FURZY CLIFF - PEVERIL POINT

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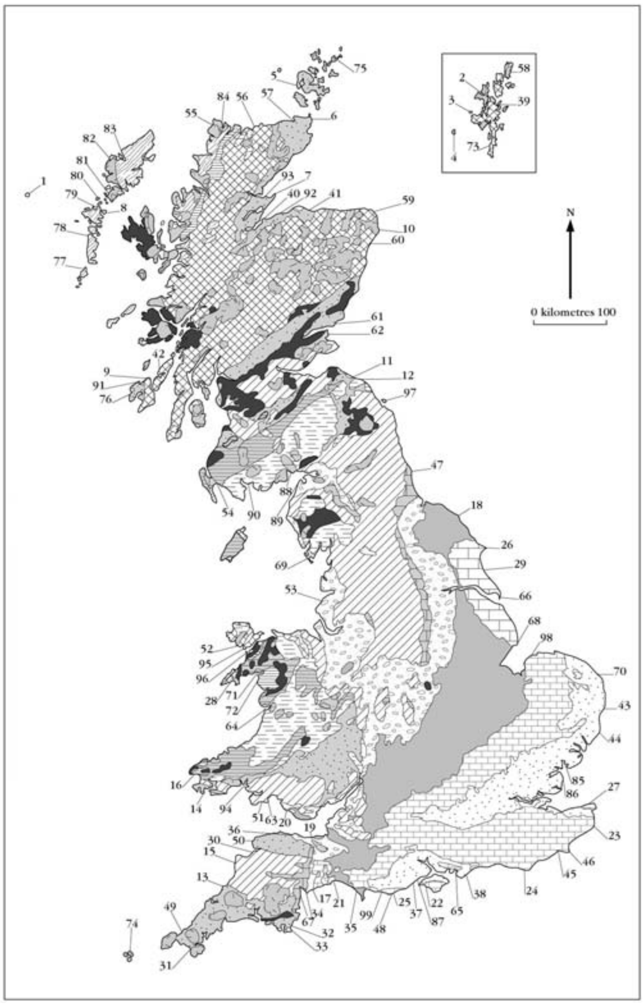
Introduction

The southern flank of the Isle of Purbeck and the coast west from Lulworth Cove is well known for its geological structures (Strahan, 1898; Arkell, 1947; House, 1993), and this predominantly cliffed coast is one of the most important locations in Britain for demonstrating relationships between rock structure, rock strength and coastal landforms (Horsfall, 1993; see Figure 1.2 for general location). The whole site forms one of the most frequently described British examples of a longitudinal coastline (e.g.Holmes, 1965; Bird, 1984; King, 1959, 1972). Within it, there are several classic coastal localities, of which Lulworth Cove is probably the most well known. This scale and range of features has attracted most attention (for example, Allison, in press; Brunsden and Goudie, 1981; Burton, 1937; Komar, 1976; Sparks, 1971; Small, 1970, 1978). A series of small bays containing beaches distinguished by local grading of sediment fed from distinct, identifiable sources (Arkell, 1947; Heeps, 1986) provides unrivalled opportunities for the study of beach development. Overall, the range of features developed on different rock-types and at a variety of scales makes this coast of paramount importance for understanding relationships between coastal form, processes and materials. This coastline is extensively used for educational purposes and tourism, and is attracting increasing research interest. In recognition of the site's importance for coastal geology and geomorphology, it is one of around 70 GCR sites that form the Dorset and East Devon Coast World Heritage site (see also Ballard Down, Budleigh Salterton, Chesil Beach, Ladram Bay Lyme Regis to Golden Cap and South Haven Peninsula GCR site reports, this volume).



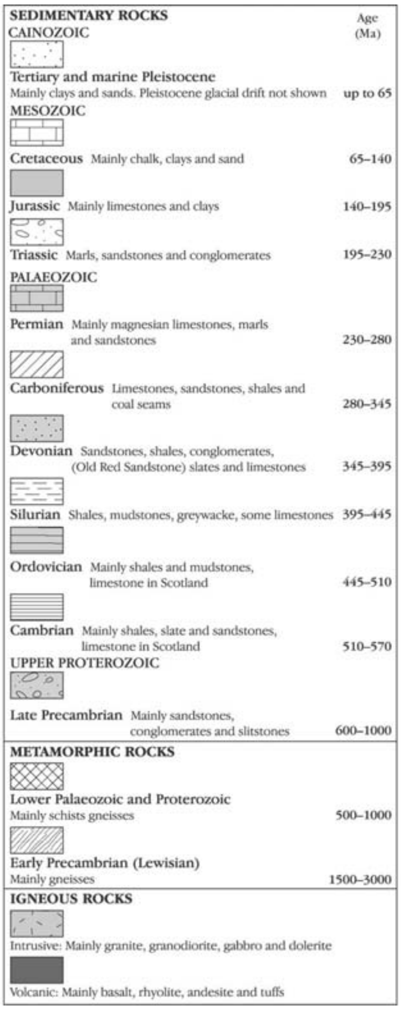


Figure 1.2: Geological map of Great Britain, also showing the locations of the Coastal Geomorphology GCR Sites. The map shows sedimentary rocks classified according to their age of deposition and igneous rocks according to their mode of origin. The numbers in the key indicate age in millions of years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

Description

The main geological strata and geomorphological units of the area are shown in figures11.32 and 11.33. The geology includes strata from the Upper Chalk to the Oxford Clay. The longitudinal coastline of south-east Purbeck between Durlston Head and Worbarrow Tout contrasts with transverse sections from Portland Stone to Chalk in Worbarrow Bay and across the Purbeckian strata in Durlston Bay. Cliffs about 30 m in height are nearly vertical and truncate several small valleys, such as at Seacombe and Winspit Bottom, which show varying levels of adjustment to changes in base level. At St Aldhelm's Head (sometimes referred to as ‘St Alban's Head'), these simple cliff-forms are replaced by large landslips that become increasingly active as clays and shales of the Portland Sand and Kimmeridge Clay are exposed around Chapman's Pool. The role of landslide debris in cliff protection is well exemplified here. The cliffs exceed 120 m but fall to 60 m or less west of Hounstout where Kimmeridgian rocks form both near-vertical cliffs and extensive platforms that extend several hundred metres offshore. To the west of Kimmeridge, the cliffs are dominated by resistant outcrops of Portland and Purbeck beds that are seen in alternating high, often vertical, cliffs and narrow submarine ridges that occasionally appear at low tide, as at Man o'War Rocks, immediately east of Durdle Door. The overall development of the bays, which include Lulworth Cove, has been seen as exemplifying different stages of coastal evolution. The relationships between structure, rock material and coastal form are well exemplified between Lulworth Cove and Bat's Head as caves, arches, rock offshore reefs, headlands and bays are developed to a greater or lesser degree.

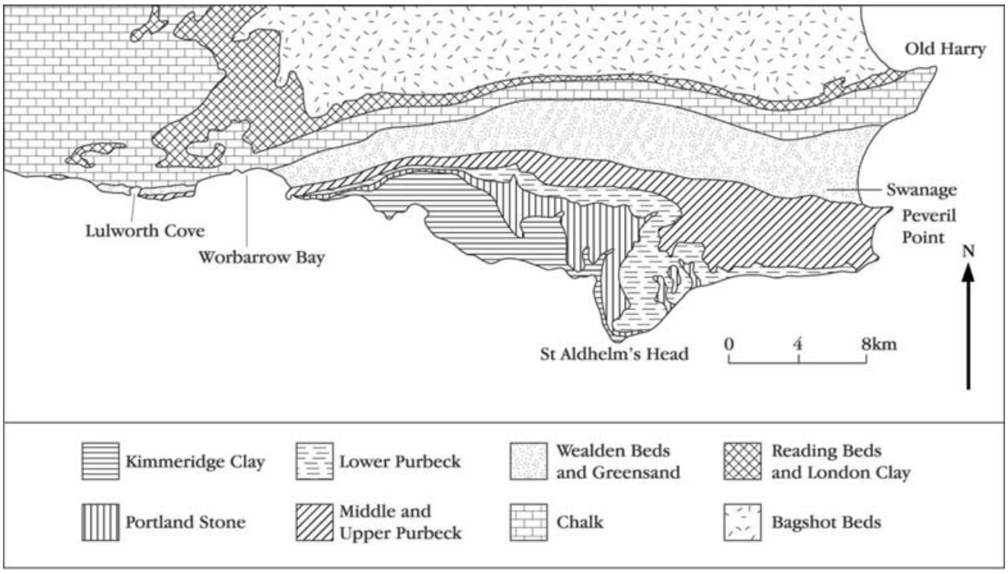


Figure 11.32: Geological map of the Dorset coast from Lulworth Cove to Studland Bay.

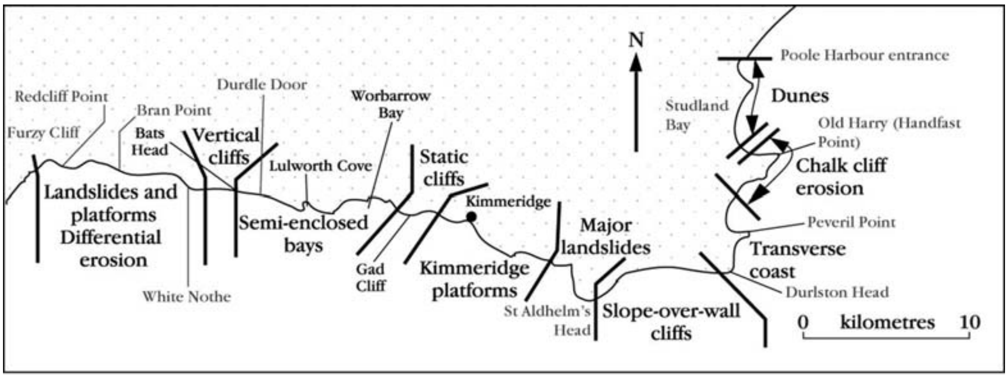


Figure 11.33: Summary geomorphological character of the coast between Furzy Cliff and Poole Harbour.

The complex structural patterns of the cliffs and platforms between Ringstead and Black Head give rise to a great variety of forms providing an excellent location for examination of differential erosion processes. From Black Head westwards to Furzy Cliff, the cliffs are dominated by several different mass-movement systems that feed the beaches with a variety of sediment ranging in size from clay to boulders.

The area is microtidal, with a range less than 2.0 m, and tidal streams are generally weak. The prevailing and dominant wave trains are south-westerly, at times with origins in the southern Atlantic Ocean, and periods of 10 seconds or more are common. Waves from the south-east are characterized by a period of 5 seconds and are restricted in fetch. They tend to degenerate with the onset of south-westerly or northerly winds. Nevertheless they can be important locally in moving beach material within the semi-enclosed bays and exposing bedrock to erosion (Heeps, 1986).

The western end of the site lies at the north-eastern extremity of Weymouth beach. The beach is in deficit, and erosion of the Oxford Clay has contributed to mass-movements in Furzy Cliff. Cliff-top retreat has averaged about 1 m a^{-1} in recent years (Figure 11.34); most change occurs in relatively infrequent landslides. May (1964) described a rotational slip at the western end in January 1964, and more recently the whole of the cliff has become affected. Within a matter of weeks much of the material brought to the cliff foot by the slides is removed by wave activity. Slides occur frequently, with spatially separated larger events taking place about every eight years. In contrast, the cliff foot east of Bowleaze Cove (cut in Osmington Oolite and

Bencliff Grit overlying Nothe Clay and Nothe Grit) is naturally armoured by boulders derived from rockfalls and reveals very little retreat of the lower cliff face. However, there have been two major failures on the upper slopes, separated by some 70 years (1900 and 1971). The first, described by Richardson (1900) affected the whole cliff, but the area remained largely unchanged apart from progressive degradation and establishment of a mature vegetation cover of brambles and grasses, interspersed with waterlogged hollows dominated by rushes *Juncus* behind the slip elements. During the 1970s this cliff once again became very active with a series of shear planes dividing a staircase of slide blocks reaching some 80 m inland of the cliff edge of the early 1970s. This part of the site thus demonstrates very vividly the effects and interplay of marine and subaerial processes on this coast.

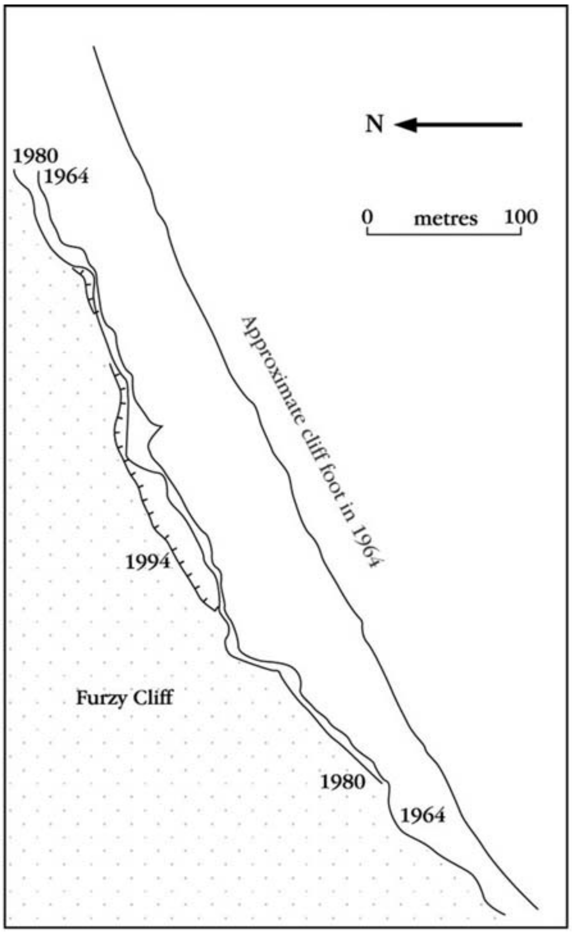


Figure 11.34: Cliff retreat at Furzy Cliff.

Between Redcliff Point and Bran Point, the nature of the cliffs varies greatly with lithology and structure, and also upon the form of the cliff foot and intertidal zone. At the western end there is a small shingle beach that normally protects the cliff foot from direct erosion, whereas farther to the east the Nothe Grit forms a resistant foot to the cliff and a beach is absent. Eastwards from Osmington Mills, outcrops of the Corallian strata marked by a series of structurally 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.

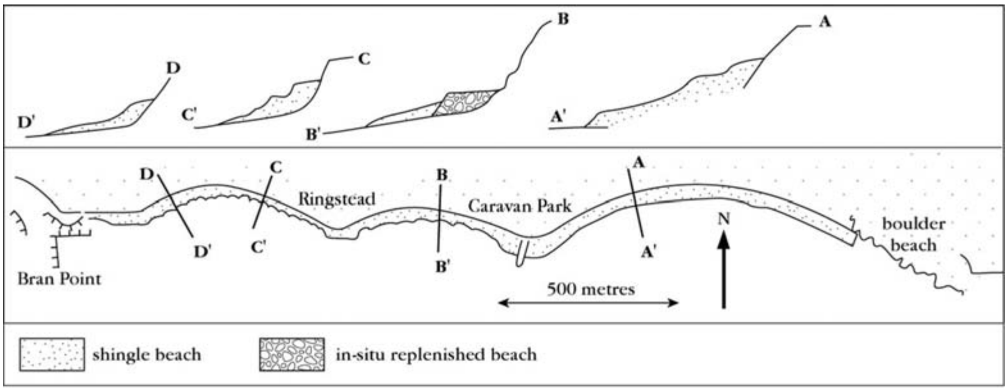


Figure 11.35: Cross-sections of the beaches of Ringstead Bay, and sketch map showing locations of sections.

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.

Since 1986, there has been considerable erosion of the low cliffs fronting the caravan park and boulders have been placed at the foot of the cliffs to reduce erosion, together with a small rubble groyne that has affected sediment movement on this section of the beach. By 1995 the central part of the beach had been lowered by over 1.5 m and only a thin veneer of shingle rested on the underlying clay and shale. The rapid depletion of the beach is attributed to a series of five southerly storms in 1993 that removed virtually all of the shingle. Unlike the beaches to the east and west, which have also been lowered from time to time, the central beach has not recovered. A coast protection scheme prepared by West Dorset District Council in late 1994 aimed to replenish the beach and to provide some stability. By October 1995, the eastern beach was severely depleted at its western end. During spring 1996, beach replenishment and further rock armouring of the cliff foot were carried out by West Dorset District Council. By June of the same year, 40% of the surface of the beach to the west comprised angular flint clasts derived from the replenishment site, and by the autumn of 1996 this material had been integrated into the top 0.5 m of the beach towards Bran Point. The replenished beach had been lowered by over 1 m but neither the former cliffs nor the underlying clay had been re-exposed. Between spring 1996 and mid-February 1998, parts of the clay cliff at the western end of the replenishment site had retreated by up to 2.8 m.

At the eastern end of Ringstead Bay, the coastal landscape is dominated by the high complex cliffs between Burning Cliff and White Nothe (Figure 11.35). The profile from the cliff top to the beach is distinguished by a near-vertical upper cliff that is interspersed with gentler grassed slopes almost reaching the cliff-top edge. Some of these slopes comprise angular flint screes cloaked by vegetation and a vestigial soil cover. In places, however, the screes themselves are exposed, forming distinct features at angles between 27° and 32° that fall to a hollow formed behind the large rotational-slip blocks that characterize the middle cliff (Figure 11.36). Below these the cliff has become active in recent years and large areas are affected by shear planes, slide scars and several zones of movement. Former-slip blocks are exposed within some of these areas.

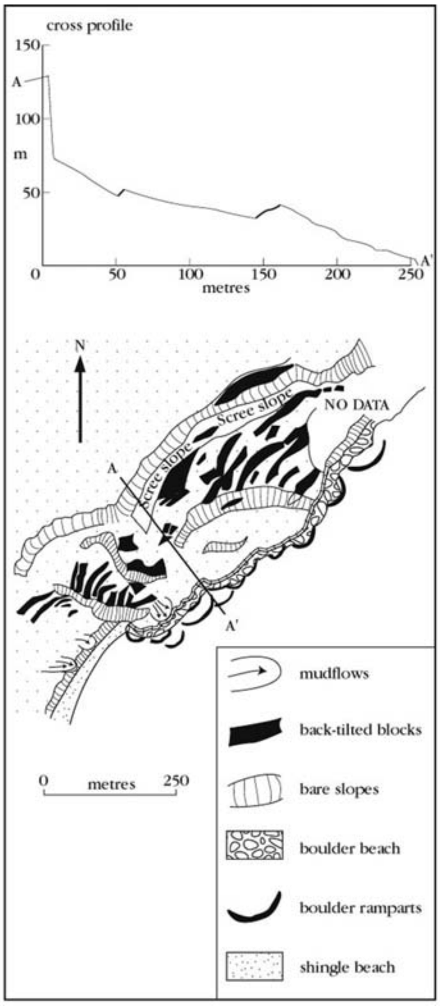


Figure 11.36: Geomorphology and cross profile of the White Nothe landslides in the Dorset Coast GCR site.

The Kimmeridge Clay crops out at the eastern end of the bay, but is progressively cloaked by chalk landslide forms. Failures in the clays are partly responsible for a complex ‘staircase' of rotational-slip blocks and active mass-movements that feed chalk to the eastern end of Ringstead Bay. The beach here, however, receives only small quantities of such material and is composed mainly of rounded flint clasts. Chalk boulders and fresh flint nodules are transported to the beach by a series of landslides. Many of the boulders remain in the intertidal zone and provide effective protection to the foot of the cliff. Both chalk and flint are broken down into shingle-sized fragments, but little reaches the main beach in Ringstead Bay because it is trapped behind the boulder ramparts on the middle and lower shoreline.

At White Nothe itself, the cliffs are much less complex, the whole cliff is composed of Chalk here. From White Nothe to Bat's Head, the cliffs truncate a series of dry or ‘combe' valleys. The beach is formed of newly deposited chalk and flint mixed with subsidiary amounts of rounded oxidized flint, the range of clasts showing a diversity in the degree of roundness. Although the beach rests on a Chalk platform, the platform is poorly developed. This is the only beach within the Chalk sector of the English coast where recently produced Chalk and flint clasts dominate the beach. The erosion of the eastern side of White Nothe, together with some landslide debris transported from the eastern end, provide the main source of clasts. There is little evidence of major falls from the cliffs behind the beach, although many small falls occur; much of the contemporary erosion is of the toes of relict talus slopes. Offshore, side-scan sonar surveys (Heeps, 1986, 1987) have shown that there are important extensions of the reef features that characterize the coast to the east and extend from off White Nothe to Worbarrow Tout. Geological structures are revealed particularly well in many of the seabed forms, despite some cloaking by thin veneers of rippled sand. The foresyncline of the Purbeck monocline that is cut by the cliffs west of Bat's Head forms a distinctive feature of the submerged coast (Figures

11.37– 11.39.)

Figure 11.37: Sonargraph of the seabed between White Nothe and Bat's Head, showing an area of tilted strata (dipping from north-east to south-west) and joint and block patterns. The upper right hand area shows blocks broken from the strata. (Image by permission of C. Heeps.)

The section of coast from Bat's Head to Man o'War Bay has been described in detail byHeeps (1986). It has three main morphological elements, high Chalk cliffs, lower cliffs or bay floors cut into the Lower Cretaceous and Upper Jurassic strata, and a discontinuous rock reef formed in Portland Beds. Its best-known feature is Durdle Door, an arch cut through the near-vertical strata of the Portland Stone. The reef continues across the bays both to the east and west of Durdle Door. Because it reduces much of the wave energy approaching the beaches and prevents the beach sediments from leaving the bays other than in suspension, the reef plays a significant part in making these bays closed sediment cells.Heeps (1986) showed that, whereas there is some supply of flint and Chalk into the beach, the overall volume of sediment held within the bay west of Durdle Door changes little although there can be substantial changes in form from time to time depending upon wave conditions. The mainly flint shingle beach rests upon a narrow chalk platform that is exposed when shingle is re-distributed within the bay. The platform slopes at angles of up to 10°, is about 15 m in width, and is covered by fine shingle beach rarely thicker than 1 m, with little berm development. Beyond the beach edge, there are scattered clasts on the platform. The seabed drops steeply outside the reef to depths of about 14 m. At the western end of the bay, Bat's Head is penetrated by a small arch along the vertically dipping bedding planes of the Chalk. A stack rises from the platform. Erosion is more rapid where dry valleys floored by solifluction materials that reach almost to high-water mark have been truncated by the retreat of the coastline.

Daily surveys of the Durdle Door beach (Heeps, 1986) for a month in the winter of 1983 show that prolonged exposure to easterly wave regimes resulted in changes that although small in magnitude were significant with respect to sediment circulation within a morphologically constrained unit (Figure 11.40). Storm action (associated with south-westerly waves) accounted for large changes in the beach volume, but the process was a simple onshore–offshore exchange, the material being returned by post-storm conditions. Easterly waves occurred less frequently, but their effect was much greater. In particular, swell from the east initiated longshore drift that brought about exposure of the Chalk platform in the west. Heeps regarded such conditions as the ‘extreme event' experienced by beaches along the south-east Dorset coast. During the longer 15-month period of Heeps' survey, the beach showed almost no variation in volume with 618 m^3 removed against 605 m^3 deposited. Her survey also suggested that within this bay there is a tendency for a sediment parting towards the western end of the Durdle Door bay.

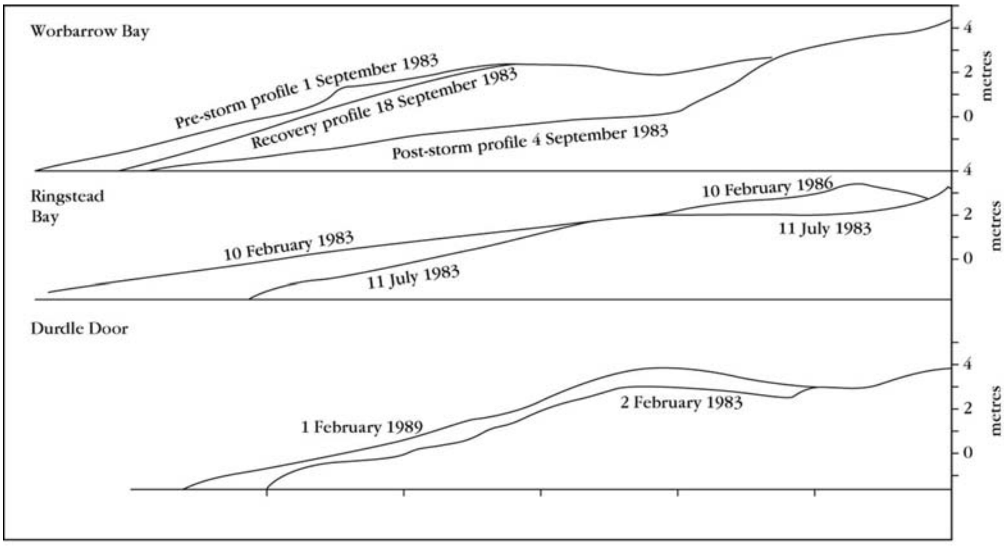


Figure 11.40: Changes in shingle beach profiles in Worbarrow Bay, Ringstead Bay and Durdle Door. Erosion and recovery of beaches can take place over very short timescales. These profiles are based upon monthly re-surveys of sample transects. (After Heeps, 1986.)

Man o'War Bay has a small shingle beach, sheltered by Man o'War Rocks, which develops a partial cuspate form in the lee of the easternmost part of the barrier. Cusps are commonly present on the beach with a distinctive grading of their dimensions from large in the centre of the bay to smaller at both extremities. Sediment size is also graded from smaller (– 2 phi) material at the ends of the bay and larger in the centre (> –3.5 phi). Both the cusp and sediment grading are characteristic of these bays. Remnant upper berms as well as contemporary berms, both with cusps, are common.

The cliffs rise eastwards from Durdle Door to a height of 138 m at Hambury Tout. Stair Hole and Lulworth Cove form the best-known features of this coast. The rounded cove cut into the Chalk back wall contrasts with the more linear form of the adjacent Stair Hole. The mudslides in the Wealden strata of Stair Hole are gradually cutting back its landward side, and wave action has opened out a series of arches in the hard Jurassic limestones that form its outer side. Waves now access the toe of the mudslides, and during storm periods and after prolonged rainfall, they become very active. Lulworth Cove is known internationally as the classic form of a near-circular bay resulting from the differential erosion of weaker strata behind a resistant and protecting outer wall of harder rock. It is described in almost all texts on physical geography both within the British Isles and worldwide.

Both east and west of Lulworth Cove, the coast is formed by vertical cliffs in the Portland Stone. At Mupe Bay, the coastline is cut into the younger beds and a small bay with a shingle beach has formed. The Portland and Purbeck strata that dip steeply here have been eroded to close to sea level but extend seawards across Worbarrow Bay to re-emerge at Worbarrow Tout. The detailed form of this offshore feature has been described byHeeps (1986) as have the nature and behaviour of the cliffs and beaches in Worbarrow Bay. The submerged reef appears to describe an arc from Mupe Rocks to Worbarrow Tout with its apex opposite Arish Mell. The reef stands as a series of prominent ridges and troughs separating a flat plain both to landward and seaward. A second reef trending south-west–north-east is aligned with Gad Cliff. It is about only 1.5 m in height and is made up of a series of very jagged, parallel ridges crossed by numerous small faults. Bifurcating and sinuous sand and shell ripples cover much of the intervening floor of the bay. The main Worbarrow Bay Portland Stone reef is a substantial feature, up to 9 m in height above seafloor (Figure 11.39). It is rugged, with a crest marked by a series of parallel ridges separated by troughs that are up to 3 m deep. On its landward side the reef has an almost-vertical wall. The seaward slope is gentler. The average depth of water seaward of this feature is 23 m, whereas to landward it is only 18 m. Opposite Arish Mell it stands at 6 m high (*c*. –12 m OD) and has a gap, probably the line of the former valley through the ridge. The presence inside the reef of unbroken shells in profusion suggests that this is a low-energy environment with little sediment movement induced by wave or current action. There are large boulder accumulations to seaward of Gad Cliff and opposite the main cliff falls at Cow Gap.

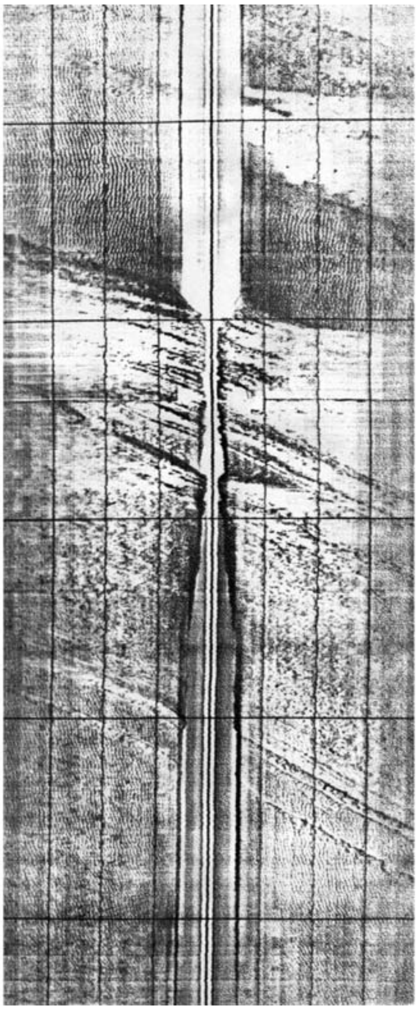


Figure 11.39: Sonargraph of the Worbarrow Bay submerged rock reef. The echo-sound profile shows the depth profile of the seabed and the distinct, steep, backwall of the ridge. Either side of the echo-sound trace, the sonar image shows the seabed patterns of the individual ridges formed by the eroded, dipping strata. The alignment of the sand ripples indicates that sand movement is alongshore. (Photo reproduced by permission of C. Heeps.)

The shape of Worbarrow Bay is strongly controlled by the outcrop pattern of Chalk and Upper Greensand, Wealden and the Purbeck and Portland Beds (Figures 11.32 and 11.41). The Chalk cliffs drop directly into the sea and there is no intertidal platform except at the extreme western end of the bay. A large shingle beach rests against the slumped cliffs cut in Wealden strata, which are affected by many small landslides (Allison and Brunsden, 1990). Despite this inherent instability and the development of mud fans on the upper beach, especially after prolonged rainfall (Heeps, 1986), the cliffs supply little sediment to the predominantly flint beach. Changes in the beach are mainly onshore–offshore; there is some longshore movement within the bay, but there is no dominant direction of movement. There is a well-developed upper berm at about 5.45 m OD that is affected only during major storm events and can be as steep as 30°. These steep profile areas are the most exposed and are composed of the coarsest and best-sorted sediments (Arkell, 1947; Heeps, 1986).

Figure 11.41: Looking eastwards across Worbarrow Bay, showing the outcrop of Purbeck and Portland beds at Worbarrow Tout, the Wealden cliffs undergoing erosion and the shingle storm-beach with cusp development. (Photo: V.J. May.)

The cliffs at Gad Cliff are very exposed (Figure 11.42), and are characterized by an upper cliff predominantly in Portland Stone and a vegetated lower slope on the Portland Sand and the Kimmeridge Clay. There are large boulder accumulations at the cliff foot that very effectively protect the cliff. The boulder fields continue offshore for several hundred metres. East of Gad Cliff, the cliffs decrease in height towards Kimmeridge Bay. Low (c. 15 m) steep cliffs in gently dipping clay and shale strata stand behind a very well-developed series of wide platforms of Kimmeridgian cementstone (Figure 11.43; Arkell, 1947). The form is mainly controlled by geological structure.

Figure 11.42: Gad Cliff. The upper cliff is in Portland Stone; the debris and boulder field, well-vegetated by scrub, lies on Portland Sand and upper Kimmeridge Clay. The boulder beach has alternating ramparts and baylets related to differential erosion (associated with bedding in the Kimmeridge Clay) and debris toes. (Photo: V.J. May.)

Figure 11.43: Broad Bench, a Kimmeridge shale platform, showing block removal at platform edge. (Photo: V.J. May.)

Between Hounstout and St Aldhelm's Head, the coast is dominated both by high (to 130 m) limestone-capped cliffs and large undercliffs. Areas of very rapid change (Figures11.44–11.47) occur via landslides wherever the Kimmeridge Clay occurs at sea level. At Chapman's Pool, a small semi-circular cove has developed between headlands formed of large boulder accumulations resulting from the landslides. Small platforms are exposed in the intertidal zone in Chapman's Pool. The stepped profile described byBrunsden (1973) for west Dorset is found here in both active and passive landslide areas, although in the latter there has been widespread degradation of many of the clay slopes. Flat-topped ridges of Portlandian limestone and sandstone lying on Kimmeridge Clay are truncated by landslides of various (but as yet undetermined) ages. The strata dip southwards and seawards at about 2° and there is a fault to the east of St Aldhelm's Head. There are three major spatial units within this landslide region (May, 1997a).

Figure 11.44: The cliffs between Hounstout and St Aldhelm's Head are characterized by large landslides of as yet undetermined age. Large Portland Stone boulder fields provide protection against wave attack, but where they are absent shoreline retreat produces steep lower cliffs. (Photo: V.J. May)

1. An active landslide at Hounstout cliff distinguished by clay slopes, frequent rockfalls, mudslides and widespread gullying. Vegetation occurs mainly on the back-tilted, rotational slip blocks. There is much standing surface water and during rainfall, runoff is high. There are many small, frequent, mass-movements. These landslides have been particularly active since about 1970 (Jones, 1980).

2. At Emmet's Hill, the landslides are not particularly active today, although back-tilted blocks of limestone and sandstone indicate significant past movements. The hollows between these blocks are filled by debris from localized rockfalls and by downwashed sand and clay. Small trees (10 m high) grow in some of these hollows. Most movements of the 20th century have been rockfalls from the high limestone and sandstone cliffs, but since 1990, the slopes in Kimmeridgian clays have been affected by shallow slides. At the cliff foot, there has been increased marine erosion.

3. St Aldhelm's Head is marked by a wide undercliff cloaked by boulders. There are a number of large debris fans produced by both natural processes and quarrying, the latter during the 19th and 20th centuries. Back-tilted blocks appear to be absent.Small (1970) suggested that these slopes may have formed under frost action during the Quaternary Period, but there is as yet no firm evidence to support this view.

East of St Aldhelm's Head, the undercliff narrows rapidly and the cliffs become lower in height, but steeper. Immediately east of St Aldhelm's Head, although there is no true undercliff, a steep grassed slope on the Portland Sand lies below the steeper upper cliff of Portland Stone. Boulders protect this from erosion in a similar way to the cliffs at Gad Cliff. To the east towards Durlston Point, the cliffs are steep. Sometimes they plunge directly into the sea, in other places they have a small coastal platform. This is most characteristic of the mouths of the small hanging valleys that characterize this coastline at Winspit, Seacombe and Dancing Ledge. At the mouth of Seacombe, the cliff face truncates a former stream valley infilled by angular debris. The slope-over-wall form of much of this coastline has been modified in places by lynchets (man-made terraces). The lower part of the slope is often cloaked by angular debris, the thickness of which appears to deepen downslope. Some slope sections are well-exposed where quarrying has cut into the slope. The valleys are floored by angular debris. At Seacombe the valley is flat-floored almost to its mouth, whereas the Winspit valley is distinguished by a series of incised meanders. Although these features are not parts of the original GCR site, they are related to the origin of the coast and the extent to which it is a contemporary feature or a reworking of earlier forms.

At Durlston Head, the coastline changes direction to become a transverse one. Much of the cliff has been affected by landslides; they recur sporadically. In late 1994, for example, a small slide affected the cliff to the north of Durlston Castle. Part of this cliff has now been modified by dumping of boulders in an attempt to protect cliff-top dwellings. The southern cliffs of Durlston Bay are more active than their well-vegetated characteristics imply. The northern extremity of the GCR site lies at Peveril Point, where a series of intertidal reefs reflect the synclinal tectonic structure here.

Interpretation

Five issues have been the focus of debate and research along this coastline:

1. The development of the headland–bay topography east and west of Lulworth Cove.

2. Whether the many truncated coastal valleys, especially in the Isle of Purbeck, were graded to formerly higher or lower sea levels.

3. The role of the submarine bathymetry and topography in limiting wave energy along parts of this coast.

4. The grading of beach sediments within the bays.

5. The relationship between the subaerial landforms and the development of the beaches.

Generally these issues have not been reviewed together, since most writers have focused upon smaller parts of the coast. There has been no comprehensive survey of the major landslides at White Nothe and St Aldhelm's Head, probably because they do not threaten property and appear to be quiescent when compared to those of west Dorset. Similarly, there has been very little debate about the submarine geomorphology until recently apart from the deeper-water surveys of the sediment patterns of the Shambles and the Lulworth Banks (Donovan and Stride, 1961; Pingree, 1978). Using side-scan sonar, Heeps (1986) elucidated some of the shallow-water topography. More recently surveys in connection with oil and gas exploration have described the sediments of Weymouth Bay and further analysis of the seabed forms is continuing (May and Drayson, 2001).

Textbooks worldwide use the Lulworth area as an example of longitudinal coastal development and the effects of differential erosion. It is also used to illustrate the principle that landforms in different stages of development can represent a time series of changes (Bird, 1984; Small, 1978; Ward, 1922; Sparks, 1971; Komar, 1976). This point of view has been challenged by Brunsden and Goudie (1981), and Small (1970) drew attention to the special character of Lulworth Cove in having been modified by the erosional activity of the stream running into it. The traditional point of view has been that Stair Hole represents the first stage in a sequence that leads via a Lulworth Cove-type situation to the form of Worbarrow Bay (Figure11.41). In this model, the sea erodes caves, then arches, in the durable Portland Stone and basal Purbeck beds, removes the much weaker Wealden sands and clays behind and opens up a cove, which, because of the restricted entrance, assumes a circular shape similar to the present-day Lulworth Cove. Bird (1984), for example, said that the ‘classic example of this is on the Dorset coast'.

Brunsden and Goudie (1981) argued, however, that the textbook scenario does not reflect the relationship between river valleys and the coastal forms. The major bays are associated with valleys, whereas Stair Hole is not. Lulworth Cove is on the line of a valley that drained both the western and eastern sides of the cove; fluvial erosion occurred when sea level was substantially lower during glacial periods. AlthoughHeeps (1986) reported several small faults on the seabed opposite the mouth of the cove, she reported no evidence of a continuation of the valley seawards in her detailed description of the submerged Portland and Purbeck beds in Worbarrow Bay. The outline of Worbarrow Bay is controlled both by the refraction of waves around the headlands and also by the shallower parts of the reef, but the main beach is predominantly related to south-westerly waves. There is no comparable valley form in the reef west of Lulworth and none of the valleys grade to sea level. They all hang well above the beach, having been truncated by retreat of the Chalk cliffs. Only at Scratchy Bottom has there been any significant gully development at the valley mouth.

Brunsden and Goudie (1981) suggested that the sequence should be Stair Hole–Durdle Door–Mupe Rocks–Man o'War Rocks, i.e. 'barrier breaching–arch formation–stack formation as a result of arch collapse–isolated rock barriers'. The role of subaerial processes in the slumping of the sands and clays is very important, but depends on the efficiency of the sea in removing the resultant debris. The individual bays formed by the breaches merge before a true circular cove can form because their eastern and western sides collapse more rapidly than the Chalk of their backwall. Jones *et al*. (1984) consider that two small dry valleys west of Durdle Door may have formed features smaller but comparable to Lulworth as the coastline retreated. They believe that these have coalesced and are responsible for the area of water between Durdle Promontory and White Nothe. The two dry valleys between Durdle Door and Bat's Head are underlain by deeply weathered materials of periglacial origin that descend almost to present-day sea level. Gaps in the offshore reef co-incide with the valleys and so it is conceivable that there were two bays here, one associated with Scratchy Bottom and the other between Swyre Head and Bat's Head. West of White Nothe, however, there are the heads of chalk combes only, and side-scan sonar surveys reveal no significant breaching of the submerged, offshore reef.

The development of Lulworth Cove and Worbarrow Bay depends on the existence of a valley cutting through the Portlandian strata, and so has more in common with the breaching of the chalk between the Isle of Wight and the Isle of Purbeck or the Western Yar (Jones *et al*., 1984). Jones *et al*. suggest that Chapman's Pool and Kimmeridge Bay are similar in origin as each results from a water gap. They regard Kimmeridge as the least-mature of the drowned valley features of Purbeck. Chapman's Pool occurs where two deep valleys cut through the Portland Limestone, enabling the sea to erode the Kimmeridge Clay. Lulworth Cove represents the next stage, with a larger bay where the Portland and Purbeck Beds have been breached and the sea has cliffed the hardened Chalk. In contrast, Worbarrow Bay has breached only the chalk at Arish Mell, and is also a more open bay as both the Portland and Purbeck Beds have been cut back and the Wealden strata have been exposed to a south-westerly fetch. In contrast with both the Brunsden and Goudie (1981) and the Jones *et al*. (1984) explanations for Worbarrow Bay, further consideration of the relationship between Worbarrow Bay and Mupe Rocks–Mupe Bay and suggests that the origin of Worbarrow Bay is likely to be composite. The Wealden outcrop widens across the bay, exposing as Worbarrow Bay was opened up increasing lengths of weak strata to the dominant waves from the south-west. In the same way as Mupe Rocks were penetrated in the Brunsden and Goudie sequence, the reef was already breached to the east and had attained the Man o'War Bay configuration, allowing a bay to develop into Mupe Bay that would merge with the expanding Worbarrow Bay (Figure11.48). Retreat of the coast of the Isle of Purbeck is thus controlled by four barriers to marine erosion (Jones *et al*., 1984), the Kimmeridge shales forming the Ledges, Portland Limestone boulder beaches, in-situ Portland Limestone and tectonically hardened Chalk. The resistance of the Portland Limestone to erosion is affected by the angle of dip, with erosion and then breaching taking place more effectively with steeper dips (Jones *et al*., 1984).

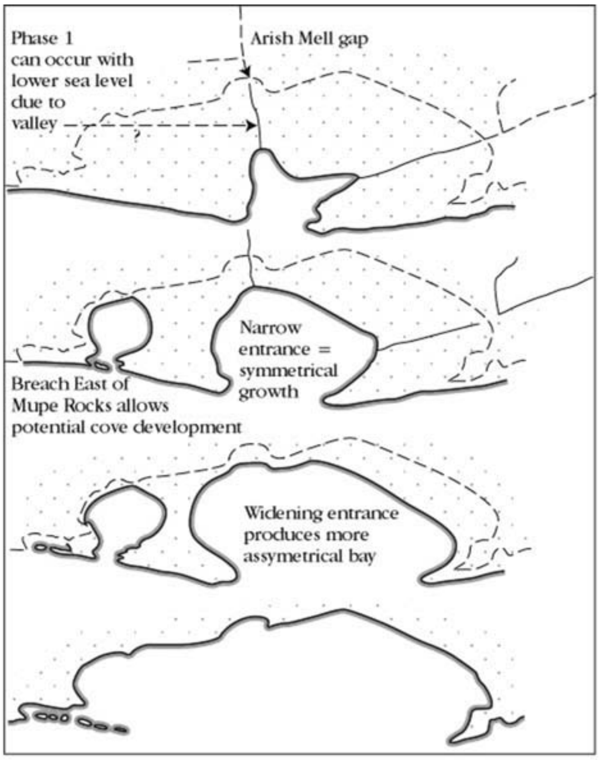


Figure 11.48: Development of Worbarrow Bay from initial flooding of former valley along line of Arish Mell gap. The breakthrough in the vicinity of Mupe Rocks develops in early stages in similar way to that at Stair Hole. Subsequently, both Worbarrow and Mupe bays merge with increasing asymmetry as the eastern shoreline of Worbarrow Bay becomes more exposed to waves from English Channel.

The relationship between the many truncated valleys and the cliffs and their changes has attracted attention. Between Durlston Point and Furzy Cliff, 23 valleys are cut by the coastline. Of these, 11 have been truncated by the sea, four having permanent or occasional waterfalls and six valleys reach the coast by a gorge or deeply incised valley. At Lulworth and Arish Mell, partially drowned valleys are cut in the Portland beds. Four occur in the Portland and Purbeck beds, seven in the Kimmeridge Clay, and eight in the Chalk. Three are in the clays of the Wealden or Oxford Clay. The rates of present-day cliff retreat in the clays are such that the lack of incision of streams could be attributed to their inability to keep pace in their downcutting with the retreating cliffline. In the Chalk, the dry valleys are truncated by the sea in a similar way to those in other Chalk sites at the Seven Sisters (Sussex) and between Kingsdown and Dover (Kent; see GCR site reports). In the Isle of Purbeck, the valleys at Winspit and Seacombe both have floors that are not graded to present-day sea level. Both have deeply incised rock valleys that are filled by angular debris. At Seacombe a cross-section of this infilled valley is exposed in the cliff face (Figure11.47), whereas at Winspit it has mostly been excavated by a series of incised meanders. The coastal slopes around these valleys have a slope-over-wall form. The lower cliff cuts across the lower part of the ‘slope', which is characteristically cloaked by angular debris.

Figure 11.47: Truncated valley infill at Seacombe Valley (SY 983 785). The altitude of the valley floor is about 7 m. (Photo: V.J. May.)

There are several possible interpretations for this combination of forms. The first is that the truncated valleys are a result of the varying ability of coastal streams to keep pace with cliff retreat in different lithologies. A second possibility is that the present-day cliffs are being reworked, having been cloaked by angular slope deposits during the last glacial period. The last 6000 years have been a time during which debris has been removed, with some erosion of the cliffs and some removal of the valley infill, especially in the Winspit valley where the stream has a higher discharge. This is comparable to present-day retreat rates of about 0.03 m a^{1}. Both to the west of Winspit and at Gad Cliff, there are high cliffs that have a vegetated slope below a vertical face. Both show very little sign of retreat and owe their present stability largely to the protection afforded by boulder accumulations at the foot of the slope. In the absence of specific dating of the slopes it is possible to only speculate on the period over which they have had this form beyond the last couple of centuries. Offshore from Gad Cliff, there are large accumulations of boulders that can be interpreted as resulting from cliff retreat during a lower or rising sea level and which would reduce the energy of waves approaching this coastline. The large landslide at St Aldhelm's Head appears to be covered in parts by angular debris, which Small (1978) suggested may have a periglacial origin. Most of the evidence for reworking of an earlier coastline is circumstantial (Mottram, 1972), in the absence of dated sediment. However, it is difficult to explain many of the forms of the hard-rock coastline without considering this possibility.

Heeps' (1986) study of the submarine topography and the additional interpretation of later side-scan sonar records reveal an intricate morphology in which boulder accumulations, submerged platforms, ridges and troughs are cloaked by a veneer of sand, shell and coarser sediments (May and Drayson, 2001). There is some evidence from repeated seabed surveys that the veneer is subject to slight changes, rather than major changes. Some of the larger boulder fields are associated with cliffs where collapse carries boulders of sufficient size to the shoreline. That these areas of boulders continue offshore argues that they have been active over much of the period of Holocene sea-level rise and of present-day sea level. Much more work needs to be done on this part of the site, but there are few other areas where the nature of a cliffed coastal zone has been investigated from the cliff top to the usual seaward limit of wave action.

Concerning the question of the grading of sediments within the bays, Arkell (1947) commented on the tendency towards coarser sediment in the centres of the bays. Heeps (1986) confirmed that this is generally the case and put forward reasons for the wave-sorting that occurs. She also demonstrated that most of these bays are closed sediment-cells, in that the enclosing headlands and the offshore barriers prevent outward sediment transfers of particles other than clays in suspension. Inward transfers also appear very limited because of the nature of the barriers and their height. The beaches, therefore, depend solely upon the addition of shingle from the erosion of the cliffs and the longevity of flint already within them. Measurement of the sedimentary product of rockfalls from the Chalk (May and Heeps, 1985; Heeps, 1986) shows that most chalk is broken down into pebbles, and then shelly fragments and fines within a few months of the original cliff collapse. Boulders of limestone and sandstone that are upwards in size of 0.5 m may survive for longer in the intertidal and shallow water zone on the seabed if they are large and resistant enough.

The relationship between subaerial processes and the development of the beaches has attracted attention in the literature. Although Bray *et al.* (1992) indicate that the net direction of sediment transport in Weymouth Bay is from east to west, this is true only of the offshore transport routes where the sediments become finer westwards. Along the shoreline itself, transport is largely confined within the bays, where reversals of drift as well as localized onshore–offshore movements occur regularly. Of the shingle beaches, only one, east of White Nothe, appears to be formed mainly of contemporary material. All the others contain substantial quantities of well-rounded, oxidized flint clasts together with varying volumes of angular and subangular, grey flint. Davies' (1972) view that flint nodules are readily quarried from the Chalk platforms and so provide an ‘abundant source of pebbles' (p. 118) is not borne out in the short term by Heeps' (1986) examination of the beaches in this area.

In summary, strike-aligned coasts are comparatively unusual in Britain. Most wave attack here is from the south-west, obliquely to the coastline, with a potential fetch of several thousand kilometres at the eastern end of the site. However, because the location is microtidal, much wave energy is concentrated in a narrow band at the base of the cliffs. A submerged rock reef along part of the coastline reduces wave energy inputs to the beaches, and sediment is conserved within each bay.

Conclusions

The Dorset Coast GCR site contains some of the most visually appealing coastal landforms in Britain. It is a world-renowned example of a longitudinal coastline, includes such classic landforms as Worbarrow Bay and Lulworth Cove, and provides an excellent field observatory for studies of cliff, beach and nearshore geomorphology. Lulworth Cove and Durdle Door are also known worldwide for their scenic value. The scientific importance of this site comes from the variety of erosional features, the debate about the sequence of their development, the linked submarine forms, the closed sediment systems of the bays, and the very large number of truncated (hanging) valleys.

This coast is a complex one, whose interpretation ranges from the analysis of the present-day processes to the unravelling of the longer geomorphological history of the site. The classic landforms have been studied at scales that often ignore the detail of smaller features and localized processes but these combine with the larger forms to suggest a complex and lengthy history for this coastline.

It is an unusual coast in having been the focus of both traditional geological and geomorphological study and submarine survey that now allows the whole coastal system to be described and analysed.

This coast is also important in containing the largest set of closed sediment-cells to have been described anywhere in the British Isles. There remain a large number of sub-sites within this site that warrant more detailed examination. It is also an most important rocky coastline on account of the assemblage of forms that occur within it, from the scale of the longitudinal coast to the individual features of the seabed, beaches and cliffs. In this totality of interest, it is of international importance to coastal geomorphology.

The Purbeck coast is also the location of Britain's first Voluntary Marine Reserve at Kimmeridge, is designated as a Special Area of Conservation under the European Union Habitats Directive and includes Jurassic stratotypes. Indeed, so important is the geology and geomorphology of this coast, that this site forms part of the Dorset and East Devon Coast World Heritage Site, which was declared on account of its Earth science features of interest in

December 2001.

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