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						

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	

		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
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				

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
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 2.3) 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 lar	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 lar	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 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 ridges	Major cuspate foreland Relict barrier beach 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 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	
	(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 (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

(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

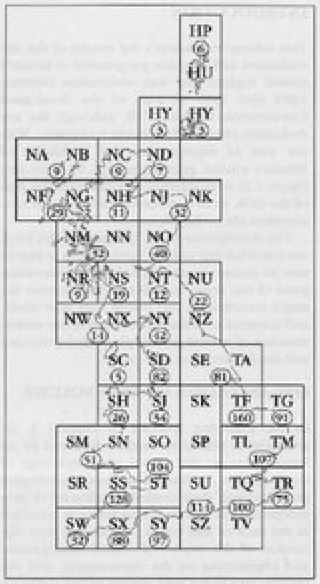

Figure 1.1 Geographical distribution of UK coastal research, based on a comprehensive computerized bibliography of books and papers on the geomorphology of the British Isles, containing some 9000 entries, compiled by K.M. Clayton. Of the 9000 entries, some 1400 are classified as dealing with coasts. 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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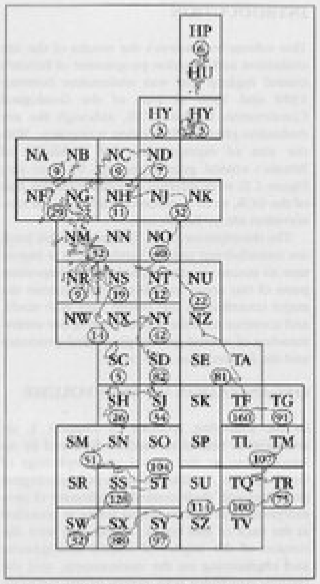

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(Table 1.2) Number of items under selected keywords (some items appear more than once as several keywords are allocated to each).

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 saltmarshes 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 colonising mud and sand	Glasswort and other annuals colonising 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.)

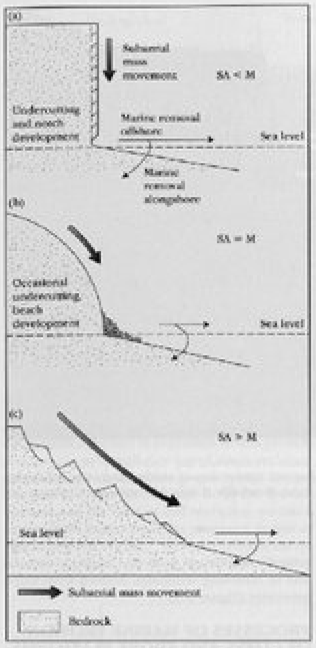

Figure 2.3 Processes of cliff retreat. SA = subaerial erosion of material, symbolized by the large arrow; M = marine erosion, symbolized by the fine arrows = eroded material is removed offshore and alongshore by marine process. (a) SA<M; here steep cliffs, undercut by marine processes, develop. (b) SA=M; 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 porewater 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)
Ardnacanach	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
0.85	Glacial drift	Grathy–Caister	100
0.85	Glacial drift	Holderness	100
0.88	London Clay, crag and glacial drift	The Naze	100
0.95	London Clay	Northern Isle of Sheppey	79
0.95	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	5.4
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	56.2
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	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 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 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 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	
	(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	
		(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; 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, hilltop 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	4.5
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	2.47
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
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.)

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	2.47
Llangennith*	15.05	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 7.4) 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	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 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	4.3
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 Mhor 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, 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	7.3

(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	2.5	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 1975, 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 2.3×10^6 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.

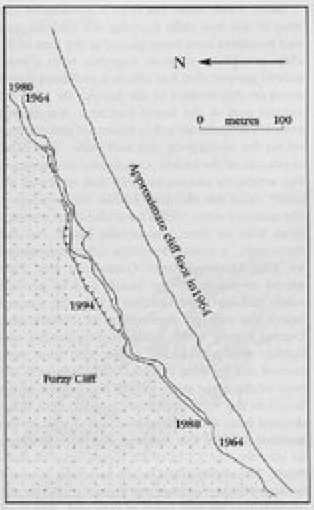

Figure 11.34 Cliff retreat at Furzy Cliff.

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.