GOLDEN CAP TO LYME REGIS

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Introduction

Between Ridge Cliff, to the east of Seatown, to Lyme Regis, there are four main cliffed areas, Ridge Cliff, Golden Cap, Cain's Folly and Black Ven, separated by valleys at Seatown, St Gabriel's Water and Charmouth (see Figure 4.1 for general location, and Figure 4.11). There are two pocket-type beaches, the larger between Golden Cap and Lyme Regis, the smaller to the east of Golden Cap at Seatown. This group of cliffs and beaches is geomorphologically important because:

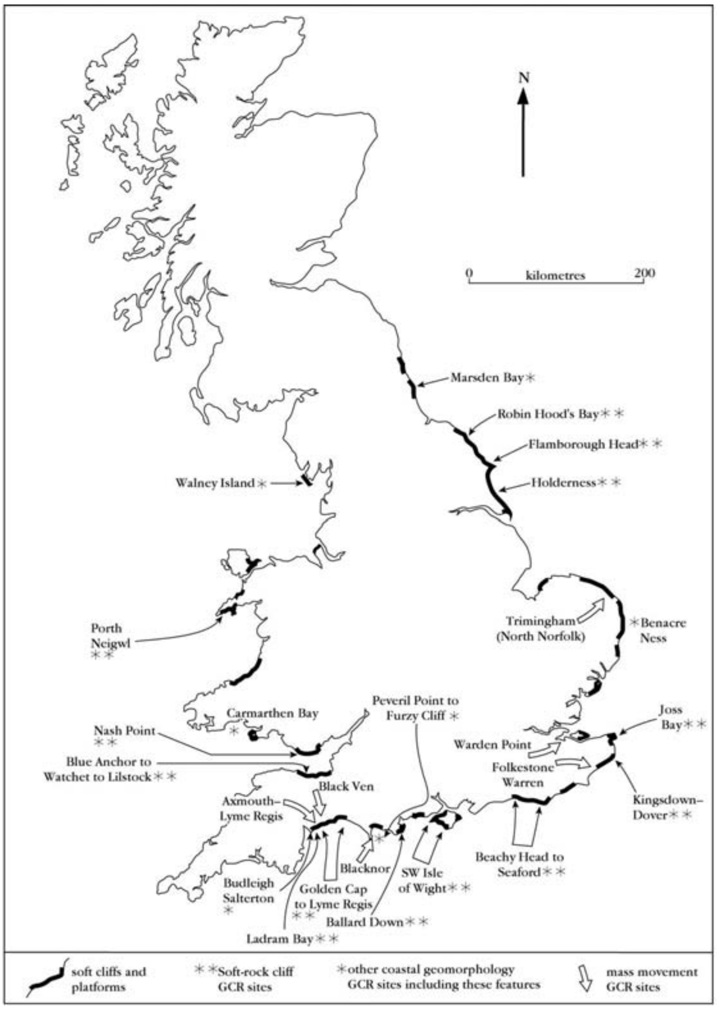

Figure 4.1: Location of significant soft-cliffed coasts and platforms in Great Britain, indicating the sites selected for the GCR specifically for soft-rock cliff geomorphology. Other coastal geomorphology sites that include soft-rock cliffs and sites selected for the Mass Movements GCR 'Block' that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

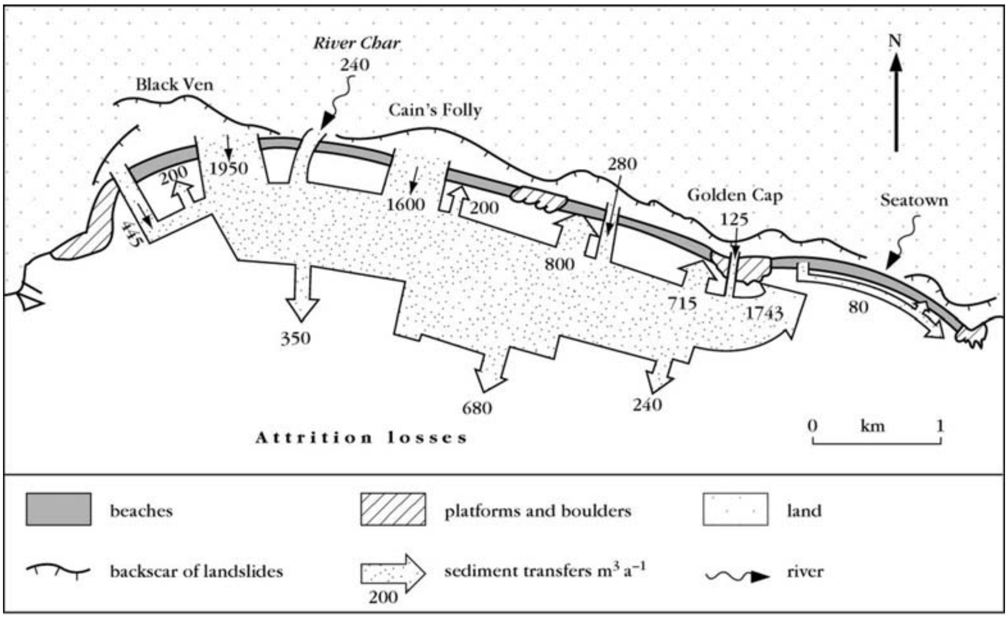

Figure 4.11: The sediment budget of beaches between Lyme Regis (to the westmost part of the map) and Seatown. (After Bray, 1990a.)

1. The cliff changes (especially the landslides at Black Ven) are probably the most fully investigated of any in the world. The international contribution to geomorphology is outstanding.

2. There are excellent examples of arcuate beach ramparts, formed by the boulder content of landslides.

3. The beaches are fed by chert and flint from the cliffs, so that it is possible to monitor the links between landslides, cliff erosion and beach-sediment budgets.

The landslides of this coast are well documented (Arber, 1941, 1973; Lang, 1914, 1928, 1942, 1944, 1955; Wilson *et al*., 1958; Brunsden, 1973, 1974, 1996; Brunsden and Jones, 1972, 1976, 1980; Conway, 1974; Denness *et al*., 1975; Brunsden and Goudie, 1981; Allison, 1990, 1992; Koh, 1992; Lee, 1992; Brunsden and Chandler, 1996; Brunsden *et al*., 1996; Pile, 1996). Many coastal texts refer to the landslides here (e.g. Bird, 1984; Steers, 1964a, 1981), but there has been much less attention to the beaches (Lang, 1914; Bird, 1989; Bray, 1986, 1990a,b, 1996) and the offshore zone (Darton *et al*., 1981).

As well as its geomorphological significance, the site is famous stratigraphically and palaeontologically and it is one of the GCR sites that form the Dorset and East Devon Coast World Heritage site, established in 2001.

Description

In general, the coastline truncates a series of NE–SW-orientated ridges that rise to between 140 m and 170 m OD. The area is composed of interbedded, firm, fissured clays, mudstones, marls and thin bands of hard argillaceous limestone of Lower Jurassic age. These are overlain unconformably by silty clays, fine-grained silty sands and chert beds of the Cretaceous Gault and Upper Greensand. Whereas the Lias dips ESE at 2–3°, the plane of the unconformity and the Cretaceous beds above it dip to the south-west at 2–2.5° (Brunsden and Jones, 1976). The sides of the ridges have a thick cover of solifluction and landslide debris. The ridge-tops are covered by a superficial layer of flint and chert head.

The eastern limit of the site is Ridge Cliff (SY 428 913) where the cliffs attain a height of 100 m in sands and clays of the Upper and Middle Lias. They decline westwards towards Seatown where a small stream, the River Winniford, enters the sea. They then rise to the highest point on the Dorset coast at Golden Cap (188 m OD; Figures 4.11 and 4.12). Here the Upper Greensand forms a steep upper section to the cliff profile, but the main part of the cliff is formed by the Eype Clays. It has been greatly affected by landsliding, but less dramatically than the cliffs to the west. The intertidal area is characterized by rock ramparts that represent the remnants of landslides that have carried Upper Greensand blocks to the foot of the cliff. Whereas the clays that form the bulk of the slide debris have since been eroded, the curved boulder aprons remain. Darton *et al*. (1981) indicated that similar features occur offshore, and Bray (1996) has confirmed this. At both St Gabriel's and Ridge Water small streams flow in hanging valleys at about 65 m before finding their way across the slipped cliff face. To the east of Charmouth, the cliffs at Cain's Folly rise to 145 m, whereas to the west their highest point is 177 m.

Figure 4.12: View looking south-east from Golden Cap, showing the depleted shingle beach at Seatown, platforms that are cut across folded strata, and the residual boulders at the west end of the beach (foreground). (Photo: V.J. May.)

Seatown Beach, to the east of Golden Cap, is formed mainly in flint and chert shingle, but it also contains pebbles of Lias shales and limestones. It lies between two headlands that inhibit longshore transport of sediment both into the beach from the west and out of it towards the east (Figure 4.12). The beach gravels are sparse and poorly sorted at the western end and there are patches of sand and exposures of the underlying strata (Bird, 1989). Towards the centre of the beach at Seatown itself, the predominantly flint and chert pebbles are found in zones of contrasting size parallel to the beach face. Cusps are often well developed. At the eastern end of the beach, beneath Ridge Cliff, the beach is higher and wider with coarser and better-sorted shingle, but following periods of easterly wind can be denuded to reveal a deeply incised platform (D. Brunsden, pers. comm.).

Over the period 1901 to 1987, this beach had an input of 190 000 m^3 of shingle, mostly from intermittent transport around Golden Cap, particularly between 1932 and 1962 when the annual input was up to 8600 $m^3 a^{-1}$ (Bray, 1996). In the past shingle was mined from Seatown Beach (Bird, 1980). Bray (1996) estimated that between 125 000 and 175 000 m^3 were extracted during World War II and a further 34 000 m^3 between 1956 and 1986. The extraction permit expired in 1987. Extraction of shingle, together with modest entrapment and attrition losses, has produced a complex series of volumetric changes with an overall deficit. Bray

(1996) estimated that, with the cessation of extraction and no input from the west, the net deficit had fallen to 39 $m^3 a^{-1}$ by 1989. An unaccounted factor in beach and cliff erosion is the erosional lowering of the platform when it is intermittently exposed.

To the west of Golden Cap, the beaches are interrupted beneath the landslides by large lobes of debris from the slides and mudflows, but they give way westwards to an intertidal area that is dominated by structurally controlled shore platforms, especially just to the east of Lyme Regis. Most of the beach material is derived from the cliffs.Bray (1986) estimated that between 1901 and 1987, about 420 000 m^3 of mainly chert gravel with a B-axis greater than 10 mm was eroded from the cliff back-scar between Lyme Regis and West Bay. The beach between Golden Cap and Charmouth is well-sorted laterally, changing from a mixed sand and shingle beach at Charmouth to a predominantly cobble beach below Golden Cap (Bird, 1989). Supply of gravel is concentrated at the western end of this site, with transport towards the east. The volume of the beach increases towards Golden Cap, but some material may leak around the headland when landslide snouts have been eroded (Bray, 1990b, 1996). However, this has not occurred since the mudslide of 1962.

The dominant features of this coast are the rapidly changing cliffs east and west of Charmouth. At Fairy Dell, Brunsden and Jones (1976) described both the historical and more recent history of the landslides. They identified three sub-parallel clifflines separated by benches covered by debris. These benches were attributed to lithological variations, the upper bench being associated with the sub-Gault unconformity and the lower bench with the outcrop of the Green Ammonite Beds. Three morphodynamic zones were identified.

1. Zone 1, an upper zone with an arcuate scar up to 45 m in height. The lower part of the scar was covered by a partially vegetated scree slope. The upper bench consisted of several large rotational landslide blocks separated by screes of chert.

2. Most of the central Zone 2 is extremely complex with deep V-shaped gullies, rotated landslide blocks, areas of gentle relief in which debris in accumulated and mudslide basins.

3. Zone 3 is a lower zone of near-vertical sea cliffs with a variable amount of accumulated debris at their foot.

The upper arcuate scar and the sea cliffs retreat at similar rates (between 0.29 and 0.71 m a^{-1}).

At Black Ven, the cliffs are marked by very active mudslides (Brunsden, 1968; Figure 4.13). The upper part of the cliff is cut into Greensand sands and cherts that lie unconformably on Lower Lias clays. Limestone layers within these clays act as local base levels over which the debris moves. The impermeability of the clays allows groundwater seepage at the base of the Greensand, which produces high levels of instability in the cliffs (Denness *et al*., 1975). Retreat of both the upper cliff and the sea cliff has been rapid, with annual rates in excess of 1 m averaged over periods longer than ten years. Over shorter periods of about two years the rate of retreat has been greater than 5 m a^{-1}. The present rapid activity is a relatively recent phenomenon, for large parts of the present upper cliff had been relatively stable prior to the major failures of 1957 and 1958 (Bray, 1996).

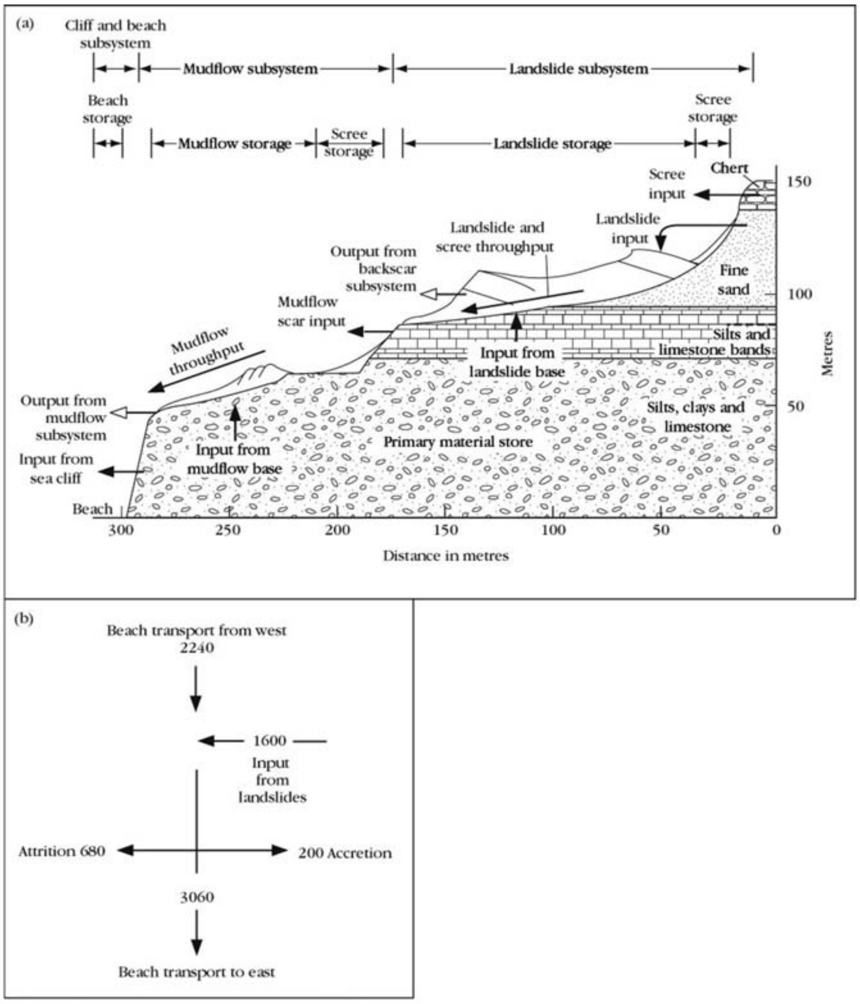

Figure 4.13: (a) Cross-section of the Black Ven system (Lyme Regis to Golden Cap GCR site) and sediment supply to its beach. See also Figure 4.11. In (b) the volumes of sediment (in m3 a–1) moving through the Black Ven beach are given. (Based on Brunsden, 1973 and Bray, 1990a.)

Interpretation

The cliffed coastline and landslides of West Dorset are important internationally because they have been the focus of research that has influenced understanding of both geomorphology in general and the coastal system in particular. Brunsden, and other workers, have demonstrated the applicability of 'systems methodology' to rapidly changing complex landforms and this led to a better appreciation of timescales in geomorphology. Denness (1972) discussed the reservoir principle of mass-movements in relationship to the cliffs at Black Ven, and later work identified the importance of secondary reservoirs to an understanding of complex mass-movements (Denness *et al.*, 1975). Bray (1986, 1990a,b, 1996) has described the sediment budget of the beaches and shown how they both depend upon and affect the landslides.

At Fairy Dell, Brunsden (1973) demonstrated how the application of system theory could be used both to elucidate the inter-related forms and processes in a complex mass-movement and to fashion the design of field experimentation. Fairy Dell, it was argued, could be explained by the following evolutionary model (Brunsden and Jones, 1976). Marine erosion both removes debris derived from mass-movements higher up the slope and maintains a more or less steady rate of cliff retreat. This increases the rate at which debris is carried across the lower bench in morphodynamic Zone 2 and brings about failure of undercliffs so that arenaceous materials move from the upper zone. Retreat of the undercliffs and removal of material from the slipped blocks of morphodynamic Zone 1 causes them to move seawards. The upper arcuate scar may also fail as a result. Thus marine erosion initiates a 'zone of aggression' which gradually affects the whole slope. The erosional events of the sea cliff were shown to be high frequency and low magnitude, whereas the events in the upper slopes were large, but infrequent (Brunsden and

Jones, 1980). The effect of such events was dramatically revealed in 1994 when a rotational slip in the upper cliff at Black Ven loaded debris below and triggered a high-velocity sand avalanche across the beach west of Charmouth. The dry sand-fall fluidized and flowed seawards over a distance of 800 m (Brunsden and Chandler, 1996).

Cambers (1976) demonstrated that large landslides often provide large sediment stores at the foot of the landslide slope. Until sufficient sediment has been removed for unloading of the slope to occur, landsliding will be reduced. Thus, sediment storage can have a critical role in regulating the transmission of the ‘zone of aggression' through the landslide system. Brunsden and Jones (1980) developed this point further to illustrate the concept of the ‘formative event', which shapes the landform most effectively. At Fairy Dell, the formative events are the large movements that both produce large features in the slope and are recognizable over long periods of time, except in the sea cliffs where the formative events are small and frequent. As a result the sea cliff lacks sediment storage and has a relatively smooth form, but the mass-movement slopes are distinguished by considerable storage of sediment and great irregularity. The landslides at The Spittles (Figure 4.14) and Black Ven have been described by Brunsden and Chandler (1996) as re-activated features from the last interglacial period.

Figure 4.14: The Spittles, east of Lyme Regis. (A) Main landslide scar – sand and chert cliff; (B) landslide storage and throughput system; (C) sea cliff and mud flows; (D) beach; (E) dissected shore platform. (Photo: V.J. May.)

Denness (1972) and Conway (1974) examined the relationship between groundwater flows and the extensive instability of the cliffs at Black Ven. The reservoir principle of mass-movement argues that where a permeable rock capable of holding and discharging ground water rests on an impermeable layer, a supply of water, independent of rainfall is introduced into areas of instability. Not only is landsliding more rapid than if surface water alone is involved, but there may be accelerated weakening of the rock fabric. At Black Ven, this ‘primary reservoir' is the Upper Greensand resting on the Gault Clay. Debris accumulations within both active and relict mass movements can also act as more localized ‘secondary reservoirs'. At Charmouth, the Higher Sea Lane landslip involves re-activation of relict mudflows that overlie the Lias clay (Denness *et al.*, 1975). The mudflows, acting as a secondary reservoir, supply water to the Lias and movements take place perpendicular in direction to the original flows. Thus, as the sea cuts the cliffs back into valley-side slopes, which are characterized by older inactive mass movements, new formative events have been triggered.

Analysis of 12 000 beach pebbles from beaches in this site shows that west Dorset beaches have similar pebble lithology and size distributions. Littoral drift from the west is suggested by an increase in roundness and sphericity towards the east (Bray, 1990b, 1996). Taken together these characteristics suggest that the beaches, including Chesil Beach, were probably interconnected in the past at a lower sea level, about 5000 years ago.

The beach most variable in volume over time is at Charmouth, which, in spite of being closest to the input from the landslides, has rapid throughputs of sediment because of the dominant drift towards the east. Accretion of shingle reduces erosion of the foot of the cliff and the landslides, and retreat rates diminish. Reduced retreat rates lessen the input of shingle to the beach and so accretion is also reduced. As a result the zones of active landsliding may migrate in the direction of longshore drift, as exemplified by an eastward shift in the area of intensive activity from the Spittles to the central part of Black Ven during the first half of the 20th century (Bray, 1990b). However, the lack of sediment at the western extremity of this beach at Lyme Regis and the progressive installation of groynes has aided the extension of landsliding towards Lyme Regis. Although not part of this site, Lyme Regis itself is underlain by numerous slides and shows substantial activity (Lee, 1992; Pile, 1996).

Within the Lyme Regis to Golden Cap GCR site, the application of systems modelling can be further developed, first by examining the sensitivity of the cliffs to high magnitude, low-frequency oceanographic events, and second, by investigating the entrapment processes within the boulder arcs left by erosion of landslide lobes. At Golden Cap, the Greensand has a much more restricted outcrop than on the cliffs between Lyme Regis and Charmouth. Mass-movements are more infrequent. The foot of the cliff is protected by a substantial accumulation of boulders, many of them in arcuate ramparts (Bird, 1985; Bray, 1986, 1990a,b, 1996), which also occur on the sea floor (Darton *et al*., 1981; Bray, 1990a, Brunsden *et al*., 1996). Thus this part of the coastline becomes more irregular as its formative events occur less frequently. Moreover, the modification of waves by refraction over such boulder zones concentrates wave energy around the flanks of the headland. Some of the sand- and shingle-sized product from the landslides travels alongshore and may accumulate against the updrift side of debris fans, thus offering some additional protection to the foot of the cliff. Lateral sorting of the beach sediments has been described (Bird, 1989), and the effects of different local sediment sources outlined, but this requires further examination. Future work should not only continue to elucidate the development of the cliffs, but also develop Bray's (1990b) integrated sediment-budget model of the whole site so that the effects of debris inputs at the western end upon the behaviour of the cliffs farther east can be predicted better. Similarly, the effects of surges in the English Channel and large waves such as those reported at Chesil Beach warrant further investigation, for until now most geomorphological investigation at this site has considered the terrestrial processes rather than integrating them with the marine processes. Recently, these cliffs have been used for the development of a model that aims to estimate the future erosion of soft-rock cliffs with accelerating rates of sea-level rise (Bray and Hooke, 1997).

This is a very actively changing site that has a long record of geomorphological investigation upon which future research and education can build. It offers opportunities not only for fine-tuning and evaluation of existing models of cliff behaviour but also the development of more complete models of the whole coastal system from cliff top to offshore. Although other cliffed coasts which are affected by mass-movements occur around the British coast, some have been greatly modified by coast protection works (for example at Folkestone Warren) and in some the longshore sediment-transport system has been modified significantly (for example on parts of the East Anglian coast). This site has been little affected by human modifications although the coast protection works at Charmouth have introduced a salient that acts as a barrier to sediment eastwards, thus further subdividing the system. The landslides between Lyme Regis and Charmouth have been investigated in more detail than any other site worldwide and as a result the complex inter-relationships between active mass-movements, marine erosion and beach development are better understood here than elsewhere. The comparatively well-understood modern processes at this site are also important in throwing light upon the development of the other coastal features of Start Bay, especially Chesil Beach, Slapton Beach and Hallsands. All these beaches contain flint and chert clasts, yet only in this site can they be shown to be contemporary in origin, and the rate of supply estimated. As a result it becomes possible to judge the extent to which beaches in this area were formerly interconnected (e.g. Bray, 1996).

The significance of this GCR site to the study of coastal geomorphology is considerable, since the research here has:

1. focused attention on the appropriate timescale for coastal studies in this site, i.e. 100 years;

2. demonstrated the critical role of the processes at the cliff foot in activating the larger, formative events of the landslide systems;

3. examined the role of the beaches in affecting the process alongshore;

4. developed models and concepts that have much wider application.

Conclusions

Major landslides at Golden Cap, Fairy Dell and Black Ven dominate this cliffed coast, but the site is also of particular interest because, unusually, the sediment system from cliff top to beach has been investigated more thoroughly than any other site in Britain, and probably worldwide. This is a very important site for coastal geomorphological studies, especially as it is possible to interpret both terrestrial and submarine landforms. Estimates of the sediment budget at the site have integrated the cliff system with the associated beaches, making this a site of considerable importance for monitoring the effects of medium-term change.

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