TECHNICAL MEMORANDUM

Seaton BMP Cliff Assessment

PREPARED FOR:	East Devon District Council
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PREPARED BY:	Paul Fish
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Scope of Work

This technical note provides an assessment of the cliffs to the west of Seaton in support of the Beach Management Plan (BMP). The cliffs are subject to slope instability and rock armour was placed at their base in the 1990s to limit toe erosion. Despite this toe protection, ongoing failures at the cliff top have resulted in Old Beer Road being narrowed and moved inland, and more recently being completely severed by failures. Therefore, a characterisation of the cliffs has been undertaken to support the development of long-list options for additional cliff stabilisation measures.

This technical note provides the following information:

- a description of the geomorphology of Seaton Bay to place the cliffs in a regional framework;
- a review of past cliff inspections and stabilisation options by others to document the current state of knowledge;
- an assessment of historical aerial photography and OS maps to document the pattern and rate of cliff recession over the past c. 100 years;
- a classification and characterisation of cliff behaviour units (CBUs), including geology and failure mechanisms; and
- a long list of stabilisation options for each CBU.

Context

The town of Seaton lies in the centre of an asymmetric bay that is broadly aligned east-west. The bay is defined by the resistant chalk headland of Beer Head in the west and extends east beyond the mouth of the River Axe towards Haven Cliff (Figure 1). The bay is broadly aligned to the dominant waves from the south-south-west, which drives sediment transport from the west of Seaton towards the east. There are less-dominant waves from the south-south-east, which can have significant impact on the beaches during storms. The net eastwards drift direction is indicated by the deflection of the mouth of the Axe towards the east by a spit that has historically prograded. This small contemporary spit is an extension of a larger and older spit/barrier feature that blocks the c. 1km wide Axe valley.

The cliffs in the lee of Beer Head, to the west of the Bay, are to some degree sheltered from the dominant south-south-westerly waves meaning that cliff recession rates resulting from toe erosion are generally low; however, to the east, the orientation of the bay means that the cliffs become increasingly less sheltered and exposed to the predominant south-south-westerly waves. As explored in this technical note, construction of a rock revetment has reduced the rate of cliff toe erosion, but failures occurring on the cliff face are attributed to weathering and groundwater levels.

Beaches are predominantly composed of 'relict' material that is a vestige of an ancient former beach that extended as a continuous barrier across much of the SW coast This 'great beach' migrated inland with rising post-glacial sea-level rise. The evidence for this former beach includes gravel deposits in the English Channel which represent 'drowned' parts of the barrier, which were unable to respond to the rate of rising sea-level; and the widespread occurrence of far-travelled pebbles in many south coast pocket beaches. This far travelled material was transported east along the barrier from a source at Budleigh Salterton in East Devon by littoral processes at a time when headlands seen today – such as Beer Head – were fronted by a continuous beach, allowing a continuous sediment transport pathway.

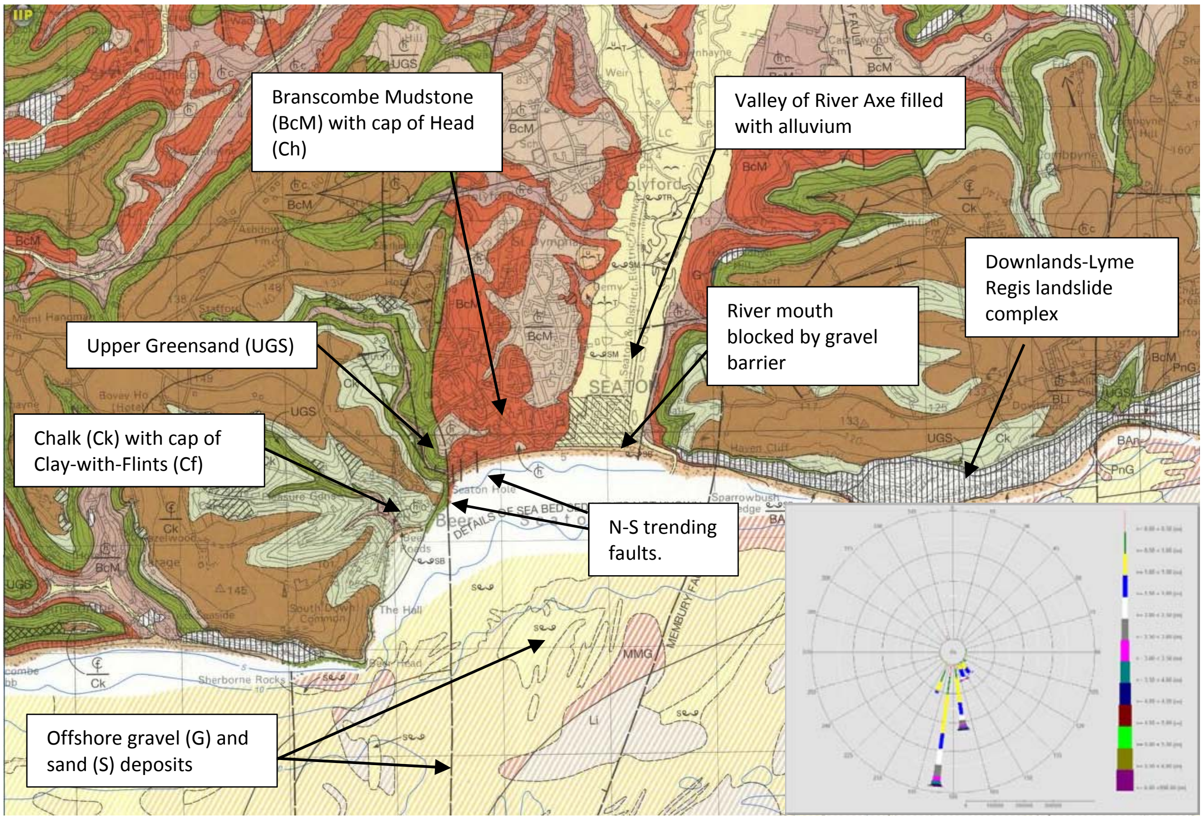

Figure 1. Geological map of the Seaton area (BGS, 2005), including inshore wave rose (CH2M, 2017).

Sediment supply to the beach today is very low and dominated by fine-grained materials that tend to be drawn offshore. Beer Head is up to 140m high and is comprised of Chalk with a low content of flints and a thin capping of deeply weathered Chalk known as 'Clay-with-Flints'. Once the cliffs are eroded, the flints are retained on the foreshore, but other materials are lost offshore. The Chalk extends to Seaton Hole, where a thin bed of Upper Greensand crops out. This material is dominated by sand, but does include occasional chert nodules and calcarenite beds that once eroded could form beach gravel. The frontage of Seaton, extending to the eastern bank of the River Axe, is comprised of Branscombe Mudstone, which is a fine-grained material containing no sediments of beach-building grade (Figure 1).

Overall, assuming absence of coastal intervention works, the geomorphological setting of the site means that in times of 'typical' south-south-westerly waves the cliffs in the west of the bay from Beer Head to Seaton Hole are sheltered from waves and would experience very low rates of average cliff recession, while the frontage immediately east of Seaton Hole to Seaton would be exposed and experience increasing rates of cliff recession. There would be progressive beach sediment loss (negative sediment budget) to the west and the area east of Seaton would experience a net gain in beach sediment (positive sediment budget).

This situation represents average long-term condition and does not imply that cliffs at Beer Head and Seaton Hole are stable. South-south-easterly storms are less frequent, but have the capability to erode the toe of the cliffs and to temporarily reverse drift directions, potentially nourishing beaches fronting west of Seaton and depleting those further east. Importantly, cliff instability and landsliding can occur by processes other than toe erosion by wave attack. Cliffs formed in soft rocks, such as the Branscombe Mudstone, respond to periods of sustained high rainfall, which elevates groundwater levels, raises pore water pressures and weakens the material to promote failures such as mudslides.

Records of past behaviour

The following documents have been provided by the client that describe historical cliff failures at Seaton:

- David Roche GeoConsulting (2000) documents a landslide at Seaton Hole (i.e. where the Seaton Fault intersects the coast) that occurred on 13 September 2000. The report notes that only part of this section of cliff benefits from a concrete toe apron constructed in the late 1980s and has experienced low rates of erosion with occasional small failures on the cliff face over the period 1889-2000. However, the September 2000 landslide resulted in up to 5m of cliff top retreat near property 'Lew Hollow' and is the largest event on record at this location. It was interpreted as a shallow failure in the upper cliff triggered by elevated groundwater levels, exacerbated by erosion of the unprotected section of cliff toe. Several springs and seepage zones are observed on the landslide. Note that 2000 was an extremely wet year with many other landslides being triggered on the south coast.
- Frederick Sherrell Ltd (2012) documents a site visit made on 18 July 2012, soon after a landslip severed Old Beer Road to the west of the property 'Ashecliffe'. The report documents that cracking in the road was first noted on 11 July 2012, and that within 48 hours the outer edge of the road had subsided by c. 1m over a distance of c. 25m. This report notes that an earlier slip in 2001, which occurred a short distance to the west in front of the property 'Upcott', was not reactivated in the summer of 2012. The report notes that this cliff benefits from a toe protection revetment and suggests that failure occurred in the weaker, weathered materials of the upper cliff that became saturated following exceptionally heavy rainfall of June and July 2012. Note that 2012 was also an extremely wet year with many landslides being triggered on the south coast.
- Frederick Sherrell Ltd (2013) documents an additional site visit to the landslip undertaken on 4 October 2012 and provides a review of engineering geology of the cliffs, past recession rates and preliminary guidance on cliff stability and risk to residents. The review of historical maps and aerial photographs concludes that some toe erosion is seen between 1904 and 1959, but subsequently cliff toe erosion has been limited, probably in response to construction of the 2m high rock revetment, which afford protection from most storms. Toe erosion can still occur when the rock armour is overtopped. In contrast, the cliff top position appears unchanged prior to 1968, after which there have been several small and localised failures in the upper cliff, resulting in development of landslide embayments. The West Walk footpath formerly extended along the cliff toe from the town and then climbed the cliff face to Old Beer Road, but this was lost by the 1968 mapping. The report concludes that while the rock revetment has been effective at limiting toe erosion, is has not stopped cliff top recession, which results from saturation of weak, weathered materials following sustained heavy rainfall.
- David Roche GeoConsulting, (Jan 2016) develops outline remediation options for the Old Beer Road landslide. Options comprise strengthening the upper part of the cliff using various combinations of shallow 'soldier' piles in the road, gabion baskets, sprayed concrete and meshing on the upper cliff face, as well as additional rock armour at the toe to protect from more significant storm events. No drainage options are presented. The implications of the SSSI and World Heritage status of the cliff is not considered.

Overall, these reports demonstrate that the cliffs have a history of low rates of erosion that masks the occurrence of episodic and localised landsliding over the last 130 years. Toe erosion from Seaton Hole to Seaton West Walk promenade has been controlled by the construction of rock armour in the 1990s and a concrete toe apron in the late 1980s but its effectiveness has diminished in recent years due to changing beach levels and movement of armour blocks. Despite toe protection, instability has occurred on the cliff face, where significant volumes of debris are stored, and cliff top recession has also occurred episodically over this time. However, it appears that events have become larger and more frequent since around the year 2000. Landslides have tended to occur in the upper part of the cliff, which is formed in weaker, weathered materials and are associated with sustained periods of high rainfall that saturate and further weaken cliff materials.

Cliff behaviour units

Introduction

In Soft Cliff Management (Defra, 2002) the term cliff behaviour unit (CBU) is used to define individual sections of cliff with similar geology, geomorphology, aspect and management. CBU types are defined based on the throughput and storage of sediment through the cliff system (Figure 2). Common CBU types are Simple Cliff mudslides, where there is a simple relationship between toe erosion and recession of the cliff top and limited debris storage; and Composite Cliffs formed from different materials, where there is a partly coupled sequence of different simple sub-systems, such as a mudslide complex in clay over a hard rock cliff.

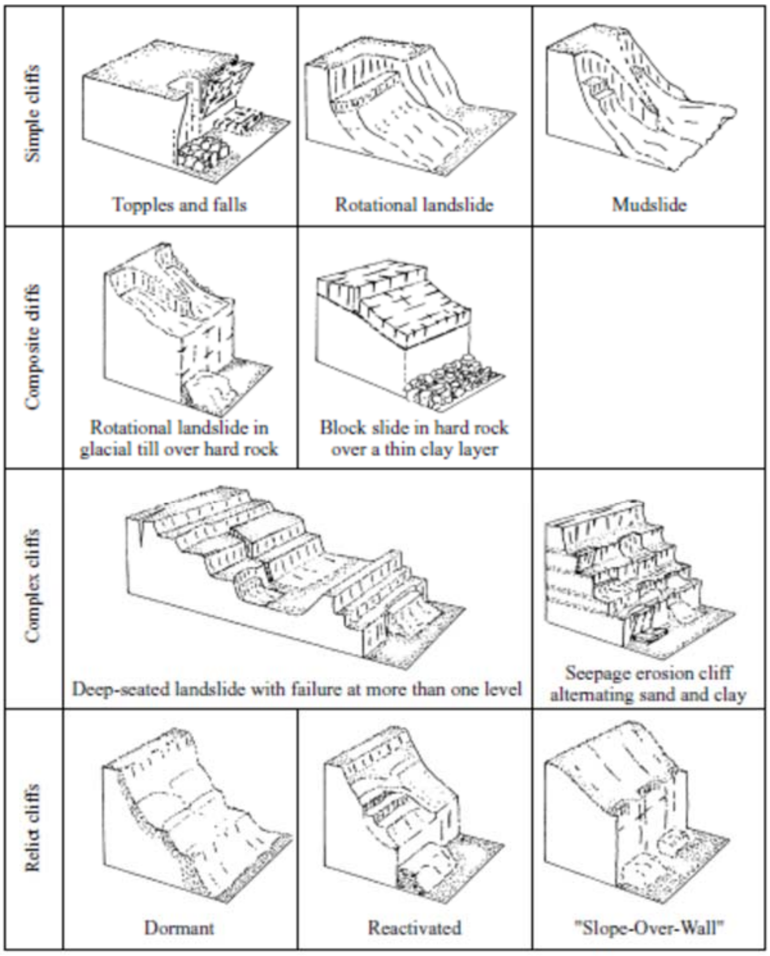

Figure 2. CBU Types.

Over time, cliffs respond to storms in a complex manner typically defined by periods of limited activity punctuated by short periods of rapid recession. Activity may be in direct response to storm event trigger, or may be lagged, requiring not only a trigger event, but also a series of preparatory factors, such as weathering or strain softening of the cliff. This pattern of activity means that assessment of historical cliff behaviour is dependent on the timescale covered by past records. Over the short-term (1 to 10 years), cliff behaviour often appears to be highly variable, with variation in cliff recession rates over time and in space. Over the medium term (10 to 100 years) fluctuation in recession rate tends to be smoothed as feedback mechanisms in the cliff system maintain constant processes and formed. Over the longer -term (1,000s of years) the behaviour may gradually change in response to environmental changes, such as changes in the pattern of climate or sea-level rise

CBUs at Seaton

Cliff behaviour units for the Seaton frontage were considered in the Futurecoast (2002) project. The cliffs between Beer Head and Seaton were subdivided into two sections based on the presence or absence of toe protection. Both sections were considered to fail through toe erosion and falls, and to have a medium susceptibility to climate change (i.e. sea-level rise and increased winter rainfall). A more refined CBU classification has been made for this study based on interpretation of aerial imagery, historical maps and a site visit undertaken on 13 October 2017. Characteristics are tabulated in Table 1, mapped in Figure 3 with photographs provided in Figure 4.

Table 1. CBUs recognised between Seaton Hole and Seaton.

CBU Name	CBU Type	Defences	Notes
CBU 1 Seaton Hole Landslide	Simple Cliff in Upper Greensand characterized by mudslides.	Concrete toe apron (post 1990 OS map?).	Landsliding last occurred in 2000. Cliff now appears stable and well-vegetated.
CBU 2 Whiteacre	Simple cliff in Branscombe Mudstone characterised by mudslides.	Rock armour at the cliff toe.	Long history of shallow instability in the upper cliff that resulted in loss of original path to beach prior to 1933 OS map. Recent mudslides in upper cliff materials.
CBU 3 – White Haven landslide	Simple Cliff in Branscombe Mudstone characterised by mudslides.	Rock armour at the cliff toe.	This landslide was first recorded on in July 2012 and led to settlement of part of Old Beer Road. Movements continued to the present day, and a 50m length of road has now been lost.
CBU 4 – Seaforth Lodge	Simple Cliff in Branscombe Mudstone characterised by mudslides.	Rock armour at the cliff toe.	Periodic small and localised failures in the upper cliff recorded since 2006.
CBU 5 Ingon House Chine 'The Pillar'	Simple Cliff in Branscombe Mudstone. The cliff is the confluence of a stream channel that flows obliquely to the cliff face, resulting in the formation of a narrow arête.	Rock armour that is set forward from the cliff toe. Gabions protect a drainage structure in the base of the chine.	Very active section of cliff that experiences regular wave erosion and outflanking.
CBU 6 Check House	Simple Cliff in Branscombe Mudstone characterised by shallow failure of the upper cliff.	Concrete toe apron.	Despite toe protection the cliff shows widespread shallow activity and evidence for historical collapses in the upper cliff.
CBU 7 West Walk	Simple Cliff in Branscombe Mudstone characterised by shallow failure of the upper cliff.	Promenade toe protection structure from early 1900s.	Despite toe protection the cliff shows widespread shallow activity.

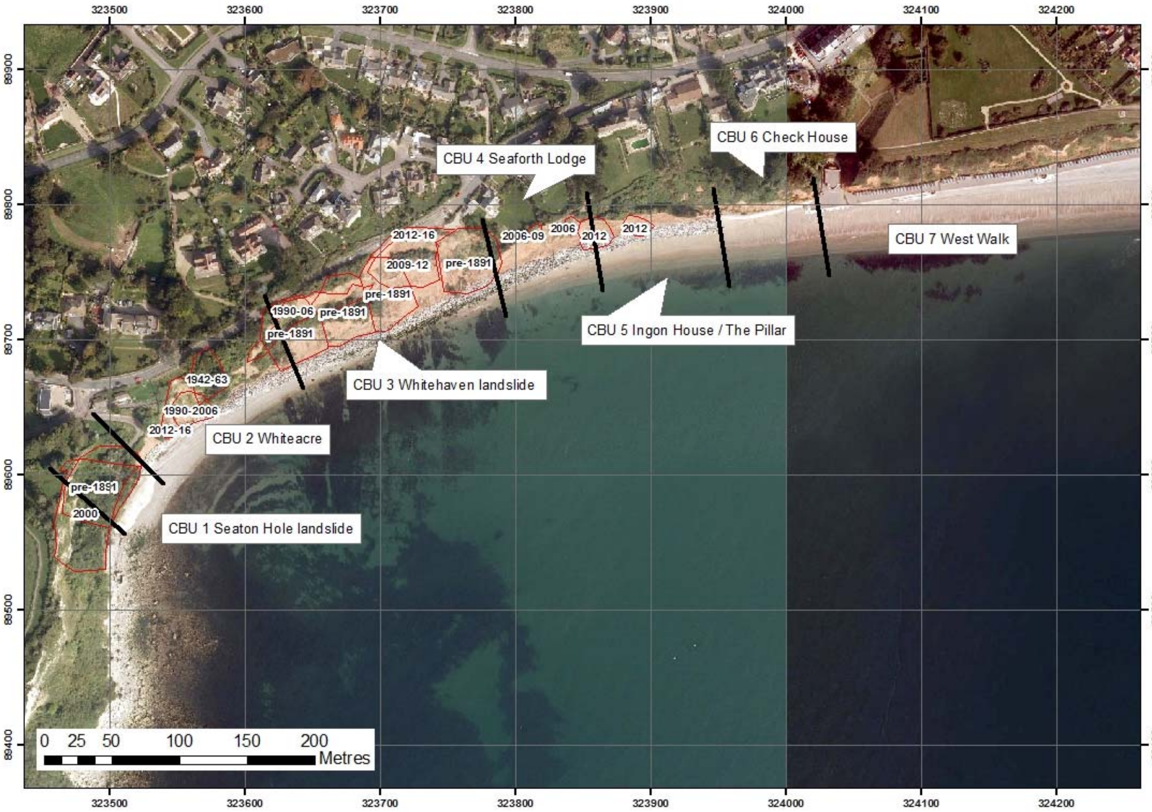

Figure 3. Cliff behaviour units and summary evidence for the date and location past cliff instability events.

Figure 4a. CBU 1. Seaton Hole landslide. Well-vegetated debris from the 2000 landslide in Upper Greensand that follows alignment of a N-S trending fault. Cliff toe protected by concrete apron.

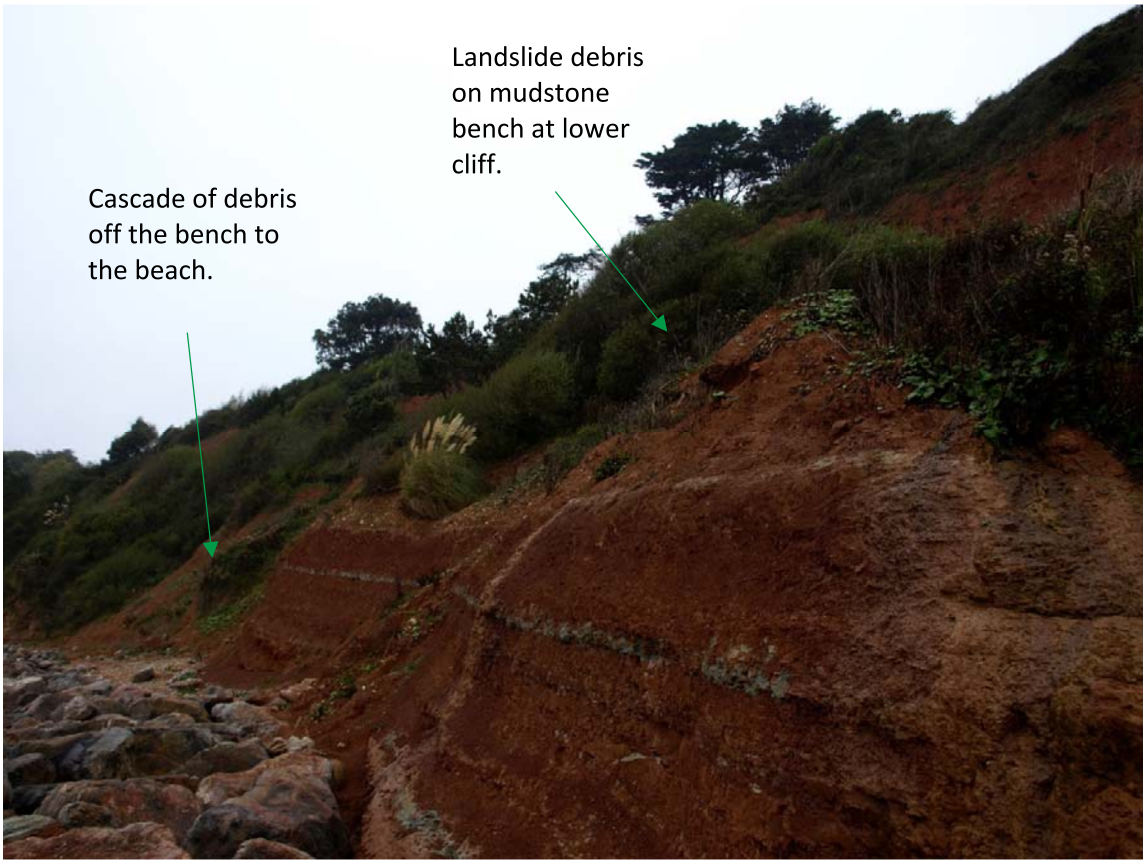

Figure 4b. CBU 2. Whiteacre. Mudstone cliff with rock armour at toe. Periodic failures in the upper cliff that is mantled with vegetated debris resting on an in situ mudstone lower cliff bench. Localised failures on the cliff produce fine grained sediment that may be delivered to the beach.

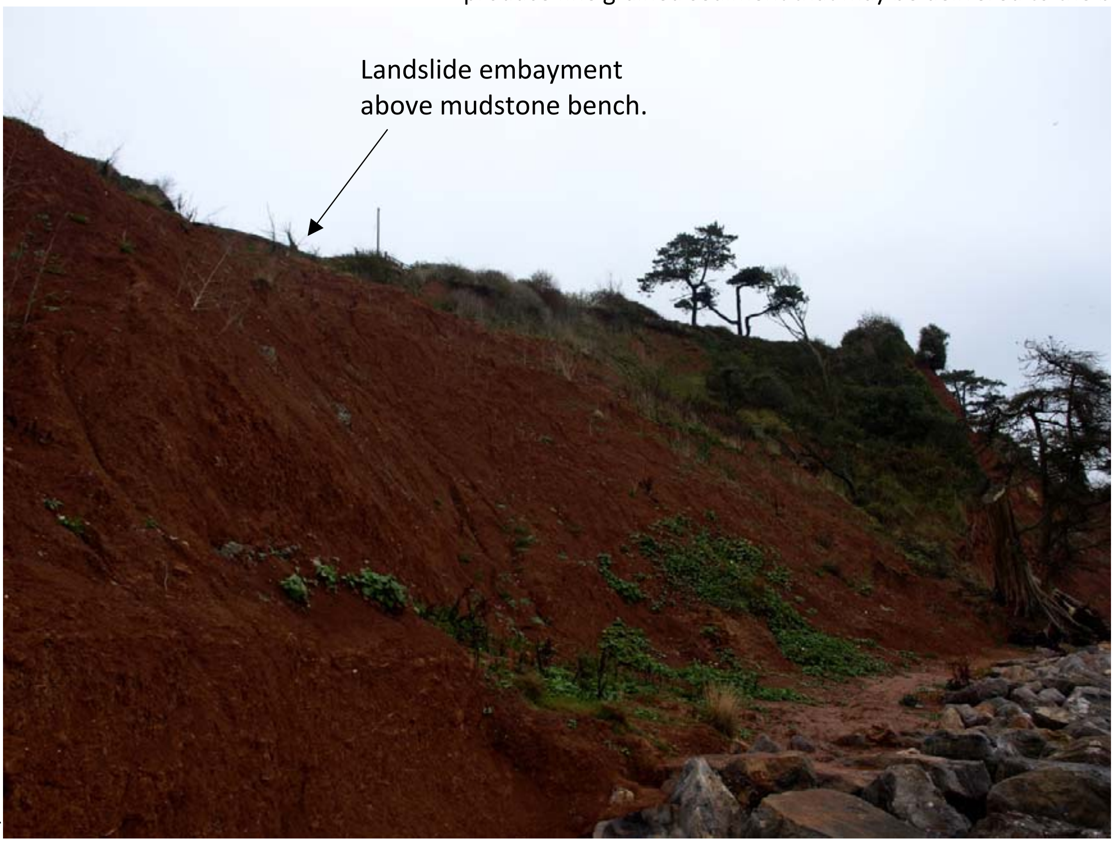

Figure 4c. CBU 3. White Haven landslide. Overview of failure in mudstone cliff showing failure of the upper cliff, debris cascade over the lower cliff and stream and wet ground at the toe. Localised failures on the cliff produce fine grained sediment that may be delivered to the beach.

Figure 4d. CBU 3. White Haven landslide. Eastern lateral shear of the failure that appears to be structurally-controlled.

Figure 4e. CBU 3. White Haven landslide. View fom cliff top showing loss of c. 50m of Old Beer Road.

Figure 4f. CBU 4. Seaforth Lodge. Mudstone cliffs with toe revetment largely obscured by beach sediment and debris. Periodic, localised failures produce fine grained sediment that is delivered to the beach. Historical landslide embayment shown.

Figure 4g. CBU 5. Ingon House Chine, 'The Pillar'. Undefended narrow mudstone cliff formed by chine that runs sub-parallel to the coast. Periodic failures deliver fine sediment to the beach.

Figure 4h. CBU 6. Check House. Mudstone cliffs with two protection. Localised failures on the cliff produce fine grained sediment that may be delivered to the beach. Historical landslide embayment shown.

Figure 4i. CBU 7. West Walk. Mudstone cliffs with promenade toe protection since early 1900s. Localised failures on the cliff produce fine grained sediment that is not delivered to the beach.

Historical cliff behaviour

In support of a new assessment of cliff behaviour, a GIS-based review of historical cliff recession has been undertaken using past editions of OS maps, aerial photography and LiDAR dating from the 19801 to 2016. Using GIS, the assessment allows changes in the cliff to be measured as accurately using historical mapping and serial imagery. The data available to this study are summarised in Table 1, which also documents evidence for cliff activity visible in each dataset. Locations and dates of these past landslides are shown on Figure 3.

Table 2. Spatial data available to this study

Dataset and date	Source	Scale/resolution	Notes
2016 LiDAR	CCO	1m	Landslide on cliff fronting 'White Haven' extends and destroys greater width of Old Beer Rd.
2014 aerial photo	CCO	0.1m	Landslide on cliff fronting 'White Haven' extends inland and destroys greater width of Old Beer Rd. Landslide on cliff fronting Swallowcliffe (Lyme Bay Care home).
2012 aerial photo	CCO	0.1m	Landslide on cliff fronting 'White Haven' closes Old Beer Rd. Two failures on the cliffs fronting Seaforth Cottage and Ingon House.
2009 aerial photo	CCO	0.1m	Small failure on the cliffs fronting Seaforth Lodge.
2006 aerial photo	CCO	0.1m	Rectification of this image at Beer Head is poor. A second failure occurred on cliff face south of 'Whiteacre' some time before 2006 image. Failure at Seaton Hole affecting cliffs fronting Lew Hollow in 2000 occurs in pre-1891 landslide embayment. Failure fronting 'Upcott' occurred in 2001. Small failure on the cliffs fronting Seaforth Lodge.
1990 mapping	OS	1:12,560	No change visible.
1963 mapping	OS	1:12,560	West Walk cliff path lost due do landslide on cliff south of 'Whiteacre'
1931-42 mapping	OS	1:12,560	No new cliff failures mapped. West Walk cliff path in place.
1906 mapping	OS	1:12,560	No new cliff failures mapped. West Walk cliff path in place.
1891 mapping	OS	1:12,560	Several landslide embayments visible in cliffs along Old Beer Road. West Walk footpath climbs cliff to junction of Old Beer Road and Beer Hill.

Note: CCO – Channel Coastal Observatory; OS – Ordnance Survey

A GIS-based mapping exercise was completed to document the position of the cliff top and cliff toe in each data set and use these data to estimate cliff recession rates in each CBU. The assessment showed that in many areas the cliff top could not be defined due to vegetation. It is also difficult to precisely map feature positions from early OS map editions which use hachures to record the cliff. The georeferencing of early OS maps is also poor in many cases, meaning measured changes are often less than the positional error. The results are summarised below:

In summary, the data show the following:

- The cliff toe erosion rate for red mudstone cliffs prior to emplacement of the rock armour was low, and probably less than 0.1m/yr.
- At CBUs 6 and 7, where toe protection in the form of the West Walk promenade has been in place since the early 1900s, no change in the cliff top position is recorded.
- It is difficult to demonstrate cliff top recession rates for most of the frontage because of vegetation cover in the aerial photography and limitations in accuracy of historical mapping. However, in most CBUs a rate of around 0.2 to 0.3m/yr is appropriate for the period since 1990.

  - Data from CBU 4 at Seaforth Lodge indicates 9m toe erosion was recorded between 1891 and 1990 at an average rate of c. 0.1m/yr and 7m erosion was recorded between 1990 OS map and 2014 aerial photo, giving an average rate of c. 0.3m/yr.
  - Data from CBU 5 at Ingon House ('The Pillar') 4m toe erosion was recorded between the 1990 OS map and 2006 photo indicating an average rate of 0.3m/yr. 5m cliff top erosion was recorded between the 1990 OS map and 2014 photo indicating an average rate of 0.2m/yr.
- Most cliff recession activity has involved failure of the cliff face, and/or reactivation of pre-existing landslide debris temporarily stored on cliff face benches. In these cases, failure does not result in cliff top retreat and may result in the position of the cliff toe advancing as debris is temporarily stored on the beach.
- In locations where failure of the upper cliff has resulted in cliff top retreat, the measured change over relatively short periods of time is significant:
  - At the White Haven landslide (CBU 3), which has severed Old Beer Road, no change in cliff top position was recorded prior to the July 2012 landslide, but in the four years to 2016, a total of 19m of cliff top recession occurred (a maximum of 13m was lost between the 2006 and 2012 imagery, but this was probably all lost during the summer of 2012; a further 4m was lost between 2012 and 2014, and 2m more was lost between 2014 and 2016.
  - At Whiteacre (CBU2) where no change in the cliff top position can be measured prior to 2006, but 10m retreat occurred in the subsequent eight years. Prior to 2006 this CBU is known to have been active, with the former beach access path being lost prior to the 1933 OS map, however this activity was limited to the cliff face and does not appear to have resulted in retreat of the cliff top.

The data indicates regular, localised episodic failures on the cliff. In most cases, failures did not lead to significant headscarp recession and principally involved collapse of debris temporarily stored on the cliff face onto the beach.

In contrast, the failure fronting 'White Haven' in CBU 3 that began in 2012 and led to the closure of Old Beer Road has resulted in significant cliff recession. The data indicates that up to around 19m was lost between the failure in summer 2012 and 2016.

The evidence indicates that the mechanism of cliff failure is mudsliding, with failure on a shallow basal shear surface in the upper part of the cliff. The shear surface is probably associated the depth of weathered mudstone. There is some evidence to suggest that the lateral extent of failure at White Haven is controlled by sub-vertical faults in the mudstone.

The summer 2012 failure at White Haven was associated with a sustained period of high rainfall and it is likely that elevated groundwater levels are the principal trigger of cliff failures. Toe erosion, leading to steepening of the cliff, is the principal preparatory factor for erosion. Despite toe protection measures being present in the cliffs for at least around 30 years, the cliffs remain steep and continue to adjust form by periodic shallow failures.

Hydrogeology

In the absence of any ground investigation or instrumentation, little is known of the hydrogeological regime, however some reasonable broad assumptions can be made as a first approximation. Groundwater in the weathered mudstone and superficial Head deposits will be recharged by the infiltration of surface water draining downslope from inland. It is also likely to be fed from springs emerging from the base of the Upper Greensand west of Seaton Hole and by the soakaways in the gardens of cliff top properties. Groundwater flow pathways will depend upon local variations in the vertical and lateral permeability of the soil, however overall the direction of groundwater flow is likely to be southwards towards the cliffs.

There is often a close association between surface water and groundwater, with surface water infiltration recharging groundwater. Groundwater pressures in slopes may have a direct and profound effect on stability by both imposing a destabilising force on a landslide mass and by reducing the frictional component of strength along the landslide shear surface. There may also be secondary effects, such as groundwater issuing at the cliff top causing seepage erosion. This theoretical understanding supports the link between heavy rainfall and slope instability. As groundwater pressures have strong destabilising effects, drainage measures may be highly effective in improving the stability of a landslide system in many cases.

Cliff stabilisation measures

The primary driver of cliff instability and retreat at Seaton is currently groundwater, because toe erosion, which would have previously been more important, has been reduced by a rock armour revetment. The condition of the rock armour is currently poor in areas and in the absence of improvements its effectiveness in controlling toe erosion will continue to diminish. If the rock armour is not improved, toe erosion will restart with a marked adverse impact on cliff stability.

Once the toe of the cliff is better protected from further marine erosion and the toe erosion rate remains very low, the cliff will continue to degrade towards a shallower, stable angle and the cliff edge will continue to migrate inland at a progressively slower rate principally because of the action of groundwater. In this instance, drainage and slope strengthening measures may be of value in:

- Drainage measures to drawdown ground water below a critical level would reduce the rate of degradation and clifftop retreat following the implementation of toe protection works. This would maintain a steeper and more stable cliff profile.
- Slope strengthening, such as netting or rock bolting to increase material strength in upper cliff would hold weak, weathered mudstone and Head deposits in place and allow vegetation to develop and further stabilise the weak materials. They may also allow large pre-failed blocks of mudstone on the cliff to be held in place.

There are many different types of drainage system with varying degrees of complexity and cost. Drainage to control local surface water run-off may in its simplest form consist of open shallow ditches, or trenches with an impermeable lining backfilled with gravel to the ground surface. Such drains have the effect of reducing infiltration of rainwater into the ground, and hence reduce groundwater pressures to stabilise the slope.

Gravel-filled trenches may be constructed to a deeper level to intercept groundwater flows as well as surface water flows. Such trench drains typically have an impermeable lining on the base and downslope face and/or a permeable geotextile wrap to prevent ingress of soil fines into the drainage system. They are limited in depth to the digging reach of the type of excavator which can access the site, typically around 4m. If sufficiently closely spaced, they may be effective for drawing down groundwater where potentially unstable material is located at relatively shallow depth, such as along Old Beer Road.

For drainage of strata over 4m deep, boreholes would need to be drilled to the required depth and measures be put in place to pump groundwater from the ground and direct it away from the slope. Given the relatively shallow nature of failures at Seaton, deep drainage may not be a viable option given its relative high cost.

There are several methods for strengthening slopes. Techniques to prevent falling material, such as soil nails and meshing of the upper cliff, would hold weak, weathered mudstone and Head deposits in place and allow vegetation to develop and further stabilise the weak materials. Alternatively, if sufficiently strong rock was encountered at depth, rock bolts could be used to hold large pre-failed blocks of mudstone on the cliff and prevent further downslope movement. Piles could be used inland of the White House landslide to strengthen the cliff top and limit further headscarp recession, but as with rock bolting, this approach requires piles to be tied into sufficiently strong bedrock material.

It is likely that a combination of measures would be most effective.

Outline options for stabilisation of the cliffs are summarised in Table 3. Very approximate costs are provided, but these may vary considerably on completion of a ground investigation and interpretation of results to support detailed design of appropriate scheme(s).

Table 3. Recommended cliff management for West Seaton

Location Reference (as per Long List Appraisal)	CBU Name	Description	Option Description	Approximate Costs (£k)
Seaton Hole	CBU 1 Seaton Hole Landslide	Relict landslide in Upper Greensand characterized by debris apron fronting sub-vertical cliff.	Shallow drainage (<4m) Deep drainage (>4m depth) Netting and rock bolting	1 to 10 10 to >100 1 to 10
Old Beer Road	CBU 2 Whiteacre	Simple cliff in Branscombe Mudstone characterised by periodically active mudslides.	Shallow drainage (<4m) Deep drainage (>4m depth) Netting and rock bolting	1 to 10 10 to >100 1 to 10
Old Beer Road	CBU 3 – White Haven landslide	Simple Cliff in Branscombe Mudstone characterised by active landsliding.	Shallow drainage (<4m) Deep drainage (>4m depth) Netting and rock bolting Piling to limit expansion of the active landslide	1 to 10 10 to >100 1 to 10
Old Beer Road	CBU 4 – Seaforth Lodge	Simple Cliff in Branscombe Mudstone characterised by periodically active mudslides.	Shallow drainage (<4m) Deep drainage (>4m depth) Netting and rock bolting	1 to 10 10 to >100 1 to 10
The Pillar	CBU 5 Ingon House Chine ‘The Pillar’	Simple Cliff in Branscombe Mudstone. The cliff is the confluence of a stream that flows obliquely to the cliff, resulting in the formation of a narrow arête.	Shallow drainage (<4m) Deep drainage (>4m depth) Netting and rock bolting	1 to 10 10 to >100 1 to 10
Check House Seawall	CBU 6 Check House	Simple Cliff in Branscombe Mudstone characterised by shallow failure of the upper cliff.	Netting and rock bolting	1 to 10
Check House Seawall	CBU 7 West Walk	Simple Cliff in Branscombe Mudstone characterised by shallow failure of the upper cliff.	Netting and rock bolting	1 to 10

Conclusion

A study of the cliffs between Seaton Hole and Seaton town has been undertaken to review past behaviour, mechanisms of failure and options for stabilisation. The coastline is predominantly formed in red mudstone with a weathered upper part and a thin capping of gravelly head deposits. The area of Seaton Hole is marked by a fault that brings Chalk and Upper Greensand to sea-level to form Beer Head.

A review of data from the 1890s to present day shows this area has a long history of cliff instability. However, because failures have typically involved collapse of material from benches midway up the cliff on to the beach the measured rate of cliff top recession has generally been very low. The pattern of historical cliff toe erosion has also been low, and since emplacement of rock armour in the 1980s, has been near zero. Despite the toe protection, periodic failures have occurred, indicating the cliff is sensitive to factors other than toe erosion. The pattern of behaviour has changed in recent years, and landsliding since the summer of 2012 has led to significant retreat of a section of the cliff top and loss of a 50m long section of Old Beer Road. Landsliding has resulted in a steep headscarp and it is likely that failures will continue for several years, potentially increasing the length of road lost and also extending further inland.

Recent landslide activity is associated with a period of sustained heavy rainfall, and it is likely that this is the primary trigger of failure of the weak upper cliff materials. Toe protection measures are locally in a poor condition, and there is a need to ensure they are improved to maintain low rates of toe erosion. Should toe protection measures become worse and erosion rates increase it is likely that the cliffs will be adversely affected. Assuming that toe protection measures are improved, additional methods to limit future cliff activity comprise drainage and slope strengthening. Given that failures of the upper cliff tend to be shallow, drainage measures could comprise machine-excavated catch-drains of nominal 4m depth that intercept shallow groundwater before it reaches the coastline. Slope strengthening measures include netting to stop lose material falling to the beach and rock bolts to hold blocks of failed bedrock in place. Given the weak and weathered nature of the upper part of the mudstone, bolts would need to be anchored at depth to be of benefit.

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