Quaternary of South-West England

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CHAPMAN & HALL

Chapter 6

The Quaternary history of the Dorset, south Devon and Cornish coasts

INTRODUCTION
D. H. Keen

Marine and periglacial deposits of the Dorset, south Devon and Cornish coasts

The Pre-Mesozoic rocks of South-West England, together with the harder Jurassic formations, provide the platforms which support intermittent outcrops of raised marine sediments and associated periglacial ('head') deposits. These deposits have an extremely protracted history of research with notable sites, such as Godrevy, having been described early in the nineteenth century (De la Beche, 1839). Although most coastal exposures comprise a simple sequence of raised beach deposits covered by head, in sheltered localities virtually throughout the Peninsula, 'sandrock', consisting of ancient dune sediments, accompanies the marine deposits. Periglacial 'heads' and related sediments occur widely throughout the region and testify to the effectiveness of frost-dominated and other (e.g. slope-wash) processes between the various phases of marine action.

At Trebetherick Point on the north Cornish coast, the occurrence of erratic boulders between the sandrock and the bulk of the head has caused some authors to consider the possibility of a glacial encroachment on to the Peninsula at some stage of the Pleistocene. The isolated gneiss boulder, known as the Giant's Rock, at Porthleven in south Cornwall also seems to suggest the former presence of glacier ice in the region (see Early glaciation; Chapter 2).

The generally acid rocks of most of South-West England provide superficial formations which are deficient in calcium. However, at a few locations (e.g. Godrevy) the calcium content is sufficient to preserve shell. Together with shells found in raised marine deposits on Devonian and Jurassic limestones at Torbay and Portland, these have provided the raw material for amino-acid age determinations which have gone some way to providing a geochronological framework for the raised beach deposits of the South-West.

The raised marine deposits

Pleistocene marine deposits found around the Peninsula occupy low topographic positions and rest on platforms cut between modern mean sea level and *c.* 5 m above it. Overwhelmingly, the beach deposits consist of gravel and cobbles, with the spectacular west-facing boulder beds of Porth Nanven, near Land's End, providing the coarsest grade material. Prior to the advent of amino-acid geochronology, the beach sediments had been regarded mostly as a coherent unit of similar age around the coast. The age of these deposits, however, was not certain, with some authors (Arkell, 1943; Mitchell, 1960; Stephens, 1970a) regarding the beaches as Hoxnian in age, on the basis of perceived stratigraphies in the overlying head, and others (Zeuner, 1959; Bowen, 1973b; Kidson, 1977) preferring an Ipswichian age.

With the revisions of chronology spearheaded by the amino-acid method, current opinion is that the sea has reoccupied the same platform on a number of occasions and that the currently visible raised beach deposits, although at roughly the same altitude and occupying the same geomorphic position in the landscape, date from at least two separate stages of the Pleistocene: Davies (1983) regarded these as being equivalent to Oxygen Isotope Stages 5 and 7 of the deep-sea record, and further detailed work by Bowen *et al.* (1985) has confirmed these ascriptions.

The general lack of fossils, in all but the beaches on the limestones, precludes any detailed comment on climatic conditions at the times the beaches were formed. Despite early statements of a 'glacial' or at least cold-climate origin for the beach deposits (Reid and Flett, 1907), there is now wide agreement that the beaches were formed by high sea levels during temperate interglacial conditions. The exact temperatures and conditions prevailing during deposition of the beaches can be determined more precisely by shells recovered from the beach deposits at Torbay (Hope's Nose and Thatcher Rock) and Portland Bill. Authors in the 1930s (Baden-Powell, 1930) still regarded the beaches here as having accumulated under cool climate conditions and cited the occurrence of molluscs, also currently found in Scottish waters, as evidence of temperatures several degrees below those of the present Channel. More quantitative analyses of raised beach molluscs at Portland Bill (Davies and Keen, 1985) and at Torbay (Mottershead *et al.*, 1987), however, show that sea temperatures during both Stage 7 and Stage 5 were no cooler than today. Indeed, the Portland Bill fauna provides some evidence that during Stage 5 the sea was warmer than now by two or three degrees.

The sediments contained in the raised beaches also reflect deposition under conditions of wave approach and energy little different to those of the present, with the calibre of the beach gravels being similar to those of the modern beaches in the same area. This is even true for the spectacular raised beach deposit at Porth Nanven which comprises water-worn boulders commonly up to 0.5 m in diameter: this west-facing site on the exposed Penwith Peninsula appears to have been subject to the same, extremely high energy conditions during both present and past interglacials.

Blown sand and fossil dunes

The common occurrence of fossil dune material overlying the raised beach deposits around the coasts of the Peninsula is exemplified by the sequence at Trebetherick Point, but similar sequences can also be found where there has been a suitable coastal configuration and sediment supply. These sands are generally lightly cemented with iron and calcium carbonate and were probably deposited during times of falling sea level. This mechanism was suggested by Arkell (1943) for the dune sands at Trebetherick Point, although he also thought that the sands were a product of a warming climate. Current views would suggest that deposition at a time of climatic cooling is more consistent with falling sea level.

The specialized nature of modern dune habitats might suggest that ancient dune deposits would be poor in fossils. However, in the dunes with a moderate calcium carbonate content, as at Godrevy and especially on the Devonian limestone at Torbay, shell does occur. This consists mostly of comminuted marine shell debris blown from the strandline, but occasionally land shells also occur, as at Hope's Nose, Torbay (Mottershead *et al.*, 1987), thus confirming the terrestrial origin of some of the sand in which they are found.

Head and related sediments

From the earliest descriptions by De la Beche (1839), it was recognized that the deposits overlying the marine horizons were of terrestrial origin and their vernacular name in the South-West, 'head', is now widely adopted. Perhaps the most representative section in the South-West is that described by Mottershead (1971) between Start Point and Prawle Point. The vital characteristics of head development are all demonstrated by this section, with easily broken bedrock to provide the clasts in the sediment, a wide marine platform to provide a foundation for head accumulation and a sheltered aspect (on the east side of Bolt Head) which has preserved the deposits from excessive stripping by modern westerly waves. Where these three criteria are met, the thickest head sequences occur. However, even at exposed places such as Porth Nanven, some head has been preserved because the original sediment bodies ('fans' or 'aprons') were large and have not therefore been removed totally by Holocene marine action.

Although numerous facies of head can be recognized in the coastal sections, many workers have divided the head deposits into a Lower or Main Head and an Upper Head (e.g. Stephens, 1970a; see Chapter 2): traditionally a 'Wolstonian' (Saalian) age has been preferred for the lower and a Devensian age for the upper. At many locations, however, the head deposits contain lenses and layers of finer-grained sediments including silts and muds. Pollen recovered from organic-rich muds in the head sequence at Boscawen, on the south Cornish coast, indicates that the periglacial processes involved in head formation may have ceased, temporarily, when tundra vegetation colonized pools on the surface of the solifluction deposits: radiocarbon dating of these organic-rich sediments suggests that the upper head here can be no older than *c.* 30 ka BP (Scourse, 1985a). Recent lithostratigraphical comparisons of head sequences in the region suggest that this twofold division is in fact widespread (Scourse, 1985a), and a Late Devensian age for the upper head is supported by thermoluminescence (TL) dating of aeolian sediments ('sandloess') intercalated with it (Wintle, 1981). However, the precise age of the lower head, at most localities, is unknown: continuing uncertainty surrounding the age of raised beach deposits which underlie the head precludes precise dating. Detritus from a number of Pleistocene cold stages (equivalent to Oxygen Isotope Stages 4 and 6) may be present, but such ascriptions must remain provisional. In this context, it is worth noting that head deposits at least as old as Stage 8 have been recognized in the similar Pleistocene sequences of the Channel Islands and Normandy (Keen, 1993; Keen *et al.*, 1996; Chapter 2).

Further subdivision of regional head sequences has, however, been possible at Portland Bill, where the thin head overlying the West Beach (Davies and Keen, 1985) is divided in two by a marked palaeosol. Below this horizon, intense weathering has caused decalcification of the head. Above it, silty head with a high shell content is indicative of sub-tundra conditions and its upper layers are highly cryoturbated suggesting a further intense periglacial phase. The evidence from Portland Bill therefore suggests three separate periglacial phases after deposition of the West Beach during Oxygen Isotope Stage 7: tentatively, these could be ascribed to cold Oxygen Isotope Stages 6, 4 and 2 (Keen, 1985).

Evidence of glaciation

In the area under consideration there is little evidence for glaciation, but at Trebetherick Point the erratic boulders, perhaps separating the two heads, may be an exception. It is nonetheless difficult to see how a glaciation extensive enough to deposit erratics at Trebetherick could avoid leaving them elsewhere (but see Chapter 7) and none has been found in the area between Trebetherick Point and Land's End. If the Trebetherick erratics were brought by ice, it is perhaps more probable that it was in the Middle or Early Pleistocene and that only remnants of the tills survived to be reworked into the head.

Further evidence for an incursion of glacier ice on to the South-West Peninsula may be provided by the Giant's Rock at Porthleven. The provenance of this famous gneiss boulder is far from certain, but the highly metamorphosed terrain necessary to provide such a rock-type can lie no nearer than Scotland or Brittany, and indeed its source may be much farther afield (see Chapter 2). A Scottish source would fit with a glacial origin, but virtually no theoretical reconstruction of ice sheets, except that of Kellaway *et al.* (1975), would allow a Breton source. Whatever its provenence, it is difficult to imagine any agency other than ice which could have been responsible for its emplacement. The type of ice is a further uncertainty. The lack of any till in south Cornwall has led to the suggestion of icebergs as the mechanism of deposition (Flett and Hill, 1912), and this still seems the most probable explanation, although a sea cold enough to carry icebergs of the size capable of floating the Giant's Rock should have occupied a much lower sea level than that of the modern intertidal platform where the rock is stranded. For the Giant's Rock alone to have survived from the glacial phase which deposited it, the glaciation would need to have been of Middle or Early Pleistocene age to allow the time for the destruction of all other glacial material. There is no other trace of such an episode in the South-West.

Geochronology

Prior to the 1980s, the age of the raised marine deposits was variously determined from their altitude (and inferred related sea level) or from the lithostratigraphy of the overlying head(s) and associated deposits. According to Mitchell (1960) and Stephens (1970a), nearly all raised beach deposits in the region were of Hoxnian age: a Lower or Main Head was of 'Wolstonian' age, the last interglacial (Ipswichian) was represented by an unconformity or weathering horizon in the head sequence, and the last major cold phase of the Pleistocene, the Devensian, saw deposition of the uppermost head layers. A different scheme proposed by Bowen (1973b), which also used evidence from Wales and southern Ireland, suggested that the raised beach deposits everywhere in the region were of the same, Ipswichian, age. The raised beach deposits and overlying head, therefore, could be accommodated by a single interglacial/glacial cycle which spanned the Ipswichian (warm) and Devensian (cold) stages.

The application of amino-acid, thermoluminescence (TL), Uranium-series and radiocarbon dating techniques has not solved all the problems, but has provided much clarification. The principal discovery, revealed by amino-acid analyses on marine mollusc shells, is that the raised beach sediments were deposited in two or more episodes (Davies and Keen, 1985; Bowen *et al.*, 1985). The most likely ascriptions for these marine phases are Stages 7 and 5 of the oceanic oxygen isotope record. An alternative interpretation of the data involves deposition of marine sediments in more than one of the sub-stages of Stage 5 (Bowen *et al.*, 1985).

Although not obtained from the GCR sites described in this volume, the Uranium-series dates derived from the caves on Berry Head, Torbay, by Proctor and Smart (1991) and Baker and Proctor (1996) are significant because they date three major high sea-level events equated by the authors with Oxygen Isotope Stages 5e, 7 and perhaps 9, and provide the potential to calibrate the amino-acid chronologies obtained from shell carbonate outside caves (Bowen, 1994b). Although it has been suggested that the amino-acid ratios obtained from shells from raised beaches below 10 m OD may indicate ages in either Stage 5e or 7 (Bowen *et al.*, 1985; Davies and Keen, 1985; Bowen, 1994b), or within Stage 5e (Bowen *et al.*, 1985), the evidence from the speleothem dates from Berry Head reinforces the former chronology of two separate high sea-level events, and adds a third series of dates around 328 ka BP for a sea level at *c.* 25 m above mean sea level (see above; Chapter 2).

The thermoluminescence and radiocarbon dating of the uppermost parts of the head and related sediments to the last 30 000 years (Wintle, 1981; Scourse, 1985a), suggests that the lower parts of head sequences could be either Early Devensian in age (Oxygen Isotope Stage 4), or date from Stage 6 (see above; Head and related sediments). Unless the underlying marine deposits are dated (see Portland West), the age of any individual head deposit cannot be determined except within these broad limits.

In the following account, the selected GCR sites are described in order around the coast from Portland Bill to Trebetherick Point (Figure A; Preface).

PORTLAND BILL

D. H. Keen

Highlights

Portland Bill is one of the most important raised beach sites in Britain. It shows evidence of pre-Stage 5 shoreline deposits and terrestrial sediments, a Stage 5 raised beach deposit and Devensian head. The beach sediments and Devensian head have yielded mollusc faunas which have been used to reconstruct former environments and for amino-acid dating.

Introduction

Portland Bill is one of the few places on the south coast where two separate raised marine deposits, in association with terrestrial sediments, can be demonstrated. The site was first described by De la Beche (1839) who noted the existence of marine deposits. Later authors mentioned aspects of the succession and its fauna (Bristow, 1850; Weston, 1852; Damon, 1860; Whitaker, 1869; Prestwich, 1875; Baden-Powell, 1930; Arkell, 1943, 1947; Green, 1943; Carreck, 1960; Pugh and Shearman, 1967; Macfadyen, 1970; Mottershead, 1977b). Of these, Prestwich's (1875) description was the most comprehensive and has been used by most later writers as a stratigraphical basis. The marine fauna was summarized in detail by Baden-Powell (1930). In recent times, full descriptions of the deposits and their included faunas have been published by Keen (1985) and Davies and Keen (1985). The latter authors also presented preliminary isoleucine epimerization data to provide a geochronology for the deposits. This method was also used by Bowen *et al.* (1985) who suggested alternative dating schemes.

Description

The full Quaternary sequence at Portland Bill (SY 677681) does not occur in superposition in any single section, and separate localities and deposits are needed to describe the sequence adequately. The key elements comprise the Portland West Beach and the Portland East Beach (Davies and Keen, 1985), and the Portland Head and Loam (Prestwich, 1875; Arkell, 1947; Keen, 1985) which are described separately below and shown in Figure 6.1.

Portland West Beach

The earliest comprehensive description of this part of the site was by Prestwich (1875). The main section today stretches for 40 m south of SY 67506860 in the grounds of the Admiralty Underwater Weapons Establishment (AUWE). The widespread occurrence of loose beach gravel, for 200 m south of the current section, probably indicates the former extent of the raised beach deposits. The beach deposit also crops out at SY 68056885 in a disused quarry 100 m south-west of the Old Lower Lighthouse (now the Portland Bird Observatory). The beach deposits rest on a lightly wave-smoothed surface cut in Jurassic limestone. In the main AUWE section, the beach consists of up to 2.5 m of well-sorted sandy gravel arranged into as many as seven fining-up units, each grading from pebbles to coarse sand (Figure 6.1). The deposits are planar-bedded and cemented by calcium carbonate, although considerable voids also occur. The pebbles of the beach comprise a variety of lithologies: flint makes up between *c.* 85–90%, with the remaining clasts comprising chert and limestone from the local Portlandian, and quartzite, chalk, and Greensand. In addition to these pebble-types, Prestwich (1875) noted ferruginous grit (Tertiary), micaceous sandstone (Devonian), red and purple sandstone (Triassic), red feldspar porphyry and red granite. The source of much of this non-local material was probably the South-West Peninsula. The Portland West Beach is largely devoid of shelly fossils, except in its basal layers, but enough fragments of rocky shore gastropods – *Nucella lapillus* (Linné), *Littorina littorea* (Linné),

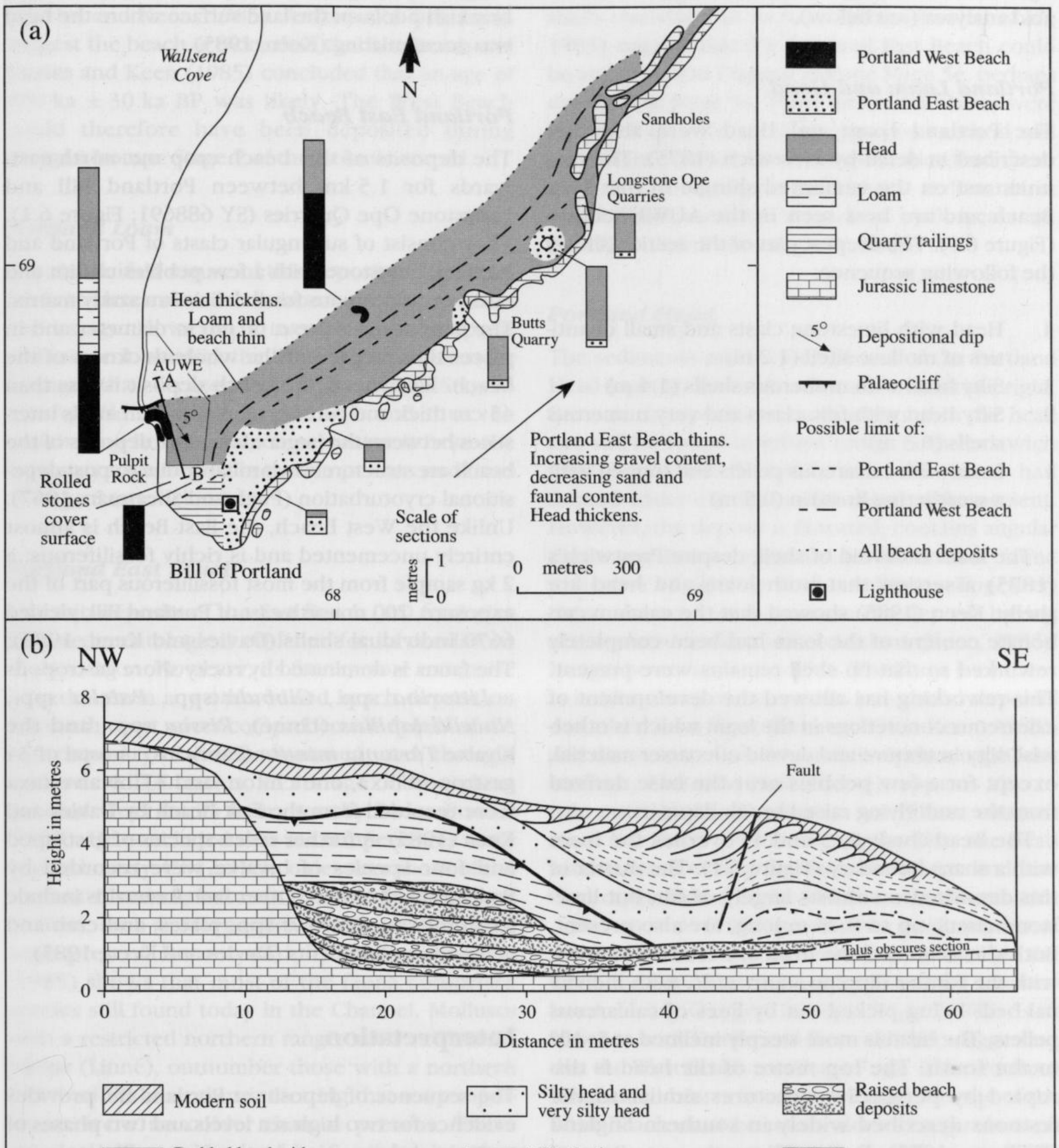

Figure 6.1 (a) Quaternary deposits at Portland Bill, adapted from Davies and Keen (1985). (b) The Quaternary sequence at AUWE, adapted from Keen (1985). The cross-section follows line A–B shown in plan above.

Patella spp. and bivalves *Cerastoderma* spp., *Mytilus edulis* (Linné) – were recovered for amino-acid analyses (see below).

Portland Loam and Head

The Portland Loam and Head were also first described in detail by Prestwich (1875). The two units rest on the cemented shingle of the West Beach and are best seen in the AUWE section (Figure 6.1). The deepest part of the section shows the following sequence:

4. Head with limestone clasts and small quantities of mollusc shell (1.2 m)
3. Silty head with numerous shells (1.4 m)
2. Silty head with few clasts and very numerous shells (0.3 m)
1. Loam with calcareous pellets and topped with a weathering horizon (0.5 m)

The loam is devoid of shell, despite Prestwich's (1875) assertion that both loam and head are shelly. Keen (1985) showed that the calcium carbonate content of the loam had been completely reworked so that no shell remains were present. This reworking has allowed the development of calcareous concretions in the loam which is otherwise silty in texture and devoid of coarser material, except for a few pebbles near the base derived from the underlying raised beach deposits.

The head (beds 2, 3 and 4) overlies the loam with a sharp boundary (Figure 6.1). The matrix of this deposit also consists largely of silt, but limestone clasts, up to 0.25 m long, are also present. Both the loam and the head are crudely bedded, with the former dipping south at 3°, with individual beds being picked out by lines of calcareous pellets. The head is more steeply inclined at 5–10° to the south. The top metre of the head is disrupted by periglacial structures similar to the festoons described widely in southern England (Williams, 1975). Deeper disruption occurs near the south-eastern end of the section where an inclined zone of disturbance reflects reverse faulting under periglacial conditions (Keen, 1985; Figure 6.1). At its eastern extreme, the entire thickness of the head deposit is disrupted by periglacial structures which extend into the Jurassic bedrock (Pugh and Shearman, 1967). The head is not decalcified and contains abundant land shells. The total fauna comprises fourteen species of which only three – *Pupilla muscorum* (Linné), *Lymnaea truncatula* (Müller) and the slug genus *Deroceras* sp. – are numerous (Keen, 1985). The head also contains fossil ostracods which may have lived in small brackish pools on the land surface where the head was accumulating (Keen, 1985).

Portland East Beach

The deposits of this beach crop out north-eastwards for 1.5 km between Portland Bill and Longstone Ope Quarries (SY 688691; Figure 6.1). They consist of subangular clasts of Portland and Purbeck limestone with a few pebbles of flint and chert and calcareous fossil debris in a sandy matrix. The largest clasts are *c.* 60 cm in diameter and in places these represent the whole thickness of the beach. Elsewhere, the beach deposit is less than 45 cm thick and consists of shell which infills interstices between the larger clasts. The deposits of the beach are structureless, probably due to post-depositional cryoturbation (Pugh and Shearman, 1967). Unlike the West Beach, the East Beach is almost entirely uncemented and is richly fossiliferous: a 2 kg sample from the most fossiliferous part of the exposure, 200 m north-east of Portland Bill, yielded 6670 individual shells (Davies and Keen, 1985). The fauna is dominated by rocky shore gastropods – *Littorina* spp., *Gibbula* spp., *Patella* spp., *Nucella lapillus* (Linné), *Rissoa* spp., and the bivalve *Turtonia minuta* (Fabricius). A total of 34 gastropod taxa, one chiton, and 17 bivalve taxa were recorded from the East Beach by Davies and Keen (1985). A further seven species of gastropod and four species of bivalve were recorded by Baden-Powell (1930). Other faunal remains include foraminifera, *Balanus* spp. plates, and crab and echinoderm fragments (Davies and Keen, 1985).

Interpretation

The sequence of deposits at Portland Bill provides evidence for two high sea levels and two phases of terrestrial deposition in the Upper Pleistocene. Amino-acid ratios (D-*alloisoleucine* : L-*isoleucine*) derived from fossil shells in the sequence, enable these events to be placed in relative stratigraphic order and provide a tentative chronological framework.

Portland West Beach

Planar bedding in this sediment indicates that the Portland West Beach was deposited under high energy conditions. The few shell fragments it contains are suggestive of sea temperatures no colder than now and a sea level perhaps 10 m higher (Davies and Keen, 1985). Amino-acid D/L ratios suggest the beach is older than the East Beach and Davies and Keen (1985) concluded that an age of 200 ka ± 30 ka BP was likely. The West Beach could therefore have been deposited during Oxygen Isotope Stage 7 of the oceanic record.

Portland Loam

The decalcified nature of this deposit makes it difficult to determine its environment of formation and its age. However, it may be a slope deposit and, since it overlies the West Beach, it must be younger than Oxygen Isotope Stage 7. A Stage 6 age for the loam seems probable and thus the weathering horizon which separates it from the head may have formed in the temperate conditions of Stage 5 (see below).

Portland East Beach

The thin deposits of the East Beach (< 0.6 m) give little sedimentological evidence for its conditions of deposition. However, its fauna, more extensive than that from any other raised beach deposit on the south coast, gives comprehensive details of the contemporary marine environment and, through amino-acid D/L ratios, of its age. The earliest detailed work on its fauna was by Baden-Powell (1930). He concluded that sea temperatures were approximately 4°F (2.2°C) colder than those of the current Channel, because 'northern' species of mollusc, such as *Margarites helicinus* (Fabricius), were present. Recent work by Davies and Keen (1985) shows that most of the fauna comprises species still found today in the Channel. Molluscs with a restricted northern range, such as *Tricolia pullus* (Linné), outnumber those with a northern distribution today, thus indicating that sea temperatures were no colder than at present. These conclusions are supported by fossil foraminifera recovered from the East Beach. These comprise, exclusively, modern-day English Channel-types, including one species – *Elphidium crispum* (Linné) – which is now found no farther north than the Channel (Davies and Keen, 1985).

Amino-acid ratios presented by Davies and Keen (1985) suggest that the Portland East Beach accumulated during Oxygen Isotope Stage 5e. The ratios were calibrated with a Uranium-series date obtained from travertine in similar raised beach deposits at La Belle Hougue Cave, Jersey, some 130 km to the south (Keen *et al.*, 1981). Further amino-acid D/L ratios derived from raised beach shells elsewhere in western Britain (Bowen *et al.*, 1985) suggest that the Portland East Beach could be younger than Oxygen Isotope Stage 5e, perhaps dating from Stage 5a. These amino-acid ratios were obtained by a different preparation method and gave slightly lower, thus younger, ratios than those obtained from other raised beach sediments in South Wales: the latter were dated by Bowen *et al.* (1985) to their Pennard, or 5e, Stage.

Portland Head

The sediments and included fauna of the Portland Head together are indicative of a terrestrial origin. Because the species of mollusc found in the head can still be found in Britain today, both Prestwich (1875) and Arkell (1947) assumed that it had formed under conditions like those of the present. However, the deposit is ill-sorted, contains angular clasts and has a restricted fossil mollusc fauna indicative of open-ground conditions. Together, these characteristics point to the deposit having accumulated under cold conditions (Keen, 1985). Its age, however, is uncertain. The fauna it contains is unlike those of Devensian late-glacial deposits described from Kent (Kerney, 1963; Keen, 1985), and the occurrence of the relatively thermophilous mollusc, *Helicella itala* (Linné), appears also to rule out a Middle Devensian age. These comparisons led Keen (1985) to propose that the head accumulated during the Early Devensian and was then cryoturbated in the Middle or Late Devensian.

Bowen *et al.* (1989) presented a small number of amino-acid ratios derived from *Trichia* shells in the head: the deposit was considered to have accumulated during Oxygen Isotope Stage 7. This is at variance with Davies and Keen's (1985) suggestion that the West Beach is of Stage 7 age. If the Portland Head indeed dates from Stage 7, then the age of the West Beach must be much older, Oxygen Isotope Stage 9 at youngest. The Oxygen Isotope Stage 7-equivalent amino-acid ratios reported from the head by Bowen *et al.* (1989) are also inconsistent with its origin as a cold-stage, periglacial, deposit. It is, however, possible that the *Trichia* shells were reworked into the head from a 'temperate' Stage 7 terrestrial deposit, but no such source has so far been identified at Portland. At present, the least problematical interpretation of the sequence is to regard the West Beach as an Oxygen Isotope Stage 7 deposit, and the overlying loam and head as cold-climate materials formed later in the Pleistocene.

Conclusion

The Pleistocene deposits on Portland Bill present a fascinating association of terrestrial and marine sediments ranging from perhaps 200 ka BP. The faunal content of the marine units is unrivalled along the south coast and allows a palaeoenvironmental reconstruction of considerable detail and value. The use of amino-acid geochronological techniques has enabled this complex of marine deposits to be dated to Oxygen Isotope Stages 7 and 5 of the deep-sea record: this preliminary ascription might suggest that the cold-climate deposits and structures at the site date from Oxygen Isotope Stages 6, 4 and 2. The evidence of two raised beach deposits, of different ages, confirms Portland Bill as a critical reference site with regard to interpreting coastal Pleistocene sequences throughout south-west Britain.

HOPE'S NOSE AND THATCHER ROCK
D. H. Keen

Highlights

The Torbay raised beach deposits are among the most fossiliferous of their kind on the south coast. Together with shelly raised beach sediments at Portland Bill, they provide a cornerstone for Pleistocene palaeoenvironmental and stratigraphic studies in the South-West.

Introduction

The raised marine deposits in Torbay have received considerable attention since their earliest description by Austen (1835). Much work was done on the sequences and their faunas in the nineteenth (De la Beche, 1839; Ussher, 1878; Hunt, 1888; Prestwich, 1892) and early twentieth centuries (Hunt, 1903, 1913a, 1913b; Ussher, 1904; Jukes-Brown, 1911; Shannon, 1927, 1928; Lloyd, 1933; Green, 1943). In recent times, Orme (1960b) provided new material, while reviews by Zeuner (1959), Macfadyen (1970) and Mottershead (1977b) drew substantially on earlier data, especially those of Hunt and Lloyd. Amino-acid ratios derived from shells in the beaches were presented by Davies (1983) and Bowen *et al.* (1985): a recent detailed study by Mottershead *et al.* (1987) uses these and other palaeoenvironmental data to establish a geochronological framework for the sequence.

Description

The raised beach deposits in Torbay occur on both of the two limestone promontories which enclose the bay. In the south, around Shoalstone Point (SX 939568), 1.3 m of beach sediment is overlain by *c.* 2 m of head. The exposures here extend nearly 300 m from Shoalstone, east towards Berry Head. On the north side of the bay, Pleistocene sediments are best seen at Hope's Nose (SX 949637) where the total thickness of marine and terrestrial deposits is around 9.5 m. Offshore, the islet of Thatcher Rock shows a thin development of both head and raised beach sediments. The maximum thickness of Pleistocene deposits here is *c.* 5 m. All of the major beach exposures are fossiliferous, principally with gastropods of rocky shorelines, but also with bivalves from a range of habitats, and a restricted microfauna. Early work on the molluscan fauna (Hunt, 1888, 1903; Lloyd, 1933) suggested that the beach was deposited by a sea colder than the present. Modern work (Mottershead *et al.*, 1987) regards both the molluscan fauna and the microfauna as indicating water temperatures no colder than in the Channel today.

The GCR site known as Hope's Nose and Thatcher Rock includes three main elements: (a) Shoalstone; (b) Hope's Nose; and (c) Thatcher Rock which are described below.

(a) Shoalstone

The deposits at Shoalstone consist of gravel and cobble beach deposits overlain by head. Mottershead *et al.* (1987) describe the following sequence at SX 939568 (maximum bed thicknesses in parentheses):

6. Sandy loam with pebbles (0.7 m)
5. Head of angular cobbles of limestone in a loamy matrix and with apparent downslope bedding (2.0 m)
4. Coarse sand with shell debris (0.3 m)
3. Cobble beach of limestone, flint and slate without sand and with little shell (0.6 m)
2. Beach gravel with abundant shells, principally of oysters, but also *Cerastoderma edule* (Linné) and gastropods (0.2 m)
1. Angular cobbles and boulders in a sandy matrix (0.2 m)

The beach deposits rest on a wave-smoothed platform of Devonian limestone and are intermittently cemented with calcium carbonate. The shells are often fractured.

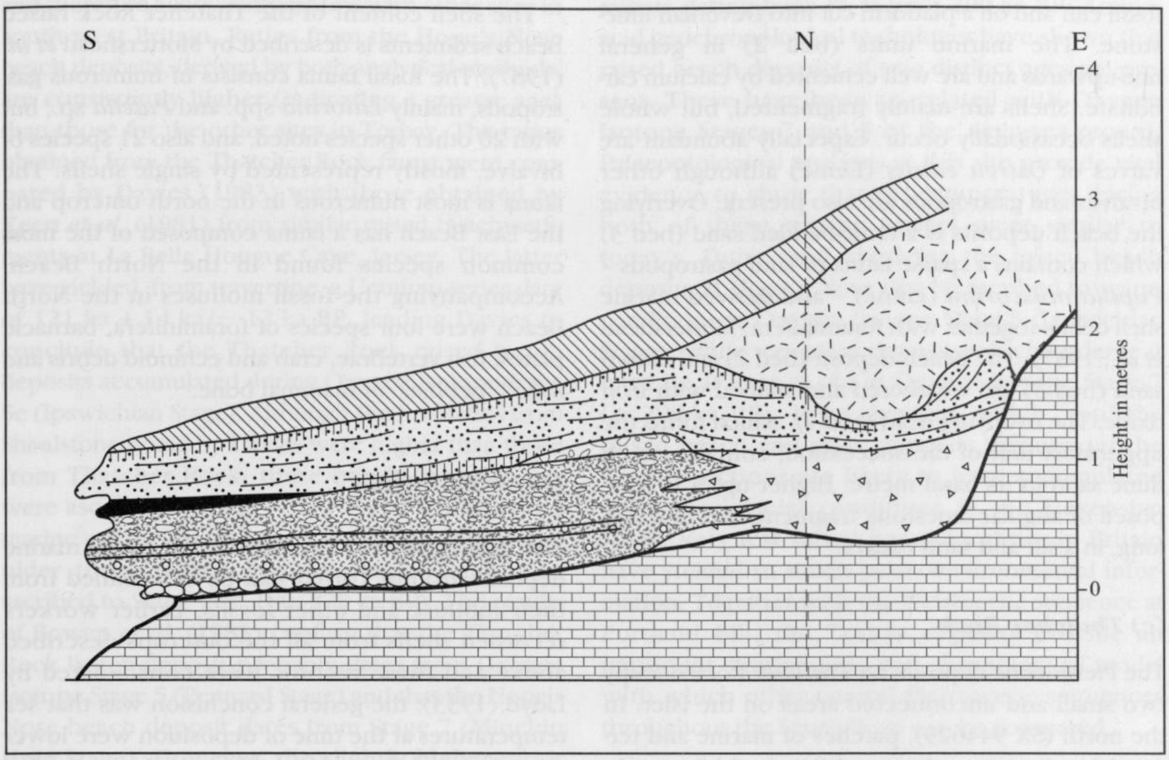

Figure 6.2 The Quaternary sequence at Hope's Nose. (Adapted from Mottershead *et al.*, 1987.)

(b) Hope's Nose

The best section occurs at the eastern extremity of the exposure, at SX 949637, and is shown in Figure 6.2. The sequence, simplified from Mottershead *et al.* (1987), is as follows:

4. Head of coarse limestone debris in a loamy matrix (4.0 m)
3. Dune-bedded sand with occasional cobbles of limestone. The boundary of the sand and head is gradational (1.5 m)
2. Coarse sand with intermittent boulders towards the top and interbedded with silt layers lower down. Shelly throughout, but with bedding planes crowded with oysters in the lower levels of the deposit (2.85 m)
1. Boulder bed resting on Devonian limestone and interdigitated with 1.0 m of angular head close to the fossil cliff (0.3 m)

The whole sequence of deposits rests against a fossil cliff and on a platform cut into Devonian limestone. The marine units (bed 2) in general fine-upwards and are well cemented by calcium carbonate. Shells are mainly fragmented, but whole shells occasionally occur. Especially abundant are valves of *Ostrea edulis* (Linné) although other bivalves and gastropods are also present. Overlying the beach deposits is a dune-bedded sand (bed 3) which contains a sparse fauna of land gastropods – *Pupilla muscorum* (Linné) – and derived marine shell debris together with foraminifera (Mottershead *et al.*, 1987). The beach deposit (bed 2) and blown sand (bed 3) are weathered and stained with iron oxide. The overlying head (bed 4), which forms the uppermost unit of the succession, contains much dune sand in its basal metre. Higher up, it is composed of angular limestone fragments, up to 0.5 m long, in a silt and sand matrix.

(c) Thatcher Rock

The Pleistocene deposits on Thatcher Rock occupy two small and unconnected areas on the islet. In the north (SX 944629), patches of marine and terrestrial sediment total up to 1.8 m in thickness. In the south-east (SX 944628), two smaller outcrops exhibit up to 5.2 m of head and beach sediment. The following sections were described by Mottershead *et al.* (1987):

North Beach

3. Head with angular blocks of limestone in a red silty sand matrix (0.4 m)
2. Sand, reddened at the top and cemented, with locally abundant shells (1.2 m)
1. Pebbles and cobbles of flint, limestone, and igneous rock. Cemented in places and penetrated by weathering (0.2 m)

East Beach

2. Head deposit of angular, crudely bedded limestone blocks in a sandy matrix (5.0 m)
1. Beach deposit of well-rounded pebbles with shells in a clay/silt matrix (0.2 m)

Both beach deposits rest on a platform and against a cliff cut in Devonian limestone. The elevation of the beach fragments, between 7.8 and 10.3 m OD, has allowed considerable recent erosion of the beach and head deposits by waves: only small areas of sediment remain on an increasingly exposed platform. The higher elevation of the Hope's Nose deposit, between 9.1 and 12.1 m OD, has preserved this beach remnant from present-day marine action.

The shell content of the Thatcher Rock raised beach sediments is described by Mottershead *et al.* (1987). The fossil fauna consists of numerous gastropods, mainly *Littorina* spp. and *Patella* sp., but with 20 other species noted, and also 21 species of bivalve, mostly represented by single shells. The fauna is most numerous in the north outcrop and the East Beach has a fauna composed of the most common species found in the North Beach. Accompanying the fossil molluscs in the North Beach were four species of foraminifera, barnacle plates, fish vertebrae, crab and echinoid debris and rolled 'pebbles' of mammal bone.

Interpretation

The local palaeoenvironment of the raised marine deposits around Torbay can be determined from their mollusc and other fossils. Earlier workers recorded shells from all the outcrops described above and these records were consolidated by Lloyd (1933): the general conclusion was that sea temperatures at the time of deposition were lower than those of the modern Channel. In particular, the occurrence of species such as *Trophon truncatus* (Ström), with a mainly Scottish distribution at present, was used to support this interpretation. Mottershead *et al.* (1987) counted over 1000 individual fossil shells from the three major beach localities, and concluded that sea temperatures were no colder then than now. This assessment is most secure for the Thatcher Rock beach deposit, where faunal remains are most extensive. For these raised beach sediments, the fauna is closely comparable to marine faunas of today, and there is no reason to suggest temperatures different from those of the modern seas around Torbay. The evidence from the Hope's Nose and Shoalstone beach deposits is less clear due to a more restricted fauna, but the inference from these localities is also consistent with a climate no cooler than today's.

Because the raised beach deposits occur in similar positions and at approximately the same height above sea level, previous authors (see Mottershead, 1977b) have assumed a similar age for them. The application of amino-acid epimerization relative dating techniques (Davies, 1983; Bowen *et al.*, 1985; Mottershead *et al.*, 1987) and further detailed stratigraphic studies, however, have established a more complex chronology. The amino-acid ratios of Davies (1983) and Bowen *et al.* (1985) were obtained by slightly different analytical methods. The data sets, however, are 'internally' consistent and therefore allow comparisons with other sites in south-west Britain. Ratios from the Hope's Nose beach deposits, derived by both analytical methods, are consistently higher (indicating a greater age) than those for the other sites in Torbay. The ratios obtained from the Thatcher Rock fauna were compared by Davies (1983) with those obtained by Keen *et al.* (1981) from similar raised beach sediments at La Belle Hougue Cave, Jersey. The latter have yielded, from travertine, a Uranium-series date of 121 ka + 14 ka/− 12 ka BP, leading Davies to conclude that the Thatcher Rock raised beach deposits accumulated during Oxygen Isotope Stage 5e (Ipswichian Stage). Although the few ratios from Shoalstone noted by Davies were higher than those from Thatcher Rock, these beach deposits also were ascribed to Stage 5. The Hope's Nose raised marine sediments, therefore, were considered to be older than Oxygen Isotope Stage 5 and were ascribed to Stage 7 (*c.* 180–220 ka BP). The results of Bowen *et al.* (1985) confirm that the Thatcher Rock beach deposit probably dates from Oxygen Isotope Stage 5 (Pennard Stage) and that the Hope's Nose beach deposit dates from Stage 7 (Minchin Hole Stage). However, the slightly higher ratios derived from shells in the Shoalstone deposits (lying on a scale somewhere between those of the Hope's Nose and Thatcher Rock deposits) suggest an intermediate age between Oxygen Isotope Stages 5 and 7 (equivalent to the 'unnamed' Stage of Bowen *et al.*, 1985). In this context, the latter may equate either with the end of Stage 7 or the beginning of Stage 5, since no discrete marine deposits can be recognized in the site's stratigraphy.

The geochronological dating of these marine events also establishes the relative age of the terrestrial deposits in Torbay. The head, which underlies or interdigitates with the Hope's Nose beach deposit, must date from at least Oxygen Isotope Stage 7. The dune sand which overlies the Hope's Nose raised beach deposit has yielded amino-acid ratios indicative of a Stage 5 age (Bowen *et al.*, 1985) and its snail fauna, and the weathering it has undergone, also suggest interglacial conditions. The head, which overlies the raised marine and/or dune sediments at all three sites, is therefore likely to have accumulated during the Devensian Stage: greater precision than this is not yet possible.

Conclusion

The Pleistocene deposits exposed in Torbay record an impressive variety of marine and terrestrial events dating back to at least 200 ka BP. Amino-acid geochronological techniques have shown that raised beach deposits of two distinct ages are present. These have been correlated with Oxygen Isotope Stages 7 and 5 of the deep-sea record. Palaeontological analyses at this site provide vital evidence to show that sea temperatures during both of these marine phases were similar to today's. Dune sand overlying the raised beach deposits at Hope's Nose can be ascribed to warm conditions in Oxygen Isotope Stage 5 (Ipswichian Stage), while terrestrial deposits which underlie it must be at least as old as Oxygen Isotope Stage 7 (*c.* 200 ka BP). Head deposits which 'cap' the raised beach and dune deposits throughout the Torbay sections are likely to have accumulated under periglacial conditions in the Devensian Stage. Very few raised beach localities in Britain have yielded so much palaeoenvironmental information. Together with the Pleistocene sequence at Portland Bill, the Torbay deposits provide an important stratigraphic and chronological model with which other coastal Pleistocene sequences throughout the South-West can be compared.

START POINT TO PRAWLE POINT

D. H. Keen

Highlights

This 6 km-section of coast provides some of the finest exposures of periglacial deposits in Britain. They demonstrate superbly the salient characteristics of coastal head deposits.

Introduction

The coast between Start Point (SX 830370) and Prawle Point (SX 773350) is extensively mantled with Pleistocene, periglacial slope deposits. These deposits are especially well developed here because the schist bedrock is particularly prone to destruction by frost-action, and because most of this coast faces south or south-east and is thus protected from westerly and south-westerly waves. Alternatively, on the exposed sides of headlands, such as the section between Bolt Head (SX 725359) and Hope Cove (SX 673398), head deposits have been stripped by marine erosion (Mottershead, 1971). Authoritative descriptions of the coastal head deposits of South-West England were first made by De la Beche (1839) who introduced the

Figure 6.3 Coastal head deposits overlying a raised shore platform at Great Mattiscombe Sand (SX 816369), 1.2 km west of Start Point. (Photo: D.H. Keen.)

term 'head'. The sections between Prawle Point and Start Point received particular mention by Ussher (1904), Steers (1946), Masson-Phillips (1958) and Orme (1960b), but the most comprehensive sedimentological and morphological descriptions were given by Mottershead (1971). The quantitative characterization of the head deposits along this stretch of the coast is detailed by Mottershead (1972, 1976, 1982b). Estimates of current rates of bedrock weathering and erosion along the shoreline are provided by Mottershead (1981, 1982a, 1982c). Morawiecka (1993, 1994) described palaeokarstic features in 'sandrock' at Prawle Point.

Description

The sections range up to 33 m in height and are banked against a fossil cliffline up to 125 m high. The head rests on former wave-smoothed surfaces at the foot of the cliffs. The maximum thickness of the head is seen only at localities such as Mattiscombe Sands (SX 816369) where subsequent erosion has cut deeply into the deposit (Figure 6.3). At other localities, such as Langerstone Point (SX 782354), sections are as little as 2 m high: these exposures occur up to 270 m away from the fossil cliff. In contrast, the thickest sections occur only a short distance from the former cliffline. The head deposits fill the mouths of coastal valleys, as at Mattiscombe Sands and are of variable thickness where the bedrock floor is gullied or irregular. They are banked against the fossil cliff in a series of 'fans' or 'aprons', the surfaces of which form concave slopes of 10–15° near the bedrock slope, declining to 2–3° away from it (e.g. Langerstone Point) (Mottershead, 1971).

The head is poorly sorted and is composed of all particle sizes from boulders to clay (Mottershead, 1971). Sediments nearer to the ancient cliff are generally coarse, often containing boulder-sized material, whereas those away from it (and the source of sediment) are generally finer-grained, consisting largely of pebble- and granule-size material.

The lithology of clasts in the head reflects the nature of the bedrock found upslope, namely a combination of quartz-mica schist and green (chlorite/hornblende) schist. Mottershead (1971) noted a general increase in the ratio of quartz to schist in the sections farthest from the fossil cliffline, which he suggested was due to comminution of the more friable schist-types during transport, and perhaps even to the selective transport of smaller clasts. All particles, however, are angular or subangular, even those found farthest away from the old cliff. The clasts in the head show a strong unimodal orientation downslope, reflecting their direction of movement away from the cliffline and sediment source. The head sometimes shows crude stratification (e.g. at Rickham Sand; SX 755367) with thin layers picked out in places by the different colours of the constituent mica and hornblende schists. Most of the head, however, is structureless.

Towards the base of many sections, the head also contains sand and rounded pebbles of marine origin. In places, possibly *in situ* raised beach deposits are covered by the head. At others, the former presence of a beach deposit is indicated by the occurrence of rolled stones within the head: some, such as those of flint, are clearly of non-local derivation.

Interpretation

Most deposits exposed in the coastal cliffs between Start Point and Prawle Point, are believed to have been derived by the action of frost on the ancient cliff which now lies upslope (Mottershead, 1971). They arrived on the ancient marine platform by mass movement processes, principally solifluction, under periglacial conditions. The morphology of the sediment bodies ('fans' or 'aprons' of head), and the sedimentological and lithological characteristics of the deposits are entirely consistent with such an origin. Alternating layers of different schist material within the head may indicate successive shallow solifluction 'flows', each derived principally from a particular bedrock lithology: other massively bedded and unstructured parts of the head sequence may denote the arrival of large thicknesses of saturated debris *en masse* (Mottershead, 1971). Whatever process variations the head may denote, there is general agreement that they indicate mass wasting under periglacial conditions, and are the products of degradation of the coastal bedrock slope (Mottershead, 1977a). These head sequences find close parallels elsewhere around the coast of South-West England (Mottershead, 1977b) although they are rarely, if ever, better developed.

Whereas their origin is not disputed, the age of the deposits is far from certain. Mottershead (1971) divided the sequences found along this coastline into a variety of facies: a Main Head (forming the bulk of the sequence); an Upper Head (distinguished by a silty texture, perhaps indicating the incorporation of loess); and a sporadic Lower Head (separated from the Main Head by raised marine sediments, for example, at Sharpers Cove, SX 786357). Although Stephens (1966b, 1970a) had earlier effected a similar division of head deposits in north Devon, he had assigned them to the 'Wolstonian' (Lower/Main Head) and the Devensian (Upper Head) because the underlying raised beach deposits were believed to be of Hoxnian age. Bowen (1973b) regarded this differentiation as unrealistic and ascribed the different head facies to various stadial phases of the Devensian Stage. Mottershead (1971) instead followed the thinking of Masson-Phillips (1958) and Orme (1960b) and suggested that the raised beach deposits had accumulated during milder, interstadial, phases of the Devensian, with head accumulating during colder periglacial phases.

Modern work has shown that none of these schemes is universally applicable. Detailed regional geochronological studies (Keen, 1978; Lautridou, 1982; Davies and Keen, 1985; Bowen *et al.*, 1985; Mottershead *et al.*, 1987) have shown that the raised marine deposits of the western Channel date from at least two high sea-level stands in the Middle and Upper Pleistocene – probably equivalent to Oxygen Isotope Stages 7 and 5 of the deep-sea record. At sites where an Oxygen Isotope Stage 7 raised beach deposit lies beneath head, the possibility clearly exists for head facies to have accumulated during a number of Pleistocene cold stages (e.g. Oxygen Isotope Stages 6, 4 and 2). Where the head overlies an Oxygen Isotope Stage 5 marine deposit, on the other hand, a Devensian age (equivalent to either or both of Oxygen Isotope Stages 4 and 2) must be assumed. With the absence of datable materials, the ages of the head and raised marine sediments between Start Point and Prawle Point remain unknown.

Conclusion

Start Point to Prawle Point GCR site provides some of the finest sections through periglacial slope deposits (head) anywhere in Britain. Although their precise age is unknown, these deposits exhibit all the characteristic features of coastal head deposits, and are believed to have accumulated during a variety of cold stages in the Pleistocene when periglacial conditions prevailed. Alternating facies of head, comprising different clast lithologies, point to deposition by a variety of individual, shallow solifluction flows, with different bedrock layers in the old cliffline successively succumbing to the effects of frost-action. Elsewhere, massively bedded head deposits suggest downslope movement of substantial quantities of probably saturated debris *en masse*. In conservation terms, the sections from Start Point to Prawle Point provide a wide variety of slope deposits and related landforms of textbook quality, against which other, less well-developed examples, can be compared and interpreted.

PENDOWER
S. Campbell

Highlights

This site provides a textbook example of a compound shore platform. Its Pleistocene succession of raised marine deposits and periglacial head and loess is one of the finest in Cornwall.

Introduction

Coastal exposures at Pendower typify the south Cornish Pleistocene succession, and show one of the finest examples of a compound shore platform overlain by raised beach sediments anywhere in south-western Britain. First described by Boase (1832) and later by Whitley (1866) and Reid (1907), the site has also featured in studies by Rogers (1909, 1910), Davison (1930), Robson (1944), Everard *et al.* (1964), Mottershead (1977b), James (1974, 1994) and Stephens and Sims (1980). The most detailed accounts of the site are those of James (1981b, 1994) and Scourse (1985a, 1996c).

Description

Pleistocene sediments are exposed more or less continuously for a distance of 8 km in Gerrans Bay, on the south Cornish coast. Perhaps the best exposures, however, are found between SW 899381 and *c.* 910380, a stretch of coast along Pendower Beach, through Spire Point to beyond Giddleywell in the east. The sequence at the western end of these exposures is shown in Figure 6.4. The following succession can be generalized from field observations and the descriptions given by Stephens and Sims (1980), James (1981b, 1994) and Scourse (1985a, 1996c) (maximum bed thicknesses in parentheses):

4. Silty sand (loess) (0.5 m)
3. Breccia (head of various facies) (*c.* 12 m)
2. Sand (coastal dune sand) (2.5 m)
1. Pebbly conglomerate (raised beach deposits) (3.0 m)

Compound shore platform

The shore platforms in Gerrans Bay can be traced almost continuously from St Anthony Head in the south-west to east of Pendower Beach (James, 1974, 1981b). They cut across south-east-dipping slates, shales and sandstones with interbedded quartz veins of the Portscatho and Veryan series. Stephens and Sims (1980) and James (1974, 1981b) divided the platform into a lower surface (coincident with the modern beach) and an elevated surface of limited extent, frequently obscured by Quaternary sediment.

The ubiquitous lower platform is notched into a small cliff below the higher platform surface at a maximum level of 4.4 m OD (James, 1974, 1981b; Mottershead, 1977b), and extends to below high water mark. The upper platform also notches a fossil cliff which, in many places, is obscured by Pleistocene sediments. The lower platform is at times more than 10 m wide (James, 1974, 1981b) and both platform surfaces are remarkably flat. Large boulders are stranded on the platform surfaces (Stephens and Sims, 1980): some may be erratics (Stephens, 1970a), but others consist of local quartzite, chert, conglomerate and spilitic lava.

Deposits immediately overlying the lower raised shore platform consist of a clast-supported conglomerate of pebbles and cobbles (bed 1) with occasional, larger, and more angular blocks of local derivation (Figure 6.5). For the most part, this bed consists of small rounded quartz pebbles with some of slate in a sandy matrix. It is strongly cemented with oxides of iron and manganese. In places, fragments of material from bed 3 (head) are also incorporated into the upper layers of the raised beach deposit. Although considered unfossiliferous (Reid, 1907; James, 1981b), shells from the raised beach deposit were reported by Rogers (1910). Scourse (1985a, 1996c) and James (1994) record that bed 1 is overlain by cross-bedded sands (coastal dunes), although James (1994) notes that this unit is locally obscured by slope-wash materials.

The succeeding breccia (bed 3) is a variable deposit consisting almost entirely of angular clasts of local shales, slates, grits and vein-quartz frag-

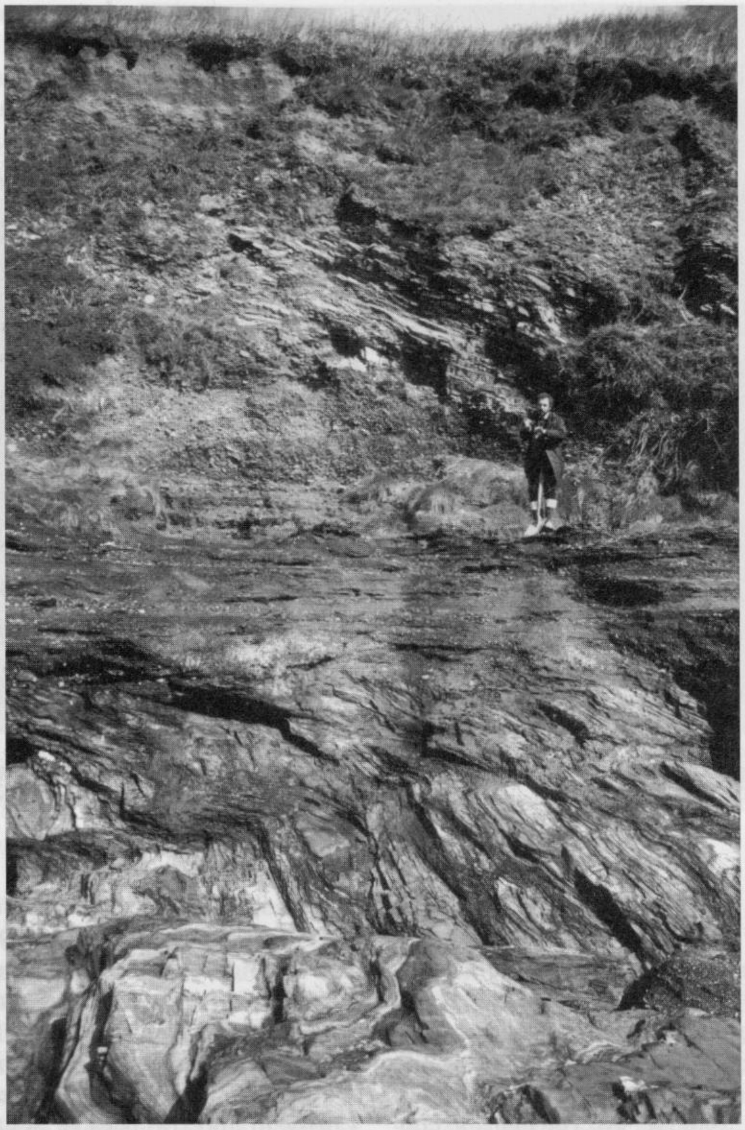

Figure 6.4 Coastal exposures at the western end of Pendower Beach, showing a compound shore platform cut across steeply dipping slates, overlain by cemented raised beach deposits and head. (Photo: S. Campbell.)

ments. In places, this bed comprises a breccia of fine shale fragments showing faint stratification: in others, it is a blocky deposit consisting of large, angular cobble- and boulder-sized fragments. Finer lenses of silt and sand also occur within this bed. In most of the sections at Pendower, the head is banked against a steep cliff and, where the deposits have fallen away, the old, apparently water-worn slate cliff (Reid, 1907) is seen. The upper layers of the head (between *c.* 0.5–1.0 m) consist of fine, sharply angular, comminuted shale and slate fragments; cryoturbation features (involutions) and fossil ice-wedge casts are also common in the upper parts of this bed (Stephens and Sims, 1980; James, 1981b, 1994). Stephens and Sims recorded one locality where the head (bed 3) was divisible into two beds, separated by sand containing only occasional rock fragments. For much of the site, however, they recognized a coarse blocky head overlain directly by a finer head.

Finally, the Pleistocene sequence is capped by a thin (up to 0.5 m) silty sand with occasional pebbles, either a loess (Scourse, 1985a) or a slope-wash deposit (Stephens and Sims, 1980; James, 1981b). Submerged forest beds are also present along this stretch of the coast (Robson, 1944).

Figure 6.5 A striking unconformity between the shore platform and overlying, cemented raised beach deposits at Pendower, viewed by members of the Quaternary Research Association in 1980. (Photo: S. Campbell.)

Interpretation

Boase (1832) referred to the 'head' in Gerrans Bay as 'Diluvium'. Reid (1907) regarded the head (bed 3) as ' ... a mass of angular rubble shattered by frost, swept down the slopes, and deposited on the lowlands when arctic conditions prevailed in Cornwall ... ' (Reid, 1907; p. 58). The climatic conditions under which the raised beach deposits accumulated were not known, the bed being unfossiliferous and there being no clear evidence for penecontemporaneous ice-carried erratics - unlike other examples of raised beach sediments elsewhere in Cornwall (Reid, 1907).

Although referred to briefly by Davison (1930), James (1974) and Mottershead (1977b), the sections at Pendower were not studied again in any detail until the work of Stephens and Sims (1980), James (1981b) and Scourse (1985a). The beds were described in detail by Stephens and Sims (1980) who, apart from interpreting bed 1 as a raised beach deposit formed during temperate, high sea-level conditions in the Pleistocene, and the head (bed 3) as a periglacial solifluction deposit, were noncommittal about the possible chronostratigraphic attribution of the beds.

James (1981b) used the thermoluminescence (TL) evidence of Wintle (1981) to provide a relative dating scheme for the beds at Pendower. Wintle (1981) gave TL determinations which supported a Late Devensian age for loess deposits (stratigraphically equivalent to bed 4 at Pendower) at locations in southern England, including south Cornwall and the Isles of Scilly. James (1981b) argued that the various facies of head (bed 3) underlying the silty sand (bed 4) at Pendower, were thus probably Devensian in age, with the upper layers and cryoturbation structures almost certainly belonging to the coldest part of that stage - the Late Devensian. He argued that the raised beach conglomerate (bed 1) was therefore most probably ascribable to the Ipswichian Stage. Where raised beach (bed 1) and head (bed 3) material was mixed at the site, he argued that marine and terrestrial deposition had taken place in latest Ipswichian or earliest Devensian times. The underlying shore platform was believed by him to have been re-trimmed, if not comprehensively formed, during the Ipswichian Stage.

Scourse (1985a, 1996c) correlates bed 1 at Pendower with the raised beach deposits at Godrevy (Godrevy Formation). He regards bed 2 as an aeolian coastal dune deposit. A TL date of between 165 ka and 252 ka BP (QTL-466; Southgate, 1984; unpublished data) from sand in bed 2 was used as evidence by Scourse to show that the underlying raised beach conglomerate was older than Ipswichian in age (Oxygen Isotope Stage 5). He regarded the head (bed 3) as a periglacial solifluction deposit (Penwith Formation), formed substantially, although not necessarily exclusively, during the Devensian Stage (Scourse, 1985a, 1996c).

In summary, the elevated shore platform is likely to be composite in age (e.g. Mitchell, 1960; Kidson, 1971; Stephens, 1973), although it was probably retrimmed during the Ipswichian (James, 1981a, 1994). Likewise, the precise age of the raised beach sediments at Pendower is not established. The TL dating from the site, although tentative, might suggest that the raised beach deposit here may be older than many of the other examples in South-West England and Wales which have been ascribed to the Ipswichian Stage (Oxygen Isotope Stage 5e – *c*. 125 ka BP). It is relevant that preliminary amino-acid data (Bowen *et al*., 1985) similarly indicate a pre-Ipswichian age for the raised beach deposits at Godrevy: these sites may therefore provide crucial evidence to demonstrate that not all of the raised beach deposits in the region are ascribable to the Ipswichian Stage. Whether they can be ascribed to Oxygen Isotope Stage 7 is unproven at present, although a distinct possibility (see Portland Bill; Hope's Nose and Thatcher Rock). The firm attribution of these raised beach beds to a pre-Ipswichian high sea-level event would be crucially important for interpreting Pleistocene successions throughout the region: some elements of the complex head and solifluction sequences, therefore, may have accumulated in cold conditions prior to the Devensian Stage. A cautionary note, however, must be added. The *Patella vulgata* shell from Godrevy which yielded the Stage 7 age, came from an isolated conglomerate 'bridge' some distance from the main Godrevy raised beach exposure (James, 1997). James regards this 'bridge' as a Stage 7 remanié section, but notes that the rest of the Godrevy raised beach section is likely to date from Stage 5e. Indeed, a recent reassessment of the geochronological evidence (James, 1995) suggests that many of the raised beach deposits in South-West England contain remanié material of earlier interglacial events (e.g. Stage 9 and/or 7), but that most of the locations were last occupied during Stage 5e.

Conclusion

Although the precise ages of the beds at Pendower are far from certain, the site provides one of the most detailed Pleistocene records in Cornwall. It is particularly notable for the fine development of the compound shore platform with its associated marine cliffs and notches. These features, together with the closely associated Pleistocene sediments (large erratics, raised beach, head and possible loess deposits), reveal an unusually complete record of the complex and protracted evolution of the south Cornish landscape.

PORTHLEVEN

S. Campbell

Highlights

One of Cornwall's most controversial geomorphological localities, Porthleven provides possibly the oldest evidence of Pleistocene glacial conditions in the South-West. Its famous 50-ton erratic of gneiss, known as the Giant's Rock, could have arrived here on floating ice.

Introduction

Porthleven has long been famous for the large stranded erratic known as the 'Giant's Rock'. Its exact origin and mode of emplacement have been much debated but never satisfactorily solved: both, however, have significant repercussions for regional Pleistocene conditions. The Giant's Rock was first described in detail by Flett and Hill (1912). Subsequently, it has figured prominently in the scientific literature (e.g. Davison, 1930; Robson, 1944; Flett and Hill, 1946; Mitchell, 1960, 1965; Everard *et al*., 1964; Stephens, 1966b, 1970a, 1973, 1980; Stephens and Synge, 1966; Kidson, 1971, 1977; Hall, 1974; Scourse, 1985a, 1996c; Holder and Leveridge, 1986; Todd, 1987; Goode and Taylor, 1988; Bowen, 1994b).

Description

The Giant's Rock (SW 623257) lies some 400 m north-west of Porthleven harbour on a wide shore platform, locally named Pargodonnel Rocks (Figure 6.6). It is fully exposed only at low tide and rests

Figure 6.6 The Giant's Rock at Porthleven, the South-West's most famous erratic – author for scale. (Photo: S. Campbell.)

in a large rock pool on the abraded platform surface from which, significantly, it is never shifted even in the heaviest storms (Flett and Hill, 1912; Hall, 1974). The erratic measures 3 m in length and weighs an estimated 50 tons. It is highly polished, brown in colour, and is composed of garnetiferous microcline gneiss, with garnet crystals up to 1 cm across (Hall, 1974; Stephens, 1980). On the remainder of the platform there are other numerous smaller boulders including those of slate, granite, gabbro and vein quartz. Towards the base of the steps, which lead down into the small cove from the cliff top, are patches of iron-stained and cemented sand and gravel (the latter quite well rounded in places) which adhere to the slate bedrock. These are probably the remains of a raised beach deposit from which other small boulders, elsewhere on the platform, may have been washed. Stephens (1973) noted that the platform extended to substantial notches (which contain the cemented raised beach gravels) in the base of a rock cliff now being re-exposed and re-trimmed by wave action.

Interpretation

Flett and Hill (1912) provided one of the most significant accounts of the erratic, establishing that the rock-type could not in fact be matched with any other British example. They later argued that it had been stranded '… by the ice floes of the Glacial Period.' (Flett and Hill, 1946; p. 168).

Modern interpretations have centred on whether the Giant's Rock was deposited directly by glacier ice or was floated into position on pack ice or on a massive iceberg. Mitchell (1960, 1965) argued that, in view of the widely held relationship between Pleistocene glacial stages and low eustatic sea levels, the erratic could only have been borne to its present position directly by an ice sheet; he used the Porthleven erratic on the south Cornish coast and the beds at St Erth (part of which he then regarded as till) to define his southernmost limits for an ice sheet of Lowestoft (Anglian) age. The St Erth Beds, however, have since been securely re-established as marine in origin (Mitchell *et al.*, 1973a; Jenkins *et al.*, 1986), and Mitchell's proposed Anglian ice limit in this region would appear to have no foundation.

Kidson (1971, 1977) propounded that large erratics found on shore platforms around the Croyde–Saunton Coast in north Devon, and indeed those along the south coast as far east as Prawle Point (including, by implication, the Giant's Rock?), were also emplaced directly by an ice sheet. He argued that the erratics at Croyde and Saunton had been derived from Wolstonian (Saalian) Irish Sea glacial sediments (which include the Fremington Clay; see Chapter 7) and then incorporated into raised beach deposits during the Ipswichian Stage. Although this Wolstonian ice sheet may also have impinged on the Cornish coast at Trebetherick Point and in the northern Isles of Scilly (Kidson, 1977), there are no coherent glacial sediments anywhere else along the south Cornish and Devon coasts which suggest a more extensive inundation by ice at this time (Stephens, 1966b; Kidson and Bowen, 1976). Recent amino-acid dating studies of raised beach deposits in the region (e.g. Andrews *et al.*, 1979; Davies, 1983; Bowen *et al.*, 1985; Davies and Keen, 1985) have shown that raised beach sediments from at least two separate interglacial phases of the Pleistocene are present. In many cases, however, the raised beach deposits are unfossiliferous and cannot be dated; the true age relationship of the erratics to the local raised beach deposits therefore remains uncertain in the vast majority of cases.

In contrast, many authors have favoured ice-rafting as the most likely mechanism for emplacement of the Giant's Rock and similar large erratics in the South-West. Indeed, Tricart (1956) also favoured this mechanism to explain the presence of large erratics on the French Channel coast. However, if floating ice carried the erratics to the south coast, then problems arise regarding contemporary Pleistocene sea levels. Mitchell (1972) sidestepped the problem of low sea levels during glacial stages by arguing that these erratics were rafted into position at the beginning of the Saalian Stage when the level of the sea might still have been relatively high after the preceding, warm, Hoxnian Stage. Similarly, Stephens (1966b) argued that the large erratics could have been emplaced by pack-ice and icebergs during the waning of an early pre-Saalian (Anglian?) glacial period when world sea level would have been high enough to allow the erratics to be 'floated' into position (Fairbridge, 1961). As an alternative hypothesis, Stephens suggested that towards the end of the Saalian ice-sheet glaciation, isostatic depression of the land had allowed the sea to move icebergs against these coasts despite a generally low eustatic sea level. Such a mechanism is similar to recently proposed models of Late Devensian glaciomarine sedimentation in the Irish Sea Basin (e.g. Eyles and McCabe, 1989, 1991). Bowen (1994b) recently suggested that the Giant's Rock could have originated in Greenland and then been transported to the South-West on ice-floes from a disintegrating, Early Pleistocene, Laurentide ice sheet.

In support of the ice-rafting hypothesis, the most convincing evidence is that the erratics are very largely confined to a narrow coastal zone, invariably below 9 m OD, and within the reach of storm waves today (Stephens, 1966b). Also, comparable very large erratics are not known from inland locations in the region, with the exception of those recorded from the Fremington Clay in the low-lying Barnstaple Bay area (Stephens, 1966b). Smaller examples, however, are found at various levels around the south coast, and some may have sources in Brittany, the Channel Isles and Côtentin (Kellaway *et al.*, 1975; Mottershead, 1977b); they may have been worked from sea-bed deposits, carried up and finally emplaced by successive transgressive Pleistocene high sea levels. Such a mechanism is not plausible for emplacement of the Giant's Rock which does not shift at all even in the heaviest of storms and wave regimes of the present day. This has led some authors to consider the possibility that the Giant's Rock is not a glacial erratic: it may have been derived from the Normannian High by means of slumping during the deposition of the Mylor Slates in Devonian times (Holder and Leveridge, 1986; Goode and Taylor, 1988). Such a view is not, however, widely held.

Conclusion

The Giant's Rock is the most impressive and intriguing of the large erratics found around the south and west coasts of Britain. Despite having attracted scientific interest for nearly a century, its exact origin and mode of emplacement are still unknown and it remains the subject of much controversy. Although some workers have maintained that the 50-ton erratic was emplaced directly by glacier ice, most believe that it was delivered to its present location on floating ice. One recent interpretation invokes Greenland as a possible source and a disintegrating Laurentide ice sheet as a transport mechanism. The Porthleven erratic and the classic examples of the Croyde–Saunton Coast (some of which are found in a stratigraphic context) are central to the reconstruction of earlier Pleistocene events in the region: they have major implications for the extent of pre-Devensian ice sheets, for Pleistocene sea levels and, more controversially, for a possible mechanism involving isostatic depressions of the land's crust proximal to ice-sheet margins.

BOSCAWEN
S. Campbell

Highlights

Organic sediments found in the head sequence here provide unique evidence for environmental conditions in Cornwall during the Devensian Stage. Pollen and radiocarbon-dated evidence shows that the bulk of head deposits at Boscawen accumulated after *c.* 29 ka BP, during the Late Devensian.

Introduction

Boscawen GCR site comprises St Loy's and Paynter's coves, and is an important Pleistocene stratigraphic locality. Organic beds within the head sequence have yielded pollen and have also been radiocarbon dated. They provide a rare opportunity to subdivide and interpret head sequences in the region. The sections were first described by De la Beche (1839), and subsequently by Reid and Flett (1907), Rogers (1910) and Davison (1930). A contemporary assessment of the deposits is provided by Scourse (1985a, 1987, 1996c) and the site is also mentioned in the BGS memoir (Goode and Taylor, 1988).

Description

Good sections in Pleistocene sediments occur between Merthen Point in the west (SW 418227), through St Loy's and Paynter's coves, almost to Boscawen Point in the east (SW 430230). The Pleistocene sequence is relatively straightforward with a rocky shore platform, cut entirely in granite, overlain by a sequence of raised beach and then solifluction deposits. The raised beach deposit overlies the shore platform at about 3.5 m OD, and reaches a maximum thickness of 1.8 m (Scourse, 1985a). For the most part, it consists of a matrix-supported deposit of granite pebbles and cobbles, although erratics are also common (including greenstone, hornfels, chalk flints, Greensand chert and purple sandstone): in places, more than half the pebbles are non-granitic (Reid and Flett, 1907).

The overlying beds (up to 12 m in thickness) consist mainly of a breccia made up of angular and subangular granite clasts (Figure 6.7). Considerable facies variations, however, occur both vertically and laterally, and sandy silt lenses can be seen particularly towards the top of the sections (Scourse, 1985a). In places, there are stratified sandy and gravelly bands, and throughout the sections slump and flow structures occur. Near the top of the sections, there is a coarse deposit of granite boulders. Towards Boscawen Point, the raised beach is underlain by a thin breccia made up of granite clasts.

At *c.* SW 423230, Scourse (1985a, 1996c) records the following sequence (maximum bed thicknesses in parentheses):

5. Breccia of granite fragments (0.5 m)
4. Sandy silt with scattered granite clasts (0.75 m)
3. Breccia of granite fragments (2.0 m)
2. Granular humic silt (0.5 m)
1. Breccia of granite fragments (0.5 m)

The silty humic sediments range from black through chocolate-brown to ochre in colour. They have yielded pollen, and have been radiocarbon dated to 29 120 +1690/− 1400 BP (Q-2414) (Scourse, 1985a, 1996c).

Interpretation

The raised beach deposits at Boscawen were noted by De la Beche (1839) but were first described in detail by Reid and Flett (1907). They recorded a Pleistocene marine-cut platform overlain by raised beach and head deposits. The erratic content of the raised beach deposit was used as evidence that it (like the overlying head) had accumulated under cold, glacial, conditions with the erratics having been derived from grounded ice-floes (Reid and Flett, 1907). This interpretation was also followed by Davison (1930).

Scourse (1985a, 1996c) recognized the same basic stratigraphy but interpreted the sequence in far greater detail. He correlated the raised beach deposit with that at Godrevy, classifying it lithostratigraphically as the Godrevy Formation. Despite this correlation, the age of the raised beach deposit

Figure 6.7 Boscawen GCR site (St Loy's Cove): solifluction deposits interbedded with organic sediments towards the base of the section. (Photo: J.D. Scourse.)

is far from certain; Scourse (1985a, 1996c) has tentatively ascribed it to a pre-Oxygen Isotope Stage 5 event (see Godrevy and Porth Nanven). The overlying beds were interpreted as consisting mainly of solifluction deposits (Penwith Formation) (Scourse, 1985a, 1996c).

The organic sediments within the head sequence at Boscawen are fundamental to Scourse's (1985a, 1996c) interpretation of the beds and the cornerstone of his scheme for Pleistocene subdivision in Cornwall. The organic sediments are arranged in a number of beds, the upper ones apparently having been soliflucted. The pollen contained in the lower, *in situ*, beds, although not zoned in the conventional manner, does however indicate a tundra vegetation and an Arctic climate: the deposits appear to have accumulated in a small pool on the surface of a solifluction flow (Scourse, 1985a, 1996c). The fossil flora is dominated by grasses. The spectrum also indicates that sedges were present in wetter areas, and the herb pollen are those from species which would have colonized the poor, disturbed minerogenic soils of a periglacial landscape (Scourse, 1985a, 1996c).

A radiocarbon age determination of 29 120 + 1690/− 1400 BP (Q-2414) from these humic sediments, if reliable, provides a maximum, Middle to Late Devensian, age for the bulk of the Penwith Formation at the site. The *in situ* organic bed, regardless of its age, also shows that the breccia accumulated on at least two separate occasions, and although a Late Devensian (Oxygen Isotope Stage 2) age for the upper part of the sequence seems likely, there is no way at present of knowing the age of the underlying head, particularly in view of the lack of a reliable age estimate for the raised beach deposits beneath. Similarly, the duration of the climatically slightly less severe interlude in which the organic sediments accumulated is not known.

Discontinuous sand lenses in the upper part of the head sequence are interpreted by Scourse as periglacial wind-blown sand ('sandloess') and correlated with the Lizard Loess (Roberts, 1985). The latter has been dated on the Lizard Peninsula by the TL method to 15.9 ± 3.2 ka BP (QTL 1e) (Wintle, 1981).

Boscawen is primarily a reference site for the interpretation of solifluction deposits in South-West England. It also provides a valuable record, in the form of raised beach deposits, for fluctuations in relative sea level during the Pleistocene. At present, the age of the raised beach deposit here is unknown. The dated organic deposits from within the solifluction beds show clearly that most of the breccia, including the lenses of wind-blown material, is probably Late Devensian in age. They also show that head deposits, indistinguishable from those above them and classified, lithostratigraphically, as part of the Penwith Formation, formed at some stage prior to *c.* 29 ka BP (Scourse, 1985a, 1996c). An Ipswichian age for the raised beach deposit (equivalent to Oxygen Isotope Stage 5e) would confine this early period of head formation to Early or Middle Devensian times. Such an age, however, is far from certain, and if the raised beach deposit proves to be older (e.g. Stage 7), then this head could equally well date from a pre-Devensian cold stage (e.g. Stage 6). The precise character and duration of the period in which the organic sediments at Boscawen accumulated has yet to be determined. It is not clear, for example, if the surviving organic beds represent the early part of an interstadial phase of the Devensian, or simply a brief, even seasonal, respite from active solifluction. Boscawen is therefore important for establishing that the head and solifluction deposits fringing the Cornish coast were not necessarily deposited in a single, synchronous, Late Devensian event or cycle.

Conclusion

Boscawen demonstrates important evidence for Pleistocene climatic and environmental conditions. Its raised beach and head deposits are in many ways typical of those along the south Cornish coast. However, organic sediments found within the head here have allowed a more detailed reconstruction of events than is usually possible. Solifluction appears to have been interrupted, *c.* 29 000 years ago, by a period of less harsh conditions when the land surface was colonized by tundra vegetation. A return to more extreme periglacial conditions and renewed solifluction is shown by thick head deposits which overlie the organic beds. Whereas the age of head deposits in most coastal sections can be determined only very broadly, the bulk of those at Boscawen can be shown to have accumulated after *c.* 29 ka BP, probably during the coldest part of the Devensian Stage (Late Devensian/Oxygen Isotope Stage 2). Head deposits below the organic sediments here must therefore be older, although like the raised beach deposits beneath them, their age is unknown.

PORTH NANVEN

S. Campbell

Highlights

Possibly the most spectacular section through raised beach deposits in Britain, the raised 'boulder' bed at Porth Nanven comprises a thick development of granite clasts, some in excess of 0.6 m diameter.

Introduction

Porth Nanven provides one of the finest examples of a raised 'boulder' beach in Britain. This classic raised beach deposit was first noted by Borlase in 1758, and was subsequently included in De la Beche's (1839) treatise on the geology of Cornwall. The site has also featured in studies by Austen (1851), Whitley (1866), Ussher (1879a), Reid and Flett (1907), Robson (1944), Guilcher (1949), Savigear (1960), Everard *et al.* (1964), Stephens (1973), Todd (1987), James (1994) and Scourse (1996c). The most detailed descriptions are provided by Scourse (1985a) and Goode and Taylor (1988).

Description

Particularly fine exposures of raised beach and head deposits occur between SW 355310 and SW 356308 in the small bay of Porth Nanven, 0.75 km south-east of Cape Cornwall (Figure 6.8). Here, a straightforward sequence occurs on top of a shore platform (Reid and Flett, 1907; Scourse, 1985a):

2. Coarse breccia of angular granite clasts (up to 4 m)
1. Large rounded cobbles and boulders, principally of granite (up to 8 m)

The shore platform, lying at *c.* 8.5 m and developed across the Land's End Granite, terminates inland at a nearby vertical granite cliff. The latter, according to Reid and Flett (1907), shows signs of being 'water-worn' almost up to 12 m above OD. Overlying the platform, and banked up against the fossil cliff, is a deposit comprising mainly large granite cobbles and boulders. This bed (bed 1 – raised beach deposit) is clast-supported, and discernibly coarser in the upper 2 m of the bed where boulders in excess of 0.6 m in diameter occur (Scourse, 1985a). The basal 4–6 m of the bed consist of cobble- and gravel-sized clasts. The bed contains much Killas and greenstone gravel near its base (Reid and Flett, 1907).

The overlying breccia or head (bed 2) consists of angular granite fragments which fine-upwards within the bed. The base of the bed consists of coarse angular boulders of granite. The sequence is capped by a thin soil developed directly on the head. The latter can be traced inland via stream sections which have been comprehensively worked for 'stream tin' (Reid and Flett, 1907; Scourse, 1985a).

Interpretation

The remarkable development of the raised beach deposits at Porth Nanven was first noted in Borlase's treatise on the natural history of Cornwall in 1758; he also referred to the overlying head as '… a load of rubbish …' (Borlase, 1758; p. 76). The spectacular development of the bed, and its unusually large cobbles also ensured that it was

Figure 6.8 Porth Nanven, west Cornwall: the spectacular 'raised boulder beach' overlain by solifluction deposits. (Photo: D.H. Keen.)

referred to in De la Beche's (1839) classic work on Cornish geology. The best early description of the Porth Nanven sequence was, however, given by Reid and Flett (1907). They regarded the raised platform as a marine surface of Pleistocene age cut into an older, Pliocene, surface. The water-worn granite face on the landward side of the platform was regarded as an ancient Pleistocene cliffline (Reid and Flett, 1907).

Although regarded as the oldest Pleistocene deposit of the region, the precise age of the raised beach deposit was not discussed. However, on the basis that similar beds elsewhere contained erratics (e.g. a pebble of 'biotite-trachyte' from nearby Priest's Cove), Reid and Flett argued that the raised beach had formed in one of the 'Glacial Stages' of the Pleistocene. Such contemporary thinking was also mirrored in other parts of Cornwall (e.g. Hill and MacAlister, 1906; Reid and Scrivenor, 1906; Reid *et al.*, 1910; Flett and Hill, 1912). The overlying head (bed 2) was also attributed to cold conditions in the Pleistocene (Reid and Flett, 1907), frost-shattering of the local bedrock having been followed by the redistribution of material along the coastal slopes and local valleys by meltwaters during the 'Glacial epoch'. It was during this latter phase that stream tin was washed from the shattered debris and deposited, selectively, within the gravel and head sequence by virtue of its high specific gravity (Reid and Flett, 1907).

Savigear (1960) briefly referred to Porth Nanven in a study of the morphology of the local coastal slopes and cliffs. He identified four narrow and fragmentary benches below the main granite cliffs at Porth Nanven, the uppermost of which was overlain by the raised storm beach and head sequence. He concluded that the main shore platform, the beach deposits, cliffs, spurs and bevels of the coastal zone all, therefore, antedated the whole, or part of the last glaciation, since they were blanketed by head up to a height of some 30 m OD.

The most recent interpretation of the Pleistocene sequence at Porth Nanven was given by Scourse (1985a, 1996c) and James (1994). Scourse also interpreted the beds as a raised beach deposit (bed 1; Godrevy Formation) overlain by solifluction deposits (bed 2; Penwith Formation). He commented that the raised beach deposit was the thickest and coarsest in Cornwall, its pronounced upward coarsening perhaps showing a regression of the high Pleistocene sea level.

Despite these preliminary lithostratigraphic correlations, the age of the Porth Nanven raised beach deposit is far from certain. Preliminary amino-acid data from fossil shell material in the Godrevy raised beach deposit indicate that it was perhaps not formed in the Ipswichian Stage (Oxygen Isotope Stage 5e) (Bowen *et al.*, 1985). If the present correlation of the Porth Nanven and Godrevy raised beach deposits (Scourse, 1985a, 1996c), based entirely on lithostratigraphy, is correct, then the Porth Nanven example too may date from a pre-Ipswichian (pre-Oxygen Isotope Stage 5e) high sea-level event. Such an ascription, however, is unproven (Pendower; this chapter).

Complementing the stratigraphic importance of the site, the nature of the raised beach deposit itself is of great interest. Its perceived coarsening-upward sequence and upper, substantial, boulder layer is unusual, perhaps reflecting a progressive regression in relative sea level. The coarseness of the bed may reflect both the nature of the sediment source (coarse, widely jointed granite) and the prevailing wave energy; the site faces due west and lies only a few kilometres from Land's End, one of the most exposed coastal locations in southern Britain today. As such, the site provides a fine example of a raised 'boulder' beach, a facies variation rarely recorded elsewhere at other British Pleistocene localities.

On the basis of a radiocarbon date (*c.* 29 ka BP) from organic sediments interbedded in the head sequence at nearby Boscawen, Scourse (1985a) has attributed the bulk of head deposits there, and other examples of the Penwith Formation, to the Late Devensian (see Boscawen). Problems in estimating the age of the underlying raised beach deposit (bed 1), however, make estimates of the age of the overlying head at Porth Nanven tenuous. The possibility clearly remains that if the raised beach deposits accumulated during a pre-Ipswichian (Oxygen Isotope Stage 5e) high sea-level event, then solifluction deposits from several subsequent cold phases of the Pleistocene may be present. It seems likely, however, that a substantial part of the head sequence accumulated in the Late Devensian (Scourse, 1985a). To some extent, the nature of the head deposits at Porth Nanven may throw light on the relative dating of the beds. The well-developed and clear fining-upward head sequence may show that in fact there was only one major phase of periglacial activity, and a single cycle of head formation at the site, the coarsest material representing the products of a previous weathering cycle (interglacial or interstadial?), and the progressive fining of the beds reflecting the diminution in availability of weathered products for solifluction.

Conclusion

Porth Nanven is an important Pleistocene stratigraphic locality providing fine examples of a shore platform, raised beach and head deposits. The raised 'boulder' beach is particularly unusual and was probably formed as a storm beach during a fall in relative sea level. Its coarseness reflects a high energy wave regime promoted by the particularly exposed westerly location of this part of the Cornish coast. Porth Nanven is also notable as one of the first raised beach localities to have been described in Britain.

GODREVY

S. Campbell

Highlights

Excellent sections through interglacial marine deposits, blown sand and periglacial head, make Godrevy one of the South-West's most important Pleistocene sites. Part of its raised beach deposit is tentatively ascribed to Oxygen Isotope Stage 7, leaving the possibility that some overlying head deposits and associated periglacial structures were formed during several Pleistocene cold stages.

Introduction

Godrevy has long been regarded as a reference site for raised beach, blown sand and head deposits. The site was mentioned in early studies by De la Beche (1839), Whitley (1866, 1882), Ussher (1879a), Reid and Flett (1907), Rogers (1910) and

Davison (1930). It has featured in more recent studies of Pleistocene chronology by Robson (1944), Stephens (1961a, 1966a, 1970a), Everard *et al.* (1964) and Mitchell (1972). The sediments and stratigraphy have also been described by Hosking and Pisarski (1964), James (1975b, 1994, 1995), Hosking and Camm (1980), Sims (1980), Scourse (1985a, 1996a, 1996c), Goode and Taylor (1988) and Morawiecka (1993, 1994). Bowen *et al.* (1985) provided amino-acid ratios from shell in the raised beach deposits.

Description

Continuous sections through Quaternary sediments extend from Magow Rocks (SW 582423) almost to Godrevy Point (SW 581430). The Quaternary sequence rests on a well-developed shore platform cut across Devonian (Mylor) slates (James, 1975b), mainly highly contorted blue (hard) and yellow (soft) slates intersected by quartz veins (Figure 6.9). The platform lies between 4 and 10 m OD (Scourse, 1996c) and in places is as much as 100 m wide. It is notched at a level of *c.* 8 m OD (James, 1975b) and, locally, its surface is fragmented (Stephens, 1966a). The following succession can be generalized from the descriptions given by Stephens (1966a), James (1975b) and Scourse (1985a, 1996c):

5. Soil
4. Silty sand (up to 1.0 m) (Holocene)
3. Head of various facies (up to 5.0 m)
2. Sand, cemented in places, with clay bands – 'sandrock' (up to 3.5 m)
1. Basal pebbles consisting mainly of local rocks, but with greenstone and chalk flints and mixed with sand in places. Occasionally cemented by iron and manganese oxides (up to 2.0 m)

Shore platform

Clay bands are common in the lower part of bed 2, especially at its junction with bed 1. They vary in thickness from 2–5 cm, form an undulating pattern and fill troughs between sand ripples (James, 1975b). In places, thicker and more numerous clay bands occur in the sand, especially below the junction with the overlying head (bed 3), which interdigitates with the non-indurated sand of bed 2 (James, 1975b, 1994). This junction is sometimes marked by a convoluted band of manganese-cemented sand. Where the sand is cemented, as at Godrevy Point, it is usually made up of pale yellow, shelly, medium to coarse sand, more than 60% of which consists of shell. Some of these sediments are characterized by large-scale, planar cross-beds (James, 1975b; Scourse, 1985a, 1996c).

In places, the sand (bed 2) is penetrated by vertical pipes (cf. St Agnes Beacon and Trebetherick Point) with an average diameter of 12.5 cm and a depth of over 1 m. Many of these pipes are now empty but others, filled with brown uncemented sand, have been observed (James, 1975b). These dark sands also form a thin layer on top of the cemented sands and beneath the overlying head. Texturally and petrologically, this sand is identical to that elsewhere in bed 2; it differs only in being decalcified (James, 1975b).

The head (bed 3) consists of a highly variable breccia of slate and quartz fragments and can be subdivided, in places, into a lower festooned bed and an upper less disturbed bed (Stephens, 1966a, 1970a). James (1994), however, notes that nearly all of the clearly observed quartz clasts are vertically aligned, indicating significant post-depositional disturbance to the upper layer. Occasionally, some stratification is present within the head (Scourse, 1985a, 1996c). Stephens (1966a) noted that the raised beach deposits, at one locality, were also underlain by a thin development of head.

Interpretation

Whitley (1882) was one of the first to describe the sections at Godrevy in any detail. He regarded bed 1 as an alluvial deposit, since it was thickest where exposed in the central part of the valley mouth, and claimed that '... it becomes obvious that the gravel bed is not a sea beach, but a valley deposit, cut back and exposed by the action of the sea.' (Whitley, 1882; p. 134). Reid and Flett (1907), however, regarded the Godrevy sections as showing raised beach deposits overlain by blown sand and head. Although most subsequent authors (e.g. Robson, 1944; Everard *et al.*, 1964; Stephens, 1966a) have accepted this broad classification, significant differences of opinion have arisen regarding the age of the beds.

Stephens (1961a, 1966a, 1970a) used Mitchell's (1960) framework of Pleistocene events in south-west Britain to interpret the sediment succession at Godrevy. He argued that the lowest head deposit (recorded at one locality beneath raised beach deposits) and the frost-shattered surface of the

Figure 6.9 Coastal exposures near Godrevy Cove, showing shore platform overlain by raised beach cobbles, sand and various head facies. (Photo: S. Campbell.)

shore platform recorded a periglacial event of unspecific, but broadly 'Early Pleistocene' age. The raised beach deposits (bed 1) were believed to have accumulated on the shore platform (and locally above head deposits) at a time of high relative sea level and during temperate conditions in the Hoxnian Stage. The overlying dune sand (bed 2) was believed to indicate falling sea level and the onset of cold conditions at the beginning of the Wolstonian (Saalian Stage). Stephens (1966a) divided the overlying head (bed 3) into two distinct facies: an upper, relatively undisturbed head; and a lower, thicker, much weathered and cryoturbated head. The lower unit was interpreted as a typical periglacial solifluction deposit which was both deposited and cryoturbated during the Saalian. Temperate conditions in the ensuing Ipswichian Stage were invoked to account for weathering of the bed. The upper part of bed 3 (Stephens' upper head) was assigned to a separate phase of periglacial conditions in the Devensian, while the silty sand of bed 4 (a mixture of blown sand and slope-wash deposits) was thought to have accumulated in Holocene times. This chronology was also adopted by Sims (1980).

James (1975b) provided new evidence for the depositional environment of the sand (bed 2). In places, the sand differs in grain size through the bed, reflecting that the basal layers may be marine, the upper aeolian (James, 1975b): occasional well-rounded pebbles are found at least 1 m above the base of the sand bed. James suggested that the clay bands found towards the base of the bed had been deposited by slow-moving water, the clay having infilled ripples on the surface of the underlying marine sand. This material was believed to have been washed from surrounding slopes prior to the deposition of wind-blown sand. James (1975b) assigned bed 4 to the Holocene but made no age ascriptions for the other beds.

Hosking and Camm (1980) suggested that the iron oxide cementing agent of the Godrevy raised beach conglomerate showed that swampy conditions had prevailed in the adjoining valley prior to the accumulation of solifluction deposits. It is likely that the iron and manganese oxides were leached from the valley bedrock and transported to the sites of oxide deposition, in the raised beach sediments, as organic complexes (Hosking and Camm, 1980).

Bowen *et al.* (1985) presented three amino-acid ratios derived from a single specimen of *Patella vulgata* Linné collected from the raised beach deposits (bed 1) by H.C.L. James. This shell yielded an average ratio of 0.175 ± 0.021, a value similar to those derived from shells in the Inner Beach at Minchin Hole Cave, Gower (Bowen *et al.*, 1985; Bowen *et al.*, 1989; Campbell and Bowen, 1989). Similar results were provided for the Godrevy raised beach deposits by Davies (1985). Such ratios, and others from raised beach deposits elsewhere in southern Britain (e.g. Butterslade and Horton Upper Beach, Gower; Saunton, north Devon; and Fistral Beach, north Cornwall), have been correlated with high relative sea levels in Oxygen Isotope Stage 7 (Bowen *et al.*, 1985) and calibrated by Uranium-series techniques (e.g. Davies, 1983) to around 210 ka BP. These shells are therefore believed to be significantly older than those characteristic of raised beaches ascribed to the Pennard D/L Stage (Ipswichian Stage/Oxygen Isotope Stage 5e) (Bowen *et al.*, 1985; Bowen and Sykes, 1988) (see Portland Bill). James (1995), however, notes that the preparation methods used by Davies (1983, 1985) and earlier workers, produced amino-acid ratios consistently higher (and therefore 'older') than the methods currently in use. He raises the possibility, therefore, that Davies' ratios from Godrevy could be taken to indicate a Stage 5e age for the raised beach deposits, and cites preliminary Infra-red Stimulated Luminescence (IRSL) dates (Richardson, 1994) in support of this Stage 5e ascription (see also Pendower; this chapter).

Scourse (1985a, 1996c) re-examined the Godrevy sections in detail. The excellent development of raised beach deposits and associated dune sands led him to use Godrevy as a regional type-site for such sediments and the deposits were classified as the Godrevy Formation. Scourse used palaeocurrent vectors derived from foreset laminae to show that the sands (bed 2) had been deposited by north-westerly winds. The overlying head (bed 3) was confirmed as a typical periglacial solifluction deposit (assigned to the Penwith Formation; Scourse, 1985a, 1996c).

Morawiecka (1993, 1994) presented details of 'pipe' phenomena developed in the calcareous sandstone (bed 2) at Godrevy. Most of the pipes occur in the upper and middle parts of the 'sandrock' profile, but none extends down to the level of the rock platform. Morawiecka concludes that the pipes developed after the overlying head (bed 3) had been deposited (cf. West, 1973). She raises the possibility that solution of the 'sandrock' occurred, perhaps quasi-catastrophically, under cold conditions close to the Devensian/Holocene transition, thus making this the youngest palaeokarst demonstrated in the UK.

Although the models of Pleistocene chronology applied to sequences in the South-West by Stephens (1966a, 1970a, 1973) and Mitchell (1960, 1972) have been criticized as unnecessarily complex (e.g. Kidson, 1971, 1977; Bowen, 1973b), recent amino-acid measurements show clearly that raised beach deposits of significantly different ages are present around the coast of south-west Britain. As far as the limited amino-acid data from Godrevy can show, the site provides a fine example of a raised beach deposit that has been ascribed to Oxygen Isotope Stage 7 (but see James, 1995). If this dating is confirmed, then the overlying head could have accumulated during several different Pleistocene cold stages, perhaps equivalent to Stages 6, 4 and 2 of the deep-sea record. James (1994, 1995), however, believes that the bulk of raised beach deposits at Godrevy date from Stage 5e, implying that the overlying head is entirely Devensian in age.

The sequence also provides a comprehensive record of Quaternary environments. Whereas the raised beach conglomerate and the head facies show extremes of climatic change in the region (from temperate high sea-level conditions, to cold periglacial environments), the intervening sands probably reflect conditions towards the end of an interglacial and before the establishment of a full periglacial regime. These sediments clearly record a fall in relative sea level and deflation of sand, probably from an exposed sea floor. The clay bands found in the sand bed may show that sheet-washing of sparsely vegetated hillslopes occurred before the onset of more severe (periglacial) conditions when the overlying head(s) accumulated. (Similar sands at Belcroute and Portelet, Jersey, contain palaeosols indicative of temperate Stage 5c- and 5a-type conditions (Keen *et al.*, 1996).)

Importantly, the Pleistocene sediments exposed at Godrevy show no direct evidence for glacial activity in this area. Some reworked erratics found in the raised beach deposit may attest to an earlier glacial event of considerable age, but otherwise the sections demonstrate that the site, and probably its immediate environs, lay in the periglacial zone during a variety of Pleistocene cold stages. The site therefore shows no tangible evidence to corroborate the reconstructed ice-sheet limits proposed by a variety of workers (e.g. Mitchell, 1960, 1972; West, 1968, 1977a; Jones and Keen, 1993).

Conclusion

Godrevy provides one of the most informative Pleistocene sequences in Cornwall. Its raised beach sediments, blown sand and solifluction deposits (head) are referred to in many important texts on the Pleistocene. Fossil shell material in the raised beach deposits here has been dated by amino-acid geochronology; a tentative correlation with Oxygen Isotope Stage 7 (warm) of the oceanic record is suggested. A fall in relative sea level and cooler climatic conditions are recorded by the overlying sand, some of which was blown inland from an exposed sea floor by north-westerly winds. The head deposits at Godrevy record a further deterioration of climate. These deposits are arranged in distinct layers which may have accumulated during different cold, periglacial phases of the Pleistocene – possibly equivalent to one or more of Stages 6, 4 or 2 of the deep-sea record. The site shows that this part of Cornwall was probably not overrun by glaciers.

TREBETHERICK POINT
S. Campbell

Highlights

This classic locality has featured in numerous reconstructions of the Pleistocene history of South-West England. Its highly controversial 'boulder gravel' has been used as evidence by some for glaciation of the north Cornish coast.

Introduction

Sections at this site reveal a complex sequence of raised beach, blown sand, 'boulder gravel' and head deposits. The controversial 'boulder gravel', in particular, has attracted much interest and debate, and has been interpreted variously as a beach deposit reworked from glacial sediment, as a head or solifluction deposit, as river or outwash gravels and as till *in situ*. The precise origin of this bed and its stratigraphic relationship to sediments exposed elsewhere are of prime importance in establishing the sequence and nature of Pleistocene events in the region. The site was described in early studies by Ussher (1879a), Rogers (1910) and Dewey (1913, 1935). It also featured in more detailed studies by Reid *et al.* (1910), Clarke (1965a, 1965b, 1969, 1973), Stephens (1966a) and West (1973): the classic account is that of Arkell (1943). It has also been referred to in regional evaluations of Pleistocene history by Robson (1944), Arkell (1945), Balchin (1946), Clarke (1962, 1968), Mitchell and Orme (1967), Macfadyen (1970) and Edmonds *et al.* (1975), and in more extensive correlations (Green, 1943; Mitchell, 1960; Bowen, 1969; Stephens, 1970a, 1973; Kidson, 1971, 1977). More recently, the site has featured in studies by Clarke (1980), Sims (1980), Campbell (1984), Bowen *et al.* (1985) and Scourse (1985a, 1985b, 1987, 1996a, 1996c). A detailed description of the site is also provided by James (1994).

Description

Trebetherick Point (SW 926779) is a promontory of Devonian rocks on the east side of the Camel Estuary. Pleistocene sediments are well exposed for *c.* 0.75 km around the Point between the southern end of Greenaway Beach (SW 928783) and the dunes at the north end of Daymer Bay (SW 928777). They fringe an ancient rock cliff and rest on a conspicuous shore platform of Upper Devonian purple and green slates which varies in height between *c.* 1–7 m OD. Stephens (1966a) divided the platform into upper and lower elements: the Pleistocene deposits rest on the higher of these.

The Pleistocene sequence is both laterally and vertically extremely variable. Arkell (1943) figures three sections and Stephens (1966a) provides eight separate stratigraphic sections to illustrate this variability. Figure 6.10 shows Arkell's 'Section A' and a revised stratigraphy for the principal exposure of the boulder gravel at *c.* SW 927781. The following succession can be generalized from the descriptions given by Arkell (1943), Stephens (1966a) and Scourse (1985a, 1996c) and from field observations (maximum bed thicknesses in parentheses):

9. Soil
8. Sand (dune sand) (2.0 m)
7. Stony loam/pebbly clay (colluvium) (0.5 m)
6. Breccia (upper head) (1.0 m)
5. Diamicton ('boulder gravel') (2.0 m)
4. Breccia (lower or main head) (3.0 m)
3. Sand (dune sand) (6.0 m)
2. Boulders, gravel and sand (raised beach deposits) (2.0 m)
1. Breccia (lowest head) (0.3 m)

Shore platform

The lowest breccia (bed 1) is not widely developed at the site and consists predominantly of fine slate fragments. Stephens (1966a) states that it rests directly on the shore platform and beneath raised beach deposits (bed 2), but Arkell (1943) shows the material to interdigitate with raised beach sediments towards the fossil cliff (Figure 6.10).

The overlying bed comprises a highly variable deposit of boulders, gravel and sand. Some of the sand is bedded and contains stringers of shingle, fine slate and occasional pebbles (Arkell, 1943). In other places, the bed consists of a poorly cemented, clast-supported deposit of pebbles and cobbles (Scourse, 1985a, 1996c). Clasts are subangular to rounded and of both local and non-local origin. Arkell (1943) recorded quartz, grit, slate, elvan (dyke rock of granitic composition), dolerite and flint from the bed as well as some very large boulders of 'greenstone' (sill material).

Bed 3 consists overwhelmingly of sand which exhibits large-scale cross-beds and is unevenly cemented. The latter gives rise to alternating hard and soft layers which make bedding conspicuous. Stephens (1966a) and subsequent authors have

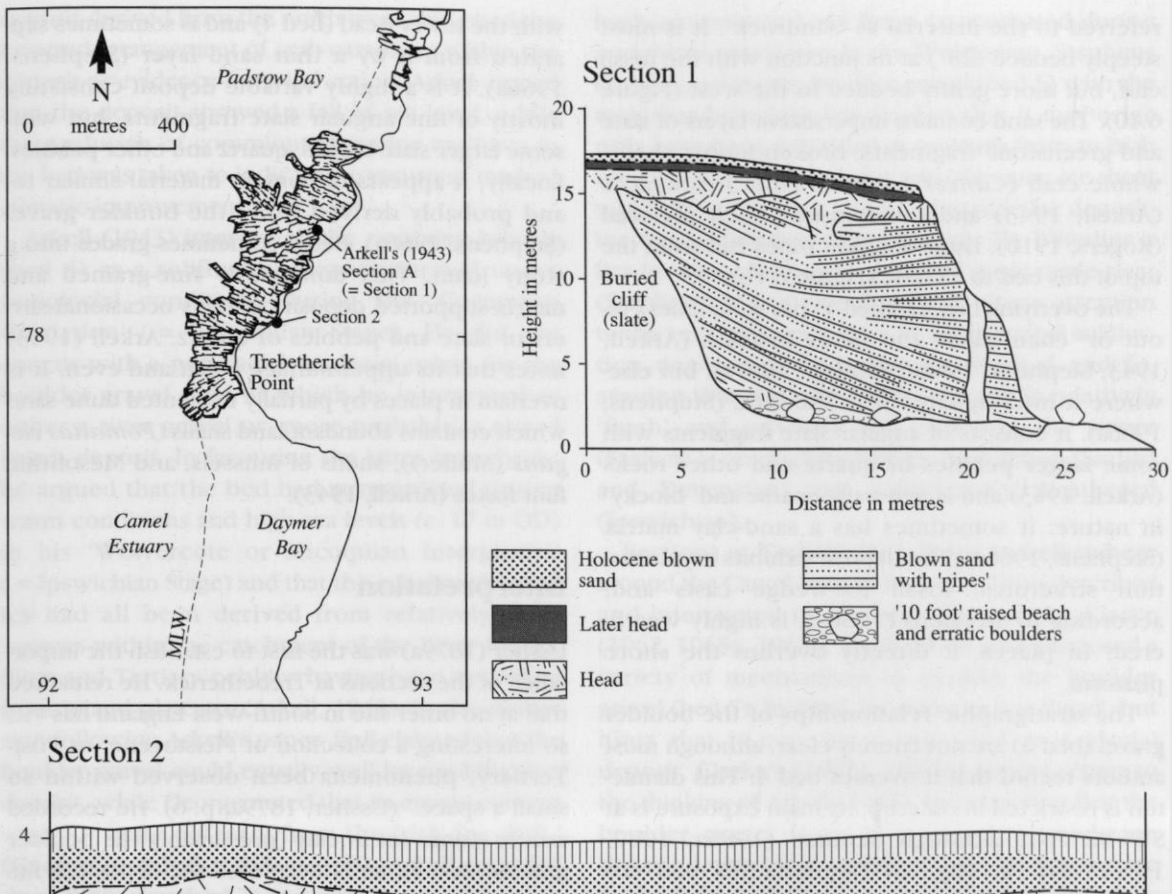

Figure 6.10 The Quaternary sequence at Trebetherick Point: Section 1 after Arkell (1943); Section 2 compiled by S. Campbell.

referred to the material as 'sandrock'. It is most steeply bedded (28°) at its junction with the fossil cliff, but more gently bedded to the west (Figure 6.10). The sand contains impersistent layers of slate and greenstone fragments, broken limpet shells, whole crab (*Cancer pagurus* Linné) carapaces (Arkell, 1943) and comminuted shell material (Rogers, 1910). Large solution pipes run from the top of this bed to its base (Figure 6.10).

The overlying breccia (bed 4) has sometimes cut-out or 'channelled' the sands beneath (Arkell, 1943; Stephens, 1966a; Scourse, 1985a), but elsewhere it interdigitates with the sand (Stephens, 1966a). It consists of angular slate fragments with some larger pebbles of quartz and other rocks (Arkell, 1943) and is generally coarse and 'blocky' in nature: it sometimes has a sand-clay matrix (Stephens, 1966a). The deposit exhibits cryoturbation structures, fossil ice-wedge casts and, according to Stephens (1966a), is highly weathered. In places, it directly overlies the shore platform.

The stratigraphic relationships of the boulder gravel (bed 5) are not entirely clear, although most authors record that it overlies bed 4. This diamicton is restricted in outcrop; its main exposure is at SW 927781, although Scourse (1985a, 1987, 1996c) also records it at Tregunna (SW 960740) and other localities around the Camel Estuary. Figure 6.10 (section 2) shows that the deposit extends for *c.* 20 m (Scourse has traced its lateral extent for *c.* 60 m) and that it grades laterally into a coarse breccia of angular slate and quartz fragments. It may, therefore, be a facies variation of bed 4 (the lower or main head). It is a largely matrix-supported, mixed lithology gravel with cobbles and occasional boulders. Many of the clasts are locally derived (purple and green slate, vein quartz, phyllite), but others appear to have come from farther afield. The latter include sandstone, conglomerate, granite, porphyry, dolerite, basalt, ironstone and flint (Arkell, 1943), mica-schist (Clarke, 1965b; Scourse, 1996c) and chert (Scourse, 1996c). Some clasts are in excess of 0.5 m diameter and many of the larger ones are subrounded to rounded. In places, the matrix consists of a breccia of very fine slate fragments (Figure 6.10). Arkell (1943) described the sediment as conspicuously bedded in its lower layers, but Stephens (1966a) contradicts this, and today there is little evidence of stratification.

The overlying breccia (bed 6) is also laterally impersistent, and elsewhere rests directly on the lower head (bed 4). It always has a sharp junction with the lower head (bed 4) and is sometimes separated from it by a thin sand layer (Stephens, 1966a). It is a highly variable deposit consisting mostly of fine angular slate fragments, but with some larger slate blocks, quartz and other pebbles. Locally, it appears to contain material similar to, and probably derived from, the boulder gravel (Stephens, 1966a). Bed 6 sometimes grades into a stony loam. This dominantly fine-grained and matrix-supported deposit contains occasional slivers of slate and pebbles of quartz. Arkell (1943) notes that its upper surface is flat and even. It is overlain in places by partially cemented dune sand which contains abundant land snails (*Pomatias elegans* (Müller)), shells of mussels, and Mesolithic flint flakes (Arkell, 1943).

Interpretation

Ussher (1879a) was the first to establish the importance of the sections at Trebetherick. He remarked that at no other site in South-West England has '... so interesting a collection of Pleistocene, or Post-Tertiary, phenomena been observed within so small a space.' (Ussher, 1879a; p. 6). He recorded erratic stones set in clay (presumably the boulder gravel – bed 5), and interpreted the deposit as fluviatile in origin. In contrast, Reid *et al.* (1910) suggested that the boulder gravel was a head deposit and that the underlying sand (bed 3) was a 'cemented sand reef' and, by implication, waterlain. Dewey (1913) fired the controversy over the boulder gravel by hinting at a glacial origin. He later referred to it unequivocally as 'boulder clay' and correlated it with the beds of clay and striated erratics at Croyde Bay and Fremington in north Devon (Dewey, 1935; p. 67) (Chapter 7).

Arkell's (1943) description of the sequence at Trebetherick is still one of the best, although some of his interpretations have since been revised. He regarded beds 2 and 3 as raised beach deposits and aeolian sand respectively, and correlated them with comparable deposits at Saunton in north Devon. He assigned the beds to the 'Boyn Hill or Middle Acheulian Interglacial' (equivalent to the Hoxnian of later terminology). He argued that the absence of shells in the raised beach deposits (bed 2) indicated deposition under relatively cold but high sea-level conditions at the beginning of an interglacial, with the constituent erratic boulders having been transported on ice-floes. He refuted the suggestion of Reid *et al.* (1910) that bed 3 was waterlain. Instead, he suggested it was an aeolian deposit derived from the north-west, and cited the inverted arrangement of crab carapaces within the deposit as evidence for wind action. Arkell argued that the deposit showed a fall of sea level, while the profusion of comminuted marine molluscs in the bed was taken to indicate a concurrent marked climatic improvement.

Arkell (1943) interpreted the overlying breccia (bed 4) as a solifluction deposit formed under periglacial conditions during the 'Cornovian Glaciation' (= Wolstonian Stage). He did not concur with a periglacial or glacial origin for the boulder gravel (bed 5) which he interpreted as either a river gravel or, more probably, a raised beach deposit. In favouring the latter hypothesis, he argued that the bed had accumulated during warm conditions and high sea levels (*c.* 17 m OD) in his 'Wolvercote or Micoquian Interglacial' (= Ipswichian Stage) and that the constituent erratics had all been derived from relatively local sources within the catchment of the River Camel, flints and Tertiary pebbles having been reworked from inland plateaux (Arkell, 1943). In the discussion following Arkell's paper, Bull claimed that the boulder gravel could equally well be a solifluction deposit, while George noted that its erratic content was '… quite different from the Irish Sea drift.' (George *in* Arkell, 1943; p. 148). Arkell regarded the pebbly clay (bed 7) as a mixture of solifluction and sheet-wash deposits reworked from the boulder gravel. Together with head deposits found elsewhere around Daymer Bay (= bed 6), these deposits were believed to represent a return to periglacial conditions during the 'Cymrian Glaciation' (= Devensian Stage). Arkell noted that the evenly planed upper surface of bed 7 supported a fossil soil which contained Mesolithic artefacts and which was believed to represent an ancient land surface.

The overlying sands (bed 8) were regarded as wind blown in origin and of Holocene age. Their contained fauna of indigenous land snails and derived marine molluscs was taken as indicating temperate conditions subsequent to a period of vigorous forest growth around the coastal margin, as attested by a now submerged forest bed in parts of Daymer Bay (Arkell, 1943).

Stephens (1966a) regarded the raised beach deposits (bed 2) at Trebetherick as Hoxnian in age and suggested that the overlying sands (bed 3) had been blown inland from an exposed sea bed as sea level fell at the beginning of the Wolstonian (Saalian Stage). The lower or 'main' head (bed 4) was interpreted as a solifluction deposit which had both accumulated and been cryoturbated during periglacial conditions in the Wolstonian. Stephens (1966a) groups the boulder gravel (bed 5) with the main head (bed 4), but implies that it may originally have been deposited as outwash from an Irish Sea ice sheet of Wolstonian age (the same ice sheet was believed to have been responsible for depositing the Fremington Clay; Chapter 7). Whether it lies *in situ* or has been soliflucted is not made clear (Stephens, 1966a). Stephens also draws attention to the very different nature of the principal solifluction deposits at Trebetherick (beds 4 and 6), arguing that the upper (Devensian) is relatively 'fresh' and unweathered, whereas the lower (Saalian) is much disturbed by frost-action (Saalian and Devensian) and significantly weathered (Ipswichian).

Sections at Trebetherick Point and elsewhere around the Camel Estuary have also been described and interpreted in a series of papers by Clarke (1962, 1965a, 1965b, 1969, 1973) who proposed a variety of mechanisms to explain the boulder gravel (bed 5). In 1962, he refers to it as 'head', but hints that it may have originated as a glacial deposit. Clarke's (1965a, 1965b) papers return to the thinking of Arkell (1943), by proposing that the boulder gravel is an Ipswichian raised beach deposit derived by '… marine erosion of a moraine in the Bristol Channel … ', but then reworked by solifluction processes in the Devensian (Clarke, 1965b; p. 274).

His later papers (Clarke, 1969, 1973) reflect the influence of a growing body of evidence for the presence of an ice sheet in the Bristol Channel and Western Approaches during Wolstonian (Saalian) times (e.g. Mitchell, 1960, 1968, 1972; Stephens, 1966b; Mitchell and Orme, 1967). His 1969 paper attempts to cover several eventualities by stating '… a tongue of this ice invaded the north projecting Camel estuary, gathering beach pebbles in its progress and leaving a patch of till.' (Clarke, 1969; p. 90). He argued that this explanation of the boulder gravel was consistent with Mitchell's (1968) evidence that Saalian Stage (Wolstonian) Irish Sea ice had surrounded Lundy Island to a height of 105 m, and also with Stephen's (1966b) evidence for Irish Sea till in the Barnstaple Bay/Fremington area, and finally with evidence for an incursion of the same ice sheet on to the Isles of Scilly (Mitchell and Orme, 1967).

In 1973, Clarke reported a further exposure of the boulder gravel west of Tregunna House on the south side of the estuary (SW 960740), and alluded to the possibility that the material was deposited by a glacier originating on Bodmin Moor. In his 1980 paper, however, he returns to the Irish Sea ice sheet hypothesis and explains the boulder gravel as part of a recessional moraine, occurrences of material at Tregunna and Little Petherick being used to define lateral margins of the moraine. This ingress of ice into the estuary was believed to have impounded the proto-Camel, forming a 'lake flat' at Trewornan (SW 988743). However, Scourse (1985b) has since shown that this feature comprises Holocene estuarine sediments.

Mitchell (*in* Mitchell and Orme, 1967) regarded Arkell's pebbly clay (bed 7) as a weathered facies of the north Devon Fremington Clay – a till believed by him to be of Wolstonian age: the boulder gravel (bed 5) beneath was regarded either as an outwash gravel or raised beach deposit. Stephens (1970a, 1973) disputed this interpretation, concluding that the boulder gravel was a mixture of head, glacial outwash and Irish Sea till, subjected to later frost-action and weathering.

Kidson took quite a different view of the evidence, rejecting a glacigenic origin for any of the deposits at Trebetherick. He noted that the boulder gravel (bed 5) graded laterally into head and might therefore be soliflucted river gravels – forming one element in a multiple facies head sequence. Moreover, George (*in* Arkell, 1943) had shown that the erratic content of the boulder gravel and pebbly clay was quite different from that of glacial deposits elsewhere which had been derived from the Irish Sea basin, the Cornish origin of many of the clasts supporting the idea that they had been derived by solifluction from within the catchment of the River Camel itself (Kidson, 1977). In refuting the presence of an *in situ* Wolstonian glacial deposit in the sections at Trebetherick, Kidson followed Zeuner (1945, 1959), Arkell (1945) and Bowen (1969) in assigning the raised beach sediment and blown sand (beds 2 and 3) to the Ipswichian Stage, and the overlying beds of head to the Devensian.

Although recent studies have clarified several important issues posed by the succession at Trebetherick, they have failed to reach a firm conclusion regarding the origin of the boulder gravel. Campbell (1984; *in* Scourse, 1996c) analysed quartz sand grains from the boulder gravel using Scanning Electron Microscopy (SEM). He concluded that the constituent grains showed features characteristic of a subaqueous origin (unspecified) but none indicative of a glacial or glaciofluvial environment of deposition.

Scourse (1996c) assigns the raised beach deposits and overlying sands (beds 2 and 3) to the Godrevy Formation of his lithostratigraphical classification, and the overlying head deposits (bed 4) to the Penwith Formation: the boulder gravel is afforded special status as the Trebetherick Boulder Gravel Member of the Tregunna Formation (the latter includes head deposits overlying bed 5 which locally contain materials reworked from it). He interpreted the bed as a partially soliflucted outwash gravel or ablation till, and provided fabric data in support of this conclusion. Its lithological content, however, was regarded as typical of the Variscan outcrops which occur both inland from the Camel Estuary and seaward of it. In determining the height of various boulder gravel outcrops around the margins of the estuary, Scourse (1996c) has concluded that only the lower-level occurrences, such as those exposed at Trebetherick Point, have been soliflucted, whereas those at higher level lie *in situ* and were the source of the reworked material. Additional clast lithological analyses from the material now point strongly to an inland source, perhaps as far afield as Bodmin Moor. The mechanism for emplacement, however, is still uncertain, although Scourse cites river ice as a possibility. Although this mechanism would explain its lithological content, Scourse concedes that the reconstructed gradient of the various boulder gravel outcrops around the Camel would be more consistent with a glacigenic (outwash) origin.

Bowen *et al.* (1985) provided an amino-acid ratio of 0.113 from a specimen of *Littorina saxatilis* (Olivi), collected by H.C.L. James, from the raised beach deposits at Trebetherick (bed 2), and ascribed the beach to Oxygen Isotope Stage 5e (Ipswichian) of the deep-sea record. Scourse (1996c) uses this geochronological evidence as well as stratigraphical evidence from the Isles of Scilly (Chapter 8) to assign a Devensian age to the boulder gravel whatever its origin.

Scourse (1996a) described trace fossils (burrows of the talitrid sandhopper) from the sand beds (bed 3) at Trebetherick. He argued that they provide independent evidence of a backshore-frontal dune environment of deposition. He notes that the ecological requirements of *Talitrus saltator* (Montagu) – the most likely burrowing agent – support an interglacial depositional environment.

Morawiecka (1993, 1994) studied the palaeokarstic 'pipes' found in the upper part of the 'sandrock' profile at Trebetherick (cf. Arkell, 1943; Figure 6.10, section 1). She concluded that they had been formed beneath a cover of head deposits under cold climatic conditions during end-Pleistocene times (cf. Godrevy).

Conclusion

Trebetherick Point is one of the most controversial Quaternary sites in South-West England. It shows a sequence of raised beach deposits, wind-blown sand and periglacial 'head' deposits. Of particular interest is the deposit known as the 'boulder gravel' which occurs within the head sequence. This highly controversial deposit has been interpreted by some as a glacial sediment and used as evidence to reconstruct the southern margin of a 'Wolstonian' Irish Sea ice sheet. Others have interpreted the material as fluvial sediment or raised beach deposits. Whatever its original mode of deposition, most agree that it was finally moved into place by periglacial (solifluction) processes. The latest suggestion is that the boulder gravel was derived entirely from within the catchment of the River Camel (some rock-types may have come from Bodmin Moor), having been transported to Trebetherick on floes of river ice similar to those seen in present-day Arctic Canada. Preliminary geochronological evidence from the site shows that the raised beach sediments were probably formed during Oxygen Isotope Stage 5e (Ipswichian) and that the overlying head deposits, including the boulder gravel, accumulated during the Devensian.