Field excursion to examine the sedimentology and engineering geology of Permian strata in the Torbay area, 5th January, 2015

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The purpose of the field excursion was to examine the sedimentology and engineering geology of Permian strata cropping out in the Torbay area. The trip included visits to four locations where a range of sedimentary features and engineering problems and solutions were evident.

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Introduction

The succession of rocks relevant to the field excursion is illustrated in Figure 1. At the base are the Devonian Saltern Cove Formation and Torbay Limestone Formation. The former, which has been dated as Frasnian to Upper Famennian in age, includes much mudstone and fine grained siltstone with some breccias including clasts of limestone (Leveridge *et al*., 2003), while the latter consists of grey thinly-bedded limestone with interbeds of calcareous mudstone to pale grey thickly-bedded massive limestone that has been dated to the transition between the Eifelian and Givetian stages (Leveridge *et al*., 2003).

Permian strata overlie uncomformably the Devonian rocks and form much of the succession (Figure 1). Breccias and conglomerates of the Torbay Breccia Formation, which are Early Permian in age (Cisuralian epoch), are the oldest beds of the New Red Sandstone in the Torbay area and have been interpreted as being flash flood deposits laid down in braided river systems, although evidence of aeolian deposition is also present (Leveridge *et al*., 2003). Clasts include rounded Devonian limestone, sandstone and slaty mudstone with subordinate vein quartz, hornfels, chert and quartz-porphyry, and are set in a matrix dominated by red-brown sand with subordinate silt and clay. Within the Torbay Breccia Formation is the 15-m thick Corbyn's Head Member which comprises medium to coarse grained cross-bedded sandstones, with some thin volcaniclastic beds. These sediments are purple- to red-brown to buff and pale green in colour and have been interpreted as deposits of fluvial or deltaic origin passing into aeolian environments (Leveridge *et al*., 2003).

The Mid to Late Permian Watcombe Formation overlies unconformably the Torbay Breccia Formation (Figure 1) and includes coarse to fine breccias, muddy siltstones and coarse sand. The breccias have clasts of sandstone, limestone and rarely quartz-porphyry, and 'shale-paste breccias' are developed locally which comprise decayed red slaty mudstone clasts in a clay matrix (Selwood *et al*., 1984; Leveridge *et al*., 2003). The breccias are thought to have been laid down by debris flows but the finer sediments may be streamflow deposits or those of a braidplain. At the base of the Watcombe Formation is the

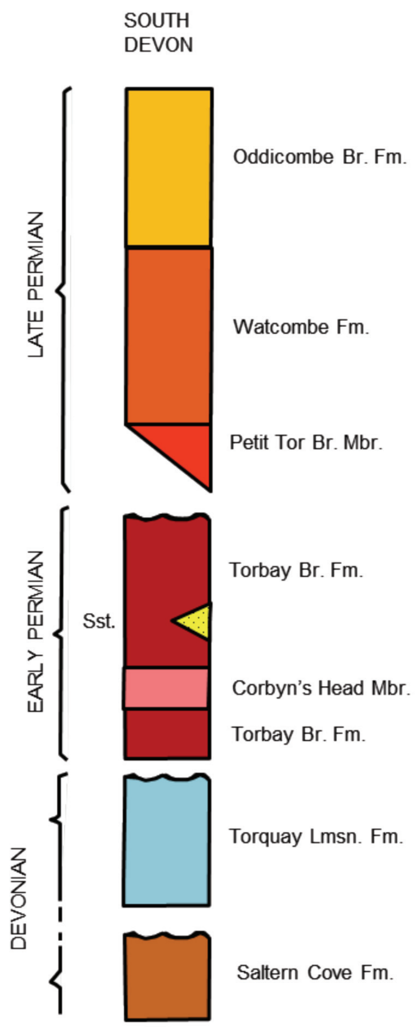

Figure 1. *Stratigraphy of rocks in Torbay area.*

Petit Tor Member that consists of large (several metres thick) blocks of locally derived Devonian limestone in a red silty mudstone matrix and has been interpreted as a local talus deposit (Leveridge *et al.*, 2003). The youngest Permian rocks comprise the Oddicombe Formation which overlies conformably the Watcombe Formation and consists of clasts of Devonian limestone, sandstone and quartz-porphry, as well as slate and arkosic (possibly Ugbrooke) sandstone suggesting derivation from the west.

The easily eroded Permian strata of the Torbay area may be susceptible to instability, and incidences of landslipping and rockfalls have been recorded especially where cliffs are steep and unprotected at their base from marine erosion.

Roundham Head [SX 896 602]

The Torbay Breccia Formation is well exposed at this locality (Figure 2) where it comprises debris flow and streamflow deposits forming part of an alluvial fan complex. Erosive channel bases, scours, cross bedding and fining up sequences from waning flows are visible, and indicate episodic deposition dominated by flash flooding from intermittent storm events. The conglomerates are dominantly matrix-supported (paraconglomerates) but clast-supported orthoconglomerates are present locally, and the lithology, although polymict, is dominated by limestone clasts.

The cliff at Roundham Head, which is 20 m high, is inclined at *c.* 50-60° (but locally much steeper) and is well vegetated, has a history of slope instability. In January 2013, following a particularly wet winter, a large, but relatively shallow, translational landslip affected the middle and upper levels. Slip debris completely blocked the promenade on the top of the sea wall at the base of the cliff. The Torbay Breccia Formation dips gently to the north and east but is dissected by relatively widely spaced, steeply inclined joints. A detailed geotechnical inspection by Frederick Sherrell Limited identified a thick crust of highly weathered rock covering the upper and mid levels of the cliff. The roots of vegetation had penetrated the crust, but larger and deeper tree roots were causing loosening of the underlying, less weathered rock. Sub-aerial erosion of weaker sandstone layers was also promoting undercutting of the stronger breccia beds.

In order to remediate the instability, the cliff was covered with a netting revetment to control soil slumping and rockfall hazards (Figure 3). The initial preparation of the cliff included cutting back vegetation, tree removal, clearance of slip debris and loose soil, and scaling with hand tools to remove loose blocks of rock. The revetment comprised a lower layer of small aperture, polyester geogrid (Fortrac 3D 40) to prevent unravelling of soil, and an upper layer of larger aperture rockfall netting (Maccaferri galvanised double twist wire netting with PVC coating) to provide additional strength. The netting was secured to the cliff using a grid of stainless steel dowels of 20 mm diameter and typically up to 2.5 m length that were drilled and grouted into the cliff face. In the west part of the site, wire cable strops were used to provide additional support to a large slender column of breccia rock, partly undermined at its base by the erosion of a weaker sandstone layer. All the products used were selected to withstand exposure to the marine environment. One of the main challenges of the project was determining the likely scope and extent of the remedial works because much of the cliff face was obscured from view by dense vegetation. During vegetation clearance several new areas of potential instability were identified including several large undercut blocks of breccia that could topple out of the face, and tension cracks where the potential for further shallow translational sliding was possible. However, these potential hazards were dealt with by minor adjustments to the planned remedial works, which extended for a total distance of about 120 m and were carried out in two phases in summer and autumn of 2013.

Figure 2. *Torbay Breccia Formation exposed at Roundham Head.*

Figure 3. *Remedial engineering works at Roundham Head.*

Preston Sands [SX 897 620]

A sandy interlayer of the Torbay Breccia Formation is exposed at this locality and represents stream dominated fan deposits and some windblown aeolian dune development. Erosive surfaces, interbeds and major bedding surfaces are evident in the cliff face (Figure 4). Ferric oxides (goethite and hematite) from the alteration and oxidation of principally biotite and ilmenite give the red colouration to the rocks (Turner, 1980; Weibel and Friis, 2004; Stel, 2009). Oxidation was controlled strongly by the Eh-pH conditions during and after burial, and under acidic conditions there is a possibility that Sr-rich alumina phosphate sulphates (APS) minerals, such as svanbergite, may form. The latter has been identified in a QEMSCAN false colour image of a rock thin section (Figure 5) from Permian strata at Shaldon Ness in south Devon, which shows these grains formed prior to deposition and may represent the reworking of red-bed deposits at the time.

Oddicombe Beach [SX 926 659]

The Oddicombe Breccia Formation has been downfaulted between Devonian limestone and shales at this locality and the deposit has a high content of rounded limestone. Although the strata are well indurated, dip of the bedding determined by original fan deposition and later tilting and faulting, together with interbeds of weaker sandstone, have made the Oddicombe Breccia Formation highly unstable, especially as bedding planes tilting towards the coastline act as conduits for water and promote slipping.

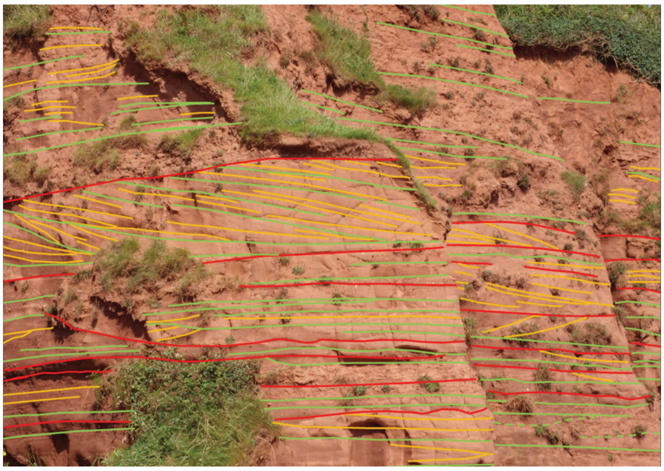

Figure 4. *The cliff face at Preston Sands looking north. Red lines = erosive surfaces, orange lines = interbeds, green lines = bedding or major surfaces.*

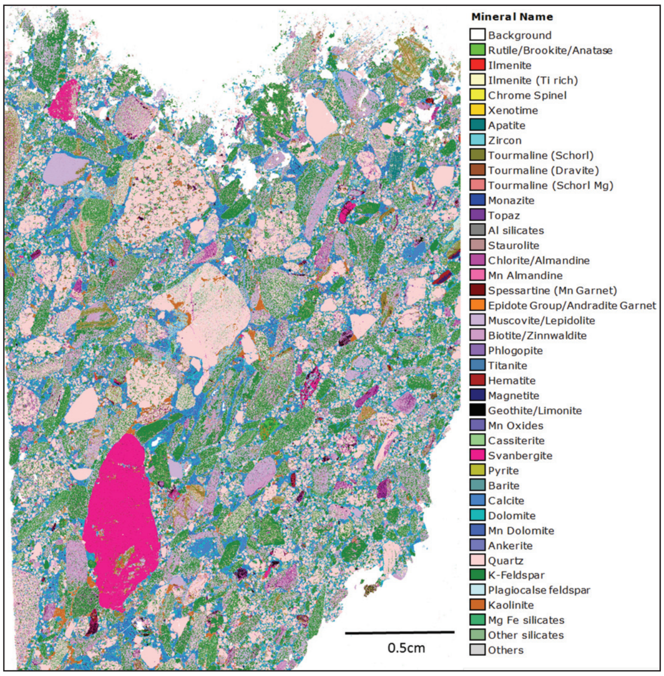

Figure 5. *QEMSCAN false colour image of a rock thin section from Shaldon Ness.*

Oddicombe Cliffs (Figure 6a), which rise to *c.* 80 m, have a history of instability (Table 1) which culminated in a massive collapse in 2013. Monitoring of the cliff had been ongoing for many years and its eventual failure was anticipated, but it was not known when this would occur. Typical signs of movement included rockfalls and the subtle changes in the appearance of cliff face, the development of cracks in hard structures

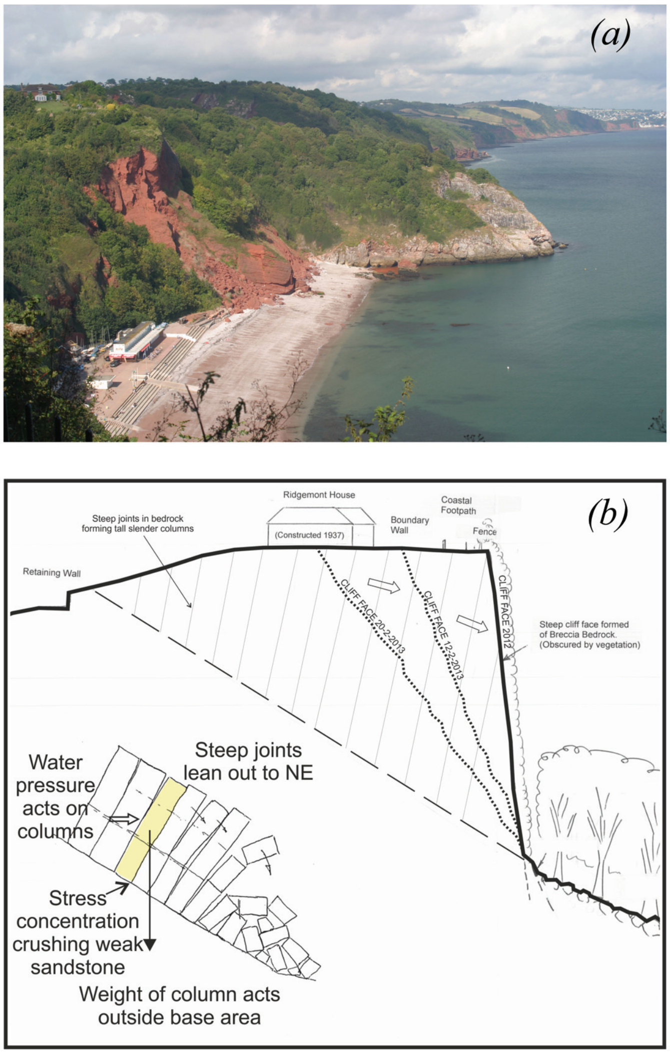

Figure 6. *(**a**) Oddicombe Cliffs in 2005. (**b**) Topple failure mechanism at Oddicombe Cliffs.*

Year	Event
1974	Rockfalls crush several beach huts
1990	Tension cracks observed at top of cliffs
1994	Large rockfall onto beach, cliff scaled and removal of 'Indians Nose'
1996	Tension cracks open up in coastal footpath at top of cliff, path repaired
1999	Large rockfall, further scaling of cliffs
2001	Numerous rockfalls, tension cracks open up, significant damage to Ridgemont House (evacuated), north end of beach and cliff top footpath permanently closed
2004	Major rockfall onto beach
2010	Major rockfall and collapse of top of cliff
2013	Massive collapse of whole cliff, Ridgemont House and gardens lost

Table 1. *Significant rockfall events at Oddicombe Cliffs.*

(buildings, garden walls, paths, etc.) and the development of tension cracks in the ground surface at the top of the cliff. Precautionary safety measures taken included closing the north end of Oddicombe Beach (and Little Oddicombe Beach), diverting the coastal footpath further inland and abandoning property at the top of the cliff.

The progressive topple failure affected a 150 m long section of the cliff in February-April, 2013. The first falls occurred at the north end of the cliff resulting in cliff-top regression of about 10 m. Later that month further falls in the same area undermined Ridgemont House. Finally in early April the remainder of the cliff to the south of the house collapsed with the loss of most of the garden. The new cliff top is now up to 50 m further inland. Most of the debris fell northeastwards onto a wooded slope and spilled out over Little Oddicombe Beach; some debris also fell onto the north end of Oddicombe Beach. The remains of Ridgemont House were demolished in 2014 and the affected areas are now permanently closed off. The topple failure mechanism (Figure 6b) is defined by two sets of steeply inclined persistent joint sets and gently dipping bedding planes. One of the joint set dips steeply towards the southwest and results in tall, slender and (in places) slightly overhanging columns in the rock mass. Within the cliff the centre of gravity of these columns acts outside its base and results in an overturning moment, but this is resisted by propping from other columns further forward. However, at the cliff face the front column is un-propped and can therefore rotate forwards and fall out of the cliff. Other factors that reduce stability include weak sandstone layers, water pressure and other hidden flaws (faults, etc.) that might be present in the rock mass.

Petit Tor [SX 926 665]

The Petitor Member of the Watcombe Formation rests uncomformably on the Saltern Cove Formation at this locality. It is dominated by limestone clasts and may reflect a collapsed karst landscape (Leveridge *et al*., 2003). The Watcombe Formation at Petit Tor is dominated by finer material with minor clast lenses and rare worm borrows (Figure 7). A marked angular unconformity between the Watcombe Formation and the Oddicombe Breccia Formation most likely represents syn-depositional fault sedimentation (McVicar Wright, 2014). The Oddicombe Breccia at this locality is relatively more stable due to more favourable bedding inclination.

Figure 7. *Rare worm burrows in the Watcombe Formation at Petit Tor.*

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