-mid 19th century | Unknown |
| **Mean sediment type** | | | | | |
| **Upper marsh** | Sandy silt | Sand/fine sand /silt: clay | Sand/fine sand /silt: clay | Sand:silt:clay | Fine sand |
| **Marsh edge** | Sandy silt | Sandy silt | Sandy silt | Fine sand | Fine sand |
| **Upper tidal flat** | Sand to sandy silt | Sand to silty sand | Silty sand | Fine sand | Sand and gravel |



(Table 10.2) Characteristic geomorphological features of some of the main Solway Firth saltmarshes.

many of the marshes lends support to this hypothesis and suggests that the developing marshes have been subject to cycles of erosion and deposition depending upon the relative proximity of river channels and the rate of sea-level change. It is likely that the broad transitions to mature upper marsh and freshwater communities that are so well displayed in the Upper Solway marshes are also related to the history of sea-level change experienced by the area. The transitions away from salt-affected vegetation so well-represented on the Upper Solway Marshes are of considerable importance because such zonations have been largely destroyed by land-claim in many other British saltmarsh systems. Although artificial embankments and walls are present along many of the intertidal reaches of rivers draining into the inner Solway and on some low-lying areas inland of Rockcliffe Marsh and Moricambe Bay, direct physical human impact on most of the Upper Solway saltmarshes remains minimal, although some of the saltmarshes have a history of turf-cutting and most are still grazed.

The Upper Solway Marshes also provide the finest examples in Britain of marsh terraces formed by the combined action of creek migration and land uplift. The terraces were first regarded by Dixon *et al.* (1926) as strong evidence for recent changes of sea level. They regarded the combination of gradual seawards decrease in altitude of the emerged 'carse' surfaces and the continued growth of Grune Point and small terraced flats on the modern saltmarsh as evidence for continuous uplift. However, Marshall (1962) interpreted the stepped nature of the marshes to be mainly erosional, since where they were present the terraces never graded into each other and the step was at an approximately constant height. This was thought to demonstrate alternation between erosion and accretion, probably the result of erosion by shifting river channels. The most likely scenario probably involves both of the above processes.

All of the marshes have eroded and accreted large areas during the 20th century. In Moricambe Bay, a loss of 39 ha of saltmarsh at Skinburness Marsh between 1860 and 1900 was balanced by accretion of 105 ha (Steers, 1946a). The *Salicornia*-dominated part of the marsh at Skinburness extended laterally by over 50 m between July 1959 and March 1961 (Marshall, 1962). At this time most of the edge of Burgh Marsh and the south-east edge of Rockcliffe Marsh the edge was characterized by high (2.0 m) cliffs, although elsewhere the marsh edge undergoing erosion was between 0.3 and 0.6 m above the adjacent sandflat (Marshall, 1962). Such erosion in this low wave-energy environment was attributed by Marshall to result largely from shifts in river channels rather than to wave activity. Indeed, with the possible exception of Cardurnock Flatts, all of the marshes are sheltered from substantial wave activity. The Moricambe Bay marshes are protected by Grune Point and a north-west-facing bay entrance that restricts the fetch of the dominant south-westerly waves. Rockcliffe Marsh lies at the head of a meandering estuary that reduces the access of westerly waves to only 1 km and is fronted by many kilometres of intertidal sandflats. As a result, patterns of erosion and accretion on the marshes are largely dictated by changes in river channels and by the long-term emergence of the coast.

Long-term estimates of erosion and accretion are possible by using areal comparisons of maps by Marshall (1962) and Pye and French (1993) over the period 1864 to 1993 (Table 10.3). These indicate that Rockcliffe and Skinburness Marshes gained area from 1864 to 1973, but

**Table 10.3** Estimated areal accretion in hectares between 1864 and 1946, 1946 and 1973, 1973 and 1993 for selected inner Solway saltmarshes. (Based on data from Marshall, 1962; Rowe, 1978 and Pye and French, 1993.) All areas in ha. Caerlaverock Marsh is in the Solway Firth (north shore) GCR site.

| Marsh | 1864 | 1946 | 1993 | 1894–1964 | 1946–1973[1] | 1946–1993[2] |
|---|---|---|---|---|---|---|
| **Rockcliffe** | 664 | 709 | 565 | +45 | +414 | −144 |
| **Burgh** | 688 | 534 | 524 | −154 | −82 | −10 |
| **Skinburness** | 445 | 506 | n/a | +61 | +100 | n/a |
| **Caerlaverock** | 194 | 607 | 563 | +413 | −93 | −44 |

1 Rowe (1978)
2 Pye and French (1993)



(Table 10.3) Estimated areal accretion in hectares between 1864 and 1946, 1946 and 1973, 1973 and 1993 for selected inner Solway saltmarshes. (Based on data from Marshall, 1962; Rowe, 1978 and Pye and French, 1993.) All areas in ha. Caerlaverock Marsh is in the Solway Firth (north shore) GCR site.

## INTRODUCTION

*V.J. May*

There are several lengths of the British coast in which, in addition to outstanding specific features such as well-developed saltmarshes or gravel beaches, the total assemblage of individual features is also outstanding. There are seven sections of coast in Britain selected for the GCR that each contain a wide diversity of individual coastal forms that together form an integrated coastal system or 'coastal assemblage' (see Figure 1.2 for locations and Table 11.1, below, for an outline of the principal features). The sites are Morrich More in the Dornoch Firth, Ross and Cromarty, and Culbin in the Moray Firth in Scotland; Holy Island, Northumberland, the North Norfolk Coast, and The Dorset Coast in England; and Carmarthen Bay and Newborough Warren and Morfa Dinlle at the western end of the Menai Strait in Wales. The origins and dynamics of each site have been the subject of considerable debate. Each of the sites falls within a different part of the British coast and is affected by different tidal and wave conditions, sediment supply and sea-level histories. Carmarthen Bay is the only member of this group of sites that is predominantly macrotidal and faces the high-energy Atlantic wave environment; there are few other sites on the European coast that combine these features with a distinctive record of sea-level change. In contrast, the north Norfolk coast is dominated by large depositional structures mainly in sand and shingle but also sheltering important saltmarshes. The links between the longshore transport regime and the development of the structures has been a focus of debate. Both Carmarthen Bay and the north Norfolk coast include a wide range of predominantly depositional features in which cliff erosion plays a limited role in the sediment budget, and reworking of the existing beaches and shallow-water sediments is more important. Both lie in situations where glaciation has played a role in the development of the coast, either in providing sources of sediments or in producing a cliffed coastline within which the sediments have been deposited and reworked.

In contrast, the coast of south-eastern Dorset

**Table 11.1** Main geomorphological features of the 'Coastal Assemblage' GCR sites.

| Site | Main geomorphological features | Tidal range (m) |
|---|---|---|
| Culbin | Extensive dune system with dunes up to 30m high; parabolic dunes; emerged gravel strandplain and spits; sandy spits; gravel spits; extensive intertidal sandflats and saltmarshes; westerly shift. | 3.6 |
| Morrich More | Emerged sandy coastal strandplain with interdigitated saltmarsh and sandy beaches on either flank; offshore sandy islands and spit; large parabolic dune system; 1 km width intertidal sandflats in Dornoch Firth. | 3.4 |
| Carmarthen Bay | Major dunes; sand-spits and barrier beaches; hard-rock and easily eroded cliffs; rias; emerged beaches; extensive intertidal sandflats; and saltmarshes. | 8.0 |
| Newborough Warren and Morfa Dinlle | Major dunes (linear and parabolic); Holocene dunes; gravel spits; hard-rock and easily eroded cliffs; extensive intertidal sandflats; estuary; saltmarshes. | 4.2 |
| Holy Island | Barrier beaches; spits; emerged beach; longshore and offshore sediment sources (Huddart and Glasser, 2002) | 4.1 |
| North Norfolk Coast | Scolt Head Island, a major barrier island; Blakeney Point, a large shingle spit; intertidal flats, beaches; dunes; saltmarshes; cliffs. One of the few areas on the coastline of England and Wales where saltmarsh morphology, including saltpans, has been examined in detail. | 6.4 (west) to 4.7 (east) |
| The Dorset Coast: Peveril Point to Furzy Cliff | Differential erosion to a longitudinal coastline; includes such classic landforms as Lulworth Cove. Hard-rock and soft-rock cliffs; platforms; landslides; pocket beaches; chines; submerged rock barriers. | 1.7 (east) to 2.0 (west) |



(Table 11.1) Main geomorphological features of the 'Coastal Assemblage' GCR sites.

is cliffed and affected by sea-level change, but one where coastal alignment and forms owe much to geological structure and lithology. Erosion has produced an unrivalled variety of cliffs, bays and beaches. Beaches are formed mainly in flint and chert but, even though the chalk cliffs are undergoing erosion, many of the beaches are not supplied with significant quantities from such sources today. Changes in sea level and in the position of the coastline have left a legacy of hanging and deeply incised valleys, in contrast to Carmarthen Bay where sediment-rich, drowned estuaries and rias feature strongly.

The origins of the Purbeck coast are not well understood, even though parts have been very well described (e.g. Brunsden and Goudie, 1981), especially the geology (Damon, 1884; Strahan, 1898; Arkell, 1947; House, 1993). The sole evidence on this coast of higher sea levels is at Portland Bill, and although the coast east of St Alban's Head may preserve relict features, there is no other direct evidence of higher sea levels here. The effects of differential erosion are well known here. Unlike the other sites, this coast has increasingly been investigated underwater and so the nature of rocky seabed geomorphology can be used to further the interpretation of the features.

Although individual features such as Lulworth Cove and Stair Hole, Dorset, or Scolt Head Island, Norfolk, are outstanding in their own right, their importance is significantly increased by their association with other features of the adjacent coast. Such localities could be included within previous chapters of the present volume, but despite their individual importance, these features are best described within the wider regional context and in association with each other. Three of the sites (Carmarthen Bay, North Norfolk Coast and Dorset Coast) are highly segmented in terms of their morpho-sedimentology, with between 31 and 35 segments each, and averaging 1.7 km in length, based on the form and dynamics of the shoreline (Table 11.2). The coast of Caernarfon Bay includes seven of the CORINE categories (see p. 21, Chapter 1), a smaller number of segments and a similar mean segment length to Carmarthen Bay. This reflects the higher proportion of long sandy beaches. This variety reflects the impact of changing relative sea levels, the resistance of materials, and large-scale deposition.

Large-scale deposition is also a strong theme at Culbin, Morrich More and Holy Island where plentiful sediment has been available for beach building during much of the Holocene Epoch, aided by a falling relative sea level. All three sites combine internationally important features within complexes of gravel features, sand beaches, spits, dunes and saltmarshes. At Culbin, in the Moray Firth, a large gravel strandplain composed of gravel ridges and spits has become elevated over the Holocene Epoch and subsequently buried by large quantities of wind-blown sand. Much of the present-day coast is dominated by

**Table 11.2** CORINE categories, data for the Carmarthen Bay, North Norfolk Coast, Purbeck (Dorset Coast) and Newborough Warren/Morfa Dinlle GCR sites; measurements are in km.

| CORINE categories | | Carmarthen Bay | North Norfolk | Purbeck | Newborough Warren and Morfa Dinlle |
|---|---|---|---|---|---|
| (A) | Hard-rock cliffs (with fringing beaches) | 10 | 0 | 7 | 4 |
| (B) | Soft rock cliffs (with fringing beaches) | 1(1) | 2(1) | 21(4) | 1 |
| (C) | Pocket beaches | 1 | 0 | 3 | 0 |
| (D) | Coarse clastic beaches | 2 | 3 | 0 | 1 |
| (E) | Sandy beaches | 9 | 15 | 0 | 5 |
| (G) | Foreshores: fine sediments | 4 | 11 | 11 | 1 |
| (H) | Estuary | 2 | 1 | 1 | 1 |
| (J) | Port/harbour zone | 3 | 0 | 0 | 0 |
| (L) | Embankment | 0 | 1 | 1 | 1 |
| (X) | Mixed beaches | 0 | 2 | 2 | 0 |
| **Mean segment length (km)** | | 2.25 | 1.47 | 1.42 | 2.30 |
| **Total segments** | | 32 | 35 | 31 | 14 |



(Table 11.2) CORINE categories, data for the Carmarthen Bay, North Norfolk Coast, Purbeck (Dorset Coast) and Newborough Warren/Morfa Dinlle GCR sites; measurements are in km.

Table 11.3 Summary of saltmarsh development in north Norfolk.

| Time | Development |
|---|---|
| 7500 years ago | First signs of marine incursion at c. –7 m OD |
| Until 5500 years ago | Sediments accumulate as sea level rises |
| Between 5500 and 4500 years ago | Peats within saltmarsh muds and silts imply stability or perhaps fall in sea level |
| About 4000 years ago | Barrier features at Scolt Head and Blakeney probably in place (Allison, 1989) |
| About 3000 years ago | Coastline at Holkham is 3km north of its present position |
| About 2000 years ago | Romano-British remains indicate inner marshes at Brancaster and Burnham |
| Last few hundred years | Outer marshes develop at Scolt Head Island, Blakeney and at Warham |
| Since 1900 | Open coast marshes grow rapidly with *Spartina* colonization between Wells and Stiffkey |
| Since 1950 | New marshes at western Scolt, Thornham, Morston, western Blakeney. Dune ridges transgressing onto marsh at Brancaster |

gle spit, comparable in size to Spurn Head. The shingle beach extends from Sheringham westwards for over 17 km, the first 5.5 km fringing low (up to about 30 m) till cliffs (Burnaby, 1950), and the central section forming a ridge fronting Salthouse Marsh and Fresh Marsh. The ridge is about 200 m wide and between 9 and 10 m in height. Hardy (1964) estimated that the whole structure contained about $2.3 \times 10^6$ $m^3$ of shingle. The western part continues as a single ridge for a further 3 km before developing a series of long recurves trending southwards that are the most recent members of a set of over 20 shingle laterals of varying length. Blakeney Point has extended and shortened several times during the last 150 years. The morphological and cartographic evidence demonstrates that the spit has grown westwards. Steers (1927) estimated that the spit lengthened by 86.4 m $a^{-1}$ between 1886 and 1904 and by 45.7 m $a^{-1}$ between 1904 and 1925. Between 1649 and 1924 the ridge moved inland by an average of about 1 m $a^{-1}$ (Hardy, 1964). There is some debate about the extent to which longshore transport is consistently in this direction and it is possible that shingle moves one way and sand in the other (Battarchaya, 1967; Hardy, 1964; Steers, 1964b; Cambers, 1975). In recent years the ridge has been eroded by storms and then re-shaped by bulldozing material back into the increasingly narrow profile, similar to Hurst Castle Spit (see GCR site report in Chapter 6). This has led to a reduction in the shingle volume of the beach and in February 1995 a 200 m-wide breach through the ridge occurred. If the loss of shingle continues it is likely that Blakeney Point will become an isolated island such as Scolt Head, unless coast protection works are carried out to provide protection for low-lying settlements such as Salthouse. The geomorphological interest lies in allowing natural processes to continue unimpeded, though with the lost shingle restored by beach nourishment.

There are active marshes either side of the Blakeney Channel, but east of Blakeney, they have mostly been land-claimed. The marshes behind the shingle ridge from Salthouse to Blakeney Point increase in age eastwards, with the oldest probably developing first during the 15th century (Pethick, 1980a). Most recently, lateral growth of new marsh has taken place at the western end of Blakeney spit since the 1950s (Pye and French, 1993). Carey and Oliver (1918) reported thin coverings of samphire *Salicornia* spp. in the central marshes, whereas the marsh closer to Blakeney Point itself appears to be older (between 1818 and 1880; Pethick, 1980a).

## Interpretation

Despite the long and detailed documentation of the north Norfolk coastline, the sources of the sediments forming the beaches and the direction of sediment transport is still open to debate. The direction of longshore transport has generally been described as eastwards and southwards along the Norfolk coast east of Sheringham, whereas the shingle features on the North Norfolk Coast site have been shown to develop towards the west (Redman, 1864; Wheeler, 1902; Steers, 1927, 1946b). This would suggest a division in the drift direction in the vicinity of Sheringham. Work by Sir William Halcrow and Partners (Halcrow, 1988) demonstrates that the direction of mean, annual, alongshore wave-



(Table 11.3) Summary of saltmarsh development in north Norfolk.

turally controlled stepped platforms. Some erosion of the detail of the platforms depends upon cobbles that are rolled along the weaker junctions. Arkell (1947, 1951a, 1955) suggested that rare events (such as the Martinstown storm of 18 July 1955, when over 280 mm rain fell, over 180 mm of which fell in 4.5 hours) may have played a significant role in re-shaping much of the coastal slope east and west of Osmington where it is dominated by clays.

Ringstead Bay, cut into the Kimmeridgian strata, lies between Bran Point and White Nothe. From cliffs about 30 m high at Bran Point it falls to a series of slumped and heavily vegetated slopes that are only 5 m high at Ringstead Bay (Figure 11.35). At its eastern end there is an active cliff between 2 and 35 m in height that retreated more than 3 m between 1996 and 1998 into the foot of the White Nothe landslide complex. The cliff top behind the landslides, however, attains an altitude of 150 m.

The beach at Ringstead is formed almost entirely of rounded oxidized flint, ranging in size from coarse sand to cobble, the latter mainly where Chalk enters the beach from the White Nothe cliffs. Heeps (1986) showed that this beach has a balanced sediment budget although considerable movements of sediment occur within Ringstead Bay. This beach, like most others to the east, has a very abrupt seaward boundary about 20–30 m offshore, where it rests on a rock platform. The beach moves between the ends and centre of the bay and between the upper and the lower beach. Thus over the period of about 15 months (1983–1984) when profiles were surveyed, a loss of about 440 $m^3$ was balanced by deposition of almost exactly the same amount. There are extensive submerged and intertidal platforms formed mainly in Corallian strata, and these filter reduce the wave energy approaching this beach. Seaweed growth has been observed on much of the platform and Heeps (1986) recorded weed-rafting of material from platform to the beach, but suggested that it plays only a small part in augmenting the sediment within Ringstead Bay.

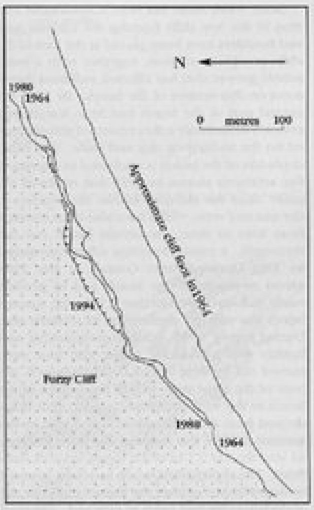

**Figure 11.34** Cliff retreat at Furzy Cliff.

**Table 11.4** Rates of cliff-top retreat since c. 1900 on the Dorset Coast.

| Mean annual rate ($m\ a^{-1}$) | Rock type | Location of retreat |
|---|---|---|
| 0.01 | Portland Stone | Durlston Head to Winspit |
| 0.18 | Chalk | Hambury Tout to White Nothe |
| 0.22 | Chalk | Worbarrow Bay |
| 0.25 | Purbeck Beds | Durlston Bay |
| 0.37 | Jurassic clays | Furzy Cliff to Shortlake |
| 0.38 | Wealden | Worbarrow Bay |
| 0.39 | Kimmeridge clays and shales | Kimmeridge |
| 0.41 | Kimmeridge clays | Ringstead |
| 0.43 | Kimmeridge clays | Chapman's Pool |
| 0.50 | Wealden | Lulworth Cove |



(Table 11.4) Rates of cliff-top retreat since c. 1900 on the Dorset Coast.