Chapter 4 Soft-rock cliffs — GCR site reports

Introduction

V.J. May and K.M. Clayton

Cliffed coastlines undergoing rapid erosion characterize much of the south-eastern British coast where they are cut into relatively 'soft' geological materials such as sandstones, clay, shale and chalk, as well as many weak superficial deposits, notably the extensive glacial till of the east coast of England (see (Figure 1.2) and (Table 4.1)). There are also many locations around the British coast where short lengths of rapidly changing cliffs occur wherever softer materials crop out, for example part of the coastline between Weymouth and Lulworth (see GCR site report for the Dorset Coast, Chapter 11). It is also common for bayhead cliffs in upland coasts to be formed in weak materials, often of glacial or fluvioglacial origin, which produce pocket beaches. In such locations, pocket beaches are often entirely dependent on the erosion of truncated valley deposits as local sources of sediment, for example at Crackington Haven, Cornwall. In contrast, some pocket beaches may depend entirely on adjacent headlands as their sole source of sediment. Additionally, small cliffs, of up to a metre or so in height, often develop at the margins of saltmarshes (see Chapter 10), exhibiting on a micro-scale many of the features of the larger soft cliffs described in this chapter.

Many cliffs are associated with shore platforms that may extend seawards for several hundred metres from the cliff foot. Most actively developing platforms are associated with cliffs that are undergoing active retreat, and so many of the sites described in this chapter are also important for their platforms. A discussion of platform development is provided in Chapter 2 of the present volume.

The selection of soft-cliffs for the GCR used the following classification, based on the cliff lithology, form, and recession rates. It is comparable to the later Jones and Lee (1994) classification of cliffs on the basis of coastal recession.

1. Cliffs that are steep in profile and are retreating rapidly. Their steep profile is largely a function of the rapidity of retreat, which commonly exceeds 0.04 m a^{-1} and may attain 1.82 m a^{-1}. Formed mainly in weak or unconsolidated sands, clays, and gravels, the sediments are often of glacial origin. They are sig nificant sources of beach sediment, for example along the Yorkshire and East Anglian coasts. Their mass-movement features are well represented at Trimingham (described in the *Mass Movements* GCR volume; Cooper, in prep.).
2. Cliffs cut into stiff mudrocks, such as Kimmeridgian clay, the Gault Clay, and Tertiary days such as the Barton Clay. Often affected by shallow slides and mudslides, these cliffs provide very little sediment for beaches because most of the fine-grained material is carried into deeper water as the toe of slides is removed. They typically retreat at rates between 0.25 m a^{-1} and 1.50 m a^{-1}. As coastal features they are represented best by parts of the cuffed coasts of the south-west Isle of Wight and Dorset, although the best example of the mass-movement features is at Warden Point on the Isle of Sheppey (Dixon and Bromhead, 1991; Cooper, in prep.).
3. Cliffs cut into sandstones, shales and chalk that retain steep profiles despite a variety of retreat rates, which range from very slow to 1.20 m a^{-1}. Parallel retreat (over a timescale of 5 to 10 years) is their most common behaviour. Although they provide potential beach sediments, these are often quickly reduced by attrition to sand or smaller-sized particles. Chert, flint and other hard materials within these rocks may provide important components for beaches. In contrast, when the cliff failures produce boulders, they may form substantial elements of the intertidal landscape and may persist for very long periods of time. These cliffs are often associated with wide shore platforms which have attracted a substantial literature. The effects of small-scale structural features such as faults and joints often contribute to the formation of buttresses, caves, arches and stacks in these coasts. Stacks are often the most distinctive persistent elements of otherwise rapidly retreating coasts.
4. Major landslides in clay that carry extensive volumes of more-resistant overlying material such as chalk, greensand, flint and chert to the shoreline and provide major inputs of potential gravel beach sediment. Typically they retreat at rates in excess of 0.35 m a^{-1}. The harder components of the debris delivered to the beach provide very important beach material, whereas the fine-grained materials are usually quickly dispersed offshore. The coastline between

Golden Cap and Lyme Regis is the best representative of this coastal system, but the mass movements are especially well-represented by Folkestone Warren and the coastline between Axmouth and Lyme Regis (Cooper, in press).

Each of these types is represented by a GCR site, or GCR sites described in the present chapter (Figure 4.1), (Table 4.1).

(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

Retreat in soft-rock cliffs

Cliffs in weaker materials retreat at rates that range from 0.01 m a^{-1}- to over 3 m a^{-1}. Although average values for cliff retreat have been used to compare the magnitude of retreat in weak cliffs, it is essential to recognize that the rate of change in such cliffs, or indeed in any cliffs, is rarely regular (see (Figure 4.2)). Competing types of geomorphological processes affecting soft cliff sites operate at different rates, or are episodic, so the local form of cliffs can change quite considerably over time; It is common to observe morphological change seasonally. Many of these cliffs are affected by large mass-movements, which produce temporarily protective areas of debris at the cliff foot, or enhance beach volumes suffi ciently to provide protection against wave attack for a time. (Table 4.1) identifies both the sites that represent soft-cliff coasts specifically and those which are described in other chapters or in the *Mass Movements* GCR volume (Cooper, in prep.).

Two examples demonstrate the irregularity in the long-term mean and short-term variations of cliff recession. At Biding Gap, six-monthly surveys of the cliff top over a decade (from 1952 to 1961) showed that there had been considerable temporal and spatial variation in the amounts lost, although over the ten-year timescale there is a high degree of consistency in the average retreat rate overall (see (Table 4.2); May, 1971a). However, at Hengistbury Head, rates of retreat —as well as cliff-face changes — were recorded by the author at both the cliff top and foot, and these measurements demonstrate that although there is also a close similarity between cliff-top and cliff-foot retreat rates, there are considerable variations in the magnitude and frequency of the retreat event. These two examples show that the mixture of materials, structures, wave climates, beach characteristics and platform development is such that rapid retreat cannot be ascribed to any single rock type or location. Cliffs cut in rocks that retreat at the highest rates in one location may show minimal rates of change elsewhere.

It is also easier to reconstruct the development of the rapidly changing cliffs of Holderness and East Anglia, largely cut into glacial deposits, than the hard-rock cliffs of western Britain. Rates of erosion vary from 0.25 m a^{-1} to 3.5 m a^{-1} in Holderness (Figure 4.2), and an average of 6 m a^{-1} since the 1930s at Covehithe in Suffolk. Such cliffs undergoing rapid erosion suffer cliff failure in large part by rotational landslides, and their significance for study of these processes has formed a major reason for their inclusion as GCR sites. Thus many are described in the GCR volume on mass movement sites (Cooper, in press.).

From the marine-process viewpoint, two features are particularly noteworthy. First, the pattern of erosion over time and space is complex (Cambers, 1973). Despite such spatial and temporal variations, overall data for the whole of the Norfolk cliffs imply a long-term average rate of retreat dose to 1 m a^{-1}. Certainly cliff positions are difficult to establish prior to the first Ordnance Survey maps, but evidence of vanished villages near Cromer in Norfolk described in the Domesday Survey (1086 AD), or maps showing the steady erosion of the streets of the medieval town of Dunwich since 1589 AD (Robinson, 1980a; (Figure 4.3) strongly suggests long-term persistence of an erosion rate comparable with that found today. This implies both the long-continued effectiveness of the long-shore and offshore removal of sediment, and the continuation of wave-energy levels at the coastline similar to those today.

Yet, second, when the extent of coastal retreat since the slowing of the Holocene rise in sea level at about 6000 years BP is considered, it is clear that a third factor has been at work — the gradual and persistent deepening of the offshore zone. Along the North Sea coast of England (e.g. Holderness and north-east Norfolk), some of this change has been contributed by relative sea-level rise, but part may also be attributed to sea-floor erosion, probably by abrasion and bio-erosion. Insofar as the rate of cliff retreat has been sustained, the gradual deepening of this submerged offshore zone (from both erosion and sea level rise) and so the maintenance of offshore gradients may well have been the basic control on wave energy and so on the rates of coastal erosion. Along these coasts a shore platform also underlies the beach, but it is often seen only after severe storms, since erosion contributes enough sediment to maintain a thin covering beach (Figure 2.1)Figure 2.1c).

An intermediate position is held by the Chalk cliffs of England. Chalk is the commonest rock of south-eastern England and crops out in coastal cliffs along a considerable length of the coast from the Isle of Thanet to Devon, as well as at Flamborough Head and at Hunstanton, Norfolk, where the Red Chalk is well exposed. Several lengths of Chalk cliffs are induded in the GCR sites described in this chapter, including the steeply dipping (and rather resistant) Chalk of the Isle of Wight and Dorset. The rate of retreat tends to be ≥1 m a^{-1} with the more sheltered sites undergoing erosion at about 0.2 in a^{-1}. Chalk cliffs differ from weaker rocks (where the platforms are usually buried by a beach) in commonly displaying shore platforms at their foot. 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 cliffs from a geomorphological viewpoint has yet been attempted (the stratigraphy of the Chalk is described in the GCR volume by Mortimore *et al.,* 2001). Again, the present GCR volume may stimulate such work.

(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

As mentioned above, several of the weak-rock cliff sites are described within the *Mass Movements* GCR volume. Further soft-rock cliff sites in the GCR are those important for the sections that they provide in deposits reviewed in the Quaternary GCR volumes (Campbell and Bowen, 1989; Gordon and Sutherland, 1993; Campbell *et al.,* 1998).

Anthropogenic influences

Because of the coincidence of soft-rock cliffs and human occupation of the south and east coasts of England, these areas are commonly modified by drainage works and coastal engineering structures aimed at arresting erosion. Current rules for funding these works are making coastal protection works more difficult to justify than has been the case over recent decades. Nevertheless, it remains important for undisturbed cuffed coasts to be protected from anthropogenic intervention if their value for geomorphological research is to be maintained, and indeed if their value in providing sections of importance to geological research is to continue. Hutchinson's work on the London Clay cliffs provides what is now a historical record of a series of coastal sectors that have been entirely modified by basal engineering works. Today that work would be impossible to carry out and it is therefore increasingly important that our remaining cliffed sites on weak rocks remain in their naturally changing state. To some extent their designation as Sites of Special Scientific Interest (SSSIs) can help to facilitate debate on options available to avoid intervention or manage the land in a way sympathetic to the conservation of the scientific features of interest.

There are now few locations along the coast between the Exe estuary and the mouth of the Tees where rapidly retreating cliffs remain unaffected by human intervention. Even in areas where they have not been affected by the construction of sea-walls, their dynamics have been altered by the obstruction of longshore sediment transport. Thus erosion of the chalk coasts of the South and North Downs has been reinvigorated by a reduction in cliff-foot beaches following the construction of major harbour walls and coast protection works at Newhaven, Seaford, Folkestone and Dover. The south-west Isle of Wight is one of the very few coastlines where there has been minimal modification both to the cliffs and the sediment transport system.

In contrast to many soft cliffs that have been investigated in detail before coast protection works were emplaced (e.g. Clements, 1994; Barton, 1991), some of the remaining unprotected cliffs have been less welt investigated, despite their critical role as feeder-bluffs.

Although much interesting work has been published, there is still more research needed before we achieve an integrated understanding of the links between cliff-foot erosion, rock type, slope processes and slope form on cliffs in weak rocks. At least on the steeper cliffs (and these are usually those undergoing the most rapid erosion) within each rock type, landslides are the major process delivering material down the cliff slope. This reflects magnitude rather than frequency, though they are spatially common along the coast concerned. As a result, casual inspection of the cliffs, especially in winter when the cliffs are wet, will suggest that small streams and mudflows contribute proportionately more to slope transport than is actually the case, for though they are common, they are individually far smaller in size than the landslides (e.g. Cambers, 1973).

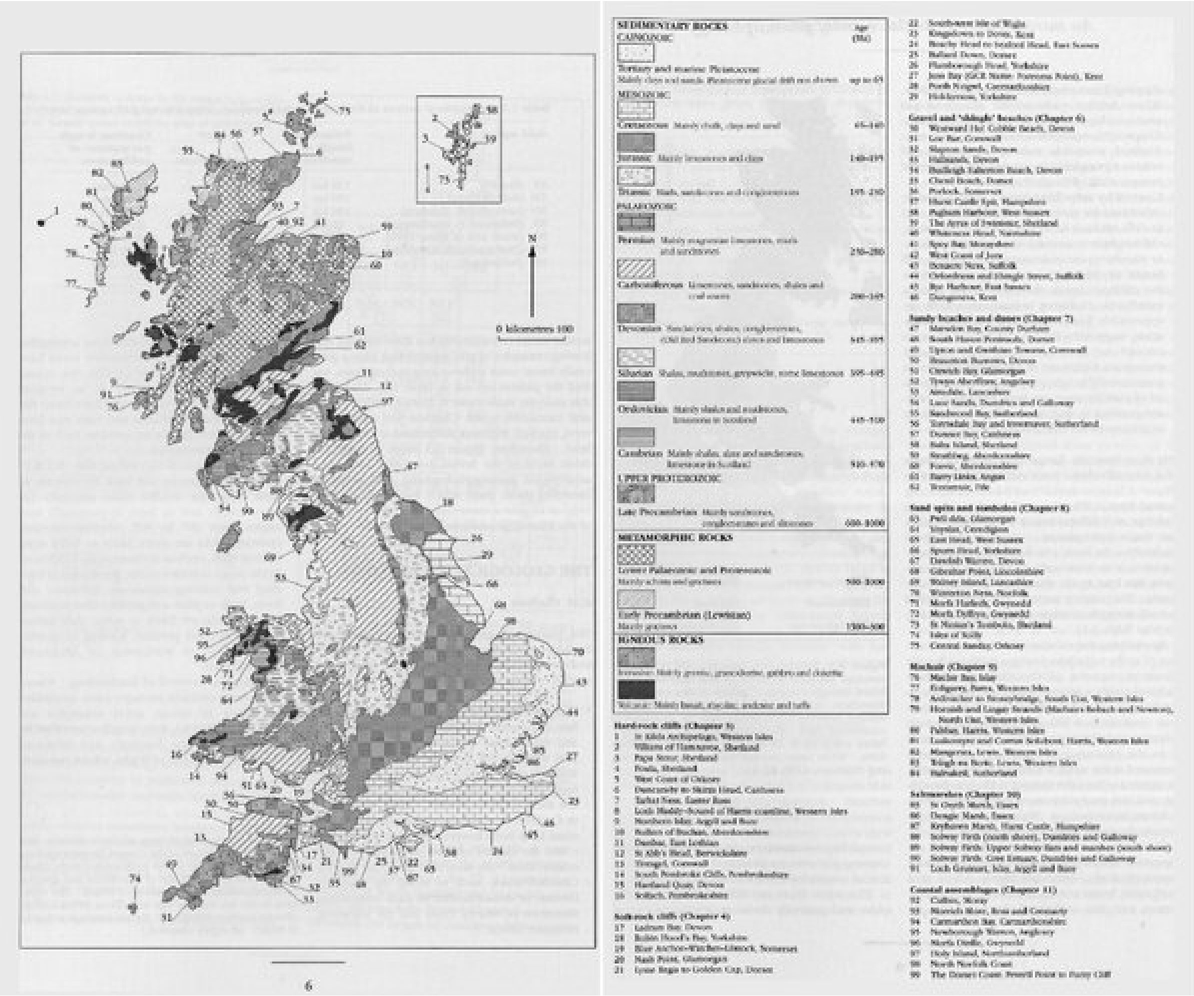
The conservation value of soft-rock cliff coasts

The geomorphological significance, and hence the Earth science conservation value, of soft-cliff coasts arises from their importance to our understanding of three linked processes:

1. the processes of retreat in cliffs that are cut into rocks of varying resistance;
2. the processes of platform development;
3. the processes of supply and transport of sediments from cliffs to beaches both below the cliffs and alongshore.

The rates at which cliffs and platforms produce sediment and the rate at which it is reduced and/or transported provides a strong feedback mechanism on cliff recession and platform lowering. The three processes are linked first by the sediment pathway from cliff to cliff foot to beach to down-drift beaches, second by the role of the sediment pathway from platform to beaches, and third by the inter-relationship between beach sediments and platform morphology and development. It is not usual to regard the erosional slope extending across the intertidal zone in poorly consolidated materials as a platform, but it is predominantly a surface of active erosion and a source of sediments. It exerts considerable effects on wave-energy dissipation, runoff and sediment transport. On many soft coasts, the erosion of cliffs provides the major source of beach sediment. Without erosion of cliffs, many beaches will cease to exist. Thus the continuing conservation of many sand and gravel beaches depends upon the continuation of cliff erosion.

In the present chapter, sites are arranged so that the soft-rock cliffs cut into the oldest rocks are described first, followed by others in decreasing stratigraphical age; in this way the important Chalk cliffs sites are grouped together and the Chapter ends with the cliffs cut into the Quaternary sediments of the Holderness coast.



(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. (NERC. All rights reserved.)

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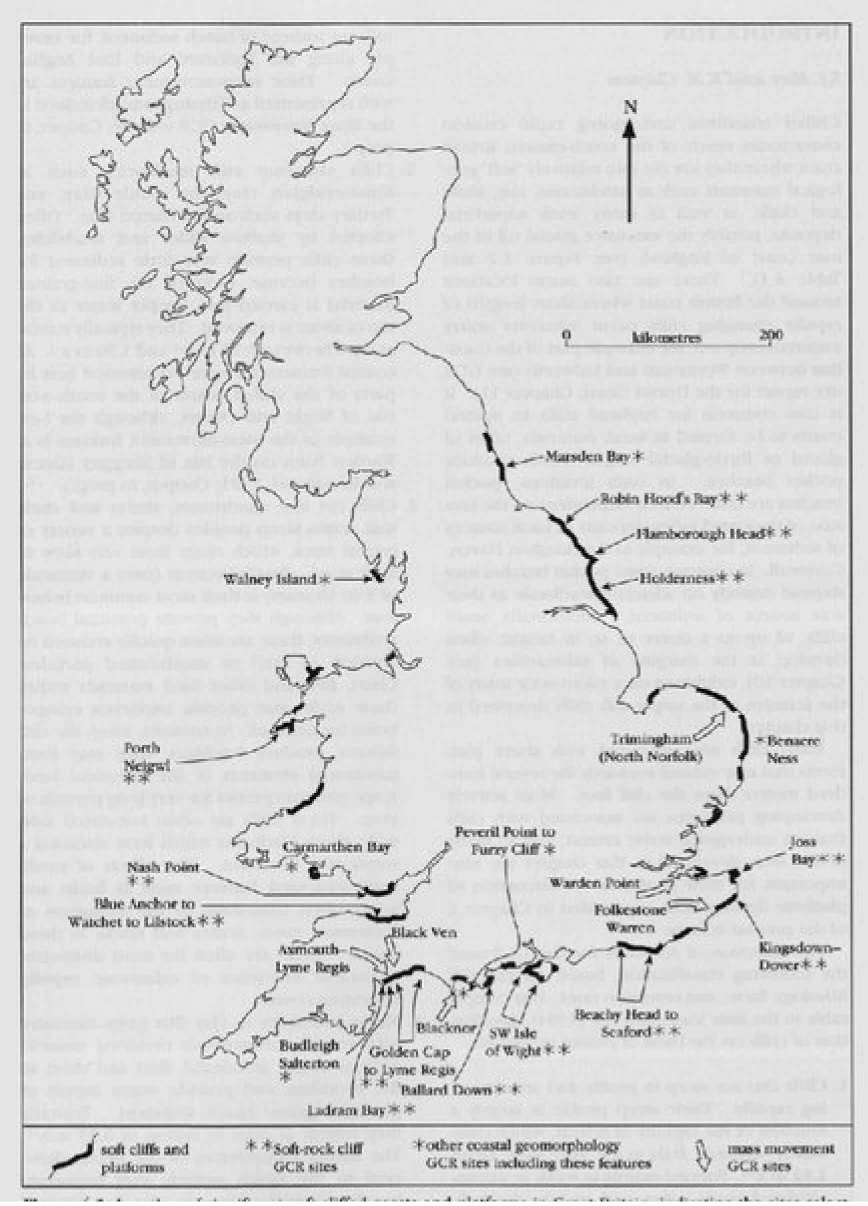
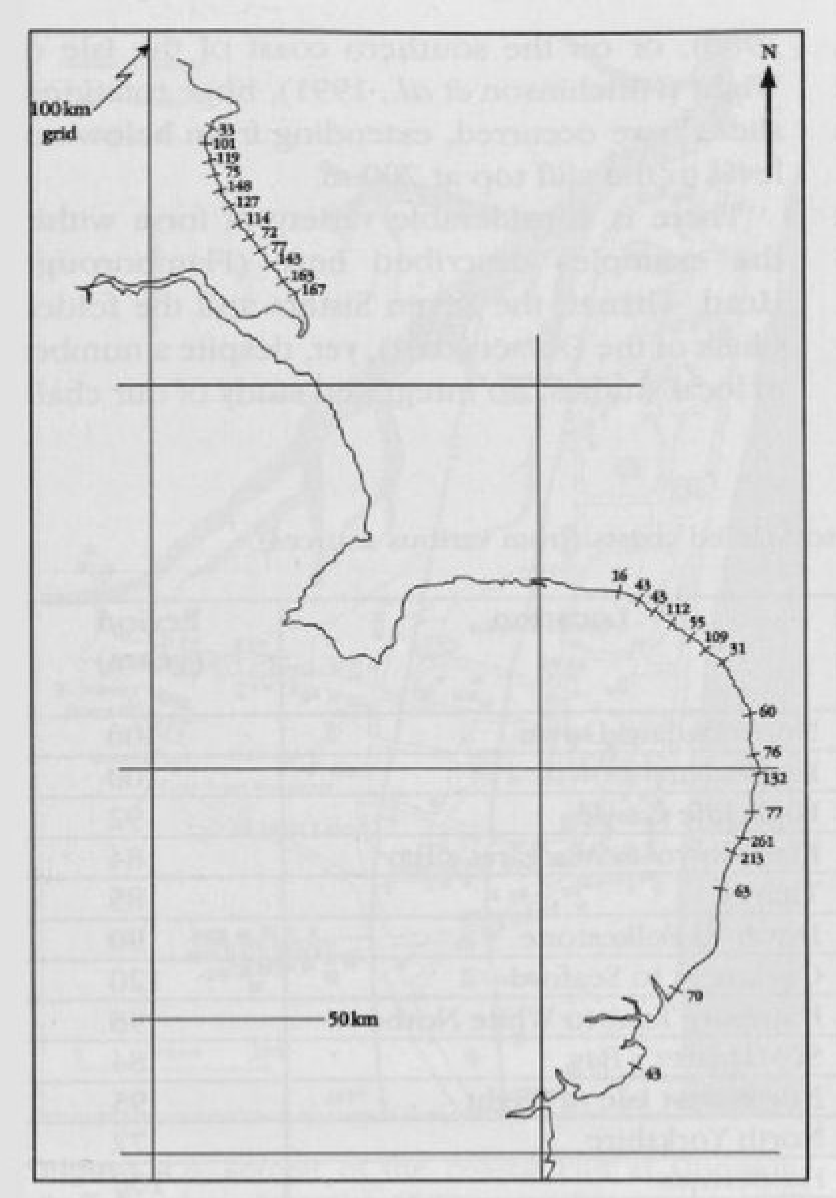


(Figure 4.1) Location of significant soft-cliffed coasts and platforms in Great Britain, indicating the sites selected for the GCR specifically for soft-rock cliff geomorphology. Other coastal geomorphology sites that include soft-rock cliffs and sites selected for the Mass Movements GCR 'Block' that occur on the coast are also shown.



(Figure 4.2) Rates of retreat along the North Sea Coast of England from Bridlington to Clacton-on-Sea. Rates are shown as averages for each length of cliff; where the length of cliff exceeds 5 km, values are every 5 km along the coast. Values are totals (metres) for 100 years to 1980. See also Table 2.1 and Table 4.2 (Compiled by K.M. Clayton)

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.

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0.29	Glacial drift	Holderness	100
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0.39	Kimmeridge clays and shales	Kimmeridge	100
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0.41	Wealden	South-west Isle of Wight	125
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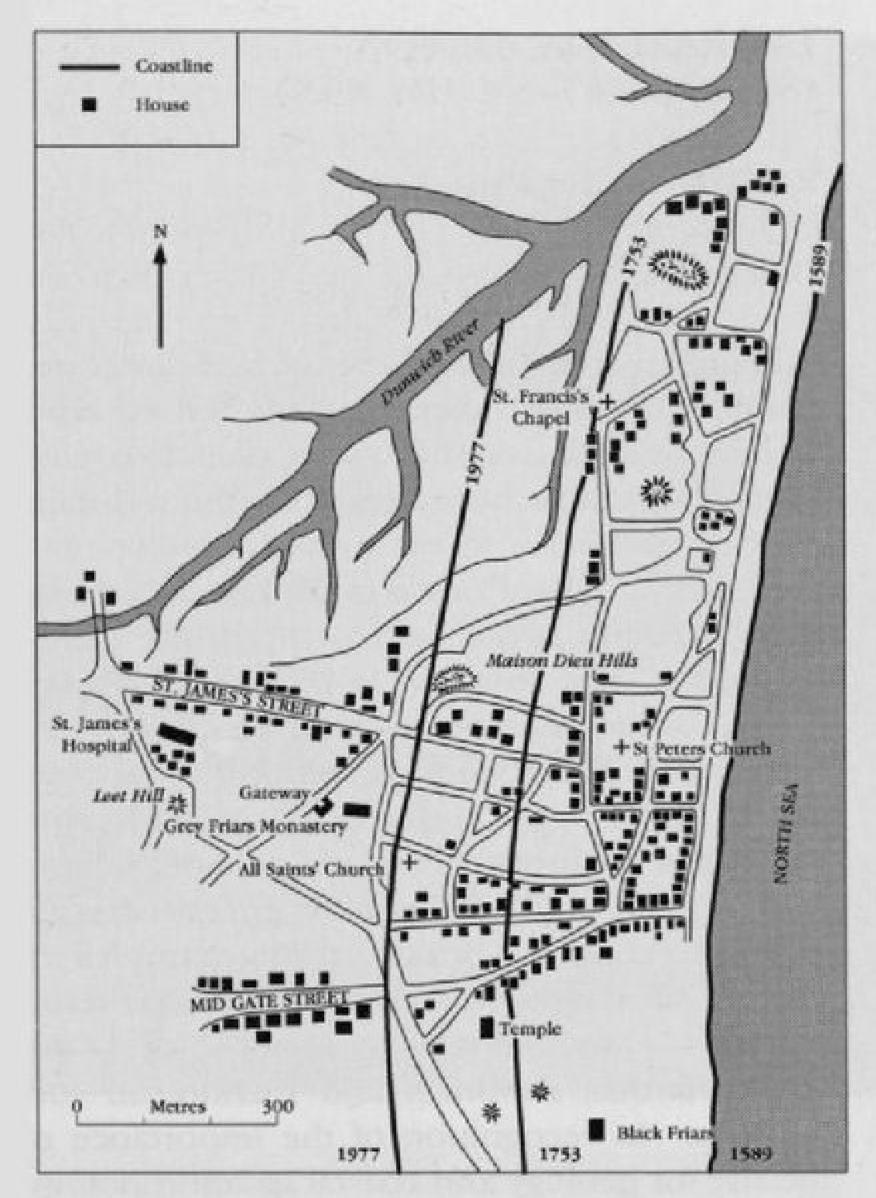
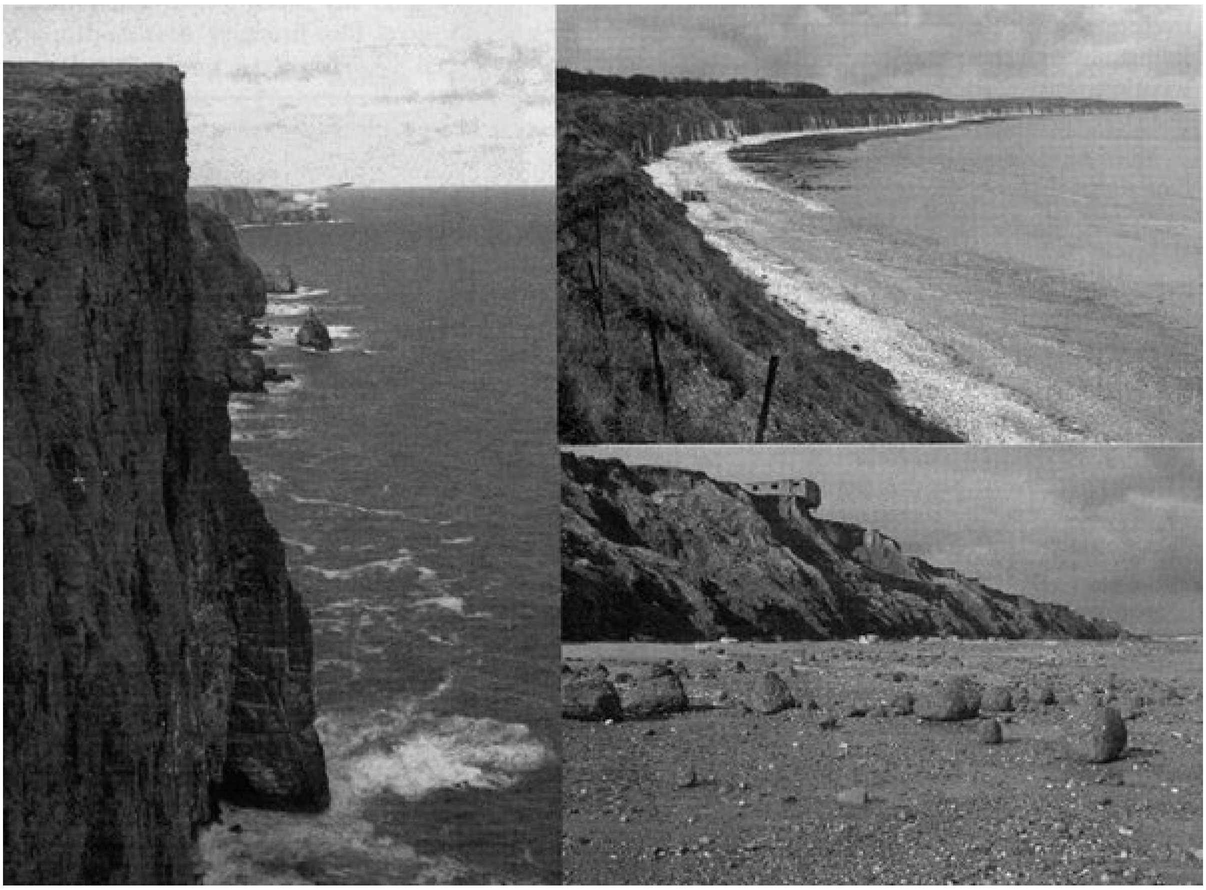


(Figure 4.3) Retreat of the coastal cliff at Dunwich, Suffolk, plotted on the 1589 map of Agas; the 1977 cliff top as surveyed by A.H.W Robinson. (After Robinson, 1980a, p.141)



(Figure 2.1) (a) Clò Mór cliff (193m) to the east of Cape Wrath, Sutherland is a good example of a plunging chit with no shore platform development, which has been inherited from former sea levels. (b) Recession of the Chalk cliff at Sewerby, west of Flamborough Head, Yorkshire, has produced a steep lower cliff with a sloping shore platform whose upper junction is obscured by a gravel beach composed of chalk gravels together with glacial gravels derived from bevelling of the cliff-top till. (c) Rapid erosion of the soft and unconsolidated glacial till cliff at Atwick, Holdemess, Yorkshire, progresses by undercutting and rotational failure that is accentuated when the cliff-foot beach is thin or absent. This view looking north shows a very thin upper beach veneer over an area of exposed till shore platform (locally called an 'ord') whose surface is strewn with till blocks eroded from the cliff. (Photos: J.D. Hansom.)