Quaternary of South-West England

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JOINT NATURE CONSERVATION COMMITTEE

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Chapter 2

The geomorphological evolution and Quaternary history of South-West England: a rationale for the selection and conservation of sites

THE PRINCIPLES AND METHODOLOGY OF THE GEOLOGICAL CONSERVATION REVIEW

S. Campbell and J.E. Gordon

Introduction

The prime aim of the Geological Conservation Review (GCR) was to select sites for conservation which are of at least national, that is British, importance to the sciences of geology and geomorphology; more than 3000 sites have been selected. The full rationale of the GCR and the detailed criteria and guidelines used in site selection are given elsewhere (Crowther and Wimbledon, 1988; Allen *et al.*, 1989; Gordon and Campbell, 1992; Gordon and Sutherland, 1993; Gordon, 1994; Wimbledon *et al.*, 1995; Ellis *et al.*, 1996): this volume presents the detailed scientific justification for the selection of sites representing the Quaternary interests of South-West England. A broad categorization of geological and geomorphological subject matter (e.g. the major subdivisions of the geological timescale) is a prerequisite to site selection. Of the *c.* 100 site selection categories used by the GCR, 24 are concerned with geomorphology and the Quaternary, reflecting the particularly widespread nature and diversity of the evidence. This volume describes sites selected in two 'blocks' of the GCR – the 'Quaternary of South-West England' and the 'Quaternary of Somerset'.

This chapter reviews the most significant topics and themes for which South-West England furnishes important field evidence. In doing so it provides an overview of the geomorphological evolution and environmental history of the area during the Quaternary, which forms an important background to subsequent chapters. In presenting these topics and themes broadly chronologically, the critical elements required in a site conservation network are clearly demonstrated. Further detailed justification for the inclusion of sites within this volume is given in the individual subject chapters and particularly within the 'Interpretation' sections of individual site accounts.

Site selection guidelines and site networks

This volume describes 63 sites which merit conservation because of their significance to the geomorphological evolution and Quaternary history of South-West England. Sites for coastal and fluvial geomorphology, in the sense of modern landforms and processes, and large-scale mass movement features are reviewed elsewhere in the relevant thematic volumes of the GCR Series. For the site selection blocks considered here, site selection was underpinned by the premise that the particular block should be represented by the minimum number of sites. Only those sites absolutely necessary to represent the most important aspects of the geomorphological and Quaternary history of South-West England were therefore selected; unnecessary duplication of interest was thus minimized (cf. Gordon and Sutherland, 1993). To compile the site network, extensive consultations were carried out with appropriate Quaternary scientists, geomorphologists and other specialists, and several hundred sites were assessed before the final listing was produced. The principal authors of this volume were involved extensively in this process but were not the only consultees.

The landscape of Britain displays a rich diversity of Quaternary features and evidence of environmental change, often with distinct regional associations, related for example to a combination of geology, evolution of river systems, mountain glaciation or patterns of sea-level change. South-West England, with its unglaciated granite landscapes, periglacial formations and raised beach deposits, is quite distinctive in its characteristics from, say, the Thames Valley, East Anglia or Scotland. Each of these regions offers a distinctive contribution to the overall picture of Quaternary landscapes and environments in Britain. A prime aim of site selection was to reflect this diversity and to select networks of sites representing the major regional variations in landscape evolution and the history of environmental change during the Quaternary in Britain; hence the regional approach adopted for site selection as in the *Quaternary of Wales* (Campbell and Bowen, 1989), the *Quaternary of Scotland* (Gordon and Sutherland, 1993), the *Quaternary of the Thames* (Bridgland, 1994) and the *Quaternary of South-West England* (this volume). These 'regions' provided a practical basis for site selection; they not only demonstrate distinctive Quaternary features and sequences, and therefore research themes, but also form manageable units. A corollary is that many Quaternary scientists specialize in the history of a particular region or topic within a region, and thus a pool of expertise with detailed knowledge could be established.

The themes and issues that form the focus of the

Quaternary history and research in a given region primarily reflect the nature of the field evidence available. For example, South-West England, by virtue of its position mostly beyond the margins of the Pleistocene ice sheets, preserves an exceptional record of the long-term evolution of the British landscape. Likewise, Scotland is particularly noted for its assemblage of glacial landforms and raised shorelines formed during the Devensian late-glacial. For the Quaternary scientist concerned with conservation, the wealth of detail present in such assemblages of Quaternary landforms and deposits presents problems as well as opportunities, namely in deciding which sites merit conservation. Within the general regional framework, the approach adopted was to identify *networks* of sites that represent the main landscape features, distinctive aspects of Quaternary history and the principal research themes. Such features and themes were recognized at two levels: (a) those relating to the specific characteristics of the area in question (e.g. granite landforms and periglacial features in South-West England); and (b) those relating to national interests or distributions (e.g. pollen biostratigraphy and sea-level changes during the Holocene) for which regional representative sites were required. It should be noted that this categorization relates to the occurrence of the interests and does not imply differences in the importance of sites in the different categories. Thus sites selected for a regionally occurring interest are nevertheless of *national* importance, for example the tors of Dartmoor or the raised beaches of Devon. Indeed, all the sites selected for the GCR Series are considered to be at least of national importance. For South-West England, the site networks considered are those representing:

- long-term landscape evolution
- granite landforms
- Pleistocene cave sequences
- Pleistocene sea-level changes
- periglacial landforms and deposits
- key sequences of deposits for interpreting the distinctive Quaternary history of the region
- Holocene vegetation history

Potential sites representing the key elements of these themes were then identified from extensive consultations and compared to ensure selection of the 'best' sites and to minimise duplication of similar features within each regional block. Site selection decisions were made on the basis of the following guidelines, fuller details of which can be found elsewhere (e.g. Crowther and Wimbledon, 1988; Allen *et al.*, 1989; Gordon and Campbell, 1992; Gordon and Sutherland, 1993; Gordon, 1994; Wimbledon *et al.*, 1995; Ellis *et al.*, 1996): 1. international importance; 2. classic examples; 3. representativeness; 4. uniqueness; 5. being part of a site network; 6. providing an understanding of present environments; 7. historical importance; and 8. research potential and educational value. Sites will fall into one or more of these categories; all things being equal, sites with multiple interests are preferred.

Some sites and areas are recognized as internationally important; they may have formal status as stratotypes, type sites/areas or World Heritage sites, or they may have informal, but widely held, international recognition. None of the sites in this volume has gained formal international status, although the 'Burtle Beds' of Somerset, reflected here by a sub-network of interrelated sites (Chapter 9), and the lengthy Pleistocene sequences such as those at Kent's Cavern and the Torbryan Caves, are demonstrably of international significance; the Palaeolithic site at Broom aspires to this level of importance on archaeological grounds alone.

Likewise, some sites are recognized as classic examples of particular features, and as such are frequently cited in standard textbooks. Examples in the Quaternary of South-West England include the Dartmoor tors (see Merrivale) and the Giant's Rock at Porthleven in Cornwall.

It can be argued that all sites are unique in one way or another, and it was not an aim of the GCR to include features or sites simply because of their 'uniqueness': rather, a unique feature, sequence or landform was only included if it contributed something special or of great significance to an understanding of the Quaternary of South-West England or Britain as a whole. For example, such unique features could be the only known part of the geological record, thus filling an important stratigraphic gap, or landscape feature of their type; they may have no counterpart in the South-West, Britain or indeed internationally. In South-West England, the site at St Agnes Beacon falls into this category, providing the only tangible evidence for the age of a widespread erosion surface (Walsh *et al.*, 1987; Jowsey *et al.*, 1992). Other examples are the unique faunal remains of Kent's Cavern, the landform assemblage of the Valley of Rocks, the remarkable Palaeolithic finds of the Axe Valley and the controversial Fremington Clay (Chapter 7).

Within most GCR site networks, by far the most common type of site selected is usually that representative of a particular rock unit, fossil-bearing bed or landform. It must be stressed that not any representative, characteristic or typical site will suffice, and a series of weightings was applied to the general guidelines to help to distinguish which is the best or most suitable site in each category: for example, preference was given to sites with the most extensive or best preserved record; with the most detailed geochronological evidence; with a particularly long history of study; or with an additional attribute or related geological interest. Thus, a site may be selected as showing the most complete regional representation of phenomena which are quite widespread. Examples include many of the Quaternary stratigraphic sites in this volume, such as those showing the best development of raised beach deposits coupled with the most intricate and informative overlying periglacial sequences (e.g. Pendower, Porth Nanven and the Croyde–Saunton Coast) or the most intensively studied of the 'Burtle Beds' sites with the most detailed faunal and geochronological evidence (Chapter 9).

In some cases, sites were selected for their contribution to a network or sub-network of related sites, for example, the Quaternary sites of the Somerset lowland. This applied especially where there is a geographical component in the scientific interest. Thus, a sub-network of sites may include different aspects of one type of phenomenon which shows significant regional variations in its characteristics, for example, in relation to factors such as underlying geology, climate or relief. Such sub-networks may comprise unique, representative, classic or other types of sites, or a combination thereof. Within a sub-network, there may be 'core' sites, perhaps those showing the most extensive and best researched sequences, while 'accessory' sites may demonstrate significant variations on the main theme. A good example of a smaller sub-network is that covering aspects of granite landform evolution in the South-West. Here, Merrivale can be regarded as the core site, demonstrating an unparalleled range of granite and related landforms – including tors, blockfields, stone runs, altiplanation terraces and earth hummocks – while Two Bridges and Bellever quarries provide critical stratigraphic evidence concerning related weathering and slope processes, which underpins theories on how the Merrivale landform assemblage and granite landscapes in general originated.

Some Quaternary interests have a widespread distribution of evidence that forms part of a national continuum, a prime example being that for vegetation history following the climatic amelioration at the end of the Devensian Stage. Nevertheless, the timing and patterns of vegetation change, for example the spread of trees during the Holocene, shows significant regional variations. Since no single site in any part of the country can encapsulate such an aspect of Quaternary history, a network of reference sites was compiled as far as possible for type regions on a wider national basis (cf. Berglund *et al.*, 1996) and incorporated within the GCR regional blocks.

Certain sites have been selected because they throw light on the development of the present ecological landscape. This is particularly true of the Holocene pollen sites in this volume, such as the Chains (Exmoor), Blacklane Brook and Black Ridge Brook (Dartmoor) which show the progressive modification and management of the landscape by human activity; also the submerged forest and associated beds at Westward Ho!, which provide evidence of a pattern of sea-level changes on a very recent timescale.

A further justification for conserving sites is their contribution to the development of geology in general, and Quaternary science in particular. In Wales, and especially Scotland, certain sites provided critical evidence which firmly established the Glacial Theory in Great Britain, for example, Agassiz Rock (Gordon and Sutherland, 1993) and Moel Tryfan and Cwm Idwal (Campbell and Bowen, 1989). In this context, Kent's Cavern in South-West England was fundamental in demonstrating the connection between early humans and extinct ice-age mammals.

Another reason for including certain sites is their research and educational value, often arising from the controversial interpretations placed upon the evidence they provide. There is some overlap here with the previous guideline, and deciding the point at which a given site-based interpretation or field-tested theory becomes a major advance in geological thought is a moot point and one that only an historical perspective can clarify. Nonetheless, some sites illustrate particularly well the development of scientific thinking on the subject of, for example, landscape history and indeed the debates about processes and chronology which characterize Quaternary studies. In this respect, Two Bridges Quarry on Dartmoor is one of the most significant geomorphological sites in South-West England: ever since D.L. Linton's classic

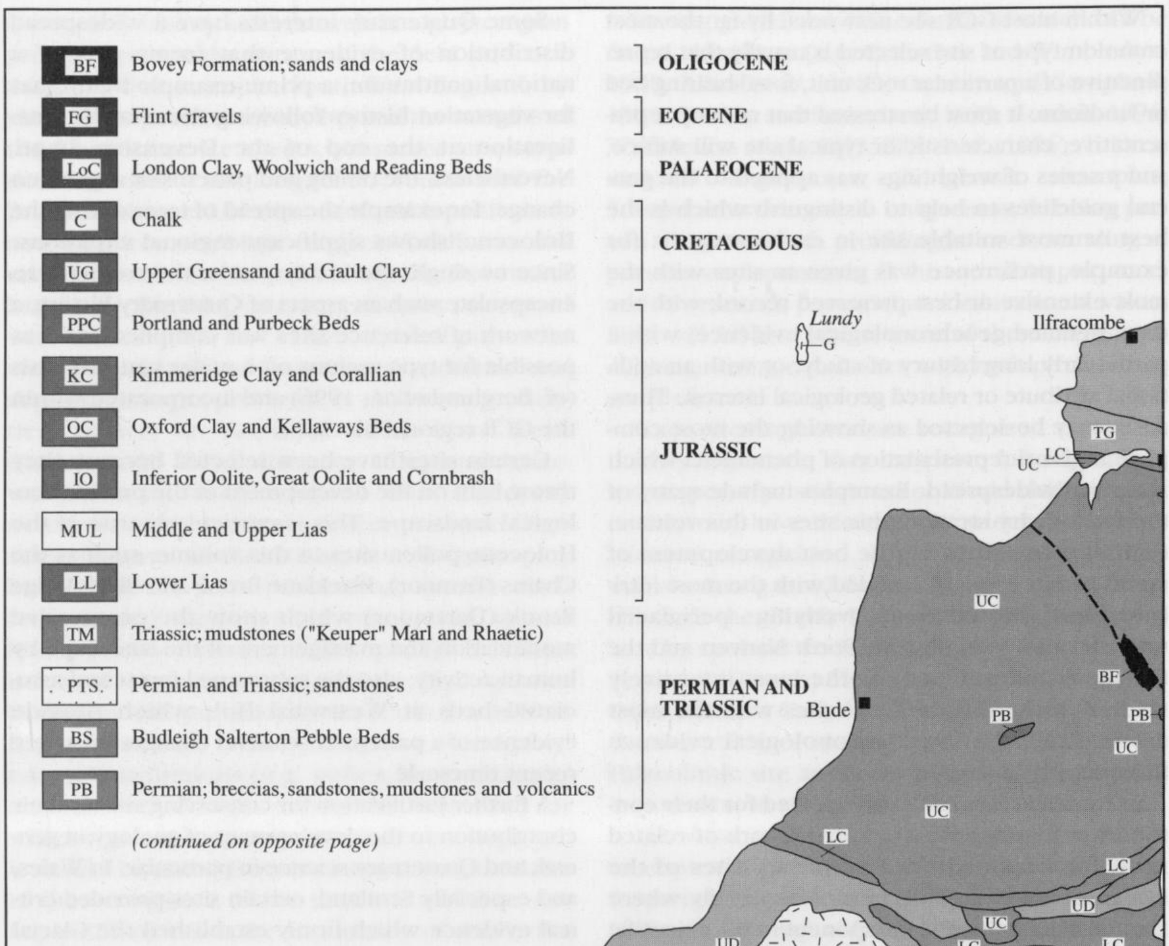
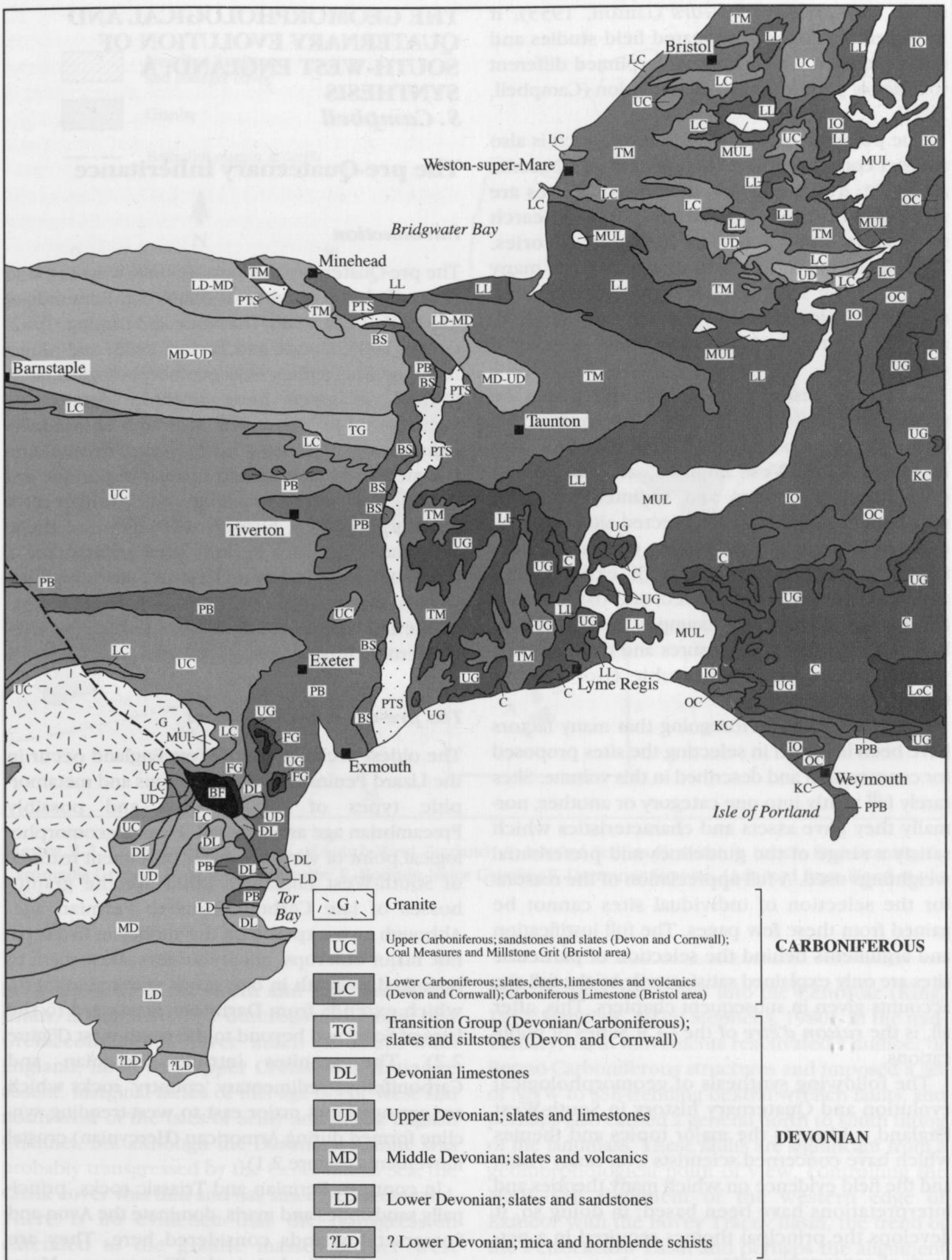


Figure 2.1 The solid geology of South-West England. (Compiled from British Geological Survey sources.)


Bristol
Weston-super-Mare
Bridgwater Bay
Minehead
Barnstaple
Taunton
Tiverton
Exeter
Exmouth
Lyme Regis
Weymouth
Isle of Portland
Tor Bay
G Granite
UC Upper Carboniferous; sandstones and slates (Devon and Cornwall); Coal Measures and Millstone Grit (Bristol area)
LC Lower Carboniferous; slates, cherts, limestones and volcanics (Devon and Cornwall); Carboniferous Limestone (Bristol area)
CARBONIFEROUS
TG Transition Group (Devonian/Carboniferous); slates and siltstones (Devon and Cornwall)
DL Devonian limestones
UD Upper Devonian; slates and limestones
MD Middle Devonian; slates and volcanics
DEVONIAN
LD Lower Devonian; slates and sandstones
?LD ? Lower Devonian; mica and hornblende schists
LiC Lizard Complex; schists with Devonian intrusive rocks
PRECAMBRIAN

study, *The problem of tors* (Linton, 1955), it has been the focus of repeated field studies and interpretations which have underpinned different theories of granite landscape evolution (Campbell, 1991).

The potential of sites for future research is also another consideration. Although new sites become available, it is important that existing sites are maintained for the application of new research techniques and for testing the latest theories. Thus, the long-term research potential of many sites has been seen as a key factor in their selection; also, some sites will provide the 'standard' against which the evidence from new sites can be compared.

The sites described in this volume can be regarded as the 'building blocks' for reconstructing the Quaternary history and geomorphological evolution of South-West England, as recorded in constituent landforms and sediments. On an entirely practical level, all selected sites must be conservable, meaning in essence: (a) that development planning consents do not exist or else amendments can be negotiated; and (b) that sites are physically viable, for example, in terms of the long-term stability of exposures and their location with respect to the water-table (Gordon and Campbell, 1992).

It is clear from the foregoing that many factors have been involved in selecting the sites proposed for conservation and described in this volume. Sites rarely fall neatly into one category or another; normally they have assets and characteristics which satisfy a range of the guidelines and preferential weightings used. A full appreciation of the reasons for the selection of individual sites cannot be gained from these few pages. The full justification and arguments behind the selection of particular sites are only explained satisfactorily by the full site accounts given in subsequent chapters. This, after all, is the *raison d'être* of the GCR Series of publications.

The following synthesis of geomorphological evolution and Quaternary history in South-West England, addresses the major topics and themes which have concerned scientists over many years, and the field evidence on which many theories and interpretations have been based; in doing so, it develops the principal themes required in a network of conservation sites.

THE GEOMORPHOLOGICAL AND QUATERNARY EVOLUTION OF SOUTH-WEST ENGLAND: A SYNTHESIS

S. Campbell

The pre-Quaternary inheritance

Introduction

The pre-Quaternary geology of South-West England is detailed in a number of texts (e.g. Edmonds *et al.*, 1975, 1979, 1985; Durrance and Laming, 1982; Green, 1985; Goode and Taylor, 1988) and only a broad outline, sufficient as geomorphological background, is given here: outcrop details are summarized in Figure 2.1. Although entitled the *Quaternary of South-West England*, this volume also describes sites which furnish important evidence for reconstructing the longer-term geomorphological history of Britain, and these essentially 'Tertiary Period' sites encapsulate a range of geological and climatic controls which were fundamental in establishing the broad outline of the landscape of South-West England in pre-Quaternary times.

The pre-Cenozoic basement

The oldest rocks in South-West England occur in the Lizard Peninsula, where igneous and metamorphic types of pre-Devonian and possibly Precambrian age are exposed. From a geomorphological point of view, the most prominent features of South-West England's relief are the granite bosses of late Carboniferous to Permian age. Although now exposed on the surface in five separate major outcrops, gravity surveys show them to be linked at depth in one major granite batholith, which extends from Dartmoor westward to the Isles of Scilly and beyond to the south-west (Figure 2.2). The granites intrude Devonian and Carboniferous sedimentary 'country' rocks which are arranged in a major east to west-trending syncline formed during Armorican (Hercynian) crustal movements (Figure 2.1).

In contrast, Permian and Triassic rocks, principally sandstones and marls, dominate the Avon and Somerset lowlands considered here. They are punctuated, particularly in the Weston-super-Mare, Bristol and Cheddar districts by inliers of Carboniferous Limestone Series rocks (Whittaker and Green, 1983). The approximate eastern limit of the area under consideration here, roughly

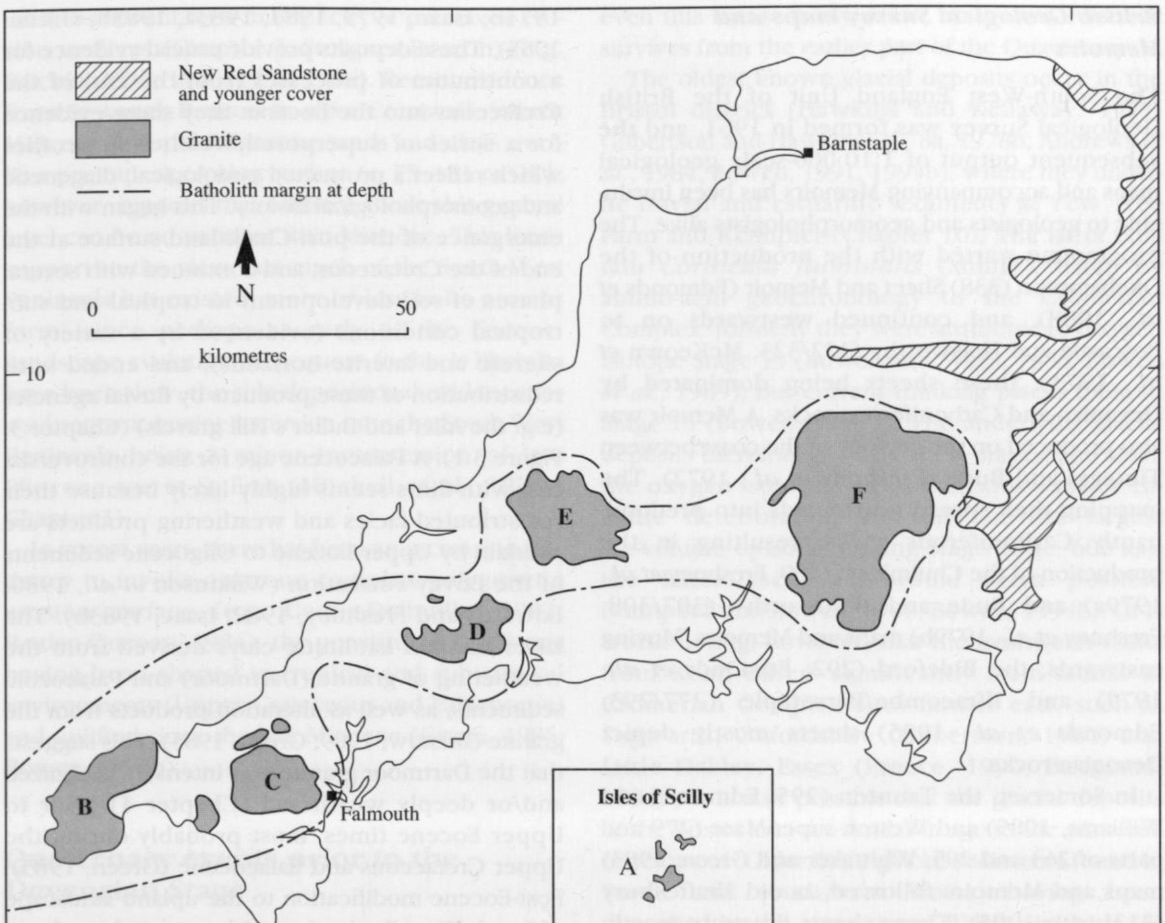


Figure 2.2 The granite intrusions of South-West England: A, Isles of Scillies Granite; B, Land's End Granite; C, Carmellis Granite; D, St Austell Granite; E, Bodmin Moor Granite; F, Dartmoor Granite. (Adapted from Floyd *et al.*, 1993.)

between Bath in the north and Portland in the south, is dominated by outcrops of Jurassic and Cretaceous strata. Over much of South-West England, however, Upper Cretaceous strata are absent: marginal facies of this age occur west and north-west of the Isles of Scilly and in the English Channel, but although the Dartmoor granite was probably transgressed by the Cenomanian Sea, the Chalk cover was thin and has since been removed. There is no evidence that the transgression extended to the granite masses farther west (Hancock, 1969).

The main outline of South-West England, as a landmass separating the Celtic Sea to the north and the English Channel to the south, evolved probably after the granites were emplaced, through Permian and Mesozoic times and into the Cenozoic (King, 1954; Hancock, 1975; Stephens, 1980). In the mid-Tertiary, earth movements reactivated a number of Permo-Carboniferous structures and imposed a set of NNW to SSE-trending dextral wrench faults, and perhaps also caused a general north to south tilting of the landmass. These faults are significant from a geomorphological point of view, controlling the NNW–SSE alignment of the western edge of Exmoor with the Bovey Tracey Basin, the trend of the Petrockstow Basin and perhaps the alignment of the troughs and ridges of east St Austell Moor (Dearman, 1963; Shearman, 1967; Everard, 1977; Stephens, 1980). Major displacements of the Lizard–Dodman–Start igneous and metamorphic complexes may also have occurred at this time.

British Geological Survey maps and Memoirs

The South-West England Unit of the British Geological Survey was formed in 1961, and the subsequent output of 1:10 000-scale geological maps and accompanying Memoirs has been invaluable to geologists and geomorphologists alike. The programme started with the production of the Okehampton (338) Sheet and Memoir (Edmonds *et al.*, 1968), and continued westwards on to Boscastle and Holsworthy (322/323; McKeown *et al.*, 1973), these sheets being dominated by Devonian and Carboniferous rocks. A Memoir was also produced on the geology of the coast between Tintagel and Bude (Freshney *et al.*, 1972). The mapping then spread northwards into predominantly Carboniferous rocks, resulting in the production of the Chulmleigh (309; Freshney *et al.*, 1979a) and Bude and Bradworthy (307/308; Freshney *et al.*, 1979b) maps and Memoirs. Moving eastwards, the Bideford (292; Edmonds *et al.*, 1979) and Ilfracombe/Barnstaple (277/293; Edmonds *et al.*, 1985) sheets mostly depict Devonian rocks.

In Somerset, the Taunton (295; Edmonds and Williams, 1985) and Weston-super-Mare (279 and parts of 263 and 295; Whittaker and Green, 1983) maps and Memoirs followed, as did Shaftesbury (313; map 1995). These sheets illustrate mostly Mesozoic strata. As the Unit expanded, work in western Cornwall led to the Penzance (351–358; Goode and Taylor, 1988) and Falmouth (342; Leveridge *et al.*, 1990) maps and Memoirs.

Maps and Memoirs have also been produced by the University of Exeter under contract to BGS. These comprise Newton Abbot (339; Selwood *et al.*, 1984), Tavistock (337; map only) and Trevose/Camelford (335–336; Selwood *et al.*, 1997). Memoirs describing the complex geology of the Bristol (Kellaway and Welch, 1993) and the Wells and Cheddar districts (280; Green and Welch, 1965) are also available.

Pre-Quaternary landscape evolution

The oldest sedimentary evidence for Tertiary conditions and landscape evolution comes from south and east Devon, where the Chalk and other strata are succeeded by a complex series of plateau deposits comprising residual flint gravels (e.g. *in situ* clay-with-flints and the Aller and Buller's Hill gravels) and associated pedogenic and diagenetic horizons (Edwards, 1973; Hamblin, 1973b, 1974a, 1974b; Isaac, 1979, 1981, 1983a, 1983b; Green, 1985). These deposits provide crucial evidence for a continuum of processes from the end of the Cretaceous into the Eocene: they show evidence for a series of superposed weathering profiles which reflect a protracted pedological, diagenetic and geomorphological history. This began with the emergence of the post-Chalk land surface at the end of the Cretaceous, and continued with several phases of soil development in tropical and subtropical conditions (evidenced by a variety of silcrete and laterite horizons), and ended with redistribution of these products by fluvial agencies (e.g. the Aller and Buller's Hill gravels) (Chapter 3; Figure 3.1). A Palaeocene age for the controversial clay-with-flints seems highly likely because their redistributed facies and weathering products are overlain by Upper Eocene to Oligocene sediments of the Bovey Formation (Wilkinson *et al.*, 1980; Edwards and Freshney, 1982; Isaac, 1983b). The latter contain kaolinitic clays derived from the weathering of granite (Dartmoor) and Palaeozoic sediments, as well as alteration products from the granite (Bristow, 1969; Green, 1985). This suggests that the Dartmoor granite was intensely kaolinized and/or deeply weathered (Chapter 4) prior to Upper Eocene times, most probably during the Upper Cretaceous and Palaeocene (Green, 1985). Post-Eocene modification to the upland landscape of South-West England would seem to have been slight in comparison.

However, over much of the South-West Peninsula, particularly in west Cornwall, a vast break in the geological succession exists, on the one hand, between the Palaeozoic and igneous basement rocks and the small remnants of rocks of Tertiary age, such as those at St Agnes Beacon (mid-Oligocene and Miocene), Polcrebo Downs and Crousa Down (unknown) and St Erth (late Pliocene) (Chapter 3). With the exception of the Palaeocene deposits of east Devon and substantial Oligocene sediments in the Bovey Tracey and Petrockstow basins, these small outliers constitute the most significant sedimentary evidence for establishing the nature and timing of land-shaping events. The remaining evidence is entirely erosional in nature (e.g. planation surfaces) and lends little precision to the interpretation of events (Kidson, 1977).

Traditionally, geomorphologists have viewed the early to mid-Tertiary as a time when the landmass of South-West England was subjected to alternating phases of marine inundation and subaerial exposure and weathering: these conditions have been used to account for a multiplicity of perceived erosion surfaces (Chapter 3; St Agnes Beacon) (e.g. Balchin, 1937, 1946, 1952, 1964). Recent evidence from St Agnes Beacon in west Cornwall, where Miocene and mid-Oligocene sands and clays overlie a prominent erosion surface (*c.* 75–131 m OD), however, suggests that surfaces above this general level can be no younger than Miocene. This lends support to the view that much of the South-West Peninsula has existed, more or less in its present form, since perhaps as early as the Eocene. Landscape evolution subsequent to this is likely to have been slow, the sole depositional evidence for a subsequent marine incursion onto the South-West Peninsula being a minor transgression of late Pliocene age at St Erth (Mitchell *et al.*, 1973a; Chapter 3).

In recent years, there has been an increasing tendency to invoke only one complex polygenetic erosion surface (e.g. Coque-Delhuille, 1982; Battiau-Queney, 1984), the constituent landforms having been shaped in tropical and subtropical environments (Upper Cretaceous and Palaeocene) and uplifted since the late Miocene (Green, 1985; Bowen, 1994b).

Quaternary events prior to the Devensian Stage

Introduction

Although in current classification, the St Erth marine beds are placed in the late Pliocene, it can be argued that they more properly represent the early part of the cycle of profound climatic fluctuations which characterizes the Quaternary (Chapter 3). This series of fluctuations, hallmarked by major falls of sea level during cold and sometimes glacial conditions, and correspondingly higher sea levels during more temperate phases, is now comprehensively demonstrated from the deep-sea sedimentary evidence (e.g. Shackleton and Opdyke, 1973). Increasingly, the land-based evidence for these profound climatic and environmental shifts is being correlated with the developing deep-sea oxygen isotope framework through a variety of geochronological and other techniques.

Early glaciation

In South-West England, the earliest evidence extends the known record to around 0.7 Ma, but even this is insecurely dated; no known evidence survives from the earlier part of the Quaternary.

The oldest known glacial deposits occur in the Bristol district (Hawkins and Kellaway, 1971; Gilbertson and Hawkins, 1978a, 1978b; Andrews *et al.*, 1984; Bowen, 1991, 1994b), where they underlie fluvial and estuarine sediments at Yew Tree Farm and Kennpier (Chapter 10). The latter contain *Corbicula fluminalis* (Müller), dated by amino-acid geochronology to the Cromerian Complex: formerly they were attributed to Oxygen Isotope Stage 13 (Bowen and Sykes, 1988; Bowen *et al.*, 1989), but current thinking places them in Stage 15 (Bowen, 1994b). The underlying glacial deposits therefore pre-date these stages, and since the oxygen isotope record indicates a major climatic deterioration and one of the largest ice-volume episodes during Stage 16 (*c.* 600 ka), the latter ascription would seem possible (Campbell and Bowen, 1989; Bowen, 1994b). (It is worth noting, however, that the freshwater fauna from Kenn differs significantly from faunas at Cromerian Complex sites farther east, such as Sugworth, Oxfordshire (Gilbertson, 1980) and Little Oakley, Essex (Preece, 1990; Bridgland, 1994).) It is also possible that the glacial deposits of the Bristol area are similar in age to the scattered outcrops of 'Older Drift' glacial sediments found in South and south-west Wales, having been deposited by the same coeval Welsh and Irish Sea ice sheet which moved eastwards, effecting deposition on both sides of the Bristol Channel (Campbell and Bowen, 1989).

Whether this Stage 16 glaciation was responsible for the giant erratics found around the coasts of Devon and Cornwall is not known. Their often extremely large size and isolated, low-level distribution have traditionally led to the view that they are the product of ice-rafting, not a major glacial invasion *per se*. This possibility is given much credence in theories which propose the likelihood of substantial glacio-isostatic depression beyond the margins of former ice sheets (e.g. Eyles and McCabe, 1989, 1991; Bowen, 1994b), and the consequent tidewater or glaciomarine character of these ice sheets. Recently, the intriguing possibility that some of these erratics could have originated from as far away as Greenland or been emplaced on ice floes from a disintegrating, pre-last glacial maximum Laurentide ice sheet, have been raised. Bowen (1994b) has also raised the possibility that enigmatic deposits on Crousa Down and glacial gravels on Lundy and in the Isles of Scilly were introduced at this time – although the latter had subsequently been redistributed by periglacial processes (but see Chapter 8).

The extent to which this earliest-known glacial event modified the landscape of the South-West is not fully known, although the survival of Tertiary sediments and other landscape palimpsests, such as erosion surfaces, and the localized distribution of erratic material, which is confined to the Somerset lowland and the Bristol and Bath areas (Hunt *et al.*, 1984; Chapters 9 and 10), probably mitigate against the Peninsula having been completely overrun by ice during this or any other stage of the Pleistocene, as does the lack of landforms characteristic of glacial erosion. Indeed, the geomorphological position of the glacial deposits in the Bristol district and the 'Older Drift' of South and south-west Wales – in the case of the latter, confined to occurrences in the entrance to Milford Haven (West Angle Bay) and to highly dissected coastal plateau deposits – suggests that the geomorphology of the coastal fringe was then similar to that of the present (Campbell and Bowen, 1989; Bowen, 1994b).

Cromerian Complex events

Although events and conditions of the Late Pleistocene in South-West England, particularly those of the Devensian Stage and later, are generally well documented and understood, evidence for the Early and Middle Pleistocene is much less clear. However, four main phases of temperate, probably interglacial, climate (not including the Holocene) can be adduced from evidence in the region, particularly raised beach sediments (see below). Cromerian Complex events, probably equivalent to Oxygen Isotope Stages 13–21 (Bridgland, 1994; Bowen, 1994b), are recorded by the estuarine deposits at Kennpier and perhaps by 'temperate' mammal remains at Kent's Cavern near Torquay (the 'sabre-tooth' cat fauna). Although a fossil mammal fauna at Westbury-sub-Mendip (Westbury 1 fauna) also probably dates from this broad period (Heal, 1970; Bishop, 1974, 1982; Stringer *et al.*, 1996), no other deposits of this age are known. High relative sea levels during this period, however, may have fashioned, in part, a variety of prominent shore platforms (e.g. Mitchell, 1960; Stephens, 1966b; Stephens and Synge, 1966; Kidson, 1971). An absence of associated fossiliferous marine deposits nonetheless precludes correlation via amino-acid geochronology with the oxygen isotope timescale. Although evidence from fossils and artefacts is far from clear, it seems highly likely that humans were well established in the region by late Cromerian Complex times (see Kent's Cavern; Cullingford, 1982). Recent work carried out on the later Westbury faunas (Westbury 2 and 3 faunas) shows them to be post-Cromerian *sensu stricto* (i.e. West Runton) and pre-Hoxnian (Stringer *et al.*, 1996).

Anglian and Saalian events

The events of the profoundly cold Anglian Stage which followed (Oxygen Isotope Stage 12; *c.* 450 ka), are not clear from landform or sedimentary evidence in South-West England. Although extensive glaciation occurred in eastern England and the Midlands at this time, and may have left its mark in South Wales (the Paviland Moraine, Gower), no specific features in the South-West are clearly attributable to the Anglian ice sheet. Possible glacial deposits on the Isles of Scilly, Lundy Island and in the Barnstaple area (the Fremington Clay) and at other locations along the north Devon and north Cornwall coasts, have attracted considerable research interest and have been ascribed to an Irish Sea ice sheet of disputed but possibly Anglian, Saalian (Wolstonian; see below) or Devensian age (see also Chapters 6, 7 and 8): Stephens (1966b) also attributed a variety of dry and misfit valleys in north Devon to meltwater erosion at the margins of a Saalian ice sheet (Chapter 7). Indeed, until the last 15 years or so, there was broad consensus that the maximum limit of Pleistocene glaciation in the South-West could be marked by a line running from the Isles of Scilly broadly north-west, fringing the coast of north Cornwall and north Devon (Figure 2.3): some workers maintained that this glacial 'maximum' was attained in the Anglian (Mitchell, 1960; West, 1968, 1977a), but many others have ascribed a 'Wolstonian' age (*sensu* Mitchell *et al.*, 1973b) to this major glacial event (e.g. Stephens, 1966b, 1970a; Kidson, 1971, 1977; Edmonds, 1972). However, in the last ten years or so, the Wolstonian Stage of the British Pleistocene, as defined by Mitchell *et al.* (1973b), has been intensely scrutinized: many deposits formerly held to be Wolstonian are now believed to be Anglian in age (Perrin *et al.*, 1979: Sumbler, 1983a, 1983b; Rose, 1987, 1988, 1989, 1991). There is also increasing evidence to suggest that more than a single climatic cycle separates the Hoxnian and Ipswichian (warm) stages (e.g. Bridgland, 1994). For convenience, therefore, the continental term 'Saalian', which recognizes this climatic complexity, is used

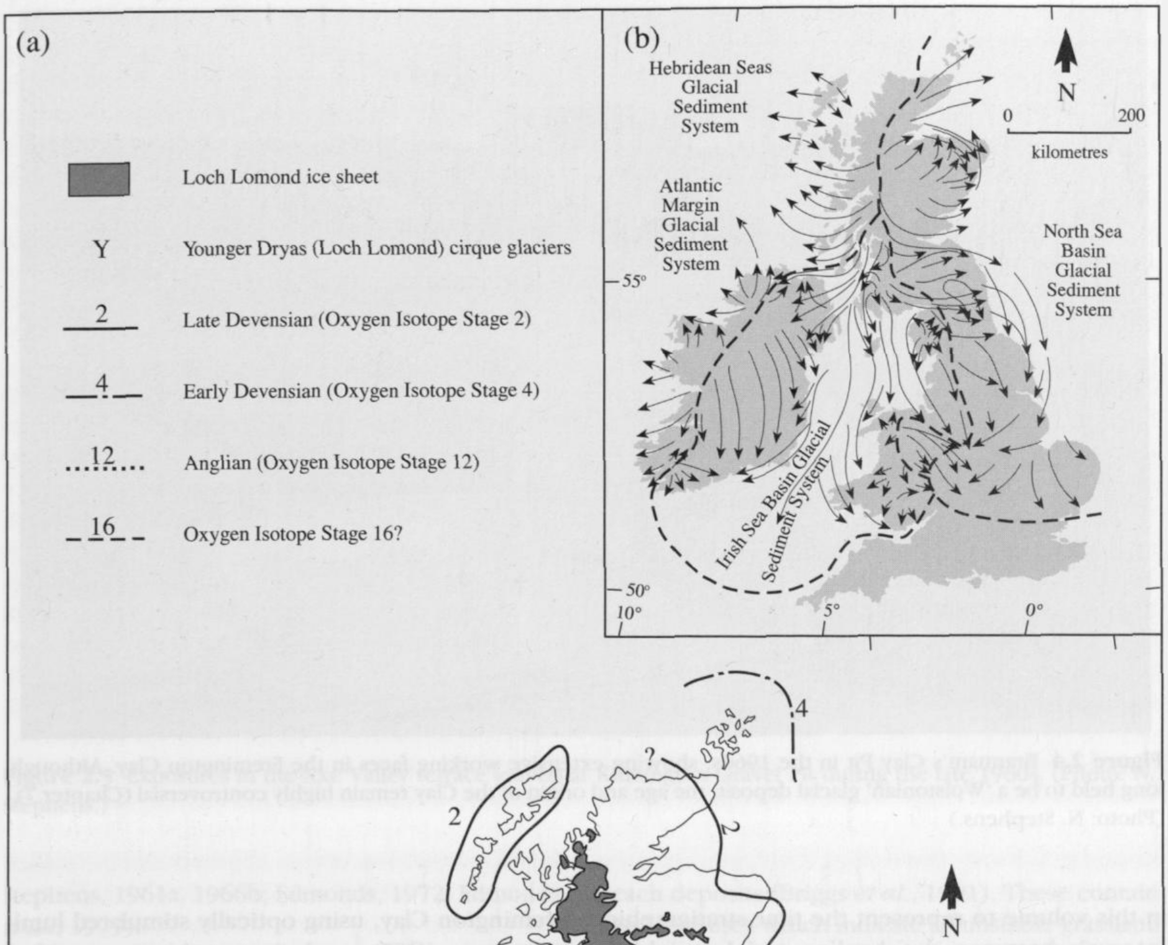


Figure 2.3 (a) Reconstructed Pleistocene maximum ice limits after Bowen (1994a) and Gray and Coxon (1991). (b) British glacial sediment systems. After Charlesworth (1957), and Bowen (1991). (But also see Figure 8.4.)

Figure 2.4 Brannam's Clay Pit in the 1960s, showing extensive working faces in the Fremington Clay. Although long held to be a 'Wolstonian' glacial deposit, the age and origin of the Clay remain highly controversial (Chapter 7). (Photo: N. Stephens.)

in this volume to represent the time-stratigraphic intervals between the Anglian and Ipswichian stages.

This redefinition raises the important question of whether deposits in the South-West, formerly regarded as Wolstonian, can now simply be redefined as Anglian in age? The answer seems to be no. Moreover, the 'glacial' sequences in the region have themselves been the subject of considerable reinterpretation, with the possibility emerging that some, such as those in the Isles of Scilly and at Fremington, are as recent as Late Devensian in age and perhaps even glaciomarine in origin (Scourse, 1985a, 1987; Eyles and McCabe, 1989; Scourse *et al.*, 1991; Bowen, 1994b) (see Devensian Stage; this chapter). For much of its length, therefore, the Pleistocene 'maximum' ice limit of previous workers is now in even more doubt.

The problematic 'Boulder Gravel' at Trebetherick on the north Cornish coast, long held by some workers to be glacigenic and Saalian in age (Clarke, 1969; Stephens, 1970a), is the subject of reinterpretation in this volume (Chapter 6): a glacial origin can no longer be sustained for this unit. The most recent attempts to date the Fremington Clay, using optically stimulated luminescence (OSL) techniques, have provided ambiguous results, although an age at least as old as Anglian seems likely (Croot *et al.*, 1996).

The contentious proposition that Anglian Stage ice (*c.* 450 ka) transported the 'bluestones' of Preseli to Salisbury Plain and ultimately Stonehenge (Kellaway, 1971; Thorpe *et al.*, 1991), has now been shown to be untenable: a ^{36}Cl age determination on an igneous rock from the Stonehenge collection, in the Salisbury Museum, shows that probably the rock was still buried at source during the Anglian (*c.* 400 ka), and did not become exposed to the atmosphere by denudation until the Late Devensian (Green, 1993, 1997; Bowen, 1994b; Bowen *et al.*, in prep.). This evidence adds to the cogent arguments put forward against transport of the bluestones by ice (e.g. Green, 1973, 1997; Kidson and Bowen, 1976; Darrah, 1993; Scourse, 1997), lending further weight to the possibility that the stones were quarried from Preseli by prehistoric people, after the Late Devensian, and taken to the site of Stonehenge. An Anglian age cannot, however, be ruled out for the giant erratics scattered along the coasts of South-West England (e.g.

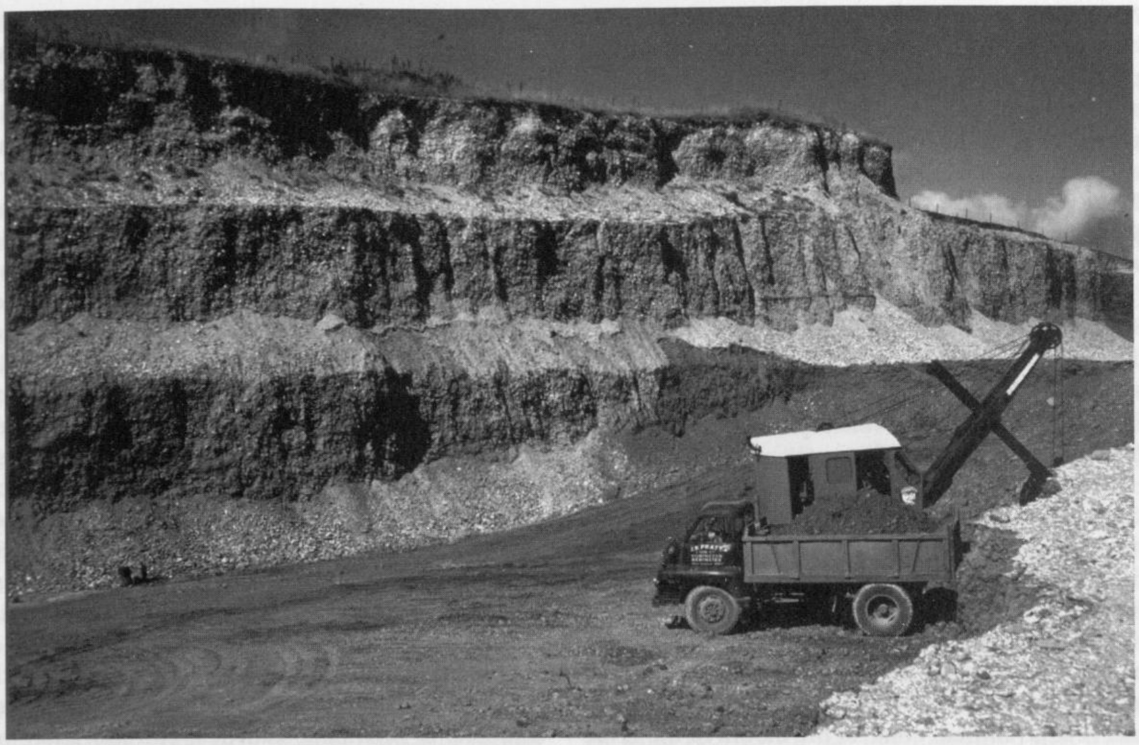


Figure 2.5 Exposures in the Axe Valley terrace gravels at Kilmington Gravel Pit during the late 1960s. (Photo: N. Stephens.)

Stephens, 1961a, 1966b; Edmonds, 1972; Edmonds *et al.*, 1979).

What is clear, however, is that during the Pleistocene cold stages between the Cromerian Complex and Devensian times (Oxygen Isotope Stages 12, 10, 8 and 6), much of the landscape of South-West England was subject to considerable modification through periglacial processes. Bowen (1994b) observes that periglacial denudation through some 50 ice-age cycles since 2.4 Ma was probably the main agent of geomorphological development. Although the uplands of the South-West, especially the elevated granite terrains of Dartmoor and Bodmin Moor, probably suffered significant cryonival modification during Pleistocene cold stages, the effects of intense periglacial activity during the Devensian Stage have tended to mask or remove evidence of earlier phases. Thick 'head' deposits are one of the most characteristic features of the region (Stephens, 1970a; Mottershead, 1971, 1977a, 1977b; Scourse, 1985a, 1987), but their chronostratigraphic subdivision is often tenuous, and there are few sites where there is unequivocal evidence for pre-Devensian periglacial activity. However, Saalian slope deposits are known from beneath the Swallow Cliff (Middle Hope) raised beach deposits (Briggs *et al.*, 1991). These contain fossil molluscs which indicate an unstable grassland environment. It is highly likely that other periglacial deposits and landforms from pre-Devensian cold stages do survive locally in South-West England, although their differentiation from Devensian products is, in most instances, highly problematic.

Even the many caves, where deposits might have accumulated and been protected, bear little clear evidence for pre-Devensian cold conditions. One of the most notable exceptions, however, is Tornewton Cave (Chapter 5), where a debris flow, containing a 'cold' fauna of possible Stage 6 age, is present. Linking cave deposits with sedimentary sequences outside them has proved difficult. There is some suggestion, however, that an ancient terrace of the River Dart, lying at *c.* 83 m OD, pre-dates Ipswichian Stage sediments lying in Joint Mitnor Cave below (Chapter 5): a Saalian age for the terrace has thus been tentatively suggested (Cullingford, 1982).

The famous terraces of the River Axe provide unique sedimentary and fossil evidence for this controversial timespan (see Broom Gravel Pits, Chapter 9; Figure 2.5), and have yielded numerous

Acheulian hand-axes. Here, a series of cold-climate, braided stream gravels and sands are interrupted by pollen-bearing floodplain deposits indicative of more temperate conditions. The terrace gravels probably accumulated during cold-climate conditions in the Saalian Stage; the still-water floodplain deposits bear witness to a more temperate intra-Saalian event (Oxygen Isotope Stage 7, 9 or 11?) for which there is currently no firm ascription (Stephens, 1970a; Green, 1974b; Scourse, 1984; Shakesby and Stephens, 1984). There is also evidence for this timespan in the terrace deposits of south-east Somerset, at Langport Railway Cutting, Portfield and Hurcott Farm (Chapter 9) and in the Avon Valley (Chapter 10).

It has been speculated that permafrost conditions during the Saalian were responsible for massive contortions in the Oligocene beds of the Bovey Basin (Dineley, 1963; Gouldstone, 1975; Jenkins and Vincent, 1981). It is possible, however, that the features were formed by basin subsidence or loading (Straw, 1974), and even if a periglacial origin is accepted, a Devensian age cannot be ruled out. A large alluvial 'cone' at the mouth of the Erme Gorge, on the southern edge of Dartmoor, has also been attributed to fluvial and mass movement processes in a Saalian (Wolstonian) periglacial environment (Gilbertson and Sims, 1974).

Raised beach sediments and amino-acid geochronology

The most significant developments in determining pre-Devensian events within the region have come from the application of amino-acid dating techniques to the widespread raised beach deposits and, most recently, to fluvial deposits. The ages of the raised beach sediments have long been disputed, with both Hoxnian (Mitchell, 1960, 1972; Stephens, 1966b, 1970a, 1974, 1977) and Ipswichian (Zeuner, 1959; Edmonds, 1972; Kidson, 1974, 1977; Kidson and Wood, 1974) ages having been suggested. In general, the coastal Pleistocene sequences of the region appear relatively simple with the shore platform(s) at many localities being succeeded by raised beach deposits and a variety of head, blown sand and colluvial horizons. However, determining the precise age(s) of the raised beach deposits in these sequences, absolutely vital to the interpretation and chronological subdivision of the overlying beds, has led to numerous disputes.

In the late 1970s/early 1980s, amino-acid and U-series studies offered, for the first time, a sound basis for dating and correlating British raised beach deposits. This work, much of which has been carried out on coastal sequences in South Wales and South-West England, has been fundamental in assigning British terrestrial sequences to the oxygen isotope framework. Early amino-acid work by Andrews *et al.* (1979), on fossil protein in gastropods and bivalves from raised beaches in south-west Britain, suggested that the latter had been formed during at least two, possibly three, high stands of Pleistocene sea level: further refinement of the technique and wider surveys upheld the hypothesis of two separate interglacial beaches (Davies, 1983). In this respect, the evidence from Portland Bill has been vital, with the raised beaches there now having been ascribed with confidence to Oxygen Isotope Stage 7 (Figure B in Preface; Bowen *et al.*, 1985; Bowen and Sykes, 1988; Campbell and Bowen, 1989) and Stage 5e (Davies, 1983; Davies and Keen, 1985; Campbell *et al.*, in prep.).

The work of D.Q. Bowen and colleagues in both South Wales and South-West England has been fundamental in providing statistical corroboration for the numbers and ages of these high sea-level events (Bowen *et al.*, 1985; Bowen and Sykes, 1988). Aminostratigraphy, standardized to *Littorina littorea*, now shows strong evidence for three high sea-level stands in South-West England. Two of these stands are correlated with Oxygen Isotope Stage 7 (*c.* 200 ka) and Stage 5e (*c.* 125 ka): an earlier high sea-level event, identified from an older reworked fauna, is ascribed to Oxygen Isotope Stage 9 (*c.* 320 ka), although *in situ* raised beach sediments attributable to this oldest event are unknown either in South Wales or South-West England (cf. Campbell and Bowen, 1989).

In situ occurrences of the Stage 7 raised beach deposits occur at Portland Bill and several other sites, and with the reworked Stage 9 fauna provide critical evidence for two intra-Saalian temperate episodes and high sea-level stands, and introduce the intriguing possibility that parts of the overlying terrestrial, largely periglacial, sequences may date from a variety of Saalian cold-climate stadial events (cf. Oxygen Isotope Stages 6, 8 and 10). The raised beach deposits at Swallow Cliff have yielded amino-acid ratios consistent with an intra-Saalian or Ipswichian age. It is still clear, however, that probably the bulk of terrestrial materials found in the coastal sections, attests to cold-climate processes in the Devensian Stage.

Virtually nothing is known about sea levels around South-West England during the colder, pre-

Ipswichian, stages of the Pleistocene, although it is generally assumed that they were low: a variety of submarine valleys and cliffs may have been cut, at least partly, during such low sea-level stands (Kidson, 1977).

Although not currently a GCR site, the sea-caves of Berry Head, Torbay, have yielded the densest concentration of Uranium-series dates on speleothem for any site in the region. This recent and detailed work (Proctor and Smart, 1991; Baker and Proctor, 1996) gives valuable evidence for dating the temperate climatic events which allowed speleothems to develop and also adds to the evidence for dating the high sea levels accompanying interglacials.

The caves on Berry Head were mainly exposed by quarrying of the Devonian limestone during the 19th century. Baker and Proctor (1996) list twelve named caves in the rocks of the Head, and provide a plot of their height against area (their fig. 58) which shows that the caves cluster strongly around 3 m, 8.5 m and 25 m above mean sea level. Proctor and Smart (1991) and Baker and Proctor (1996) conclude that these cave heights represent former sea levels, and thus the sediments and speleothems in the caves provide a datable sequence of Middle Pleistocene temperate and marine events. The dates obtained from the caves were mostly from Corbridge Cave, heights below 10 m above mean sea level, but some dates were also determined from The Hole-in-the-Wall No. 1 and Hogberry Caves at around 25 m OD.

The dates obtained also centre on three timespans which match the three height concentrations. The lower levels have yielded age determinations of between 155 and 116 ka BP. The only temperate stage to fall within that time slot is Oxygen Isotope Stage 5e, whose deposits at Thatcher Rock on the north side of Torbay were dated by Mottershead *et al.* (1987), primarily by amino-acid geochronology, to the same temperate phase. The levels around 8.5 m gave dates concentrated around 210 ka BP (range 184–244 ka BP), within Oxygen Isotope Stage 7, and match the suggested estimates of Mottershead *et al.* (1987) for the age of the Hope's Nose raised beach which occurs at a slightly higher level on an open site on the north side of Torbay. The higher levels, at 25 m, which have no expression in raised beach deposits outside caves in the area described in this volume, have given dates with a mean of 328 ka BP (range 287–412 ka BP). These cannot be younger than Stage 9.

These dates provide good evidence for the ages of the major late Middle Pleistocene high sea-level events in South-West England, and also provide calibration of amino-acid chronologies derived from raised beach sites outside the caves (see Bowen, 1994b). Continuing work by Baker and Proctor (1996) is beginning to use annual laminae within the speleothems to determine depositional palaeotemperatures. The undoubted importance of these caves clearly necessitates future consideration of their conservation status.

The Ipswichian Stage

Raised beach deposits attributable to the Ipswichian Stage (Oxygen Isotope Stage 5e) are very common in the coastal sequences of the South-West. They bear witness to temperate conditions with sea levels close to those of the present day, perhaps a few metres higher (Bowen, 1994b). The most widespread interglacial marine deposits in the region are the Burtle Beds of the Somerset lowland (Bulleid and Jackson, 1937, 1941; Kidson *et al.*, 1974; Kidson, 1977; Hughes, 1980; Chapter 9). Until recently, it has been assumed that these deposits bear witness to a major marine transgression in the Ipswichian, and while this holds true in some areas, recent aminostratigraphic studies have revealed a range of ages for marine sediments in this area (Hunt *et al.*, 1984; Chapter 9). The same is likely to be the case for interglacial marine sediments in the Vale of Gordano, Bristol (ApSimon and Donovan, 1956; Chapter 10).

The most modern amino-acid measurements also suggest that there may even have been two separate sea-level stands during Oxygen Isotope Stage 5e itself (cf. Sherman *et al.*, 1993), and that these could correspond to orbitally tuned Oxygen Isotope events 5.53 (*c.* 125 ka) and 5.51 (*c.* 122 ka) (Martinson *et al.*, 1987; Bowen, 1994b). It cannot therefore be assumed that Oxygen Isotope Stage 5e was a period of climatic and sea-level uniformity, and raised beach deposits of both stands are likely to be present in the region although they have yet to be differentiated with any certainty. This lends support to Sutcliffe's (1976, 1981) contention that two 'temperate' faunas of different but Ipswichian ages are present in some cave sequences (see below).

Away from the coast, the evidence for temperate conditions both in the Ipswichian and Saalian stages is more isolated, again being largely restricted to 'protected' locations such as caves. Whereas rich 'cold' mammal faunas from the Devensian Stage are common in the Devon and

Mendip caves, evidence for temperate events and conditions is again more sparse. Probably the richest faunal assemblage attributed to the Ipswichian Stage comes from Joint Mitnor Cave in Devon (Sutcliffe, 1960) where the remains of at least 18 species including *Hippopotamus*, hyaena and *Palaeoloxodon antiquus* provide the hallmark of the stage and clearly bear witness to temperate conditions. On the assumption that a widely recorded British interglacial fauna with *Hippopotamus* is everywhere of Ipswichian age (e.g. Sutcliffe, 1981), then fossiliferous deposits which include *Hippopotamus* at Durdham Down near Bristol (Donovan, 1954; Stephens, 1970a), Tornewton Cave near Buckfastleigh (Sutcliffe and Zeuner, 1962) and Eastern Torrs Quarry and Milton Hill caves, Devon (Sutcliffe, 1960) are also likely to date from this time: an Ipswichian age for the remarkable accumulation of *Hippopotamus* material, the bone remains of at least 17 individuals, found during excavations for the Honiton by-pass (Turner, 1975) is also likely. Further evidence for temperate conditions during the Ipswichian Stage came from a brick pit in Barnstaple, where remains of straight-tusked elephant were discovered in 1844 (Arber, 1977), in an area mapped subsequently by Edmonds (1972) as an Ipswichian terrace.

Other evidence of Ipswichian temperate conditions comes from the Hutton Bone Cave (Weston district), where a single bone of *Hippopotamus amphibius* was found, and possibly Bleadon Bone Cave where a 'temperate' to 'cold' fauna including *Palaeoloxodon antiquus* is also recorded (Donovan, 1954, 1964; Hawkins and Tratman, 1977; Whittaker and Green, 1983). Molars of *Dicerorhinus kirchbergensis* recorded from a fissure in a quarry at Milton, Weston-super-Mare, also indicate a warm climate: an Ipswichian age is possible, but an earlier episode cannot be ruled out (Whittaker and Green, 1983). The lower cave earth at Rhinoceros Hole (Wookey Hole) contained bones and teeth of straight-tusked elephant, extinct rhinoceros (*Stephanorhinus (Dicerorhinus) hemitoechus*) and *Hippopotamus amphibius* for which an Ipswichian age is likely (Stuart, 1982a, 1982b).

During the Ipswichian Stage (Oxygen Isotope Stage 5e), it is likely that substantial weathering and soil formation took place. Clear evidence for this is generally lacking from the region, although a variety of weathering profiles found in presumed deposits of Saalian age (such as the Fremington Clay and a variety of head deposits), have been attributed to subaerial chemical weathering in the Ipswichian (Stephens, 1970a, 1977). Any products of Ipswichian weathering of the granite terrains of the South-West have either been redistributed by periglacial processes in the Devensian Stage (see below), or are thus far indistinguishable from the products of earlier weathering episodes, such as those which occurred during previous interglacials and particularly during Upper Cretaceous and Palaeocene times.

Good evidence for Ipswichian rubification and calcrete development, however, is known from the pre-Ipswichian terrace gravels at Hampton Rocks Cutting and at Langport Railway Cutting, and a well-marked rubified palaeosol of probable Ipswichian age is present at Bourne (Chapters 9 and 10).

The Devensian Stage

Early and Middle Devensian sub-stages

Much landform and sedimentary evidence in the South-West can be attributed with confidence to cold-climate processes during the colder parts of the Devensian Stage (Oxygen Isotope Stages 5d, 5b, 4 and 2), particularly during the Late Devensian Dimlington sub-stage (occurring within Oxygen Isotope Stage 2): evidence for temperate episodes and conditions within the stage, however, is extremely rare. Some such evidence is available for the southern Somerset lowland, where isolated deposits are interbedded with cold-stage fluvial gravels (Hunt, 1987).

Although recent work has demonstrated the possibility of an Early Devensian glaciation in North Wales (Addison and Edge, 1992) and eastern Scotland (Bowen, 1991; Gordon and Sutherland, 1993), there is no evidence that ice sheets reached the South-West at this time. Indeed, convincing evidence of Early and Middle Devensian sub-stages is generally lacking, although it is highly probable that Oxygen Isotope Stage 5e raised beach deposits at many localities are succeeded by head deposits which include Early, Mid- and Late Devensian facies (e.g. Scourse, 1985a, 1987, 1991, 1996b). The complex climatic fluctuations which characterize the transition from Ipswichian to Devensian times, so clearly demonstrated by stratigraphical, fossil and geochronological evidence from Bacon Hole Cave on the northern side of the Bristol Channel (Stringer *et al.*, 1986), and in Jersey to the south (Keen *et al.*, 1996), are rarely recorded in South-West England. Nonetheless, falling Oxygen Isotope

Figure 2.6 The massive 'terrace' of raised beach, wind-blown sand ('sandrock') and periglacial head flanking Saunton Down in north Devon. (Photo: N. Stephens.)

Stage 5e sea levels may be demonstrated by the transition from marine to aeolian sand along the Croyde–Saunton coastline (Gilbert, 1996; Figure 2.6). The non-periglacial character of immediately post-Stage 5e times may also be also demonstrated by cliff-fall materials in the head sequence at Brean Down, and, almost certainly, at many other coastal locations: the Pleistocene sequences of the South-West are closely comparable to those of South Wales, especially Gower, in this respect (Campbell and Bowen, 1989).

The deterioration of the climate in the Early Devensian, to fully periglacial conditions, is marked by head formation at a number of localities. At Holly Lane, Clevedon, a series of alternating breccias and aeolian sands may represent cold moist phases (breccia) separated by cold arid periods (sand) within a periglacial environment (Gilbertson and Hawkins, 1974). Recent fossil evidence from the site, however, indicates progressively deteriorating conditions in a cold steppe environment (Chapter 10).

It is quite likely that with the onset of periglacial conditions in the Devensian, the first deposits to be moved downslope and rearranged by solifluction would be older unconsolidated Quaternary sediments: there is clear evidence at some sites for parts of raised beach sequences to have been redistributed by solifluction (e.g. Westward Ho! in north Devon and Porth Seal in the Isles of Scilly), and certainly any remnant river gravels, glacial or glaciofluvial sediments from the Saalian would have been highly susceptible to remobilization during an early periglacial phase or phases. The Trebetherick Boulder Gravel in north Cornwall and glacial gravels on Lundy and the Isles of Scilly may have been partially redistributed in this way during the Devensian (Scourse, 1991, 1996b). Again, a close analogue comes from Gower where pre-Devensian glacial materials (Western Slade Diamicton), colluvial beds and limestone scree were soliflucted down the coastal slopes under periglacial conditions in Early and Middle Devensian times (Bowen, 1970, 1971, 1973a, 1973b, 1974; Henry, 1984a, 1984b; Campbell and Bowen, 1989).

The generally deteriorating climate of Early Devensian times was, as elsewhere in Britain, punctuated by warmer phases. One such period is demonstrated at Low Ham in the Somerset lowland, where sediments and fossils provide unique evidence in the South-West for high relative sea levels during an Early Devensian interstadial: a correlation with Oxygen Isotope Stage 5a is tentatively suggested, providing a close analogue with the evidence from Bacon Hole Cave, Gower (Stringer *et al.*, 1986). Other evidence in the South-West for warmer episodes within the Devensian Stage prior to the Devensian late-glacial is rare: the ascription by ApSimon *et al.* (1961) of mollusc- and vertebrate-bearing beds at Brean Down to the Allerød has, however, been questioned (Currant, unpublished data), and an earlier interstadial event may be present (Chapter 9). With the exception of a Stage 3 faunal assemblage at Tornewton Cave (Chapter 5), there is little clear evidence in the South-West for conditions which prevailed in the Middle Devensian.

Glaciation

There is little doubt that periglacial denudation was the chief land-forming process throughout the Devensian Stage in the South-West. With the exception of the Fremington Clay and mixed lithology drift (Scilly Till and associated meltwater sediments) on the Isles of Scilly, no glacigenic sediments of Late Devensian age are known: even these recent ascriptions are controversial (Chapters 7 and 8). The Fremington Clay or 'till', near Barnstaple, has been a source of debate since its discovery in 1852 (Maw, 1864), and most workers have argued that it was deposited by Irish Sea ice during the Saalian Stage (e.g. Mitchell, 1960; Stephens, 1966b, 1970a, 1977; Kidson, 1977): Saalian glacio-lacustrine conditions have also been invoked to account for its unusually fine texture and 'dispersed' erratics (Edmonds, 1972). Recent interpretations of Pleistocene sequences throughout the Irish Sea Basin, however, have led to the suggestion that the Fremington Clay may have been deposited as a distal mud 'drape', well beyond the southern margin of a Late Devensian, marine-based (floating) Irish Sea glacier (Eyles and McCabe, 1989, 1991; Campbell and Bowen, 1989; Bowen, 1991, 1994b). The possibility that glacial materials in the Isles of Scilly were deposited either directly from the Late Devensian Irish Sea ice sheet (Scourse, 1985a, 1987) or a glaciomarine sediment plume from it (Eyles and McCabe, 1989, 1991) is given consideration in Chapter 8, and rests on the validity of radiocarbon dates (Bowen, 1994b), thermoluminescence (TL) dates, the correct diagnosis of sedimentary provenance and type and whether the deposits lie *in situ* or have been reworked (Scourse, 1985a, 1987; Scourse *et al.*, 1991). However, the maximum southward extent of the combined Welsh and Irish Sea Late Devensian ice sheet, particularly across South Wales, is well charted (Bowen, 1970, 1971, 1974, 1977, 1982; Campbell, 1984) and the interpretation of materials in the Isles of Scilly as *in situ* Late Devensian glacial sediments necessitates radical revisions of previously held views regarding maximum offshore ice limits (Garrard and Dobson, 1974; Garrard, 1977; Doré, 1976; Scourse *et al.*, 1991). Scourse *et al.* (1990) have argued that the glacial advance which affected the Isles of Scilly and the Celtic Sea was a short-lived thin-ice surge beyond a more established terminus in St George's Channel.

If glaciomarine conditions persisted in the Irish Sea Basin, as suggested by some workers, then the distal margins of the ice sheet would have been controlled by sea level (not climate). Ice-rafting under such circumstances could account for some erratics found around the shores of the South-West. With the exception of the Tregarthen Gravel of the Isles of Scilly (Scourse, 1991; Chapter 8), unequivocal deposits associated with deglaciation of the Late Devensian ice sheet, that is glaciofluvial rather than glaciomarine, are unknown.

Devensian sea levels

There is little unequivocal evidence in and around South-West England for establishing the pattern of Devensian sea levels. It has normally been assumed that during cold or stadial phases, sea levels were generally well below those of the present: eustatic levels between 100 m and 130 m below OD have generally been suggested for the Late Devensian (Oxygen Isotope Stage 2), with significant volumes of water becoming effectively 'locked-up' in ice sheets (Aharon, 1983; Lowe and Walker, 1984). There is, however, some evidence for a transition from grounded to floating ice at − 135 m OD in the Celtic Sea associated with an extra-glacial shoreline at between *c.* − 60 and − 90 m OD (Scourse *et al.*, 1990). The warmer, interstadial, phases almost certainly saw higher sea levels: Donovan (1962) assigned the Swallow Cliff (Middle Hope) platform and beach to high relative sea levels during the Upton Warren Interstadial and suggested that the main terrace of the River Severn and a variety of erosional features around the Bristol Channel were related to the same base level. Although Wood (in Callow and Hassall, 1969) reported radiocarbon dates from the Middle Hope raised beach deposit to support this ascription, most authors have assigned the Swallow Cliff raised beach to the Ipswichian (Gilbertson, 1974;

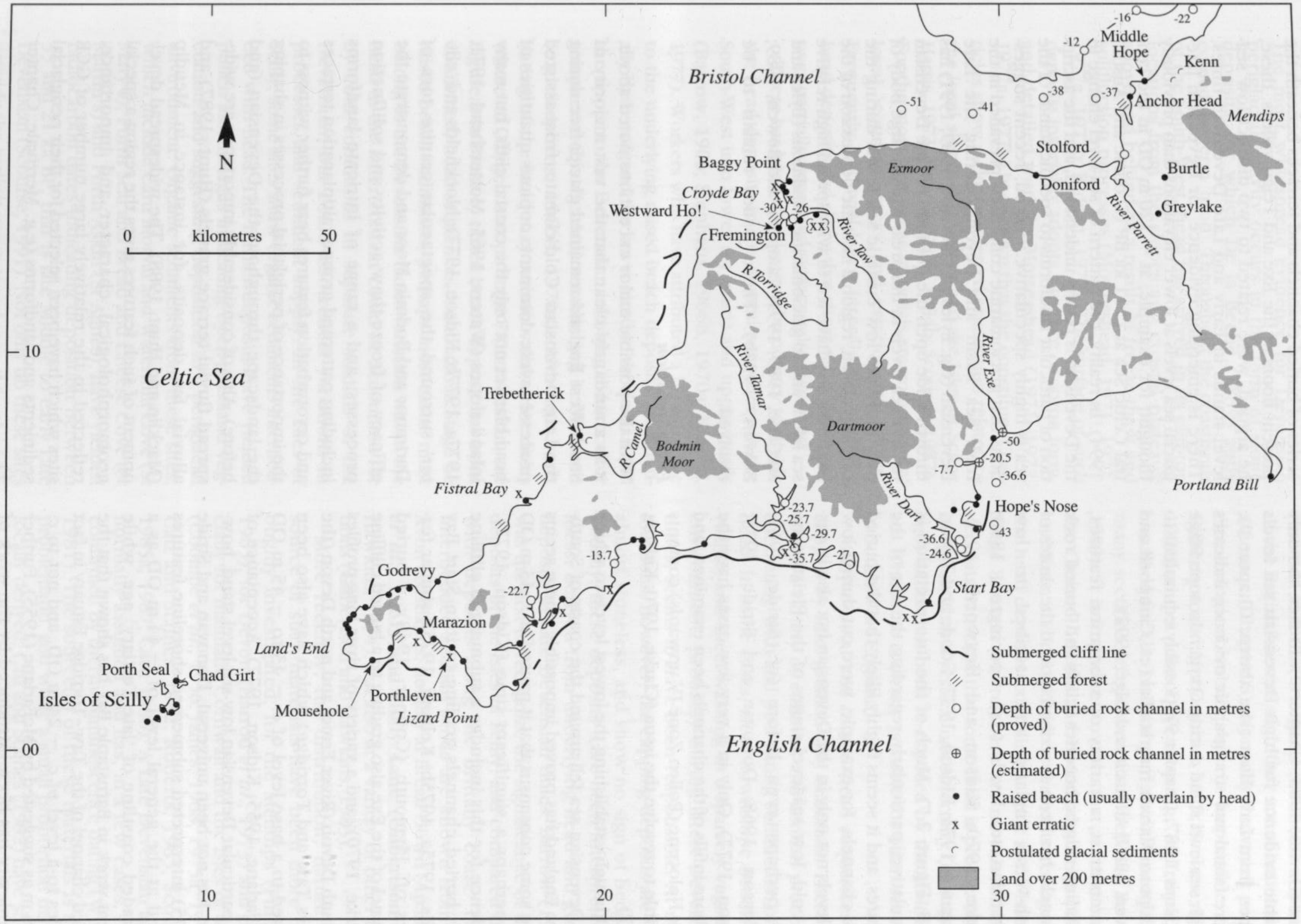


Figure 2.7 Quaternary coastal landforms and deposits around South-West England. (Adapted from Kidson, 1977.)

Gilbertson and Hawkins, 1977) or an even earlier event (Davies, 1983; Chapter 9). In fact, the only reliable evidence for high Devensian sea levels comes from Low Ham (see above; Chapter 9), where faunal and stratigraphic evidence indicates a high sea-level stand during Oxygen Isotope Stage 5a (Hunt, 1987; Chapter 9), possibly equivalent to the Upton Warren Interstadial (cf. Campbell and Bowen, 1989; Addison and Edge, 1992).

In contrast, a variety of submarine features, including ridges, benches, cliffs and buried rock channels, has been described around the shores of South-West England and ascribed to low Devensian sea levels (e.g. Codrington, 1898; Clarke, 1970; Kidson and Heyworth, 1973; Durrance, 1974; Kidson, 1977; Goode and Taylor, 1988; Figure 2.7). Much of the interpretation is speculative, particularly regarding the age of the features, and it seems highly likely that the buried rock channels, for example, were cut during low sea levels not only in the Devensian but also in earlier cold, low sea-level stages of the Pleistocene and perhaps even before (cf. Stride, 1962; Anderson, 1968; Donovan and Stride, 1975; Kidson, 1977). Only in a very few cases have the offshore infills of the channels been examined, and their Holocene (Pollen Zone IV upwards) contents do little to resolve the issue (Clarke, 1970; Kidson, 1977).

Although establishing the lowest levels to which the Devensian sea fell around the coasts of South-West England has proved impossible, there seems to be some consensus that it paused at − 43 m OD for perhaps a significant time (Kidson, 1977). Evidence for this includes a submerged cliffline with buried channels grading to it in Start Bay (Hails, 1975a, 1975b; Kelland, 1975); similar features off Plymouth (Cooper, 1948); a buried channel of the Exe also grading to a buried cliffline (Clarke, 1970); and a variety of river long-profiles in south Devon (River Erme) and north Devon (the rivers Taw and Torridge) which have also been related to a base level of *c*. − 43 to − 45 m OD (McFarlane, 1955; Kidson, 1977). Acceptance of this particular Devensian low sea-level stand, however, has not been universal. Donovan and Stride (1975) interpreted submerged shoreline features found at the general level of − 44 m OD as a degraded coastline of 'late Tertiary' age, while recent work in Barnstaple Bay has shown that the buried channel of the Taw–Torridge Estuary in fact grades to a level of *c*. − 24 m OD, and not to *c*. − 46 m as suggested by McFarlane (1955). Further complexity has been introduced by the work of Durrance (1969, 1971, 1974) who identified a series of buried channels and terraces beneath the present floors of the Exe and Teign valleys: these, he argued, were related to two distinct low sea-level stands in Early and Late Devensian times. There is emerging evidence for Devensian late-glacial sea levels at lower elevations than previously thought; for example, at − 120 m OD in the central Celtic Sea at *c*. 11 ka BP (Scourse and Austin, 1994). In reality, the pattern of sea-level change in the Devensian is poorly understood, and the ascription of particular landforms to specific stands of the sea is highly speculative. Indeed, recent suggestions that glaciomarine conditions prevailed in the Irish Sea Basin and beyond during the Late Devensian (e.g. Eyles and McCabe, 1989, 1991) has thrown wide open the question of Late Devensian relative sea levels in this area: while a large body of data indicates low eustatic sea levels during the Late Devensian, regional isostatic depression of the landmass may have led to widespread high relative sea levels and to glaciomarine conditions (Eyles and McCabe, 1989, 1991; Campbell and Bowen, 1989; Bowen, 1994b). These issues remain to be resolved.

Periglaciation

With the possible minor exceptions noted above, it is abundantly clear that the vast majority of South-West England remained glacier-free during the Late Devensian. Cold-climate, frost-assisted processes were dominant: copious quantities of head blanket not only the coastal cliffs, but many inland slopes (Waters, 1965; Mottershead, 1971, 1977a, 1977b; Kidson, 1977); blockfields and 'clitter' surround the spectacular granite tors of Dartmoor and Bodmin Moor and demonstrate the efficacy of freeze-thaw activity and solifluction processes; and a range of intricate landforms including patterned ground, altiplanation terraces and cryoturbation features bear further witness to the importance of periglacial processes in shaping the landscape throughout the Devensian (and before). Also of considerable importance are widespread fluvial terrace gravels (Hunt, 1987) and alluvial fan deposits, for instance in Mendip (Macklin and Hunt, 1988). The widespread development of such features gives the region a special geomorphological character and importance, reflected in the relatively large number of GCR sites which have been selected for their periglacial sediments and landforms (e.g. Merrivale; Chapter 4).

Head and loess

The most widespread evidence for Devensian periglacial activity occurs in the form of slope deposits, for which De la Beche (1839) aptly coined the term 'head'. Throughout the coastlands of the South-West, head has arrived in its cliff-top locations from the slopes and coastal plateaux above and behind as a result of freeze-thaw and solifluction processes (Mottershead, 1971, 1972, 1977a, 1977b; Kidson, 1977). The surface of such deposits invariably adopts a terrace or apron form, and detailed work by Mottershead (1971, 1972, 1977a, 1977b) has shown that the constituent particles show a clear preferred orientation related to the local slopes (cf. Gower and the Isles of Scilly; Harris, 1973; Henry, 1984a, 1984b; Scourse, 1987). For the most part, these materials are composed of local 'country' rocks and erratics are scarce. Frequently, colluvial layers interdigitate with the head deposits and show that sheet-wash processes over partially vegetated surfaces also occurred.

There has been a widespread tendency to divide the head deposits in the coastal sequences in the South-West into lower (or main) and upper heads (Barrow, 1906; Stephens, 1966b, 1970a; Kidson, 1977). Workers who have attributed a Hoxnian age to the underlying raised beach deposits, traditionally have assigned the lower head to the Saalian and the upper to the Devensian, invoking evidence for temperate (Ipswichian) weathering in between (e.g. Stephens, 1966b, 1970a). Although such dating of the head may remain valid at localities where an Oxygen Isotope Stage 7 (intra-Saalian; see Figure B in Preface) raised beach deposit has been confirmed, head sequences found above Stage 5e raised beach sediments, perhaps most cases, must belong to the Devensian: facies variation within the head in the latter context could be accounted for by cold conditions in separate stadials of the Devensian, but could also reflect variations in processes and sediment supply. In the Isles of Scilly, some sites show organic sediments interbedded with head. The former deposits have yielded pollen assemblages indicating open-grassland vegetation and suggesting deposition in a periglacial environment. Organic sediments from these sites, which include Carn Morval and Watermill Cove (St Mary's), Porth Seal and Bread and Cheese Cove (St Martin's) and Porth Askin (St Agnes), have yielded radiocarbon dates indicating deposition between 35 and 21 ka BP, that is late Middle to early Late Devensian (Scourse, 1991). Not only do these sites provide the earliest vegetational record for the Isles of Scilly, but they cover a period very poorly represented in terms of organic sediments in the rest of the British Isles: as such they are of national significance (Chapter 8). Normally, however, precise chronological subdivision is impossible (e.g. Gilbertson and Mottershead, 1975; Scourse, 1987, 1991) and a Late Devensian age is frequently assumed for the bulk of periglacial materials in many sections (cf. Gower; Campbell and Bowen, 1989). It is important to note that at locations in the Channel Islands and Normandy, Keen (1993) and Keen *et al.* (1996) have demonstrated ages for the head deposits extending at least as far back as Stage 8: even where there are no raised beach deposits, it is clear that some head is pre-Devensian in age and has a vertical unconformity (of Stage 5e age) which has been re-exposed by the Holocene sea. The same is clearly possible for other sections in South-West England.

Many coastal and inland head sequences are capped by finer-grained silty materials. These testify to a variety of colluvial and aeolian processes alternating with and post-dating solifluction of the head. In some cases, clear downslope bedding is visible, and sheet-washing in a sparsely vegetated environment, probably during latest Devensian times, seems to have been responsible. At many locations, however, the capping deposits are silty, almost stoneless, and show no sign of bedding. Usually, these deposits have been interpreted as loess, derived from underlying head and glacial deposits in Late Devensian times. Barrow (1906) was the first to recognize the significance of these deposits in the Isles of Scilly, and compared them with deposits along the Brittany coast. Thick interbedded aeolian sands are known from the Avon coastlands, notably at Brean Down (ApSimon *et al.*, 1961) and Holly Lane (Gilbertson and Hawkins, 1974), but also at a variety of other locations (Gilbertson and Hawkins, 1983).

More recently, the distribution, nature and source of such materials have been more thoroughly investigated; for the Mendips (Findlay, 1965), for Devon (Harrod *et al.*, 1973) and especially for mainland Cornwall and the Isles of Scilly (Coombe *et al.*, 1956; James, 1968, 1975a, 1975b; Catt and Staines, 1982; Roberts, 1985; Scourse, 1985a, 1987; Catt, 1986). A Late Devensian age is normally assumed and has, in a few cases, been confirmed by thermoluminescence dating (Wintle, 1981). The source(s) of these materials is more problematic, and while a small proportion may be locally derived, Catt and Staines (1982) have shown that the bulk of material in the Cornish loess was

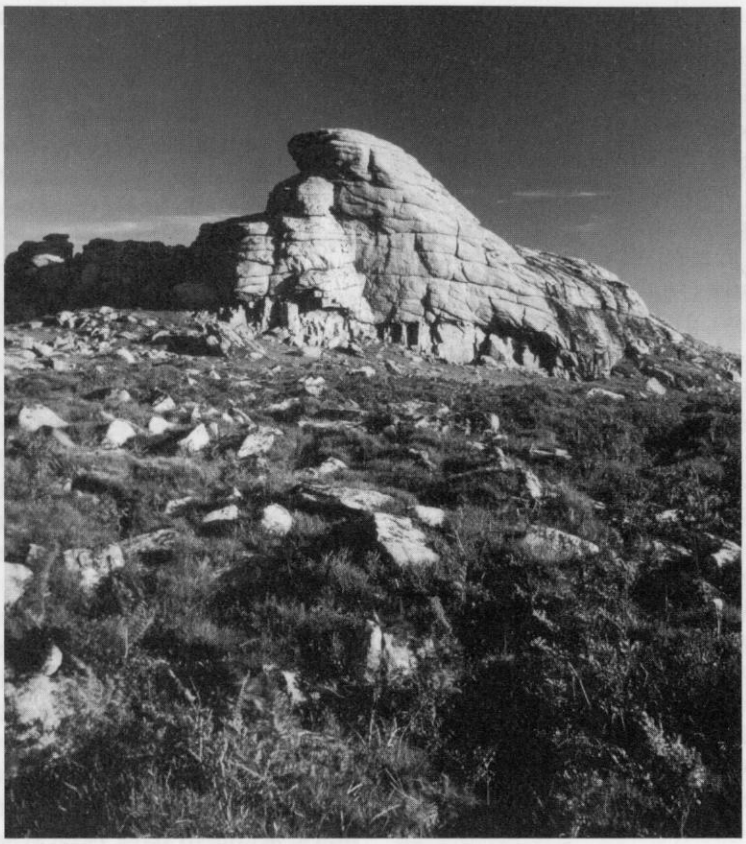


Figure 2.8 Haytor Rocks, Dartmoor. Although tors such as these have evolved over an extremely protracted timescale, their final form, and that of the slopes around them, was fashioned by periglacial processes in the Devensian (Chapter 4). (Photo: S. Campbell.)

blown from glacial outwash deposits in the southern part of the Irish Sea Basin (cf. Gower; Case, 1977, 1983, 1984). The glacigenic sediments of the Celtic Sea and Isles of Scilly are mineralogically similar to the Cornish loess and a genetic association has been proposed (Scourse *et al.*, 1990). The implications of the presence of subaerially exposed, offshore glacial sediments during the Late Devensian, with respect to proposals for glaciomarine conditions at this time, have yet to be explored fully.

Many sections in head and loess display a marked discontinuity some 0.5 m below the surface, where upper layers with friable consistency and crumb or blocky structure give way to lower, extremely well-compacted or indurated layers with a platy structure (Clayden, 1964; Stephens, 1980). These differences have been interpreted as the result of permafrost development, with the upper horizon representing the active layer where seasonal thawing occurred, and the lower layer attaining its structure under permanently frozen ground conditions (Stephens, 1980). The upper parts of many coastal sequences also exhibit clay-filled cracks, some with margins of light-grey clay or re-precipitated iron (e.g. Prah Sands (Cornwall), Fremington Quay (north Devon) and the Camel Estuary (Scourse, 1987)). The precise environmental conditions under which these cracks formed are unknown, although desiccation and frost-cracking are possible mechanisms (cf. Gower; Bowen, 1970; Campbell, 1984). Such features are often intimately related to cryoturbation structures such as involutions and frequently cross-cut them: collectively they bear witness to a variety of post-solifluction periglacial processes in latest Devensian times (see Devensian late-glacial; below).

This pattern of activity is also repeated inland, and the stripping of frost-shattered and weathered materials by solifluction from around the Dartmoor and other tors is well documented (Chapter 4; Figure 2.8), and was fundamental in establishing present slope configurations. The division of inland head sequences, such as those on Dartmoor, into lower (fine) and upper (coarse) heads, reflecting an inversion of normal granite weathering profiles (Waters, 1964, 1974; Mottershead, 1976), has been shown to be unrealistic: many sites show the reverse relationship or even greater facies complexity (Green and Eden, 1973; Gerrard, 1983, 1989a).

However, despite the many well-documented periglacial sedimentary sequences in the South-West, the extent of permafrost during the various cold phases of the Devensian Stage (and before) is still disputed (Williams, 1969, 1975; Straw, 1974; Ballantyne and Harris, 1994).

Although the development of periglacial landforms such as altiplanation terraces (see Merrivale; Chapter 4) is unlikely to have been accomplished during a single Devensian stadial, patterned ground such as stone stripes and polygons, and the widespread clitter on many hillslopes in the vicinity of tors, probably reflect a late stage of periglacial ornamentation, certainly of Late Devensian, possibly even partly Younger Dryas age (Gerrard, 1983). It is quite likely, however, that much of the material, especially that making up the more substantial landforms such as solifluction lobes, is older and has merely been rearranged by later periglacial activity.

Fluvial deposits and landforms

Fluvial deposits and landforms of Devensian age are widespread in the South-West, although they have received relatively little recent attention from researchers. Morphostratigraphic work, for instance on the Dart (Brunsden *et al.*, 1964) and Exe (Kidson, 1962), has rarely been followed up by investigation of the deposits underlying the terrace surfaces.

In the Somerset lowland, east Dorset and in the valleys around Dartmoor, Exmoor and other uplands, cold-stage fluvial sedimentation was widespread. Typically, most of the valley-floor was occupied by flashy ephemeral gravel- and sand-bedded streams, leading to the accumulation of often substantial thicknesses of planar- and trough cross-bedded sand and gravel. Periods of aggradation alternated with periods of incision: Hunt (1987) reported four substantial sand and gravel aggradations of Devensian age from the Somerset lowland (Chapter 9). The fluvial sediments usually pass laterally into, and interdigitate with, valley-side head deposits. At Doniford, for instance, coastal exposures over 2 km in length are cut through 5 m of head interdigitating with trough cross-bedded gravel and sand (Chapter 7). Interstadial fluvial sedimentation was from small meandering streams, and the deposits from these are seldom preserved.

Around upland areas like Mendip, large alluvial fans can in part be attributed to Devensian fluvial activity (Findlay, 1965, 1977; Pounder and Macklin, 1985; Macklin, 1986; Macklin and Hunt, 1988). In the Bourne fan, Devensian aeolian and fluvial deposits were laid down over an interglacial palaeosol. At Wookey Station, fossil evidence suggests that the fan gravels accumulated in an Arctic desert landscape with little vegetation cover. The deposition of fan gravel was synchronous with a phase of aeolian sedimentation (Chapter 9).

Cave deposits

Fossil and archaeological evidence from the Devensian, particularly the Late Devensian, is profuse in the South-West, and lends an important insight to changing climatic and environmental conditions during the stage. Most of this evidence is preserved in cave sequences, where the bulk of material is Devensian in age and characterized by accumulations of cold-climate thermoclastic scree often containing a characteristically 'cold' fauna, typically including woolly mammoth, woolly rhinoceros, reindeer, horse, brown bear, spotted hyaena and the narrow-skulled vole (Sutcliffe, 1969, 1974; Cullingford, 1982), as well as Upper Palaeolithic artefacts (Campbell, 1977). Excellent summaries are provided by Donovan (1954, 1964) and Hawkins and Tratman (1977) for sites in the Mendip, Bristol and Bath areas and by Sutcliffe (1969, 1974) for those in Devon.

Notable sites include Kent's Cavern, where a rich Devensian fauna including woolly rhinoceros, woolly mammoth and reindeer is found in association with Upper Palaeolithic artefacts; and Tornewton Cave (Torbryan) where the Reindeer Stratum with its distinctive small mammal assemblage has been taken as evidence for cold conditions in the Devensian Stage (see Tornewton Cave; Chapter 5).

Although the totality of artefact, sedimentary and fossil evidence from the cave sites of the South-West is enormous, its contribution to a precise reconstruction of Devensian Stage events and environments has not been fully realized, and the interpretation of 'derived' faunas and pollen sequences is, as elsewhere, fraught with difficulties. The major process evidenced by the cave sequences appears to have been the formation of thermoclastic scree, by the collapse of materials from cave walls and roofs; in some places, mass flow events appear to have been responsible for the accumulations and were instrumental in reworking older deposits (e.g. Tornewton Cave). In some caves, evidence from pollen, land snails and artefacts shows a progression of climatic conditions through the coldest part of the Late Devensian into the Devensian late-glacial (see below).

The Devensian late-glacial and Holocene

Introduction

Devensian late-glacial and particularly Holocene environments have been the focus of much attention in South-West England. Although sites demonstrating evidence from these periods were selected as a discrete national network of the GCR, they are included within subsequent regional accounts for convenience (Chapters 4, 7 and 8): to avoid unnecessary repetition, a general synthesis of Devensian late-glacial and Holocene events, and an introduction to these sites, is given here.

The Devensian late-glacial

Latest Devensian Stage events which occurred between the deglaciation of the main Late Devensian ice sheet and the beginning of the Holocene (= Flandrian or 'post-glacial') fall within Devensian late-glacial time. There have been major problems regarding definition of this period, and a variety of climatic, geological, geochronological and chronostratigraphic terms has been used, interchangeably and unhelpfully, to classify evidence from this time interval. Although the start of the Devensian late-glacial is diachronous, a timespan for the period of *c.* 14.5 to 10 ka BP is generally involved.

Originally, a threefold sequence of cold–temperate–cold environments was adduced from the Late Weichselian (= Late Devensian) in south Scandinavia from plant macrofossil and lithostratigraphic evidence. Three chronostratigraphic stages – the Older Dryas (cold), Allerød (warm) and Younger Dryas (cold) were erected and have been recognized in sequences elsewhere by distinctive, climate-dependent, pollen assemblage biozones. An additional temperate event, the Bölling Interstadial, within the Older Dryas has also been recognized. Late-glacial pollen diagrams in Britain have customarily been zoned on this basis (Mitchell *et al.*, 1973a).

The Scandinavian sequence of events, however, is not precisely comparable with the British evidence, and there was considerable regional diversity in the development of vegetation in Britain after the Late Devensian glacial maximum: ice-free conditions were not attained everywhere at the same time and the diachronous nature of events has, in part, led to the different terminology used to describe the changing climate and conditions of the period. The terms Older and Younger Dryas and Allerød have generally been applied to evidence described in South-West England (e.g. Conolly *et al.*, 1950; Brown, 1977; Pennington, 1977; Caseldine, 1980). The latter is broadly equivalent to the Windermere Interstadial in northern England (e.g. Pennington, 1977), and the Younger Dryas is more or less synonymous with the Loch Lomond Stadial. The widely used term 'Lateglacial Interstadial', derived from studies of the Scottish Devensian late-glacial (e.g. Gordon and Sutherland, 1993), accommodates the Older Dryas, Bölling and Allerød events. Devensian late-glacial events fall within Stage 2 of the oxygen isotope framework.

A simpler interpretation of the Devensian late-glacial is to regard it as a period of climatic warming during and after deglaciation of the main Late Devensian ice sheet. This warming was interrupted latterly by a deterioration in climate leading to the establishment of glaciers in upland Britain between *c.* 11 000 and 10 000 radiocarbon years ago, that is during the Younger Dryas (Watts, 1980; Lowe and Walker, 1984; Campbell and Bowen, 1989).

Detailed records of the Devensian late-glacial are rare in the South-West, reflecting a lack of suitable depositional basins. The fullest and most reliable record comes from Hawks Tor on Bodmin Moor, where the classic tripartite stratigraphy is well demonstrated: pollen, plant macrofossil and lithological evidence shows clearly two periods of Arctic conditions, characterized by a sparsely vegetated, treeless landscape and active solifluction and sheet washing (equivalent to the Older and Younger Dryas), separated by a warmer interlude in which birch woodland developed in sheltered locations (Allerød). This was the first terrestrial site in Britain where the Devensian late-glacial was recognized. It is highly likely that this broad pattern of environmental change was repeated elsewhere in the South-West, and significant landscape modification, particularly during the Younger Dryas, is almost certain.

However, unlike areas of Britain covered by the Late Devensian ice sheet, there is no profound lithological change from glacial to periglacial sediments in the South-West (perhaps with the exception of parts of the Isles of Scilly; Chapter 8), and periglacial conditions are likely to have continued, albeit diminished in intensity, until the climatic warming of the Allerød: there is no evidence in the region of temperate conditions or deposits dating from the full glacial phase of the Late Devensian (*c.* 21 to 13 ka BP), and none for a temperate oscillation (cf. the Bölling) prior to the Allerød. Solifluction, sheet-washing and the formation of patterned ground probably continued into the Older Dryas and was renewed, particularly in upland locations such as Dartmoor and Bodmin Moor, during the Younger Dryas. It is highly likely that the final periglacial 'ornamentation' of the landscape occurred in the Younger Dryas, although differentiating the sedimentary products and landforms of this phase from those of earlier Devensian times is impossible in the vast majority of locations. Certainly, large areas would have resembled tundra if not polar desert, and there may have been discontinuous permafrost with snowbeds persisting in suitable locations (Williams, 1975).

Evidence for Devensian late-glacial conditions is probably widely recorded in the cave sequences of the South-West, although it has rarely been demonstrated convincingly. Campbell (1977) has shown that the formation of thermoclastic scree in a number of Mendip caves continued unabated from the coldest part of the Late Devensian right through into the late-glacial (the equivalent of Older Dryas time): pollen evidence from Wookey Hole Hyaena Den, Sun Hole and Gough's Cave shows clearly the climatic improvement of the Allerød (marked by a peak in birch pollen) and also the return to colder conditions and renewed scree formation in the Younger Dryas. The presence of humans is widely indicated in these sequences by the presence of later Upper Palaeolithic (Creswellian) artefacts (Campbell, 1977). The reliability of pollen evidence from caves, however, is generally low and some sequences, for example that at Badger Hole, show no differentiation of the Older Dryas, Allerød and Younger Dryas events: instead, a general improvement of conditions from the peak of the last glacial to the Holocene is indicated.

The only reliable dated evidence for the beginning of warm conditions in the Allerød comes from Hawks Tor, where organic sedimentation began at *c.* 13 ka BP (Brown, 1977). Here, open grassland gave way to juniper scrub by about 12 ka BP and was followed by the spread of birch between *c.* 11.5 and 11 ka BP. Although birch woodland appears to have been restricted to carrs in sheltered valleys in the uplands of Bodmin Moor, it seems highly probable that the lowlands of the South-West were more densely covered, although there is no clear evidence for the actual extent of interstadial woodland (Caseldine, 1980). Coleoptera from Hawks Tor show that the period of maximum interstadial warmth may have been somewhat earlier than the thermal maximum adduced from pollen evidence. It is also probable that the transition from Arctic to interstadial conditions was vastly more rapid than suggested from the pollen data (Caseldine, 1980): this is in keeping with pollen and insect evidence from other areas of the British Isles (e.g. Coope and Brophy, 1972; Coope, 1977).

Other evidence in the South-West for conditions in the Allerød is generally lacking. Although a palaeosol at Brean Down may be attributable to this phase, widespread evidence for soil development is not recorded elsewhere: the products are likely to have been destroyed and redistributed during the more rigorous climate of the succeeding Younger Dryas. Neither is there firm evidence for establishing the pattern of Devensian late-glacial sea levels; all such evidence in the South-West now lies under the sea or is deeply buried. Eustatic sea levels at *c.* 14 ka BP, however, are likely to have been between *c.* 60 m and 90 m below those of the present (Fairbridge, 1961; Jelgersma, 1979; Fairbanks, 1989; Scourse and Austin, 1994; Lambeck, 1995; Bard *et al.*, 1996).

The cold Younger Dryas event, which saw renewed glacier development in other parts of upland Britain, is most clearly recorded in the South-West by palynological evidence at Hawks Tor (Conolly *et al.*, 1950; Brown, 1977; Caseldine, 1980). A return to periglacial conditions, an unstable soil cover, the disappearance of woody elements from the flora and the existence of widespread snowbeds, are all hallmarks of the stage (Caseldine, 1980). The onset of colder conditions at Hawks Tor has been established at *c.* 11 ka BP, but a lack of other suitable sites precludes the precision of environmental reconstruction achieved elsewhere in the British Isles, particularly with respect to charting the movements of the Polar Front. It is likely that the processes of frost-heaving (patterned ground) and aeolian transport of silt and sand (loess and coversand) were all renewed during the Younger Dryas, but few, if any, deposits or landforms can be attributed to the phase with certainty. A return of large areas to a tundra vegetation and discontinuous permafrost is likely. Eustatic sea level towards the end of the period is likely to have been in the region of − 43 m OD (Hawkins, 1971).

The Holocene

Introduction

By international agreement, the Holocene (Flandrian or 'post-glacial') commences at 10 ka BP. Evidence for Holocene conditions in the South-West is widely recorded, both inland and offshore: numerous peat and 'forest' beds, now lying partly beneath the sea, bear witness to formerly more extensive wooded lowland areas and allow the progressive rise of the Holocene sea to its present position to be charted in detail (Figure 2.4). Organic sequences such as those in the Somerset Levels and in upland areas such as Dartmoor and Bodmin Moor, have, in parallel, enabled a reconstruction of Holocene terrestrial environments and vegetational history.

Pollen analysis and radiocarbon dating have provided the principal means of establishing the rate at which the rising Holocene sea flooded the land surface, and for correlating the offshore organic sequences with those inland.

Sea levels

Around the coastline of South-West England, as in Wales, the Holocene transgression can be reconstructed from a series of alternating peat, 'forest' and marine clay beds, the most obvious manifestations being the widely recorded 'submerged forest' beds which are normally covered by sand or mud and only exposed at low tides and times of low beach levels (e.g. Hawkins, 1971, 1973; Kidson and Heyworth, 1973; Kidson, 1977; Figure 2.4). These 'submarine forests' drew much early attention (e.g. Borlase, 1757, 1758; Boase, 1828; Carne, 1846; Henwood, 1858; Ussher, 1879a). In describing tree remains in the intertidal areas of Mount's Bay, Borlase (1757) correctly concluded that St Michael's Mount had once been surrounded by woodland, but argued that the trees had subsequently been drowned as a result of 'subsidence of sea-shores'.

Often, these forest beds contain large trunks and stumps of oak and pine trees in growth position: frequently, the tree remains are rooted in thin soils which developed on bedrock or solifluction deposits, and can be traced inland for some distance (Kidson, 1977; Durrance and Laming, 1982). The forest beds and associated peats occur down to and below the levels of the lowest tides. Clarke (1970) recorded a peat bed at − 24 m OD off Teignmouth in south Devon, while Austen (1851) reported tree stumps rooted in terrestrial sediments and overlain by marine deposits at − 20 m OD off Pentuan in Cornwall: boreholes in the Somerset Levels have shown peat to rest on bedrock at depths in excess of − 21 m OD (Kidson and Heyworth, 1973; Kidson, 1977).

While important evidence for changing Holocene sea levels has documented widely around the coastline of South-West England – for example, at Westward Ho! in north Devon (Rogers, 1946; Churchill and Wymer, 1965; Balaam *et al.*, 1987) and in the English Channel (Boase, 1828; Reid and Flett, 1907; Clarke, 1970; Pascoe, 1970; Welin *et al.*, 1973; Hails, 1975a, 1975b; Goode and Taylor, 1988) – the pattern of change is undoubtedly best demonstrated in the Somerset Levels and Bridgwater Bay (Godwin, 1943, 1948; Godwin *et al.*, 1958; Kidson and Heyworth, 1973, 1976; Kidson, 1977). The following reconstruction relies heavily on evidence from these areas.

It is likely that much of the continental shelf, including all the Bristol Channel area and parts of the Western Approaches, was dry land during the Late Devensian: at the beginning of the Holocene, sea levels may have been as low as − 43 m OD (Hawkins, 1969, 1971). The submerged and buried terrestrial deposits, including the peat and forest beds, cover a vertical range of at least 47 m (Kidson, 1977) and record stages in the drowning of the land surface by the transgressing Holocene sea.

Sea-level rise began very early in the Holocene and, as Kidson (1977, p.286) observed, '... took place initially so rapidly that by 6000 BP only about 6 metres of rise remained to be achieved at a decelerating pace' up to the present day. As sea level rose, many deeply entrenched valleys, rock channels and shoreline features, cut at times of lower base level, were drowned progressively along with their vegetation (e.g. Goode and Taylor, 1988). The sub-Holocene surface of the Somerset Levels and Bridgwater Bay is particularly well established, and here it has been possible to reconstruct the migration of the shoreline inland at 1 ka intervals, from 9 to 4 ka BP (Kidson and Heyworth, 1973; Kidson, 1977). With the rise in sea level, superficial deposits including glacial and periglacial detritus were reworked, and much sand-, pebble- and cobble-sized material was transferred from offshore areas to the nearshore zone and on to modern beaches (e.g. Hails, 1975a, 1975b; Kelland, 1975; Kidson, 1977). With the exception of a major basal peat bed, the deposits of the early Holocene are largely thick, inorganic marine clays, silts and sands – reflecting the fast initial rate of sea-level rise: other peat beds from this time are rare and generally thin (Kidson, 1977).

By about 6 ka BP, the rate of rise had slowed and sea levels were sufficiently high to affect groundwater tables, cause waterlogging and accelerate peat growth. A succession of alternating peats and clays, particularly in the Somerset Levels, reflects the complex interplay between marine and terrestrial sedimentation and peat growth. At times, the rate of terrestrial sedimentation was more rapid than sea-level rise, and vegetation colonized a near-horizontal land surface and peat formation resumed; at others, the reverse was true (Kidson, 1977). In some areas of the Somerset Levels, peat growth consistently outstripped the rate of sea-level rise, resulting in a thick peat or 'raised bog' layer which now forms the land surface, and which effectively excluded the sea from large areas for as much as 5000 years. In other areas, the intercalations of peat and clay record a more complex story: where fen and carr peats occur, the relationship between sea level, groundwater and peat growth is particularly clear (Kidson, 1977). Indeed, in these areas, Godwin (1960) identified a series of flood episodes which he suggested had prompted the building of wooden trackways across the bogs in prehistoric times: it is likely that these flooding episodes can be related to contemporaneous high sea levels (Kidson and Heyworth, 1973; Kidson, 1977).

With the exception of areas of raised bog and dune sand, it is clear that all Holocene sediments which infill the Somerset Levels were laid down at or very close to sea level. The regional sea-level curve established by Kidson and Heyworth (1973) shows a smooth, almost exponential, rise. There is no evidence during later Holocene times for minor transgressions or regressions of the sea, either in the Somerset Levels or more generally in South-West England. Indeed, Kidson and Heyworth (1973) and Kidson (1977) have argued that the complex intercalations of peat and clay which date from the last 5000 years or so, accumulated in response to minor variations in the relative rates of sedimentation and sea-level rise. Even the thicker marine clays which fringe the seaward side of the Somerset Levels, and which were interpreted by Godwin (1943, 1956) as indicating a significant transgression in Romano-British times, are more likely to reflect the cumulative effects of occasional high sea levels caused by exceptional storms, storm surges and long-period tides (Kidson and Heyworth, 1973; Kidson, 1977).

The diminishing rate of sea-level rise in later Holocene times is perhaps most graphically illustrated by various parts of the Isles of Scilly where hut circles, stone cists and field walls are sometimes exposed on the foreshore at low tide: this archaeological evidence shows that most of the islands (except Agnes, Annet and Gugh) were still connected as a single landmass until roughly between the 7th and 13th centuries AD, when the central low-lying area was finally flooded by the sea (Fowler and Thomas, 1979; Bell *et al.* 1984; Thomas, 1985). Interestingly, the rate of relative sea-level rise around the Isles of Scilly today appears to be greater than in neighbouring areas, at 4 mm per annum (Scourse, 1996b).

In terms of the overall scale of environmental and landscape change during the early Holocene, changes in the coastal zone since mid-Holocene times have been relatively minor (e.g. Steers, 1946; Arber, 1949; Robson, 1950; Everard *et al.*, 1964; Todd, 1987). The principal geomorphological effects have been the re-occupation and undercutting of ancient clifflines (e.g. Arber, 1949, 1974; Savigear, 1960, 1962), the development of coastal barriers, spits and storm beaches (e.g. Spratt, 1856; Martin, 1872, 1876, 1893; Ussher, 1904; Worth, 1904, 1909, 1923; Rogers, 1908; Toy, 1934; Robson, 1944; Kidson, 1950; Robinson, 1955, 1961), the siltation of estuaries, in part caused by the obstruction of estuary mouths by spits and barriers (Symons, 1877; Everard, 1960a; Witherick, 1963; Everard *et al.*, 1964) and the reactivation of coastal landslips (Arber, 1940, 1946). Perhaps the most significant coastal development during late Holocene times, however, has been the widespread accumulation of dune sand, for example, the Braunton and Northam Burrows in north Devon (Rogers, 1908; Kidson *et al.*, 1989; Chisholm, 1996) and the Cornish 'towans' such as those at Penhale and Gwithian (Crawford, 1921; Harding, 1950; Burrows, 1971).

The chronology of these recent sand accumulations is in general poorly understood, despite a series of molluscan studies (e.g. Spencer, 1974, 1975; Evans, 1979) and a wealth of archaeological evidence (e.g. Crawford, 1921; Harding, 1950; Bruce Mitford, 1956; Megaw *et al.*, 1961; Megaw, 1976; Whimster, 1977). From an archaeological point of view, the dunes effectively seal extensive areas of former land surface (Bell *et al.*, 1984) and appear to post-date significant forest clearance in the region (see below). A clear pattern of Holocene dune formation, however, has not been established, although archaeological and documentary evidence shows that movement of sand was particularly active during both Roman and Mediaeval times (cf. Jones *et al.*, 1990).

Finally, there is no evidence in the South-West for isostatic rebound during the Holocene, and the sea-level curve derived for Bridgwater Bay (Kidson and Heyworth, 1973; Kidson, 1977) matches well with data derived more recently from west Wales (Heyworth *et al.*, 1985), indicating no differential movement between the two areas. Sea levels during the Holocene never attained levels higher than those of the present day (Kidson and Heyworth, 1973; Kidson, 1977).

Terrestrial environments and anthropogenic effects

The rapidly rising sea levels of the early Holocene were accompanied by significant climatic warming, the return of North Atlantic Drift waters to the coast and renewed vegetational and soil development. Within 500 years, the tundra conditions of the Younger Dryas had been replaced by a climate at least as equable as that of the preceding Allerød. Evidence based on indications of marine temperatures from elsewhere in Britain suggests that the bulk of this thermal improvement may have taken place in as little as 40 years (Peacock and Harkness, 1990). On land, one of the first effects was the immigration of thermophilous insects, although this is scantily recorded in the South-West (Caseldine, 1980). While the temperature rise indicated by the pollen is more gradual, the same general improvement in conditions is clear. The Younger Dryas vegetation, dominated by taxa indicative of disturbed ground and by those of open habitats, was quickly succeeded in the earliest Holocene by open grassland and shrub and scrub vegetation with juniper and crowberry.

By about 9 ka BP, it is likely that substantial areas of South-West England had been colonized by birch woodland. Trees, however, were less quick to colonize more exposed and elevated areas such as Bodmin Moor (see Dozmary Pool) and Dartmoor (see Blacklane Brook). By *c.* 9 ka BP, these areas were still probably open moorland, with birch copses and hazel and oak scrub being restricted to sheltered valleys and hillsides (Brown, 1977; Caseldine, 1980). Despite the lack of trees in these areas, there is evidence that Mesolithic communities were already exploiting the moorland (Jacobi, 1979). This compares with Scotland, for example, where the earliest evidence of human activity in the post-glacial dates to a little before 5 ka BP (Gordon and Sutherland, 1993).

The spread of forest vegetation had profound effects on fluvial planform and depositional style, with a change from gravel aggradation to single-channel incising streams around 9 ka BP (Macklin and Hunt, 1988).

From about 9 to 5 ka BP, climatic conditions continued to improve, with woodland expanding to its maximum in the late Boreal/early Atlantic (the 'climatic optimum'). In the lowlands and more sheltered locations, the forest thickened and diversified in composition, with hazel and oak becoming dominant. In many upland areas, open woodland developed, although it is likely that, even at the time of maximum forest cover, the most exposed areas of Cornwall remained under grassland or heather moor (Caseldine, 1980). Even where a tree cover was established in exposed upland areas, species diversity is likely to have been low: oak faced little competition, pine never became established and elm was restricted by a lack of suitable soil parent materials. Brown earth soils were probably developed over wide areas (Caseldine, 1980).

Estimating the treeline of the early to mid-Holocene in the upland areas of South-West England has proved contentious: there are few blanket bogs of this age in which tree remains are preserved. Throughout the Holocene, tree pollen found in the peats of Bodmin Moor never exceeds *c.* 50–70% of the total, reflecting a persistent suppression of woodland cover by exposure to strong westerly airflows (Brown, 1977; Caseldine, 1980). While some areas of the moors remained open and treeless, the environs of Dozmary Pool were colonized by open oak forest, and tree cover was certainly extensive in even more elevated areas such as Dartmoor (Simmons, 1964a; Maguire and Caseldine, 1985). Tree remains in peat at Blacklane Brook on Dartmoor show that trees extended to at least 457 m OD, prompting the suggestion that all but the most exposed and elevated summits of the moor were tree-covered (Simmons, 1964a, 1969). The best estimates place the mid-Holocene forest maximum treeline on Dartmoor at altitudes between *c.* 497 and 547 m OD: this provides, with the exception of Bodmin Moor, one of the lowest treeline estimates in Britain for this time

(Caseldine, 1980; Maguire and Caseldine, 1985).

Despite the uncertainties about the exact position of the treeline in upland areas during the mid-Holocene forest maximum, it is highly likely that the remainder of the South-West was thickly wooded. The distribution of tree remains in submerged forest and peat beds all around the coast of South-West England (Kidson, 1977; Figure 2.4), bears witness to the greater extent of woodland prior to its submergence, by about 6 ka BP, by the rising Holocene sea. Offshore peat beds with tree remains provide convincing evidence that large areas, now drowned, were once wooded. Pollen and plant macrofossil evidence from Higher Moors on St Mary's, shows that woodland even extended to the Isles of Scilly during the mid-Holocene. Such evidence has significant implications for studies of tree migration and dispersal given that the islands are situated 45 km south-west of the mainland, against the direction of the prevailing winds.

Following establishment of the 'climatic optimum' vegetation, during the later Boreal and early Atlantic periods, vegetational development in the South-West has been influenced by two main factors – climate and human activity; as with other parts of Britain, divorcing the effects of one from the other has proved difficult. The most notable recurrent pollen change of the post-glacial in Britain, namely the 'elm decline' at around 5 ka BP (Smith and Pilcher, 1973), is revealed at some sites but not at others. Because of consistently low levels of elm pollen in the upland areas, such as Bodmin Moor, the decline is not apparent, and even in areas where it is recorded, such as in the Somerset Levels, its timing and causes are complicated (see below) (Pennington, 1977; Beckett and Hibbert, 1978, 1979; Caseldine, 1980).

Changes in pollen assemblages (e.g. Blacklane Brook) and the presence of charcoal and artefacts (Dozmary Pool), show that by about 7.5–7 ka BP Mesolithic humans were already clearing the forest and modifying the landscape of Dartmoor and Bodmin Moor (Simmons, 1969, 1975; Jacobi, 1979; Caseldine, 1980). Although traditionally Mesolithic people have been regarded as 'hunters, fishers and gatherers who did not affect their environment much beyond their immediate surroundings' (Godwin, 1956), it has become increasingly clear that in the South-West, Mesolithic forest clearance in marginal areas, although relatively minor in extent, may have led to irreversible environmental changes, including the podsolization of soils on high ground after clearance, and perhaps even, indirectly, the inception of blanket bog growth (Simmons, 1969, 1975; Merryfield and Moore, 1974).

It is equally clear from evidence in the region that, by about 6.5 ka BP, the climate had become wetter, resulting in the development of raised and blanket bogs and the rapid spread of alder (Scaife, 1984).

Many sites in the South-West, including those on Dartmoor, Bodmin Moor and the Isles of Scilly, demonstrate the progressive clearance of woodland by humans during the Neolithic and later. While the Mesolithic episodes were probably minor and restricted to the mainland, those of the Neolithic were more extensive and long-lasting; evidence for post-forest clearance regeneration, however, is evident at some sites. By the Bronze Age, significant areas of woodland had been cleared, allowing light-demanding hazel to become dominant in some areas (Dimbleby, 1963; Bayley, 1975; Caseldine, 1980). The progressive modification of the woodland stand to allow cultivation from Neolithic times onward, is indicated by the pollen of cereals, weeds and ruderals. Certainly, the general view is that the removal of woodland in many areas had become irreversible by the Bronze Age, and that by Iron Age times a relatively open landscape, similar to today's, had been created (Christie, 1978; Caseldine, 1980).

Nowhere in the South-West, however, is the influence of humans on the environment better illustrated than in the Somerset Levels. Here, the discovery of the 'lake villages' at Glastonbury and Meare stimulated much early interest (Bulleid and Gray, 1911, 1917, 1948; Gray and Bulleid, 1953; Gray, 1966). A series of palaeobotanical studies by Godwin and his colleagues established both the vegetational history of the peatlands and set the burgeoning archaeological discoveries in an environmental context (Godwin, 1941, 1943, 1948, 1955a, 1955b, 1960, 1967; Clapham and Godwin, 1948; Godwin and Willis, 1959; Dewar and Godwin, 1963). The basic sequence of vegetational development has since been elaborated in studies which have used modern palynological techniques and radiocarbon dating (e.g. Beckett, 1977, 1978a, 1978b, 1979a, 1979b, 1979c; Beckett and Hibbert, 1976, 1978, 1979), plant macroscopic remains (e.g. Beckett, 1978a, 1978b, 1979a, 1979b; Coles and Orme, 1978; Caseldine, 1980(a); Orme *et al.*, 1981), beetle remains (e.g. Girling, 1976, 1977a, 1977b, 1978, 1979a, 1979b, 1980; Coles and Orme, 1976, 1978) and wood decay and tree ring evidence (e.g. Girling, 1976, 1979b, 1980; Morgan, 1976a, 1976b, 1977, 1978, 1980, 1982; Carruthers,

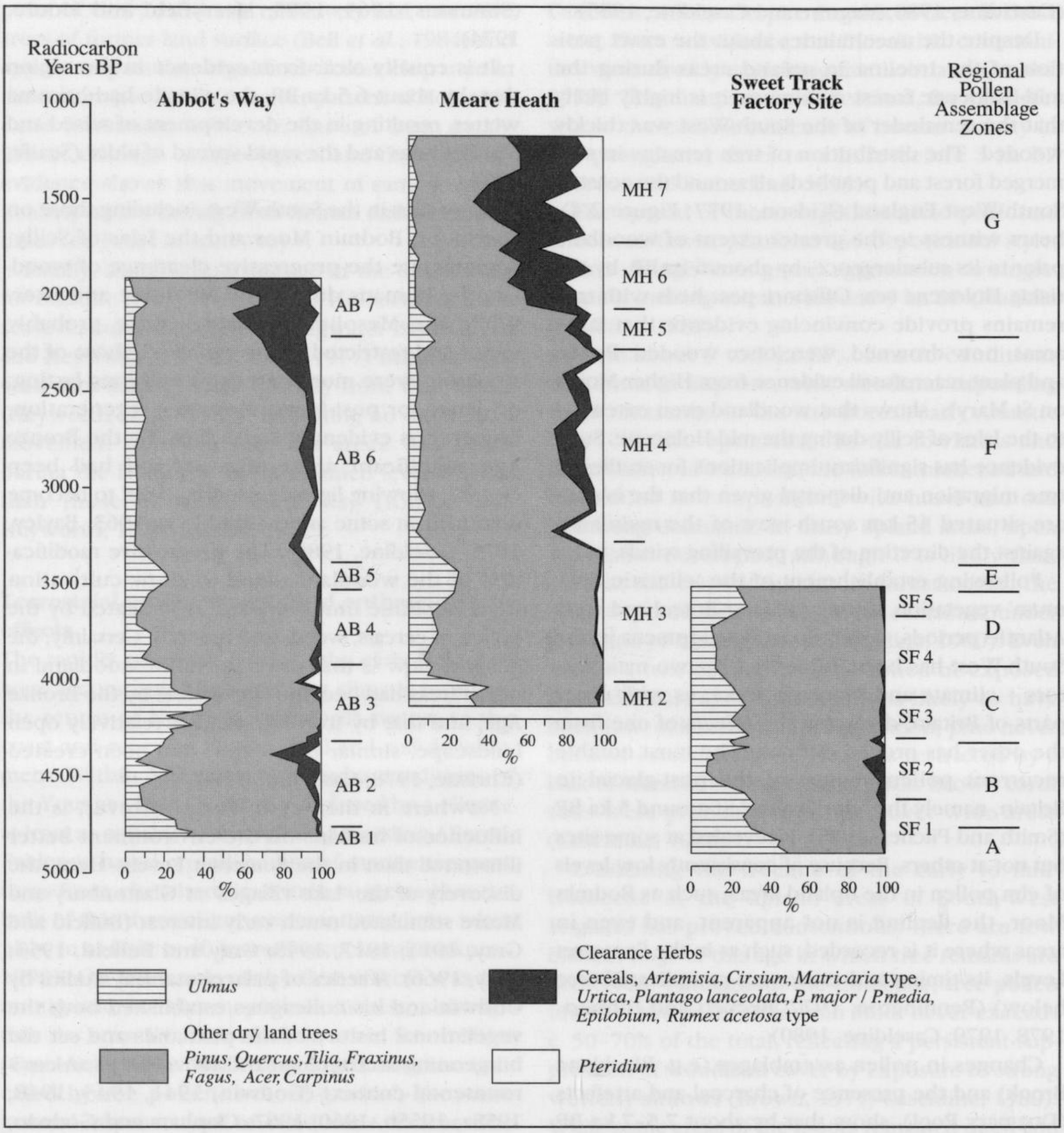


Figure 2.9 Summary Holocene pollen diagrams from the Abbot's Way, Meare Heath and Sweet Track Factory sites in the Somerset Levels (selected taxa only). The vertical scale is based on dates in uncorrected radiocarbon years BP (before present 1950). (Adapted from Beckett and Hibbert, 1979.)

1979; Bevercombe, 1980) to chart vegetational development in the area and anthropogenic effects on the environment: over 40 sites in the Levels have furnished palaeoenvironmental information, summaries of which are provided by Bell *et al.* (1984) and Beckett and Hibbert (1978, 1979).

Suffice to say here, that the Holocene deposits of the Somerset Levels consist, towards the coast, of intertidal and brackish clays, silts and sands with intercalated peats (Godwin, 1941; Bell *et al.*, 1984). Inland, thick peat, often divisible into a highly humified lower layer and a poorly humified upper layer, overlies estuarine clay and is itself overlain in places by clay (Godwin, 1941). Preserved within the peat are prehistoric wooden trackways, which evidently linked the surrounding higher drier land – the 'islands' of bedrock and Burtle Beds (Bell *et al.*, 1984).

Peat formation in the Somerset Levels began at about 5.7 ka BP, as reedswamp colonized a waterlogged surface of estuarine clay (Kidson, 1977; Bell *et al.*, 1984). By *c.* 4 850 BP, trees had started to colonize the reedswamp, resulting in a 'fenwood' (Bell *et al.*, 1984). At this time, the area above the Levels appears to have been densely wooded: alder and birch fringed the waterlogged areas, while elm, oak and lime dominated the higher, better-drained land (Beckett and Hibbert, 1979: Regional Pollen Zone A; Figure 2.9). This woodland is comparable to the 'climax forest' found throughout much of southern Britain in Atlantic times. There is no evidence in the pollen record to suggest that Mesolithic people had a significant effect on the vegetation cover at this time.

At about 4.7 ka BP, a major change in the vegetational composition of the drier land, both within and surrounding the peatlands, is suggested by the pollen record (Regional Pollen Zone B; Figure 2.9). A major decline of elm pollen, as well as that of other trees, indicates the first major phase of forest clearance to support a largely pastoral economy. It was around this time, at the Atlantic/Sub-Boreal transition, that some of the earliest Neolithic trackways, such as the Sweet Track and Abbot's Way, were constructed. Also around this time, there was a major change in the peatlands themselves, with fenwood vegetation giving way to the development of raised *Sphagnum* bog. This change, which began in the vicinity of Abbot's Way at *c.* 4 650 BP, reaching other areas such as Shapwick Heath at a much later date (*c.* 4 050 BP), reflects increased waterlogging (see Holocene sea levels; this chapter) (Beckett and Hibbert, 1979; Bell *et al.*, 1984). The clearance phase itself lasted until *c.* 4.3 ka BP, when increasing amounts of elm pollen and decreasing values of herb pollen denote a likely diminution of human activity in the area, lasting perhaps until about 4 ka BP (Regional Pollen Zone C; Figure 2.9; Beckett and Hibbert, 1979).

Between about 4 and 3 ka BP (Regional Pollen Zones D and E; Figure 2.9), a minor phase of forest clearance followed by modest regeneration is indicated (Beckett and Hibbert, 1979; Bell *et al.*, 1984). Regeneration, however, was shortlived: a further fall in elm values and a rise in the pollen of *Plantago lanceolata*, *Rumex* and other herbs (Regional Pollen Zone F; Figure 2.9) suggest increased human activity, substantial forest clearance and re-establishment of a pastoral economy in and around the Levels, from between *c.* 3.3 to 2.2 ka BP. These changes coincide with continued raised bog development and the construction of later Neolithic and Bronze Age trackways (Clapham and Godwin, 1948; Dewar and Godwin, 1963; Coles *et al.*, 1975). Many of the tracks appear to have been built in response to flooding of the raised bog, a first phase of which lasted from about 2.7 to 2.3 ka BP (Clapham and Godwin, 1948; Beckett and Hibbert, 1979; Bell *et al.*, 1984). Towards the end of this period, the Iron Age village at Meare was constructed on higher land at the bog's margins.

From about 2 200 to 1 350 BP, the uppermost layers of peat in the Levels were formed. Their pollen content, dominated by herbs (grasses, docks and sorrels), denotes massive forest clearance during the Iron Age and into Romano-British times (Beckett and Hibbert, 1979). By these times, wide areas had been cleared for agriculture, and the presence of cereal pollen grains and those of their associated weeds, implies that both arable and pastoral farming were being practised throughout the higher drier land of the region, such as at Meare 'island'. It seems likely that during this period, birch growth was renewed on bog surfaces, while scrub woodland may have invaded once-cleared areas, already abandoned as a result of soil exhaustion (Beckett and Hibbert, 1979). Peat formation appears largely to have ceased by this time, although a precise reconstruction of events and conditions has been hampered by peat cutting.

One of the chief effects of the establishment of soil and vegetation covers in South-West England during the Holocene, together with its milder climate, was a marked diminution of geomorphological activity, especially in comparison with the preceding Younger Dryas. However, large volumes of unconsolidated periglacial debris have been remodelled by rivers, as witnessed by Holocene river terraces (Macklin, 1985, 1986; Macklin and Hunt, 1988), and significant landslides and mudflows have taken place (e.g. Arber, 1940, 1973; Brunsden and Jones, 1976; Grainger *et al.*, 1985, 1996; Brunsden, 1996; Grainger and Kalaugher, 1996; Kalaugher *et al.*, 1996). There is no clear evidence in the region for the climatic deterioration known as the 'Little Ice Age', and, with the exception of controversial earth hummocks on Dartmoor (Gerrard, 1983, 1988; Bennett *et al.*, 1996), virtually none for contemporary periglacial processes. Although the transport of sand and silt by wind and slope processes may have continued from the Younger Dryas into the earliest Holocene, the mid- and later Holocene appear to have been mostly times of relative geomorphological inactivity. Human impact on fluvial processes and sedimentation patterns has, however, been significant, with mining phases on Mendip causing the destabilization of fluvial regimes and the aggradation of significant alluvial units (Macklin *et al.*, 1985; Macklin, 1986). However, in recent centuries, as elsewhere in Britain, sand movement was reactivated (see above), although dune accumulation was not synchronous everywhere.