

A CONCEALED SEA CLIFF AND LOW-STAND WAVE-CUT PLATFORM ON THE ISLE OF PORTLAND, DORSET, UK

R. W. GALLOIS



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A topographical feature at the foot of an extensive landslipped area on the Isle of Portland, which appeared at first sight to be the back-face of a small coastal landslide, was proved by continuously cored site-investigation boreholes to be the top of a concealed c. 35 m-high cliff in Kimmeridge Clay that is fronted by a wave-cut platform at c. -20 m below present-day sea level. The platform is overlain in part by sand and gravel which is interpreted as a beach or shallow marine deposit. The cliff and wave-cut platform are now concealed beneath Pleistocene solifluction and landslide deposits of presumed late Pleistocene age. Comparison of the height of the Portland wave-cut platform with those of submerged wave-cut platforms and raised beaches elsewhere on the Western Approaches and English Channel coasts, some of which have been dated by amino-acid or radiometric methods, does not enable the age of the Portland platform to be determined. Differences in the rates of crustal subsidence and uplift along the English and French coasts during the past 500,000 years make it impossible to determine the heights with respect to global sea level at which the raised beaches and submerged platforms were formed. In the absence of quantitative evidence the simplest interpretation is that the Portland wave-cut platform formed in a cool temperate climate during a still-stand period when sea level was falling, possibly in the early cooling phase of Marine Isotope Stage 5, c. 110,000 years ago.

92 Stoke Valley Rd., Exeter EX4 5ER, U.K.
(E-mail: gallois@geologist.co.uk).

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INTRODUCTION

A closely spaced pattern of continuously cored boreholes was drilled to investigate the ground conditions beneath and adjacent to a proposed underground gas-storage site on the Isle of Portland (Figure 1). The Upper Osprey site, formerly Ministry of Defence, on the north east coast of the island is underlain by artificial (Made Ground) and natural (Head and Landslide Deposits) Quaternary deposits (collectively referred to as Drift Deposits on British Geological Survey maps) which wholly conceal the outcrop of the Kimmeridge Clay Formation. The Made Ground consists of waste from extensive Portland Stone quarries on the plateau that overlooks the site, and locally sourced materials which have been shaped into embankments and levelled areas. The Head and Landslide Deposits include large blocks of Portland Stone derived by toppling failures from the cliffs above the site, and laterally and vertically variable landslide and solifluction materials. The site-investigation boreholes drilled onshore and in the adjacent offshore area proved Drift Deposits ranging from 1 to 28 m in thickness. These have been interpreted as four types on the basis of their distribution and lithology (Gallois, 2007):

- 1) Translational landslide deposits derived from the Portland Group: fine-grained sand and silty sand with angular limestone clasts ranging from granule size to blocks up to 10 m across; well exposed in sea cliffs adjacent to the site.
- 2) Solifluction and/or translational landslide deposits derived from the Portland Sand and the highest part of

the Kimmeridge Clay: sandy and silty clay matrix with mostly small- and medium-sized siltstone clasts.

- 3) Solifluction and/or translational landslide deposits derived from the Kimmeridge Clay and reworked Portland Group debris: grey clay matrix with common small- and medium-sized siltstone, limestone and sandstone clasts.
- 4) Solifluction/mudflow deposit derived wholly from the Kimmeridge Clay: grey clay with few or no clasts.

DESCRIPTION

The Quaternary Deposits at the Upper Osprey site can be divided into two distinct groups based on their distribution and thickness. In the middle and upper parts of the site, uphill from a well defined change in slope angle (Figure 1) that is interpreted here as the top of a concealed cliff (see below), the Drift Deposits form a relatively thin (1.0 to 9.5 m thick) undulating sheet-like deposit made up of lenticular layers of drift types (1) to (3) that roughly mimic the shape of the ground. They represent successive mudflow and translational landslide deposits that moved across the top of the Kimmeridge Clay. At their base, they locally rest on a layer of *in situ* complexly folded Kimmeridge Clay with dips of up to 75°. This and similar structures in Lias Group mudstones at Lyme Regis and Seatown in west Dorset have been interpreted as creep folds that formed intermittently in partially frozen, near-surface

layers in a periglacial climate in the Pleistocene (Gallois, 2010). The Quaternary Deposits beneath the lower part of the site and the adjacent offshore area are markedly thicker (18 to 28 m) and more Kimmeridge-Clay rich than those beneath the middle and upper parts of the site. They comprise interbedded silt-rich (types 2 and 3) and clay-rich (type 4) deposits, the last of these being confined to that area.

The change in thickness and gross lithology of the Quaternary Deposits takes place along the line of a marked topographical break (Figure 2) with gently sloping ground (<math><5^\circ</math>) on the landward side and slopes of up to c. 18 to 20 m below Ordnance Datum (O.D.) which is interpreted here as a former wave-cut platform (Figure 2). Sand and gravel was recorded by

the driller in several of the cored offshore boreholes resting on undisturbed *in situ* Kimmeridge Clay, but this was mostly retrieved as loose gravel or was lost during drilling. The core samples from one borehole (OBH 3) comprised a dark grey, Kimmeridge Clay-rich solifluction deposit with small limestone and siltstone clasts resting on fine- and medium-grained sand with small angular shell fragments. This in turn rested on fine gravel and coarse sand with well-rounded pebbles and small angular chert and limestone clasts which passed down into larger limestone, siltstone and chert clasts in a loose sand matrix which rested on unweathered Kimmeridge Clay. The sand with shell debris is interpreted as a beach or intertidal deposit. Loose samples from Borehole OBH 1 included silty clay with angular shell fragments and rounded pebbles that were presumed to rest on *in situ* Kimmeridge Clay, and a core loss immediately above the Kimmeridge Clay in Borehole OBH7A was presumed to be in sand and gravel.

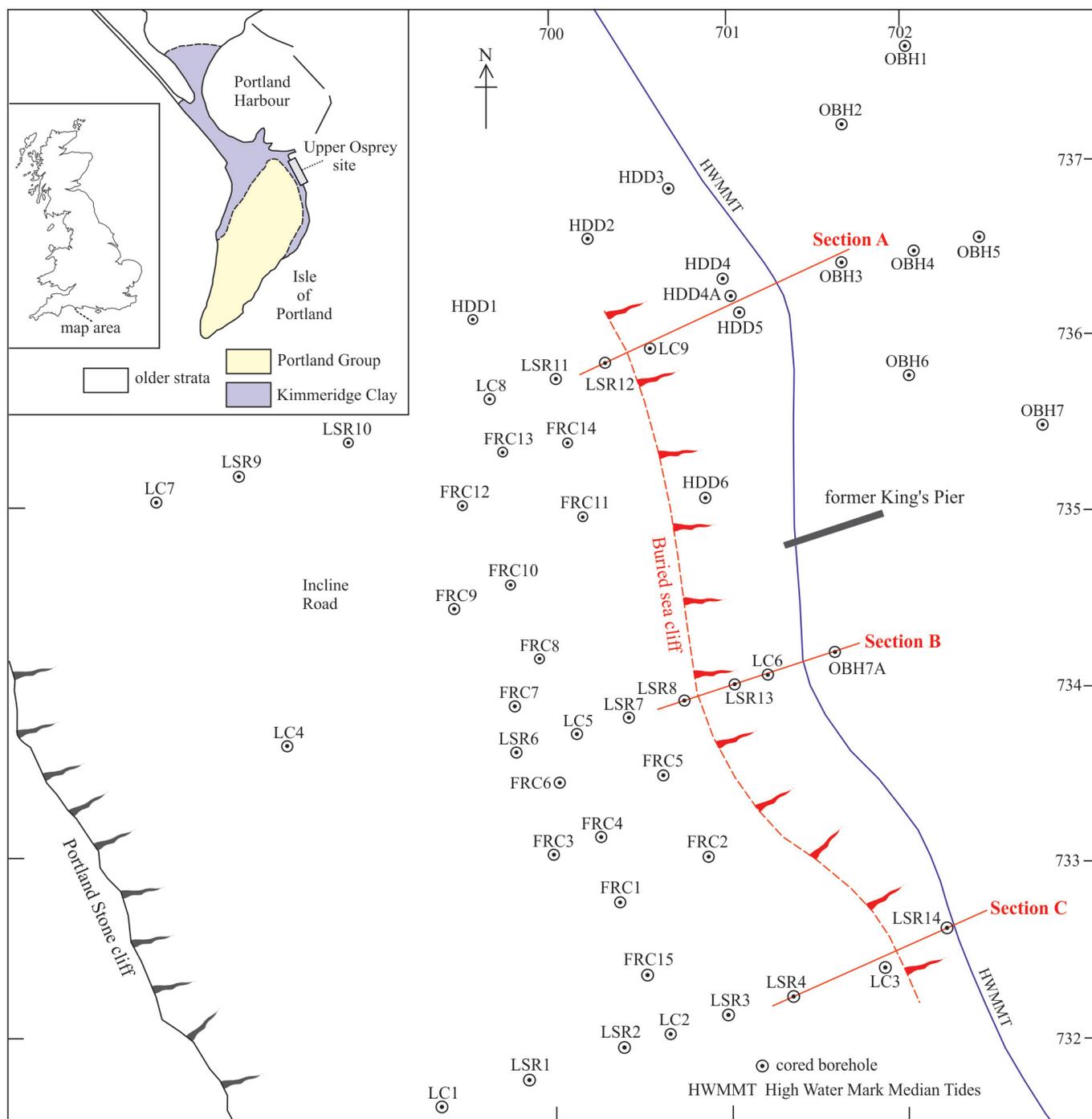


Figure 1. Upper Osprey site map showing the positions of the cored boreholes, buried sea cliff and sections referred to in the text.

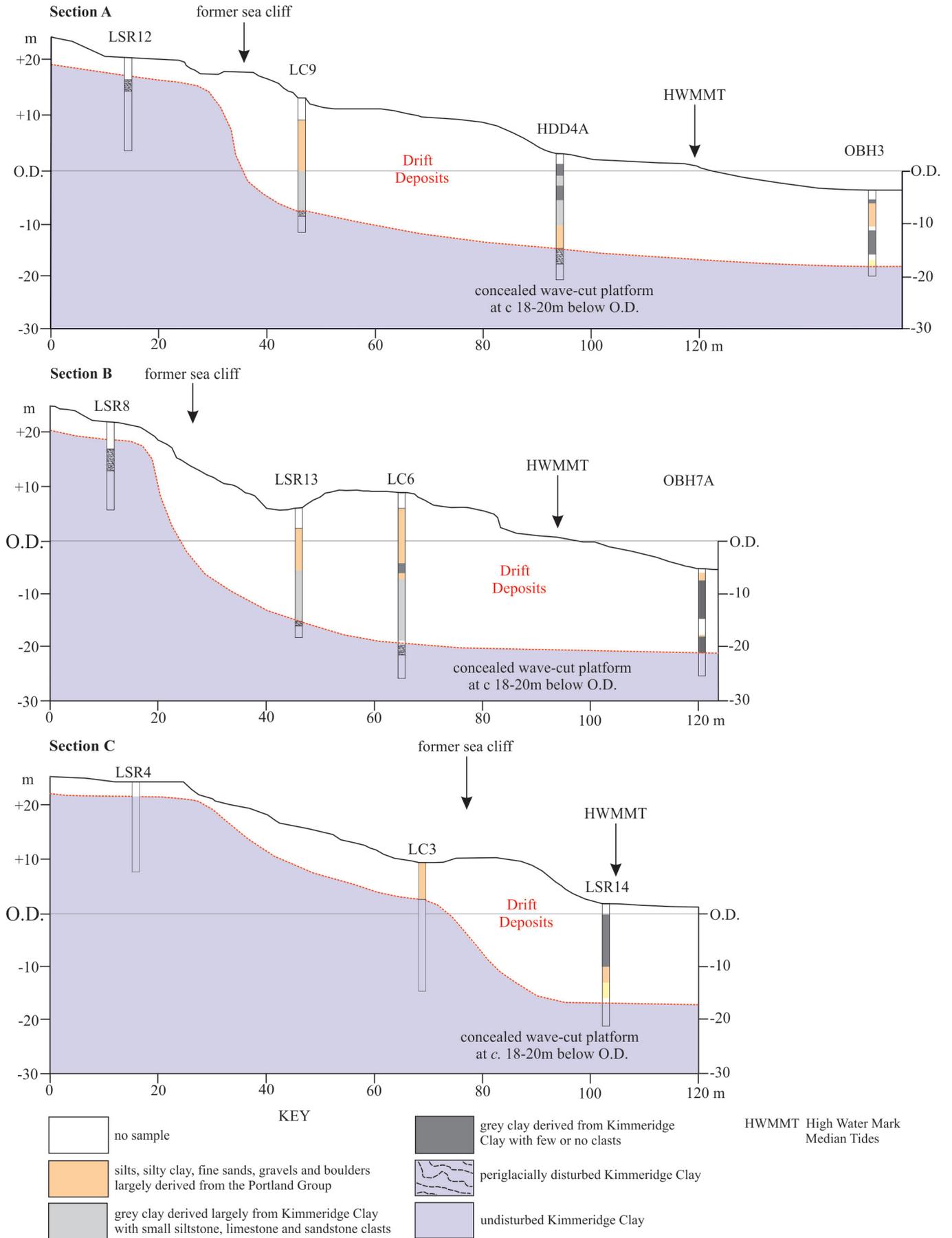


Figure 2. Sections across the concealed cliff: no vertical exaggeration. See Figure 1 for lines of sections.

DISCUSSION

Evidence of Quaternary sea levels in the form of submarine and uplifted wave-cut platforms, the latter with and without overlying marine beach deposits, is relatively common on the coasts of the Western Approaches and English Channel where such features are largely protected from Atlantic storms. There are published descriptions of raised beaches at heights ranging from 1 to 40 m above O.D. on the English and French coasts, some of which have been correlated with Marine Isotope Stages (MIS) as far back as MIS 13 (c. 500 ka BP) by amino-acid or radiometric dating and/or biostratigraphy. In South-West England they include shelly raised-beach deposits between Hallsands (MIS 5e) and Start Point (MIS 7) in Start Bay (Bates *et al.*, 2003), Cornwall, and at Thatcher Rock (MIS 5e), Hope's Nose (MIS 7) and Berry Head (MIS 5e, 7 and 9?) in Torbay, Devon (Proctor and Smart, 1991). On the French coast, Coutard *et al.* (2006) recorded raised beach deposits in Normandy at heights of 1 to 38 m above the Nivellement Général de la France (NGF) which they correlated with the high sea levels of interglacial phases in MIS 5, 7, 9 and 11. On the Isle of Portland, Dorset shelly raised-beach deposits exposed at Portland Bill at heights of c. 8 m [SY 6774 6828] and c. 14 m above O.D. [SY 6755 6860] were determined by Davies and Keen (1985) to be 125,000 (MIS 5e) and 210,000 (MIS 7) years old respectively using amino-acid dating.

Cliff-like breaks of slope that have been interpreted as former wave-cut platforms were recorded by Kelland (1975) at 54 m and 65 m below O.D. in Start Bay, and a submerged cliff line with a base at c. 40–45 m below O.D. has been recorded around much of the SW coast with the buried offshore extensions of the channels the Rivers Plym, Tamar and Taw-Torridge graded to it (Donovan and Stride, 1975; Kidson, 1977; Eddies and Reynolds, 1988). There is no direct evidence of the age of the sea-level still-stands at which any of these submerged cliffs were formed.

Despite the relative abundance of evidence, the history of changes in relative sea-level (RSL) with respect to land level in southern England and northern France during the Quaternary remains poorly understood because of the geographically fragmentary nature of the evidence and the complex history of land-sea movements. Global (eustatic) sea level is principally governed by the volume of the sea and its temperature, both of which changed more rapidly in the Quaternary in response to fluctuations in global temperatures than at any time since the Permian. Local sea levels are governed by a combination of eustatic changes, isostatic depression and uplift in and adjacent to those areas overlain by continental ice sheets, epeirogenic (crustal underplating) and tectonic (orogenic) crustal movements. In the coastal areas of South-West England, the effects of glacial isostatic rebound can be ignored from the Mid Pleistocene onwards as there is no reported evidence for a thick continental ice sheet south of the maximum extent of the Anglian Glaciation (MIS 12), 100 km north of the Channel coast. Epeirogenic movements related to basaltic underplating beneath the western British Isles have also been hypothesised as a cause of differential uplift in the Pleistocene in SW Britain (Westaway, 2010), but the evidence for neither the underplating nor the presumed Quaternary movements is well documented at the present time.

During the last 40 years estimates of the maximum amount of global sea-level change in the Quaternary has remained relatively unchanged at c. 120 m \pm 5 m (Donn *et al.*, 1962; Muhs *et al.*, 2003). In contrast, even within southern Britain there are variations of several hundred metres in the present-day heights of Middle and Late Pleistocene near-shore marine and freshwater deposits principally as a result of compressional and extensional movements related to changes in the tectonic stress field consequent on the continuing collision of the European and African Plates and the opening of the Atlantic Ocean. These movements affected relative sea levels across southern Britain unevenly in the Quaternary when existing fault lines were reactivated to a greater or lesser extent. For example,

freshwater peats in the Bardsey Loom Formation (MIS 13 c. 550 ka) are at 300 m below O.D. in the Celtic Sea (Tappin *et al.*, 1994) and their probable correlatives at over 400 m below O.D. beneath the southern North Sea (Cameron *et al.*, 1992). Their presumed onshore correlatives, the Cromer Forest Bed Formation in Norfolk (Trimmer, 1851) and the Slindon Formation in Sussex (Prestwich, 1859), are at c. O.D. and 35–40 m above O.D., respectively. If the correlations are correct and if these formations were deposited close to sea level as indicated by their sedimentology, the difference in RSL attributable to tectonic movements greatly exceeds that attributable to eustatic changes in global sea level. None of the topographical heights at which the Pleistocene beach deposits and wave-cut platforms in the SW region are preserved can therefore be used independently as a guide to their ages.

In a comprehensive review of variations in Quaternary sea-levels on the Atlantic, Pacific, Gulf, Arctic and Hawaiian coasts of the USA Muhs *et al.* (2003) compared local rates of uplift and/or subsidence of datable beach deposits and coral reefs to obtain a global sea-level curve for the past 500 ka. No comparable study is available for the Pleistocene of the UK largely because of the scarcity of reliably datable deposits. However, different rates of RSL change in the Holocene over distances (<100 km) that are too small to have been affected by eustatic, isostatic or epeirogenic movements have been recorded by Shennan and Horton (2002). They concluded that the relative rates of sea-level rise over the last 4,000 years had been 0.63 mm year⁻¹ for the Sussex coast, 0.49 mm year⁻¹ for the Dorset coast and 1.43 mm yr⁻¹ for the Devon coast. World-wide studies have shown that global sea level has risen by c. 2 m or less since 4,000BP (Fleming *et al.*, 1998). The fall in RSL that can be attributed to tectonism is therefore close to zero for the Dorset coast (0.49 minus 0.5 mm year⁻¹) and 0.93 mm year⁻¹ (1.43 minus 0.5 mm year⁻¹) for the Devon coast during this period. If a similar differential rate had been present over the past 10 ka, then a wave-cut platform formed on the Devon coast in 10 ka BP would now be c. 9 m lower than a platform formed at the same time on the Dorset coast. The most likely explanation for this difference over so short a distance is that the active Sticklepath Fault separates tectonic terranes that are subsiding at different rates. This is reflected in the drainage patterns in the region in which all the major rivers west of the fault (Dart, Tamar, Fowey, Fal) enter the sea via drowned valleys while those to the east of the fault (Teign, Exe, Otter, Axe) enter via sediment-filled estuaries. When allowance is made for the high degree of uncertainty and probable large errors in measuring past rates of RSL, it is clear that the present-day topographical positions of raised beaches and wave-cut platforms are not a reliable guide to former global sea levels.

SUMMARY AND CONCLUSIONS

In the absence of quantitative data, the age of the submerged wave-cut platform and the associated beach deposits and concealed cliff on the Isle of Portland are unknown. Assuming that the only factor that has affected their present position with respect to RSL are eustatic variations in sea level, then these features were formed either in a still-stand period during a period of rising sea level in a warming phase or during a fall in sea level during a cooling phase. These conditions were most recently present in MIS 1 at c. 10 ka BP when sea level was rising and in MIS 5 at c. 110 ka BP when it was falling. The former is not a possibility because the cliff and wave-cut platform are overlain by periglacial deposits that could not have formed in southern England after the end of the Pleistocene Period (11.7 ka BP; Williams, 1965). The simplest assumption is that the wave-cut platform was formed early in MIS 5 in what would have been a cool temperate climate following the warm temperate climate of MIS 5e. The following succession of events (Figure 3) is suggested:

Phase 1, MIS 5d: stable cliff line and wave-cut platform develop during a still-stand period in a falling sea level in a cool temperate climate. After a period of warm temperate climate

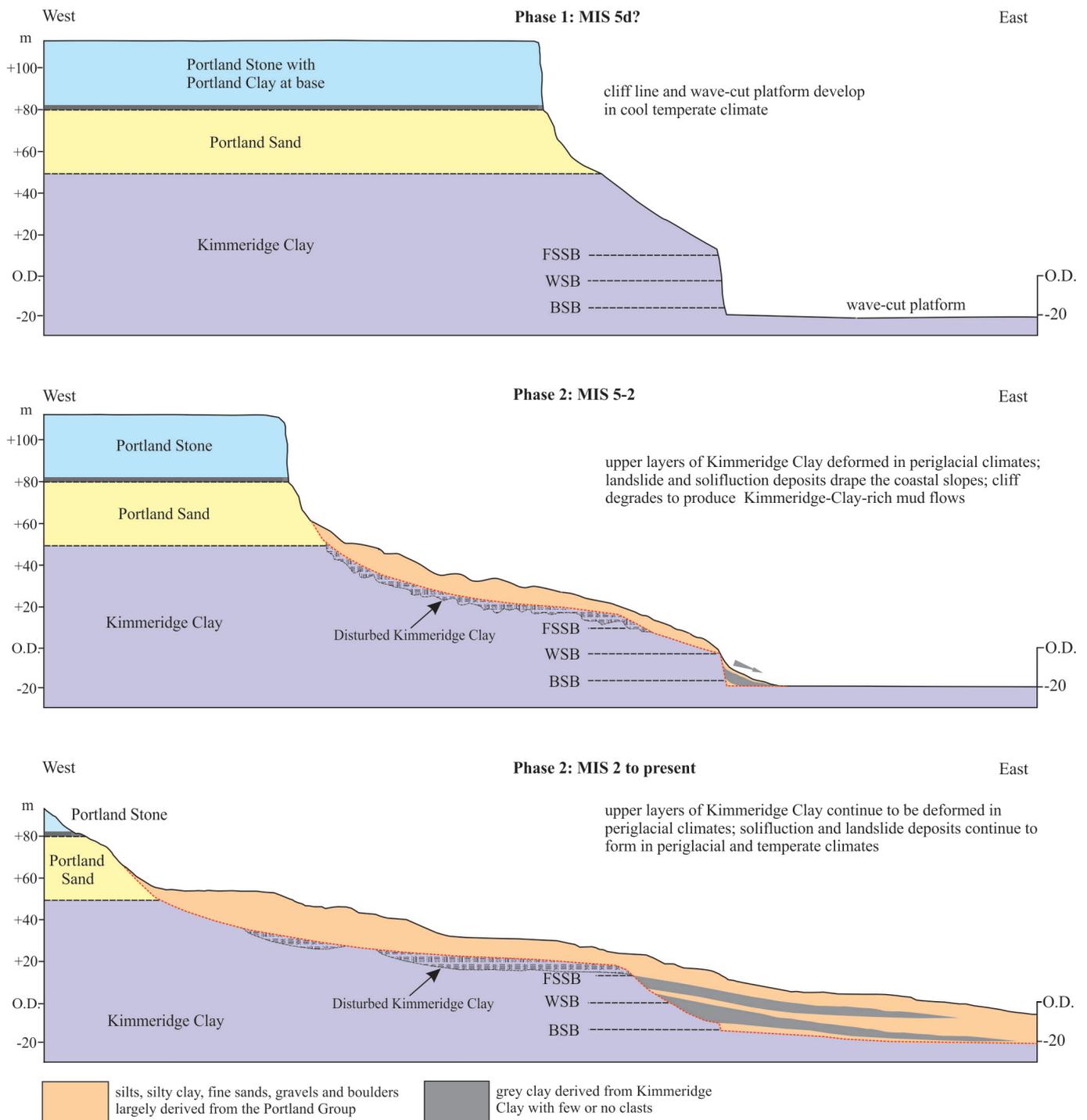


Figure 3. Sketch sections to illustrate the possible mechanisms for the formation of the concealed cliff, Head Deposits and disturbed Kimmeridge Clay at the Upper Osprey site. BSB = Basalt Stone Band, WHB = White Stone Band, FSSB = Freshwater Steps Stone Band.

and high sea level in MIS 5e during which the superficial deposits of earlier periglacial climates were removed, the cliff profile would have been similar to that of the present-day at Chapman's Pool [SY 955 770], Dorset. There, Kimmeridge Clay mudstones with strong limestone bands (Basalt Stone Band, White Stone Band and Freshwater Steps Stone Band at the same stratigraphical level as that at the Upper Osprey site) form vertical cliffs. The weaker, higher parts of the formation and the Portland Sand Formation form steep slopes overlain by near-vertical cliffs of Portland Stone Formation.

Phase 2, late MIS 5 to MIS 2: rock-block landslides in the Portland Stone Formation and the collapse of the Portland Sand Formation are initiated by failures in the Portland Clay Member in periglacial climates; landslide and solifluction deposits drape

the slopes and over-ride the sea cliff; the upper layers of Kimmeridge Clay become deformed in periglacial climates; the cliff degrades to produce Kimmeridge Clay-rich mudflows.

Phase 3, MIS 2 and MIS 1: the upper layers of Kimmeridge Clay continue to be deformed in periglacial climates and solifluction and landslide deposits continue to form in periglacial and temperate climates.

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