



The Rocky Coast of South Devon and Its 'Disappearing' Village

12

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Abstract

The rocky coast of South Devon epitomises the coastal landscapes of the western extremities of the unglaciated lands of southwest Britain and northwest Europe. Both have a commonality of Variscan foundations, and a shared history of tectonic and climatic change throughout the Quaternary period. The Start-Prawle coastal landscape of South Devon exhibits the impact of periglacial conditions on coastal slopes, and multiple shorelines as key features of sea level change. Under contemporary conditions, the local greenschist responds to the coastal weathering environment by exhibiting rapid rates of rock decay and associated landforms at different scales, as demonstrated both by natural exposures and by local greenschist stone utilised in coastal constructions. As an example of the human influence on a landscape, the impact of nearshore dredging on a coastal settlement shows how lack of adequate prior understanding of local coastal processes may unwittingly lead to irreparable damage of a community.

Keywords

Quaternary • Periglacial • Tafoni • Shore platform • Weathering • Storm

12.1 Introduction

For the purpose of this chapter, the coast of South Devon is defined as that bounded by the estuary of the River Tamar to the west, and that of the River Exe to the east, a generalised coastline length of approximately 90 km. The bounding

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estuaries are outlets for rivers which head in North Devon, and drain the flanks of the Dartmoor massif, with catchment lengths of >60 km. In central South Devon, the southern flanks of Dartmoor are drained by the rivers Erme, Avon, Dart and Bovey/Teign with catchment lengths of 20–40 km.

These boundaries define the southward bulge of South Devon towards the English Channel culminating in the Start-Bolt peninsula, the focus of this chapter. Its rocky coastline extends from the west-facing coast of Bigbury Bay to the east-facing coast of Tor Bay. The former is directly exposed to storms and swell waves from the Atlantic Ocean with a fetch of ~7000 km; the latter is exposed to storm waves travelling down the English Channel with a fetch of ~370 km. To the south, the fetch is limited to 150–200 km by the opposing coastline of northern Brittany.

12.2 Regional Setting

This chapter focuses on a relatively small area of southernmost Devon, the Start-Prawle promontory, a stretch of coastline some 6 km long (Fig. 12.1). The overall story of landscape evolution of this distinctive terrain is then illuminated by reference to a broader canvas, including the adjacent land surfaces to the north. Important keys to the regional landscape are present also at sites further afield in Torbay, where significant and relevant features are developed in limestone rocks.

12.2.1 Geological Foundations

The southwest (Cornubian) peninsula of England extends south-westward for approximately 200 km, embracing the counties of Cornwall, Devon and part of Somerset. It is formed largely of rocks of Variscan age (Edmonds et al. 1975). There are four main groups of rocks which form the foundations of the geomorphological landscapes of South Devon.

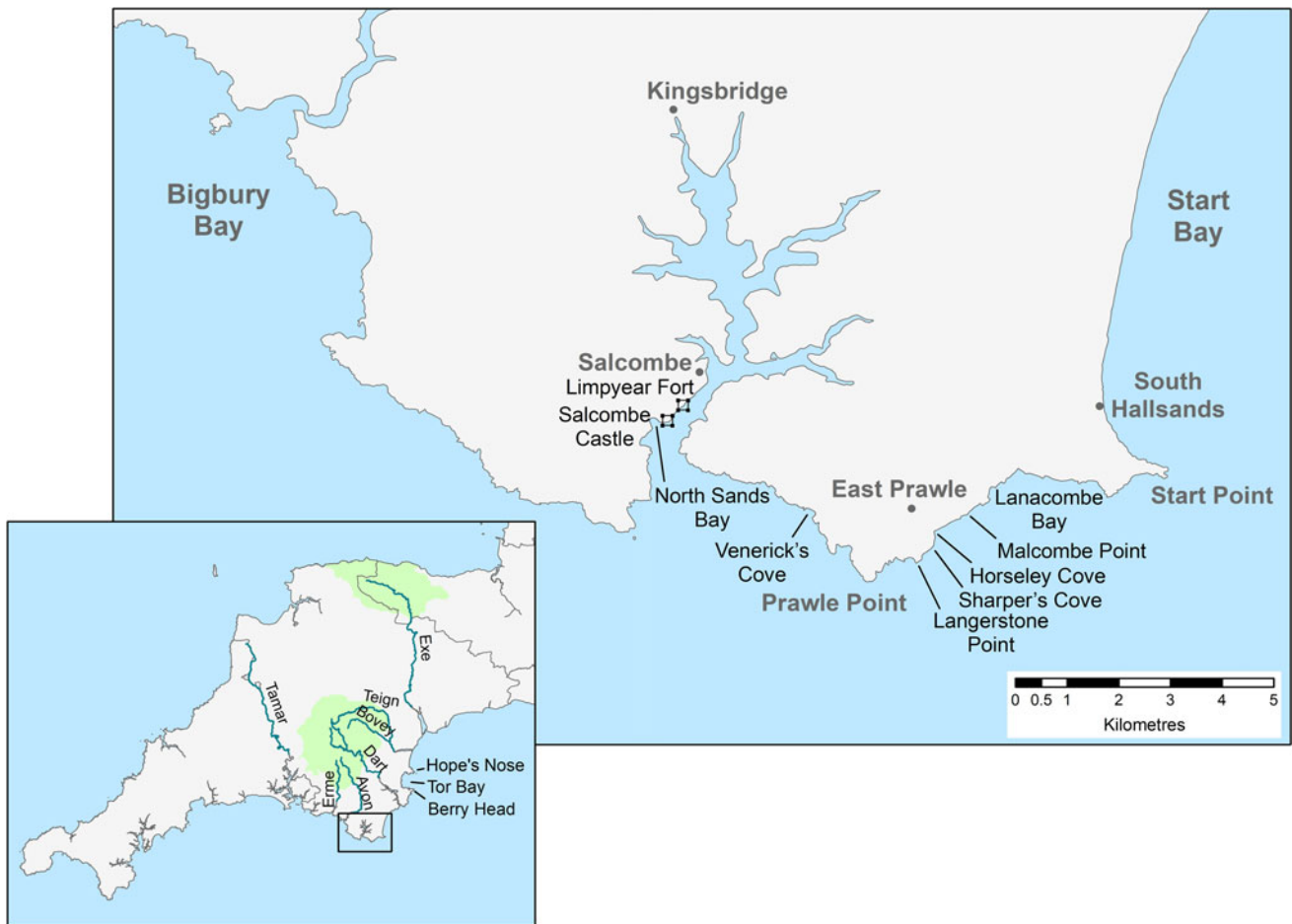


Fig. 12.1 Topography and site locations of the South Devon coast. Inset: Relevant locations in the wider region

The Dartmoor granite batholith, one of a series of igneous intrusions along the spine of the peninsula, forms much of the headwater catchment area of the South Devon rivers. To the south of Dartmoor, Lower, Middle and Upper Devonian rocks of the Dartmouth Formation comprise a range of strongly folded sedimentary rocks—slates, siltstones, sandstones and conglomerates striking E-W across the landscape. Restricted but geomorphologically important outcrops of Lower Carboniferous limestones occur on the east and west margins of the study area around Torbay and the Plymouth area, respectively (Ussher 1903; Leveridge et al. 2003). At the southern margin of the study area schists form a distinctive belt of plateau terrain up to 9 km from east to west, terminating in Start Point, and up to 4 km north to south. These rocks are dated as ~ 300 Ma in age, placing their formation in the late Carboniferous (Dodson and Rex 1971). The southernmost coast of South Devon between Prawle Point and Start Point, a major focus of this chapter, is formed in these rocks.

A significant factor in understanding the evolution of the current geomorphological landscapes of southwest England during the Quaternary period (the past 2.59 Ma) is that of vertical crustal motion. This has been modelled by Westaway (2010), based on topographic surface reference points of known elevation and age, such as river terraces, marine platforms and cave floor levels. These landforms are often associated with sedimentary and other deposits which permit age determinations. Westaway inferred that at ~ 3.1 Ma BP, a time approximating to the onset of the Quaternary, erosional flats cut across folded rocky terrains at the current elevation of 135 m asl (above sea level) were formed by marine action. It follows from this that surfaces above 135 m asl were formed prior to the Quaternary, in the Neogene period and earlier, whereas South Devon landscapes at lower elevations were formed by processes active within the most recent 2.59 Ma. It is estimated that some 60 m of the uplift of South Devon has occurred within the most recent 0.9 Ma. It follows that all landscapes below 60 m asl have been

sculpted subaerially during that timespan. The pulsed uplift throughout that period has led to landscapes predominantly characterised by plateaux and interfluvial surfaces, and terraced surfaces inset into them by river incision.

12.2.2 Topography

The major rivers draining towards the South Devon coast—the Exe, Teign, Dart, and Tamar, flow across plateau landscapes into which they are sharply incised, especially in their lower reaches. They cascade down a staircase of river terraces which are associated with planation surface remnants, termed 'flats', on interfluvial plateaux (Brunsden et al. 1962). Based on landforms alone, this combination of river terraces and associated planation surfaces has led to a general recognition that the Cornubian landmass has risen relative to sea level throughout the Quaternary and, furthermore, that the rise has been stepwise rather than smooth, with episodic uplift separated by periods of crustal stasis.

Bridgland (2000) demonstrated that these episodes are driven by alternating periods of incision by erosion and accumulation by deposition during alternations between glacial and non-glacial climatic conditions through the Quaternary. Each of the four major South Devon rivers emerges into the English Channel through an estuary, beneath which the bedrock floor has been eroded down to depths of 35–45 m, and subsequently refilled by sediment (Campbell 1998). These drowned valleys were formed in glacial periods when sea level fell up to >100 m lower than now, creating a land surface on which the South Devon rivers formed tributaries to a major river channel which drained much of the land surface of western Europe along the axis of the English Channel and into the Atlantic Ocean throughout the last two major glacial episodes (Antoine et al. 2003).

The upward vertical motion of the crust reflects rates of surface erosion, which in turn reflects the climatic oscillations powering erosion processes and their variations through time. The reduction of the landmass by surface erosion processes affects the loading and thickness of the crust below. In this way, the cyclic nature of Quaternary climate change is reflected in a temporal pattern of landscape denudation and consequent pulsed crustal uplift.

In terms of landscape interpretation, South Devon has an unusual juxtaposition of landform features in the form of marine terraces, fluvial terraces and subterranean caves, all of which may preserve archives of environmental change and crustal uplift (Bridgland 2000). Their elevation provides a marker of relative sea level against the landmass. They provide sites which may capture and accumulate sediments indicative of relative sea level and changing climates, and

may also offer information regarding the processes involved in their formation.

The materials that accumulate may present a range of items which can date their formation. Thus, marine organisms can be interpreted in relation to their known requirements of habitat type and temperature requirements, in addition to being susceptible to both amino acid racemisation and ^{14}C dating. Accumulations of unconsolidated sediments such as quartz and feldspar sands are susceptible to luminescence dating, and accumulations of calcite are susceptible to uranium-series dating.

12.3 Coastal Landscapes and Landforms

Figure 12.2 illustrates the characteristic form of the coastal slopes of South Devon which is particularly well developed between Prawle and Start Points. Here the south-facing coastline is protected by its bounding promontories from destructive storm wave attack from both west and east. The characteristic slopes comprise several distinct bedrock slope elements mantled with associated unconsolidated sediment materials. The relationship between slopes and associated surface materials is shown in profile form in Fig. 12.3.

12.3.1 Slope Profile Facets

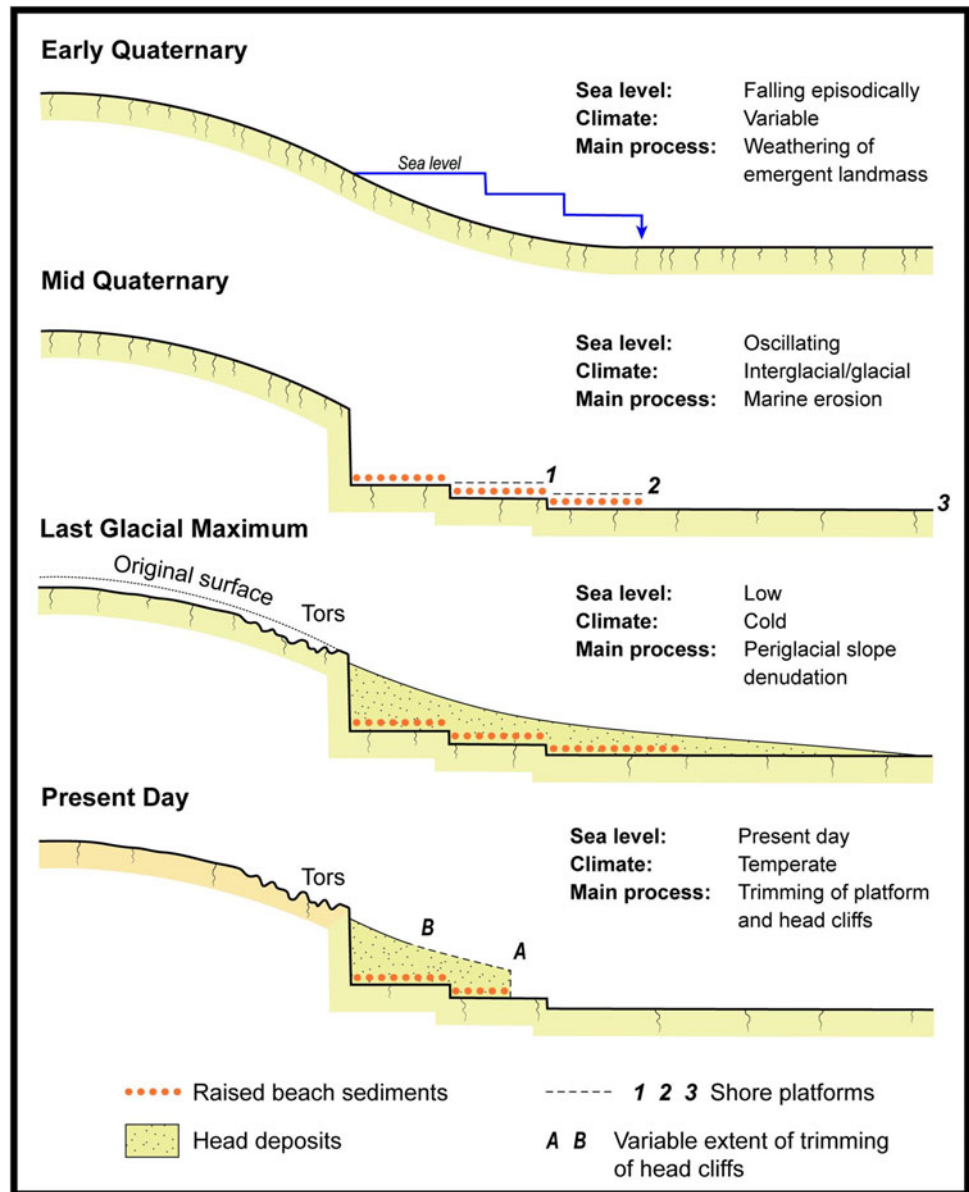
12.3.1.1 Summit Plateau Surface and Bedrock Cliffs

The Start-Bolt promontory is formed by a plateau at 100–130 m asl which terminates at a sharp break of slope at the head of the coastal cliffs (Fig. 12.4). Bedrock cliffs below, commonly exceeding 30° in gradient, are formed on the hillslope by rugged outcrops of schist, where they make striking contributions to the landscape. These rock outcrops (Fig. 12.5) form tors, and are associated with spreads of angular boulders and blocks of rock strewn across the land surface at the foot of the craggy schist cliffs to form rocky aprons termed blockfields. These forms are characteristic of mechanical weathering processes such as frost weathering, which is particularly active under periglacial conditions.

12.3.1.2 Tafoni

A notable feature of the rock masses exposed on the cliffs is the cavernous weathering forms hollowed out into cliffed rock faces which are termed tafoni (singular *tafone*) (Fig. 12.6). These features characteristically form in weathering environments in which salts are freely available, such as coasts and deserts. They are particularly well formed in the greenschist cliffs near Prawle Point (Mottershead and Pye 1994).

Fig. 12.2 Profiles illustrating the evolution of the Start-Prawle coastal landscape through the Quaternary period, in terms of climate, sea level and geomorphic processes



The Prawle tafoni face out towards a range of compass orientations from 60° through to 280° without apparent preference. Their gross dimensions are measured in metres, with mean values of width and height of 3.1 m and 1.9 m respectively, and a mean depth to backwall of 1.3 m with occasional individuals exceeding 2 m. Single tafoni may grow laterally and merge with their neighbours to exhibit a complex pattern of caverns and ledges which is not susceptible to simple morphometric description.

A common tafone feature is a curtain of rock extending either vertically downwards (termed a visor) or laterally across the orifice, behind which the tafone opens out. These rock visors are 4–15 mm thick and often exhibit identifiable faint mineral staining on their outer face, evidence of case hardening of the exposed rock surface. This

appears to be a result of a preliminary stage of rock weathering within the rock mass before exhumation, whereby iron minerals released by initial chemical weathering of ferromagnesian-rich silicate minerals are reprecipitated along joints where it accumulates, blocking rock pores and increasing the mechanical strength of the rock. In this way, the greenschist is compartmentalised into rock masses encased by a resistant patinated zone of rock. Exhumation by denudation then exposes the patinated joint surfaces to subaerial weathering to which they are more resistant than the core from which the weathered mineral components had been leached. This creates the initial conditions for tafone development whereby the less resistant core is more easily weathered than its more resistant casing, a process termed differential weathering.

Fig. 12.3 Panoramic view of the Prawle coast looking east from Prawle Point. Landscape facets as follows: 1—Intertidal platform, 2a—Shore platform, intensely weathered zone just above High Water Mark, 2b—Shore platform, less weathered zone upshore, 3—Cliff created by current marine erosion in head deposits, 4—The topographic apron formed by head deposits, 5a—Tors exposed due to removal of formerly surrounding regolith by mass movement during periglacial conditions, 5b—Erosion surface formed by removal of former regolith by solifluction, 6—Planar skyline formed by the erosion surface of the South Hams plateau (Photo Derek Mottershead)

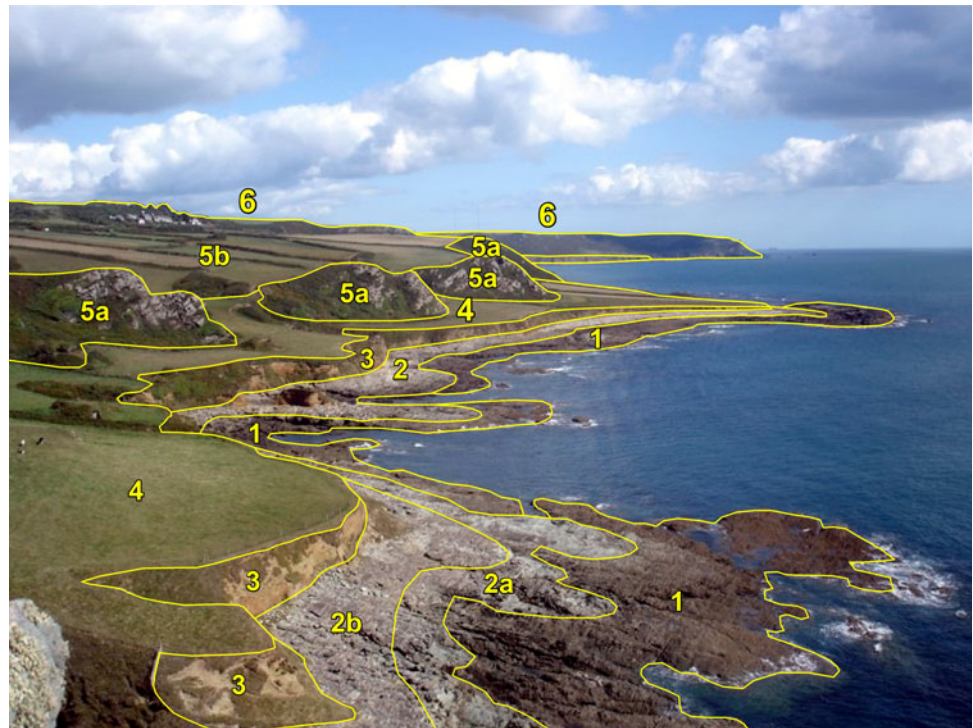


Fig. 12.4 Greenschist outcrops formed by erosion of formerly surrounding regolith, now exposed as rugged cliffs up to 20 m high (Photo Derek Mottershead)



The presence of a vertical overhanging visor by its very presence creates a domed ceiling in the tafone. Since the visor is a coherent and integral part of the rock mass from which the tafone is hollowed out, it follows that the dome

must be created by vertical recession opposing gravity of the ceiling of the tafone, an autonomous process taking place within the shelter of the cavern without the assistance of any external mechanical agency.



Fig. 12.5 View north across the South Hams plateau; the broad summit plane is at an elevation of ca. 130 m a.s.l.; the higher ground forming the skyline is the granite massif of Dartmoor (Photo Derek Mottershead)

Additionally, ceilings are often characterised by well defined cylindrical alveoli which penetrate upwards, commonly normal to the foliation (Fig. 12.6c). These features, circular or elliptical in planform and with a slightly domed ceiling as 10 cm, and diameters of 10–30 cm may attain depths of >10 cm. Alveolised ceilings are indicative of a process that is extending the cavern ceiling upwards.

At a smaller scale, where present as petrographic features, blades of quartz and crystals of magnetite stand proud of the rock surface, implying that crystal size and composition are both controls on recession rate.

The features described above point towards rock weathering as the mechanism primarily responsible for surface recession. The interior rock surface is much softened, and readily yields when scratched with a coin. On ceilings, packs of loose flakes may be present which are easily detached with the slightest stroke of a finger. Here a smooth, lightly crusted layer 2–3 mm deep may form, and where the ceiling steepens downwards towards the cavern walls this becomes ribbed and rippled to create a microtopography akin to that of stalactite flowstone. When moistened, which occurs under conditions of onshore sea mist, this film attains the consistency of a slurry, implying a slow gravity-driven flow down the interior tafone walls.

The accumulation of sandy silt debris to a depth of several centimetres in natural sediment traps on ledges on tafoni

walls and in basins on the floors shows that the dominant mechanism of rock breakdown is weathering at the granular scale. SEM imagery shows the weathered granules to be slightly edge-rounded suggesting that weathering by chemical corrosion may be responsible for initial weakness at inter-crystal boundaries causing detachment of individual particles from the tafone surface.

The development of the tafoni thus appears to be a two-stage process. The early stage weathering creates the case-hardened margins adjacent to joints, later to be exposed at the surface through the denudation of overburden. Once exposed to surface processes, the case hardening becomes breached, leading to the exposure of less resistant rock within the mass, previously weakened by the early stage weathering and translocation of iron compounds from the original minerals.

Examination of both subsurface rock and accumulated weathering residue reveals high concentrations of chloride, indicative of its contribution to chemical corrosion in this particular weathering environment.

12.3.1.3 Smooth Hillslopes

Smooth slopes concave in profile stretch from the bedrock cliffs down to the base of the coastal slope, forming chutes between cliffed outcrops and the aprons below them. Sweeping down from the plateau in some instances, they

Fig. 12.6 Tafoni features.

a Tafoni on a vertical surface with protruding visors, over 10 mm thick in places, aligned along a joint where the adjacent rock has become impregnated with and case-hardened by iron minerals. Within the encased rock mass, weathering has caused the rapid recession of the rock surface.

b Cylindrical holes penetrating upwards into the rock of an overhanging rock mass, which itself forms a large visor. These alveoli range in diameter up to 30–50 cm, and in depth up to 10 cm. At an elevation of 40 m asl only a limited range of potential weathering agencies is capable of accessing these tafoni from below (Photo Derek Mottershead)



decline in gradient from 15° to 2° over a distance of 10 to 300 m and terminate in the form of shoreline cliffs formed in very coarse unconsolidated sediments.

12.3.1.4 Unconsolidated Shoreline Cliffs

These features (Fig. 12.7) form a major component of the coastal landscape. Situated atop the shore platforms, the cliffs are formed by the sequence of unconsolidated sediments accumulated at the base of the hillslope. These cliffs

are readily eroded during episodic large storms, freshly exposing strata which record a history of environmental change and the associated development of the geomorphological landscape through late Quaternary time. The cliffs represent the truncation of the Head deposits by recent and current storm waves, and clearly indicate that during the lower sea levels associated with glacial phases the Head had extended across the exposed land surface below current sea level well beyond its current truncated limit. Subsequently it

Fig. 12.7 View west from near Peartree Point, showing the range of slope facets including tors, smoothly graded slopes formed by the Main Head, the coastal cliffs, and underlying shore platforms. The Head exposure reaches a depth of ca. 35 m in places. Three shore platform levels are visible in the centre of the image, with pinnacles of Main Head isolated on platforms which have been dissected by erosional chasms along weathered-out joint planes (Photo Derek Mottershead)



has been trimmed back to its current position by the Holocene marine transgression which terminated some 6 ka before present.

12.3.1.5 Shore Platforms

The multiple shore platforms (Orme 1960) are a remarkable feature of the Start-Prawle coast (Fig. 12.8). They are particularly well preserved between Prawle Point and Start Point, where they are sheltered from direct attack by high Atlantic storm and swell waves travelling eastwards along the English Channel.

The shore platforms are well displayed on the current foreshore, extending seaward from beneath the unconsolidated cliffs. The platforms are dissected by numerous chasms excavated out along joints formerly occupied by weathered rock, and now occupied by loose beach sediment. Close inspection of Google Earth imagery of 23.09.2017 suggests that the platform surface only slowly submerges as it extends seaward from the shoreline. These submerged rock surface patterns continue seawards visibly from Horseley Cove (50.211° N; 03.703° W) out for at least as far as 1100 m, suggesting seaward continuity of the submerged platform to that distance. At 1100 m from shoreline the 5-fathom bathymetric contour (=−9 m) implies a submerged platform gradient of no greater than 0.009 (=9 m per km). Landward from the unconsolidated cliff the rockhead landscape is buried by the unconsolidated sedimentary strata. Where the rocky hillslope extends right down to the shore (as at Sharper's Cove 50.2163° N; 03.690° W), it clearly forms a landward limit to the platforms. Where, however, the hillslope is set back from the coast and fronted by the

smooth slope formed by unconsolidated sediments there appears no good reason not to surmise that the rock platforms extend right up to the slope foot. At Horseley Cove this lies some 200 m inland from the Malcombe Beach, implying a total platform width at this location of up to 1300 m.

The three platforms form a staircase rising landward, each separated from its neighbour by a vertical cliff 2–3 m high. The surface of each slopes seaward with a gradient of $\sim 3^\circ$. At the head of each of the three platforms an erosional notch can be found, at approximate elevations of current sea level, +4.5 m and +7.5 High Water Mark Spring Tides (HWMST). Previous authors have identified them by supposed age or elevation. Since the age of the platforms is not well defined, and the fact that each one varies in elevation on account of its gradient, apparently precise designations based on age or elevation are not necessarily helpful. They are better designated as low, middle and high platforms, respectively.

In general, the high platform is more restricted in exposure, and is best displayed where salients of bedrock breach the unconsolidated cliffs; the lower ones are well developed in the bays. Good examples are present at Sharper's Cove and Capstone Cove (50.204° N; 03.719° W). The platforms are best viewed at low tide which tends to highlight the low platform and facilitate its distinction from the middle one.

A further platform bounded by a cliffline is reported by Hails (1975) in Start Bay, submerged by the Holocene transgression and standing at an elevation of −42 m. This complements the higher platforms at terrestrial elevations and is an integral part of the development of the geomorphological landscape.

Fig. 12.8 Shore platforms at Great Mattiscombe Sand (300 m W of Peartree Point). The Low platform is exposed at low tide in the foreground, with a cover of beach sand present to the shoreward (1); the fragmented Middle platform, some 2 m higher, overlooks it across the image in the near middle ground (2); the High platform, in the rear middle ground, extends seawards from beneath two isolated pinnacles of Main Head (3) (Photo Derek Mottershead)



The platforms are indicative of periods when the sea stood at a particular level relative to the landmass for long enough for waves to create a platform by lateral erosion at the base of the cliff. Clearly, high energy storm waves will be more effective in this, concentrating high amounts of energy at the cliff foot, and eroding an undercutting notch which will lead to toppling of the mass of the cliff above as it becomes unstable, thus extending the head of the platform shoreward. Thus, the rate of cliff retreat is also the rate of shorewards platform extension.

This creates a means of estimating the time taken for shore platforms to develop. Sunamura (1992) recognised that the rate of cliff retreat is highly variable, ranging over five orders of magnitude. It is strongly dependant on the mechanical strength of the rocks forming the cliff; thus, granite cliffs may retreat at a rate measured as 10^{-3} ma^{-1} , whereas unconsolidated Quaternary sediments may erode at rates measured in 10^3 ma^{-1} . Prémaillon et al. (2018) classified rocks into resistance categories based on parameters evaluating mechanical strength. They grouped rocks into three categories, in which schists fall into the 'hard' category. They quote a median value of cliff retreat in such hard rocks such of 29 mm a^{-1} . This implies that the 1300 m wide platform at Horseley Cove could have been formed by $\sim 45,000$ years of wave action at a stable sea level. This is less than the duration of a single interglacial phase ($\sim 60 \text{ ka}$), such as the most recent Ipswichian interglacial

(MIS 5), which could comfortably have accommodated its formation based on the retreat rate assumed.

Evidence from South Hallsands, however, casts further light on shore platform history (see Sect. 12.6.2). In the late nineteenth century, the foreshore was formed by a barrier of shingle, up to 40 m wide. Following the dredging of shingle from its coastal face, subsequent storms eroded the remaining shingle to expose a planar shore platform at intertidal level. This platform is at least 20 m wide and undercuts a backing cliff with a lateral cliff-foot notch up to 2 m deep. It now forms a rocky foreshore in direct contrast to the pre-dredging shingle barrier. Clearly this rock platform did not form overnight during the twentieth century storms. The effect of the storms was simply to expose it from beneath its former shingle cover. This sea level platform must now be interpreted as a historic form developed over a long period in some previous era or eras when the sea also stood at its present high level. It was buried by the deposition of shingle by wave action when sea regained its current level during the Holocene transgression around 6000 BP (Hails 1975).

The considerations above have significant implications for the Start-Prawle platforms. First, the low platform at current sea level, extensively developed along the Start-Prawle coast and apparently a contemporary feature, is shown by the evidence of South Hallsands not to be so, and that it originated instead from in an earlier phase or phases of

interglacial high sea level. And secondly, coastal erosion processes are shown to be capable of creating shore platforms in a relatively short timespan on the Quaternary scale, and measurable in tens of thousands of years.

12.3.2 Unconsolidated Sedimentary Landforming Materials

12.3.2.1 Ancient Beaches

Ancient beaches are commonly described in existing literature relating to the field area as raised beaches. In this area, however, sedimentary units interpreted as historic beach units may also be found in a stratigraphic sequence at approximately high tide level in direct contact with the current beach. It is therefore more appropriate to describe this group of sedimentary units as ancient, rather than raised, beaches.

They can be found as intermittent isolated exposures at various points along the Start-Prawle coast, from South Hallsands (50.234° N; 03.659° W) to Venerick's Cove (50.215° N; 03.737° W), and commonly form the basal unit of a sedimentary sequence beneath the Main Head layer.

They are also associated with the rock platforms at levels upward from around High Water Mark (HWM), most commonly at the higher levels of the middle and upper platforms. They rest on the bedrock surface of the shore platform, although at Malcombe a rough gravel bed directly underlies the beach and bedrock was not seen. At Sharper's Cove, in contrast, rounded pea-sized quartz-rich gravel is compressed into a bedrock crevice above the middle platform. These ancient beaches vary from indurated beds incorporating cobble sized clasts (South Hallsands, visible from the viewing gallery) to well sorted medium grade sand and are rarely more than 2 m thick. A particular feature is the decay of small rock fragments in the top 20 cm of the unit, from which iron has been weathered out to form a rusty halo around each one. This suggests post-formation weathering of these units, although it is not clear whether this took place when the units were exposed to weathering agencies before or after burial by the overlying Main Head.

A carbonate-rich sandy formation at Venerick's Cove, however, differs in many respects from the other sites (Morawiecka 1993, 1997). It is at least 12 m deep and, although largely obscured by a vegetation cover, is not visibly directly overlain by other Quaternary sediments. It is consolidated as sandrock in its basal layers, and partially consolidated in some visible upper layers. The basal layer is interpreted as beach sand (Ussher 1904), whereas the upper sand units are considered to be of aeolian origin. A distinctive feature of the sandrock is that the top surface of the basal unit (in situ and as nearby detached boulders) displays well

developed vertical karstic pipes formed by gravity-driven solution (De Waele et al. 2011). They are formed where the hostrock has been disaggregated by focused dissolution of its calcite cement in an apparently random spatial pattern. The individual pipes are circular in planform, though more complex when two or more have coalesced laterally. Pipe diameters range from 70 to 750 mm, with a mean depth of 320 mm, although this latter figure measures the depth only as far down as the top surface of any infill blocking the pipe. The infill comprises sand particles liberated by dissolution, which may or may not become recemented within the pipe. Cementation may also occur on the walls of the pipe itself in the form of a tubular calcrete crust.

12.3.2.2 Stratified Terrestrial Sediments

This generic term is here used to embrace a range of deposits at the base of the Main Head. At many points a sedimentary unit comprising various proportions of clay, silt, sand and stony fractions forms a sandwich of strata in the lower part of the stratigraphic sequence, sandwiched between the ancient beaches and the Main Head. Although apparently continuous along this coastline, this unit is exposed only intermittently at any given time or point. The unconsolidated cliffs are susceptible to slope failure caused by storm wave erosion at their base, leading to the abundant slumps which obscure much of the cliff foot. In this way, exposure of basal sediment units will vary through time, revealing different sections at different times.

These sediments may vary in colour between red and buff, with a blue gley colour in one earlier exposure now degraded by recent weathering. In places there is an irregular contact with the overlying base of the Main Head; in another instance, it appears to form a detached raft of clayey sediment encased by overlying and underlying gravels.

Their singular characteristic is the high proportion of fines, in contrast to the dominant Main Head. The origin of the clay material is presumed to be a regolith which developed across the landscape prior to the deposition of the Main Head. This may be indicative of an origin as former soils which were stripped by slope processes and redeposited. The varied mixtures of different fractions, including occasional small stones and chips of rock are likely to be indicative of a range of local depositional processes, varying from one exposure to the next.

12.3.2.3 Erratic Boulders

Three boulders of non-local origin are present on the shore near Malcombe Point (50.213° N; 03.697° W). Their lithologies are identified as quartz diorite, granite-gneiss and altered dolerite, respectively. Their provenance is unknown, but it is generally regarded that they derive from an igneous/metamorphic domain to the west, possibly the Irish Sea or an

even more distant source (Harker 1896; Hunt and Ussher 1901; Mottershead 1977a).

The one boulder visible on a field visit in 2018 was situated at 2.5 m from the adjacent cliff formed by the Main Head (Fig. 12.9). In stratigraphic isolation other than contact with the current beach, there is no direct means of identifying how it attained its current position. There appear to be two possibilities.

1. It was delivered to its present resting place by an iceberg which became stranded onshore at the foot of the Main Head cliff or,
2. It was delivered to this point prior to the formation of the Main Head, and then became buried beneath it, subsequently to be re-exposed as the Main Head was stripped back by coastal erosion in the 6000 years following the termination of the Holocene transgression.

The keys to this issue are the proximity of the erratic to the Holocene cliff and the contemporary rate of cliff recession by coastal erosion. There are no known formal observations of the latter, although there is abundant field evidence that the unconsolidated cliffs formed by the Main Head are very unstable in the face of regular impacts of storm waves at the

base of the cliffs and the evident presence of multiple cliff face slumps. This suggests that cliff retreat is currently a process which has been active since the end of the Holocene transgression. For the boulder to have been deposited at the cliff foot would require a post Holocene cliff retreat rate to have been constrained to as little as 0.42 mm a^{-1} , a very unlikely circumstance in the case of such unconsolidated material directly exposed to storm waves. This points strongly to the interpretation that the erratics have been exhumed from beneath the Main Head and therefore predate its deposition.

It is generally agreed that the delivery of the boulder to this position was by iceberg rafting, most probably from a source to the west, such as the Irish Sea domain or even beyond. The difficulty with this explanation is that the boulder was deposited at a temperate high sea level, whereas phases of extensive glaciation coincide with low sea levels at -100 m or more. It is possible to reconcile this dilemma by postulating a Heinrich event, when a rapid disintegration of an ice sheet released a swarm of large icebergs into a northern ocean. They were then dispersed by ocean currents to distant shores, carrying them eastwards up the English Channel. This event must have predated the deposition of the overlying Main Head, but would also have occurred at a time when global sea level was close to its current level. This

Fig. 12.9 Erratic boulder near Malcombe Point. Note its smooth rounded surface which contrasts greatly with the adjacent angular, jointed and rough schist boulders which have been released from the Main Head cliff behind. This is one of three such boulders in the vicinity variously visible at different times according to the disposition of modern beach material. The provenance of these boulders is generally accepted as the western extremities of the British Isles or Brittany (Photo Derek Mottershead)



points towards a stage in the glacial cycle such as a glacial/interglacial transition when such a circumstance would have prevailed.

These boulders are part of a suite of coastal erratics around the English Channel coast, notably including that named Giant's Rock at Porthleven, Cornwall, and extending eastwards to Sussex (Kellaway et al. 1975; Mottershead 1977b). They also occur in Brittany and on the floor of the English Channel. Supporting evidence is present on the North Devon coast at Croyde Bay, where such an erratic boulder is found beneath a sedimentary cover dated at MIS 5, implying that the glacial event occurred prior to that time (Campbell and Gilbert 1998). This may provide an appropriate analogue for the Start-Prawle field site.

12.3.2.4 The Main Head

Throughout the 6 km length of coast between Prawle and Start points, the Main Head is the major stratigraphic unit in the sequence (Fig. 12.10). It extends seawards up to 270 m from the hillslope, and ranges in depth from ~35 m close to the hillslope to as little as 2 m at the distant Langerstone Point (Mottershead 1971; Keen 1998).

The sedimentology of the Main Head is characterised primarily by textural coarseness, angularity of clasts and lack of sorting. It consists of angular boulders and stones set in a matrix of red sandy silt and clay. The largest clasts commonly attain an a-axis length of >0.8 m; almost a quarter of samples examined contained a clast with a long axis of >250 mm, implying that significant force was required to transport them to their present position. The mean stone content (clasts >4 mm) is high at 54%. The lack of sorting indicates that it has not been significantly affected by any sorting agent such as running water or wind. The shape of the clasts in terms of roundness/angularity is dominated by those in the angular class. This means that they have not been rounded whilst in transport, and thus retain facets reflecting planar joints along which they fractured either during their formation by weathering or (possibly) during transport.

A further feature of the sedimentology is the preferred orientation of the clasts with a tendency towards parallel alignment of their long axes. Clasts are strongly oriented in the downslope direction, with their longer sides parallel to the direction of transport. Their mean orientation changes

Fig. 12.10 Section in Main Head deposit at Sharper's Cove. Angular clasts of locally derived greenschist are set in a matrix of fines dominated by sand and silt. A rough stratification is visible, with a layer of large boulders at the base and diminishing upwards. The basal layer includes an abundance of red sandy material, most likely former raised beach material that has been incorporated into the sedimentary mix during solifluction. At the top of the sequence a brown layer of fine sediment including some stones is the Upper Head, which incorporates a significantly higher silt content (Photo Derek Mottershead)



along the coast according to the general aspect of the local slope, swinging round from SSW to SSE normal to the contours of the coastal slope.

The particle size distribution of the <2 mm fraction of the fine sediments can usefully be compared with frost susceptibility curves (Caillieux and Taylor (1954). All are shown to lie within the frost susceptible domain. The Liquid Limit (LL) is a property which measures the behaviour of a fine sediment in relation to water. All the samples tested showed an LL of 25–30%, indicating that they liquify at a relatively low saturation level and begin to behave as a fluid. These properties collectively demonstrate that the matrix of the Main Head responds actively to both freezing and saturation, enhancing its propensity to downslope mass/gravity movement under such conditions.

The Main Head is therefore interpreted as a product of simple downslope gravitational mass movement. This becomes enhanced under periglacial environmental conditions during which alternate freezing and thawing causes a downslope creep, and seasonal thawing leads to mobile saturated soils. This combination of mechanisms creates accelerated rates of downslope movement of surficial materials, termed solifluction.

Ill-defined bedding is evident in some places, suggesting episodic deposition of the apparent stratigraphic units. This would appear to be characteristic of a mobile mantle of regolith and soil moving downslope in the form of solifluction terraces (Mottershead and White 1970).

12.3.2.5 Upper Head

A bed of finer sediment, 0.3–1 m deep, commonly overlies the Main Head. It forms the layer in which the topsoil is formed and is distinguishable in section from topsoil in both colour and texture. Sedimentologically, it is clearly distinguished from Main Head by its low stone content and lack of coarse clasts. Often buff in colour, it is cohesive and sometimes shows a columnar blocky fracture pattern.

Significantly the fines fraction also possesses a 20% higher silt content in comparison with the Main Head. This admixture of silt is consistent with the stratigraphic position of loessic material widely distributed in Devon (Harrod et al. 1973; Cattell 1997), Cornwall (Catt and Staines 1982) and other regions along the English Channel coasts as far east as Kent. The Prawle material, however, cannot be regarded as a pure loess of exclusively wind-blown origin; its characteristic stone content implies some degree of mixing during downslope transfer to its present position. It is therefore interpreted as deposited formed by solifluction.

These sedimentary components of the surface landscape represent a historical archive of depositional events which have created the current geomorphological landscape. They

are in several cases datable, providing valuable clues to the chronology of landscape evolution.

12.4 Geochronometric Markers

The geomorphological landscapes of today have evolved over time. In order to track their development, it is first helpful to place the various landscape elements in order of formation on the basis of their field relationships. By seeking age determinations from datable materials, it is then possible to construct a chronological sequence of landscape development.

The oldest elements in the South Devon landscape are the plateaux. The terrain of the Start-Bolt promontory is dominated by the South Hams plateau at around 130 m above sea level. It is accordant in elevation with similar planation surfaces in adjacent parts of the region which Westaway (2010) suggests as dating from approximately early Quaternary time, along with much of the Variscan terrain south of Dartmoor with its broad plateau skylines.

From the mid-Quaternary onwards, the foundations of the South Devon coastal landscape are the shore platforms at current sea level, and broadly at 4.5 m and 7.5 m OD. Clues to their age of formation are present at margin of the study area at Berry Head (Paignton) where caves with datable carbonate materials are associated with marine sediments and raised shore platforms (Proctor 1988; Proctor and Smart 1991; Baker and Proctor 1996). Uranium-series dating is applied to speleothems in Corbridge Cave in close association with laminated muds, thus enabling the sediments to be dated.

Major caves have developed at specific levels which correlate well with raised shore platforms both at Berry Head itself and more widely around South Devon, including those on the Start-Prawle coast. These caves and their contents provide precise markers both in form and age. The caves contain stratified mud sediments including a fauna of marine origin and speleothem structures which are datable by uranium-series isotopes. Speleothems associated with marine laminated muds at different levels are dated at around 155 ka and 210 ka, respectively. These indicate marine transgressions up to 5.8 m High Water Mark Spring Tide (HWMST) during MIS 5e and to >7.2 m HWMST during MIS 7. These conclusions indicate sea levels at 2.2 m and at least 3.6 m higher respectively, than its current level.

The limestones of Torbay also host several raised beach sites which preserve datable material in the form of the carbonate shells of marine organisms. These have been studied at Hope's Nose, Thatcher Rock and Shoalstone (Bowen et al. 1985; Mottershead et al. 1987). Raised beach deposits dated to MIS 5 and MIS 7 are indicative of marine

transgressions up to ~ 10 m asl, although the ambiguity of the local stratigraphy implies that the interpretation of these dates be treated with caution.

In a study of palaeokarst piping features in the Quaternary sandrocks throughout the Cornubian peninsula, an erosional remnant of a piped beachrock on the middle platform at Venerick's Cove (Morawiecka 1993, 1997; Pazdur et al. 1995; Walsh and Morawiecka 1999) was dated using thermoluminescence (TL) and radiocarbon techniques ^{14}C by Pazdur et al. (1995). It is perhaps unfortunate that the TL ages are difficult to reconcile with the ^{14}C dates which, as pointed out by Morawiecka (1997), are reliant on a number of significant caveats. For that reason, this chapter restricts consideration to the TL dates alone.

Pazdur et al. found that a single sample of grains from the sandrock mass dated at 116 ka BP, whilst two samples from the pipe infill yielded a mean age of 39 ka BP. This readily permits the interpretation that the initial deposition of the beach sand occurred during MIS 5e, the maximum of the Ipswichian interglacial, whilst the evidently younger pipe infill samples show mid-MIS 3 ages (Weichselian High Glacial). This would place the accumulation of the beach sand in a phase of high sea level and temperate conditions when higher temperatures would have facilitated crystallisation to create an indurated hostrock susceptible to karstification. It would also place the karstification of the hostrock as pre mid-MIS 3, during MIS 4 and early MIS 3, when cold climate conditions would have prevailed at a site at that time 150 km inland from the glacial low coastline (Antoine et al. 2003). These climatic conditions would have concentrated the flow of water through the landscape into a short melt season when snow and ice thawed, thereby creating conditions for focused dissolution at the low temperatures at which calcite is more soluble. Such a combination of conditions would appear to be highly favourable for the creation of the karstic solution pipes. This interpretation would appear to offer an explanation consistent with respect both to the mutual stratigraphic relations between beach sand, sandrock and piping and also the broader climatic and environmental context and likely geomorphic process domains prevailing at the relevant times.

Bedded fine terrestrial sediments overlain by Main Head near Malcombe Point include a bluish silty clay layer containing charcoal fragments, susceptible to ^{14}C dating (Mottershead 1993). This unit yielded ^{14}C ages of $17,880 \pm 260$ for the fine fraction, and $22,011 \pm 240$ for the $>125 \mu\text{m}$ fraction (Scottish Universities Research and Reactor Centre, Allocation 140/0780, Samples SRR-1855a, b). The possibility of contamination by modern rootlets implies that a more reliable value would be $> 22,000$. These dates are comparable to dates in the range of 21–29,000 BP for basal solifluction deposits in Cornwall (Scourse and Furze 1999)

and the Isles of Scilly (Scourse 2006). This would place the formation of the Main Head deposit in the early stages of MIS 2, the Last Glacial Maximum (LGM) cold phase.

The Main Head in South Devon has yielded no material suitable for dating, although the Upper Head has been dated in adjacent regions. Wintle (1981) has dated loessic sediments in similar stratigraphic position along the south coast of England from the Scilly Isles to Hampshire. The stratigraphic position, the strong silt component and the tendency to blocky fracture all suggest that there is a commonality of origin between the dated sediments and those of the South Devon coast. Thermoluminescence dates with a mean age of 17 ka were obtained, which may serve as an indicative minimum age constraint for the undatable Main Head beneath. This would appear to place the cessation of Main Head deposition in the Late Devensian during MIS 2 to be followed by the Upper Head shortly afterwards.

12.5 Quaternary Landscape Evolution

The story of the development of the South Devon landscape since the early Quaternary is that of a peninsular landmass rising episodically relative to sea level. At 3.1 million years ago, just prior to the early Quaternary, sea level in South Devon stood 135 m higher relative to the landmass than currently Westaway (2010). From then onwards, the sea regressed stepwise relative to the land, planing the summits of watersheds and facilitating the development of river terraces accordant to each new sea level associated with a pause of the marine regression.

This sequence was disturbed by the advent of glaciation around 0.8 Ma ago, as sea level oscillations of increasing magnitudes developed, associated with a cyclic pattern of glacial and interglacial conditions. Sea level has subsequently ranged in elevation according to major oscillations with a periodicity of $\sim 100,000$ years, during which phases of interglacial sea levels approximating to the current level alternated with phases of glacial sea levels as much as -100 or -120 m below it. During the glacial maxima, the view from the South Devon coast would have been of a vast plain across which, some 80 km to the south (now the location of the Hurd deep) a large river flowed by from east to west—the 'Fleuve Manche' (English Channel River), in a valley up to 140 m deep, draining much of north and central continental Europe towards the Atlantic coast to the west (Bourillet et al. 2003). Interglacial phases saw the sea level rise again to levels whereby it was able to erode coastal platforms around the Cornubian massif. It is not possible to date the formation of the platforms. Although they do retain marine sediments in the form of ancient beaches, these are not necessarily coeval with the platforms on which they sit,

since the age of the erosional form of the underlying platforms may be substantially greater. It is also possible that a particular level was visited by the sea during more than one interglacial sea level, as indicated by the extraordinary width of low platform at Prawle with its implication of a very long period of erosion. Notwithstanding such constraints, Proctor and Smart (1991) show that the correlatives of the high and intermediate platforms retain sedimentary evidence of marine transgressions during MIS 7 and MIS 5 in Corbridge Cave at Berry Head in the form of laminated muds. The evidence of an MIS 5 transgression at Berry Head would appear to correlate with the deposition of marine sand at Venerick's Cove, which accumulated in MIS 5 and subsequently became karstified by solution piping (Morawiecka 1993, 1997; Pazdur et al. 1995; Walsh and Morawiecka 1999).

The next geochronological marker is found in the bedded fine sediments above the fragmentary ancient beach sequences along the Start-Prawle coast. They are rarely more than 0.5 m thick and overlie MIS 5 beach sediments broadly interpreted as over 100,000 years old. The ^{14}C date of ~ 22 ka BP from the blue clay suggests that little change took place in this landscape over a period of $\sim 80,000$ years. The fine sediments indicate only limited deposition, and the remaining presence of thicknesses of ~ 1 m of beach sand suggests a lack of erosion also. It would appear that geomorphic activity was largely subdued during this cold dry period.

The age of the Main Head deposit is constrained by the dates of the subjacent clay at ~ 22 ka BP and the overlying Upper Head at ~ 17 ka BP. During the LGM the nearest (Atlantic) shoreline would have lain some 150 km to the SW and 120 m lower than present (Antoine et al. 2003). During this period regolith was apparently stripped from the upper slopes, thus exposing bedrock salients as tors and mantling the lower slopes with a carpet of unconsolidated periglacial head deposits which would have extended out across the rock platforms and beyond, including terrain now submerged below sea level. This relocation of regolith from higher slopes and its redeposition on lower ground to depths of up to 35 m created the smooth slope profiles visible today and considerably reduced the relative relief in the landscape.

The subsequent post-glacial Holocene transgression, as it rose towards its current level in the landscape, then eroded the unconsolidated seabed sediments over which it then transgressed, trimming them back towards the unconsolidated cliffline position of today. This transformation of the landscape in perhaps as little as 5000 years is largely responsible for the detailed appearance of the South Devon coastal landscape of today with its emphasis on rugged rock outcrops, smoothly graded hillslopes and the cliffed terrace of Main Head which extends along the length of the study area above the shoreline.

This sequence of events and similar associated geomorphological landscapes are widely recurrent throughout the southwest peninsula of Britain and, more widely, the English Channel domain including the exposed coasts of north and west Brittany.

12.6 Geomorphological Landscape/Human Interactions

We now consider two cases in which human activities have inadvertently intervened in geomorphological processes. Both, in their very different ways, have led to an increased understanding of how geomorphological processes currently effect local landscapes, and their implications for human activities.

12.6.1 The Durability of Greenschist Rocks in the Coastal Environment

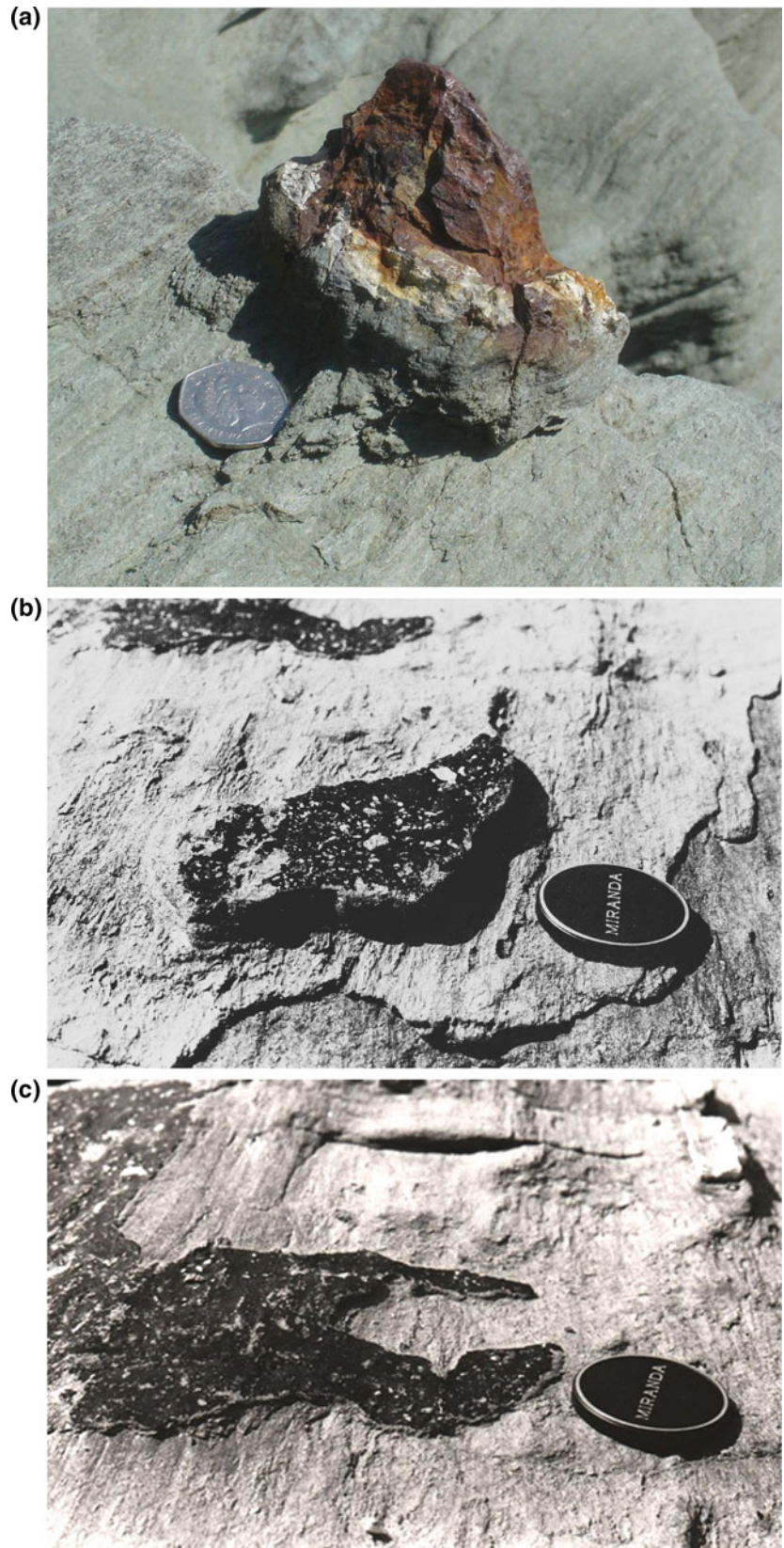
Attention was first drawn to the susceptibility of greenschist to coastal weathering by the casual observation on the Prawle coast of the remnant foot of a metal stanchion anchored in cement sitting atop a greenschist pedestal (Fig. 12.11a). The pedestal rises emergent from the surrounding surface of the rock platform below. This observation indicated that the cement and metal structure was more resistant than the surrounding rock to weathering and erosion processes.

Further observation locally revealed patches of oil residue sitting atop similar rock protuberances just a few metres upshore from the high-water line. Small pedestals and plateaux up to 10 mm in height were moderately abundant on shoreline rock platforms across a wide area (Mottershead 1981, 1982). It can reasonably be assumed that the oil represented inadvertent spillages from the busy shipping traffic in the adjacent English Channel. These microrelief features varied in planform from broadly circular to roughly elliptical under firm or sticky oil to amoebic forms where the oil had evidently been of runny consistency (Fig. 12.11b, c). A common but telling feature was that the relief forms were almost exactly congruent in planform with the oil patches beneath which they were formed.

This startling observation immediately implied that the oil was more resistant to weathering and erosion processes than the surrounding rock, and that the presence of oil was therefore protecting the immediately subjacent rock. Furthermore, since oil and tar are not renowned as particularly resistant substances, it is implied that the greenschist is remarkably vulnerable to weathering in this particular environment.

Accordingly, micro-erosion meter stations were established during 1979 order to make observations of the rate of

Fig. 12.11 Small scale forms indicative of rapid weathering and erosion. **a** The metal stanchion is seated on a bed of cement formerly at the base of a hole drilled into the greenschist surface to form a foothold. The underside of the cement marks the bottom of hole in which the station was originally seated. The greenschist surface has subsequently been lowered by weathering and erosion to the extent that the whole structure now stands on a rough rocky plinth protruding above the current platform surface (coin is 28 mm in diameter). **b** A rock pedestal created by a patch of oil, into which sand and gravel have become embedded. The pedestal is 10 mm high (lens cap is 55 mm in diameter). **c** A rock pedestal formed beneath oil whose planform suggests an initial runny consistency. Its low height (~ 3 mm) suggests that it is younger than the nearby plateau pedestal in Fig. 12.5b (Photo Derek Mottershead)



lowering of the rock surface at sites close to Langerstone Point (50.206° N; 03.708° W). With over 30 observation points a lowering rate of 0.6 mm^{-1} was recorded over an annual cycle, a value that was later confirmed following a total of seven years of monitoring (Mottershead 1982, 1989). That is a very high rate of erosion for an indurated rock, and is equivalent to 60 mm C^{-1} .

This raises the broader question of the durability of greenschist in the coastal weathering environment. In a further and deliberate human intervention in natural processes, greenschist has been employed in the construction locally of several structures directly adjacent to the sea. Overlooking the mouth of the estuary at Salcombe are three historic structures composed of greenschist comprising defensive structures of two kinds, namely, military and storm defences. They range in age from the mid-sixteenth to mid-nineteenth centuries. Formed of hewn rocks emplaced in fixed positions, each structure may be interpreted as a weathering experiment, with clearly identifiable potential controlling variables such as elevation, aspect, exposure and time (Mottershead 1997).

The stonework was studied at three sites studied—Fort Charles (50.229° N; 03.777° W), Limpyear Fort (50.232° N; 03.772° W) and the seawall at North Sands Bay (50.231° N; 03.781° W). Several forms of weathering were shown, including isolated pits, honeycomb, tafonisation and face recession (Fig. 12.12). For ease of comparison, the

simple variable of weathering depth was then used to interpret spatial patterns of weathering.

Spatial variations in weathering depth along the sea wall were found to reflect the degree of shelter/exposure along its length, from the southern end sheltered by a headland, to its northern end directly exposed to incoming waves. Fort Charles shows the greatest depths of weathering at the base of the south face of its Drum Tower, which directly faces the open sea and where storm waves have direct access to the rock face. There is a gradient of decreasing weathering depths upwards from sea level as the frequency of direct wetting by storm waves diminishes.

The role of seawater in the decay of this rock is implicated by the relationship between concentration of chlorine within the rock and weathering rate. Chlorine is an abundant element in seawater and its concentration is easily determined. Figure 12.13a shows that it is very closely correlated with erosion rates, thereby implicating seawater including all its saline elements in the process of rock breakdown. Under these circumstances, it is evident that greenschist is highly vulnerable to marine weathering and erosion and thus only poorly durable in such environments.

This study shows the maximum rates of greenschist weathering through each timespan indicated (Fig. 12.13b). Here a bounding rate of recession of 0.6 mm a^{-1} neatly encompasses the four study sites, with the exception of the Bastion, Salcombe Castle, where it appears likely that in the

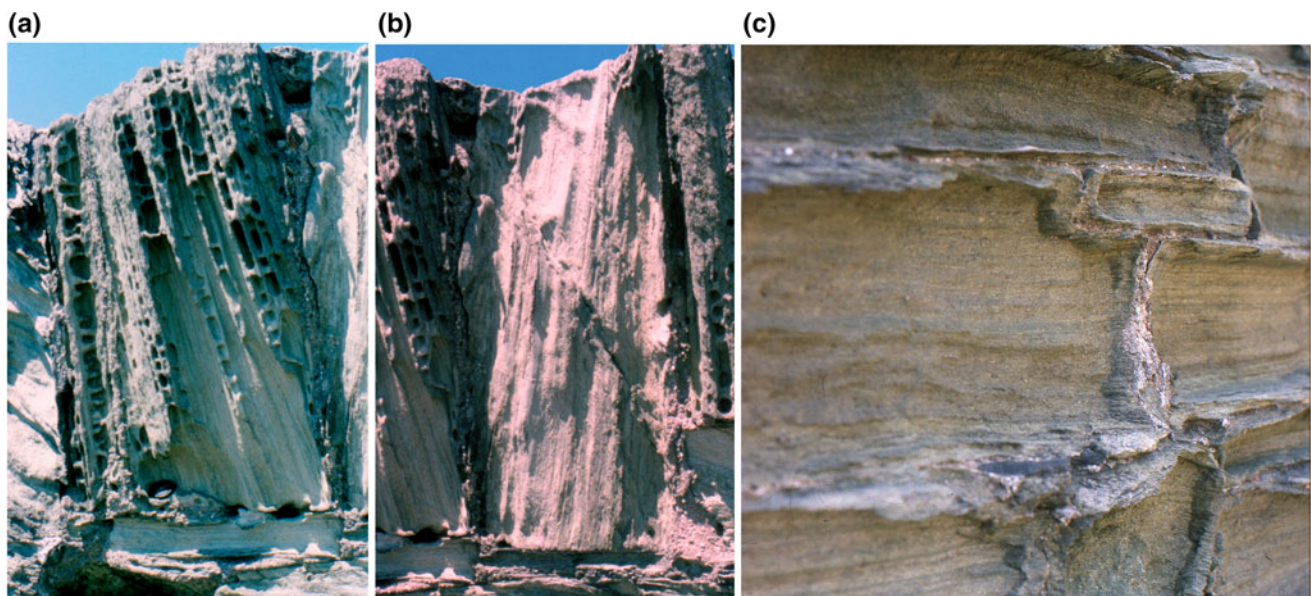


Fig. 12.12 Varying weathering styles of the coastal greenschist at Salcombe. **a** Honeycomb weathering, characterised by multiple holes drilling into the rock; there is a degree of structural control by the foliation of the greenschist, causing the alveoli to form a regular alignment parallel to the foliation of the rock and adopt an elliptical planform. **b** Differential etching of the face of a stone block along the foliation creates parallel ridges and troughs in the surface. **c** Face recession, whereby the rock face

weathers at a uniform rate, creating a plane surface. In this case the outer casing of the rock is impregnated by minerals leached out of the mortar which then crystallise in the pores of the adjacent rock to impregnate and strengthen the external surfaces of the rock, a process known as case hardening. The outer surface thus becomes more resistant to weathering and erosion than the interior rock, such that it stands proud of the general rock surface (Photo Derek Mottershead)

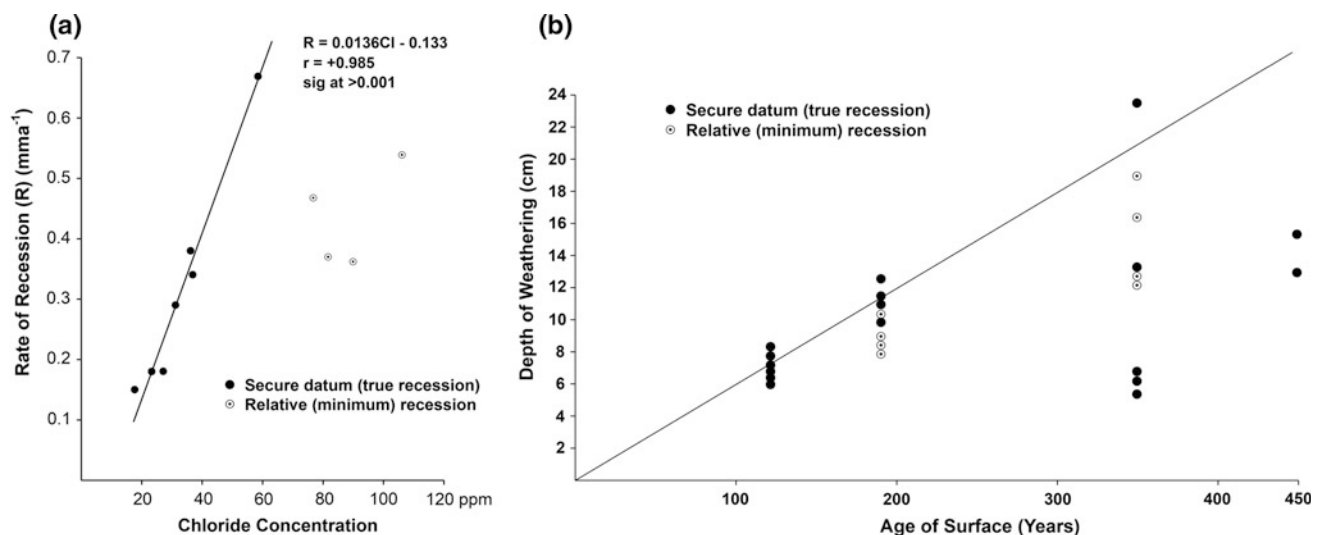


Fig. 12.13 Greenschist weathering and erosion. **a** Relationship between rock chloride content and weathering rate on the Drum Wall, Salcombe Castle, at sample locations with and without a secure datum.

b Depth of weathering at the sample sites throughout 450 years at Salcombe Castle, plotted relative to a line indicating a long-term rate of 0.6 mm a^{-1} . Each sample represents the mean of ten individual stones

areas of greatest weathering and erosion, any traces of original surface have been removed over the 450 years of its existence, thereby depriving that particular section of its initial baseline surface. This appears to validate the maximum weathering rate observed on the Prawle shoreline as a rate of weathering and erosion characteristic of greenschist in the coastal environment over a period measurable in centuries.

Furthermore, this particular study highlights one of the pleasures of the field sciences, in that a chance observation of oil patches on the foreshore can lead to what, in effect, became a stone durability trial spanning 450 years.

12.6.2 The 'Disappearing' Village of South Hallsands

The village of South Hallsands, situated at the foot of the cliffs towards the south end of Start Bay, was established in the sixteenth century. It was founded on a rock platform running along the foot of the east-facing cliffs at 6–8 m asl, apparently surviving safely over the centuries. By the late nineteenth century it was a long-established village of some 37 dwellings including a hotel with stables whose records go back to 1784, a post office, greengrocer, bakery, piggery and a chapel. It was home to a population of ~ 126 people whose livelihood was largely dependent on fishing (Worth 1904).

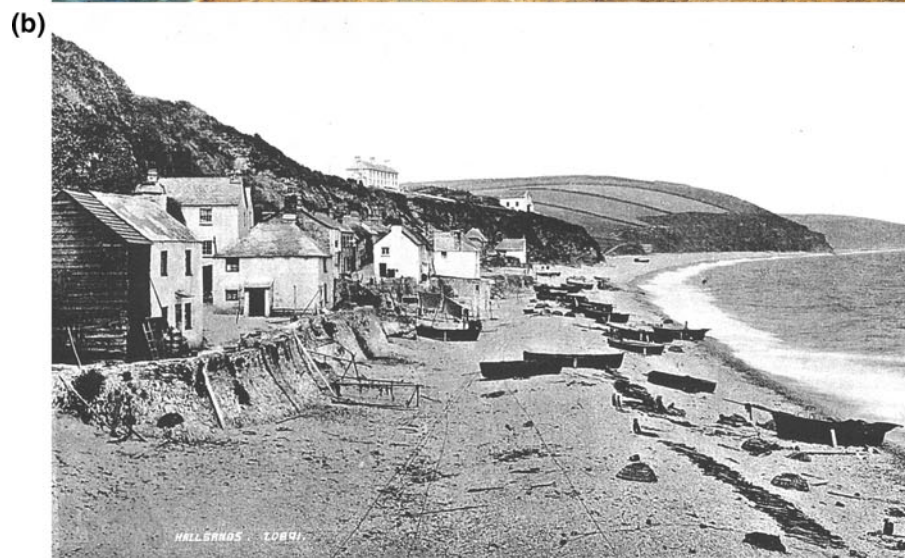
The properties were arranged in two rows, either side of a street which ran between them, extending for approximately 200 m along a strip of land some 25 m wide. Images (Fig. 12.14) from 1869 (Painting by W. Lidstone) and 1894

(Valentine postcard, 28 June) show the situation of the village in relation to the late nineteenth century shoreline. A retaining wall approximately 3 m high and apparently constructed of rough-hewn rocks formed the seaward boundary of the village and acted as a defensive barrier against the sea. From the base of the wall a shingle beach reached down to the shoreline, where the OS map of 1884 suggests that High Water Mark Ordinary Tides (HWMOT) lay at a distance of between 8 and 40 m from the retaining wall. The beach was wide enough to defend the village from waves and storms and to enable fishing boats to be drawn up on it for safety.

In 1896 it was decided to extend the docks at Royal Naval dockyard at Devonport, near Plymouth. Dredging began in Start Bay in April 1897 in a zone extending from just north of the village to Tinsey Head (50.245° N ; 03.657° W); some 1600 tonnes of gravel, shingle and sand per day were removed from the face of the 'beach between high- and low water marks at and opposite Hallsands and Beeson Sands' (Worth 1904).

Within a month of the commencement of dredging, the beach had become visibly reduced, and concerned villagers approached their MP for assistance. By 1900, after three years of dredging the sea was able to approach to within one metre of the village at high spring tides, rather than the up to 40 m prior to the onset of dredging, and began to undermine the sea wall. Structural cracks started to appear in houses at the south end of the village. In November of that year the villagers petitioned their MP regarding damage to their properties. Further campaigning by the villagers resulted in the revoke of the dredging licence in 1902. Five years of offshore dredging had resulted in the removal of some

Fig. 12.14 The 'disappearance' of South Hallsands, 1869–1985. **a** South Hallsands viewed from the north in 1869 as painted by David Lidstone. Note the substantial barrier of shingle forming the foreshore and protecting the village behind. **b** South Hallsands viewed from the south in 1894. The shingle barrier beach protects the village with its sea defence wall constructed with the local stone. Full use is made of the shingle barrier to beach the fishing boats, store fishing equipment and to set fish out to dry. The structure protruding seawards in the centre of the image houses the stables of the London Inn, which was to become severely damaged in the 1917 storm. **c** The gaunt remnants of dwellings in 1985. Note the newly exposed rocky shore platform with a thin spread of beach shingle at the base of the 4 m high cliff bounding the raised platform. Following the erosion of the shingle, this is now shown to be dissected by chasms normal to the shoreline (Photo Derek Mottershead. Fig.12.14c)



650,000 tonnes of shingle, representing a volume of some 400,000 m³, some 97% of the original volume of the beach.

The story continued, however. By 1903, the beach level had already fallen by 3–4 m and high-water mark had advanced landward by up to 30 m. Further severe storms in 1903 and 1904 caused serious damage to some properties, and in 1904 a new sea wall was constructed with the intention of protecting the village against further storm wave attack.

For several years the wall appeared to be a success. On 29 January 1917, however, a further damaging storm struck. A combination of a high spring tide, strong winds from the northeast and 12 m high waves struck dwellings with such force that walls caved in and roofs collapsed, causing inhabitants to flee for their lives. This proved to be the death knell of the village. On 28th January 1917, *The Kingsbridge Gazette* newspaper summarised the catastrophe with the headline ‘The beach went to Devonport and the cottages went to the sea’. The inhabitants realised that their severely damaged properties were no longer in a safe position. Although some inhabitants had left following the 1903/4 storms, all the remaining properties bar two were now abandoned (Milton and Milton 2007).

This progress of events is illustrated by Fig. 12.15 with a sequence of images taken from approximately the same position and centring on the London Inn. The captions tell the story from the pre-dredging days (Fig. 12.15a) to the 1903 storms and the ensuing construction of the concrete sea defence wall and the breaching and undermining of that wall in 1914 together with the consequent destruction of the London Inn and other properties. A detailed record of the above events is recorded in a sequence of papers by Worth (1904, 1909, 1923).

The story is still not complete, however, since the removal of the protective shingle then allowed storm waves to attack directly the base of the cliffs, rendering them unstable. The consequence was a cliff-face landslide in 2012 which created a 10 m broad scar and a fall of rocky rubble to the cliff foot, destroying the access road to the village which is now (2020) inaccessible by normal means.

What is surprising is the rapidity of the initial response, measurable in months, of the beach to offshore dredging. Perhaps less surprising is the slowing decline, measurable in decades, to what appears now to be an equilibrium level. This is, perhaps, a textbook example of a geomorphic response to a perturbing event.

This whole series of tragic events took place at a time when understanding of coastal current and sediment dynamics was at rudimentary level. This enabled the authorities of the time to assume and claim that coastal

processes would naturally replenish the beach, although advised otherwise by local engineer R. Hansford Worth. As a result of more recent studies, however, the understanding of beach dynamics has been substantially advanced.

A study by Hails (1975) investigated the submarine topography (bathymetry) of the sea bed in Start Bay, and the sedimentary deposits lying on it. He showed that the origin of shingle lay mostly offshore on the English Channel bed, and was most likely transported to its current position by transgressive storm waves during the Holocene transgression to form the barrier beach. This event was a one-off occurrence and would not be repeatable. There was no local store of flint gravel waiting to replace that dredged from the sea. Furthermore, Hails demonstrated that the local sea bed topography is such that waves approaching from the north east are refracted to focus their impact on the coastline at Beesands and Hallsands, concluding that the dredging aggravated a delicately balanced stability on the Hallsands coast.

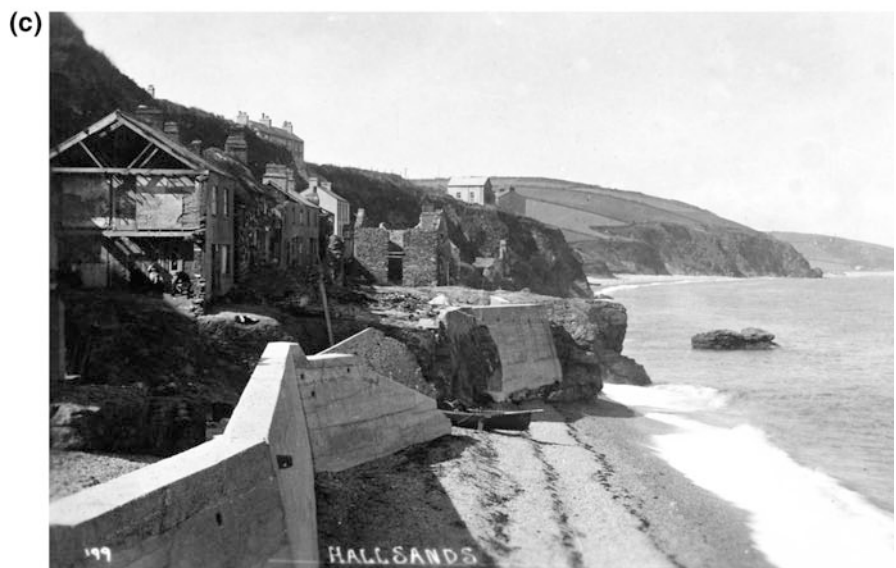
More recently Wiggins et al. (2019) noted the crescentic planform of the Start Bay coastline in relation to the two major storm wave directions, from NE and SW, respectively. The former acts to drive coastal sediment southwards, the latter to drive it northwards. Thus, within Start Bay the relative contributions of wave power from these two dominant wave directions act in opposition to each other. It is shown that there are cyclic temporal patterns in the relative dominance of these two forces, leading to oscillating variations in the accumulation of beach sediment between north and south ends of the bay, a process termed beach rotation.

It is now known that cyclic variations in the winter North Atlantic Oscillation (NAO) Index occur over a decadal timescale. Wiggins et al. noted that a phase of positive NAOI in the period 1900–1930 would coincide with depletion of the South Hallsands beach, and the consequent accumulation of shingle at the north end of Start Bay. The recognition of such an atmospheric mechanism offers a further understanding of local coastal processes, and one which may well have been a contributing factor to the loss of the village of South Hallsands.

Several lessons can be learned from this story:

- An intertidal shore platform currently washed by the sea is not necessarily formed under contemporary conditions.
- Contemporary beach sediment is not necessarily of recent origin and does not necessarily indicate a continuing supply of beach material.
- The non-renewal of the beach indicates that beach material does not circulate around Start Bay, and also that new sedimentary material does not enter the bay from outside.

Fig. 12.15 The progressive damage at South Hallsands as exemplified by the London Inn stables. **a** 1896, prior to storm damage. **b** Post 1904, new concrete defensive walls, close to camera and defending the London Inn. A slipway is now required to access the substantially lowered beach. The structure housing the stables is not significantly damaged. **c** Post 1917, the 1903 concrete wall is now breached below the London Inn stables which, in addition to other adjacent structures, have been severely damaged by storm wave action



- The depletion of the beach and subsequent disastrous effects emphasise a need for a thorough understanding of local coastal processes before such large-scale works are undertaken, lest irreparable damage be unwittingly caused.
- The timescale of degradation of this significant beach system indicates how rapidly adjustments can occur in the coastal system.
- An unstable situation may develop over time but may not manifest itself until a major episodic high energy event occurs with catastrophic consequences.
- The perturbation of geomorphological processes by human agency can create a rapid initial response measurable in months and years, and yet an equilibrium state may not be re-established until over 100 years later.

12.7 Conclusions

The coastal landscapes of South Devon are distinctive in that they are composed of a particular set of well developed slope facets. South Devon is a structurally integral part of the southwest peninsula, and also the Western Channel coastal domain. This local area, however, broadly shares an environmental history with cognate regions. In this way, instructive comparisons and connections can be made with the geomorphological landscapes of Cornwall (Charman et al. 1996; Scourse and Furze 1999) and the Scilly Isles (Scourse 2006) to the west, and the Channel Islands (Keen 1993) and Brittany (Van Vliet-Lanoë et al. 1997; Gibbard and Lautridou 2003) to the south, where coastal landscapes display a similar geomorphology in keeping with their shared history.

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