Chapter 1

A Brief Time of History

David L. Higgitt

1.1 Aims and Objectives

The landscape of Britain displays an enormous variety of scenery in a comparatively small space. The diversity of rock types, the influence of geological structure and the impact of successive glaciations in moulding the uplands and redistributing material provide the student of geomorphology with a wide assortment of landforms to inspect and appreciate. Numerous volumes have been conceived to celebrate and explain the geology and landforms of Britain (Trueman, 1949; Goudie and Gardner, 1992; Goudie and Brunsden, 1994). It might be considered somewhat ironic that so many geomorphologists should inhabit an island where the inland contemporary geomorphology is, to all intents, dominated by low-intensity processes operating on an essentially relict landscape. Tectonic processes are almost negligible, with volcanic activity last experienced in the Tertiary. The impact of natural hazards is mercifully low, if not entirely absent. In short, there are more exciting parts of the Earth to investigate active geomorphological processes. What relevance, therefore, does a volume on geomorphological processes in Britain during the last 1000 years hold?

Students of scenery, in its broadest sense, can point to the varied and profound changes that have occurred during the last millennium. Regional forest clearance may have been well under way by AD 1000, but deforestation continued, and agricultural activity expanded into the hills as climate warmed, then switched to grazing as the climate cooled. Many villages and towns expanded, while some settlements were abandoned. Fields were enclosed. Mining produced both wealth and large quantities of sediment supply. Water resources have been exploited from the development of mills through to the construction of reservoirs. Again, there are numerous volumes that examine the evolution of agriculture, townscapes and settlement patterns and the shaping of the cultural landscape of Britain (Hoskins, 1955; Coones and Patten, 1986; Whyte and Whyte, 1991). In these narratives the physical landscape is often treated as a backcloth upon which human activity adapted and created scenery. But to what extent did the operation of geomorphological processes in the physical landscape constrain human use of the land or react to human-induced changes? What evidence is available to reconstruct geomorphological process activity in the past 1000 years?

The principal aim of the volume is to provide an overview of the nature of geomorphological process activity and landscape change in Britain over the last 1000 years. The impact of the driving forces of climate change and human action are considered through the framework of the sediment cascade. The production of sediments through weathering processes generates a supply that can be transferred from slopes to channels and transported through river basins to the coast. The relationship between the production and availability of sediment and the ability of prevailing geomorphological processes to transfer that sediment is examined. The contents are organized by considering process components of the sediment cascade, starting with hillslopes and moving down-basin towards the coast. In evaluating the evidence for sediment transfer, it becomes clear that the period of the last 1000 years offers a number of challenges to geomorphologists, both in terms of the techniques and methodologies available for identifying and reconstructing data and in terms of the conceptual approaches to evaluating change over this timescale. The book, therefore, aims to examine the nature of the evidence for geomorphological change, to evaluate the role of human impact and of climate control, and to assess the suitability of available techniques and concepts to interpret environmental change. Although the focus is geographically constrained on the landscape of Britain, the approaches to evaluating millennial-scale changes have much wider application. The relatively intensely studied field sites in Britain provide some experience of the information about past geomorphological processes that can be yielded but also identify the considerable gaps in our present knowledge. Such information is not only of interest to geomorphologists but, increasingly, has a role in complementing the interpretations of archaeologists, historians and ecologists. Understanding how landscape components respond to forcing conditions of land use change, to the climatic regime and to individual events has implications for evaluating the hazards that geomorphological processes might pose for society and for the conservation and management of habitat and scenery. A growing collaboration between geomorphologists, ecologists and engineers has emerged in recent years. This leads to the final objective of the book: to evaluate the role of geomorphology for the mitigation of natural hazards and for the promotion of environmental management.

1.2 The Millennium in Perspective

A rationalist might reasonably ask whether the theme presented within this volume is merely a reaction to the millennium bandwagon. Separating the most recent span of 1000 years risks compartmentalizing geomorphological change that has been progressing throughout the Holocene. It is, of course, absurd to suppose that any socially constructed span of time has any pre-ordained or unique relevance to the operation of geomorphological processes and the characteristics of landscape. There are, however, several reasons why it is worth reflecting on the last 1000 years at this juncture, among which is the empathy for reflecting about the past and speculating about the future that has been displayed in many quarters as the 'millennial theme'. Five features of note are the significance of human impact, the need to integrate understanding of contemporary process dynamics with reconstructed environments, the growing appreciation of historical geomorphology for conservation purposes, the challenge of managing risk from natural hazards and the implications of past and future climate change.

First, the span of the last 1000 years has witnessed significant human impact on the landscape. This introduction has been written in a university a few hundred metres from the magnificent cathedral of Durham. Now designated a World Heritage Site, building of the present structure began in 1093. This enduring symbol of architectural achievement has stood for almost all of the last millennium – the period over which geomorphological change is to be considered. The imposing splendour of Durham's 'massive piles, half Church of God, half castle 'gainst the Scot' (as immortalized in the poem by Sir Walter Scott), owes much to its location high above the incised meander of the River Wear. The meander loop is cut through the Coal Measures, most probably as a result of meltwater diversion during the Late Glacial. The combined vista of cathedral, steep wooded gorge and river projects an image of permanence and durability that has repelled change for ages past – a massive display of Norman strength (Pocock, 1996) defended by the steep slopes of the peninsula. There is little doubt, geomorphologically, that the physiography of the River Wear meander gorge owes much to the combination of meltwater discharge and isostatic recovery. The Wear has a buried rock-cut channel, formed during an earlier period of lower sea level, which was choked by glacial diamict, forcing the river to adopt a new course when the ice wasted away. Subsequent isostatic uplift incised the meander loop and it has undergone comparatively minimal topographic change throughout the Holocene. Like much of the British landscape, the landforms are fundamentally inherited from formative processes that operated in the Late Glacial. The last 1000 years might, at first glance, appear irrelevant to the scene. It can be argued that the significance of geomorphological processes may have been limited since the foundation stones of the cathedral were laid in the eleventh century, but that there has been a range of process activity experienced during this period.

The walls of the cathedral, fashioned primarily from local sandstone, exhibit some intricate patterns of weathering. It would be possible, with care, to estimate the net rate of disintegration, as has been recently attempted for fifteenth- and sixteenth-century structures on the south-west coast of England (Mottershead, 2000) which probably amount to a few millimetres per century. Close to the western façade of the cathedral, a rotational failure measuring about 10 m across by 20 m in length closed a hillside footpath in 1999. It is apparent that small-scale mass movements have affected several of the slopes of the peninsula, causing some inconvenience to the foundations of the buildings on the peninsula, but their significance is tiny compared to the impact of quarrying and coal mining. Neither is there clear evidence for any recent change in the course of the Wear, which is effectively locked into its postglacial gorge. The history of the bridges that cross the Wear around its meander loop (Elvet, Prebends and Framwellgate) says something about fluvial processes. Remnants of piers of the original twelfth-century Elvet Bridge suggest a possible small lateral shift of the channel as it enters the gorge, but it is clear that the millennium has seen little physical change to the view. Of more significance is the geomorphological work accomplished through the transport of water and sediment, and the action of humans to harness and control it. Archival records of ancient floods are scarce, but in the North-East of England much information has been assembled by Archer (1992). As early as AD 1400, Framwellgate Bridge had been swept away in a flood. Documentary records indicate a number of floods in the seventeenth century, including two major events in the 1680s – one of the wettest decades in the reconstructed millennial climate record. Upstream of the gorge, where the river is incised into a wide floodplain, the bridge at Shincliffe was destroyed in February 1753, while Sunderland Bridge was damaged three times in the early eighteenth century (Archer, 1992). The most remarkable flood, however, was that of 17 November 1771, by far the largest on record, which also affected the neighbouring Tyne and Tees. Several bridges in Weardale were destroyed, while in Durham itself, the medieval Elvet Bridge was severely damaged and Prebends Bridge completely swept away (Archer, 1992). A succession of flood events followed in the 1820s and many others have followed in the past two centuries. The year AD 2000 has witnessed two major flood events on the Wear, on 4 June and 6–7 November. Geomorphologically, each flood resulted in substantial amounts of bank collapse upstream of Durham, although the evidence from the summer flood was quickly masked by vegetation. Academically, the June flood had a dramatic impact on a riparian venue that was being used for university examinations! While the summer flood was reasonably localized, the November flood was but one of many that affected many parts of Britain. From the millennium perspective, it can be noted that floods on this particular English river have occurred at different times of year, and have resulted from rapid snowmelt, cyclonic rainfall or convectional storms. Although the physical change to the landscape view of the cathedral during its lifetime is limited, fluvial processes have conveyed substantial amounts of sediment past the scene, especially in the eighteenth and nineteenth centuries when metal mining augmented sediment supply, and floods have caused considerable damage to riverside property and their inhabitants. Deliberate modification is also apparent. The original flood embankments upstream of Durham are of Cistercian origin. There are two ancient weirs on the meander loop, providing intake for mills. The lower weir (Framwellgate) was raised by over 1 m in 1935. Downstream of this weir, the channel was widened in 1964 and dredged in 1967 (Archer, 1992). The interweaving of deliberate and incidental human interaction with episodic natural processes is a pervading theme for geomorphology at the 1000 year timescale.

Second, the timescale of 1000 years provides an opportunity to address the apparent schism that has developed between process-orientated geomorphological studies and stratigraphical analysis of Late Quaternary environmental change. In some locations much more is known about the nature of the environment through the Late Glacial and early Holocene than during the last millennium. The development and refinement of dating techniques and modelling approaches offer the opportunity to begin closing the gap between the reconstruction of the recent past and of the Holocene. Moving between reconstructions of a few hundred years to 1000 years has long been identified as a challenge to geomorphology (Brunsden and Thornes, 1979). Passmore and Macklin (2000) provide a neat example of overcoming some of these difficulties by using a combination of radiocarbon, palaeomagnetic, pollen, lichenometric and trace metal measurements with cartographic evidence to examine phases of incision and aggradation in tributaries of the Tyne.

Third, there has been a recent resurgence of interest in notions of landscape sensitivity and geological conservation. In some cases individual facets of landscape, such as Holocene stratigraphic sections or particular landforms, constitute features of interest for conservation purposes. Existing procedures for Earth science conservation involving SSSIs or RIGS (Regionally Important Geological/Geomorphological Sites) are relevant. In other cases, larger-scale landform assemblages will hold interest, either explicitly as a landscape feature that demands management, or implicitly by recognition of the role of geomorphological process systems in influencing habitat characteristics. As the current state of the landscape is dominantly represented by adjustment to interglacial conditions, management intervention may be necessary to retain transient-state landforms or to protect relict features from contemporary disturbance. Practical guidelines for quantifying limits of acceptable change on a protected landscape feature are contingent on an awareness of process–form relationships and the range of probable magnitudes and frequencies of formative events. Appreciation of geomorphological change over the timescale of 1000 years provides a basis for environmental management.

Fourth, the millennial timescale provides an important framework for appreciating the risks associated with geomorphological change and natural hazards, especially extreme events. This can be readily illustrated with reference to the design of flood defences. To be 95% certain that the defences will not fail within a design lifetime of 50 years, it would be necessary to design for the 1000 year event. In the past, dam failures have led to some of the most catastrophic flood events in Britain. As a consequence, the safe design and maintenance of these structures is strictly controlled under the Reservoirs Act 1975. Large raised reservoirs with a capacity of over 25 000 m^3 are placed in four hazard categories, mainly according to the level of downstream development (table 1.1). Category A reservoirs are those where a breach will endanger lives in a community. The minimum design standard for these dams is the 10 000 year flood. Category B reservoirs are those where a breach might endanger lives in a community or result in extensive damage. The minimum design standard for these dams is the 1000 year flood. The relationship between the probability of a potentially damaging event (often expressed as a return period) and the lifetime of a development or structure also illustrates the need to be aware of millennial-scale changes in the landscape, especially for high-value or high-risk (i.e. those where the consequence of failure would be unacceptable) projects. The probability of a 1000 year event (annual

Table 1.1 Reservoir flood and wave standards by dam category (after Institution of Civil Engineers, 1978)

	Dam design flood inflow			
Category	*Initial reservoir condition*	*General standard*	*Minimum standard if rare overtopping is tolerable*	*Alternative standard if economic study is warranted*
A. Reservoirs where a breach will endanger lives in a community	Spilling long-term average daily inflow	Probable Maximum Flood (PMF)	0.5 PMF or 10 000 year flood (take larger)	Not applicable
B. Reservoirs where a breach: (i) may endanger lives not in a community; (ii) will result in extensive damage	Just full (i.e. no spill)	0.5 PMF or 10 000 year flood (take larger)	0.3 PMF or 1000 year flood (take larger)	Flood with probability that minimizes spillway plus damage costs; inflow not to be less than minimum standard but may exceed general standard
C. Reservoirs where a breach will post negligible risk to life and cause limited damage	Just full (i.e. no spill)	0.3 PMF or 1000 year flood (take larger)	0.2 PMF or 150 year flood (take larger)	
D. Special cases where no loss of life can be foreseen as a result of a breach and very limited additional flood damage will be caused	Spilling long-term average daily inflow	0.2 PMF or 150 year flood	Not applicable	Not applicable

Table 1.2 The percentage probability of the *N*-year flood occurring in a particular period

Number of years in period	*N = average return period, T_r, in years*							
	5	*10*	*20*	*50*	*100*	*200*	*500*	*1000*
1	20	10	5	2	1	0.5	0.2	0.1
5	67	41	23	10	4	2	1	0.5
10	89	65	40	18	10	5	2	1
30	99	95	79	45	26	14	6	3
60	–	98	95	70	31	26	11	6
100	–	99.9	99.4	87	65	39	18	**9**
300	–	–	–	99.8	95	78	45	26
600	–	–	–	–	99.8	95	70	45
1000	–	–	–	–	–	99.3	87	64

Where no figure is inserted, the percentage probability < 99.9.

In bold type: there is, on average, a 9% chance that a 1000 year event (annual probability of 0.001) would occur within a 100 year time period.

probability of 0.001) occurring within 'engineering time' (generally recognized to be 50–150 years) is around 10% (table 1.2). Thus, the potential for major landslide events, coastal change or river channel migration and so on needs to be taken into account in the planning and design of major engineering projects. The content of the volume serves, therefore, to draw attention to the nature and scale of geomorphology-related issues that might have an influence on a project in a particular location. Forewarned is forearmed.

Fifth, the millennial scale provides an opportunity for developing scenarios for the possible impacts of climate change and sea-level rise. Indeed, it is possible to match climatic records over the last 300–400 years with documentary accounts for major events and early map sources. Within this period there have been notable variations in storminess, not only from year to year but also over decades and centuries. Analysis of the number of storms of different severity class since 1570 reveals marked periods of increased storminess: prior to 1650, between 1880 and 1900, and since 1950 (Lamb, 1991).

The storminess prior to 1650 is widely believed to reflect the period of colder climate known as the 'Little Ice Age'. This period was characterized by frequent severe winters, reduced run-off – Thom and Ledger (1976) suggest that run-off was 89% of present levels – and the occurrence of surface winds of strengths unparalleled in this century. Indeed, most of the major wind-blown sand events are from this period (e.g. the Culbin Sands disaster of 1694 and the Breckland storms of between 1570 and 1588). The end of the Little Ice Age was marked by a wetter, more extreme and variable climate, which may offer an analogue to the current phase of atmospheric warming (Newson and Lewin, 1991). This period from 1700 to 1850 has been associated with marked increases in autumn and winter floods, as identified in north-eastern England (Archer, 1987); major river channel changes, in both the uplands of northern England and in floodplain locations (Macklin et al., 1992); an increase in the reported incidence of major coastal landslides in southern England, such as the 1810 landslip on the Isle of Wight and the Great Bindon landslip of 1839 (Jones and Lee, 1994); and an increase in debris flow activity in the Highlands of Scotland (Innes, 1983). At the time of writing, much of southern Britain is gripped by severe floods that have re-awoken political and media concern with climate change, flood defence policy and planning. The 1000 year perspective on geomorphological process and event magnitude has much relevance for development objectives.

1.3 Evidence for Geomorphological and Climate Change

1.3.1 Inheritance and legacy

The span of 1000 years is insufficient for substantial geomorphological change or landform development except in particularly active or sensitive environments. In a regime of predominantly low-intensity processes following a transition from glacial to interglacial conditions, the rate of modification of landforms is generally low. The effectiveness of geomorphological processes can be considered as a function of the geological structure (the rock type and faulting patterns); the geological history (tectonics and changes in relative relief); past geomorphological processes (Pleistocene oscillations, changes in sea level and the aftermath of glaciation); present geomorphological processes (climate and role of extreme events); and human impact (in terms of deliberate intervention and the indirect consequences of land use change). The geomorphology of Britain is developed on a complex but essentially ancient geological structure, which has seen negligible tectonic activity in recent times. Past geomorphological processes have been considerably more active than the present-day regime. At the maximum extent, Pleistocene ice sheets reached as far south as the north Devon coast and the approximate line between the Severn and Thames estuaries. In areas that were actively glaciated, the impacts are profound but spatially variable. Even in an area such as the Lake District, where there are many classic landforms of mountain glaciation, many remnants of older surfaces can be seen. South of the maximum glacial limits, periglacial processes accomplished much landform change through enhanced weathering and solifluction. The legacy of the transition from glacial to interglacial conditions has been the assemblage of characteristic landforms inherited from past geomorphological process environments and an abundant supply of unstable and unconsolidated sediments. The term 'paraglacial' has been applied to environments that are directly conditioned by glaciation (Church and Ryder, 1972). The 'nearness' of glacial influence can be considered both in space (distance from active glaciation) and time (elapsed since deglaciation). Paraglacial conditions lead to the formation of distinctive landform assemblages in previously glaciated upland environments, such as alluvial fans and debris cones, where the abundant sediment supply, limited vegetation cover and energy input from precipitation permit rapid rates of sediment transfer. On the less dramatic relief of southern England, paraglacial conditions facilitated many mass movements. The transition towards the full interglacial is therefore characterized by the depletion of sediment supplies and the establishment of a vegetation cover that offers some resistance to sediment transfer.

Geomorphological process activity through the Holocene in Britain can be considered in terms of the interplay between the energy input for sediment transfer and the availability of sediment to be transported. The former is fundamentally a function of climate, while the latter is related to both the depletion of the legacy of glacial sediment supply and the role of vegetation cover in inhibiting transfer. Deterioration of the climate to wetter and/or stormier conditions and the role of humans in disturbing the natural vegetation cover or generating fresh sediment supplies are the main themes for a consideration of geomorphological process activity within the Holocene. The relative influence of climate change and of human activity has been a favoured, but distracting, theme (Ballantyne, 1991). The Holocene has traditionally been subdivided by the Blytt–Serander climate scheme into five periods that reflect changing European pollen assemblages. These are the Pre-Boreal (IV, warm, dry and birch-dominated); the Boreal (V/VI, warm, dry and pine-dominated); the Atlantic (VIIa, warm and wet, with the spread of oak and elm); the Sub-Boreal (VIIb, warm and dry); and the Sub-Atlantic (VII, cool, wet and characterized by the onset of forest clearance and the elm decline). Not surprisingly, as further research has investigated Holocene climate and vegetation change, the applicability and synchronicity of the scheme has been called into question. Nevertheless, it is helpful to superimpose the evidence for human impact on the British landscape on to the climate change record in setting the scene for the last millennium. The action of Neolithic farmers (in the early Sub-Boreal) had already reduced woodland locally, especially on the sandy and calcareous soils of the south, but by the start of the Bronze Age, Britain was still largely forested. Radiocarbon dating of pollen assemblages for the margins of the Pennine uplands indicates initial clearances between about 3900 and 3400 BP (Tinsley, with Grigson, 1978). Podsolization, declining fertility and soil erosion were consequences of some clearances. Between 2750 and 2500 BP, climate conditions deteriorated in the transition towards the Sub-Atlantic Period, with a decrease in temperature and increasing wetness. As upland settlement retreated, woodland regeneration was limited in many places, and the heath and bog communities developed on land that had been used previously for grazing. By the onset of the last millennium, much regional forest clearance had been accomplished, and the combined affect of climate deterioration and earlier deforestation had led to irreversible changes in soil properties and natural vegetation communities. The continuing adjustment to the glacial–interglacial transition, the legacy of glacial sediment supply and its reworking and depletion, Holocene fluctuation of climate and the increasing influence of humans set the scene for the operation and effectiveness of geomorphological processes in the most recent 1000 years. The evidence for climate change during this period is summarized below.

1.3.2 The climate of the last millennium

In the final years of the first millennium AD, a number of Norse colonies in Greenland and Newfoundland were established. The expansion of agriculture into the British uplands by Norse farmers a few decades later supports, but does not prove, the hypothesis that climate was markedly warmer at this time. The long-established view is that first few centuries of the last millennium were characterized by warm conditions that have become known as the ‘Little Optimum’ (Lamb, 1977) or the ‘Medieval Warm Period’. This was followed by a deterioration to colder and stormier conditions from the fourteenth century. The cold conditions experienced between the Middle Ages and the mid-nineteenth century have become known as the ‘Little Ice Age’ (Grove, 1988). As more detailed information about environmental reconstruction is assembled, it has become apparent that there is some considerable spatial and temporal heterogeneity in the conditions experienced. Much of the debate has been built upon the pioneering efforts of Hubert Lamb and of Gordon Manley to characterize past climate.

Lamb's index of medieval climate is based on a wide range of evidence for a warm epoch, which was used to establish relative changes in seasonal climate (such as winter severity, and summer wetness/dryness) on a decadal scale (Lamb, 1965). The Central England Temperature (CET) record, devised by Gordon Manley, is a homogenous temperature series based on a three-station average from Lancashire and the south Midlands. When published (Manley, 1974), it provided a monthly record back to 1659, but it has subsequently been upgraded to a daily basis from 1772 (Parker et al., 1992), updated and corrected for some data discrepancies. The CET has become the most studied climate record in the world (Jones and Hulme, 1997), from which fluctuations and trends can be derived. Present annual temperatures are about 0.7°C warmer than at the start of the record, which is close to the nadir of the Little Ice Age.

Evidence about the British climate during the last 1000 years, from which the indices described above are derived, comes from three types of source – the instrumental record, documentary sources and proxy data (Lamb, 1982). The invention of the thermometer at the turn of the seventeenth century made it possible for the direct recording of weather to begin, and some intact temperature records are available from various European stations from the early eighteenth century. The longest temperature records, as mentioned above, are from Central England. However, systematic procedures for recording daily weather were not widespread until the mid-nineteenth century. Measurements of rainfall exist from the eighteenth century, but again the procedures for measurement were not standardized until more recently. The England and Wales rainfall series has been reconstructed back to 1766 (Wigley and Jones, 1987), but the number of gauges available before the 1830s is limited. The direct record, therefore, provides information on only a fraction of the last 1000 years.

Inferences about weather prior to the instrumental record can be drawn from documentary sources. Here, compilations of weather events by Short (1749), Lowe (1870) and Mossman (1898) are of obvious value. The accounts of eyewitnesses such as Defoe (1704) and Samuel Pepys provide an indication of the scale and impact of great storms and floods. The earliest known diary specifically relating to weather observations was compiled by William Merle, in Oxford, for the seven-year period from January 1337 (Ogilvie and Farmer, 1997). Chronicles, charters and ecclesiastical histories provide some qualitative evidence, although some may have been compiled long after the event. Manorial account rolls are particularly useful from 1300 and make reference to events that affected agricultural productivity. The interpretation of weather records from medieval documents is fraught with a number of difficulties, principally concerning the precision of the dates and the reliability and representativeness of the observations. The switch from the Julian to the Gregorian Calendar, adopted in England in September 1752, necessitates the addition of a few days to pre-1752 dates to make inter-annual comparisons. More often, however, the timing of a meteorological event is described more loosely by the season. The term 'autumn' normally refers to the harvest season and 'spring' to the regeneration of biological growth, such that neither can be regarded as a fixed period when comparing records (Ogilvie and Farmer, 1997). The representativeness of records about the weather that are derived from medieval documents also requires consideration. In manorial account rolls, the weather is generally only mentioned when it has some impact on agricultural yield. There is a bias towards more records for the seasons of summer and autumn when an impact on agriculture might be observed and through a lack of commentary on 'normal' weather. Ogilvie and Farmer (1997) note that a large proportion of English summers between AD 1220 and 1430 were described as dry, which may suggest some over-exaggeration in the reporting and/or the onset of a longer-term period of lower rainfall. In general, records of extreme seasons can only be corroborated when they are mentioned by a number of different manors. The screening of medieval documents to generate reliable information about past weather conditions is a time-consuming process. It is unfortunate, although not unexpected, that many of the pioneering attempts to develop indices of medieval climate, including the Lamb index, built upon existing sources of weather information. The uncritical use of secondary sources has led to a number of misinterpretations being included, and it is for this reason that the clear signals of a Medieval Warm Period followed by the Little Ice Age are rather more complex than at first imagined.

A third source of evidence about the climate comes from proxy data. There are various physical and biological indicators that are suitable for Holocene palaeoclimatological reconstruction. The physical evidence of glacier retreat and advance is not applicable to Britain in the last 1000 years, but reconstructions in Norway and the European Alps indicate marked oscillations throughout the last millennium (Grove, 1988). The oxygen isotope record from high-latitude or high-altitude ice cores can be interpreted as an indicator of temperature at the site. A good correlation has been noted between the Crête, Greenland $\delta^{18}O$ record and the Lamb Index of English temperatures (Dansgaard et al., 1975). Ice cores from Peru and the South Pole also indicate relatively warmer phases in the early centuries of the last millennium and relatively cool phases between the seventeenth and nineteenth centuries (Hughes and Diaz, 1994), but this pattern is not coincident in all ice cores nor does it provide unequivocal evidence of climate in Britain. Of biological indicators, the tree ring record (dendrochronology) offers the prospect of precise dating of events. Chronologies for England and Ireland are based on oaks (Baillie, 1995). In addition to dating wood remnants or timber preserved in archaeological contexts, tree ring patterns are indicative of past phenomena that have impaired growth (such as fire scars or volcanic dust veils) and can be used to infer climate variables from growth rates, relative abundance, episodes of growth initiation or tree death. The archaeological record also provides evidence of episodic phases of building that indicate variable rates of deforestation. The mid-fourteenth century, for example, marks a hiatus of building activity in Britain, assumed to result from the Black Death epidemic (Baillie, 1995). Pollen, plant macrofossil and diatoms can be used to infer climatic conditions, although the relationship between the occurrence of the indicator and the character of the environment does not preclude non-climatic influences. The pollen assemblages that indicate the character of surrounding vegetation may be used to infer changes in temperature and precipitation, but are more likely to reflect anthropogenic impacts. Diatoms, preserved in lake sediments, respond to water chemistry, from which changing catchment hydrology and water quality can be inferred. Plant macrofossil remains in peat bogs have been used to reconstruct changing surface wetness, which in turn can be related to periods of desiccation or to enhanced drainage as the bog surface is incised and eroded (Tallis, 1997). Proxy indicators offer enormous scope for environmental reconstruction but the difficulty of separating climate-induced transitions from land use change is apparent.

As more information about the environment of the last millennium has been compiled, it has become clear that the traditional distinction between a Medieval Warm Period and the Little Ice Age is open for reinterpretation. A generalized sequence of climatic phases is presented in table 1.3. There is a general agreement among climate historians that the opening centuries of the last millennium were warm, perhaps as warm as anything experienced in postglacial times. The Fennoscandian tree ring record (Briffa et al., 1992), glacier fluctuations of the Swiss Alps (Grove and Switsur, 1994) and the British documentary record (Ogilvie and Farmer, 1997) suggest that much of northern and western Europe enjoyed a drying and warming trend from AD 1200, although conditions in Iceland and Greenland appear to have become more severe at this time. Cooling is apparent from the mid-thirteenth to the mid-fourteenth century, with a brief return to warmer conditions in the first half of the sixteenth century. Thereafter, conditions were cooler until the mid-nineteenth century. Even within the warmer phases

Table 1.3 The generalized climatic characteristics of the last millennium. The division, although somewhat arbitrary, indicates that conditions did vary significantly between and within the traditional Medieval Warm Period – Little Ice Age classification. The timing of these phases was not necessarily synchronous or as marked across all parts of Britain

Date (approximate, AD)	*Principal climatic characteristics*
900–1250	Medieval Warm Period. Higher temperatures with drier summers and slightly wetter winters. Higher rates of evapotranspiration, reduced surface wetness and low snowfall, fewer snowmelt events
1250–1420	Climatic deterioration from the relatively warm and dry MWP with some notably wet summers. The glacier advance in the Alps by 1350 is often considered as the start of the 'Little Ice Age' (Grove and Switsur, 1994)
1420–1470	A cool and damp period with lower temperatures, higher rainfall totals and increased storminess (Lamb, 1982). Several cold winters and failed harvests. Some abandonment of marginal settlements
1470–1550	Climatic amelioration – a brief return to warmer conditions
1550–1700	The nadir of the Little Ice Age (the most recent Holocene neoglaciation). Cold, damp and stormy, particularly during 1550–1610 and 1670–1700, with a less cold period between. Annual temperatures 1.5°C below MWP. Cold autumns and severe winters with increased snowfall. A high incidence of landslides
1700–1740	Climatic amelioration. The 1730s were markedly warm
1740–1850	A cool period. Cool autumns and cold winters with enhanced snowfall. Many river basins experienced episodes of severe flooding in late eighteenth century (Rumsby and Macklin, 1996) and a high incidence of reported landslides (Jones, chapter 3)
1850–2000	The start of the current warming phase. An overall rise in temperature, but with cooler/wetter phases during the late nineteenth century and from the 1950s to the 1970s. Increasing summer dryness and warmer and wetter winters in the last two decades of the twentieth century

of the Medieval Warm Period, there are documentary records of severe winters – 1205, for example, has an early report of the Thames being frozen. Other years, such as 1314 and 1318, had markedly wet summers that led to widespread crop failures (Ogilvie and Farmer, 1997). Neither is the evidence for the timing and severity of the Little Ice Age clear-cut and distinct. Alpine glaciers had already occupied advanced positions by AD 1350 (Grove and Switsur, 1994) before receding until the seventeenth century. Although the CET record indicates that temperatures have risen since the mid-seventeenth century, there are several fluctuations. The coldest periods were from about 1560 to 1610 and from 1670 to 1700, when mean annual temperatures were depressed by 1.4–1.7°C compared with the preceding Medieval Warm Period (Lamb, 1985). The autumns were cold and the winters particularly severe. Commencing with the 'Great Winter' of 1564–5, there were frequent 'Great Frosts', accompanied by the widespread freezing of lowland rivers, conditions that have become immortalized by the landscape paintings of the time and in the culture of Christmas. Average annual snow lie was 20–30 days in lowland areas in 1670–1700. The winter of 1683–4 is the coldest on record and 1740 has the lowest annual temperature (Jones and Hulme, 1997). The last two decades of the seventeenth century appear to have been exceptionally wet, as there are several records of floods and crop failures from this period. But within the so-called Little Ice Age, the 1730s and 1830s were markedly warmer decades (Parry, 1978). Nevertheless, recent Northern Hemisphere reconstructions confirm the persistence of cooler conditions back to AD 1500 equivalent to a temperature reduction between 0.5 and 1°C (Mann et al., 1998; Huang et al., 2000).

These particularly cold episodes were flanked by two periods of lesser cooling, the first lasting from 1420 to 1470 – when cool winters and a succession of 'failed summers' led to some settlements being abandoned or 'deserted' – and from 1740 to 1900, which is characterized by cool autumns and by depressed winter temperatures with relatively large numbers of 'cold' days prior to 1850. The evidence from northern parts of Britain points to a broadly similar pattern of change, except that the severity of the reduction in temperatures during cold episodes appears to have been greater. Thus temperatures in the Scottish Lowlands during the period 1670–99 are thought to have been 2–3°C lower than the average recorded for 1930–59, as compared with an equivalent lowering of 1.0–1.1°C in central England (Lamb, 1985). As a consequence, there are many reports of permanent snowfields on the crests of the Cairngorms (1200–1300 m) between 1805 and 1823, thereby pointing to their likely increased extent and persistence in earlier times.

The direct influence of temperature on geomorphological processes is limited, albeit that it may influence the degree of freeze–thaw activity that may be important for mechanical weathering, upland slope processes and bank erosion. Indirectly, the influence of temperature on agricultural activity accounts for land use change that has potential geomorphological consequences. Parry (1978), for example, has demonstrated the substantial amount of abandoned arable land in the Southern Uplands of Scotland. Over 20% of the existing moorland of the Lammermuir Hills has evidence of former cultivation. It is likely that colonization occurred in the eleventh and twelfth centuries following the introduction of the moldboard plough, but reduced temperature and increased wetness from the fourteenth century onwards made some of this land sub-marginal. Several settlements were abandoned in the seventeenth century. As noted above, the 1690s were particularly severe, and are referred to in Scottish folklore as the Seven Ill Years (Whyte, 1981). Conditions for the people were bleak and the cultivation limits retreated downslope by as much 200 m (Parry, 1978). From a process viewpoint, information about precipitation is more important than the temperature record. Attempts to reconstruct British rainfall patterns since the mid-eighteenth century (Wigley and Jones, 1987) show little evidence of systematic trends. Seasonal precipitation totals are highly variable from year to year, but there is some evidence that winters have become wetter and summers drier (Jones and Conway, 1997; Jones et al., 1997), particularly in the last 25 years. The early instrumental records show that much of Europe experienced dry decades between 1730 and 1760 but relatively wet years between 1760 and 1780 (Jones and Bradley, 1992). Estimates of pre-instrumental precipitation totals suggest that the Medieval Warm Period experienced drier summers and wetter winters, with annual precipitation up by about 3%, while the Little Ice Age had decreases of around 7–10% against the 1916–50 mean (Lawler, 1987). The implication of episodic climate change for geomorphological response is considered further in chapter 2, but it is clear that decadal and annual variations mask the potential influence of short-term events (individual storms or floods) that are capable of accomplishing much geomorphological change. Higher-resolution climate reconstruction is possible using schemes such as the Lamb Classification of Daily Weather Types. The classification is based on the direction of general air flow and the motion of synoptic systems, and covers the period from 1861 to the present. Wilby et al. (1997) report strong correlation between the frequency of winter cyclonic Lamb weather type and variations in lake-based sediment yields.

1.3.3 The historical record of geomorphological change

Much of our knowledge of the geomorphological changes over the last 1000 years relies on the historical archive of public records, journals, diaries, newspapers, photographs, maps and charts. However, the archive does not provide a consistent or unbiased record of the last 1000 years, either from a temporal or process/event perspective. Where pronounced or noticeable changes have occurred in the landscape, they may have been recorded on maps or charts (Hooke and Kain 1982; Hooke and Redmond, 1989). So-called ‘county’ maps date from Elizabethan times to the nineteenth century and are of variable scale and quality. Carr (1969), for example, describes their use in defining coastal changes at Orford Ness. In Scotland, Roy’s Military Survey of Scotland (1745–55) provides a fairly accurate record at 1 inch to 1000 yards (1 : 36 000 scale). The earliest manuscript maps (estate maps, tithe or enclosure maps) date from the late eighteenth and early nineteenth centuries. They vary considerably in scale and standard of cartography. Detailed scale (3–6 chains to the inch – between 1 : 2376 and 1 : 4752 scale) tithe maps were produced for 75% of England and Wales between 1838 and 1845, in compliance with the Tithe Commutation Act of 1836. The first Ordnance Survey maps were produced at 1 inch to the mile (1 : 63 360 scale) between 1805 and 1873, but are considered to be of dubious accuracy (Carr, 1962; Harley, 1968). Larger-scale, 1 : 2 500 and 1 : 10 560 maps were produced from the 1870s onwards. The number of subsequent editions of these maps depends largely on the amount of development in an area.

Analysis of change from historical maps is not without its problems. Although the positional accuracy of many defined objects on Ordnance Survey maps is estimated to be ± 0.8 m, inaccessible features of ‘marginal importance’ situated away from settlements may not be mapped with comparable accuracy (Carr, 1962, 1980). Often, landscape features of interest are not clearly defined in the field, and their map position may be based on a surveyor’s perception of their form. As a result, plotting on different editions or different sheets of the same edition may be sensitive to operator variance (Hooke and Kain, 1982). Not all features are revised for each new map edition, so it is sometimes uncertain exactly when a particular feature was last revised.

Significant geomorphological events may have been recorded in journals or diaries. However, these sources provide only a very limited picture of the first half of the millennium. It is possible to use such sources to define the major flood events on the larger rivers. On the Thames, for example, the Anglo-Saxon Chronicles record severe flooding on the East Coast in 1099. However, probably the earliest reliable record of a landslide event dates from 1571, near Kynaston, Herefordshire:

> on the 17th of February, at six o-clock in the Evening, the Earth began to open, and a Hill with a Rock under it . . . lifted itself up a great height, and began to travel, bearing along with it the Trees that grew upon it, the Sheep folds and Flocks of Sheep abiding there at the same time. In the place from where it was first mov'd it left a gaping distance forty foot broad, and fourscore ells long; the whole Field was about 20 acres. Passing along, it overthrew a Chapel standing in the way . . . (Baker, 1674).

Over the last 150–200 years, newspapers have become an important vehicle for recording dramatic events. For example, the major floods of the nineteenth century, such as those of October 1875, were described in considerable detail, sometimes occupying almost entire newspapers. Often, the accounts may contain references to previous similar events. As an example, the following summarizes an article appearing in the *Nottingham Daily Guardian* for 2 January 1901:

> A heavy and prolonged downpour on Sunday, 30 December 1900. It was recorded locally as 1.684 inches, and compared with the year's previous heavy fall of 1.286 inches on June 11 1900. The water-level rose rapidly during the night of Monday 1 Jan/Tuesday 2 Jan 1901, and by the morning of the 2nd flooding was taking place over both banks of the river. By Tuesday night the flood level had passed the 1869 flood mark and had almost reached the 1852 flood mark.

The value of local newspaper sources has been highlighted by Lee and Moore (1991), who established the pattern of contemporary ground movement in the Ventnor landslide complex, Isle of Wight, from a systematic search of local newspapers from 1855 to the present day. The search identified over 200 individual incidents of ground movement and allowed a detailed model of landslide potential to be developed that formed the basis for planning and management. More subtle changes or less dramatic events in isolated areas are not generally recorded in the historical archive. Thus, while we might know something of the suspected increase in major landslide activity during the Little Ice Age (Jones and Lee, 1994), we know relatively little about hillslope erosion, floodplain accretion, saltmarsh growth and other less spectacular processes throughout this period. Here, our knowledge is limited to sedimentological evidence (with associated problems of dating) and very recent (i.e. within the last 30 years) scientific monitoring data or chance records.

Finally, in attempting to examine geomorphological change in Britain during the last 1000 years, geographical variability should not be overlooked. The temptation to link reconstructed geomorphological events between regions, or even within catchments, requires caution. The incidence of upland gully erosion and renewed aggradation of alluvial fans in the Howgill Fells (Harvey et al., 1981) and the Forest of Bowland (Harvey and Renwick, 1987) have been radiocarbon dated to the early eleventh century, a time when Viking settlers were colonizing the upland margins. A similar timing of fan aggradation is apparent at sites in the Southern Uplands of Scotland (Tipping and Halliday, 1994). These upland examples of instability have recently been accompanied by evidence of a major soil erosion event and deposition of clastic material in Slapton Ley on the South Devon coast (Foster et al., 2000). The silty-clay unit is dated at two locations at 910 ± 160 and 960 ± 140 BP (conventional radiocarbon ages) and is evident in the floodplain sediments of other Devon rivers. Any millenarian looking for signs that the transition between the first and second millennium AD was afflicted with wrathful landscape instability might find solace in this apparent coincidence in timing across distant parts of Britain. Furthermore, the non-materialization of the end of the world at AD 1000 was excused by some millenarian clerics of the age to indicate that the Apocalypse would be unleashed when 1000 years had elapsed since Christ's passion rather than His nativity (Gould, 1998). Not only did the requisite year of AD 1033 have reports of widespread famine in Europe, but it fits neatly within the radiocarbon age ranges for the various archives of instability identified in Britain. However, it should be remembered that age ranges are indeed ranges. Tipping and Holliday (1994) have demonstrated through careful stratigraphical analysis that deposits in the upper Tweed valley, although broadly synchronous in age, relate to more than one event. There is an ongoing challenge to improve the precision of dating and further develop techniques of palaeoenvironmental reconstruction. This will enable investigations to move beyond general inferences about the temporal coincidence of possible causal effects towards more subtle questions about the mechanisms and timing of geomorphological process activity.

1.4 The Structure of the Book

The ten chapters of this book evaluate the evidence for geomorphological process activity over the last 1000 years, the techniques that are suitable to decipher such activity and the implications for both landscape development and the management of the landscape. As such, the authors draw on material from the published literature, consultancy reports and their own research projects. Throughout the book, calendar dates are referred to as AD and general periods of time in terms of centuries. Where evidence is deduced from radiocarbon dates, these are usually reported as BP (before present, AD 1950). Radiocarbon dates should be assumed to be conventional (i.e. uncalibrated) dates, unless specifically indicated. The authors were given specific subject briefs, but our definition of Britain has remained somewhat fluid. It is not the intention to provide an exhaustive geographical coverage of landscape change but, rather, to illustrate the principles through well chosen examples and case studies. Some geographical bias within individual chapters may reflect the research histories of the authors, but some care has been taken to ensure that examples are provided from England, Scotland Wales and Ireland. The authors also use examples from overseas temperate environments as analogues.

Denys Brunsden (chapter 2) provides some context by considering the boundary conditions for geomorphological activity over a 1000 year timescale. Invited to address the International Association of Geomorphologists, Brunsden (1990) defined a set of ten propositions about geomorphological behaviour that have earned wide circulation and some notoriety. These propositions are employed as a guiding framework to ask what change is possible over a timescale of a millennium. The curious main title is a Dorset dialect expression that captivates the essence of a living history. Chapters 3–6 are framed by the sediment cascade that considers geomorphological process activity from source to sink. David Jones (chapter 3) considers hillslope processes during the last 1000 years, with particular emphasis on the ways in which human activity has increased the propensity for erosion. Estimates of anthropogenic redistribution of earth surface materials suggest that geomorphological processes have become much less significant than humans in remoulding the British landscape. Having delivered some sediment from slopes to valley floors, Barbara Rumsby (chapter 4) evaluates the significance of valley-floor and floodplain processes, and identifies two major phases of enhanced fluvial activity in the eleventh and late eighteenth centuries. Developments in techniques to reconstruct process environments are covered in this chapter. Janet Hooke (chapter 5) focuses on the evidence for river channel change and provides a number of case studies of millennial-scale reconstruction. The extent and early history of modification in British river channels becomes apparent and yet the spatial variability in response is marked. Moving downstream, Mark Lee (chapter 6) investigates estuarine and coastal processes. Whereas many inland areas have remained insensitive to change during the last 1000 years, the British coast is a dynamic environment that exhibits much change and plenty of opportunities for applied geomorphology, as partly reflected in the large number of consultancy reports from which data are derived. In order to emphasize the importance of linkages in the sediment delivery system, two further chapters consider sediment transfer. David Higgitt, Jeff Warburton and Martin Evans (chapter 7) examine upland sediment transfer, reviewing attempts to develop chronologies for significant events in upland environments and to quantify upland sediment yields. Ian Foster (chapter 8) provides the complementary review for lowland rural environments, focusing on the identification of retention mechanisms, conveyance losses and transfer processes. Although understanding of sediment transfer mechanisms and pathways has improved in recent years, in both upland and lowland environments, many questions remain unanswered.

With the exception of coastal systems and some sensitive fluvial environments, process activity in Britain over the last 1000 years has been relatively modest. That is not to say that geomorphological expertise does not have relevance in many engineering situations. Mark Lee (chapter 9) reviews the various ways in which geomorphological processes present management issues for the effective use of land. There is a long history of economic and human loss associated with natural hazards, particularly flooding, which raises many questions concerning future land development and the prospects of climate change. The volume ends with a short concluding chapter by the editors, that focuses on the impact of humans on the British environment over the last 1000 years and the challenges that such an interaction raises for geomorphology.

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