

NATURAL AND ARTIFICIAL INFLUENCES ON COASTAL EROSION AT SIDMOUTH, DEVON, UK

R. W. GALLOIS



Gallois, R.W. 2011. Natural and artificial influences on coastal erosion at Sidmouth, Devon, UK. *Geoscience in South-West England*, **12**, 304-312.

Like many small coastal towns in the UK, Sidmouth in Devon was founded on the valley sides adjacent to a river outfall that provided a natural harbour. Subsequent expansion of the town in the late 18th and early 19th centuries, when living by or visiting the sea became popular for health reasons, involved the entrainment of the river and building on land that was subject to marine flooding. Engineering works in the 19th and 20th centuries that were designed to protect the low-lying parts of the town included the construction of sea walls, and groynes and offshore bunds to protect a ridge of storm-beach gravels that acts as a natural sea defence. These works have collectively had an effect on erosion rates in the cliffs of Triassic sandstone and mudstone on the east side of the town. Natural landslide mechanisms in the cliffs adjacent to Sidmouth include rock-block and toppling failures induced by marine undercutting, and hydraulic stoping along faults and major joints at the foot of the cliffs. The principal landslide mechanism is the collapse of unconsolidated Head deposits and deeply weathered mudstones in the highest (mostly 3 to 5 m) part of the cliff. The falling material commonly destabilises the underlying well-jointed sandstones and mudstones. Artificial factors that have influenced erosion rates in the cliffs east of the River Sid outfall in the last 100 years have included the refraction of waves adjacent to the end of the river wall, and interference with the easterly longshore drift of the beach gravels. A secondary factor has been the destabilising influence of a Victorian railway tunnel that was dug parallel to and up to 25 m from the cliff face on the east side of the town. In the absence of quantitative monitoring data, published estimates of the rates of cliff erosion are significantly higher than those obtained in the present study from a comparison of maps made between 1802 and 2006.

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

Keywords: Landslide mechanisms, coastal erosion, Sidmouth, Devon, Triassic.

INTRODUCTION

The Sid Valley, and the adjacent Otter Valley to the west and the Axe Valley to the east, have developed along N-S trending fracture zones in the underlying sandstones and mudstones of the Triassic Otter Sandstone and Sidmouth Mudstone formations. At their seaward end, all three valleys are now largely blocked by a gravel storm beach that is replenished by a predominant west to east longshore drift. The gravels are almost entirely composed of quartzitic rocks derived from the Budleigh Salterton Pebble Beds in the Otter Valley, and by chert and flints derived from the Upper Greensand and Chalk in the Sid and Axe valleys. All three valleys had ports located at the outfalls of their rivers at the time of the Domesday Survey (1086). Sidmouth was listed at that time as Sedemude, a small fishing village with salt workings adjacent to a natural harbour at the outfall of the River Sid.

At the mouth of the Otter Valley at Budleigh Salterton and at the mouth of the Axe Valley at Seaton, there are degraded river cliffs that show that the river outfalls were originally on the west sides of the valleys. At Sidmouth, any evidence of a similar cliff has been destroyed by landscaping and urban development. All three ports continued to be locally important until the mid 14th Century when a succession of storms caused the beach gravels to extend eastwards. This blocked the harbour entrances and diverted the river outfalls to the east side of the valleys, where they remain to this day. Historical accounts suggest that the shingle movement probably started in about

1350, and that it eventually wholly or partially blocked all the harbour entrances in east Devon. For example, by 1450 the River Otter was described as "clean barred" (www.seatonbay.com/information/history.html). All attempts to open access channels through the shingle ridges to reinstate the former harbour entrances were defeated by influxes of more gravel. At Sidmouth, the harbour was re-sited adjacent to the new outfall in an area (now built over) that is still referred to as Port Royal (Figure 1). A sandstone cliff and rock platform (Chit Rocks) on the west side of the town provided some natural protection from south westerly gales, and a series of sandstone reefs on the east side provided protection, albeit minimal, from south easterly storms.

MAN-MADE STRUCTURES

Sidmouth experienced a period of rapid expansion in the mid 18th Century when the River Sid was diverted to run in an artificial channel at the foot of a rock face cut into the Otter Sandstone on the east side of the valley (Figure 1). The earliest detailed map of the area (Donn, 1765) shows the river in its present position, and some of the low-lying marshland on the landward side of the beach ridge as a built-up area. This included the area now occupied by Old Fore Street, Fore Street and Market Square. The town became popular as a genteel coastal resort in the late 18th Century with the result that houses

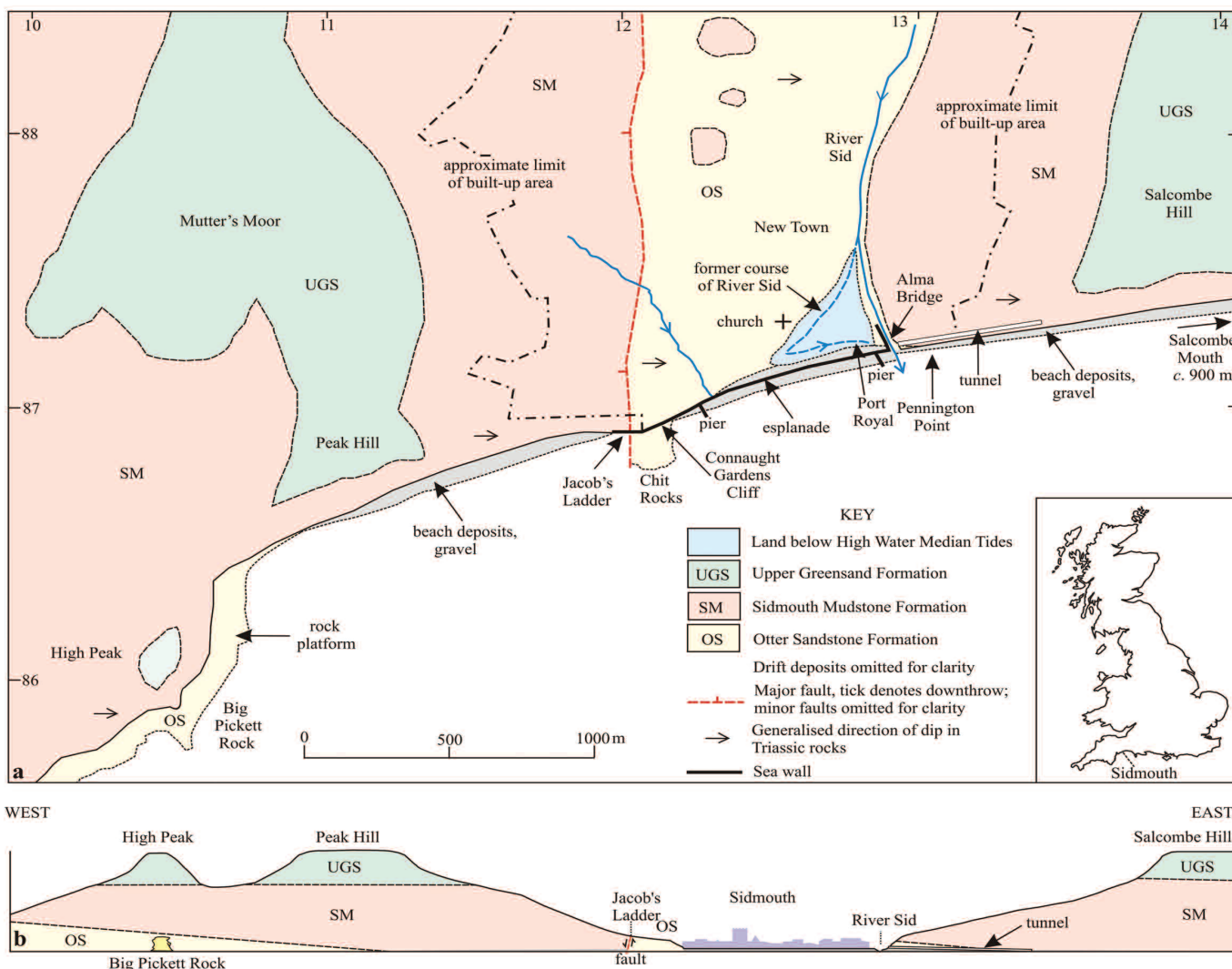


Figure 1. (a) Geological sketch map of Sidmouth and the adjacent area showing the positions of location referred to in the text. Geological boundaries based on British Geological Survey 1:50,000 Series Sheet 326 (Sidmouth). (b) Geological sketch section approximately parallel to the coast. Vertical exaggeration c. 2x.

were built not only on the higher ground of the valley sides, but also along the top of the gravel beach. Access to the beach-front properties was initially via a paved way along the top of the ridge (Figures 2a and 2c), but this did not protect them from storm waves.

Sea walls and groynes

Wooden groynes were installed in c. 1830 in an attempt to stabilise the gravel ridge, but according to Hutchison (1857) these proved to be ineffective and soon fell into disrepair. By the time work started on a sea wall in 1835 the whole of the sea front was occupied by 2- and 3-story properties designed to take advantage of the sea views (Figures 2a and 2c). When completed in 1838 (Hoskins, 1954), the sea wall and esplanade ran from the eastern end of Connaught Gardens Cliff to the end of the sea-front residences. At its eastern end the sea wall was joined to the curved end of the river wall to provide the river with a c. 100 m wide exit to the sea.

In 1855 the Alma Bridge (named after the battle of 1854) was opened to allow a shorter foot access between the town and Salcombe Regis. The first bridge, 38 m long (Figure 2e), was replaced by a brick-and-wood structure in 1900 (Figure 2f). The eastern end of the sea wall was extended in 1870 to allow a gas works (1874) to be built on part of the former Port Royal area. The sea wall was extended again in 1921 over what remained of the former harbour to provide a turning area for traffic and hard standing for fishing-boats. The river wall was

extended at the same time with the result that the outfall of the river, now entrained between the river wall and the Otter Sandstone cliff, was reduced to 25 m at its mouth (Figure 2f).

At the western end of the town, a path cut into the steep cliff of Mercia Mudstone west of Connaught Gardens that gave access to a popular beach collapsed in 1870. It was replaced by a long, straight wooden ladder (Jacob's Ladder) which was itself replaced by the forerunner of the modern, more negotiable, structure in 1900. A sea wall and a wide esplanade were opened in 1934, and this was joined to the town by a walkway and sea wall under Connaught Gardens Cliff in 1936.

The history of the main sea wall and esplanade can be summarised as a succession of breaches and remedial measures. Their construction was largely successful throughout most of the 19th Century, but became increasingly vulnerable during the latter part of the century and the early part of the 20th Century. The sea wall and/or esplanade was damaged during storms in 1871, 1873, 1877 and 1878, one result of which was the installation of additional groynes in 1891 (Andrews, 1996). The beach was again reported to be much depleted in parts in the early part of the 20th century with the result that there was more damage to the sea wall and/or esplanade in 1915, 1919, 1920 (twice) and 1924. Surprisingly, the beach gravels were worked as a source of aggregate for road construction until the late 1920s, and c. 300 tons was even used to repair the sea wall in 1924 (Tindall, 1929). These failures culminated on January 1st 1925, at the end of a week of storms, in the undermining of the sea wall and the collapse of a 36.5 m

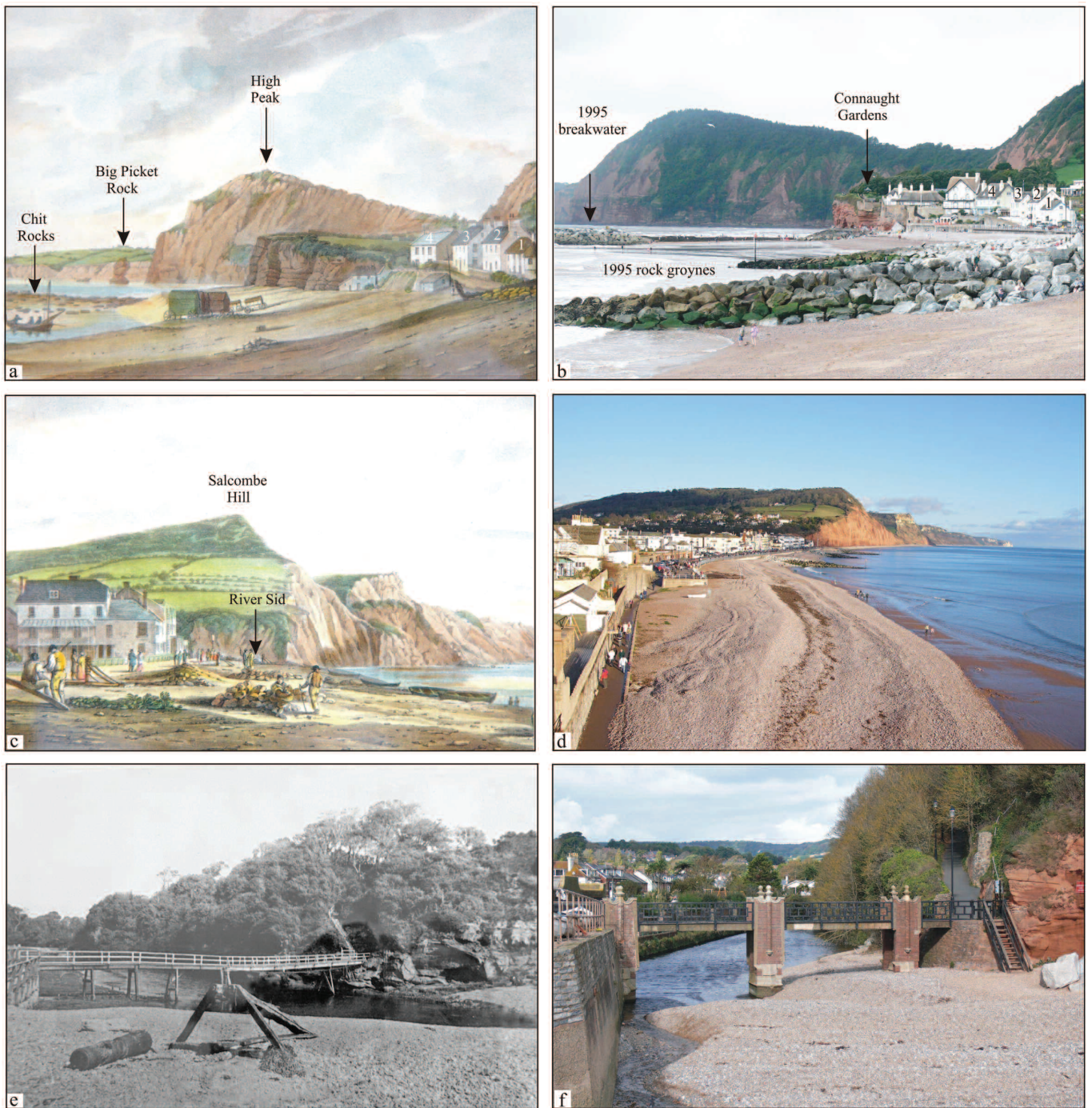


Figure 2. (a) View west of the western part of Sidmouth beach in 1815. An unbroken, wide shingle beach extends from Sidmouth to below Peak Hill. Part of a panorama of Sidmouth sea front by John Wallis Junior (Wallis, 1815). (b) View west, January 2005. The shingle beach is confined to areas between the rock groynes and between the most westerly groyne and the rock armour that protects the sea wall at the foot of Connaught Gardens Cliff. The cottages on the beach in (a) were destroyed in a storm in 1824. Houses 1 to 4 are still in place and now protected by a sea wall. (c) View east in 1815: part of the same panorama as (a). (d) View east from Connaught Gardens, December 2006. Most of the imported gravel that was emplaced evenly along the full length of the beach in 1995 migrated westwards during south easterly storms in the winter of 1995-96 and is now trapped in the quiet-water area between the sea wall and the offshore breakwaters. (e) The original (1855) Alma Bridge in 1890. Downstream from the 38-m long bridge the mouth of the River Sid was c. 100 m wide and blocked by beach gravels. Photograph courtesy Sidmouth Museum. (f) The replacement (1900) Alma Bridge, which consisted of four brick pillars supporting three spans, was c. 35 m long. It was reduced to two spans in 1921 when the river wall (left) was extended. Photographed in October 2011 at a time when the beach level was high.

long section of the sea wall and a 5 m deep section of the esplanade and road (Figures 3a and 3b). The cost of the damage was estimated at £30,000 (c. £ 1.3 million at current prices) (British Pathe News) and although the low-lying part of the town was not flooded, it was clearly at risk. A new sea wall was constructed at a cost of £100,000, and opened on March 20th, 1926 (*Sidmouth Observer*, March 24th, 1926).

An uneven distribution of the beach gravels resulted in the installation of closely spaced wooden groynes along the whole of the sea front in 1953 to 1957, but in the absence of adequate natural replenishment the beach was again reduced in level and total volume by the 1980s (Andrews, 1996). The beach level was further reduced during the stormy winter of 1989-1990 when the foundations of the sea wall were locally exposed, and



Figure 3. (a) Storm damage to the sea wall and the Esplanade in January 1925, view west. The western pier (The Hump) and Connaught Gardens Cliff are visible in the background. (b) Storm damage in January 1925, view east. The storms persisted for several days. Emergency repairs including the installation of sheet piling (bottom right) were carried out at times of low tide. (c) The western end of the railway tunnel in 1910. The River Sid percolated out through the beach gravels, as it did in October 2011. (d) View east inside the tunnel in February 2004 about halfway along its original length. The tunnel is in the lowest part of the Sidmouth Mudstone Formation at this point. Parts of the rounded arch shape of the tunnel are still well preserved. Almost all the roof falls are joint-bounded rock-block failures in thickly and thinly bedded mudstones. Photograph by and courtesy of Peter Glanwill. (e) View west towards Peak Hill from the top of Jacob's Ladder, December 2004. Beach gravels, almost all chert and flint derived from the Upper Greensand and Clay-with-flints, are banked up against the 1934 esplanade. (f) Oblique aerial view of the outfall of the River Sid, May 2005. Low tide at a time when the level of the beach gravels east of the river was high. Photographs a, b and c courtesy Sidmouth Museum.

the sea wall was breached in February 1990. A new sea wall was completed in 1991, but beach levels remained low. Construction work was carried out in 1994-1995 to replenish the beach and protect it from future erosion at a cost of £6.5 m (1995 prices). The wooden groynes were replaced by three large rock groynes, and two rock breakwaters were constructed adjacent to Chit Rocks to prevent the beach being eroded

during south westerly gales (Figure 4). Ninety thousand tonnes of granite in blocks up to 12 tonnes in weight were imported by sea for the groynes and breakwaters, and 165,000 tonnes of Budleigh Salterton Pebble Beds were imported by road from quarries at Black Hill, Woodbury (Simm and Cruickshank, 1998).



Figure 4. Composite aerial view of Sidmouth seafront showing the principal localities referred to in the text. Based on parts of Channel Coast Observatory (CCO) frames SY 11 86 NE, 12 86 NW, 12 87 SW, 12 87 SE, and 13 87 SW, 2nd June 2008. Reproduced courtesy and copyright of the CCO.

Railway tunnel

In 1836 the Sidmouth Harbour Company obtained an Act of Parliament to construct a harbour at the western end of the town with a breakwater founded on the Otter Sandstone at Chit Rocks (Figure 1). The stone for the harbour walls was to be obtained from the Upper Greensand Formation (Salcombe Stone) at Salcombe Regis, 2.6 km ENE of Sidmouth, and brought to the site on a railway that ran along the beach from Salcombe Mouth [SY 145 877]. Part of the railway was completed in 1837, but this was destroyed during storms during the following winter (Messenger, 1974). A new railway was constructed with the most vulnerable part of the route in a tunnel that ran from the east bank of the River Sid downstream from the Alma Bridge (Figure 3c) to the top of the storm beach c. 540 m to the east. The tunnel, 2.0 m high and 2.3 m wide, was excavated in the top part of the Otter Sandstone Formation and the lowest part of the Sidmouth Mudstone Formation, up to 25 m inland from the cliff face (Figure 1). It was designed for use with a steam engine that was being built at the Abbey Ironworks at Neath, formerly West Glamorgan (Perkin, 2009). When it arrived, the engine was too large for the tunnel (Hutchinson, 1857), and although a smaller engine was made and attempts were made to revive the harbour project, none of them succeeded.

The western entrance to the tunnel (Figure 3c) was visible in the cliff until the 1950s when it was eroded away. The eastern end of the tunnel, at that time c. 400 m ENE of the river outfall, collapsed in a cliff fall in 2001. About 150 m of tunnel remain including a ventilation adit halfway along its preserved length that allows access from the beach. Much of what remains is now blocked by roof falls (Figure 3d) and part of it is flooded (Glanvil, P. www.darkanddeep.co.uk). A landslide in 2010 revealed the western end of the tunnel, 120 m ENE of the River Sid outfall. Andrews and Davin (2009) concluded that the tunnel did not present any increased risk to the coastal footpath that runs adjacent to its eastern part. It appears, however, to have contributed to several landslides in that area in the past 20 years.

LANDSLIDE MECHANISMS

Natural factors affecting landslide mechanisms

The original Sedemude was sited in the sheltered embayment between two outcrops of Otter Sandstone Formation (Figure 1). On the west side of the town, the sandstones crop out in Connaught Gardens Cliff and the adjacent wave-cut rock platform. On the east side, where the sandstones crop out along the east bank of the River Sid and in the adjacent sea cliff, they form a series of offshore ledges that mark the site of the former Pennington Point. There have been few landslides in the Otter Sandstone on the west side of the

town where the formation comprises strong sandstones with common calccrete horizons. Watercolour paintings made by Hutchinson in 1848 (reproduced in Butler, 2000, figures 48/10/28-1 and 48/10/28-2) show the beginnings of small sea caves developed along the intersections of major joints in Connaught Gardens Cliff. Comparison of Hutchinson's painting with the present-day cliff shows the same indentations in the cliffs, and indicates that there has been little erosion in that area in the past 150 years. The cliff is now protected by a sea wall which is itself protected by rock armour. The principal landslide feature during that time has been small falls of weathered rock and soil from the highest part of the cliff. These were stabilised in 1999 using a combination of rock bolts and rock netting (Roche, 2001).

Adjacent to the outfall of the River Sid and for 25 m eastwards from there, the lowest part of the cliff exposes strong sandstones similar to those at Connaught Gardens Cliff. Above this, the Pennington Point Member at the top of the Otter Sandstone Formation consists of laterally variable channel sandstones interbedded with weak mudstones (Gallois, 2004) overlain by the relatively uniform mudstones of the Mercia Mudstone Group. These last are brought down to beach level 200 m ENE of the river outfall by a steady easterly dip. Only the lowest part of the group, the Sid Mudstone and Salcombe Hill members of the Sidmouth Mudstone Formation, crop out beneath and adjacent to the eastern limit of the Sidmouth built-up area.

Landslide mechanisms on this part of the east Devon coast are markedly influenced by relatively small differences in the bulk lithologies of the members that make up the Otter Sandstone Formation and the Mercia Mudstone Group. Rock-block and toppling failures as a result of marine undercutting and hydraulic stoping along fracture zones adjacent to faults and joints are the predominant mechanism in the more massive parts of the Otter Sandstone. These give rise to relatively small landslides (a few tonnes) in the lowest part of the cliffs. Larger toppling failures (up to hundreds of tonnes) occur in the Pennington Point Member and the Sidmouth Mudstone along sets of joints that run normal and subparallel to the cliff faces. The larger landslides (up to thousands of tonnes) observed in recent years have been initiated by the collapse of Head deposits and deeply weathered mudstones in the near-surface layers at the top of the cliff. These have triggered secondary joint-bounded failures in the middle and lower parts of the cliffs.

An example of this type of mechanism was captured in a series of photographs taken over a period of one minute by Eve Mathews, a local photographer, on the 5th February 2009. It involved a few tens of tonnes of material that fell from the cliff 50 m E of the Sid outfall. The landslide began with the collapse of a block of Head deposits with deep dessication cracks that rested on loose sand, the deeply weathered top of a sandstone

in the Pennington Point Member (Figures 5 and 6a). This dislodged some of the underlying sandstones and mudstones in the middle part of the cliff (Figures 6b to 6d), but the lower part of the cliff remained largely undisturbed. At the top of the cliff, the failure in the Head deposits and weathered mudstones progressed eastwards as a series of toppling failures and dislodgements (Figures 6e and 6f). This included a large concrete slab (a former viewing platform at the edge of the coastal path) that had been overhanging the beach for several years (Figure 6f). Debris and small blocks of material continued to fall from the cliff for ten minutes after the initial event. The same 'top-down' mechanism was inferred for a larger landslide (several thousand tonnes) that occurred in the Sidmouth Mudstone 420 m ENE of the river outfall in October 2001 (Gallois, 2001). In both examples, the well-jointed nature of the Triassic rocks in the middle and lower parts of the cliff was an important factor in their collapse.

Artificial influences on coastal erosion

Coastal erosion was not a problem at Sidmouth until the mid 18th Century when the river was diverted to allow land that had previously been a salt marsh to be built on. The subsequent construction of substantial buildings on top of a ridge of mobile

storm-beach gravels added to the problem. Not only did the inland part of the town need to be defended from river flooding and high spring tides, but the storm beach also needed to be stabilised. In trying to defend the town little attempt seems to have been made to take account of what was already known about the natural processes involved. For example, a daily analysis between July 1981 and June 1982 showed that 29% of the waves approached Sidmouth beach from the south west, 40% from the south, and 31% from the south-east (Laver, 1985). It was also known that south easterly storm waves have a longer unimpeded fetch than those from the south west. Nevertheless, the migration of the bulk of the replenished beach gravels to the western end of the beach shortly after the construction of the offshore breakwaters in 1995 seems to have come as an unintended consequence that required further remediation.

None of the succession of engineering works undertaken in the 19th and 20th centuries has been lastingly successful. In addition, some of the structures that were built to enhance the town's amenities had the effect of depleting the gravel ridge. The construction of a west pier (The Hump, removed in 1935) and an east pier (now partly hidden by a rock groyne) in the late 18th Century to allow access for pleasure steamers, partly obstructed the predominant west to east longshore drift of the

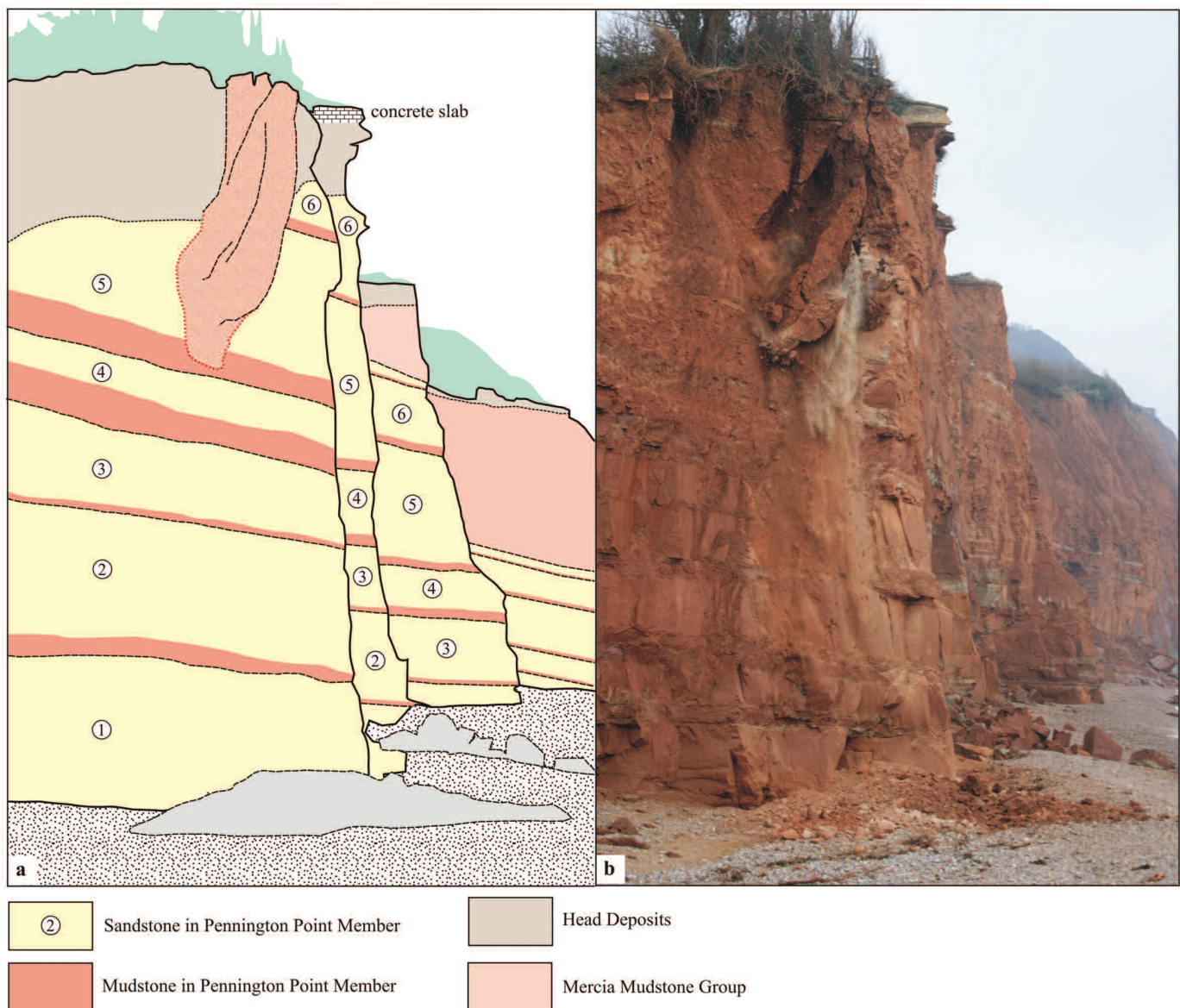


Figure 5. (a) Geological sketch of the initial stage of a landslide 50 m east of the River Sid outfall at 10.35 a.m. on February 5th 2009. (b) Photographed by Eve Matheus of Sidmouth. Reproduced courtesy and copyright of Eve Matheus.

beach gravels. The construction of the esplanade at Jacob's Ladder in 1934 cut off the western supply of gravel to the sea-front beach. Prior to that, there had been a wide, unbroken gravel beach ridge up to 6 m high that stretched from beneath High Peak, 2 km west of the River Sid outfall, to Beer Head, 9.5 km to the east.

Past and future rates of erosion east of the town

The most complete study of the rate of retreat of the cliffs east of the river outfall is that of Andrews and Davin (2009) based on a comparison of historical maps and recent air photographs. They concluded that the cliff top had retreated at average rates of 0.15 m per year between 1888 and 1996 and at 0.41 m per year between 1997 and 2008 with a maximum local rate of 0.98 m per year between 1997 and 2008. Other analyses have concentrated on the last 30 years. Posford Duvivier (2001) concluded that the cliffs receded at 1.5 m per annum between

1980 and 1995 and at 1.7 m per annum between 1990 and 1996 (c. 27 m between 1980 and 1996) and Portsmouth University (2004) estimated that they had retreated 30 to 40 m between 1980 and 2001. An environmental impact statement (Posford Haskoning, 2002) written in support of a scheme to build sea defences at the foot of the cliff for 200 m east of the River Sid, concluded that the then rate of erosion was 1.6 to 2.0 m per year.

Comparison of a selection of maps published between 1802 (Anon, 1802) and 1935 with recent (2006) air photographs shows that the rates of erosion over the past 200 years are less than these estimates, in some cases markedly so (Figure 7). When allowance is made for the differences in the projections and mapping scales, the cliff top for 300 m to 500 m east of the river outfall does not appear to have retreated by more than 10 m and mostly < 5 m in the past 200 years. This is difficult to reconcile with a prediction (Halcrow, 2011) that, even with Managed Realignment, this part of the cliff top will retreat by c. 70 m within the next 50 to 100 years.



Figure 6. Landslide shown in Figure 5 photographed over a period of one minute by Eve Mathews. Small debris falls continued to occur over the next 10 minutes. Reproduced courtesy and copyright of Eve Mathews.

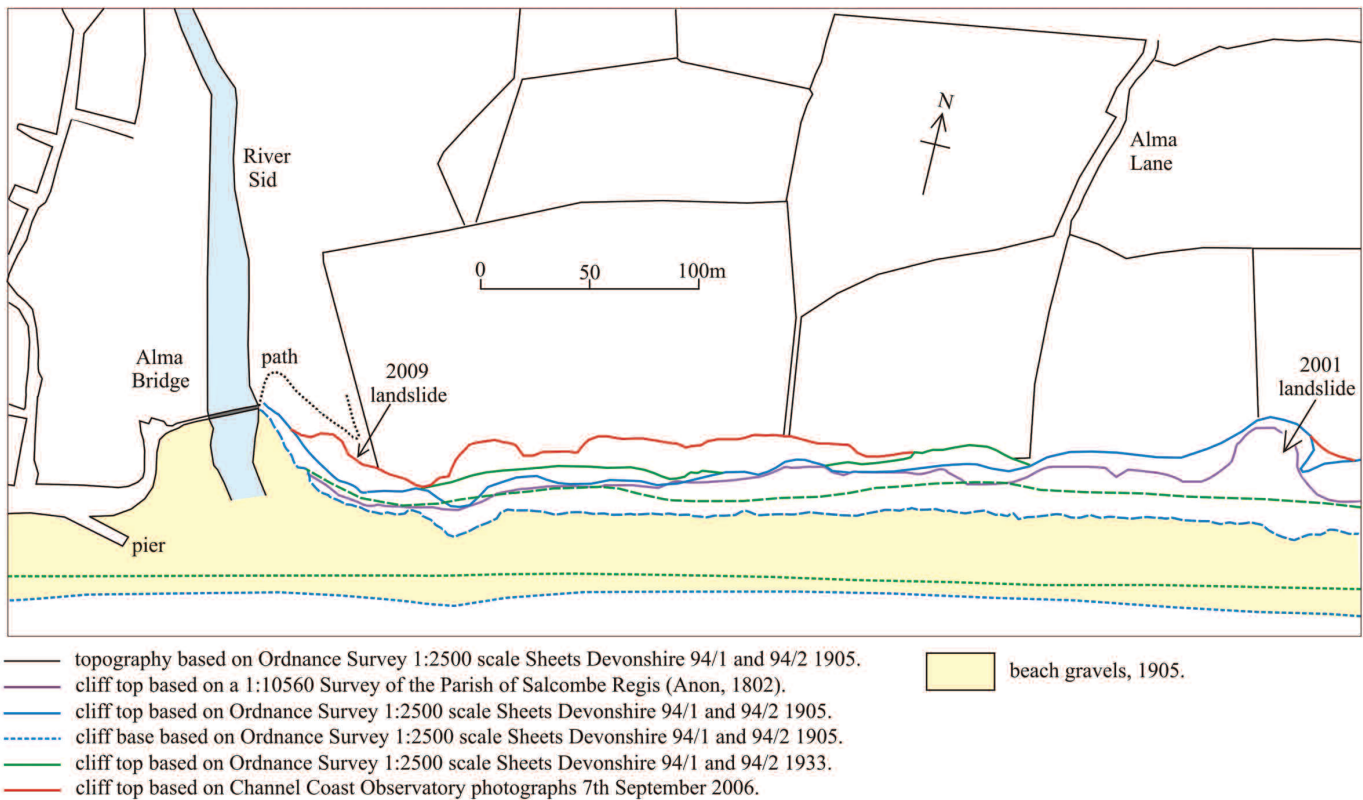


Figure 7. Selected stages in the retreat of the cliffs east of the outfall of the River Sid. See text for explanation and descriptions of the 2001 and 2009 landslides.

The historical records show that the largest changes in the past 200 years have occurred between the river outfall and 300 m east of there, where the cliff top has mostly retreated by 20 m to 30 m (Figure 7). About 50% of this change occurred between 1933 and 2006 but, as might be expected from the geology, there have been marked differences at different localities, and between the top and bottom of the cliff. For example, the Ordnance Survey map of 1905 shows a cliff profile comprised of rock faces overlain by steep vegetated slopes, but the 1933 maps shows a narrower profile made up of continuous, almost vertical rock faces. This implies that the rate of retreat of the foot of the cliff was faster than that of the top. During the past 10 years the cliff top in the area at and

adjacent to Pennington Point has retreated faster than the base, and some parts of the bottom and the top have experienced little or no movement. For example, the sandstones at the foot of the western end of the cliff have not been eroded during that time, and the concrete slab shown in Figure 6 projected out from the top of the cliff for at least 7 years before it fell in February 2009.

Most of the landslides in recent years have been relatively frequent (one or more per year) collapses in thick drift deposits in the highest part of the western end of the cliff close to the river and adjacent to the coastal footpath (Figure 8). These have been visible from the Esplanade and, as a consequence, have attracted much publicity.

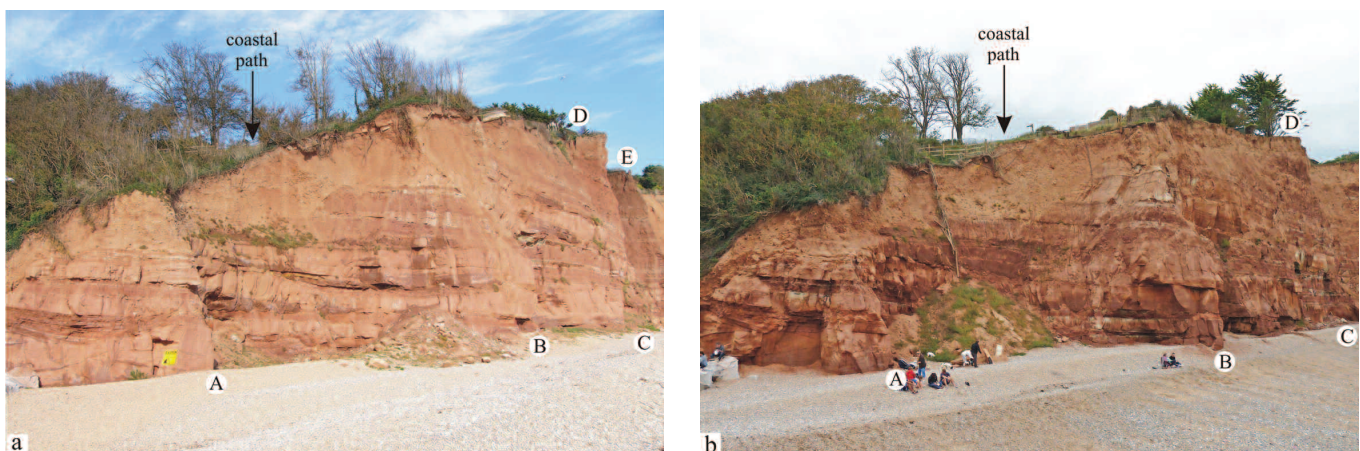


Figure 8. The western end of the cliff adjacent to the outfall of the River Sid at times of high beach level viewed from the river wall (a) 7th January 2004 and (b) 30th August 2011. There has been little change in the lower part of the cliff in the outcrops A, B and C of the sandstones and mudstones in the Pennington Point Member. In contrast, the collapse of Head Deposits and weathered mudstones in the upper part of the cliff adjacent to the coastal path (in 2008, 2009 and 2010), between there and the promontory D (in February 2009) and at promontory E have resulted in the local retreat of the cliff top by up to 2 m.

SUMMARY AND CONCLUSIONS

The problems that have arisen at Sidmouth as the result of a succession of sea-defence works have not been repeated in the adjacent valleys. To the west, a continuous gravel beach at the seaward end of the Otter Valley runs from a cliff on the west of Budleigh Salterton to the river outfall on the east side of the valley. There are no groynes or other man-made structures that might interfere with the predominant west to east longshore drift. As a result, pebbles derived from the Budleigh Salterton Pebble Beds move from their source in the western cliff to the river outfall without interruption. At Seaton, a similar shingle ridge at the seaward end of the Axe Valley is partly built on and protected by a sea wall. However, there are no groynes to impede the longshore drift and a continuous gravel beach runs from White Cliff on the west side of the town to the river outfall 2 km to the east.

Given the need to continue to defend the town from marine erosion what is likely to happen next at Sidmouth? The Department of Environment, Food and Rural Affairs (DEFRA) Shoreline Management Plan (SMP) for Sidmouth and the adjacent coast for the next 100 years has recommended a policy of *Hold the Line* for the sea-front area between Jacob's Ladder and the outfall of the River Sid (Anon, 2011). This would involve maintaining the current sea wall, offshore breakwaters and rock groynes; improvements to the river wall; and replenishment of the gravels on the eastern part of the beach. The recommendation for an unspecified length of coast east of the river outfall, at and adjacent to the former Pennington Point, is *Managed Realignment* designed to reduce the rate of retreat of the cliff line. The only proposal put forward for planning approval to date has been to protect the foot of c. 250 m of cliff with rock armour. This scheme is based on assumptions about the rate of retreat of the cliffs that have not been based on quantitative observations, and on the hypothesis that the principal cause of the retreat of the cliff top is marine erosion at its foot. Some of the estimates of the amount of cliff-top retreat that has occurred during the last 30 years exceed that shown by historical maps to have occurred in the last 200 years.

Predictions of the future rate of retreat based on estimates of the rate of retreat during the past 10 to 20 years vary by more than a factor of 10. All have assumed that the rate of retreat of the cliff top is controlled by erosion at the foot during the relatively short periods (tens of days per year on average) when the beach level is low, and that sea-defence works at the foot of the cliff would stabilize it. However, there is no quantitative evidence and little qualitative evidence to support this hypothesis. The initial event in the larger landslides in recent years has been the collapse of weak drift deposits and weathered sandstones and mudstones in the upper part of the cliff.

ACKNOWLEDGEMENTS

The author would like to thank Mr and Mrs R. Barnard and Bob Symes at Sidmouth Museum for help with their news archive and for copies of historical photographs; Eve Mathews for her first-hand description of the 2009 landslide and for permission to publish her photographs; and the staff at the Devon Records Office and the West Country Studies Library for access to historical maps.

REFERENCES

- ANDREWS, J. 1996. The Sidmouth Phase 2 Coast Protection Scheme. *Proceedings of the 31st Ministry of Agriculture, Food and Fisheries Conference on River and Coastal Engineering (Keele)*, 9.3.1-9.3.5.
- ANDREWS, J. and DAVIN, M. 2009. *Pennington Point: cliff erosion review*. Unpublished report by Royal Haskoning for East Devon District Council. Project No. 9T7799.
- ANON. 1802. *MS A map of the Manor of Salcombe Regis in the County of Devon*. Six inches to one mile scale (1:10,560). Alex Law and Thos Bradley, surveyors.

- ANON. 2011. *Final Report to DEFRA of the Jurassic Coast Pathfinder Project*. Jurassic Coast Pathfinder Steering Group. www.jurassiccoast.com/403/category/public-documents-250.html.
- BRITISH GEOLOGICAL SURVEY. 2005. England and Wales 1:50 000 Sheet 326 and part of 340, Sidmouth. Natural Environment Research Council, Swindon.
- BUTLER, J. 2000. *Peter Orlando Hutchinson's travels in Victorian Devon*. Devon Books, Tiverton.
- DONN, B. 1765. *MS A map of the County of Devon with the city and county of Exeter*. Reprinted in 1965 as a facsimile with an Introduction by RAVENHILL, W.L.D. Percy Lund, Humphries and Co., London and Bradford.
- GALLOIS, R.W. 2001. *Stability of the Coastal Footpath at Salcombe Hill Cliff, Sidmouth*. Unpublished report for East Devon District Council.
- GALLOIS, R.W. 2004. The junction of the Mercia Mudstone Group and Otter Sandstone Formation (Triassic) at Pennington Point, Sidmouth, Devon. *Geoscience in south-west England*, **11**, 51-58.
- HALCROW. 2011. *Durlston Head to Rame Head Shoreline Management Plan 2*. Unpublished Report for the Department of Environment, Food and Rural Affairs.
- HOSKINS, W.G. 1954. *Devon*. David and Charles, Sidmouth.
- HUTCHINSON, P.O. 1857. *A new guide to Sidmouth and its neighbourhood*. Thomas Perry, London.
- LAVER, F.J.M. 1985. Beach Cusps at Sidmouth. *Reports and Transactions of the Devonshire Association for the Advancement of Science*, **117**, 83-99.
- MESSENGER, M.J. 1974. The Sidmouth Harbour Company of 1836. *The Industrial Railway Record*, No. 55, 282-285.
- PERKIN, J. 2009. *Sidmouth Harbour Railway Company. The history of Sidmouth's abandoned coastal steam railway*. Sid Vale Association, Sidmouth.
- PORTSMOUTH UNIVERSITY. 2004. *Sediment Transport Study: Otterton Ledge to Beer Head*. Unpublished report for the Standing Conference on Problems Associated with the Coastline (SCOPAC). <http://stream.port.ac.uk/environment/scopac5/otbr/photos/photo3.htm>
- POSFORD DUVIVIER. 2001. *Pennington Point Coastal Study*. Unpublished report for East Devon District Council.
- POSFORD HASKONING. 2002. *Proposed coastal protection at Pennington Point/Salcombe Hill*. Unpublished consultation document for the Environmental Impact Statement for East Devon District Council.
- ROCHE, D.P. 2001. Engineering geology of cliff stabilization and management at Connaught Gardens Cliff, Sidmouth. *Geoscience in south-west England*, **10**, 252.
- SIMM, J. and CRUICKSHANK, I. 1998. *Construction risk in coastal engineering*. Thomas Telford Ltd, London.
- TINDALL, J. 1929. Sidmouth Foreshore. *Reports and Transactions of the Devonshire Association for the Advancement of Science*, **61**, 327-342.
- WALLIS, J. 1815. *A panoramic view of Sidmouth, Devon taken from the beach*. Wallis, London.