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The Southwell Topple – reassessment of a very large coastal toppling failure on the Isle of Portland

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Key words: n/a

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Abstract

The Southwell Topple is a spectacular example of a toppling failure on the southeastern coastline of the Isle of Portland, on the south coast of England. Types of mass movements, which occur around almost the entire coastline of Portland and include some other much smaller but well-known topples, vary depending on local geological and topographic contexts. The 'Southwell Landslide' of 1734 (i.e. the Southwell Topple), differs in most respects from all the others, not least in its size. We examine the historical and geological contexts of the Southwell Topple in order to explain its origins and characteristics. The recently published bathymetric data from the DORIS project reveals the tectonic context for the landslide, particularly the frequent transform faults parallel to the southeastern coastline of Portland and the axis of the Shambles Syncline forming Portland's 'central depression'. It appears that the Southwell Topple resulted from coast-parallel tectonic discontinuities – probably a single joint and/or transform fault – through the Portland Stone combined with preferential marine erosion of the underlying weaker Portland Sand.

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Toppling failures are generally not well known in the British Isles. De Freitas and Watters (1973) described some examples from North Devon, South Wales and the West Highlands of Scotland, and very small topples have been recorded along parts of the east coast of England (BGS 2020a).

However, the Isle of Portland, on the south coast of England, displays probably the best known and most accessible toppling failures among its landslide-dominated coastal landscapes. These include what is probably the largest topple in the British Isles, the Southwell Topple, a spectacular example of this type of mass movement (Fig. 1). The aim of this feature is to present the characteristics of the Southwell Topple, including its geological and indeed historical contexts, in order to be able to explain its appearance and likely origins. The latter, in particular, appear to relate to geological features revealed by recent bathymetric data that support new hypotheses concerning structural controls on the Isle of Portland's coastal landslides.

The Isle of Portland forms part of the UK's 'Jurassic Coast' World Heritage Site (JCT 2020). It lies just south of Weymouth, separating Lyme Bay from Weymouth Bay and Purbeck (Fig. 2). Portland is not a true island in that the barrier beach known as Chesil Beach (which is technically a tombolo) connects its northwest corner to the mainland, although Portland may have been a true island at some time in the past. It is effectively a gently southward sloping layered block of Jurassic rocks 6 km long and up to 2.5 km wide, up to around 140 m high at the northern end and descending almost to sea level at Portland Bill in the south.

More than one third of the land area of the Isle of Portland is affected by landslides and other types of mass movements, mostly around the circumference (Fig. 3). Those on the extreme north of the island, beneath the former Naval Base and under the village of Chesilton, are very deep-seated with basal slip surfaces well below present sea level (seated in the Kimmeridge Clay in some cases). Along the northeast-facing coastline compound slides dominate (Fig. 4), sometimes with basal shear surfaces at a higher level (Brunsden *et al*. 1996), but much of the landslide morphology has been obscured by quarry waste dumped over several hundred years (Privett 2019). Where the rear scarps of such landslides are high and formed in Portland Stone (i.e. the unit commonly referred to as 'Portland Limestone'), small toppling failures are relatively common, leading to cliff falls and formation of scree slopes. The latter can be seen more clearly along the northwest coast at West Weare (Fig. 5) where marine erosion maintains steeper slopes below the upper cliffs (Fig. 3). In a few places small but complex zones of instability have required engineering interventions, such as realignment of the main road up to the Portland plateau at Priory Corner, above the northern end of West Cliff at West Weare (Pugh *et al*. 2000). However, the Southwell Topple (Fig. 1) is unique even for the Isle of Portland.

Description and historical context

The Southwell Topple probably occurred in 1734 (Fig. 9 in Brunsden et al. 1996), although published accounts are not entirely consistent in this regard. Indeed, a brief description of the 1734 landslide in Brunsden et al. (1996, p.222) seems to refer to a completely different location! Nevertheless, it is a multiple toppling failure which, despite being modified by some quarrying and deposition of quarry waste, is still accessible and provides an excellent example of its type. Parts of the original displaced block are clearly visible in Google Earth at 050°32'04"N, 002°25'57"W (UTM 540225 mE, 5598220 mN) and 050°32'11"N, 002°25'51"W (UTM 540340 mE, 5598420 mN), these two sections corresponding with Brunsden et al.'s (1996, Fig. 16) 'Southwell landslip' and 'Great Southwell landslip' respectively (Fig. 6). The earliest map that we have found, dating from 1710, shows that the village of Southwell already existed, probably as a hamlet of no more than a few houses, but the map unsurprisingly lacks any details. The first edition of a large scale Ordnance Survey map was not produced until more than a century after the landslide supposedly occurred, but the '1860s' edition (possibly the first for this location, exact date unknown) clearly shows there to have been a recognisable single block more than 300 m long parallel to the coast and around 15 m wide (Fig. 7). Outward rotation of this block created a 10-15 m wide 'chasm' upslope of the block along much and possibly all of its length (Fig. 8).

The exact northern extent of the topple is unclear from the 1860s map although it seems to correspond with the features visible in Google Earth at 050°32’14”N, 002°25’47”W (UTM 540409 mE, 5598520 mN) near Church Ope Cove (Fig. 6). As an aside, it is not known whether ‘Ope’ (as shown on all modern maps) may be simply ‘Hope’ with a dropped ‘h’, or some dialect word the meaning of which has become lost. Some maps show that the surveyors clearly considered the former to be the case. The southern end of the topple block was very clearly defined on the 1860s and 1900s maps: the block did not extend as far south as the present car park, instead ending at about 050°32’02”N, 002°25’59”W (UTM 540180 mE, 5598146 mN). The early surveyors marked a very prominent ridge parallel to the coast and labelled it as the ‘Southwell Landslip’ (Fig. 7). Later editions of the mapping show progressively less detail as quarry waste increasingly covered parts of the site, leading to the present condition of the site as shown in Fig. 6.

In the late 19th century a railway was built from Weymouth to Easton (1 km NW from Church Ope Cove) to transport the limestone extracted from the rapidly expanding quarries of northern Portland to the markets, particularly London. By the time of the survey for the 1900s map (i.e. dating from between 1900 and 1909) a branch line had been constructed from Easton to the top of the cliffs above the Southwell Landslide to facilitate the removal and dumping of overburden and other waste from the quarries. Initially this branch line extended to 050°32’07”N, 002°25’56”W (UTM 540235 mE, 5598300 mN), i.e. where the main footpath now provides access from the road towards the lower cliffs (identified by ‘A’ in Fig. 7). By the time of the 1920s map the railhead had been moved back to 050°32’12”N, 002°25’53”W (UTM 540290 mE, 5598460 mN) (‘B’ in Fig. 7), much of the middle part of the topple having been buried, the chasm infilled (Fig. 9) and, in one part, a section of the topple block removed for some reason (indicated in Fig. 6) – serendipitously providing an excellent cross-section for contemporary visitors!

The earliest map (Fig. 7) shows the main topple block to have probably been almost continuous in appearance throughout its significant length. Closer field inspection shows the main topple block to comprise two or more sub-parallel slices with a dip-and-fault differential movement (Figs. 1 and 10). Not clear from any of the maps is that other slices with greater rotations are visible seaward of the prominent feature shown on large-scale OS maps (Figs. 11 and 12), although these are not persistent throughout the length of the main block. These more seaward topples are subsided further than their additional degrees of rotation alone can account for, and comprise different numbers of densely fractured 'columns' along the length of the failure. In many respects the overall form and character of much of the Southwell Topple appears to be very similar to the toppling failure in the upper Rhondda Valley as described by De Freitas & Watters (1973).

The existence of the seawards topples (Fig. 12) 'armours' the coast against wave attack to a certain degree, which means the 1734 failure cannot reasonably be *directly* explained in terms of undercutting by marine erosion. However, the relationship between the main topple block and the seaward topples requires some further consideration. We examined possible failure mechanisms for the main block of the Southwell Topple previously but, pending detailed stability and deformation modelling (requiring subsurface data), could only conclude that it was not related to any anthropogenic factors or to any sort of deformation of the Kimmeridge Clay (Dykes *et al*. 2016). We did, however, suggest that the most likely cause of the 1734 movement was 'external forcing' in the form of accumulations of rainwater and/or ice, associated with Little Ice Age climatic conditions, in coast-parallel fractures through the rock. This explanation included the movement being inhibited by the previous seaward topples, i.e. assuming they significantly pre-dated the recorded event.

What if the seaward topples were actually the initial stages of the 1734 failure event? The sea depth does not exceed 10 m until around 200 m offshore according to the 6 fathoms (36 feet or 11 metres) contour drawn in Fig. 5 of Donovan & Stride (1961). The seabed profile between the shoreline and that position – probably strongly influenced by active marine erosion during the early Holocene sea level rise – is not known but can be envisaged as meeting the toe of an active sea cliff at some point in history. The weak Portland Clay lies slightly above present mean sea level and progressively higher northwards along the length of the landslide, but this is merely the upper unit of the generally weak Portland Sand that straddles sea level throughout the site (Fig. 10). Thus the combination of (i) an unsupported toe resulting from preferential marine erosion of the Portland Sand below the Portland Limestone, (ii) a seaward dip of ~1.5° in the bedding at this location (Brunsden et al. 1996) and (iii) coast-parallel fractures through all of the rocks, could be expected to give rise to some form of instability. These geological controls are examined in the next section. Whether initial toppling failure at the toe progressively unloaded the entire slope so that the climatic 'external forcing' could bring about the major movement of the main block, or whether the latter loaded the seaward units causing them to fall outwards onto the adjacent seabed, cannot be determined due to the absence of relevant subsurface data.

The geological setting

The geological sequence of the region has been recorded on numerous occasions, and has been revised more than once (West 2019). Eastwards along the Dorset coast, Cretaceous rocks progressively and unconformably overstepped the folded and faulted Jurassic strata, with upper Cretaceous strata deposited onto an erosion surface. Subsequently, erosion has exposed the underlying Jurassic strata and structure. Originally based on lithology alone, dominant fossils were later used to refine the stratigraphy of Portland, leading to inconsistencies between schemes. A detailed account of the stratigraphy is provided by Brunsden *et al*. (1996); a widely used simplified lithology-based version (after the traditional quarrying-derived system) is shown in Fig. 10.

The cliffs along the southeast coast of Portland display the typical sequence with a variable thickness of Purbeck Beds and possibly other overburden covering the economically valuable Freestone Series of the Upper Portland Beds, commonly referred to as the 'Portland Limestone'. These are exposed in the southern block of the Southwell Topple (Fig. 8). Immediately beneath the Portland Clay, the West Weare Sandstones of the Upper Portland Sand (Fig. 10) probably coincides with sea level, with the remaining beds being mostly buried beneath displaced landslides masses and quarry waste. The top of the Kimmeridge Clay, however defined, may be more than 20 m below sea level along this part of the coastline.

The broad framework of the regional geology has been well known since, in particular, the detailed acoustic seabed survey undertaken in 1959 (Donovan & Stride 1961). More recently a high resolution bathymetric survey conducted for the 'DORIS' project (DORset Integrated Seabed study: Dorset Wildlife Trust 2019) in Weymouth Bay has been interpreted into a seamless bedrock map (Sanderson et al. 2017) available also on the BGS website (BGS 2020b). Portland lies on the southern limb of the asymmetric Weymouth and Purbeck anticline (the 'Weymouth dome'), the axis of which trends roughly east-west (Fig. 13). The DORIS mapping confirms that the Purbeck anticline is a decapitated dome structure, but shows that the dome is riven by a series of closely spaced right-lateral transform faults (some of which were identified earlier by Donovan & Stride). These are most apparent in the strata that dip towards the southern edge of the dome, but are difficult to detect where the strata are subhorizontal or obscured by later sediments. In the vicinity of the Isle of Portland, the faults are aligned with the southeast coast of the island.

It has been long known from studies in quarries, and observations at other coastal locations including Portland Bill, that the Isle of Portland bedrock is dissected by a series of subparallel open joints running dominantly NNE-SSW (e.g. Coombe 1981, cited in Brunsden *et al*. 1996). What these are has been subject to some conjecture, but we now consider it probable that the pattern of faults highlighted by the DORIS bathymetry is also present within the Isle of Portland where, due to the absence of any areas of high angle dip, they had hitherto been interpreted exclusively as a pattern of joints (e.g. Brunsden *et al*. 1996). Indeed, Donovan & Stride had suggested that the faults 'may share a common cause with the major joints in the Portland Stone on the Isle of Portland' (1961, p.308). Furthermore, we would expect to see many smaller faults associated with the mapped larger ones.

To the south and southwest of the Purbeck anticline is the Shambles syncline, the axis of which mostly trends WNW-SSE (Figs. 13 and 14). Brunsden *et al*. (1996, after Donovan & Stride 1961) show the syncline axis to turn towards the west in the NW direction, cutting across the southern tip of Portland. However, the area covered by Donovan and Stride's interpretation (1961, Fig. 2) of the westernmost extent of the Shambles Syncline was not surveyed for their study, with only around half of the seabed surveyed further south. Consequently their interpretation of this structure is couched in assumptions and probabilities. In fact, marker beds mapped in Fig. 13 form a Λ-shape almost symmetrically about the centre of northern Portland. We interpret this data, with mapped dips of the bedding, as showing the syncline axis to turn towards the north in the NW direction, i.e. up through Portland (Fig. 14) – crossing the coastline in the vicinity of the Southwell Topple. This alignment is consistent with mapped dips of bedding (Fig 2 in Brunsden et al. 1996). Privett (2019) shows both of these 'axes' as forming part of the same gentle bowl-shaped plunging syncline, but the marker beds show a more definitive feature.

This means that the depression up through the wider northern part the Isle of Portland (described by Brunsden *et al*. 1996) appears to be a structural feature of tectonic origin (Privett 2019). Our interpretation of the DORIS data is that this structure, itself part of the Shambles syncline, arises from the interference between the southwestern side of the Weymouth and Purbeck anticline and whatever was occurring further west to produce the Shambles syncline. Furthermore, taken with the absence of any geotechnical evidence for 'clay extrusion' or related mechanisms at East Weare (Privett 2019, 2020), it appears that the 'clay extrusion' hypothesis for the structural features of Portland is superceded by a tectonic explanation. Indeed, the Shambles syncline and the coastline parallel with the transform faults (or perhaps joints) intersect at an angle so they probably result from different phases of the regional tectonism, highlighting the underlying complexity of an apparently relatively simple geological context that influences or even determines the nature of the landsliding around the Isle of Portland. Conditions favouring large-scale toppling at Southwell therefore arise from the unique juxtaposition of the coast-parallel (sub)vertical planes of weakness cutting through very slightly seaward-dipping beds with down-dip support removed by marine erosion.

Conclusions

The Southwell Topple is a rather exceptional example of a brittle block topple failure, and is almost certainly the largest example of a topple in the British Isles. Most such failures involve a column of rock creeping towards a stability threshold beyond which accelerating outward rotation leads quickly to catastrophic collapse. At Southwell, a significant and relatively rapid movement occurred that involved a topple of limited rotation and overall displacement, but this may have been simply the final phase of a much larger and longer-lasting toppling failure, i.e. following this general pattern. It occurred along a stretch of coastline where the upper cliffs are parallel to the alignment of the mapped transform faults northeast of Portland, as revealed by the DORIS bathymetry, and where the relatively weak Portland Sand constitutes the seabed and (including the Portland Clay) the foot of the coastal slope. This combination of structural preconditioning – possibly a fault plane if not a major joint – with more erodible rock than the Portland Stone at present-day sea level, does not occur anywhere else around the coastline of Portland and is superimposed on a very slight seaward dip which, incidentally, probably varies almost indiscernibly with proximity to the axis of the Shambles Syncline. Toppling occurs in numerous other places on Portland particularly where there are much higher cliffs of Portland Stone overlying weaker beds (Fig. 15) – but nowhere near on the same scale or extent as in the Southwell Topple.

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Author contributions **APD:** conceptualisation (supporting), writing – original draft (equal + all photos), writing – review & editing (lead); **ENB:** conceptualisation (lead), writing – original draft (equal + all drawn maps/diagrams), writing – review & editing (supporting)

Conflict of interest The authors declare no known conflicts of interest associated with this publication.

Data availability statement Data sharing is not applicable to this article as no datasets were generated during the current study.

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Figure 5. Small toppling failure developing in the Portland Stone at West Weare, Isle of Portland.

Figure 6. Oblique aerial view of the Southwell Topple looking north. The two currently visible sections of the main topple block are labelled *sensu* Brunsden et al. (1996). © Google Earth (2020), image date 26 May 2017.

Figure 7. Extract of the Ordnance Survey map from the 1860s showing the Southwell Topple as a distinct continuous block. The red line indicates the railway that was built later to bring waste from the quarries for disposal by tipping over the cliffs. Initially, in the 1900s, the railway was built to point 'A' but by the 1920s it had been cut back to 'B'. Distance A to B is approximately 200 m. © Crown Copyright and Landmark Information Group Limited (2020). All rights reserved. Image quality is that of the digitised materials made available by Digimap (Edina 2020).

Figure 8. The Freestone Series of the Upper Portland Stone inside the chasm behind the toppled block (right) at the Southwell Landslide, Portland (view towards the north).

Figure 9. View south along the northern part of the Southwell Topple. The visible upper surface of the block is inclined at around 20° towards the sea and may have lost its cover of Purbeck Beds and overburden by sliding following the main topple event. The line of the infilled chasm is marked by the visible step in the slope above-right of centre. In the distance is God Nore, where the Cherty Series of the Portland Stone has descended to sea level to form the sea cliff and the Freestone Series has been quarried from above the cliff.

Figure 10. Stratigraphy of the Isle of Portland (after Clark 1988, Brunsden *et al*. 1996, West 2019 and cited examples therein). The Lower Purbeck and the Freestone Series of the Portland Limestone are shown as visible and surveyed at the location shown in Fig. 1(a), showing sea level at the extreme left.

Figure 11. More rotated (older?) topples seaward of the southern end of the Southwell Topple block.

Figure 12. Toppled strata along the lower cliff below the Southwell Topple block. Note the people above-right of centre for scale.

Figure 13. (a) Offshore mapping of the Weymouth Bay area produced by the DORIS project. Top: Bathymetry image, with OS Panorama topography for onshore areas. Bottom: Geological map produced from the new digital imagery. ARF, Abbotsbury–Ridgeway Fault; PF, Purbeck Fault. Source: Figure 1 of Sanderson *et al*. (2017) (slightly cropped and reorganised). (b) Extract from the interactive web viewer of the same new mapping. The Isle of Portland is the triangular 'raised slab' in the left-centre of the image. The yellow band with pink spots represents the Portland Sand, the remainder of the yellow band being the Portland Stone. The 'cm' labels refer to named beds within the Kimmeridge Clay, some corresponding with the coloured lines in (a). Image source: BGS (2020b) reproduced by permission [Permit Number CP20/049 Contains British Geological Survey materials © UKRI 2020, contains © University of Southampton material. All rights reserved, Source: (www.bgs.ac.uk/research/marine/DORIS.html)]. OS Base Map topographic information covered under Ordnance Survey Digimap licence © Crown copyright and database rights 2020 Ordnance Survey (100025252).

Figure 14. Simplified geological map of Portland indicating the new structural interpretations. The Isle of Portland is highlighted as darker versions of the stratigraphic units (represented as in Fig. 10). Large black arrows indicate measurements of dip (direction) presented by Brunsden et al. (1996). The axis of the Shambles Syncline shows two versions: black = Brunsden et al. (1996) after Donovan & Stride (1961), red = our interpretation.

Figure 15. Larger topple developing in the Cherty Beds of the Portland Stone at West Weare, Portland. The vertical displacement of around 5 m suggests that the underlying weaker Portland Sand has been crushed.

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(b)

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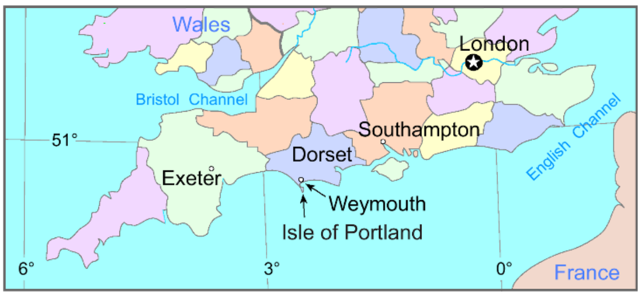

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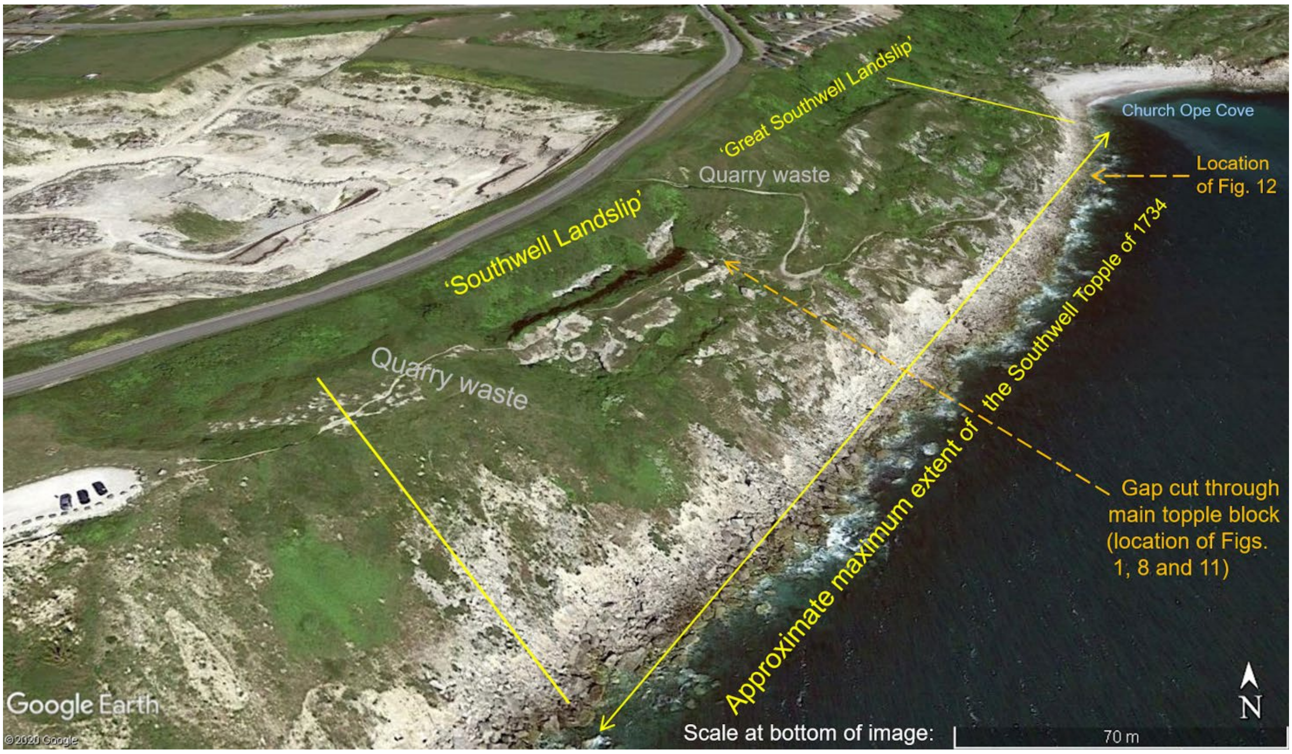


Figure 6. Oblique aerial view of the Southwell Topple looking north. The two currently visible sections of the main topple block are labelled *sensu* Brunsden et al. (1996). © Google Earth (2020), image date 26 May 2017.

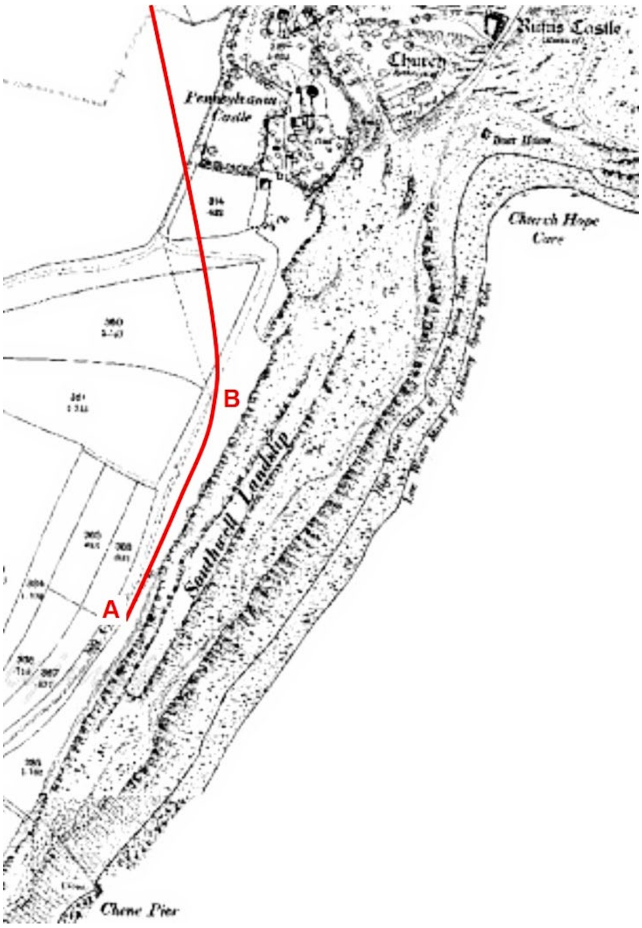


Figure 7. Extract of the Ordnance Survey map from the 1860s showing the Southwell Topple as a distinct continuous block. The red line indicates the railway that was built later to bring waste from the quarries for disposal by tipping over the cliffs. Initially, in the 1900s, the railway was built to point 'A' but by the 1920s it had been cut back to 'B'. Distance A to B is approximately 200 m. © Crown Copyright and Landmark Information Group Limited (2020). All rights reserved. Image quality is that of the digitised materials made available by Digimap (Edina 2020).

Figure 8. The Freestone Series of the Upper Portland Stone inside the chasm behind the toppled block (right) at the Southwell Landslide, Portland (view towards the north).

Figure 9. View south along the northern part of the Southwell Topple. The visible upper surface of the block is inclined at around 20° towards the sea and may have lost its cover of Purbeck Beds and overburden by sliding following the main topple event. The line of the infilled chasm is marked by the visible step in the slope above-right of centre. In the distance is God Nore, where the Cherty Series of the Portland Stone has descended to sea level to form the sea cliff and the Freestone Series has been quarried from above the cliff.

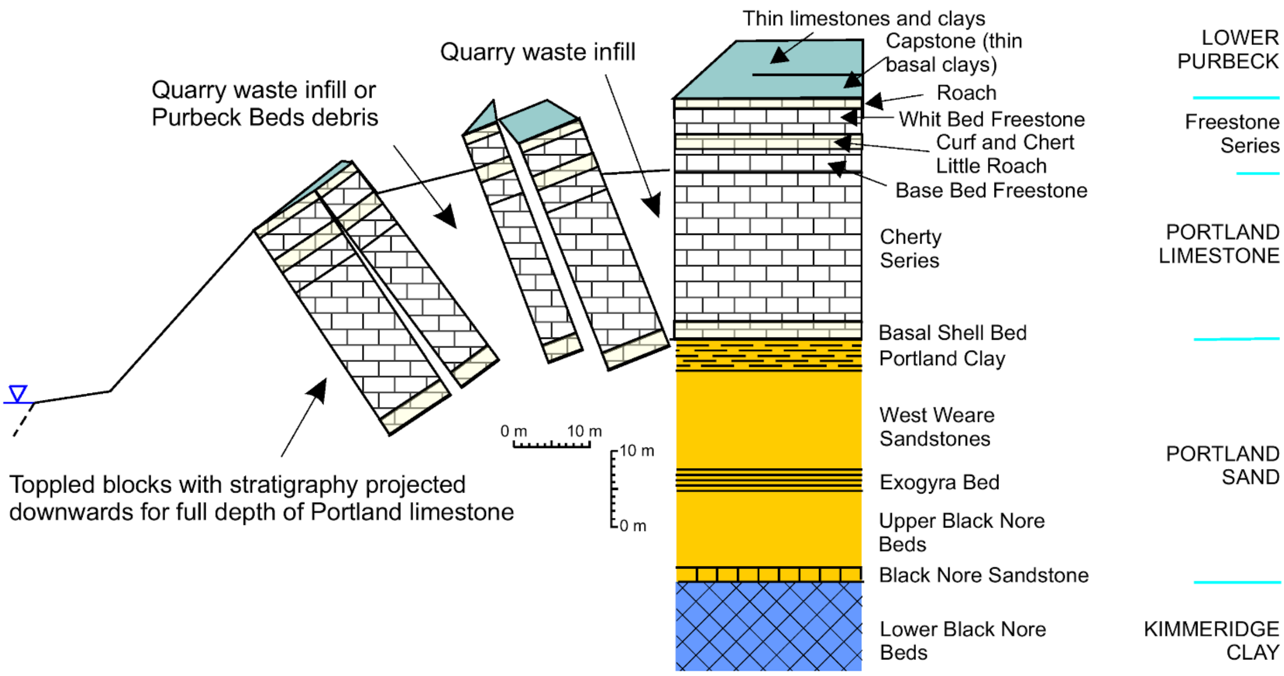
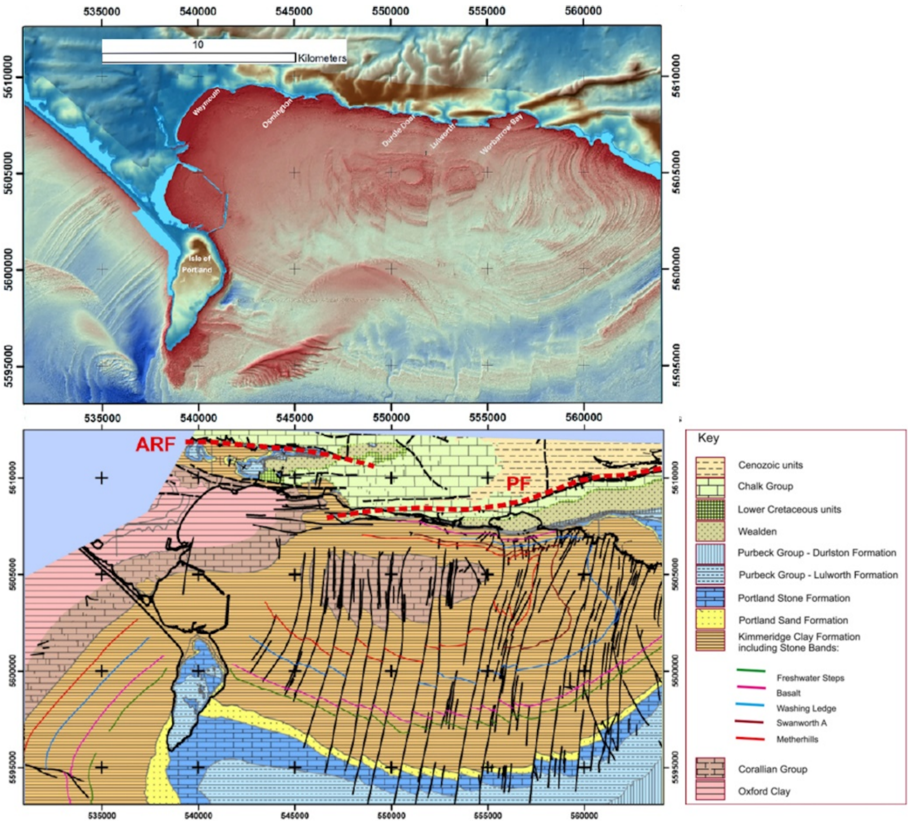


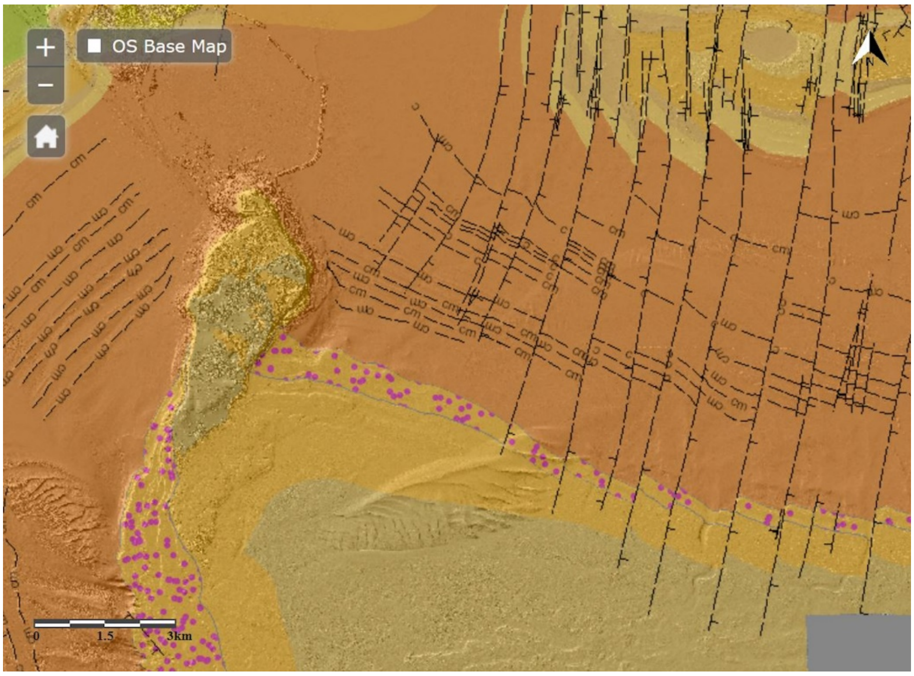
Figure 10. Stratigraphy of the Isle of Portland (after Clark 1988, Brunsden *et al*. 1996, West 2019 and cited examples therein). The Lower Purbeck and the Freestone Series of the Portland Limestone are shown as visible and surveyed at the location shown in Fig. 1(a), showing sea level at the extreme left.

Figure 11. More rotated (older?) topples seaward of the southern end of the Southwell Topple block.

Figure 12. Toppled strata along the lower cliff below the Southwell Topple block. Note the people above-right of centre for scale.



(a)



(b)

Figure 13. (a) Offshore mapping of the Weymouth Bay area produced by the DORIS project. Top: Bathymetry image, with OS Panorama topography for onshore areas. Bottom: Geological map produced from the new digital imagery. ARF, Abbotsbury–Ridgeway Fault; PF, Purbeck Fault. Source: Figure 1 of Sanderson *et al*. (2017) (slightly cropped and reorganised). (b) Extract from the interactive web viewer of the same new mapping. The Isle of Portland is the triangular ‘raised slab’ in the left-centre of the image. The yellow band with pink spots represents the Portland Sand, the remainder of the yellow band being the

Portland Stone. The ‘cm’ labels refer to named beds within the Kimmeridge Clay, some corresponding with the coloured lines in (a). Image source: BGS (2020b) reproduced by permission [Permit Number CP20/049 Contains British Geological Survey materials © UKRI 2020, contains © University of Southampton material. All rights reserved, Source: (www.bgs.ac.uk/research/marine/DORIS.html)]. OS Base Map topographic information covered under Ordnance Survey Digimap licence © Crown copyright and database rights 2020 Ordnance Survey (100025252).

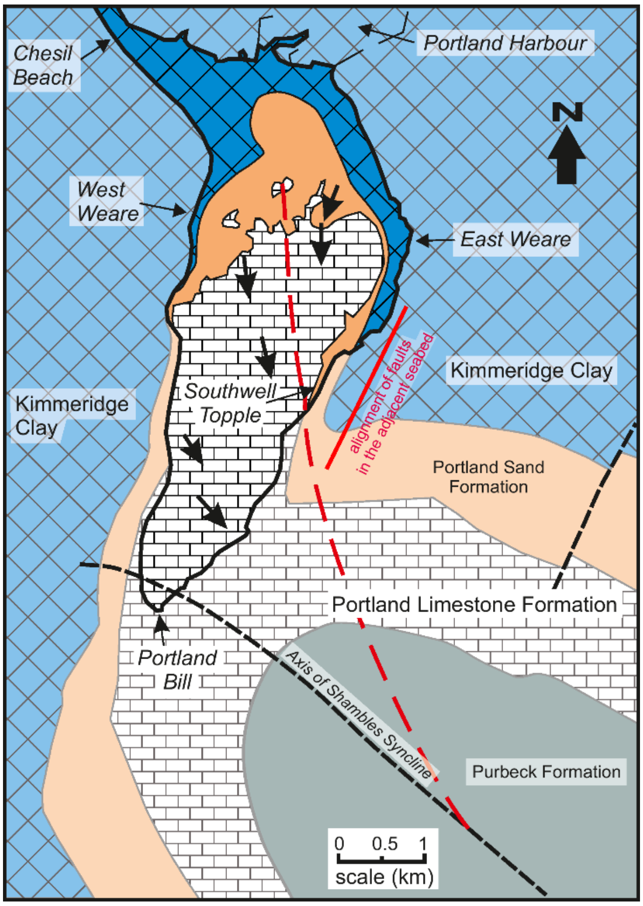


Figure 14. Simplified geological map of Portland indicating the new structural interpretations. The Isle of Portland is highlighted as darker versions of the stratigraphic units (represented as in Fig. 10). Large black arrows indicate measurements of dip (direction) presented by Brunsden et al. (1996). The axis of the Shambles Syncline shows two versions: black = Brunsden et al. (1996) after Donovan & Stride (1961), red = our interpretation.

Figure 15. Larger topple developing in the Cherty Beds of the Portland Stone at West Weare, Portland. The vertical displacement of around 5 m suggests that the underlying weaker Portland Sand has been crushed.