Fluvial Geomorphology of Great Britain

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Chapter 4

Fluvial geomorphology of north-west England

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HOLOCENE FLUVIAL DEVELOPMENT IN NORTH-WEST ENGLAND

The river systems of north-west England fall into five main groups, the Mersey, Ribble, Lune and Eden drainage basins, and the radial drainage of the Lake District (Figure 4.1). Almost all have undergone a similar sequence of Late Pleistocene and Holocene development (Harvey, 1985a). With the exception of a small part of the Dane headwaters in the Mersey system, the whole area lies within the Devensian glacial limits and therefore was under glacial ice at the Devensian maximum (i.e. *c.* 18 000 BP). The Loch Lomond Readvance (*c.* 10 000 BP) affected only small parts of the Lake District mountain catchments (Sissons, 1980). The modern river systems were therefore initiated during the Devensian deglaciation between *c.* 18 000 BP and *c.* 14 500 BP, by which, approximately, the margins of the Lake District had become ice-free (Gale, 1985; Thomas, 1985; Vincent, 1985), and by implication when the regional ice sheet had melted from outside the Lake District, leaving still under ice only the Lake District valleys, and possibly the far north of the region within the limits of the disputed Scottish readvance (Thomas, 1985).

There then followed a period of periglacial activity, interrupted by warmer conditions during the Windermere interstadial, culminating in the intensely cold phase of the Loch Lomond stadial, before hillslope stabilization under an increasing vegetation cover took place in the Early Holocene (Pennington, 1970; Gale, 1985). Apart from sedimentation in estuaries, drowned as the result of the post-glacial sea-level rise (Tooley, 1985), there is little evidence of fluvial change during the early Holocene, other than incision into Pleistocene deposits (Ferguson, 1981; Harvey, 1985a). A relatively stable early Holocene landscape under an almost complete woodland cover must be envisaged, providing little sediment to what were presumably relatively stable rivers. However, for the later part of the Holocene, there is considerable evidence for fluvial change resulting from increased hillslope erosion as the woodland cover decreased, perhaps in part as the result of climatic deterioration, but increasingly under direct human impact.

Three major themes underlie spatial variations of Holocene fluvial activity in north-west England. These are: (1) the legacy from the Pleistocene; (2) the relative impact of climatically and human-driven environmental change during the Holocene; and (3) variations in the geomorphic sensitivity of the fluvial systems.

There are regional variations in the fluvial response to Late Pleistocene – Holocene climatic change. As the ice sheets melted during the Late Pleistocene, sediment was fed into proglacial river systems. Later incision into glacigenic sediments has left a legacy of fluvioglacial terraces along many of the main rivers. Within the small area subject to the Loch Lomond Readvance, glacial conditions again existed at the end of the Pleistocene and streams fed by these glaciers were proglacial. In that area there was a rapid transition from glacial conditions to temperate conditions in the Early Holocene, without an intervening periglacial period. Elsewhere in the upland areas, periglacial conditions persisted during the Late Pleistocene, with subsurface permafrost active, and hillslope scree and solifluction processes transporting sediment downslope, feeding what were probably braided river systems (Lewin, 1981b). Periglacial activity ceased at the beginning of the Holocene. In those areas which had been most heavily glaciated, it is probable that sediment, made available by glacial processes, continued to be supplied to the fluvial system for some time during the early Holocene until exhaustion of supply. Such paraglacial (*sensu* Church and Ryder, 1972) conditions have been described in western Scotland by Brazier *et al.* (1988), and probably occurred in the Lake District. Late Pleistocene fluvial conditions were spatially variable, with contrasts between proglacial, periglacial and paraglacial regimes. Each type of regime influenced the sediment availability for the postglacial fluvial conditions of the Holocene.

During the later part of the Holocene there is evidence for increased fluvial activity, following the low level of fluvial activity of the Early Holocene, in the form of increased lake sedimentation rates (see Gale, 1985), aggradation of younger Holocene river terrace sediments, and tributary junction alluvial fans (see Harvey, 1985a). These changes followed climatic deterioration from the mid-Holocene Atlantic climatic optimum (Musk, 1985), and may have been in part a direct response to climatic change or the consequence of climatically induced vegetation change. However, there is increasing evidence of human-induced stress on the geomorphic system during the later Holocene. In the recent debate on the relative influence of climatic and human causes of Holocene fluvial change, there is evidence for the influence of both sets of factors (Ballantyne, 1991a). A number of

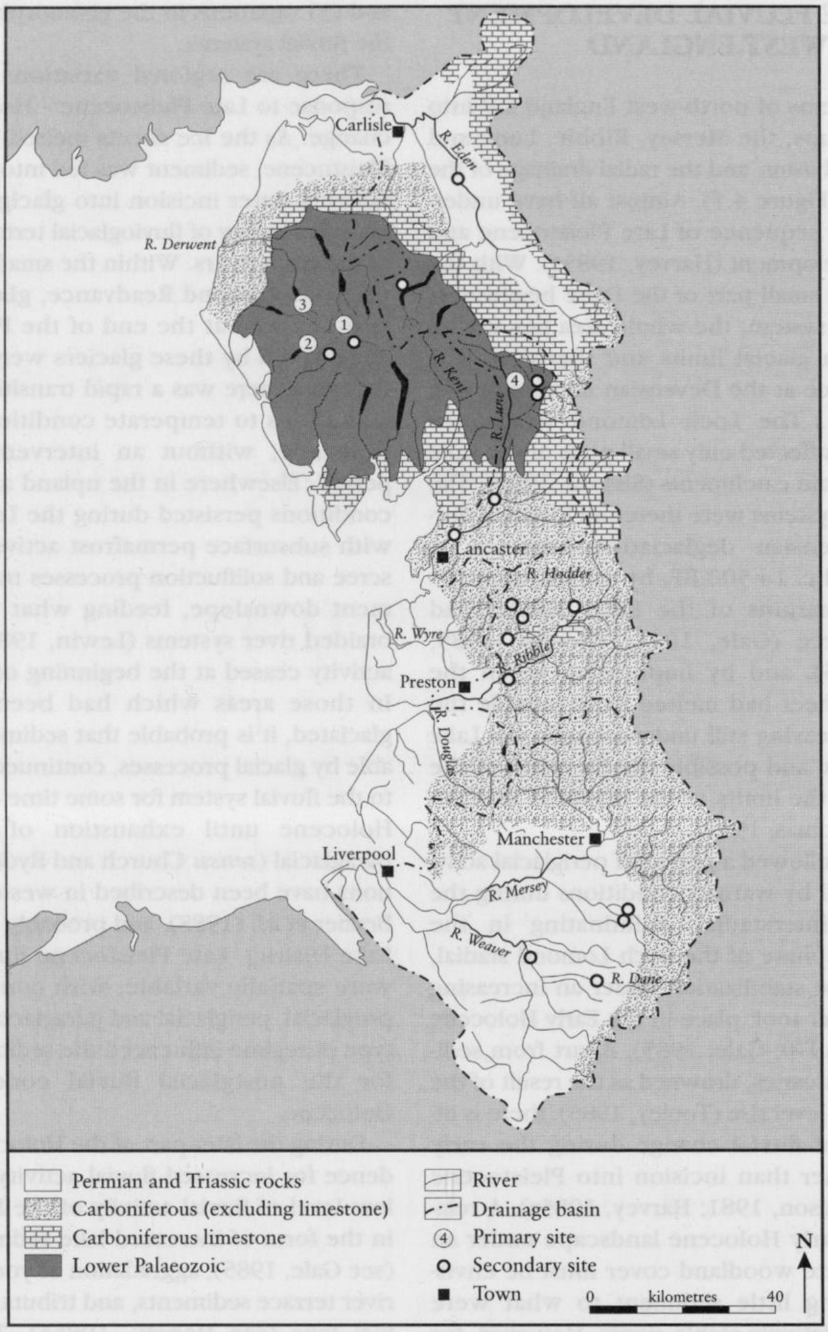

Figure 4.1 A location map showing the fluvial geomorphology GCR sites in the north-west England GCR Block. 1 Langstrathdale (potential GCR site); 2 Wasdale (potential GCR site); 3 Buttermere and Crummock Water (potential GCR site); 4 Carlingill Valley; 5 Langdale and Bowerdale; 6 Langden Brook; 7 River Dane.

studies, based on upland northern Britain, have stressed the importance of the effects of climate on flood incidence, and the adjustment of river systems to flood sequences (e.g. Macklin and Needham, 1992; Macklin *et al.*, 1992a,c; Passmore *et al.*, 1992; Rumsby and Macklin, 1994). Others have stressed the importance of sediment supply, and hence the influence of human-induced erosion on fluvial activity (e.g. Harvey *et al.*, 1981; Hooke *et al.*, 1990; Harvey, 1992a; Tipping and Halliday, 1994). It may well be that in proximal upland sites, where coupling between hillslope sediment sources and the channel system is strong (Harvey, 1992a, 1994), the impact of variations in sediment supply is high; hence the potential for response to human-induced erosion. In piedmont reaches (*sensu* Newson, 1981) variations in stream power may be more important, therefore these larger rivers may be more responsive to a climatically induced flood signal. Both factors have almost certainly influenced Late Holocene fluvial geomorphology of northwestern river systems, and interactions between the two may account for spatial variations between mountain, upland, piedmont and lowland environments.

Holocene fluvial response to environmental change also depends on the sensitivity of the system (Brunsden and Thornes, 1979), and on its nearness to geomorphic thresholds (Schumm, 1977), especially to the threshold of critical power (Bull, 1979), relating actual stream power to that required to transport the sediment supplied. These conditions may be modified by time lags (Brunsden and Thornes, 1979) and by coupling within the system (Harvey, 1992a, 1994). The fluvial systems most susceptible to environmental change are high-energy systems, draining steep catchments in areas of the most severe climates, either those prone to severe winter conditions, or those susceptible to high-magnitude floods (Harvey, 1985a, 1986; Newson, 1992). Again there are contrasts between the mountain, upland, piedmont and lowland river systems in the north-west.

GEOLOGY, RELIEF AND HYDROLOGY

The themes outlined above set the context for the development of the modern river systems, but other factors have influenced their style of development, of which geology, relief and hydrology are the most important. The influence of geology is both direct, through its influence on sediment calibre, and indirect, through its influence on relief. There is a strong contrast between the upland and lowland areas (Johnson, 1985a,b). The uplands include areas of folded Lower Palaeozoic rocks, volcanics in the central Lake District, and compact but fissile sedimentary rocks in the Howgill Fells and Lake District margins (Broadhurst, 1985). Elsewhere the uplands comprise less strongly folded Carboniferous strata, of two types of terrain. The first is on gently dipping Carboniferous Limestone in the Lake District margins and, together with the overlying Yoredale series of limestones, sandstones and shales, in those western parts of the central and northern Pennines that are drained by the headwaters of some northwestern rivers. The second is on the folded sandstone and shales of the Forest of Bowland, the Rossendale upland and the northern and western margins of the Peak district, drained by northwestern rivers (Broadhurst, 1985).

In the lowland areas, Upper Carboniferous rocks occur in west Cumbria, the central Lancashire lowland and lowland Lonsdale, but the main lowland areas, the Cheshire/Lancashire plain and the Vale of Eden/Solway lowland, are underlain by Permo–Triassic marls and sandstones. Except in the mid-Cheshire ridge and in parts of the Vale of Eden, bedrock is generally covered by a blanket of Quaternary sediments (Longworth, 1985; Worsley, 1985).

Within the upland areas the overall relief has been accentuated by glacial erosion (Johnson, 1985b). In most cases the rivers follow pre-existing valley systems, but there are numerous examples of glacial diversions of the drainage (King, 1976; Harvey, 1985a). In the lowlands the modern river system is in most cases totally new, developing on a glacial depositional surface, although often inherited from glacial meltwater channel systems (e.g. Knowles, 1985).

The hydrology is dominated by high rainfall and low evapotranspiration in the uplands (Ward, 1981). The major rivers have high discharges per unit drainage area when compared with other English rivers (Harvey, 1985a; Newson, 1981) and, because of the steep terrain and generally impermeable bedrock in the upland catchments, tend towards a flashy regime with a high short-term variability. An exception to this pattern are the Lake District rivers downstream of the major lakes, where the flow is naturally regulated by storage in the lake basins. On all the rivers there is a low seasonal variability. Floods may occur at any time of the year; in the steep headwaters summer storms are important, but on the main rivers major floods tend to result from heavy cyclonic rain, particularly in autumn and winter, or occasionally from heavy rain and snowmelt (Newson, 1981; Harvey, 1985a).

FLUVIAL LANDFORMS AND PROCESSES IN NORTH-WEST ENGLAND

The fluvial geomorphology of north-west England reflects the influence of the factors outlined above on the developing fluvial system during the

Holocene. In the Lake District, within the Loch Lomond stadial limits and in valleys occupied by Late Devensian valley glaciers, glacial erosional and depositional landforms are fresh. The river system is young. Steep bedrock channels and gorges through glacial erosional terrain alternate with alluvial reaches through the intervening basins. These alluvial reaches often have braided channels or wide shallow single-thread gravel-bed channels, and some may have been dominantly aggradational since deglaciation. Where rivers enter lake basins there are well-developed lakehead deltas and small steep fan deltas from tributary streams (Hay, 1926). Sediments within these forms probably span the whole period since deglaciation.

Within the Lake District, Late Pleistocene glacial erosional forms and depositional forms have been largely unaltered during the Holocene. Locally, there has been incision by ravines in areas of more resistant bedrock, and by gully development in softer rock areas. These erosional forms fed sediment to debris cones and alluvial fans at the slope base, but so far in the absence of research on these forms in the Lake District, they cannot be definitively ascribed to either the Late Pleistocene or the Holocene, or ascribed to paraglacial or strictly postglacial conditions.

In other upland areas, Late Devensian solifluction transported debris to the lower parts of the hillslopes into which the modern streams are now incised (Harvey, 1985a). The overall trend since the Late Devensian has been one of incision (Ferguson, 1981). Where the incising rivers encountered bedrock, small gorges were created, but elsewhere the incision was punctuated by river terrace formation, including major Late Devensian terraces, and minor Late Holocene terraces. In several areas, notably in the Howgill Fells and the Forest of Bowland, the periglacial hillslopes have been deeply dissected by gully erosion during the Holocene (Harvey, 1985a; 1992a). These gully systems, now largely stabilized, fed sediment to debris cones and alluvial fans at slope-base and tributary junction sites, often grading into low river terraces (Harvey *et al.*, 1984). Hillslope gullying and associated fan deposition in these areas appear to be almost wholly Late Holocene (Harvey *et al.*, 1981; Harvey and Renwick, 1987; Harvey, 1992a), in response to human-induced vegetation changes, especially during the 10th century AD. There are smaller areas of more recent active gully erosion (Harvey, 1974, 1992a), contributing sediment to the modern stream system, and influencing modern channel styles (Harvey, 1977, 1987a, 1991; Harvey *et al.*, 1979).

Many of the modern alluvial channels in the uplands tend to be fairly stable, single-thread, locally meandering gravel and cobble-bed channels. On some, sediment transport rates are high (see Newson, 1981; Newson and Leeks, 1985), and where sediment inputs are high the channels tend to be wide and shallow, less stable, and locally braided (Hitchcock, 1977a,b; Thompson, 1986, 1987; Harvey, 1991).

In the piedmont and lowland areas, Late Pleistocene to Holocene incision again predominates, with river terraces dating from the Late Devensian and the Late Holocene. There is no clear-cut evidence of terraces relating to the early part of the Holocene. In the lowest, estuarine river reaches, sedimentation has been dominant, especially in relation to the Flandrian sea-level rise (Tooley, 1985). In interfluve areas the landscape is dominantly a Late Pleistocene, glacial or fluvioglacial landscape, with little or no evidence, apart from incised tributary streams, of Holocene landform development. Human-induced soil erosion related to woodland clearance, for which there is a growing body of evidence (see Hooke *et al.*, 1990), appears to have been diffuse, and, although producing valley floor sedimentation, did not produce a suite of recognizable erosional hillslope forms.

The present day river channels in the piedmont and lowland areas are generally meandering channels. Those on piedmont rivers, fed by upland sources, tend to be active (see Knighton, 1972; Mosley, 1975a,b; Hooke and Harvey, 1983; Hooke, 1984a,b; 1986, 1996) whereas the lowland meandering channels tend to be stable (see Harvey, 1985a).

The recent human impact on the fluvial systems of north-west England has been considerable, especially in the Mersey basin. Numerous upland catchments have been impounded, water is abstracted and diverted, channelization has taken place in urban areas, and some streams and rivers are grossly polluted (Walling and Webb, 1981). Fortunately, the most extreme effects are restricted to the central part of the Mersey basin. However, this does underline the need for conservation of the more important sites elsewhere in north-west England.

FLUVIAL GEOMORPHOLOGY GCR SITES IN NORTH-WEST ENGLAND

The sites described below have been selected for the GCR to be representative of fluvial conditions throughout the Holocene to the present day in north-west England. By definition, the final list of GCR sites includes only those of national importance, but also considered in this discussion are other sites of regional rather than national significance. This discussion is subdivided into mountain (Lake District) sites, upland sites, piedmont and main river sites. No truly lowland sites are included. Estuarine areas are also excluded.

Mountain areas

Three sites in the Lake District have the potential for inclusion in the GCR: Langstrathdale, Wasdale and Buttermere. All show features of an immature Holocene fluvial system adjusting to a relatively recently deglaciated mountain environment. Langstrathdale Beck is a large mountain river with bedrock reaches exhibiting small gorges and waterfalls, alternating with alluvial reaches exhibiting braided channels. The site includes the presumed downvalley limit of Loch Lomond stage glacial ice (Sissons, 1980). Also included are undated postglacial hillslope gullies and debris cones. The Wasdale site exhibits a rich variety of mountain fluvial forms (Boardman, 1988): erosional forms including gullies, ravines and incised bedrock channels, and depositional forms including debris cones, alluvial fans, braided river channels, a lakehead delta and several fan deltas issuing into Wasdale Lake. The best developed fan deltas in England occur at the Buttermere site, which also includes a range of smaller scale debris cones. There has been no published work on these features since Hay's (1926) work.

Several other sites in the Lake District, though not proposed for the GCR, exhibit a fine range of mountain fluvial features. Upper Eskdale (GR NY20), is a mountain river with bedrock and alluvial reaches, similar to Langstrathdale. Oxendale (GR NY20), a tributary at the head of Langdale, is a steep mountain catchment in glacial erosional terrain, with bedrock-controlled channels, gorges and waterfalls in the upper reaches, and postglacial stream terraces, small alluvial fans and boulder/cobble bed reaches downstream. Another site of regional importance is at Aira Beck (GR NY31, NY32, NY41, NY42), at the position of a major glacial drainage diversion, showing a spectacular waterfall and bedrock channel leading to a large fan delta where the beck issues into Ullswater. Surprisingly, there is little recent research into Holocene fluvial landform development in the Lake District, although there has been some work on modern and recent processes (see Newson and Leeks, 1985; Carling, 1987a).

Upland areas

Outside the Lake District three important upland sites have been selected for the GCR, two in the Howgill Fells and one in the Forest of Bowland. The two in the Howgills, at Carlingill and Langdale/Bowderdale, represent a superb suite of Holocene fluvial landforms and zones of current erosion and deposition. They are both important sites for research. The Carlingill site has features associated with stream capture (see King, 1976; Harvey, 1985a), including waterfalls and incised gorges, but more importantly a superb suite of Holocene hillslope gully systems, alluvial fans and stream terraces (see Harvey, 1985a, 1992a; Harvey *et al.*, 1984). There are also gullies active at present where erosion processes have been monitored for over 25 years (Harvey, 1974, 1977, 1987a,b, 1992a; 1994; Harvey and Calvo-Cases, 1991; Harvey *et al.*, 1979). The Langdale and Bowderdale valleys also include important Holocene sites, particularly gully systems and alluvial fans (Harvey, 1992b,c; Harvey *et al*, 1981), which have provided the basis for one recent PhD thesis on Holocene soils and geomorphology (Miller, 1991). Another reason for inclusion is that they preserve the effects of a major flood (Harvey, 1986), including channel pattern changes and excellent examples of alluvial fan and debris cone deposition (Harvey, 1986, 1991; Wells and Harvey, 1987).

Another interesting upland site in the Howgills, although not a GCR site, is at Cautley (GR SD69). This site contains a range of glacial erosional and depositional landforms, and periglacial landforms as well as Holocene gullies, alluvial fans and terraces.

The Langden Valley, in the Forest of Bowland, is included in the GCR because of a good dated record of Holocene erosion and deposition preserved in alluvial fan and terrace sediments (Harvey and Renwick, 1987). The modern channel is one of the most mobile and best-developed, cobble-bed braided channels in northern England (Wilcock, 1967a, 1971; Hitchcock, 1977a; Thompson, 1985, 1986). This valley has provided a field base for several doctoral theses (Wilcock, 1967b; Wilkinson, 1971; Hitchcock, 1977b; Thompson, 1984; Miller, 1991).

Piedmont and main river sites

Only one piedmont or main river site is selected for the Fluvial Geomorphology of North-West England GCR Block, the River Dane at Swettenham, Cheshire. This is an important site for piedmont fluvial geomorphology, with a well-developed set of dated river terraces that contains an excellent record of the fluvial sequence from the Late Devensian to the present day (Hooke *et al.*, 1990). The modern channel is little disturbed by human activity, and exhibits a fine suite of active meanders that have developed since dissection of the youngest terrace at some period prior to 1840 AD (Hooke and Harvey, 1983). Research continues on fluvial processes and morphology of this channel (Hooke, 1996).

In addition to these GCR sites there are a number of other regionally important piedmont and main rivers in the northern and central part of the area, namely the Eden, the Lune and the Ribble, which each show differing styles of Holocene river development, illustrated by the following four sites. The River Eden at Armathwaite (GR NY54), forms a deeply incised gorge reach, with a channel locally in bedrock and locally braided. Upstream of the gorge the river meanders through a wide floodplain, and downstream there is a dominantly meandering channel within a narrow floodplain, set below postglacial terraces. The River Lune at Arkholme (GR SD56), near the confluence with the Greta, is a channel poised close to the meandering/braided threshold (Thompson, 1984), that has shown frequent changes over the past *c.* 100 years. The mobile channel in a fairly wide floodplain exhibits excellent sedimentary bar features. Lower downstream the River Lune at Caton (GR SD56) has a wide gravel-bed channel forming large unconfined meanders. Towards the Crook of Lune bedrock gorge, the floodplain becomes narrower and increasingly confined between terraces. The River Ribble at Balderstone (GR SD63), has confined meanders as the result of Holocene incision, with arcuate terraces on the insides of the bends.

Three smaller rivers, all within the Ribble system, together with Langden Brook (see above), illustrate the range of channel pattern types on the margins of the Forest of Bowland. The River Hodder at Burholme Bridge (GR SD64) is a cobble-bed piedmont river with a wide shallow, but relatively stable channel. There is a partly dated, very clear terrace sequence here (Harvey and Renwick, 1987). Skirden Beck near Bolton by Bowland (GR SD74) has mobile tortuous meanders that exhibit recent cutoff bends (Thompson, 1984). There are also terraces towards the confluence with the Ribble. The River Loud near Longridge (GR SD63) is really a lowland river, fed entirely by a drift catchment, but is unusual in that it becomes more of a piedmont stream downstream, as it receives 'upland' tributaries. Upstream the channel is highly sinuous, but stable, and has hardly changed its pattern over the past 100 years (Thompson, 1984).

Three sites on meandering piedmont rivers in Cheshire are of regional importance, and complement the GCR site on the Dane at Swettenham. Further downstream the River Dane at Northwich (GR SJ67), has an active meander belt of tortuous meander bends, including recent and imminent cutoffs. Two small streams to the north of the Dane, the River Bollin at Mottram Bridge (GR SJ88) and the smaller River Bollin Dean at Batley Bridge (GR SJ88) both show documented, well-developed, active, tortuous meanders (Knighton, 1972; Mosley, 1975a,b; Hooke, 1996). Both have a postglacial history of terrace development, although that on the Bollin is clearer and better exposed.

The seven sites described below are of national importance for demonstating the Holocene development of British fluvial systems, as well as modern fluvial processes and morphology.

LANGSTRATHDALE, CUMBRIA (NY 2609 – 13, 2812 – 13) POTENTIAL GCR SITE

Highlights

The site comprises a large river with alternating bedrock and alluvial reaches, typical of mountain environments (Figures 4.2 and 4.3).

Introduction

The valley exhibits typical features of a 'young' Holocene fluvial system adjusting to Late Pleistocene glacial erosional topography. The area was intensively glaciated during the main Devensian glaciation, first by ice-cap glaciation, then by valley glaciers moving down Langstrathdale and the Greenup Valley. Loch Lomond stage glaciers occupied the head of the Greenup Valley and Langstrathdale as far down valley as Blackmoss Pot (Sissons, 1980). Upstream of this point the valley

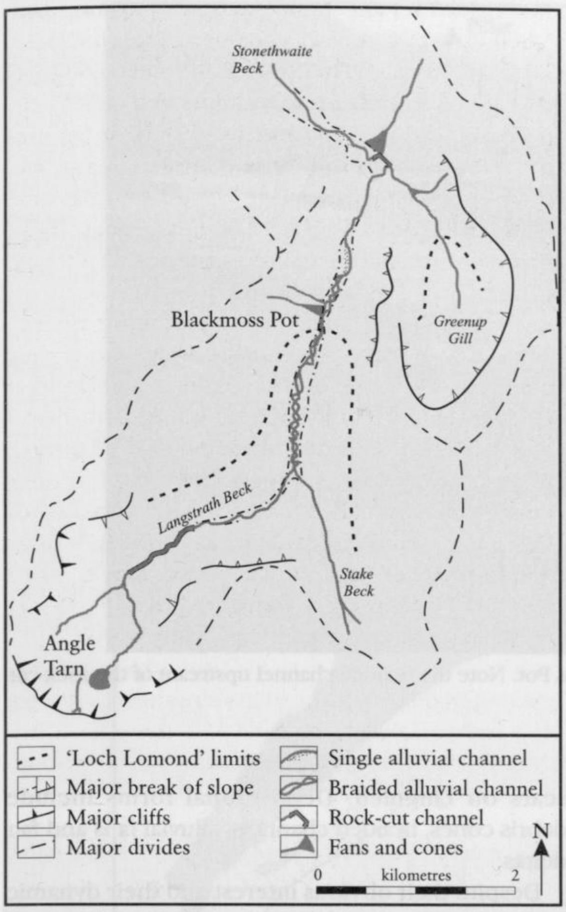

Figure 4.2 Langstrathdale: a geomorphological map.

floor is wholly Holocene, whereas lower downstream and on the lower part of the Greenup Gill the postglacial features relate both to the Late Pleistocene and the Holocene.

There has been no recent published work on this valley, but it includes a wide range of fluvial features typical of a 'youthful' mountain river.

Description

Three steep valley-floor segments alternate with gentler, former basin reaches. In the steep segments the modern channel is cut in bedrock and the detailed channel morphology exhibits rock-controlled small gorges and waterfalls. The intervening basin reaches have been characterized by aggradation during the Holocene. Within the uppermost of these aggrading reaches, the modern channel exhibits a well-developed braided channel pattern. Lower downstream the alluvial reaches demonstrate a rapid downstream decrease in sediment size with distance away from each bedrock reach. Also included are Late Pleistocene to Holocene slope forms, incised gullies with alluvial fans/debris cones at their bases.

On the upper part of the Langstrath Beck, above Tray Dub, the channel is cut in bedrock, and exhibits immature erosional features: small gorges, waterfalls and an irregular profile. Between there and Blackmoss Pot, Holocene alluviation has filled a glacially scoured rock basin, initially presumably by Late Pleistocene proglacial outwash during recession of the Loch Lomond glacier. The modern channel is a well-developed braided channel with multiple bars and islands. At Blackmoss Pot the channel crosses a rock bar, which Sissons (1980) interpreted as marking the Loch Lomond stage glacial limit. Below the steep bedrock reach is another alluvial reach, presumably an earlier outwash-filled rock basin, before the channel enters a steep gorge at Johnny's House. From here to beyond the Greenup Gill confluence the channel is confined by the gorge, and includes several waterfalls before entering the bouldery alluvial reach of Stonethwaite Beck beyond Galleny Force.

Each of the alluvial reaches demonstrates a marked decrease in sediment size away from the bedrock outcrops. In addition to the channel features, these valleys exhibit postglacial hillslope gullies with debris cones at their base. These are of uncertain age.

Interpretation

Langstrathdale Beck is a typical 'youthful' mountain river exhibiting an excellent suite of fluvial landforms characteristic of an immature river system adjusting to a recently deglaciated landscape. Although there has been no research on either the Holocene geomorphic sequence or on the contemporary channel, the valley is an excellent example of its type.

Conclusions

The valleys of Lanstrathdale Beck and its tributary Greenup Gill contain a fine suite of mountain fluvial landforms, representative of steep, immature mountain river systems. These channels alternate between steep bedrock-controlled and alluvial reaches. The hillslopes exhibit a series of, as yet undated, postglacial gully and debris cone forms.

Figure 4.3 Langstrathdale, looking upstream from Blackmoss Pot. Note the braided channel upstream of the rock-cut reach. (Photo: A.M. Harvey.)

WASDALE, CUMBRIA (NY 1607, 1707, 1806 – 18, 1907 – 09, 2007 – 09, 2107 – 09) POTENTIAL GCR SITE

Highlights

This site comprises a steep mountain catchment issuing into Wastwater, with a rich variety of postglacial erosional and depositional landforms (Figures 4.4 and 4.5).

Introduction

The Lake District was intensively glaciated during the Devensian glaciation by ice-cap and then by valley glaciation, creating the classic glaciated mountain topography of the Wasdale Valley. These glaciers had probably melted by *c.* 13 000 BP, but small glaciers formed at the Head of Wasdale and Lingmell Valleys during the Loch Lomond stadial (Sissons, 1980). The freshly deglaciated, steep mountain forms have been dissected by an active fluvial system during the Holocene. This site includes a rich variety of mountain fluvial forms, including erosional bedrock channels of Piers Gill and Gable Beck. Also included are the gullies and scars on Lingmell. Depositional forms include debris cones, braided channels, alluvial fans and fan deltas.

Despite their obvious interest and their dynamic character, there have been no serious recent studies of either the Holocene geomorphic sequence or the contemporary process system. A short summary is provided by Boardman (1988).

Description

The fluvial features include erosional forms at the valley heads, the steep headwater ravine of Piers Gill, the waterfall- and gorge-dominated bedrock channel of Gable Beck, and the hillslope gullies and scars on Lingmell in the catchment of Lingmell Gill. Further downstream, depositional features dominate, a bouldery braided channel on Lingmell Back below Piers Gill, a small debris cone where Gable Beck joins Lingmell Beck, an extensive former braidplain and a more restricted modern braided channel along Wasdale, and a large delta where Mosedale and Lingmell Becks empty into the head of Wastwater. This adjoins the steep fan delta of Lingmell Gill. There are also two small fan deltas on the north shore of the lake at Netherbeck and Overbeck. These fan deltas each include a subaqueous portion and a subaerial alluvial fan portion.

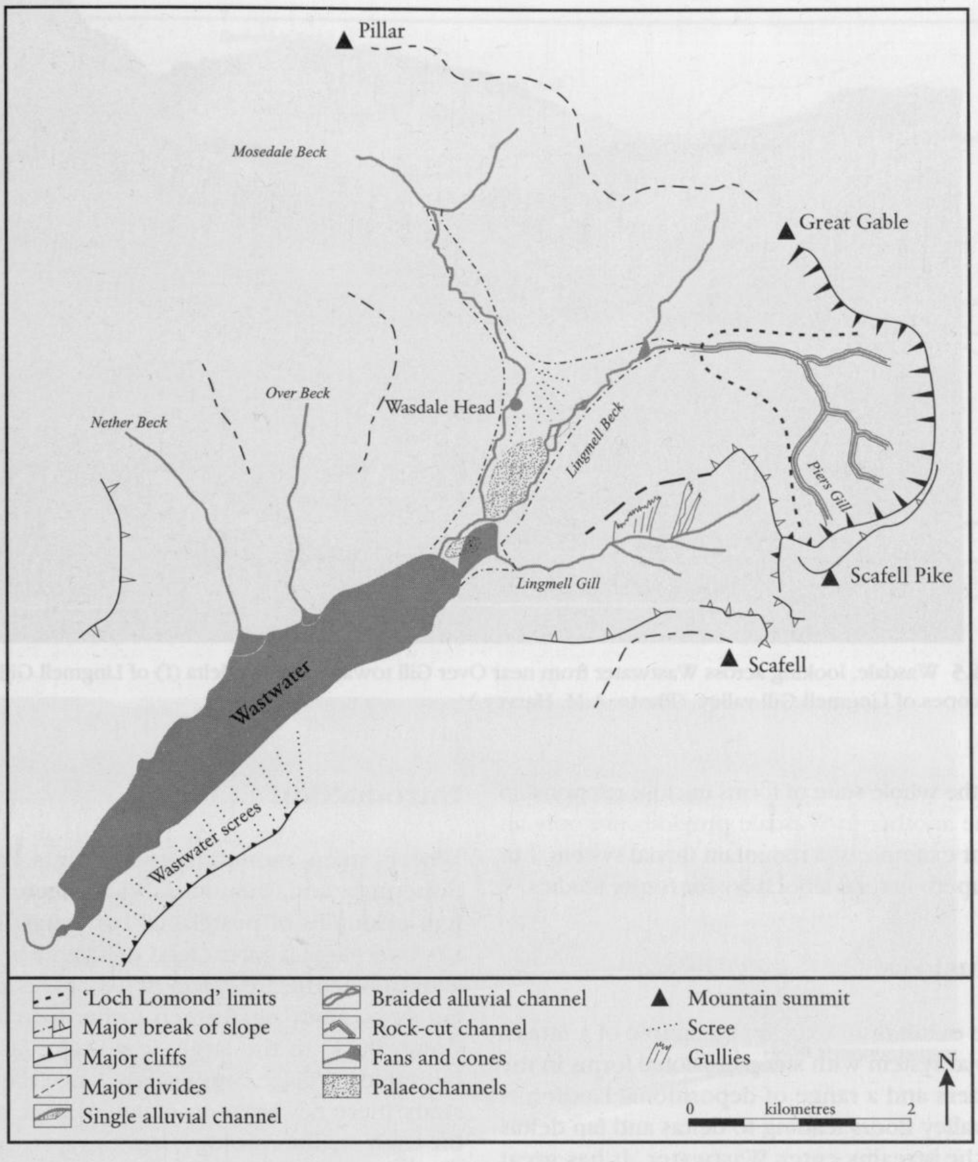

Figure 4.4 Wasdale: a geomorphological map.

Interpretation

Although there has been little work on the Holocene geomorphic sequence, the Holocene regional vegetation sequence is well-known (e.g. Oldfield, 1963; Pennington, 1970; Gale, 1985) and inferences about erosional history can be made from lake diatom sequences (e.g. Haworth and Allen, 1982). Both types of evidence suggest a relatively stable Early Holocene following an unstable Late Pleistocene, but increasing erosion rates in the later Holocene. No studies relate these sequences directly to landform development. The modern active fluvial features are of late Holocene age, but the fan deltas have probably been developing throughout the late Pleistocene and the Holocene. Apart from an early study of the Lake District deltas by Hay (1926), there have been no detailed studies of their sedimentology, stratigraphy or morphometry.

Wasdale includes an excellent suite of mountain fluvial landforms, and despite the lack of recent work on the fluvial landforms has the potential to provide evidence to link lake sediment studies directly with erosional and depositional landform development. Although individual landform types may be better developed in other Lake District

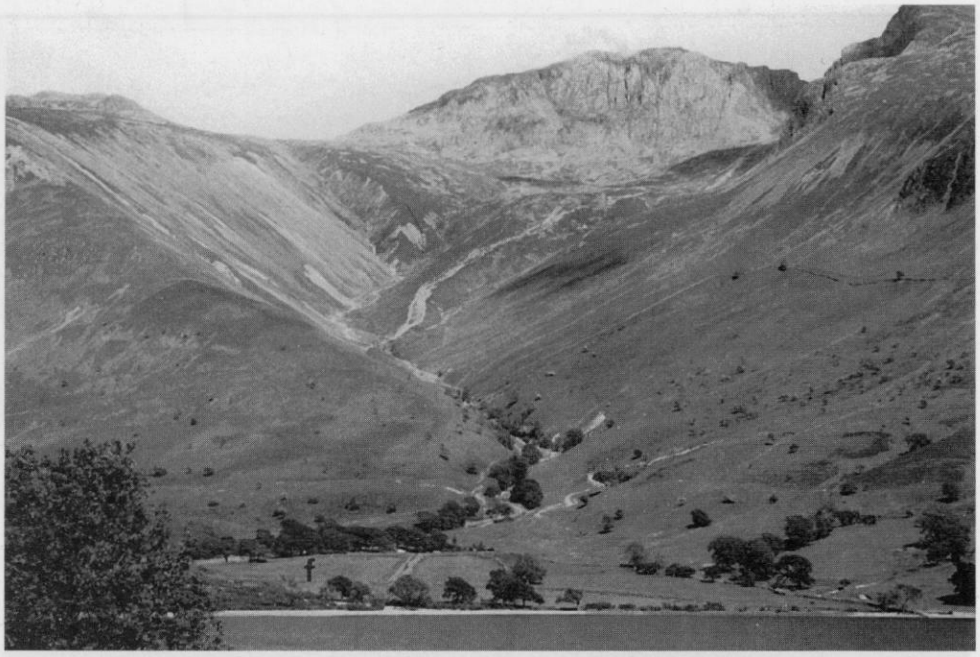

Figure 4.5 Wasdale, looking across Wastwater from near Over Gill towards the fan delta (f) of Lingmell Gill. Note the gullied slopes of Lingmell Gill valley. (Photo: A.M. Harvey.)

valleys, the whole suite of forms in close relationship with one another in Wasdale provides not only an excellent example of a mountain fluvial system, but also a superb natural laboratory for future studies.

Conclusions

Wasdale exhibits an excellent example of a mountain fluvial system with steep erosional forms in the headwaters and a range of depositional landforms on the valley floors leading to deltas and fan deltas where the streams enter Wastwater. It has great potential for the study of mountain fluvial systems but also contains in its sediments a record, so far unexplored, of the Late Pleistocene and Holocene geomorphic sequence.

FAN DELTAS AT BUTTERMERE AND CRUMMOCK WATER, CUMBRIA (NY 1418 – 19, 1517 – 19, 1616 – 19, 1716 – 17, 1814 – 15, 1915) POTENTIAL GCR SITE

Highlights

The site includes excellent examples of postglacial fan deltas (Figures 4.6 and 4.7).

Introduction

Where steep mountain catchments issue into Buttermere and Crummock Water, there are excellent examples of postglacial fan deltas. Each one has two parts: a submerged delta and an exposed alluvial fan. The area proposed includes a range of fan sizes, from small steep forms such as that at Comb Beck, to the large, low-angle, fan delta at Buttermere Village. Surprisingly, since Hay's (1926) study there has been no detailed work published on their sedimentology, stratigraphy and morphometry, but they offer scope for further study of the geomorphology of British Holocene alluvial fans and fan deltas, and contain in their sediment an as yet unexplored record of postglacial geomorphic events in the Lake District.

Description

The Lake District was intensively glaciated during the Devensian glaciation by ice-cap and then by valley glaciers, creating the classic mountain glaciated mountain topography of the Buttermere area. The lakes Buttermere and Crummock Water were formed as one lake during the decay of the Late Devensian valley glacier. Small mountain streams feeding directly into the lakes have

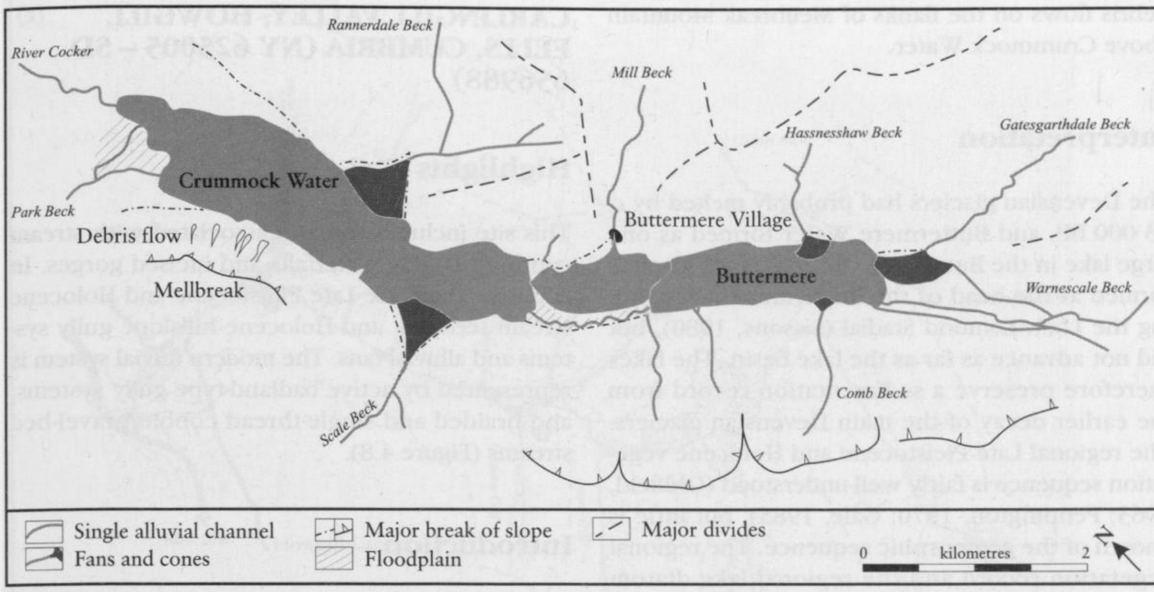

Figure 4.6 Buttermere: a geomorphological map.

Figure 4.7 Buttermere, looking across the fan delta of Hassnesshaw Beck to that of Comb Beck. Note the lake shore reworking of Hassnesshaw fan delta sediments into a small spit. (Photo: A.M. Harvey.)

deposited fan deltas during the Late Pleistocene and Holocene, and Mill and Salt Becks deposited the large fan delta at Buttermere Village, dividing the former large lake into the two modern lakes. The individual fan deltas proposed exclude the main headwater of the Buttermere valley because of human modification to the channel, but include others ranging in size from the large Buttermere Village fan delta fed by Mill and Salt Beck catchments, through intermediate-sized features at Gatesgarth, Rannerdale, Scale Beck and Crag Wood to the small steep fan of Comb Beck, fed by a steep bedrock-dominated mountain stream. Also included are steep debris cones and recently active debris flows on the flanks of Mellbreak Mountain above Crummock Water.

Interpretation

The Devensian glaciers had probably melted by *c.* 13 000 BP, and Buttermere Water formed as one large lake in the Buttermere trough. Small glaciers formed at the head of the Buttermere valley during the Loch Lomond Stadial (Sissons, 1980), but did not advance as far as the lake basin. The lakes therefore preserve a sedimentation record from the earlier decay of the main Devensian glaciers. The regional Late Pleistocene and Holocene vegetation sequence is fairly well-understood (Oldfield, 1963; Pennington, 1970; Gale, 1985), but little is known of the geomorphic sequence. The regional vegetation record and the regional lake diatom sequence (e.g. Haworth and Allen, 1982) suggest a late glacial period of major sediment input, followed by a stable Early Holocene and an increase in erosion rates during the Late Holocene. The fan deltas are important as they offer the potential for linking the lake sediment record with landform development within their mountain catchment areas, in addition to their inherent value as the best developed suite of fan deltas in England. Little is understood of sediment transport by Lake District mountain streams. Only one recent study (Newson and Leeks, 1985) deals with sediment transport in the Buttermere area, but the fan deltas offer the potential for relating sediment transport to fan delta sedimentation.

The Buttermere and Crummock Water fan deltas are the best developed suite of such features in England. Despite the lack of recent work on their geomorphology they provide the potential for further understanding of Holocene alluvial fans and fan deltas, as well as containing a record of sedimentation since the Late Pleistocene, that might allow a link to be made between lake sediment sequences and erosional and depositional landform development in mountain catchments.

Conclusions

Buttermere and Crummock Water exhibit an excellent suite of fan deltas, formed over the period since the Late Pleistocene. They include a wide variety of sizes and morphologies, as well as providing potential sites for further investigation of the Holocene landform sequence in the Lake District.

CARLINGILL VALLEY, HOWGILL FELLS, CUMBRIA (NY 625005 – SD 656988)

Highlights

This site includes features associated with stream capture, namely waterfalls and incised gorges. In addition, there are Late Pleistocene and Holocene stream terraces, and Holocene hillslope gully systems and alluvial fans. The modern fluvial system is represented by active badland-type gully systems, and braided and single-thread cobble/gravel-bed streams (Figure 4.8).

Introduction

The Carlingill valley is of exceptional importance for fluvial geomorphology, exhibiting a wide range of spectacular landforms related to the development of the fluvial system over three main timescales: (1) long-term (Pleistocene) development through river capture; (2) Holocene terrace, hillslope gully and alluvial fan formation; and (3) the adjustment of the modern channel system to sediment supply from currently active hillslope gullies. All have been the subjects of considerable research.

Some important early studies (Marr and Fearnsides, 1909; Hollingworth, 1929, 1931) related the capture of the Uldale headwaters by Carlingill to the regional development of the drainage pattern and glaciation during the Pleistocene; more recent summaries are given by King (1976) and Harvey (1985a).

The Howgill Fells in general and Carlingill in particular have become key areas in understanding the Holocene fluvial sequence in upland Britain (Harvey, 1985a,b). Cundill (1976) studied the vegetation sequence at Archer Moss and Carlingill, and one of his radiocarbon dates allows a major post-Roman phase of alluvial fan formation to be identified. A 10th century AD phase of gully erosion and fan deposition has been confirmed by radiocarbon dates from other parts of the Howgills (Harvey *et al.*, 1981; Harvey, 1985a) and by radiocarbon dates from a soil and sediment sequence at Blakethwaite, at the head of Carlingill (Miller, 1991; Harvey, 1992a, 1996). The Blakethwaite site complements the Holocene soil and geomorphic sequence in Carlingill itself (Harvey, 1985b; Harvey *et al.*, 1984).

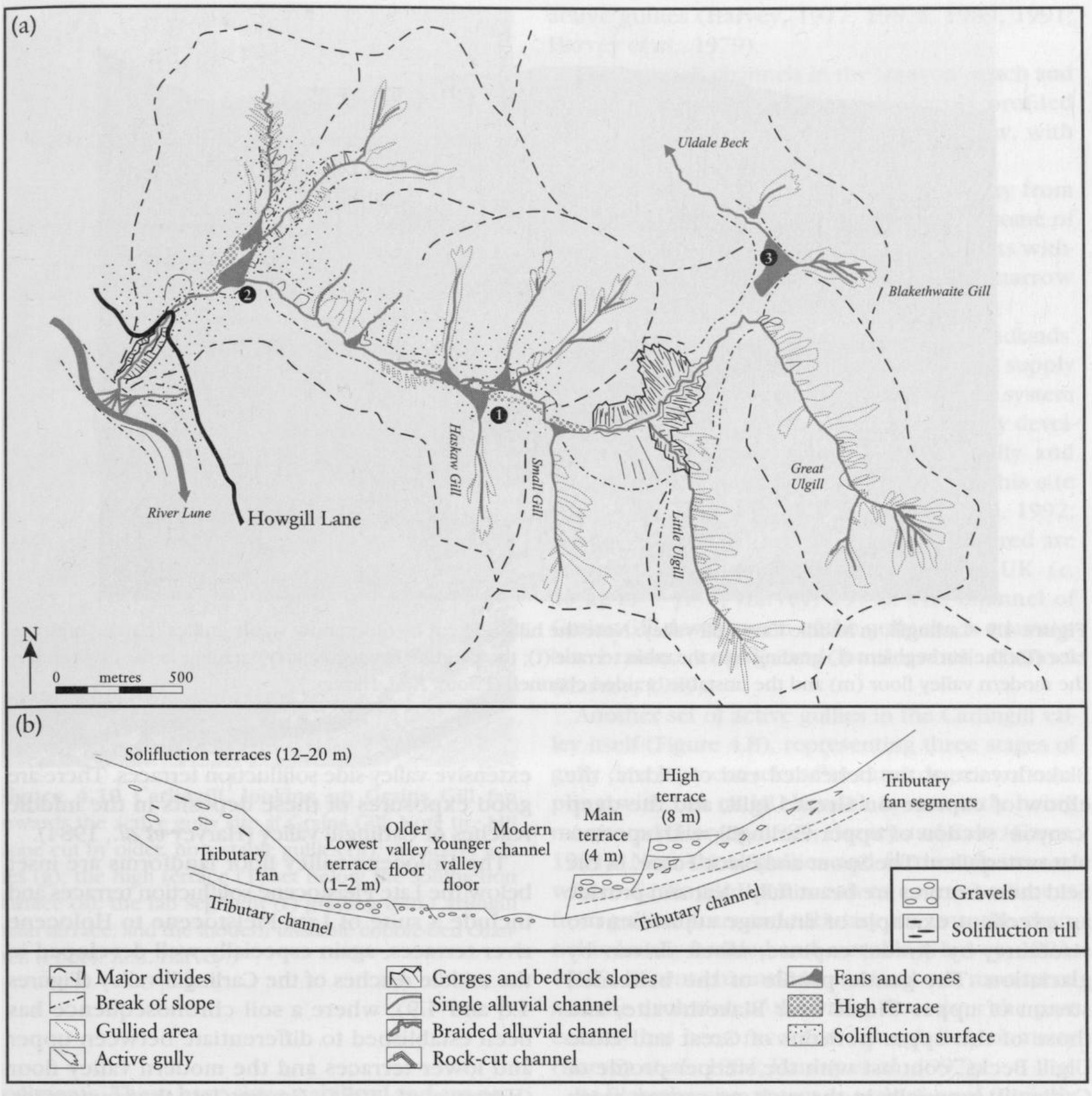

Figure 4.8 Carlingill: (a) geomorphological map. (After Harvey, 1992.) (b) Stratigraphic and geomorphic relationships of features in middle Carlinghill. (After Harvey *et al.*, 1984.)

Carlingill is also a key site for the understanding of the dynamics of modern upland fluvial systems. Gully erosion rates have been monitored at Grains Gill for over 25 years (Harvey, 1974, 1987a,b, 1992a), and continue to be monitored at Grains Gill and in Carlingill (Harvey and Calvo-Cases, 1991; Harvey, 1994). Coupling between hillslope sediment supply and the channel, as well as rates of channel change have been studied at these sites (Harvey, 1977, 1987a, 1989, 1992, 1994, 1997; Harvey *et al.*, 1979, 1984). Studies of Holocene sequences, soils and contemporary erosion and deposition continue, mainly by a group from the University of Liverpool.

Description

Within the Carlingill valley there is an exceptional range of upland fluvial landforms related to longer-term (Pleistocene), Holocene and contemporary timescales.

The longer-term (Pleistocene) development.

During the Late Pleistocene, probably associated with ice or meltwater, strike-aligned upper Carlingill captured the Great and Little Ulgill headwaters of Uldale Beck. The features associated with these captures include the open col at

Figure 4.9 Carlingill, in Middle Carlingill valley. Note the hillslope cut by older, now stable gullies (h); the high terrace (T); the fan segment (f) grading into the main terrace (t); the younger fan segment (y) grading to the low terrace; the modern valley floor (m) and the unstable braided channel. (Photo: A.M. Harvey.)

Blakethwaite at the beheaded end of Uldale, the elbow of capture on Great Ulgill, and the deep 'canyon' section of upper Carlingill, with spectacular waterfalls at The Spout and Black Force. In the field these features are beautifully clear and provide an excellent example of drainage adjustment to structure, by stream capture, albeit driven by glaciation. The gentle profile of the beheaded stream of upper Uldale near Blakethwaite, and those of the upper portions of Great and Little Ulgill Becks, contrast with the steeper profile of Carlingill, especially in the rock-cut canyon reach at the capture site. These landforms provide the context for geomorphic development during the Late Pleistocene and Holocene.

The Late Pleistocene and Holocene Sequence

The Devensian ice sheet had probably melted from this area by *c.* 14 500 BP, and there is no evidence in the Carlingill area of any late stage readvance. Rather, the Late Pleistocene is represented by periglacial forms, which include extensive screes above the 'canyon' reach of the valley. These have locally remained active during the Holocene as the result of continued incision at their base. Elsewhere the lower parts of many of the hillslopes are blanketed by soliflucted glacial till, which forms extensive valley-side solifluction terraces. There are good exposures of these deposits in the middle reaches of Carlingill valley (Harvey *et al.*, 1984).

The Holocene valley floor landforms are inset below the Late Pleistocene solifluction terraces and include a suite of Late Pleistocene to Holocene river terraces, again especially well developed in the middle reaches of the Carlingill valley (Figures 4.8 and 4.9), where a soil chronosequence has been established to differentiate between upper and lower terraces and the modern valley floor (Harvey *et al.*, 1984). Grading into the younger terraces are Late Holocene debris cones and alluvial fans. They are particularly well-developed at Grains Gill and at Blakethwaite, as well as in the middle reaches of Carlingill valley. At Grains Gill a radiocarbon date on buried organic sediments established the main phase of sedimentation as post 2000 years BP (Cundill, 1976) and at Blakethwaite (Figure 4.8) a series of radiocarbon dates establishes and confirms a 10th century AD date for alluvial fan formation (Miller, 1991; Harvey, 1992b, 1996). These findings accord with work elsewhere in the Howgills (Harvey *et al.*, 1981; Miller, 1991), and in the Bowland Fells to the south (Harvey and Renwick, 1987).

The fans and cones were fed by a system of erosional gullies cut into the solifluted glacial

Figure 4.10 Carlingill, looking up Grains Gill fan towards the active gully site at Grains Gill. Note the hill slope cut by older, now stable gullies (h); the active gullies (g); the high terrace (T) set below the solifluction surface (s); the fan segment (f) grading into Carlingill main terrace; and the modern unstable cobble-bed channel. (Photo: A.M. Harvey.)

sediments. These have since stabilized and are preserved as fossil gullies. They are well developed in Upper Grains Gill, Small Gill, Great and Little Ulgills, and at Blakethwaite.

The Modern Fluvial System

Three types of channel characterize the modern fluvial system: (a) rock-cut channels in the 'canyon' reach of Carlingill, and also downstream of the Howgill Lane bridge; (b) narrow, single-thread, often meandering, relatively 'stable' channels; and (c) wide, often multi-thread, unstable channels. The 'stable' channels occur in valleys with little contemporary gully erosion or active hillslope sediment supply, whereas the unstable channels occur downstream of major sediment supply points or active gullies (Harvey, 1977, 1987a, 1989, 1991; Harvey *et al.*, 1979).

The bedrock channels in the 'canyon' reach and below Howgill Lane bridge are steeply profiled with rapids and waterfalls. They are narrow, with little chance for sediment storage.

The channels in parts of Carlingill away from point sources of coarse sediment, and in some of the tributary valleys which drain catchments without active gullying (Harvey, 1991) have narrow single-thread stable alluvial channels.

At Grains Gill, modern active gullies of 'badlands' type dissect older 'fossil' gully systems, and supply large quantities of sediment to the stream system (Figures 4.8 and 4.10). Rates of erosion, gully development, and the coupling between gully and stream system have been monitored at this site since 1969 (Harvey, 1974, 1977, 1987a,b, 1992; Harvey *et al.*, 1979). Erosion rates measured are amongst the highest recorded in the UK (*c.* 40 kg m^{-2} yr^{-1}; Harvey, 1974). The channel of Grains Gill downstream of the gully site is an unstable braided cobble and boulder-bed channel (Harvey, 1989).

Another set of active gullies in the Carlingill valley itself (Figure 4.8), representing three stages of gully development related to three degrees of coupling with the main channel, is currently being monitored (Harvey, 1994; Harvey and Calvo-Cases, 1991). Near these gullies and further upstream, where Carlingill Beck receives coarse sediment from gullies, scars and tributary streams, the channel is locally braided and unstable (Harvey, 1991, 1997). Recent channel change has been monitored and the evolution of the valley floor over the past century has been recorded through lichenometry (Harvey *et al.*, 1984; Harvey *et al.*, 1997).

At Blakethwaite, recent re-activation of formerly stabilized gullies has caused renewed sedimentation on Blakethwaite alluvial fan. This is an excellent example of a small Holocene alluvial fan, with good sections through the (radiocarbon dated) fan deposits. The recent dissection has created a classic alluvial fan morphology with a small fanhead trench to an intersection point in mid-fan with current unconfined distal aggradation below.

There is no evidence of sustained aggradation on the main channel of Carlingill, nor on Grains Gill, despite the high rate of sediment supply to the fluvial system from active gullies. Indeed, during floods the lower reaches of Grains Gill flush away the bulk of the sediment supplied by modern gullying. That sediment reaches a small fan at the confluence of Carlingill and the River Lune.

Interpretation

The Carlingill valley contains an exceptional range of upland fluvial features which relate to three main timescales: the Pleistocene, the Holocene and contemporary processes. The area is open semi-natural grassland and, apart from changes in grazing pressure, both during Holocene deforestation and at the present day, there is and has been no major direct human impact on the fluvial system. This is as near a 'natural' upland fluvial system as exists in England. Furthermore, the area has been the subject of intense study, especially by the University of Liverpool, over the past 25 years, in the contexts of both the Holocene sequence and the contemporary fluvial system. Four areas within the valley are of exceptional importance: (i) Blakethwaite (gully system and alluvial fan, important for both Holocene and contemporary studies); (ii) the 'canyon' reach of upper Carlingill (important for the longer-term development of the drainage system); (iii) the middle Carlingill reach (important for the Holocene terrace and fan sequence, and modern braided channel behaviour; Figure 4.9); and (iv) Grains Gill (the full range of Late Pleistocene, Holocene and contemporary landforms are present here, with gully/fan and gully/channel relationships exceptionally well shown; Figure 4.10). Each of these sites complements the others within the context of the Carlingill valley system as a whole. Features and sequences of deposits have been dated, thus enabling the changes, chronology and interrelationships to be understood more fully. Each of the assemblages of landforms would be distinctive and rare in their own right, but their combination makes this a very valuable site. It has become very important for the degrees and dynamics of coupling between slopes and channels.

Conclusion

Carlingill contains an outstanding assemblage of Late Pleistocene, Holocene and contemporary upland fluvial features. It is important for contemporary studies of Holocene geomorphology and modern processes in relatively undisturbed upland environments. It includes features produced by river capture, exposures of Pleistocene deposits, Holocene slope and channel forms, an alluvial fan with dated stratigraphy, active gullies and recent channel changes.

LANGDALE AND BOWDERDALE VALLEYS, HOWGILL FELLS, CUMBRIA (SD 678977 – NY 675021)

Highlights

These valleys include Holocene alluvial fans and terraces, and meandering and braided channels (Figure 4.11). Features resulting from the effects of a major storm in 1982, which had a recurrence interval in excess of 100 years, are represented by channel changes and alluvial fan and cone deposition.

Introduction

The Langdale and Bowderdale valleys of the northern Howgills are important localities for fluvial geomorphology on two counts: (1) the sequence of Late Pleistocene and Holocene terraces, and Holocene alluvial fans and debris cones; (2) the modern fans and channel systems, especially as affected by the major 1982 flood, an event with a return period in excess of 100 years. The area formed part of Marr and Fearnsides' (1909) study of the drainage evolution of the Howgill Fells and was included in Hollingworth's (1931) study of the effects of glaciation in the same area. In a general sense, the area is described by King (1976). No other studies of the Holocene fluvial landforms were made until recent studies at the University of Liverpool, of the Holocene landform sequence (Harvey *et al.*, 1981; Harvey, 1985a,b, 1992b,c; Miller, 1991), and of the dynamics of the modern fluvial system, especially its response to a major flood event (Harvey, 1985a,b, 1986, 1987a, 1991; Wells and Harvey, 1987).

The area continues to be studied today by the Liverpool group. One recent PhD thesis (Miller, 1991) is based on this area.

Description

As in most other parts of the Howgill Fells, glaciation appears to have ceased with the decay of the Devensian regional ice sheet at *c.* 14 500 BP. Only at Cautley, south of Bowderdale, is there any evidence of (undated) later persistence of glaciation. The Late Pleistocene saw periglacial processes effective throughout the Langdale/Bowderdale area, with screes developing on the steeper slopes,

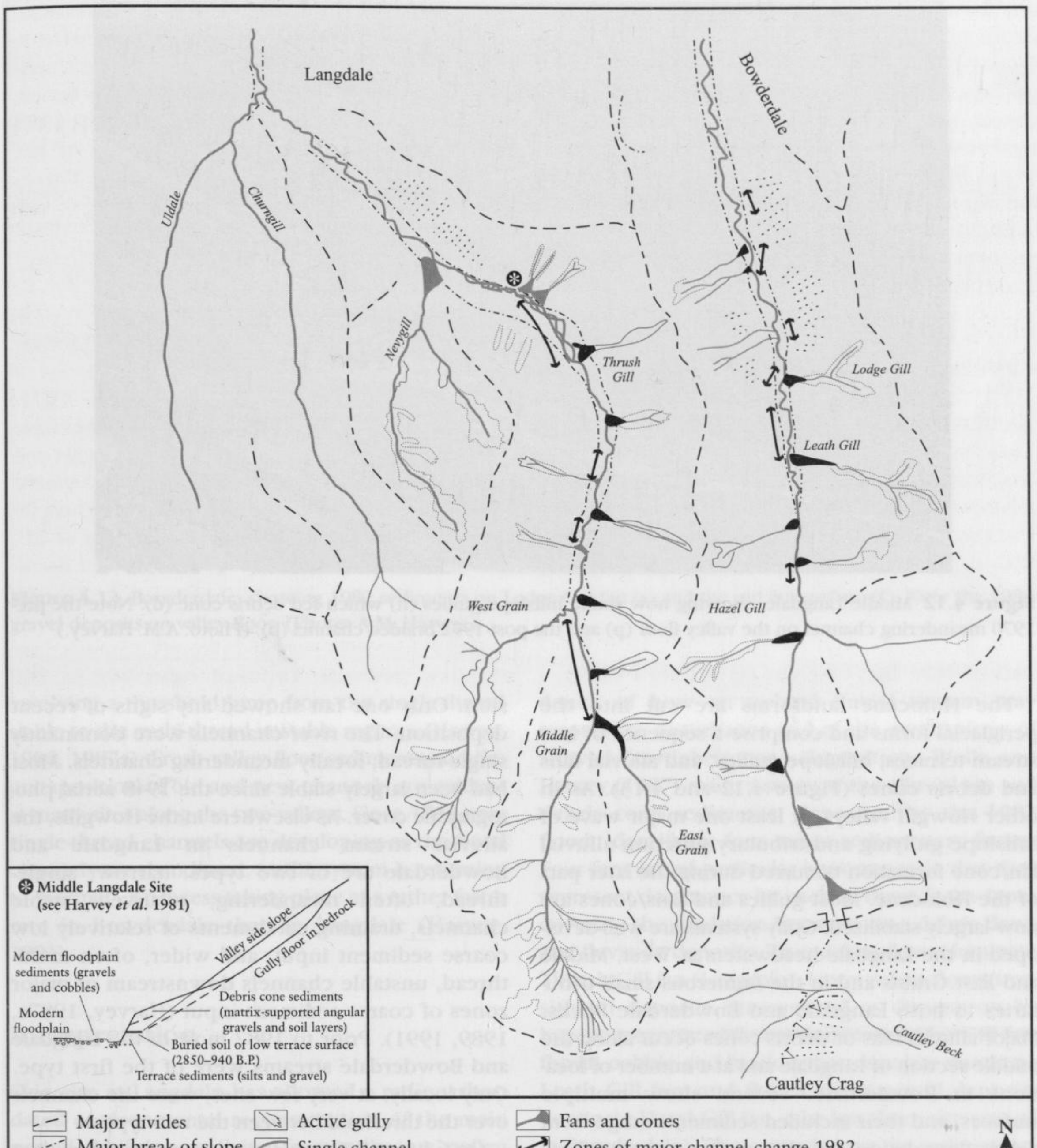

Figure 4.11 Langdale and Bowderdale geomorphological map. The inset shows stratigraphic relationships of the dated sediments in Middle Langdale. (After Harvey *et al.*, 1981.)

as on Langdale Knott in Langdale, and on Hooksey and near Thickcomb in Bowderdale, and stone stripes and garlands formed on the slopes of Hooksey in Bowderdale. There are several arcuate hollows on the north-east facing slopes of Westfell, Bowderdale which may be nivation features. Elsewhere, as throughout the Howgills (Harvey, 1985a), the hillslopes are clad with soliflucted glacial sediments which form gently sloping solifluction terraces towards the base of the valley sides. There is a large area of moulded drift terrain near Woofler Gill in Bowderdale.

Figure 4.12 Middle Langdale, showing now stable hillslope gullies (h) which fed debris cone (d). Note the pre-1970 meandering channel on the valley floor (p) and the post-1982 braided channel (b). (Photo: A.M. Harvey.)

The Holocene landforms are cut into the periglacial forms and comprise a sequence of low stream terraces, hillslope gullies, and alluvial fans and debris cones (Figure 4.12 and 4.13). As in other Howgill valleys, at least one major wave of hillslope gullying and tributary junction alluvial fan/cone formation occurred during the later part of the Holocene. Most gullies and fans/cones are now largely stabilized. Gully systems are well-developed in the Langdale headwaters at West, Middle and East Grains and in the numerous small tributaries to both Langdale and Bowderdale Becks. Major alluvial fans or debris cones occur along the middle section of Langdale and at a number of locations in Bowderdale. Several show multiple surfaces, and their included sediments range from debris flow deposits in the smaller cones to fluviatile gravels in the larger fans (Harvey, 1992b,c). A study of the Holocene soil and geomorphic sequence includes a radiocarbon dated Holocene pollen sequence for Bowderdale, and has developed a regional correlation between the Holocene soil sequences in Bowderdale, Langdale, Blakethwaite and the established sequences in Carlingill (Miller, 1991; Harvey *et al.*, 1984).

Prior to 1982 there had been little recent hillslope erosion or fan deposition. Most of the hillslope gully forms had long been stable, with only a few at the valley heads showing modern erosion. Only one fan showed any signs of recent deposition. The river channels were dominantly single-thread, locally meandering channels. Most had been largely stable since the 1948 aerial photographic cover. As elsewhere in the Howgills, the alluvial stream channels in Langdale and Bowderdale are of two types: narrow, single-thread, often meandering, relatively stable channels, draining catchments of relatively low coarse sediment input; and wider, often multi-thread, unstable channels downstream of major zones of coarse sediment input (Harvey, 1987a, 1989, 1991). Prior to 1982 most of the Langdale and Bowderdale streams were of the first type. Only locally, at very few sites, were the channels over the threshold between the two types.

On 6 June 1982 a major storm occurred, with at least 70 mm of rain falling in about 2 hours over the Langdale and Bowderdale catchments; the storm was estimated to have a return period in excess of 100 years (Harvey, 1986). The geomorphic effects were spectacular. Slope failure occurred on many hillsides, often re-activating formerly stable gullies, and supplying large volumes of very coarse sediment to the stream system. Major deposition took place on 13 debris cones and alluvial fans, in some places completely burying the older forms. Major channel changes occurred at a number of reaches in the two valleys,

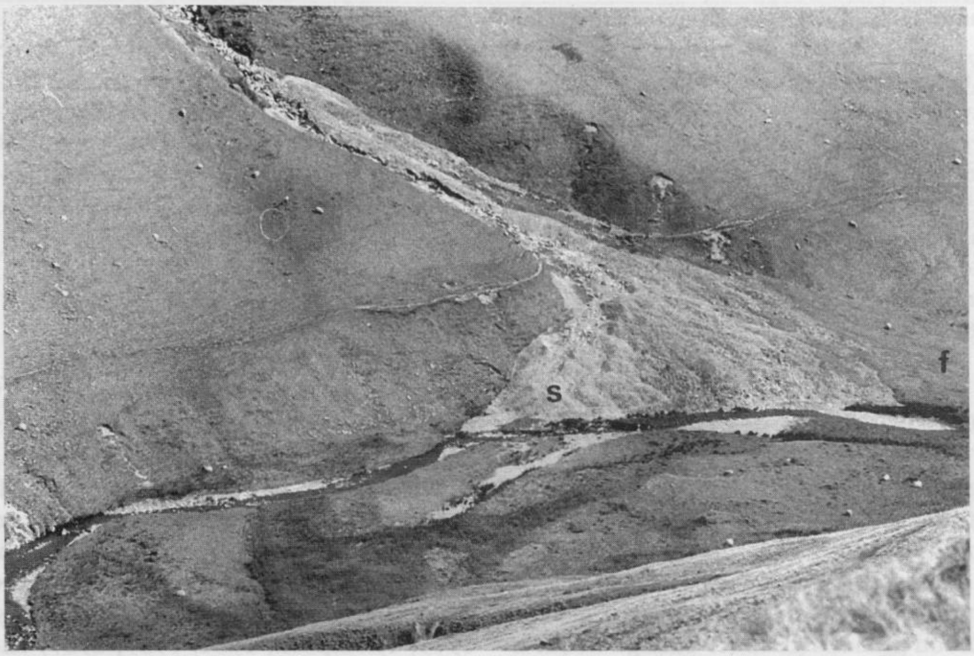

Figure 4.13 Bowderdale, showing 1982 sediments on Lodge Gill fan (s) and the old fan surface (f). Note the 1982 gravel deposits on valley floor. (Photo: A.M. Harvey.)

involving a threshold jump from the single-thread stable to the multi-thread unstable regimes (Harvey, 1986, 1987a). Fresh valley floor sediments and the juxtaposition of old and new channels are evident at many sites along the two valleys. Since 1982 new single-thread channels are developing as the flood channels are abandoned, so the system is returning to 'normal', a process taking place at a rather faster rate in Bowderdale than in Langdale (Harvey, 1991).

Interpretation

One site at Langdale has allowed a radiocarbon dated environmental reconstruction of the main period of hillslope gullying, from sediments, pollen and mineral magnetic evidence (Harvey *et al.*, 1981). Two radiocarbon dates from this site (Harvey *et al.*, 1981), several from Blakethwaite on the Langdale/Carlingill drainage divide (Miller, 1991; Harvey, 1992c, 1996), and several from Bowderdale (Miller, 1991) suggest that the major Holocene period of erosional/depositional activity in these valleys was *c.* 1000 BP. This appears to have been a regional phenomenon, with a similarly timed phase in the Bowland Fells to the south of the Howgills (Harvey and Renwick, 1987).

The response to the 1982 flood provided evidence of how an upland fluvial system may respond to disturbance and of the mechanisms of alluvial fan/debris cone deposition. Wells and Harvey (1987) made a study of the alluvial fan and debris cone sediments, deposited by the 1982 flood, identifying four major sedimentary facies. Four fans are of particular importance in that they represent dominance by each of these facies types covering the gradation between true debris flows and fluviatile deposits. True debris flows dominate Thrush Gill fan (Langdale); stony debris flows/transitional deposits (interpreted as deposition by hyperconcentrated flows) dominate Lodge Gill fan; fluvial cobble and boulder bar deposits dominate Leath Gill fan; and fluvial sheet gravel deposits dominate Hazel Gill fan, (the last three sites are all in Bowderdale). The controls over the sedimentary facies deposited by the 1982 flood (Harvey and Wells, 1987), are similar to those over sedimentary facies forming the 10th century AD alluvial fans and debris cones (Harvey, 1992b,c).

The Langdale and Bowderdale valleys are important for fluvial geomorphology for two reasons. Firstly, they preserve an excellent record of the Holocene upland fluvial sequence, characteristic of the Howgill Fells and possibly other areas of northern Britain, particularly in the well-developed gully systems and associated alluvial fans. Secondly, the 1982 flood has created an important and documented suite of contemporary alluvial fan deposits, and provides an example of flood-induced threshold exceedence between channel pattern types. Furthermore, the area has experienced very little direct human impact and represents as near a 'natural' upland fluvial system as can be found in northern England. Analysis of the impacts of extreme events is important in evaluating their role in landform development and in understanding the mechanisms of change in the landscape.

Conclusions

The Langdale and Bowderdale valleys represent important Holocene and contemporary fluvial localities, exhibiting an excellent suite of Holocene hillslope gullies and alluvial fans and providing a field example, rarely documented or preserved so well, of flood-induced channel change about a major threshold, and recovery from that flood.

LANGDEN BROOK, BOWLAND FELLS, LANCASHIRE (SD 576507 – SD 624505 – SD 595481)

Highlights

This valley has unstable braided reaches, which are relatively rare in north-west England, and has Holocene alluvial fans with good exposures and dating of the sedimentary sequences.

Introduction

The Langden valley is an important fluvial site, exhibiting one of the most active unstable cobble-bed, mainly braided channels in northern England, and preserving a valuable record of Holocene erosion and deposition in a series of dated tributary alluvial fans and cones. Only recently has the Holocene and contemporary fluvial geomorphology received much attention. Previous work on the area deals with Devensian glaciation and has been summarized by King (1976) and by Johnson (1985b). In the past 30 years the Holocene fluvial geomorphology of the area has received considerable attention including four PhD studies from the University of Liverpool (Wilcock, 1967b; Hitchcock, 1977b; Thompson, 1984; Miller, 1991) and one from Newcastle upon Tyne (Wilkinson, 1971). Fluvial studies have previously related to hydraulic geometry (Wilcock, 1967a, 1971), sediment transport and channel changes (Hitchcock, 1977a; Harvey *et al.*, 1979; Thompson, 1985, 1986, 1987) but have also included studies of the Holocene fluvial sequence (Harvey, 1985a; Harvey and Renwick, 1987; Miller, 1991).

Description

The channel of Langden Brook is an active, unstable, cobble-bed channel, with a high rate of coarse sediment transport (Wilkinson, 1971; Hitchcock, 1977a) (Figure 4.14). Two reaches have had a long history of switching between single and braided channels. Changes at both reaches have been monitored over a period of more than 10 years (Hitchcock, 1977a; 1977b; Harvey *et al.*, 1979; Thompson, 1984; 1985; 1987) and documented over a *c.* 100 year period (Hitchcock, 1977b; Thompson, 1984).

Major sediment supply is from Carboniferous gritstone bedrock, exposed especially in the 'canyon' reach in the upper valley, and from periglacial slope deposits derived from this same bedrock. In the upper reaches, gullies cut through the periglacial deposits into underlying bedrock and are a major current source of sediment. In the highest reaches, blanket peat preserves an, as yet unstudied, history of accumulation and dissection.

The major Holocene landforms include a large landslip below Holdron Moss and a series of river terraces in the upper part of the valley. The most interesting Holocene forms are a suite of tributary junction alluvial fans, some of which include organic deposits, for which a series of radiocarbon dates have been derived (Figure 4.15).

Interpretation

Thompson (1984, 1985, 1986, 1987) has analysed the role of different-magnitude events in producing changes in the channel pattern. He interprets the Langden channel as part of a braided to meandering continuum of cobble- and gravel-bed channels, the patterns of erosion and deposition of which reflect the relationships between pool–riffle units and secondary flows. Different-magnitude events and the sequence of flows have been shown to have a profound effect upon the degree of braiding.

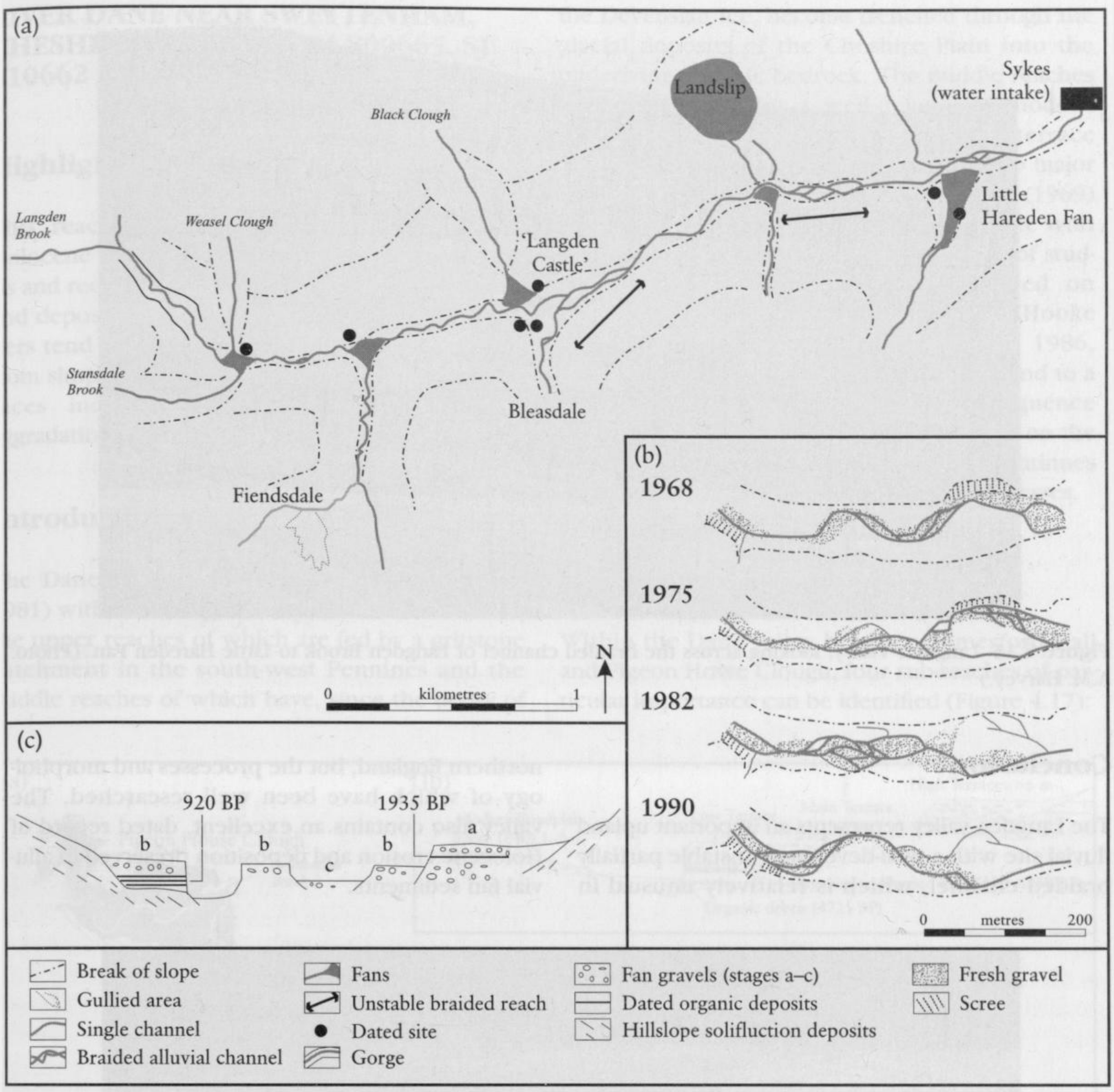

Figure 4.14 Langden (a) geomorphological map. (b) Sequence of channel change upstream of Little Hareden, 1968–90. (After Thompson, 1987.) (c) Stratigraphic relationships of dated sediments at Little Hareden Fan. (After Harvey and Renwick, 1987.)

The radiocarbon dates, obtained from organic layers within the Holocene alluvial fans, suggest two major periods of Late Holocene fan formation, one between *c.* 4000 BP and *c.* 2000 BP and one at *c.* 1000 BP (Harvey and Renwick, 1987; Miller, 1991). The younger phase coincides with a period of fan formation in the Howgill Fells further north (Harvey *et al.*, 1981; Harvey, 1985a, 1992b, 1996; Miller, 1991), and is attributed to accelerated erosion following deforestation in Viking times. The dated fans are at Weasel Clough, Fiendsdale, Langden Castle and Little Hareden Clough (Figure 4.15). A soil chronosequence has been established in relation to the Holocene geomorphic sequence, and put into the context of the Holocene vegetation sequence (Miller, 1991).

Langden Brook is an important site for fluvial geomorphology, primarily because it provides an excellent example of an unstable cobble-bed channel (Figure 4.16) with a history of switching between single-thread and braided habits. It has received a considerable amount of detailed study, which has contributed to our understanding of the relationship between hydraulic geometry, sediment transport and channel stability. It also exhibits a valuable record of Holocene erosional and depositional sequences, preserved in the alluvial fan deposits.

Figure 4.15 Langden Valley, looking across the braided channel of Langden Brook to Little Hareden Fan. (Photo: A.M. Harvey.)

Conclusion

The Langden valley represents an important upland fluvial site with a well-developed unstable partially braided channel, which is relatively unusual in northern England, but the processes and morphology of which have been well researched. The valley also contains an excellent, dated record of Holocene erosion and deposition preserved in alluvial fan sediments.

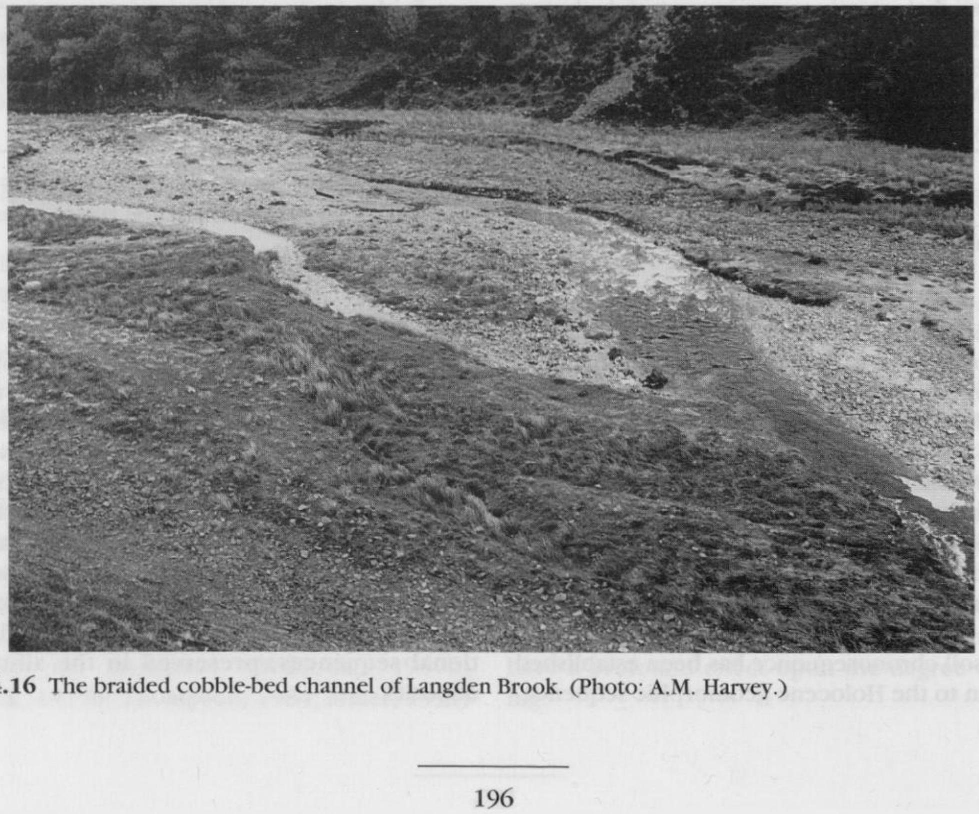

Figure 4.16 The braided cobble-bed channel of Langden Brook. (Photo: A.M. Harvey.)

RIVER DANE NEAR SWETTENHAM, CHESHIRE (SJ 790673, SJ 800665, SJ 810662 AND SJ 819652)

Highlights

This reach includes mobile meanders and a Holocene river terrace sequence. Historical analysis and recent monitoring has shown bank erosion and deposition rates are high, and that the meanders tend to exhibit a sequence of development from simple to complex forms. The Holocene terraces indicate distinct phases of stability, aggradation and incision.

Introduction

The Dane is a piedmont river (*sensu* Newson, 1981) with a mixed gravel/sand/silt sediment load, the upper reaches of which are fed by a gritstone catchment in the south-west Pennines and the middle reaches of which have, since the decay of the Devensian Ice, become trenched through the glacial deposits of the Cheshire Plain into the underlying Triassic bedrock. The middle reaches of the river exhibit a well-developed modern meander belt and a complex postglacial terrace sequence (Figure 4.17). There had been no major study of the fluvial landforms until Johnson (1969) attempted to correlate the terrace sequence with that of the Mersey. More recently, a series of studies, dominated by Hooke, have focused on meander geometry and channel change (Hooke and Harvey, 1983; Hooke, 1984a, 1985, 1986, 1987, 1996; Hooke and Redmond, 1992), and to a lesser extent on the Holocene terrace sequence (Harvey, 1985a; Hooke *et al.*, 1990). Work on the terrace sequence continues and Hooke continues to monitor contemporary meandering processes.

Description

Within the Dane valley between Somerford Hall and Pigeon Howe Clough, four sub-reaches of particular importance can be identified (Figure 4.17):

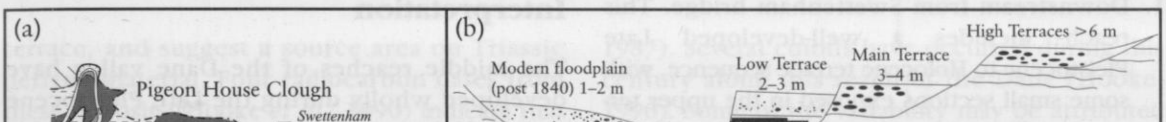

Figure 4.17 River Dane: (a) geomorphological map. (From mapping by J.M. Hooke and A.M. Harvey.) (b) Stratigraphic relationships of dated site downstream Swettenham Bridge. (After Hooke *et al.*, 1990.)

Figure 4.18 The River Dane near Holly Banks, showing the main terrace (T), the low terrace (t), the modern floodplain (f) and the meandering channel with a well developed pool–riffle sequence. (Photo: A.M. Harvey.)

1. Downstream from Swettenham bridge. This reach includes a well-developed Late Pleistocene to Holocene terrace sequence, with some small sections exposed in the upper terrace sediments and excellent river bank exposures of the youngest terrace, including two sites from which three radiocarbon dates have been obtained (Hooke *et al.*, 1990). In the part of this reach between Swettenham Bridge and a point *c.* 700 m to the north-west is a complex series of bends, where development over the past 140 years demonstrates 'double-heading' and the initiation of new meander bends.
2. From Dane Edge upstream for *c.* 700 m. This reach includes the most rapidly changing bends and a major 20th century bend cutoff.
3. From Swettenham Hall upstream to Holly Banks (Figure 4.18). This reach is one of the rapidly migrating bends, but its real value lies in the lack of human interference. Undisturbed wetland habitat occurs in areas of recent channel migration.
4. Somerford Hall Reach. This reach includes active meander bends with very recent and historical cutoffs (Hooke, 1996; Figure 4.19). There are also good terrace sections, demonstrating the stratigraphic relationships between the main and lower terraces. Bend development to double-heading has been monitored in this reach (Hooke and Harvey, 1983; Hooke, 1996).

Interpretation

The middle reaches of the Dane valley have developed wholly during the Late Pleistocene and the Holocene. The river course was probably initiated as a meltwater channel during the recession of the main Devensian ice sheet, perhaps at *c.* 16 000 BP (Worsley, 1985; Harvey, 1985a). Since then it has trenched through the Devensian glacially-related sediments of this part of the Cheshire Plain into the underlying Triassic bedrock. This incision has been marked by the development of a series of river terraces, an upper group of Late Pleistocene age correlating with the main terrace of the Mersey (Johnson, 1969).

There are two groups of younger terraces: the main terrace (Harvey, 1985a; Hooke *et al.*, 1990), composed largely of gravels and sands, apparently derived in part from the gritstone bedrock in the Dane headwater valley in the western part of the Peak District; and the extensive, youngest terrace which differs from the others in that it is composed dominantly of finer material, presumably related to soil erosion in the central part of the catchment, and clearly represents a major phase of recent aggradation. Mineral magnetic analyses (Hooke *et al.*, 1990) indicate a totally different sediment source than for the main

Figure 4.19 The River Dane near Somerford Hall, showing a very tight meander bend that has since developed into a cutoff. (Photo: A.M. Harvey.)

terrace, and suggest a source area on Triassic derived material. Four radiocarbon dates from these deposits (Hooke *et al.*, 1990) indicate that dissection of the main terrace had taken place prior to *c.* 4000 BP and aggradation of the youngest terrace occurred post-1200 BP. Dissection of this youngest terrace has taken place only recently. Inset below the terrace is the modern floodplain, a first-generation floodplain, almost all of which postdates 1840 AD (Hooke and Harvey, 1983; Harvey, 1985a). The implication is that dissection of the terrace occurred not very long before this date. There are excellent sections in the terrace deposits at a number of locations within the area. Soil development differentiates between these two terraces and the floodplain surfaces (Hooke *et al.*, 1990).

The modern floodplain has been deposited by rapid meander migration since 1840. During this time sinuosity has progressively increased (Hooke and Harvey, 1983), but to varying degrees through the reach. Some of this variation can be attributed to progressive changes in bend morphology as individual bends develop through a sequence that characteristically involves migration, followed by growth and finally by a process of double-heading whereby new bends are formed (Hooke and Harvey, 1983; Hooke, 1985, 1987). Several cutoffs have occurred during this century along this reach of the Dane (Hooke, 1996). Some of the variability may be attributed to slope differences (Hooke, 1984a) and some to the development of mid-channel islands (Hooke, 1986). Particularly important is that the Dane displays a range of meander morphologies, and is one of the few actively meandering piedmont rivers in northern England, with relatively little direct human modification of the channel. Important in this context to the conservation of the natural erosional and depositional features, and to wildlife conservation potential, would be a cessation of intermittent channel maintenance by the Environment Agency.

The River Dane is an important fluvial site, demonstrating active meandering and rapid channel change in a relatively undisturbed valley floor environment. It also preserves valuable evidence of Holocene erosion and deposition in the terrace suite. It is one of the few rivers in north-west England, draining an essentially rural basin, where major changes in erosion and deposition in historical times have been documented. More work needs to be done to understand fully the causes of these changes or to model and predict future meander development. The Dane forms an interesting comparison with neighbouring rivers where channel changes have been identified, but in drainage basins more directly affected by urban and industrial development (Knighton, 1972; Mosley, 1975a,b; Hooke, 1996).

Conclusion

The middle Dane exhibits an excellent suite of active meanders, including a range of meander types at various stages of development. They have developed progressively since *c*. 1840 as the river dissected the low terrace and formed the modern floodplain. There is a well-preserved terrace sequence that contains an excellent record, in the sediments, of Late Pleistocene to modern fluvial development.