The Eastern Coast of Dorset

9

Andrew S. Goudie and Piotr Migoń

Abstract

The Eastern coast of Dorset, running from Portland to Bournemouth, has some remarkable coastal features, including major mass movements behind Weymouth Beach, at Osmington Mills and White Nothe. Further east, there are two sets of landforms that illustrate the evolution of coastal scenery through time. The first location is centred on Lulworth Cove, where fluvial and coastal erosion have produced a series of different bay forms developed in Jurassic and Cretaceous rocks, including Durdle Door and Scratchy Bottom. The second location is the South Haven (Studland) Peninsula, where coastal dune evolution over more than four centuries has been established. Both the dunes at Studland and the salt marshes in Poole Harbour display the role of vegetation in coastal evolution.

Keywords

Coast erosion • Cliffs • Sand dunes • Dry valleys • Vegetation succession

9.1 Introduction

The part of Dorset Coast between Weymouth Bay in the west and the Poole Harbour in the east is known as the Purbeck Coast and offers some magnificent landscapes. Backed mainly by Chalk uplands, for most of its length, it takes the form of high cliffs, up to 150 m in total, whereas the coastline itself is contorted, with numerous bays alternating with headlands. Just offshore are numerous picturesque stacks, especially around Lulworth Cove and at Handfast Point. The geology is impressive, providing insights into changing sedimentary environments from the Middle Jurassic to the Upper Cretaceous, thus spanning 100 million years of the Earth's history in an almost continuous succession. This stretch of the English coastline is also famous for its landslides, representing various types and mechanisms of movement, beautifully exposed due to generally scarce vegetation cover, dominated by grasslands. At the northeastern extremity, in Studland Peninsula, the coast becomes depositional, with multigenerational beach ridges, mudflats and lagoons. Geological and geomorphological values of the East Dorset coast received international recognition when, in 2001, the status of UNESCO World Heritage was awarded to the East Devon and Dorset coast, including nearly the entire section presented in this chapter.

A. S. Goudie (✉)
School of Geography and the Environment,
University of Oxford, Oxford, UK
e-mail: andrew.goudie@stx.ox.ac.uk

P. Migoń
Institute of Geography and Regional Development,
University of Wrocław, Wrocław, Poland

9.2 Geology

The sedimentary succession of the East Dorset coast spans the period from the Middle Jurassic, c. 165 Ma ago, to the end of the Cretaceous, some 70–65 Ma ago (Ensom and Turnbull 2011; Fig. 9.1). The strata dip generally to the east, so that going eastwards one encounters younger and younger units, but the presence of east-west trending anticlines complicated the picture. Table 9.1 summarises this succession and relates its different components to characteristic morphologies.

Some of the Mesozoic strata are extremely rich in fossils, and this is one of the reasons that have made the East Dorset coast famous. They yielded ammonites, belemnites, gastropods, bivalves, fish, as well as remains of large marine reptiles such as plesiosaurs and ichthyosaurs. From the terrestrial Purbeck and Wealden sediments dinosaur tracks are known, as well as crocodile bones and turtle carapaces. Fossilised remnants of tree trunks occur in the Purbeck beds near Lulworth Cove, forming the Fossil Forest.

Although there is generally little distortion of Mesozoic strata along the East Dorset coast, some spectacular

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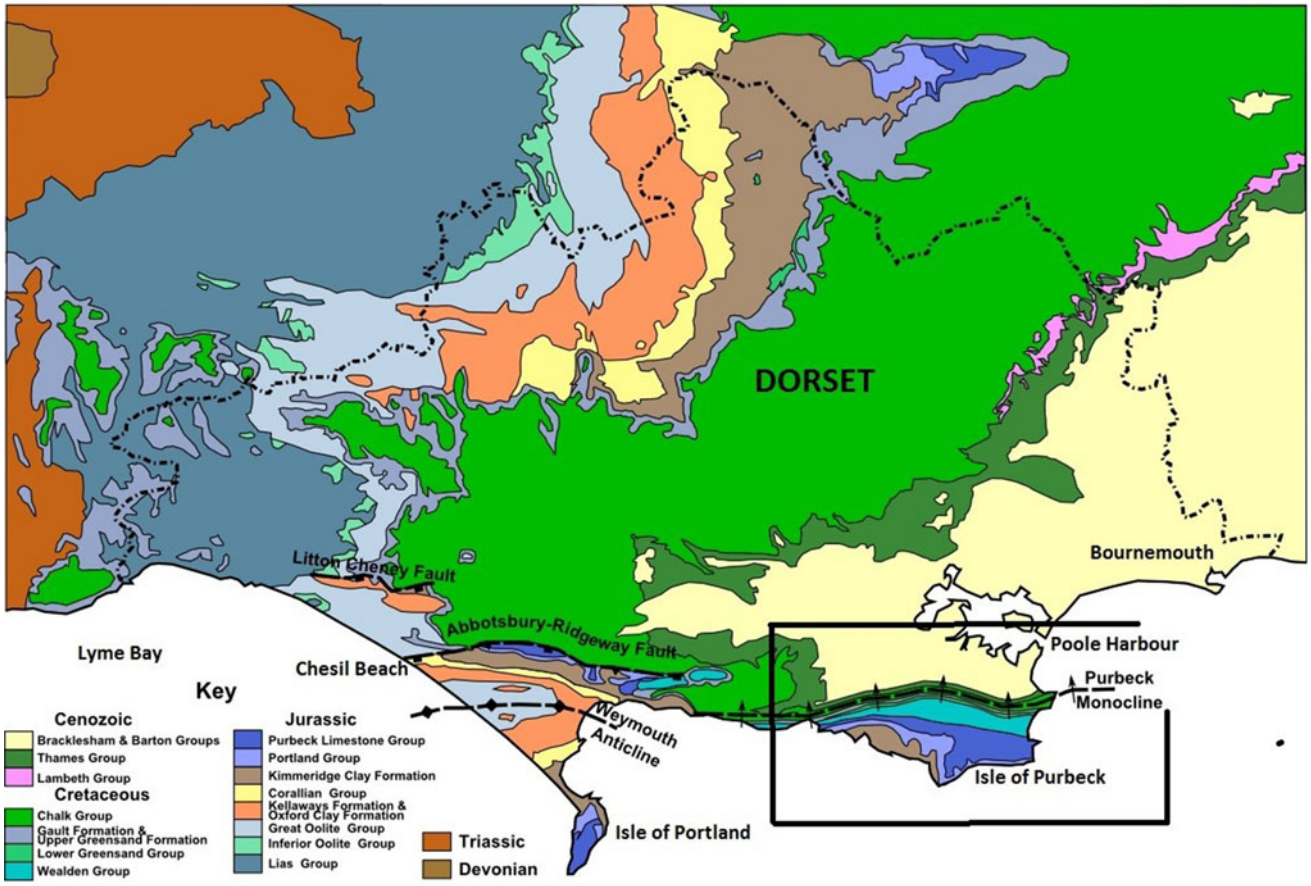

Fig. 9.1 The location and geology of the eastern Jurassic Coast. Modified from https://en.wikipedia.org/wiki/Geology_of_Dorset#/media/File:Dorset_Geology.png (Accessed 1st November 2017). The box (bottom right) shows the area covered in this chapter

Table 9.1 Sedimentary succession of the East Dorset coast (simplified, after Ensom and Turnbull 2011)

Period	Age (Ma)	Name of the unit	Environment and lithology	Associated landforms
Upper Cretaceous	99–65	The Chalk	Marine—chalk	Steep cliffs, stacks, ridges, dry valleys
Lower Cretaceous	102.7–99	Upper Greensand	Marine—sandstone	Moderately inclined cliffs
	107.3–102.7	Gault	Marine—clayey silt and sand	Low cliffs, mudslides and mudflows
	124.8–107.3	Lower Greensand	Marine—clay, mudstone, sandstone, limestone	Low cliffs, mudslides and mudflows
	136.8–124.8	Wealden Group	Terrestrial fluvial—clays, mudstone, sandstone	Low cliffs, mudslides and mudflows
	144.8–136.8	Purbeck Group	Terrestrial to marine—clay, shale, limestone	Moderately inclined cliffs
Upper Jurassic	147.6–144.8	Portland Group	Marine—sandstones, limestones	Steep cliffs, vertical ridges, arches, stacks
	154.7–147.6	Kimmeridge Clay	Marine—mudstone, dolomite	Low cliffs, mudslides and mudflows
	159.5–154.7	Corallian Group	Marine—clay, mudstone, sandstone, limestone	Low cliffs, mudslides and mudflows
Middle Jurassic	164.7–159.5	Oxford Clay	Marine—clay, mudstone	Low cliffs, mudslides and mudflows

Fig. 9.2 The landslide complex at White Nothe (Photo P. Migoń)

examples of deformation occur and can be seen in coastal outcrops, with the folded layers exposed in Stair Hole being the prime example. Genetically they are linked with the steeply dipping Purbeck Fault of W–E extension, reactivated during the Alpine orogeny in the Cenozoic. The large-scale structure, less obvious when seen from a single observation spot, is the Purbeck Anticline which underlies the eastern part of the area, the Isle of Purbeck. Only its northern limb is exposed onshore, with the Kimmeridge Clay forming the core and younger strata dipping rather steeply to the north, passing into the Purbeck Monocline. An analogous structure in the western part is the Weymouth Anticline, with the Oxford Clay exposed in the core.

In addition to the Mesozoic succession, whose youngest member—the Chalk—builds the uplands of the Isle of Purbeck, Early Cenozoic deposits occur just to the north, underlying the large topographic depression between Dorchester in the west and Poole in the east. These are mainly clays, silts and sands, laid down in an environment changing from shallow marine through littoral to floodplain (Curry 1992).

9.3 Landslides Between Weymouth and Ringstead Bay

To the east of the Isle of Portland (see Chap. 11), the coast continues to offer magnificent landscapes. Weymouth Beach is backed by two coastal wetlands—Radipole Lake and Lodmoor Country Park. These represent infilled estuaries. The most northerly part of Weymouth Beach is backed by the Oxford Clay cliffs at Furzy Cliff and Bowleaze Cove, and these show many highly active mass movements, including recent landslips. Further eastwards there is Black Head and Osmington Mills, and here also, because of the presence of both Kimmeridge and Gault clays, there are other examples of active mass movements.

The coast from Ringstead to White Nothe is fascinating because a shallow fold brings the Chalk, Upper Greensand and Gault into contact with the Portland, Purbeck and Kimmeridge beds. It starts with a section called Burning Cliff, the name recalling an unusual event that occurred in the 1820s. Organic-rich shales exposed in the cliff,

Fig. 9.3 Lulworth Cove and Stair Hole (foreground) as drawn by J.M.W Turner in 1814

apparently due to an earlier mass movement, spontaneously ignited and burned for three consecutive years. This reaction was caused by the decay of pyrite, aided by some bacterial activity (Ensom and Turnbull 2011). Similar phenomena were recorded also elsewhere along the East Dorset coast, for the last time to the east of Kimmeridge Bay in 1972–1974.

The result of the juxtaposition of permeable and impermeable beds is a huge landslide complex at White Nothe (Fig. 9.2). This is a multiple rotational slide, with as many as six displaced and back-tilted blocks, separated by waterlogged furrows, some with small ponds. The landslide crown is at an elevation of c. 150 m a.s.l., whereas the toe is undercut by the sea and is seen as a chalk-debris scarp, below which a boulder beach extends. Underwater boulder ramparts indicate the positions reached by secondary mudflows and mudslides from the landslide body. The entire landslide complex is 1 km long and nearly 400 m wide. Further east still, the coastline becomes even more magnificent, comprising the spectacular geomorphological features of Scratchy Bottom, Durdle Door and Lulworth Cove.

9.4 Lulworth Cove and Its Neighbours

This portion of England's Jurassic Coast World Heritage Site has some sets of landforms that illustrate the nature and history of long-term coastal erosion. The first of these sets lies between Bat's Head and Worbarrow Bay and includes Lulworth Cove. This much visited site has attracted great artists, including J.M.W Turner (Fig. 9.3). Lulworth Cove is used for teaching exercises because it is held to illustrate two general principles (Goudie and Brunsden 1997): namely that stage of development is an important consideration in understanding landforms, and that it is possible, to use sequences of landforms to illustrate change through time—a procedure called space-for-time substitution or ergodic reasoning. The traditional three-stage model put forward by Sir Aubrey Strahan (Strahan 1898, p. 3) to explain the nature of this exceptionally beautiful piece of coastline is that the sea breaks through a resistant barrier of limestone beds, initially eroding a sea cave. This enables the sea to excavate the weak Wealden Clay behind, so that a small bay, Stair Hole, is

Fig. 9.4 The arch of Durdle Door. Note also the near-vertical dip of the Purbeck Beds and the narrow outcrop of erodible Wealden Beds, forming a low col between the Purbeck Beds and the Chalk (Photo A. S. Goudie)

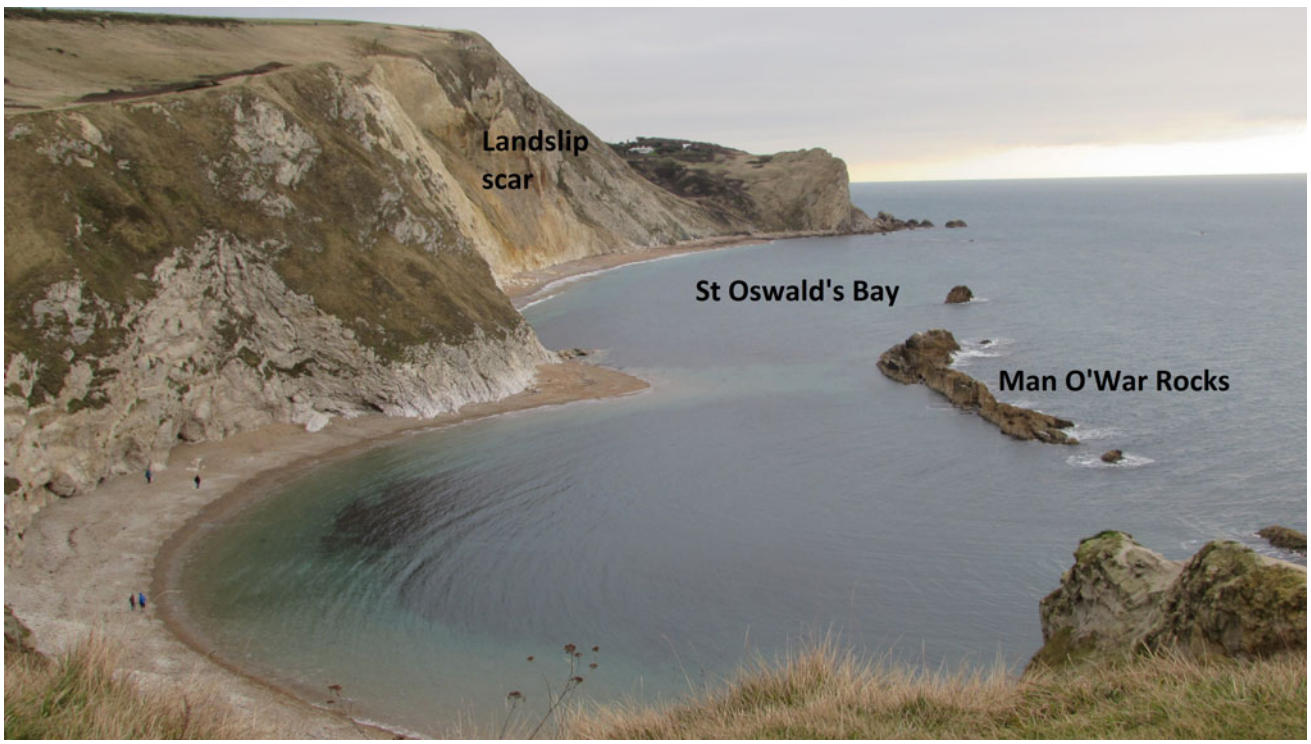

Fig. 9.5 Man O'War Rocks. In the background, in St Oswald's Bay, there is the scar of a fresh cliff failure developed in the Chalk in April 2013 (Photo A. S. Goudie)

Fig. 9.6 Satellite image of the Durdle Door area (Courtesy © 2017 Google Earth). Scale bar 1008 m

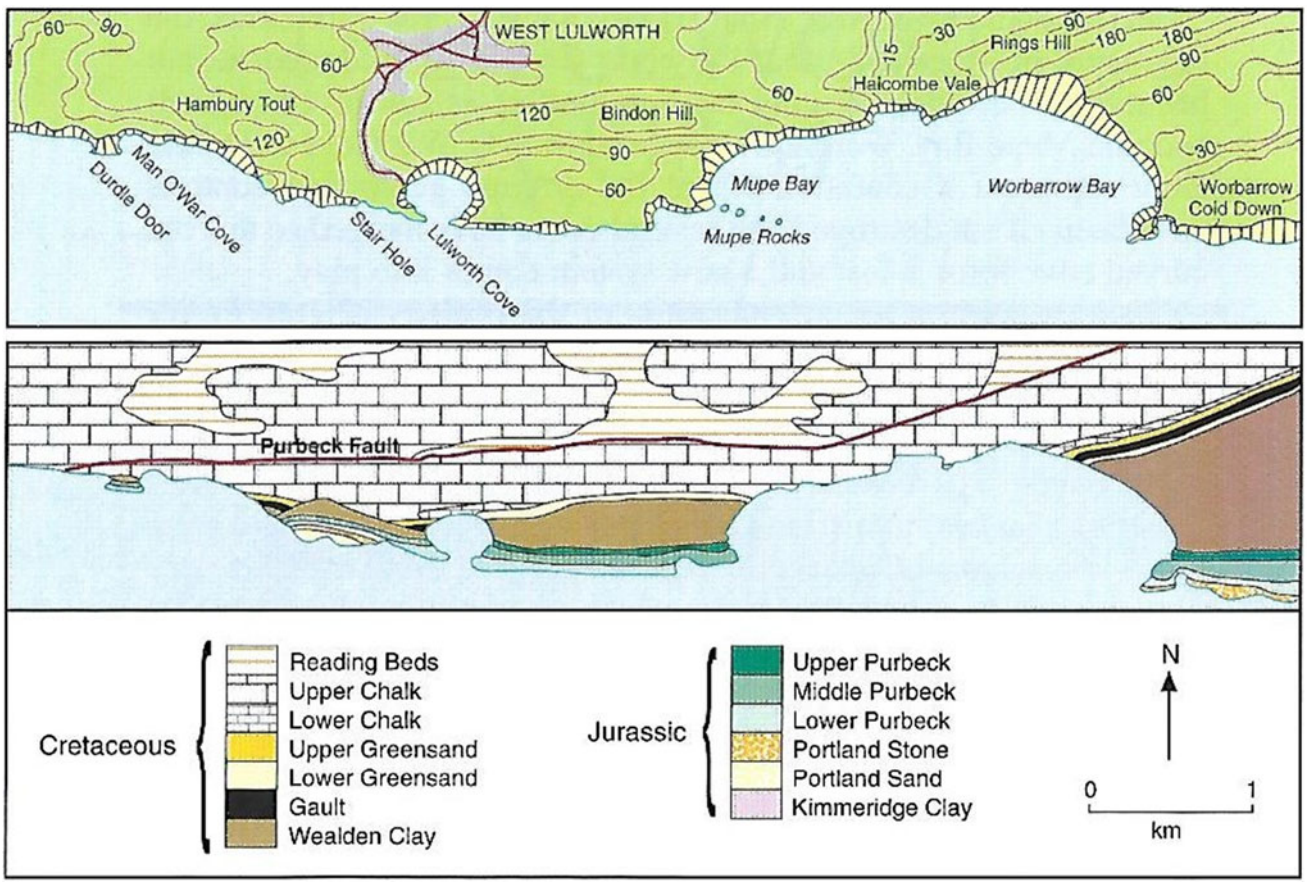

Fig. 9.7 The west to east change in the geology of the area (from Goudie and Brunsden 1997, Fig. 8)

Fig. 9.8 Satellite image of Lulworth Cove (Courtesy © 2017 Getmapping plc). Scale bar 251 m

opened up. Initial erosional ingress may have been facilitated in particular locations by the presence of faults (Nowell 1997, 1998). As time goes on, it is argued, further erosion enlarges the bay until a much larger feature is formed, namely Lulworth Cove. This is stage two. Amalgamation of adjacent coves gives even larger bays (Worbarrow, Mupe and Durdle Bays). This is stage three, and continued erosion of the limestone beds of Portland and Purbeck age leaves only isolated arches (the presence of Durdle Door at the tip of a headland tends to be interpreted in this way) (Fig. 9.4 and a series of offshore reefs and stacks, such as the Bull, the Calf, the Cow, the Blind Cow and Man O'War Rocks (Figs. 9.5 and 9.6) (Burt and Goudie 1994). It is possible that some of these stacks are beheaded stumps which once supported rock arches similar to Durdle Door before the arches collapsed.

This model rests on an understanding of the area's geology, for there is a distribution inland of Late Jurassic to Upper Cretaceous rocks more or less parallel to the coastline. The very steeply dipping and contorted Jurassic strata of relatively resistant limestones include the famous Lulworth Crumple. The inclination of these beds relates to events round about 25 million years ago when the African tectonic plate collided with the European plate. The huge pressures generated heaved and folded rocks to create the mountain chain we know as the Alps. Ripples from that collision affected south Dorset and Purbeck. These beds present a rampart against marine erosion. Behind them occur much less resistant Cretaceous rocks, including Wealden Clays, Upper Greensand and Gault. To the rear of these lies a Chalk escarpment.

Unfortunately, this appealing model does not stand up to detailed scrutiny. First of all, it is not possible to apply the space–time substitution idea too rigorously, because rock conditions are not constant along this coast. The outcrops of the beds widen towards the east (Fig. 9.7). Thus it would have required more time for Worbarrow Bay to develop, and successively less time for the bays towards Durdle Door. Stair Hole is small because the erodible Wealden Bed outcrop there is narrow, whereas, by contrast, Worbarrow Bay is large because the outcrop of the Wealden Beds is much wider.

Secondly, the processes operating at Stair Hole are different than those at Lulworth. Stair Hole does not contain a valley system, whereas Lulworth Cove does (Fig. 9.8). It is likely that a lot of the erosion of Lulworth Cove has not been due to marine processes but to fluvial activity (Fig. 9.9) (Burton 1937). In the Pleistocene, under periglacial

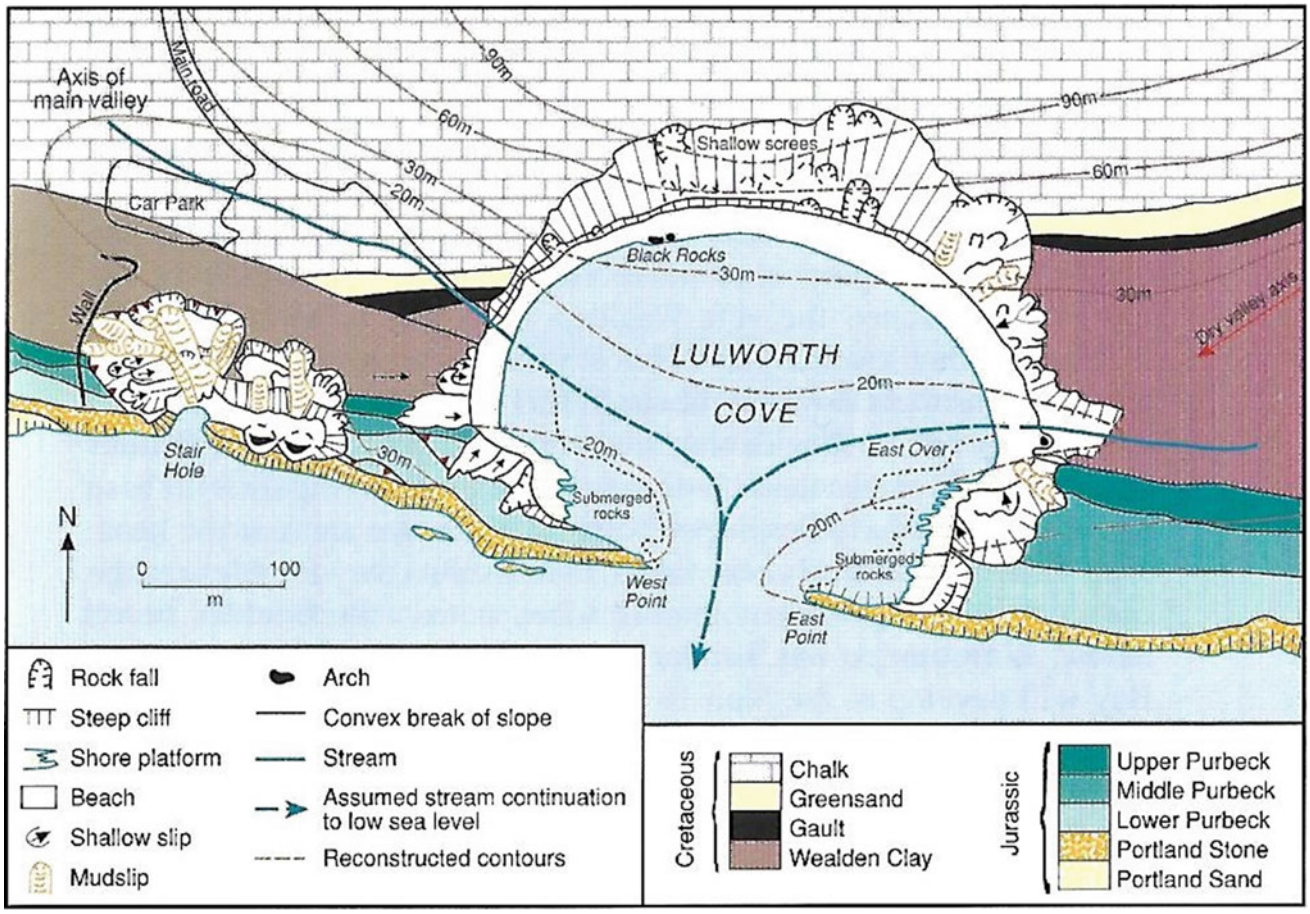

Fig. 9.9 Geomorphological map of Lulworth Cove (from Goudie and Brunsden 1997, Fig. 9)

conditions, and at a time when sea level was low, intense river erosion occurred. It may, therefore, be argued that Lulworth Cove represents a partially submerged river valley that was flooded by the rise of sea level in post-glacial times and which has subsequently been trimmed into a near-circular shape by fluvial and mass movement activity, aided by wave attack. Rock falls are a major hazard that occur on the steep chalk cliffs that occur to the rear of the beach.

To the west of Durdle Door, a Chalk dry valley, called Scratchy Bottom, gives a very clear picture both of the size of some of the coastal dry valley systems, and the periglacial sediment and frost shattered and soliflucted Chalk that occurs in their bases (Fig. 9.10). Here, however, coastal erosion has truncated the valley which formerly would have cut down to below present sea level. Still further west is a small opening that protrudes through the Chalk headland known as Bat's Head—the Bat's Hole. Over time, it will likely enlarge to a much bigger natural arch before its roof collapses leaving only a stack in front of the receding headland.

Spectacular coastline landforms continue to the east of Mupe Bay, where the cliffs are built of the Chalk. Bedrock differences dictate the pattern of mass movement. Mudslides and mudflows typical for clays and mudstones are replaced by translational slides along steeply dipping joint planes. Nevertheless, the Chalk disintegrates while in motion and forms steep, unvegetated cones at the base of the cliffs which for some time offer protection against storm waves until they will be eroded away and the basal part of the cliff re-exposed. The largest landslide, c. 400 × 280 m, undercuts the Chalk ridge of Rings Hill, on the eastern side of Worbarrow Bay. Here the clayey Gault formations are exposed at sea level and this is where cliff instability is

Fig. 9.10 Scratchy Bottom: a periglacial relic. Top: the coastal section, showing the frost-shattered chalk in the base of the valley and solifluction debris on the far slope. Bottom: the steeply incised, and joint controlled, upper course of the dry valley (Photo A. S. Goudie)

Fig. 9.11 Satellite picture of Worbarrow Bay to show the landslide-affected section of the cliff and how landslides contributed to the partial destruction of an Iron Age hill fort (Courtesy © 2019 Terrametrics). Scale bar 207 m

initiated. Long-term cliff retreat due to landsliding caused partial destruction of the Iron Age hill fort of Flower's Barrow (Fig. 9.11).

9.5 South Haven Peninsula

The UNESCO World Heritage Site comes to an end at Old Harry Rocks. These consist of a series of striking stacks that have developed through erosion of the Chalk which onshore forms a W–E trending elevation of Ballard Down. Here the Chalk cliffs face southeast and continue over some 1.5 km, reaching a height of 20–50 m. The cliff line is not entirely straight but consists of alternating headlands and wide bays. Among the stacks, those at the very end of the cliffy sections are the most famous and include the largest one named Old Harry, his equally massive companion, and several much slender needles projecting into the sea—the Old Harry's 'wife'. Small arches at the base of some stacks and headlands indicate that the process of differential cliff retreat is ongoing, and given the erodibility of the Chalk, it is suspected to be quite dynamic.

North of this headland lies Studland Bay, which is backed by Eocene strata. Whereas Lulworth Cove and its neighbours show the development of a coast of erosion, the South Haven Peninsula behind Studland Bay shows the development of a coast of accumulation, with outstanding dunes and an extensive sandy beach (part much used by naturists). In particular, we can see the developmental sequence of some coastal dunes (Diver 1933), for this is one of the few locations in southern Britain that is for the most part actively prograding (May 2003) (Fig. 9.12). A major source of sand lies in Poole Bay for there is an extensive stretch of cliffs with Eocene strata. These include the Poole Formation of sands, clays and lignite, formerly known as the 'Bagshot Beds'.

The story starts with the formation of active, sharp-crested dunes at the foreshore, with sand-containing lime being trapped by such plants as marram grass (*Ammophila arenaria*). As this stretch of coastline builds outwards, as has been demonstrated by the study of ancient maps produced by cartographers such as Saxton, new dunes may develop the seaward of the original ridge. When this occurs, the inner dunes will start to decay, because they are

Fig. 9.12 South Haven Peninsula. Top: satellite image of the area, including the location of dune ridges (denoted by 'R') (Courtesy © 2017 Terrametrics). Scale bar 1111 m. Bottom: cross-section across the Peninsula, showing the different dune ridges (from Goudie and Brunsden 1997, Fig. 14)

cut off from their sand supply. As they stabilise they become colonised by more and more vegetation, including heather, gorse, and, finally, trees. The calcium carbonate content of the dunes is reduced by leaching, the organic content builds up, and marked podzolic soil profiles develop. Between the dune ridges are low lying areas, called 'slacks', which are wet areas with their own vegetation assemblages. In theory, we have here an example of geomorphological evolution related to plant succession (Wilson 1960), but this is sometimes disrupted by burning, grazing, trampling, and, in the past, bombing.

Before about 1600 AD, the coastline was considerably to the west of its present position (Fig. 9.13) and probably consisted of a low cliff of Tertiary sands and gravels (Bracklesham Group). Since that time, archival and cartographic research has revealed that the land built out seawards by c. 800–850 m in the north and by 300–350 m in the south. A sequence of four dune ridges and inter-dune slacks developed, and as this went on some lagoons were formed. These have gradually become isolated from the sea to produce freshwater lakes known as Little Sea and Eastern Lake. The sequence of development is shown in Fig. 9.14.

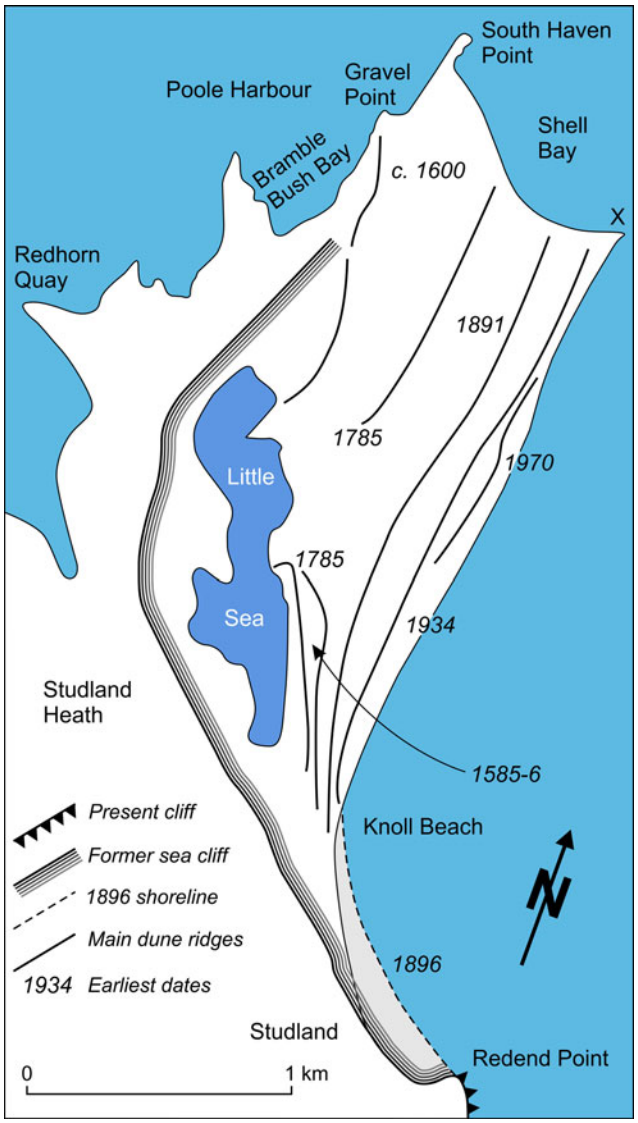

Fig. 9.13 The ages of the landforms on South Haven Peninsula (modified from May 2003, Fig. 7.4)

Examples of two maps used to reconstruct this evolution are shown in Fig. 9.15. The innermost (western ridge), conventionally called Third Ridge, had more or less been completed by the 1720s, the second dune complex, Second Ridge, seems to have been fully developed by the 1840s and First Ridge by about 1900. Zero Ridge has developed since the 1950s and continues to do so (Carr 1971).

Inland from the South Haven Peninsula is Poole Harbour. This large feature, which is a drowned valley into which the rivers Frome and Piddle currently flow, was probably created by the post-glacial rise of sea level, which was more or less complete around 5000–6000 years ago. Since that time the Harbour has become progressively silted up and mudflats and salt marshes have developed. Just as various grasses proved to be fundamental in the formation of the dunes at Studland, various halophytic silt-trapping plants, including *Spartina*, have played a fundamental role in marsh development.

9.6 Conclusions

In this book, we have included three chapters that relate to the Jurassic Coast World Heritage Site (WHS). This is because it is the only natural (as opposed to cultural) WHS in England and Wales, and was nominated because of the superlative nature of its geological history and geomorphological development. The links between geological history and landform development from the Jurassic through to the Holocene are well revealed in eastern Dorset. Here there are some remarkable coastal features, including major mass movements behind Weymouth Beach, at Osmington Mills and White Nothe. Further east, in the vicinity of Lulworth Cove, fluvial and coastal erosion have produced a series of different bay forms developed in Jurassic and Cretaceous rocks, including Durdle Door and Scratchy Bottom. At South Haven (Studland) Peninsula, the course of coastal

Fig. 9.14 The evolution of the South Haven Peninsula since c. 1600 AD (from Goudie and Brunsden 1997, Fig. 12)

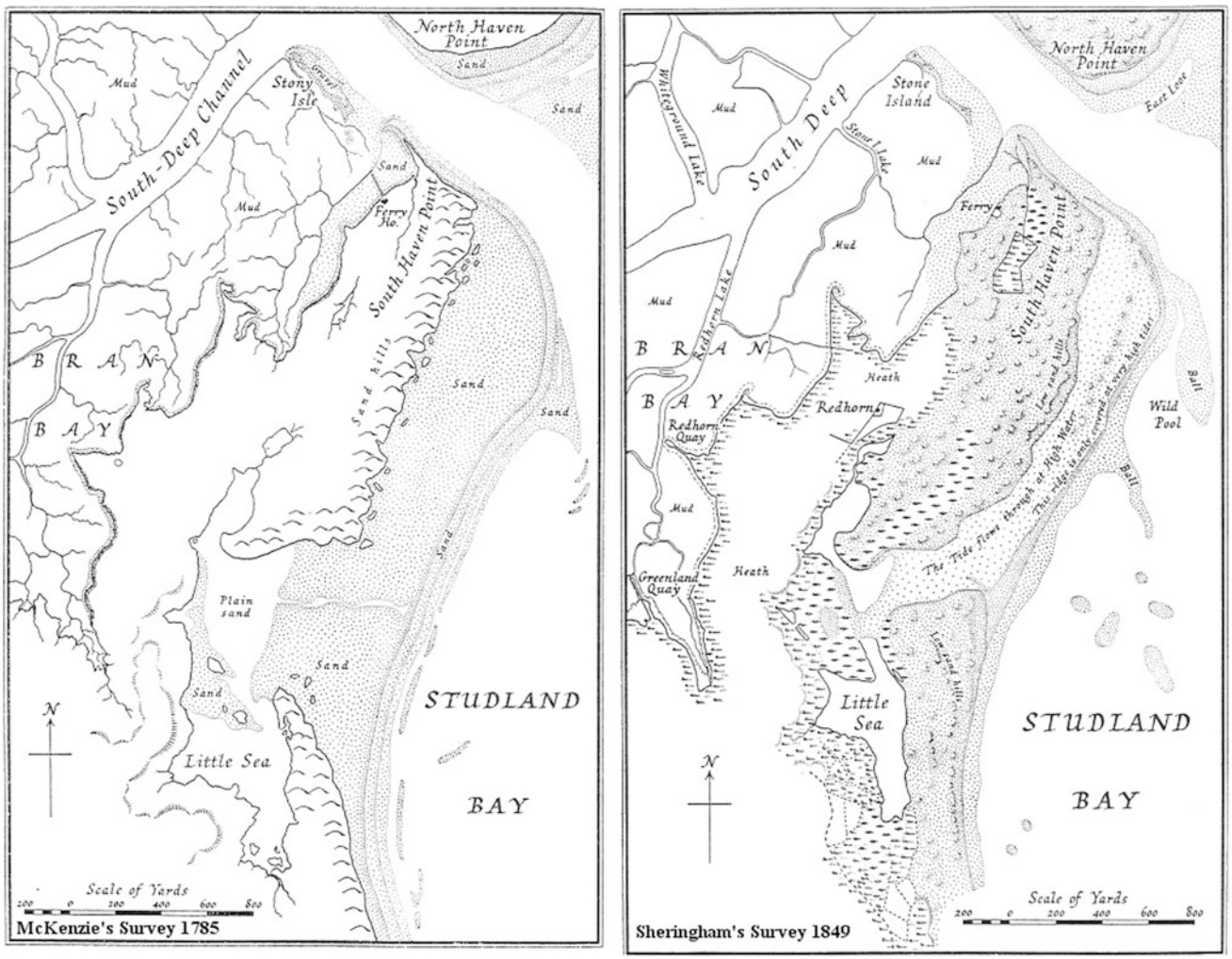

Fig. 9.15 Two maps of the South Haven Peninsula from 1785 to 1849, which are of particular interest as they show the evolution of the Little Sea (modified from Diver 1933)

dune evolution over more than four centuries has been established. Both the dunes at Studland and the salt marshes in Poole Harbour display the role of vegetation in coastal evolution in the late Holocene.

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Andrew S. Goudie DSc, Emeritus Professor of Geography at the University of Oxford and the former Master of St Cross College is a geomorphologist

who led the Kimberley Research Project in 1988. He is a recipient of a Royal Medal from the Royal Geographical Society, the Mungo Park Medal of the Royal Scottish Geographical Society, and the Farouk El-Baz Award of the Geological Society of America. He is a Fellow of the British Society of Geomorphologists. He has been Chair of the British Geomorphological Research Group, President of the Geographical Association, and President of the International Association of Geomorphologists. He is the author of *Discovering Landscape in England and Wales* (1985), *The Landforms of England and Wales* (1990), *Great Warm Deserts of the World* (2002), *Great Desert Explorers* (2016) and *The Human Impact* (2018).

Piotr Migoń is Professor of Geography at the University of Wrocław, Poland. His principal subject of research is rock control in geomorphology. Other explored issues include weathering, mass movement in mountain terrains, and long-term landform evolution. The Sudetes Mountains in Central Europe are his main research area, but he was also involved in projects in other European countries (Czechia, Sweden, Great Britain, Portugal), in the United States, Mexico, China, Korea, Jordan and Namibia. In 1997–2001 he served as the Secretary of the International Association of Geomorphologists, was IAG Vice President in 2009–2013 and is currently the member of Executive Committee. His publication record includes *Granite Landscapes of the World* (Oxford University Press, 2006), a textbook on geomorphology published in Poland (2006), and more than seventy papers in international peer-reviewed journals, including *Geomorphology*, *Catena*, *Earth Surface Processes and Landforms* and *Earth-Science Reviews*. Since 2013 he has been Series Editor of *World Geomorphological Landscapes* book series (Springer Nature).