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Excerpt
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PART 1
Introduction and context

Throughout much of the last two million years, the landscape of Great Britain evolved under climatic conditions very much colder than those of the present. The most dramatic consequence of such cooling was the development of glaciers in the mountains of Britain and their subsequent expansion across the adjacent lowlands. Though these glaciers sometimes achieved remarkable dimensions, even overrunning most of the English Midlands and East Anglia, on no occasion was all of the present land surface completely buried under ice. Always there remained a zone, the *periglacial zone*, that experienced prolonged exposure to intensely cold nonglacial conditions. Often, indeed, the periglacial zone was much more extensive than the area covered by glacier ice, and even when periods of warmer climate interrupted the prevailing cold, periglacial conditions continued to affect the highest ground. This volume examines the effects of such periglacial conditions in modifying the British landscape, and describes the various landforms, deposits and sedimentary structures that have survived from the frigid past, as well as those still actively developing on British mountains during the milder present. The first three chapters provide the context for this examination. The opening chapter defines the nature of periglaciation, traces the historical development of periglacial research in Britain and introduces the aims and rationale of the volume as a whole. Chapter 2 sets the study of periglaciation in chronological context by tracing the broad outline of environmental changes that have affected Britain over the last million years or so. The third chapter introduces some of the principal characteristics of present-day periglacial environments, particularly those of the arctic and subarctic, which are similar in many respects to those that prevailed in Britain in the recent geological past.

1
Introduction

The term *periglacial* refers to 'the conditions, processes and landforms associated with cold, nonglacial environments' (Harris *et al.*, 1988) and is used in this sense throughout this book. *Periglacial geomorphology* is concerned with our understanding of the landforms, deposits and processes of cold nonglacial environments. *Periglacial environments*, past or present, are those in which cold-climate nonglacial processes have produced distinctive landforms and deposits, often (but not always) as a result of ground freezing. The concept of *periglaciation* is perhaps less familiar, and is used here to describe the collective and cumulative effects of periglacial processes in modifying the landscape, much as 'glaciation' describes the general effects of glacial action.

A volume devoted to the periglaciation of Great Britain may appear something of a paradox. This island lies far to the south of the arctic tundra, supports no mountains of alpine stature and presently experiences a maritime temperate climate with mild winters. Over much of the country the only 'periglacial' effect that may be evident under present conditions is the growth of needle ice in fallow land during an exceptional frost. Heavy snowfall in lowland areas is sufficiently unusual to be elevated by the weather-conscious populace to the status of a rather enjoyable natural catastrophe. Moreover, to the professional eyes of geomorphologists, much of the northern two-thirds of the island are dominated by the inherited effects of Pleistocene glaciation. Glacier ice sculpted the British uplands into a landscape of corries, arêtes and troughs, and the landscapes of all but the southernmost lowlands are dominated by a cover of glacial drift. The role of periglaciation in modifying the British landscape has been more subtle but more widespread. In southern Britain, beyond the limits of maximum glaciation, cold climates recurred during successive glacial episodes, creating what is essentially a relict periglacial landscape. Moreover, since the waning of the last great ice sheet all parts of northern Britain have experienced periglacial conditions, and these linger on even today in the highest mountains. The legacy of periglaciation across the country is a rich variety of landforms, deposits and sedimentary structures, many of which provide insights into the nature and severity of the sweeping climatic changes that affected Great Britain during the final millennia of the Pleistocene Epoch.

The general aim of this volume is to present a comprehensive picture of current knowledge concerning the periglaciation of Great Britain. Subsumed within this aim are four particular objectives. The first concerns evaluation of the geomorphological and environmental implications of relict periglacial phenomena in the British landscape. A basic tenet of much geological and geomorphological research is James Hutton's dictum that the present represents the key to understanding the past. To permit accurate interpretation of the significance of relict periglacial phenomena in Britain, reference must be made to modern analogues in high latitude and high altitude environments where periglacial conditions currently prevail. Over the past two decades, much research has been devoted to establishing a deeper understanding of the physical, chemical and hydrological processes that operate in such environments (cf. Clark, 1988a; Williams & Smith, 1989). Many areas of uncertainty and contention remain unresolved, but such work has nevertheless placed our understanding of cryogenic (freeze–thaw) activity on increasingly secure theoretical foundations. A particular aim of this book is to integrate recent findings on the mechanisms of periglacial processes and the significance of periglacial phenomena with field observations of such phenomena in Great Britain. For this reason, most chapters are prefaced with a review of recent theoretical developments, against which the British evidence may be assessed. Inevitably, this sometimes involves reinterpretation of the significance of certain sites and landforms.

Our second objective in writing this book has been to attempt a synthesis of evidence recorded from different parts of the country. Periglacial research in Great Britain has often proceeded on a site-by-site basis; great attention has been lavished on particular areas, individual mountains and isolated critical sections. Whilst this approach is of great value in elucidating detail and establishing stratigraphic or geomorphological relationships, it inevitably militates against the establishment of regional patterns. A number of syntheses have demonstrated the value of collating evidence from wider areas within Britain (e.g. Williams, 1965, 1975; Kelletat, 1970a; Watson, 1977a; Worsley, 1977, 1987; Ballantyne, 1984, 1987a; Bryant & Carpenter, 1987; Harris, 1987a), and this approach is extended and developed here. Conversely, we have also tried to identify sites that are outstanding in representing particular phenomena, and have where possible described and illustrated these in detail. In periglacial research, as in other branches of earth science, field experience is indispensable; our aim has been to highlight sites that will both stimulate interest and deepen understanding. A fourth objective has been to identify some priorities for future research. Our quarrying of the literature has revealed numerous gaps in understanding as well as opportunities for future work. Should this volume stimulate fellow researchers to take up the challenge of hitherto unresolved problems or unrecognised possibilities, so much the better.

The overriding aim of this book, however, is to demonstrate the importance of periglaciation in modifying the British landscape and the immense diversity of its manifestations. Despite the relatively limited compass of this island, few periglacial phenomena are unrepresented in relict or active form. For this reason, we believe that synthesis and reassessment of current knowledge will be of interest not only to researchers within Great Britain, but to all earth scientists whose work encompasses the interpretation of periglacial phenomena. There is much that remains to be learnt about – and from – the periglaciation of Great Britain.

The development of periglacial research in Great Britain

The study of periglacial phenomena in Great Britain has a long but somewhat erratic history. Identification of significant milestones in its progress is inevitably arbitrary, but for convenience we have grouped developments into three broad periods. The earliest involved the growing awareness amongst geographers and geologists of the existence of deposits and landforms of periglacial origin in the British landscape, and extended from the subject's hesitant beginnings in the nineteenth century until around 1940. The following quarter century, from 1940 until 1965, witnessed a steady increase in appreciation of the effects of periglaciation, an increase that reflects the quickening pace of Quaternary research in this country. Such developments have reached fruition in the present phase, in which periglacial phenomena have become of primary concern not only to geomorphologists, but also to a wide range of earth scientists whose interests encompass such diverse fields as Quaternary geology and stratigraphy, present-day geomorphic processes, soil science, engineering geology and climatic change.

Early beginnings

The first periglacial phenomenon to have excited the interest of British geologists was the presence of widespread sheets of 'rubble drift' or *head* deposits in southern England. The earliest account of head deposits is attributable to Borlase (1758, p.76) who described '...a rough yellow clay, charged here and there with small and large stones, all with their angles on...' overlying raised beach deposits in the coastal cliffs of Cornwall. Chalky head or *coombe rock* in SE England was subsequently described by Mantell (1833) and considered by him to represent a manifestation of the 'diluvium' supposedly deposited by the biblical flood. The local quarryman's term 'head' was given to the rubble drift by De la Beche (1839), and such deposits were first attributed to periglacial processes by Austen (1851). In a paper remarkable for its astuteness of observation, Austen attributed the head deposits of Devon and Cornwall to rock decomposition and mass movement over low-gradient slopes. 'They are', he noted, 'so totally beyond the power of any present agencies, that it seems necessary to call in the operation of cold to adequately account for them' (p.130). Unhappy with the then novel idea of ice ages, however, Austen invoked massive uplift and then subsidence to explain the existence of such periglacial deposits at present sea level.

Not all Victorian geologists, however, were satisfied with Austen's explanation. Head and coombe rock were variously attributed to earth tremors (Murchison, 1851), torrential snowmelt floods (Ussher, 1879) and even catastrophic pulsed uplift (Prestwich, 1892), a hypothesis judged by an eminent contemporary to be 'more ingenious than convincing' (Geikie, 1894). Gradually, however, Austen's proposed explanation of head as a cold-climate deposit gained acceptance. Wood (1882) ascribed the angular drift of nonglaciated areas of England to 'sludging' of frost-riven debris, and in an outstandingly percipient paper Spurrell (1886, p.31) proposed that head may have accumulated by the 'intermittent flowing, under its own weight, of a soil undergoing thaw, that is, in a viscous state'. This description is remarkably consonant with present understanding of the process of *gelifluction*, and indeed with the current interpretation of head deposits. Spurrell also noted the occurrence of up to three units of head separated by wash deposits, and inferred that each represented a distinct cold period. By the end of the nineteenth century, the head of southern England appears to have been regarded by most geologists as a periglacial gelifluction deposit that represents the stratigraphic equivalent of the 'Newer Drift' deposited by the last ice sheet farther north (Geikie, 1894; Edmunds, 1930; Dines *et al.*, 1940).

The accumulation of head on low ground was not the only periglacial effect recognised in southern England by Victorian scientists. Spurrell (1886) suggested that the blind-ended dry valleys or 'coombes' that dissect the South Downs were excavated under periglacial conditions 'by the ice-laden and tumultuous floods of summer' when the ground was frozen and thus impermeable, a process independently advocated by Reid (1887) the following year and still widely accepted as being responsible for at least the final stages of coombe evolution. The rounded 'bowl' shape of the heads of many coombes was subsequently attributed by Bull (1936, 1940) to the operation of *nivation* or snowpatch erosion under periglacial conditions. Nineteenth century researchers also showed a lively awareness of the stratigraphic possibilities of periglacial deposits exposed in coastal cliffs. A fine example was provided by Reid (1892), who noted that Pleistocene deposits on the Sussex coast contain erratics apparently transported by floating ice, and who observed the grounding marks of ice floes in the underlying Tertiary clays. Marine beds overlying these erratic-bearing deposits were found to contain a temperate molluscan fauna, and are themselves overlain by chalky head. From this evidence, Reid inferred that the marine deposits represent a temperate interglacial that separated two distinct periglacial periods.

The interest excited by head deposits and related features in southern England did not extend to most other periglacial phenomena until the present century. Geologists were aware of the importance of frost action, but tended to emphasise its effects in terms of the disintegration of cliffs and the resulting accumulation of scree or *talus* downslope (e.g. Geikie, 1865, pp. 37–38; Avebury, 1902, pp. 220–222). In the evocative language of the day, for example, James Geikie (1877, p. 321) invited his readers to note how '...the hill-tops are buried in their own ruin, and how the flanks are in many places curtained with long sweeps of angular blocks and rubbish, that shoot down from the base of cliff and scaur to the dark glens below. All this,' he added, 'is the work of rain and frost...the havoc affected by frost is yet very considerable'. Early recognition was, however, accorded to *protalus ramparts*, which are ridges of rock debris that accumulate at the foot of perennial snowbeds. Features of this origin were first described by Ward (1873) in the English Lake District, and attributed to former periglacial conditions by Marr (1916, p.202). To Marr also belongs the distinction of identifying *debris cones* (or 'dry deltas' as he termed them) that had formed through the reworking of talus by repeated debris flow activity. The spectacular *tors* or upstanding rock residuals of granite areas and their surrounding *clitter* of frost-weathered boulders also attracted early attention. The importance of periglacial processes in exposing the monolithic tors of Dartmoor was first considered by Jones (1859) and subsequently by Bate (1871) and Albers (1930) in accounts which introduced ideas that were to be hotly debated in later years.

More subtle effects of periglacial activity on British mountains did not entirely escape the attention of early researchers. Small-scale *patterned ground* (the regular arrangement of stones by freezing and thawing of the soil) was first recorded by Ward (1896) on high ground in the Lake District and formed the subject of several articles in the 1930s (e.g. Simpson, 1932; Hay, 1936). Officers of the Geological Survey working in Scotland in the early years of the twentieth century provided succinct descriptions of *mountain-top detritus*, and attributed its formation to frost-weathering of bedrock in Lateglacial times, after the last ice sheet had downwasted below the level of mountain summits (Crampton, 1911; Peach *et al.*, 1912, 1913; Crampton & Carruthers, 1914). These same geologists also gave brief but perceptive accounts of landforms and deposits associated with such detritus, including vegetation patterns, small terraces produced by periglacial mass movement and windblown sand deposits on high plateaux.

This exploratory period was brought to a close by the publication of three important papers that anticipated different strands in the future development of periglacial research in Great Britain. In the earliest of these, Hollingworth (1934) provided an outstanding account of active periglacial processes and landforms in the Lake District. In this he discussed the origin of frost-sorted patterned ground, *solifluction lobes* produced by the downslope movement of soil subject to seasonal freezing and thawing, vegetation patterns, and *turf-banked terraces* that reflect the combined action of wind and periglacial mass movement. The second seminal contribution from this period was made by Paterson (1940), who compared the present effects of frost action in the arctic with structures in bedded gravels near Cambridge. This appears to be the earliest attempt in Britain to interpret relict periglacial phenomena through direct comparison with high-latitude analogues. As a result of his arctic experiences, Paterson was able to demonstrate that large-scale relict polygonal structures on the ground surface are the product of frost-cracking under arctic conditions; that wedge-shaped structures exposed in section in the bedded gravels are the relict equivalents of ice wedges formed in *permafrost* or perennially-frozen ground; and that *involutions* or contorted strata within the Cambridge deposit are similar to those developed in the zone of seasonal thawing (the *active layer*) above permafrost in arctic environments. Others were quick to follow Paterson's lead (e.g. Carruthers & Anderson, 1941). All three types of evidence were to assume great importance in reconstructions of Quaternary palaeoclimates, a major theme of modern periglacial research. Finally, Dines *et al.* (1940) reviewed earlier work on the origin and significance of head deposits and described how such deposits could be mapped and interpreted as climatostratigraphic units within Quaternary successions. This work presaged later research in which the interpretation of periglacial (or periglacially-modified) deposits assumed a vital role in the establishment and correlation of Quaternary chronosequences. By 1940, therefore, some of the main themes of periglacial research in Great Britain had been outlined. Ensuing decades were to witness their recapitulation, development and enrichment.

1940–65: The widening perspective

The quarter century following the appearance of the three classic accounts summarised above saw the publication of some 50 research papers devoted to periglacial phenomena in Great Britain, though inevitably periglacial features also received frequent mention in Soil Survey Monographs, Memoirs of the Geological Survey and articles devoted to Quaternary stratigraphy. Most of these papers appeared in the final decade of this period. They reveal increasing awareness of the widespread nature of periglacial phenomena in Great Britain, the rich variety of features represented and the importance of periglaciation in Quaternary landscape evolution. Such findings were summarised in a series of contemporary reviews by FitzPatrick (1956a, 1958), Te Punga (1957), Galloway (1958, 1961a) and Waters (1964a,b, 1965).

Amongst the research developments in the British uplands was the recognition of landforms interpreted as *cryoplanation terraces* and *nivation benches*, broad terraces apparently cut across bedrock by the operation of frost-weathering, nivation and solifluction during episodes of Quaternary periglaciation (Guilcher, 1950; Te Punga, 1956; Waters, 1962; Gregory, 1965). Attention was also focused on the contribution of periglacial processes to the formation of tors (Linton, 1955, 1964; Pullan, 1959; Palmer & Radley, 1961; Palmer & Neilson, 1962) and on the role of frost action in the genesis of upland regolith (Tivy, 1962; Waters, 1964a) and talus (Andrews, 1961). Lateglacial solifluction was invoked to account for the development of drift terraces and lobes on the flanks of British hills (Metcalfe, 1950; Galloway, 1961b; Pissart, 1963a, b) and the current importance of wind as a geomorphic agent on high ground emerged strongly from the work of ecologists on the Cairngorm Mountains (Watt & Jones, 1948; Metcalfe, 1950; Burges, 1951). This period also saw the emergence of the earliest studies of the rates and processes of periglacial activity on British mountains. These concerned the operation of frost creep and frost sorting of bare ground on mountains in Snowdonia, the Lake District and the Southern Uplands of Scotland (Miller, Common & Galloway, 1954; Tallis & Kershaw, 1959; Caine, 1963a, b).

Research on periglacial phenomena in lowland Britain during the period 1940–65 not only built on earlier discoveries, but also led to the identification of a number of landforms and soil structures hitherto unrecorded in Britain. The head deposits of southern England continued to attract attention, with studies of their texture, structure, stratigraphy and distribution (e.g. Waters, 1960; Kerney, 1963, 1965; Hodgson, 1964, Gallois, 1965). Attention was also focused on the possible significance of thaw of frozen ground in inducing *cambering* and *valley bulging*, both of which are associated with the deformation of mudrocks overlain by more resistant strata (Hollingworth, Taylor & Kellaway, 1944; Kellaway & Taylor, 1953). In addition, numerous publications during this period demonstrated the widespread occurrence of periglacial involutions and ice-wedge casts in Quaternary drifts (e.g. Arkell, 1947; Dimbleby, 1952; Curtis & James, 1959; Waters, 1961; Watson, 1965a). These were observed to occur not only in areas that remained outside the limits of the last ice sheet, but also well inside these limits, thereby demonstrating the persistence of permafrost conditions after ice-sheet retreat. In Scotland, for example, an appeal by the editor of the *Scottish Geographical Magazine* for information on periglacial phenomena brought reports of ice-wedge casts as far north as Midlothian (Common & Galloway, 1958), Angus (Rice, 1959) and Argyll (Gailey, 1961). The wider distribution of such features in Scotland was ably summarised by Galloway (1961c).

Further evidence of former permafrost in lowland Britain was inferred from the occurrence of *indurated horizons* in soils. Such horizons were first identified by Glentworth (1944, 1954; Glentworth & Dion, 1949) and were attributed to repeated freezing and thawing of the former active layer (FitzPatrick, 1956b; Stewart, 1961; Crampton, 1965). Large-scale patterned ground was also interpreted as indicative of former permafrost conditions in southern and eastern England (Watt, 1955; Shotton, 1960; Williams, 1964). A number of periglacial phenomena previously unrecognised in lowland Britain were first described in the period 1955–65. These included *thermokarst depressions* resulting from the melt-out of massive lenses of ground ice (Cailleux, 1961), circular ramparts resulting from the collapse of former *pingos* or ice-cored hills (Pissart, 1963c), stratified slope deposits or *grèzes litées* (Watson, 1965b), and deposits of *loess* (windblown silt) and *coversand* indicative of powerful wind action across tundra landscapes (e.g. Coombe *et al.*, 1956; Waters, 1960; Straw, 1963).

Many of the papers cited above demonstrate growing awareness of the potential of relict periglacial phenomena for the reconstruction of Late Quaternary palaeoclimates. This awareness was most fully realised by Williams (1965) in a paper devoted to analysis of the former distribution of permafrost in England during the last glacial period. From the distribution of a wide range of relict periglacial phenomena, including ice-wedge casts and polygon structures, involutions and large-scale patterned ground, Williams inferred that continuous permafrost had underlain the Midlands and eastern and southern England, but not ground below 300 m in the south-west of the country. From this evidence he suggested that that under full-glacial conditions the -6 °C (mean annual temperature) isotherm lay along a line from Sussex to the southern edge of Exmoor. This important paper represents the first of several attempts to reconstruct regional palaeoclimates on the basis of evidence provided by relict periglacial phenomena.

Recent research themes

The years since 1965 have seen continued growth in the sophistication and status of periglacial studies in Great Britain. Roughly 200 papers devoted largely or exclusively to British periglacial phenomena were published in this period, and the role of periglacial activity has increasingly formed an intrinsic part of research on such diverse topics as the reconstruction of former glaciers, slope stability, Holocene landscape evolution, Pleistocene stratigraphy and Late Quaternary palaeoclimate. The aims and approaches involved within such research have been equally varied. A major concern of many researchers has been interpretation of relict periglacial deposits and structures in Quaternary stratigraphic sequences. Climatically-diagnostic sediments such as head, coversand and loess have been used along with glacial and fluvioglacial deposits and the evidence provided by peat layers and *palaeosols* (relict soil horizons) to reconstruct the changing nature of the environment through successive stadial (cold) and interstadial episodes (e.g. West, 1980a; Gibbard, 1985; Rose *et al.*, 1985a; Connell & Hall, 1987). Ice-wedge casts in drift deposits have proved particularly valuable as indicators of former permafrost (Worsley, 1987), and involutions in Quaternary sediments have been widely interpreted as indicative of former periglacial conditions (e.g. West, 1980a; Hall & Connell, 1986).

Allied to the use of periglacial deposits as climatostratigraphic indicators within drift sequences has been increasing use of dating techniques to establish ages for such sediments. Radiocarbon (^{14}C) dating of buried or incorporated organic material has been employed to establish the age of head or solifluction deposits dating to the period of the last glacial maximum or earlier (Connell *et al.*, 1982; Sutherland & Walker, 1984; Sutherland, Ballantyne & Walker, 1984; Scourse, 1987), to the Lateglacial period (Dickson, Jardine & Price, 1976; Hall, 1984) and, on Scottish mountains, to the present interglacial (Mottershead, 1978; Ballantyne, 1986d). Radiocarbon dating has also been employed to establish a Lateglacial age for periglacial mudslide deposits (e.g. Chandler, 1976) and post-glacial ages for various upland sediments, such as debris-flow deposits (e.g. Harvey *et al.*, 1981; Brazier, Whittington & Ballantyne, 1988) and windblown sand (Ballantyne & Whittington, 1987). Because of its restricted temporal range, however, radiocarbon dating has proved of limited use in dating sediments deposited before *c.* 30 ka BP (i.e. 30 000 'radiocarbon years' before present). For older periglacial sediments, particularly loess and periglacial river deposits, the application of thermoluminescence (TL) dating techniques shows particular promise (e.g. Wintle, 1981, 1990; Seddon & Holyoak, 1985; Wintle & Catt, 1985a, b).

Sedimentological analysis of periglacial deposits has also engaged numerous researchers over the past 25 years, with a wide range of increasingly sophisticated techniques being employed to determine the origin, transport history, geotechnical properties and palaeoenvironmental significance of such deposits. These have included provenance studies of constituent clasts and fines, analyses of clast size and shape, particle-size analyses, measurement of macrofabric and microfabric, scanning-electron microscope studies of grain morphology, micromorphological studies of thin sections, geotechnical analyses, laboratory simulations and stratigraphic differentiation of sedimentary units. Such techniques have been widely applied to head and coombe rock (e.g. Mottershead, 1976, 1982; Harris & Wright, 1980; Harris, 1981a, 1987a; Wilson, 1981; Douglas & Harrison, 1987; Scourse, 1987; Gallop, 1991) as well as to upland regolith (Ragg & Bibby, 1966; Innes, 1986), loess and windblown sand deposits (e.g. Wilson, Bateman & Catt, 1981; Catt & Staines, 1982; Ballantyne & Whittington, 1987) and even coarse upland talus accumulations (Statham, 1976a; Ballantyne & Kirkbride, 1986). A noticeable development has been increased awareness amongst engineering geologists of the geotechnical significance of periglacial deposits (Higginbottom & Fookes, 1971). In particular, much of our understanding of *periglacial mudslides* (translational failures over former permafrost) results from research by engineering geologists on such features and their implications for slope stability (e.g. Hutchinson, 1967, 1974, 1991; Weeks, 1969; Chandler, 1970a, 1976; Hutchinson, Somerville & Petley, 1973; Skempton & Weeks, 1976; Skempton, 1988; Spink, 1991).

Palaeoclimatic reconstructions based partly or exclusively on relict periglacial phenomena have also been attempted. Those for southern Britain refer primarily to the period of the last glacial maximum, *c.* 18–17 ka BP, and have been based on the distribution of climatically-diagnostic features such as ice-wedge casts, involutions, large-scale patterned ground, pingo ramparts, ground-ice depressions, loess and coversands (e.g. Williams, 1975; Watson, 1977b). Northern Britain lay under the last ice sheet at this time, and palaeoclimatic reconstructions for Scotland have therefore been limited to consideration of the Loch Lomond Stadial of *c.* 11–10 ka BP, the last period of severe periglaciation to affect Great Britain (e.g. Ballantyne, 1984). In mountain areas, the distribution of relict periglacial phenomena of Loch Lomond Stadial age has also been extensively employed to delimit the extent of contemporaneous glaciers (e.g. Thorp, 1981, 1986; Ballantyne, 1989a), which themselves provide vital evidence for the reconstruction of stadial palaeoclimate.

Data on former rates of periglacial activity, however, remain sparse. Williams (1968) pioneered such investigations by establishing the travel distances of boulders in head deposits, and Ballantyne & Kirkbride (1987) used the volume of debris in Loch Lomond Stadial protalus ramparts to assess contemporaneous rockfall rates, but estimation of former rates of mass transport has otherwise received little attention. More surprisingly, the same is true of current rates of periglacial mass movement on British mountains. Site-specific measurements exist concerning present rates of frost creep, solifluction and rockfall activity, but only one attempt has been made to compare the relative effectiveness of different agencies of periglacial mass movement under present conditions (Ballantyne, 1987a). British geomorphologists have also made curiously little effort to avail themselves of the opportunity provided by periglacial landforms on high ground to study periglacial processes. Conspicuous exceptions include studies of the movement of *ploughing boulders*, which move downslope faster than the surrounding regolith (Tufnell, 1972), nivation processes (Ballantyne, 1985) and the genesis of sorted stripes (Warburton, 1987). A more promising development has been recognition of the importance of bedrock characteristics in determining the nature of frost-weathered regolith, and hence the nature and distribution of periglacial landforms and deposits (e.g. Potts, 1971; Ballantyne, 1984, 1987a, 1991a; Harris, 1987a).

Despite the long history of periglacial research in Britain prior to 1965, appreciation of the scope of periglaciation has continued to widen over the last 25 years. For upland Britain, this has taken the form of the discovery of hitherto unrecorded landforms and deposits, including *protalus rock glaciers* produced by the deformation of ice-rich sediment under talus accumulations (e.g. Dawson, 1977; Sissons, 1979a), valley-floor *solifluction terraces* (e.g. Crampton & Taylor, 1967; Douglas & Harrison, 1987), *earth hummocks* (e.g. Tufnell, 1975; Ballantyne, 1986c), *avalanche impact landforms* (Ballantyne, 1989b) and high-level aeolian or *niveo-aeolian* deposits (e.g. Pye & Paine, 1983; Ballantyne & Whittington, 1987). There has been increasing awareness, too, of the former role of frost action in shoreline development. Sissons (1974a, 1981a) first proposed that certain raised rock platforms on the west coast of Scotland were cut by a combination of frost weathering and wave action under stadial conditions, a hypothesis subsequently strongly developed by Dawson (1980; Dawson, Matthews & Shakesby, 1987). This mechanism has also been invoked to explain the cutting of erosional shoreline platforms across resistant rock at the margins of former glacier-dammed lakes (Sissons, 1978) and a proglacial lake that occupied the site of Loch Ness in the Scottish Highlands (Firth, 1984). It has also become increasingly recognised that certain abandoned fluvial landforms represent alluviation by braided rivers with flashy *nival* (snowmelt) regimes under periglacial conditions. In lowland areas, periglacial alluviation is represented by floodplain terraces with a complex lithofacies architecture typical of unstable and rapidly-switching gravel bed channels (e.g. Castleden, 1980; Bryant, 1983a,b; Dawson, 1987). In upland areas, fluvioperiglacial sedimentation is represented by relict alluvial fans at the mouths of tributary valleys (e.g. Rowlands & Shotton, 1971; Peacock, 1986).

A number of review papers have attempted to summarise various aspects of the developments outlined above. Some have dealt systematically with topics such as loess and coversands (Catt, 1977), permafrost stratigraphy (Worsley, 1987), solifluction deposits (Harris, 1987a) and ramparted ground-ice depressions (Bryant & Carpenter, 1987). Others have considered periglaciation on a regional basis, for example in northern England (Tufnell, 1969; Boardman, 1985a), southern England (Jones, 1981), upland Britain (Ballantyne, 1987a) and Scotland (Kelletat, 1970a; Sissons, 1976c; Ballantyne, 1984). Others still have provided summaries of the periglacial landforms and deposits within smaller areas, such as Snowdonia (Ball & Goodier, 1970), the Scilly Isles and Cornwall (Scourse, 1987) western Dartmoor (Gerrard, 1988b) and the Isle of Skye (Ballantyne 1991a). Several of the accounts cited above appeared in a single volume, *Periglacial Processes and Landforms in Britain and Ireland* (Boardman, 1987) that represented the outcome of a conference on this topic in 1985. This conference may be seen as marking the coming of age for periglacial research in the British Isles, and recognition of the significant role played by cold-climate nonglacial processes in shaping the evolution of the British landscape. In his introduction to the resulting volume of papers, however, Boardman sounded a cautionary note: progress, particularly over the last quarter century, may have been substantial, but many problems remain to be overcome before the potential of periglacial phenomena for the reconstruction of Quaternary stratigraphy and palaeoenvironments is fully realised. This is probably the major challenge to be confronted by periglacial research in Britain as we enter the new millennium.

Approaches to synthesis: the organisation of this book

Synthesis of current knowledge concerning periglacial phenomena in Great Britain poses three problems of organisation. The first stems from the amazing variety of periglacial phenomena present. These range in scale from microscopic soil structures to entire periglacially-modified landscapes, and often pose difficulties of classification. The second problem concerns spatial variations: many periglacial phenomena occupy specific 'habitats', and are rare or nonexistent outside of these areas; few (if any) occur throughout Great Britain. Finally, periglacial phenomena in Britain have developed at different rates over a very long timescale. Some relict structures exposed along the Norfolk coast, for example, may be over a million years old, whilst certain microforms on the higher parts of Scottish or Welsh mountains may have developed over the last few winters.

These three organisational problems suggest three different modes of treatment: a systematic (topic-by-topic) approach, a regional (area-by-area) approach and an historical (time-slice) approach. In this volume we have attempted to combine these three approaches. Most chapters are organised systematically on a topic-by-topic basis, but are grouped regionally in terms of two major contrasting areas, lowland Britain (Chapters 4–8) and upland Britain (Chapters 9–13). Within these chapters, the phenomena under consideration are placed in temporal context with respect to the Quaternary chronology of Great Britain, and their significance for the reconstruction of particular past environments is assessed. Prefacing this systematic discussion of periglacial phenomena are two further introductory chapters. The first of these (Chapter 2) outlines the temporal pattern of Quaternary environmental change in Great Britain, and thus provides the chronological framework for subsequent discussion. Chapter 3 consists of a brief introduction to the general characteristics of periglacial environments, and is included primarily for the benefit of readers with little prior experience in this field. The final chapter (14) attempts to draw together earlier material in terms of environmental reconstructions relating to three time periods. The book thus falls into four parts: (1) introduction (Chapters 1–3); (2) the periglaciation of lowland Britain (Chapters 4–8); (3) the periglaciation of upland Britain (Chapters 9–13); and (4) reconstruction of periglacial environments (Chapter 14).

Upland and lowland Britain

The rationale behind the division of subject matter in terms of lowland Britain and upland Britain deserves explanation. The prime motive behind this subdivision can be traced to the distribution of periglacial phenomena, in that it is possible to identify distinct 'lowland' and 'upland' assemblages. The 'lowland' assemblage includes a wide range of relict features that are largely or entirely absent on high ground, such as ice-wedge casts, tundra polygons, cryoturbation structures, thermokarst phenomena and pingo scars, together with loess deposits, certain types of mass-wasting deposits and large-scale slope structures. Conversely, upland landscapes support a range of phenomena rarely or never encountered in the British lowlands, such as blockfields, tors, cryoplanation terraces, talus slopes, avalanche landforms, protalus ramparts and rock glaciers. A further fundamental distinction is that whereas the higher mountains of Britain support a number of active periglacial features, the periglacial phenomena of lowland Britain are entirely relict, having been formed under climatic conditions much more severe than those of the present. It would be misleading, however, to present upland and lowland landscapes as mutually exclusive in terms of the range of periglacial phenomena they support, as there is a certain amount of overlap. In particular, patterned ground and solifluction features occur in both upland and lowland environments, though in general such landforms are better preserved in upland areas, where they have not been obscured by cultivation.

In part, the distinction between upland and lowland periglaciation is a consequence of altitude and relief. The restriction of active periglacial phenomena to high ground reflects the much more severe climate of mountain areas, where ground freezing and snowcover persist throughout much of the winter and strong winds have often stripped away much of the vegetation cover. Similarly, certain landforms such as avalanche boulder tongues, protalus ramparts and rock glaciers occur only at the foot of steep mountain slopes, and hence are absent from the lowland zone. The differences between upland and lowland periglaciation, however, also reflect a number of rather more subtle controls. Foremost amongst these are the effects and limits of glaciation. In upland areas the role of glaciers has been primarily erosive, so that many mountain slopes form rocky cliffs and even gentle slopes support only a thin cover of frost-weathered (and often mobile) regolith. In contrast, the landscape of much of lowland Britain is thickly mantled by glacial, fluvioglacial and periglacial drift deposits. These have formed host materials for the growth of various forms of ground ice and hence the development of a wide range of periglacial features that reflect ground-ice growth and decay, such as ice-wedge casts, ground-ice depressions and cryoturbation structures. The limits of successive Pleistocene glaciations have also exercised a strong control on the *age* of periglacial phenomena in different areas of Britain. The southernmost parts of this island have never experienced glaciation, and here the landscape has adopted its present form during successive episodes of Pleistocene periglaciation. In more northerly lowlands, episodes of periglacial activity have alternated with those of glaciation, so that periglacial processes have modified the deposits laid down by successive ice sheets and their associated meltwater rivers. In the mountains of Britain, though, glacier ice persisted until the very end of the last cold period some 10,000 years ago, and in such areas the imprint of periglacial activity is much more youthful.

The contrasts outlined above have stimulated radically different approaches to the study of periglacial phenomena in upland and lowland Britain. In mountain areas, where periglacial deposits tend to be thin, localised and relatively recent, geomorphologists have concentrated their research within a fairly limited timescale (roughly from the time of the downwastage of the last ice sheet until the present day), as only post-deglaciation landforms and deposits occur in such areas. Periglacial research in the British uplands has therefore concerned mainly Lateglacial and recent landscape evolution, current periglacial processes and rates of activity, and the morphology, distribution, origin and climatic significance of periglacial landforms. In contrast, much research in lowland Britain has been devoted to elucidating the stratigraphic and palaeoenvironmental significance of periglacial soil structures and deposits that developed over a timescale that stretches back a million years or so. Such different research aims imply completely different approaches and techniques, and tend to have attracted different practitioners. Whilst the 'upland' periglacialist clambers across the windswept summits of Scottish or Welsh mountains in pursuit of remote and reclusive landforms, his 'lowland' counterpart is never happier than when ensconced in

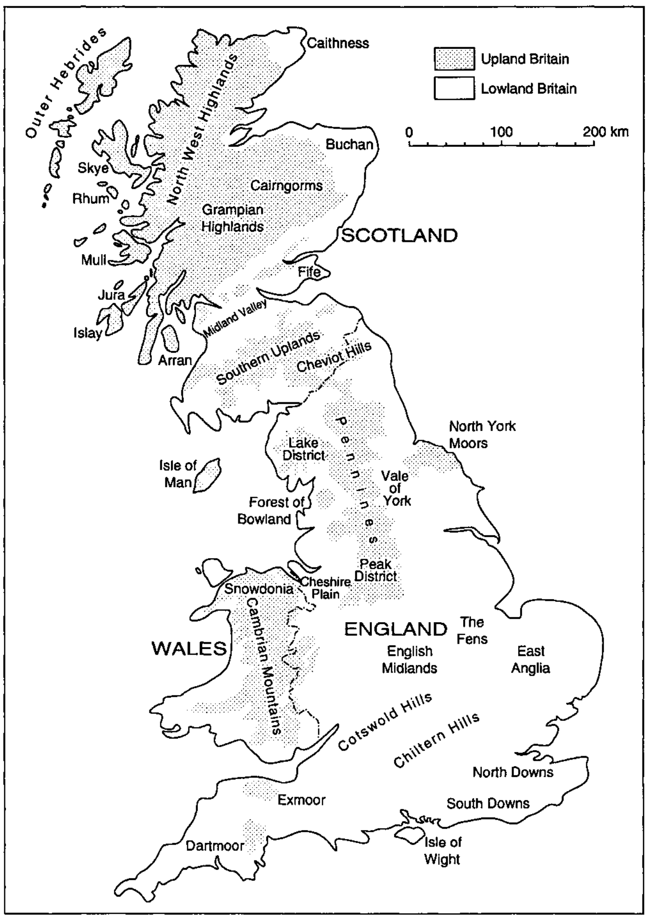

Figure 1.1 Upland and lowland Britain, differentiated principally in terms of relief and altitude. Upland areas are characterised by steep gradients and achieve elevations exceeding about 400 m; lowland areas are generally flat or undulating and lie at lower altitudes.

a deep gravel pit, examining structures created by the melting of ground ice some tens or hundreds of thousands of years ago.

Whilst the terrain characteristics that differentiate 'upland' from 'lowland' Britain are readily identified, it is more difficult to define a precise boundary between the two. In general, the landscapes of upland Britain are characterised by steep slopes, maximum elevations greater than about 400 m, a thin or discontinuous drift cover and absence of arable cultivation. Those of lowland Britain generally lack steep slopes, lie below 400 m, often support a thick cover of drift and for the most part have experienced cultivation. In some areas, of course, these criteria conflict, but there is nonetheless a strong element of spatial correlation amongst them, and it is possible to delimit the two types of terrain in a general way (Figure 1.1). Inevitably, though, areas of intermediate altitude and relief (such as Dartmoor) contain characteristics of both 'upland' and 'lowland' terrain, and indeed 'upland' and 'lowland' periglaciation; the boundary between the two is transitional, not abrupt.

A question of time

One of the most fascinating aspects of the periglaciation of Great Britain is the timespan represented by periglacial phenomena. Some half a million years ago, a soil developed across wide areas of eastern England under a climate fairly similar to that of the present. When climatic deterioration ensued, freezing of the ground caused the development in this soil of numerous periglacial structures, such as ice wedges, frost cracks and involutions, forming a distinct horizon now known as the Barham Structure Soil (Rose *et al.*, 1985a). Sand and silt particles blown across an arid tundra landscape settled on and were incorporated within the Barham Soil, which was then buried by the deposits laid down by an extensive ice sheet. The Barham Soil therefore represents a very ancient periglacial landsurface, yet one that contains remarkably well-preserved periglacial structures that closely resemble similar forms developed beneath the present land surface as little as 11 000–10 000 years ago. At the other end of the periglacial timescale are features that have developed within years or decades rather than millennia. Frost-sorted patterned ground on Scottish and Welsh mountains, for example, is capable of developing over a few winter months, and there is some evidence for a marked increase in mountain-top erosion, solifluction and debris-flow activity within the past two or three centuries (Ballantyne, 1991b). It is important, therefore, to be able to relate the periglacial phenomena of Great Britain to an appropriate timescale of environmental change, such as that outlined in the next chapter.