Fluvial Geomorphology of Great Britain

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Chapter 3

Fluvial geomorphology of Wales

FLUVIAL LANDFORMS AND PROCESSES IN WALES

J. Lewin

Introduction

Fluvial systems in Wales possess three noteworthy characteristics. Firstly, they have an extended evolutionary history of considerable interest, including, in particular, phases of rejuvenation and of glaciation; together, such phases have produced a well-known and attractive landscape mixture of waterfalls, gorges, plateau uplands and flat-bottomed valley troughs. Secondly, present-day fluvial processes acting in Wales create a considerable variety of river types, ranging from upland source area streams, active boulder-bed channels, meandering and braided reaches, through to highly sinuous channels and stable lowland rivers. Thirdly, over recent years a combination of academic interest in fluvial systems and pragmatic concern over river management (the latter arising because river erosion problems are costly, and remedial activities sometimes ineffective) has led to a considerable body of study and research such that many Welsh river reaches have become 'archetypes' that are now internationally well-known.

At the same time, the impacts of afforestation, land drainage and improvement, and river channelization, are modifying fluvial features in the landscape to an increasing extent. These activities are understandable in a country where the land has to serve so many purposes, and their effects on fluvial systems are not without scientific interest. However, in the context of a Welsh 'natural laboratory' it is important that these activities are undertaken wisely and with the greatest care, so that a fully representative range of geomorphologically important sites — where features evolve naturally — remains, and that irremediable modification to river systems does not eradicate or threaten important 'type' sites.

This presents something of a management problem for the conservation of dynamic fluvial systems within designated sites: one may wish natural processes such as erosion and deposition to continue, but decisions must be made about where lines must be drawn around sites so that changing river channel positions (by 2 m or more per year) can be accommodated without either the short-term need to shift site boundaries, or the protection of vast areas encompassing entire fluvial systems which might restrict necessary land use activities. It is essential that the conservation of fluvial systems, at least at a minimum number of sites, allows the ongoing action of fluvial processes and the evolution of river features. Inevitably, this will entail erosion of valley-bottom land in one place and the accumulation of river sediment in another.

The geomorphological development of the Welsh landscape

The long-term geomorphological development of the Welsh landscape has been subjected to many different interpretations. In particular, the various plateau levels have been viewed as the product of either fluvial or marine planation at time periods ranging from the Devonian to the Quaternary. Some may have been exhumed from beneath a Mesozoic cover. An extreme paucity of dated terrestrial sediments that can be linked to planation levels has in fact allowed ideas to range with extreme freedom. In recent years this situation has been somewhat modified both in the light of plate tectonic models (creating a better understanding of the effects of the widening of the North Atlantic and the development of the faulted Welsh massif in a trailing plate margin environment, for example) and also as a result of new and offshore evidence from boreholes such as that at Mochras, Gwynedd, and other land-based sites, and from exploration work in the Irish Sea. These, like the reinterpretation of weathering products fragmentarily preserved, tend to emphasize the Tertiary reduction of landscape features to low-relief surfaces, but also the importance of Neogene faulting and then relative uplift of the Welsh uplands (Battiau-Queney, 1984; Dobson and Whittington, 1987; Penn, 1987).

Quaternary glaciation added trough-like valleys and a widespread (if often thin) veneer of glacial sediments to the region. Again the sequence of events is not very well understood, although it is improving, particularly following examination of marine and coastal sites and the use of better dating techniques (Bowen, 1973; Bowen *et al.*, 1986). Details are not appropriately discussed here, but it must be appreciated that fluvial processes are strongly conditioned by prior glacial activity. During the most recent ice-sheet glaciation, valleys were partially infilled with sediments that present rivers are currently removing. In some places, valleys may also be largely filled with glacial sediment, such that newer gorge sections have been excavated in bedrock to bypass them.

In the Holocene, the landscape has been evolving under fluctuating climatic and human influences; involving, for example, the development of a forest cover followed by its removal, and the development of upland and lowland peat deposits over the past several thousand years. Such conditions have produced fluctuating environments and a range of features.

A simplified model of a Welsh valley, showing the context for present fluvial forms, is given in Figure 3.1. More detailed discussion is available in Lewin (1981b). Streams may rise in high-relief mountains (e.g. Cadair Idris, northern Snowdonia) or on peat-covered moorlands. Waterfalls mark the passage of streams from moorland plateau to valley, although they may also occur in the valley-floor, as in the case of the limestone streams in South Wales (Hepste, Mellte). Slopes may be of cliff and scree type, with debris flows forming a distinctive feature on some steeper slopes.

Valley-bottom features tend to follow a down-valley sequence involving a change from boulder-bed channels, through active braided and meandering reaches, to stable but highly sinuous lowland rivers (Lewin, 1987). Such rivers may be bordered by terraces which generally appear to date from the last (Devensian) glaciation; some valley bench features are probably older, although these are rather poorly studied as yet. Several terrace levels have in fact developed in the past few thousand years, representing a response to varied river patterns (braided, meandering) and sediment supply (notably enhanced soil erosion following deforestation and the impact of mining).

Channel patterns in Wales provide important field evidence for the development of gravel-bed rivers. For example, there are some braided reaches, although these are not common and have probably been largely eliminated by river channelization over an extended time period. Actively meandering channels are common although much modified artificially in the middle reaches of Welsh rivers; in places these may be confined between terrace deposits or narrow valley walls. This gravel-bed meander type is now becoming better known worldwide. Finally, some reaches developed in finer sediments or even lowland peats are comparatively stable.

Both scientific study and management do require that this valuable range of channel types remains available for field study.

GCR site selection

Sites chosen for the 'Fluvial Geomorphology of Wales' GCR Block aim to encompass and represent the broad range of fluvial 'archetypes' discussed

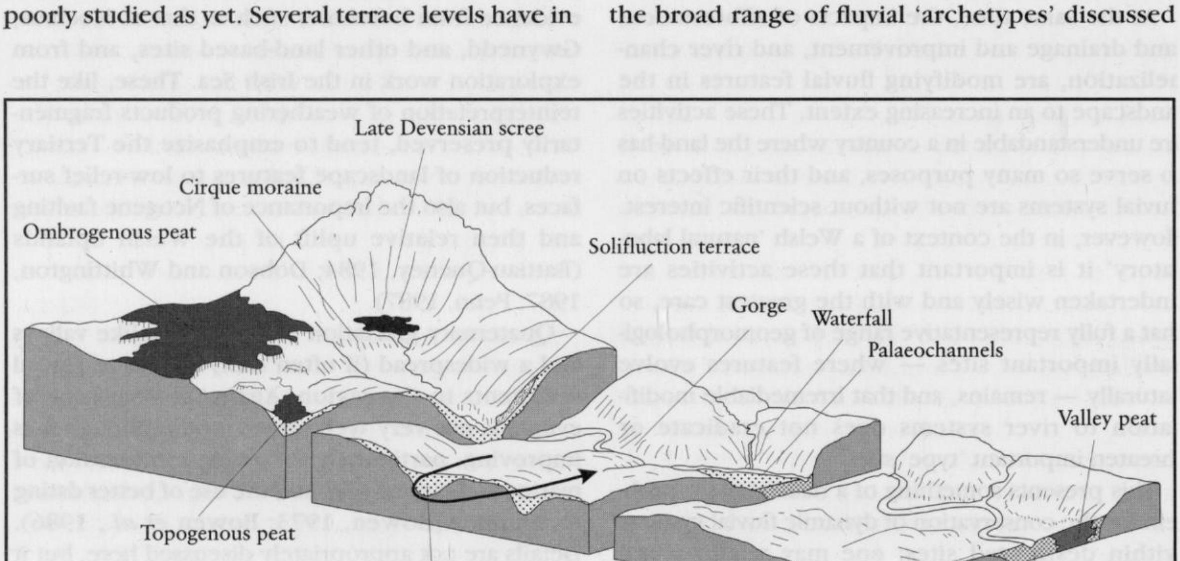


Figure 3.1 The Pleistocene legacy in upland geomorphology: block diagram showing typical slope and valley morphology and deposits. Fluvial activity is seen as superinposed on the morphology and deposits of glaciation and periglaciation. (After Lewin, 1981.)

above. Thus major features developed in bedrock, including both entrenched and ingrown valley meanders, waterfalls, gorges, and the distinctive features of limestone lithologies are represented. Rejuvenation features along river long profiles are also included in the suite of GCR sites. Alluvial sediments and terraces are represented at three sites at which features and developmental phases are known and have been studied.

Finally, features resulting from contemporary processes, ranging from debris flows and pipes in headwater areas through to lowland channel types, are represented in the GCR. Several of these features are included within sites where a considerable amount of scientific work has been undertaken or is anticipated. For example, the behaviour of natural soil pipes on the Maesnant has been the subject of considerable research, and the site may be regarded as a 'benchmark' international site for hydrological work. Similarly, an extended 17.5 km reach of the upper Severn, one of the most unstable sections of natural channel remaining in England and Wales, has been the subject of intensive scientific investigations.

Overall, the GCR sites selected and described in this chapter vary considerably in size and sensitivity to possible modification by inadvertent or deliberate action. It is intended, however, that the conservation of this small number of sites will both allow natural development of their features and enhance the opportunities for future scientific work.

Although sites have been chosen to be prime representatives of the fluvial features of Wales, the landscape has clear affinities with other mid-latitude, humid climate plateau terrains in Europe (e.g. the Ardennes, Thuringia and Bohemia, Brittany and the Vosages) and North America (Appalachia). Therefore, while such landscapes contrast with tectonically active steepland landscapes (such as those in Japan or New Zealand), where fluvial processes may be much more dramatic in form and rate of operation, the Welsh sites do also form valuable comparisons and this adds to their conservation value. Thus the classic braided rivers of South Island, New Zealand, have closely similar sediments to those of the Welsh rivers developed on Palaeozoic shales, so that Welsh and New Zealand gravel-bed rivers do have very valuable points of comparison in process terms, although their tectonic settings are very different.

In summary, the selected GCR sites represent the range of fluvial environments in the Welsh landscape — source areas for water and sediments (including debris flows), bedrock channels and waterfalls, and a range of river types. Conservation of this representative range ensures the continuing existence of archetypal reaches, which in turn allows comparison with UK and worldwide fluvial environments.

AFON LLUGWY BETWEEN SWALLOW FALLS AND BETWS-Y-COED, ABERCONWY AND COLWYN (SH 764577 – SH 791568)

G. Higgs

Highlights

Scenically valuable waterfalls in the Welsh landscape are often associated with glacially deepened valleys. The Llugwy has an assemblage of characteristic forms within a small area, which provides typical examples of geomorphologically important fluvial features.

Introduction

The section of the Afon Llugwy between Swallow Falls and Betws-y-Coed represents the response of the river to the headward extension of the River Conway. There are four major knickpoints (breaks of slope) on the river, set within a glacially overdeepened valley (Figure 3.2). Such deepening occurred, it is suggested, through subglacial drainage rather than glacial scouring (Howells *et al.*, 1978). This has resulted in hanging valley features just west of Betws-y-Coed at Rhiwddolion (777566). Knickpoints in the Llugwy Valley are at Pont-y-Pair (791567), near Miners' Bridge (779571), Swallow Falls (765577) and Cyfyng Falls (735571). These falls are probably the result of the difference in the level between the Conway and the captured stream (Howe and Thomas, 1963); a similar series of four knickpoints can be seen on the Afon Lledr and Afon Machno, although at different levels, which can similarly be attributed to river capture by the Conway.

The source of the Afon Llugwy is in the Carneddau Range at 800 m — just above the remote lake of Ffynnon Llugwy. Like many of the river valleys of the Snowdonia area, the general pattern of the Llugwy seems to be unrelated to the geological structure of the country, in that it cuts across the geological 'grain' of the country and

Figure 3.2 At this GCR site, there is an assemblage of characteristic fluvial landforms within a small area, representing the response of the Afon Llugwy to the headward extension of the River Conway, associated with glacial deepening. (Photo: S. Campbell.)

flows in a direction opposite to the prevailing dip of the strata. However, downstream of Swallow Falls, faults of an easterly to ESE trend partly control the course of the Llugwy. Between Pont Cyfyng and Pont-y-Pari the river descends 150 m in a 7.5 km reach over a series of cataracts. The river flows over slates of the Upper Carneddau Group (Ordovician) as well as igneous intrusions (of the Crafnant–Snowdon Volcanic Group) in which had been cut a series of gorges (e.g. at Swallow Falls and Miners' Bridge). These gorges were formed by a combination of glacial overdeepening and increased fluvial activity through a rejuvenation of the Llugwy by river capture (Howe and Thomas, 1963).

Description

At Pont Cyfyng (735571), 1 km downstream of Capel Curig, the river changes from a low-gradient, non-confined stream with depositional features such as point bars and boulder islands (e.g. at 732576) where the banks alternate between bedrock and fine sediments of alluvial or lacustrine origin, to a 50 m reach immediately downstream of the road bridge where the river is confined, to 3 - 4 m in places, and falls obliquely over a series of rock steps for a combined height of approximately 20 m. Resistant beds stand out to produce a series of rapids, which are separated by deep pools. There are three main cascades, the largest being approximately 5 m in height, separated by confined sections of river. Downstream of these falls the river resumes a low-gradient course with deposits of boulders in mid-channel (e.g. the Stepping Stones at 742572). Downstream of Ty-hyll (756575) the river has a rejuvenated appearance with 2 - 3 m banks of fine sediment which, it is suggested, may represent lake deposits formed by the ponding of meltwater behind the knick point of Swallow Falls (765577) (Howells *et al.*, 1978). Before entering the 50 m gorge, the river widens and forms a series of rapids. There are also depositional features such as mid-channel islands (some of which are vegetated) in this section.

The river flows through the gorge at Swallow Falls for approximately 100 m. Within the gorge there are three main falls, the upstream one of which is the widest. This is a multi-branched fall of about 15 - 20 m in total where the river falls over two main rock benches. The two remaining downstream falls are narrower and more confined. They are also lower in height — 10 m and 5 m respectively — although of a similar type, and are separated by pools in which some deposition of boulder-size material has occurred. Immediately below the gorge the river flows over a series of rock ledges as rapids. There is also a series of embayments where the river has exploited weaknesses in the rock downstream of the falls.

Overdeepening of the main river valley has resulted in the formation of smaller falls on tributary streams, such as the Afon Rhiwddolion (SH 777568) at Rhaeadr Garth. The stream enters the Llugwy at Miners' Bridge, falling over a 12 m precipice, and provides evidence for the rejuvenation of the main Llugwy. Upstream of Miners' Bridge there is a 150 m bedrock-lined section containing a series of rapids. At Pont y Pair in Betws-y-Coed, downstream of a vegetated boulder island, the river crosses a hard sandstone band as a multibranched 3 m fall. The river then becomes confined at the road bridge before becoming more depositional in nature upstream of the confluence with the Conway (798574).

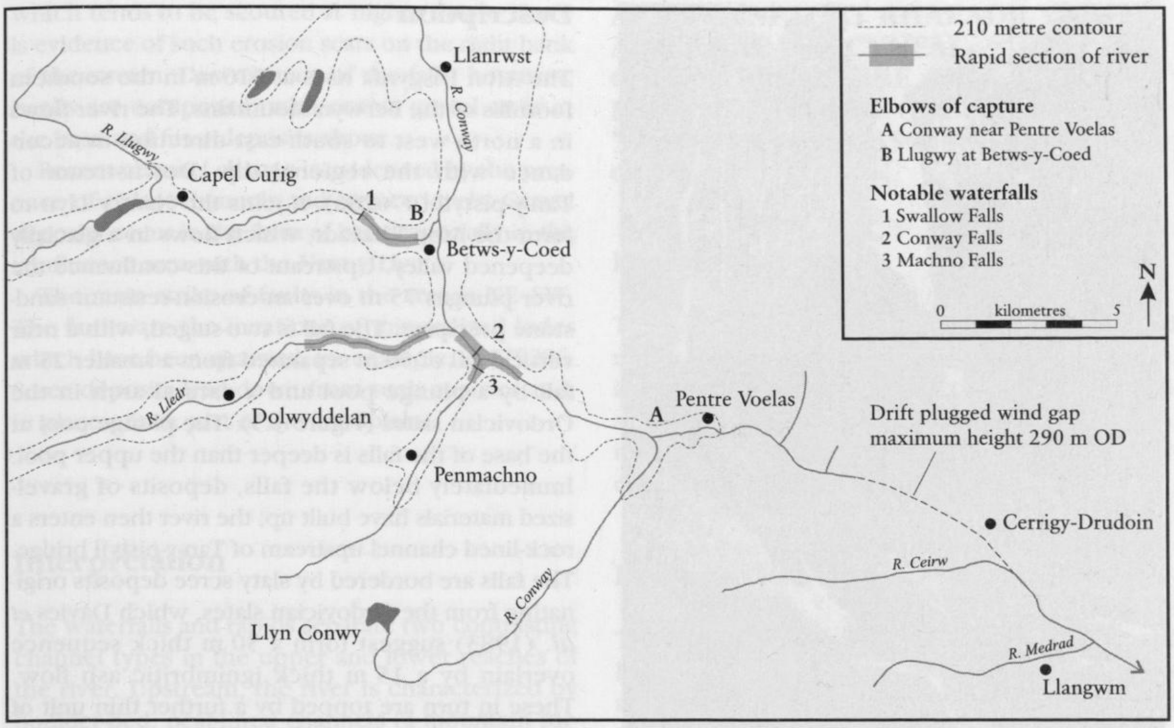


Figure 3.3 The Afon Llugwy: capture of the proto-Dee by the Afon Conwy.

Interpretation

The features of the Llugwy downstream of Ty-hyll are the result of the Afon Conwy retreating along the faulted junction between Ordovician volcanics and the overlying Silurian sediments, and capture of the headwaters of the proto-Dee near Betws-y-Coed. This rejuvenation led to increased river erosion in an already glacially overdeepened valley and to spectacular gorge sections at Pont Cyfyng, Swallow Falls and Miners' Bridge, gorge sections which are also mirrored on the Lledr and Machno tributaries of what is now the Afon Conwy (Figure 3.3). Such overdeepening, it was suggested, was achieved 'by subglacial drainage rather than glacial scouring' (Howells *et al.*, 1978). Few tracts of boulder clay remain in the present valley of the Llugwy. However, fine sediments exist upstream of the four knickpoints of the Llugwy, in the form of lacustrine deposits which are now being reworked by the present river. Further evidence for the overdeepening of the river valley occurs in the form of the tributary streams which enter the main stream as waterfalls. The importance of this site therefore arises from the overall assemblage of features within a relatively confined area, and from the three sets of falls separated by more typical mountain torrent zones.

Conclusion

The Llugwy site comprises a series of waterfalls and gorges separated by low-gradient, less confined reaches. These features were formed by steepening due to river capture and glacial overdeepening of the valley, and are excellent representatives of such landforms, which are quite common in Wales, particularly in Snowdonia.

AFON RHAEADR AT PISTYLL RHAEADR, POWYS (SJ 068297 – SJ 078287)

G. Higgs

Highlights

The falls at this site are the largest in Wales, and are spectacular under high-flow conditions. In detail, they illustrate the close relationship between their form and underlying lithology and geological structure.

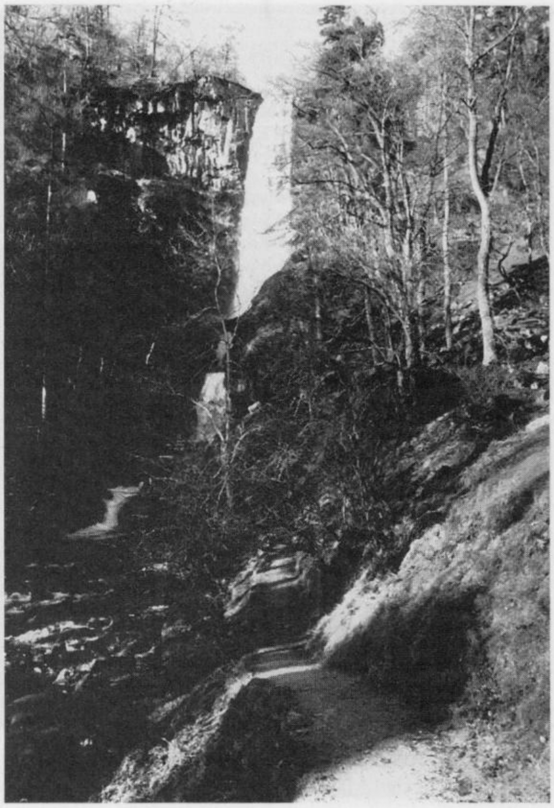


Figure 3.4 Pistyll Rhaeadr. With a drop of 75 m from a sandstone precipice, this waterfall is the highest in Wales. (Photo: S. Campbell.)

Introduction

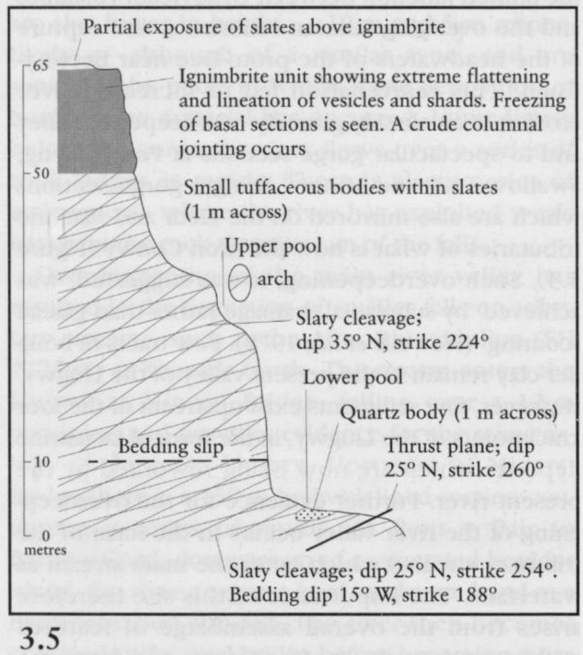
Pistyll Rhaeadr on the Afon Rhaeadr is, at 75 m, the highest waterfall in Wales (Figure 3.4). It is at the head of Cwm Blowty, 6 km north-west of Llanrhaeadr-ym-Mochnant. The falls mark the boundary between an upland boulder-lined channel originating in peat, and downstream sections with characteristic point bar depositional features. Water falling over the protruding bedrock benches of Ordovician slates has created a series of plunge pools. The upper and lower pools of the fall are separated by an arch formed by the river exploiting weaknesses in the bedding planes of the slate.

Below the waterfall, the river widens and there is a reduction in velocity such that for a distance of half a kilometre or so, boulders of up to 1 m in diameter have been deposited. More resistant beds of rock below the falls have resulted in the formation of a series of rapids.

Description

The Afon Disgynfa rises at 610 m in the southern foothills of the Berwyn Mountains. The river flows in a north-west to south-east direction in accordance with the regional dip. Downstream of Tan-y-pistyll (076286), it joins the Nant y Llyn to form the Afon Rhaeadr, which flows in a glacially deepened valley. Upstream of this confluence the river plunges 75 m over an erosion-resistant sandstone precipice. The fall is two-staged, with a near vertical fall of 50 m separated from a smaller 25 m fall by a plunge pool and a natural arch in the Ordovician slates (Figure 3.5). The plunge pool at the base of the falls is deeper than the upper pool. Immediately below the falls, deposits of gravel-sized materials have built up; the river then enters a rock-lined channel upstream of Tan-y-pistyll bridge. The falls are bordered by slaty scree deposits originating from the Ordovician slates, which Davies *et al.* (1983) suggest form a 50 m thick sequence overlain by a 15 m thick ignimbritic ash flow. These in turn are topped by a further thin unit of slate.

Upstream of the falls, the river drops 40 m in the space of 100 m by way of two smaller waterfalls, the lower of which is separated into three minor branches before entering a plunge pool. In this upstream section, the channel has a boulder bed, but the banks are dominated by finer material



3.5

Figure 3.5 A section through Pistyll Rhaeadr, at SJ 073295.

which tends to be scoured at higher flows. There is evidence of such erosion scars on the right bank of the stream. Downstream of the falls, however, banks are composite, with coarse gravel units at the base and finer deposits above.

Recent channel change is evidenced by the presence of palaeochannels and terrace levels. Gravel deposits occur in the form of bars, especially in the confluence area with the Nant y Llyn.

The main strike of faults in the area is NE–SW. The faults are the locations of mineralized lodes which have been quarried, for example, at 075286. Scree deposits lead down from such quarries and, in places, form part of the floodplain.

Interpretation

The waterfalls and rapids separate two contrasting channel types in the upper and lower reaches of the river. Upstream, the river is characterized by boulder-bed, peat-lined channels (a mountain torrent type channel), whereas downstream the channel is more typical of a meandering river, with gravel bars and composite banks. Juxtaposition of the two types of channel is particularly abrupt here, and the contrast is on a more spectacular scale than at many other sites at which the transition is progressive. The falls themselves owe their origin to the outcrops of resistant slate and ignimbrite, and the effects of glacial overdeepening of the downstream valley. The detailed characteristics of the falls are influenced by the structural and lithological variations in the Ordovician bedrock. There is evidence of channel change across a glacially overdeepened valley floor. The falls at Pistyll Rhaeadr are, in addition, the largest in Wales at 75 m and have unique features, such as the natural arch formed by weaker bedding planes in the Ordovician slates.

Conclusion

The Rhaeadr falls are the highest in Wales and mark an abrupt transition from an upland mountain torrent flowing through boulders and peat, to a lowland meandering stream. The formation of the falls themselves and their detailed structure are due to the geological characteristics and the glacial history of the area.

AFON CYNFAL AT RHAEADR Y CWM AND RHAEADR CYNFAL, CAERNARFONSHIRE AND MERIONETHSHIRE (SH 701413 – SH 714409 AND SH 735414 – SH 741417)

G. Higgs

Highlights

This series of confined bedrock channels and rapids, with associated features such as potholes, is thought to have been formed by successive incision of the channel over a long timescale. As such, it is a good representative of what is termed 'polycyclic' river development.

Introduction

The Afon Cynfal between Rhaeadr y Cwm and Rhaeadr Cynfal provides an excellent example of an integrated river system with a sequence of waterfalls and rapids set within two steep-sided gorge sections (Cwm Cynfal and Ceunant Cynfal; Figure 3.6) separated by a low-gradient section with more active planforms and with a range of depositional features . There are thus important contrasts between the upper and lower reaches of the river as well as between the characteristics of the two sets of waterfalls themselves. The river provides a good example of 'polycyclic relief' (Howe and Thomas, 1963) and it has been suggested that the river has responded to at least three distinct base levels, with two main platform levels at 400 – 500 m and at 200 m.

Description

The Afon Cynfal drains westward from Migneint in an area composed of Cambrian rocks and which is characterized by prominent platforms or 'surfaces' in the relief.

The Afon Cynfal, like the nearby westward-flowing Teigl and Prysor rivers, displays a long profile characterized by conspicuous knickpoints (breaks of slope) separated by wider river valley sections. It rises at 500 m at the Migneint moorland region (in Llyn Dywarchen) and for the first 3.5 km flows over a 400 – 450 m plateau as a low-gradient stream, with banks dominated by fine peaty materials and with pools separating rapids resulting from outcrops of resistant Cambrian grits and

Figure 3.6 A steep-sided gorge section of the Afon Cynfal. (Photo: S. Campbell.)

shales. Approximately 500 m west of Pont yr Afon Gam, the first prominent knickpoint on the Cynfal is evident as a gorge section culminating in Rhaeadr y Cwm (736415). The gorge is approximately 600 m long and separates the upland plateau from a 200 - 250 m platform at Bont Newydd (714408). The river drops 125 m in this gorge before assuming a low-gradient course at Cwm Farm (734413). There are six major cascades with minor rapids lower down the gorge.

The river is largely rock-lined, although in places there are local deposits of coarse gravel derived from adjacent scree slopes — especially those on the right bank. The bed is lined by boulders, some over 1 m in diameter, and transport processes are dominantly of the bedload type. The largest fall in the series is approximately 20 m, over two stages, with a vertical drop over a protruding bedrock bench of about 15 m. Plunge pools separate cascades, which appear multi-branched at low flows. Approximately 100 m downstream of the lower falls, the river fans out into a wider valley section. Here the river is characterized by depositional forms such as mid-channel bars (e.g. at Cwm Farm), some of which have been vegetated. The river at this point is tree-lined and has created a small floodplain.

The river then flows over this 250 m platform for 2 km. However, another conspicuous knickpoint is seen in the gorged section of Ceunant Cynfal downstream of Bont Newydd (714408), where again there are large-scale sequences of cascades and waterfalls controlled by bedrock. This tree-lined gorge of the Cynfal extends to 100 m in depth at the Cynfal falls (704413). In places, flow is confined by slot gorges to approximately 1 m in width. This has concentrated erosion in downstream sections so that there are local embayments within the gorge with etch marks at varying levels 2 - 3 m above low flow, indicating erosion at high flood flows. In places, material has slumped into the river creating localized deposits of boulders, some 2 m in diameter. In other places, for example 20 m downstream of a footbridge (705412), angular blocks of material derived from the adjacent slopes are present at the base of the gorge. Between this footbridge and the Cynfal falls there is a column of bedrock rising 7 - 8 m above the stream, known locally as Hugh Lloyd's Pulpit. Upstream, there is a series of rapids resulting from the presence of resistant beds of the local Cambrian slates. The section also provides examples of potholes at a variety of scales, which are clearly visible at low flows. The reach is dominantly bedrock, although there is evidence of local deposition downstream of the railway bridge (709409) and where tributary valleys enter the main gorge of the Cynfal. Below the 20 m falls at Rhaeadr Cynfal the river enters a 100 m gorge, before entering the Afon Dwyryd 2 km downstream.

There are minor falls (generally less than 5 m) upstream of the railway bridge . The gorge narrows to less than 5 m wide at such falls and has resulted in embayments in the sides of the gorge immediately downstream, in which cobble-sized material is deposited in low flows. The river broadens out in a reach approximately 20 m upstream of the railway bridge but is again confined to a 10 m wide section. There are three main sets of falls downstream of the railway bridge; the first of these are 2 - 3 m in height, and the second set is a two-stage fall about 10 m in height with a prominent plunge pool in which have been deposited boulder deposits, downstream of which the river is confined to 1 m in places, suggesting much lower width : depth ratios in this reach than those further upstream. At 100 m below this footbridge the Cynfal falls down three steep declivities of rock for a total of about 20 m. The stream is approximately 7–8 m wide at the top of these falls, but narrows again so that embayments at varying levels are obvious at low flows in this section. The gorge section downstream of Bont Newydd is approximately 1200 m long and the river eventually joins the Dwyryd at 10 m above OD, providing an important contrast to those reaches of Cwm Cynfal where the channel is less constricted and features are depositional rather than erosional.

Interpretation

The long profile of the Afon Cynfal represents the response of the river to rejuvenation that developed over a considerable period of the Quaternary. Such a process occurred at three base levels, as suggested by the two prominent steepenings, interpreted as knickpoints at Rhaeadr y Cwm and Rhaeadr Cynfal adjusted to base levels associated with the 400 m, 250 m and near present surfaces respectively. The rejuvenation has led to a dramatic change in river character at these points, and has created a range of features that contrast with those of reaches flowing over the intervening plateau areas. The channel morphology also provides an example of the response of a river to bedrock control in its lower reaches, with flow being confined to 1 m in places and embayments forming immediately downstream where erosion has been concentrated at varying levels. There has been considerable channel steepening, leading to the formation of prominent stepped waterfalls and rapids in the lower Cynfal. In addition, the nature of the gorge leads to high velocities in flood flows such that large boulders have been deposited in some sections. Further evidence of rejuvenation appears in the form of tributary streams (e.g. at 738417) which have a hanging valley relationship to the main stream. Howe and Thomas (1963) suggest that these features of a stepped long profile are common to the westward-flowing rivers of North Wales, and in particular to the Teigl and Prysor rivers, and that '... the Cynfal thus presents a superb example of polycyclic relief with three distinct base levels' (Howe and Thomas, 1963).

Conclusion

At this site there is a series of confined bedrock sections and falls with associated features such as potholes. The confined sections occur at different levels, separated by the falls. It is thought that each represents a phase of development related to that base level and that the falls were formed by incision to the next lower level. As such, the whole is interpreted as a particularly good representative of what is termed polycyclic development, which has resulted in these large-scale stepped profiles, characteristic of westward-flowing streams in North Wales.

AFON TWYMYN AT FFRWD FAWR, POWYS (SN 869955 – SN 873940)

G. Higgs

Highlights

This is an unequivocal case of upland river capture by a steeper westward-flowing river. At this site there is a set of classic features that is rarely so complete, although the features are not easily dated or straightforward to interpret.

Introduction

The Twymyn at Ffrwd Fawr (SN 873939) provides an excellent example of the response of a river system to rejuvenation, in this case due to the capture through headwater retreat of a river that originally flowed eastwards to enter the Clywedog catchment (8893). Subsequently, the river flowed northwards, leaving remnants of an old river valley as a dry col. Little work has been done to identify the date of such a capture, but a later period of glacial deepening of the valley has created a spectacular gorge section. The river downstream of the gorge reverts to one characterized by downvalley meander loop translation, with gravel deposition features and evidence of recent channel change, including abandoned channels (Lewin, 1983).

Description

Three kilometres from its source, the Afon Twymyn falls 50 m over Silurian sandstones at Ffrwd Fawr before entering a 350 m deep gorge. Downstream of the waterfall, the river is constricted to a bedrock channel less than 2 m wide in places. Harder bands of shales and grits are preserved as overhangs on the face of the falls, which is one of the highest virtually unbroken descents of

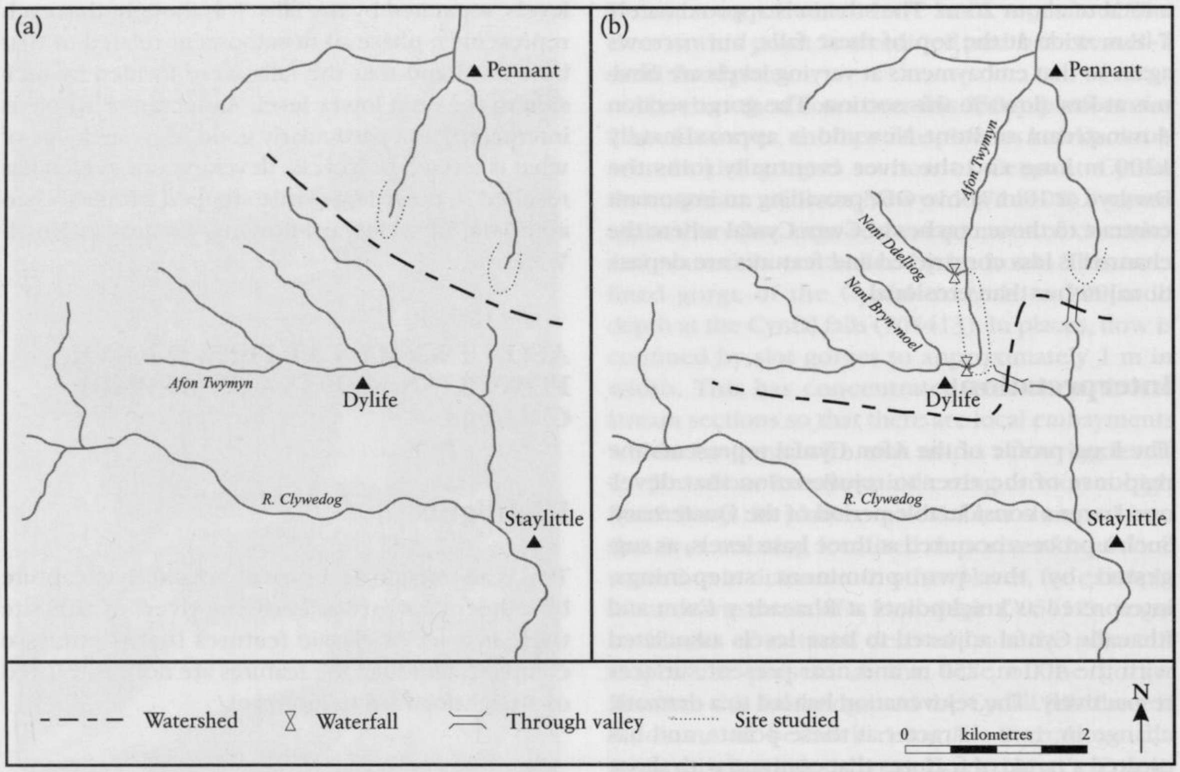


Figure 3.7 The Afon Twymyn: drainage changes near Dylife.

water in Wales. At the base of the falls there are blocks of sandstone up to 2 m in length. The bedload of the river at this point is largely angular, suggesting that the face of the falls as well as the adjacent rock slopes provide active inputs to the system. For 50 m below the waterfall, the river flows in a relatively shallow gradient bedrock channel before being confined further at a smaller waterfall (with a 20 m fall). The gradient increases for a further 100 m upstream of a sharp elbow-bend in the river course, which represents the point at which the river once flowed eastwards but now has been captured (Figure 3.7). The right bank of this section shows evidence of soil creep and erosion scars where there has been active input into the system of finer material, whereas the left bank is characterized by scree deposits at the base of rock slopes. In some places such debris has been colonized by vegetation and is relatively stable at low flows. However, there is evidence of some basal undercutting of such deposits at higher flows with overhanging vegetation, so that, in addition to the active input from the adjacent scree slopes of largely angular material, there is also input to the system of finer silt-sized material in flood events. This has been aided in places by the effects of sheep grazing which has resulted in the destabilization of banks.

After a decrease of just over 100 m in altitude over 1.25 km, the river enters a widened valley as it approaches Pennant (875955). Here the section is characterized by depositional features such as gravel point and counterpoint bars. Such features, as well as the nature and extent of channel change, have been examined for a lower section of the Twymyn (SN 885998) by Lewin (1983).

As well as rejuvenation of the main stream, river capture has resulted in the downcutting of the tributaries of the Twymyn, and in particular that of Nant Bryn-moel (SN 864947), upstream of the falls, and that of Nant Ddeiliog (SN 867953) downstream of Ffrwd Fawr. These tributaries have coarse material in their channels, but provide active inputs to the system only during extreme events. There is evidence of erosion of bedrock in places and of the undercutting of superficial debris by such tributaries. These materials are deposited as scree at the base of slopes, which is removed only during extreme events.

Interpretation

The formation of the Ffrwd Fawr waterfall and the spectacular gorge of the Twymyn has been attributed to the actions of glaciers in the overdeepening of the valley, and in the headward erosion of cirque glaciers. The original flow of the Twymyn was eastwards, until it joined the Clywedog (Figure 3.7a). However, the headward retreat of the watershed resulted in the capture of this proto-stream (Millward and Robinson, 1978). This capture was aided by local faults (which were the locations of the minerals mined in the 1870s and 1880s (notably the Ty Isaf and Llechwedd lodes)), and by the differential erosion resulting from the geological strata of shales, grits and sandstones of the Middle and Lower Llandovery series (Silurian). The dry valley that remained after this capture (Figure 3.7b) is now occupied by conifer trees and is at a higher level than the present channel, suggesting that capture has resulted in the rejuvenation of the stream. Such a hypothesis, Millward and Robinson suggested, is supported by the generally easterly flow of the tributaries, Nant Bryn-moel and Nant Ddeiliog, and the rejuvenated nature of the latter, which culminates in a waterfall. It was further proposed that such capture was recent, although no work has been done to confirm this. The misfit stream of the Afon Nachog which enters the Clywedog Reservoir (885923) is totally out of proportion to the size of the valley, which would tend to confirm the case for river capture. Thus the features of the Twymyn would seem to result from a combined effect of river capture, glacial overdeepening and preferential erosion of softer Silurian rocks, together with the influence of local geological structure (fault zones). The river is unique in terms of the assemblage of features in such a confined area, showing the relationship between river capture, glacial effects and geological controls.

Conclusion

This site comprises features typical of river capture, but waterfalls and a gorge also owe their formation to glaciation and the influence of bedrock control.

AFON GLASLYN AT ABERGLASLYN, CAERNARFONSHIRE AND MERIONETHSHIRE (SH 595458 – SH 592472)

G. Higgs

Highlights

This is a gorge section with steep-gradient rapids on a relatively large Welsh river, which has a suite of representative river features. It is transitional between reaches of more gentle gradient with floodplains. The bedrock channel contains some large, locally derived slope materials.

Introduction

The Afon Glaslyn at Aberglaslyn is an example of a laterally stable channel confined by a 200 m deep gorge, where the size of the sediment currently occupying the channel is out of all proportion to anything transported by the present-day river (Figure 3.8). The reach consists of a boulder-bed channel, with such boulders ranging up to a maximum of 5 m in diameter. The characteristics of this 600 m reach — in terms of bedload, bank types, mobility and long profile — contrast with sections both upstream and downstream of the gorge of Pont Aber Glaslyn (593462) where the river is less confined, more laterally unstable and has a range of depositional features not observed in the gorge section. There is limited active input from the slopes of this gorge, so that the present-day river must be reworking deposits left by previous glaciations. Sediment transport is dominantly by bedload, although there is evidence of the overbank sedimentation of fines, especially in the wake of vegetated islands after high-magnitude events. The composite profiles of the Glaslyn valley may represent successive stages in episodic rejuvenation of the river to former base levels.

Description

For the majority of its course, the Afon Glaslyn flows in a glacially overdeepened valley where it is largely unconfined such that traces of old channels and/or terraces are seen locally (e.g. between Beddgelert (592481) and the footbridge at 592474), indicating a degree of lateral mobility. Upstream of Beddgelert the river passes through Llyn Dinas and

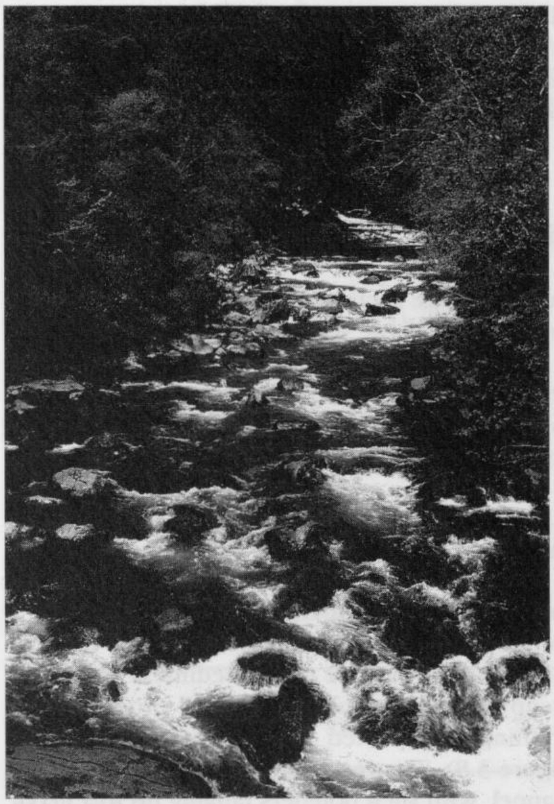


Figure 3.8 Steep-gradient rapids on the Afon Glaslyn. (Photo: S. Campbell.)

Llyn Gwynant. At Beddgelert it is joined by the Afon Colwyn. The river at this point is typical of many lowland rivers of Wales, with composite banks comprising up to 30 cm of fine to medium gravel, overtopped by a finer 70 cm unit of sediment that contains cobble-sized material. The river is of a shallow gradient, typically has riffle–pool sequences and has depositional features such as point bars, counterpoint bars and mid-channel islands. The channel is migrating across a 500 m wide floodplain and there is evidence of meander scrolls and sections of abandoned channels. In the case of the meander immediately upstream of the footbridge (592474), abandonment has been carried out artificially by the construction of a wall at the neck of the channel, so that an area of slackwater remains.

Between the footbridge and Pont Aber Glaslyn (595462) the characteristics of the river change in that it becomes steeper in gradient and is confined in a 200 m deep gorge. The channel here is lined by bedrock, in some places up to 4 m in height, especially on the right bank. The left bank is characteristically dominated by bouldery deposits, with some boulders up to 5 m in diameter, which were derived from a previous period of glacial erosion and subsequent periglacial activity on the slopes of the gorge. The river cuts obliquely across a series of rock bars, creating a sequence of rapids in the section (e.g. at 596464), some of which fall over 2 – 3 m of bedrock. Much of the material present is angular, suggesting that it has not been fluvially transported but is derived from the adjacent slopes. Immediately downstream of the largest sequence of rapids is a deep pool where there are deposits of boulders up to 1 m in size, orientated in a downstream direction. In the lee of such deposits, finer gravels accumulate at low flows. There are also deposits of boulders in mid-channel which are not being moved under present river conditions, even during extreme events.

Downstream of the gorge section the river is characteristically of lower gradient, with deposits of finer gravels and riffle–pool sequences. The river has a meandering thalweg and there are depositional features such as mid-channel bars (e.g. opposite Aberglaslyn Hall (595462), where a bar up to 40 m in length has been formed). In addition, there are point and counterpoint bars 50 m downstream of Pont Aber Glaslyn. Much of this material is transported through Aberglaslyn Pass during extreme flooding events. There are also floodplain features such as palaeochannels and terraces.

Interpretation

The channel changes from a 'typical' mountain torrent with a bed of coarse boulders and a confined planform to a wandering gravel river more typical of lowland Welsh rivers, with gradual lowering of channel slope and widening of the floodplain. There is an area of extensive deposition immediately downstream of the gorge section where older, more stable depositional features are intermixed with recent active point bars. The reach, therefore, appears to be one in which transport processes during extreme events are dominated by bedload mobilization. Fluvial deposition within the confined reach is restricted to an area just upstream of the A4085 road bridge on the outside of the bend. The deposited material tends to be of a more coarse nature than that further downstream in the unconfined reach. Some coarse, angular material within the gorge shows no evidence of fluvial transport and has been derived from the slopes under glacial and periglacial conditions.

The section of the Glaslyn in Aberglaslyn Pass provides an excellent example of a steep-gradient, bedrock-confined reach in the lower reaches of a Welsh river. The river is notable for a major transition in character in the space of less than a kilometre from a low-gradient, laterally active stream to a 'typical' mountain torrent (with characteristic boulder deposits and resistant bedrock benches leading to rapids) and back to a lowland-type stream where depositional features such as mid-channel bars and point and counterpoint deposits are prominent. The river then enters a wide floodplain area, some of which is of marine origin, where transport of dominantly finer sediments occurs.

Conclusion

An excellent range of contrasting river features is represented within a short distance on the Afon Glaslyn, with a transition from a low-gradient, mobile and unconfined stream to a gorge containing large boulders, and then back to a lowland meandering stream with typical depositional features.

AFON TEIFI AT CENARTH, CARMARTHENSHIRE (SN 269416 – SN 276418)

G. Higgs

Highlights

Glacial infilling of entrenched valleys, with subsequent fluvial erosion of new bedrock gorges, has produced distinctive narrow incised sections on some lowland Welsh rivers, of which this is an excellent representative.

Introduction

Gorges are a persistent feature of the middle and lower Teifi Valley (Figures 3.9 and 3.10). There are nine major gorges (Allt-y-Cafan, Llandysul, Craig Gwrtheyrn and Llanllwni studied by Price, 1977; and Kenllan, Newcastle Emlyn, Cenarth, Cilgerran and Cardigan mentioned by Lear, 1986). In his 1965 paper, O.T. Jones has described each gorge and divided them into two general types: those that are cut through a rock spur projecting into clay-filled meanders, of which the Cenarth site is an

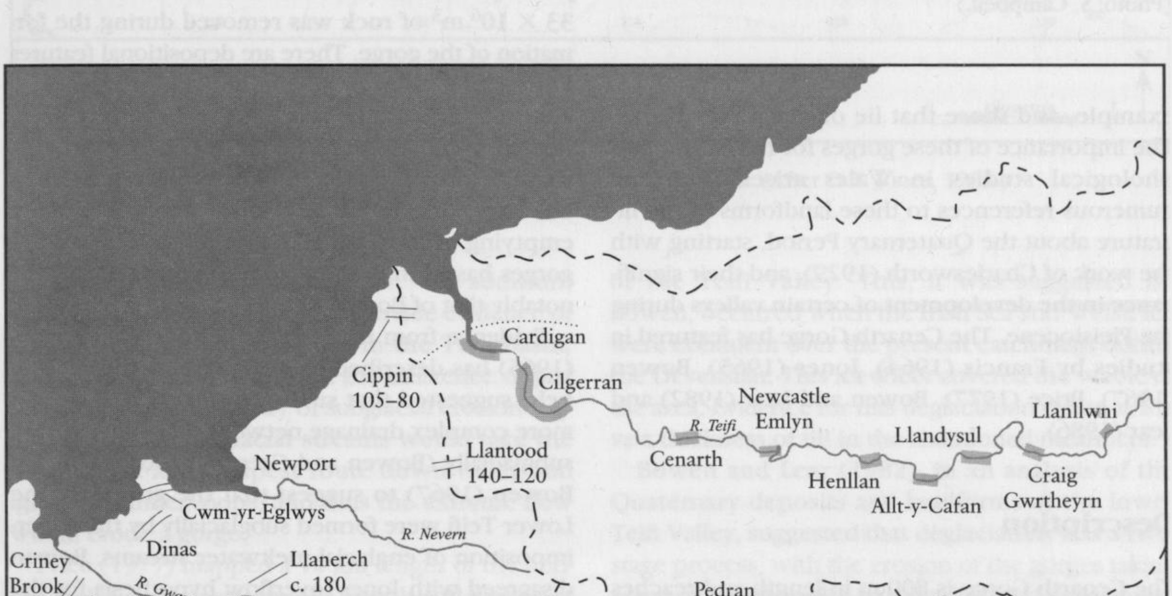


Figure 3.9 The lower Teifi Valley and the overflow channels of the Teifi lakes. (After O.T. Jones, 1965.)

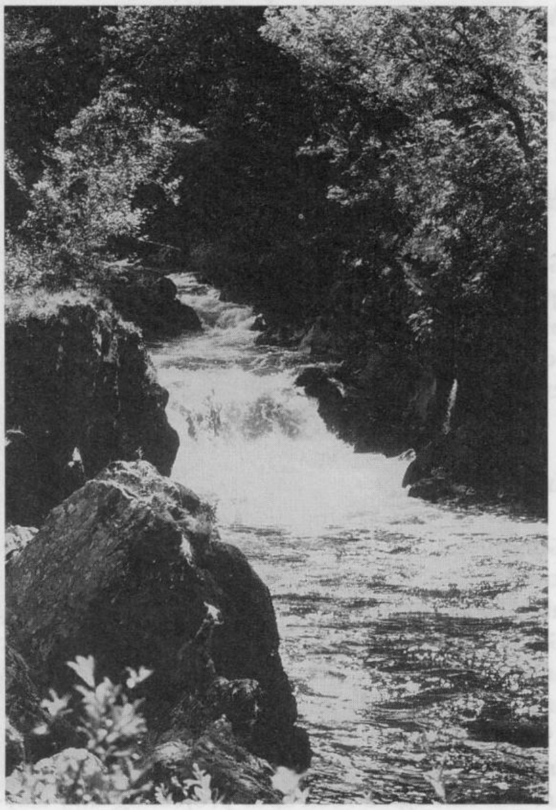


Figure 3.10 A narrow incised section of the Afon Teifi. (Photo: S. Campbell.)

example, and those that lie on the valley flanks. The importance of these gorges for fluvial geomorphological studies in Wales arises from the numerous references to these landforms in the literature about the Quaternary Period, starting with the work of Charlesworth (1929), and their significance in the development of certain valleys during the Pleistocene. The Cenarth Gorge has featured in studies by Francis (1964), Jones (1965), Bowen (1967), Price (1977), Bowen and Lear (1982) and Lear (1986).

Description

The Cenarth Gorge is 800 m in length and reaches a maximum depth of almost 50 m. Upstream of the gorge, the river is meandering across a confined floodplain. There are examples of abandoned meanders to the north and south of the gorge (Figure 3.11). Seismic investigations of these meanders revealed that the level of the rock floor in the northern meander was at −10 m OD (Francis, 1964). These meanders were formed by rejuvenation following uplift in the region and the incision into the valley floor, which was then followed by a period of deposition. The Cenarth Gorge and its associated meanders are the most studied and most spectacular of the features of the Lower Teifi. The gorge is 120 m in width at its rim, with a river width varying from 25 m at the upstream end to 80 m at the downstream end, where a rock platform fans out, creating a series of waterfalls. The river is tree-lined through the gorge, creating stable banks. The gorge section continues downstream to the bridge, from where the floodplain recommences.

Interpretation

There are two schools of thought regarding the formation of such features on the Lower Teifi. Firstly, Jones (1965) and Charlesworth (1929) postulated a Lake Teifi, which was impounded by the Irish Sea ice sheet at the mouth of the Teifi Valley. The subsequent melting of the ice-dam barrier led to a rapid surge of meltwater from this lake which, it was suggested, would lead to the formation of such gorges by erosion through the valley fill (chiefly lake clay). Jones (1965) estimated that between 28×10^6 and 33×10^6 m^3 of rock was removed during the formation of the gorge. There are depositional features in the Teifi Valley which would confirm the presence of such a lake (e.g. in the Lampeter area; Bowen, 1967), although Price (1977) suggested that there is evidence for the existence of more than one lake in the Teifi Valley. Jones' hypothesis of the emptying of the Teifi lake and the erosion of the gorges has been questioned in subsequent studies, notably that of Bowen (1967).

Evidence from the Fishguard area, where Jones (1965) has described ice-marginal overflow channels, suggested that such features were part of a more complex drainage network that was initiated subglacially (Bowen and Gregory, 1965). This led Bowen (1967) to suggest that the gorges of the Lower Teifi were formed subglacially by the superimposition of englacial meltwater streams. Bowen disagreed with Jones' overflow hypothesis for the formation of such gorges for three reasons. Firstly, it was suggested that there was no evidence for an Irish Sea ice sheet trespassing across mid-Wales in this area. Secondly, such a model assumes that the Teifi Valley was ice-free during this period of Irish Sea ice advance. The third point of contention was Jones' hypothesis that meltwater ignored the

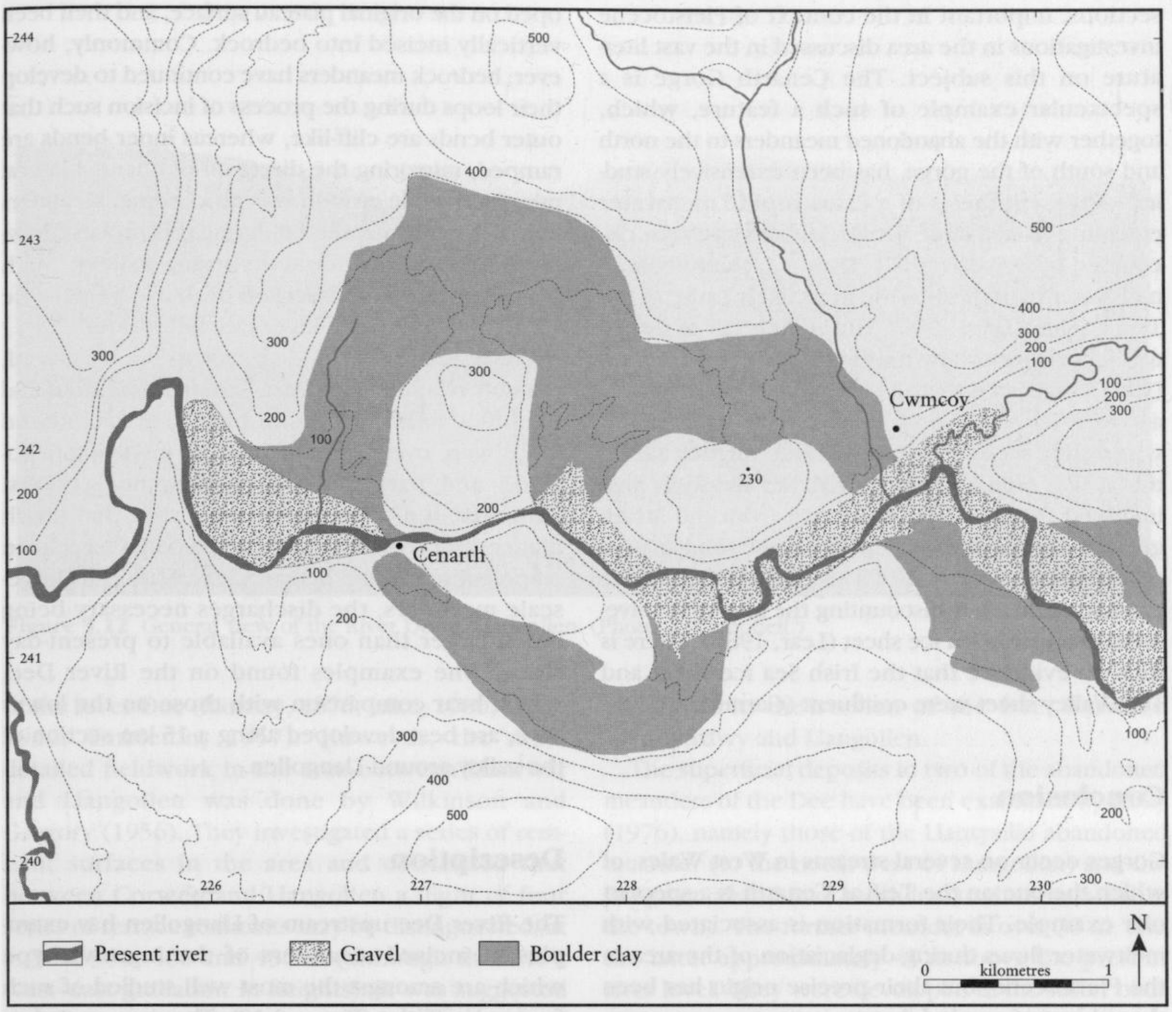


Figure 3.11 The Afon Teifi: a geological map of the area around Cenarth. (After O.T. Jones, 1965.)

existing preglacial valley floor. In addition, although deposits exist which provide evidence of glacial ponding of meltwater in the Teifi basin, there was nothing to suggest the existence of just one lake. Bowen's theory of subglacial erosion suggested that the englacial streams would take the most direct and steepest route down valley and ignore meander loops, and thus the extreme flow would erode a gorge.

Price (1977) mapped a 10 km length of the middle Teifi Valley upstream of Cenarth and looked at the origin of the Allt-y-Cafan, Llandyssl, Craig Gwrtheyrn and Llanllwni gorges. She substantiated the idea of glacial ponding of meltwater. It was suggested also, from evidence of the Allt-y-Cafan Gorge, that Bowen's theory of subglacial initiation of the gorges of the Teifi was preferred and was thought to have occurred during the deglaciation of the Teifi Valley. This, it was suggested by Bowen, occurred when the Irish Sea and Welsh ice were confluent over the present catchment during the Devensian. This ice sheet covered the whole of the area. Evidence for this deglaciation exists in the vast thickness of till in the abandoned meanders.

Bowen and Lear (1982), in an analysis of the Quaternary deposits and landforms of the lower Teifi Valley, suggested that deglaciation was a two-stage process, with the erosion of the gorges taking place earlier than the impounding and subsequent catastrophic drainage of the Lake Teifi upstream of Cardigan. Evidence from the Cilgerran Gorge was used to support Bowen's (1967) theory of the superimposition of englacial and subglacial streams across spurs that were laid across the valley axis.

The Afon Teifi, like many of the westward-flowing rivers of Wales, is characterized by gorge sections, important in the context of Pleistocene investigations in the area discussed in the vast literature on this subject. The Cenarth Gorge is a spectacular example of such a feature, which, together with the abandoned meanders to the north and south of the gorge, has been extensively studied. The hypothesis of a catastrophic meltwater emerging from a large proglacial lake has been discounted by Bowen (1967). Thus '… the subglacial meltwater hypothesis is the most likely cause of the Teifi gorges' (Lear, 1986). The complexity of the situation is illustrated by the fact that whereas Bowen (1967) suggested that deglaciation of the Irish Sea and local ice sheets prior to gorge erosion occurred when they were confluent, it was further added that it was unlikely that an Irish Sea ice sheet was involved (Lear, 1986). Evidence from the stratigraphic relationships of deposits in the Henllan area pointed to deglaciation of a single ice sheet as the eroding agent, thus discounting the idea of involvement of an Irish Sea ice sheet (Lear, 1986). There is thus no evidence that the Irish Sea ice sheet and Teifi Valley sheet were confluent (Garrard, 1977).

Conclusion

Gorges occur on several streams in West Wales, of which the one on the Teifi at Cenarth is a spectacular example. Their formation is associated with meltwater flows during deglaciation of the area in the Pleistocene, but their precise origin has been the subject of much debate.

RIVER DEE AT LLANGOLLEN, DENBIGHSHIRE (SJ 182425 – SJ 177443 – SJ 191433)

G. Higgs

Highlights

These incised and ingrown meanders are classics of the British landscape. They are large-scale features and a major component of the landscape, but have not been studied in depth in recent years.

Introduction

Bedrock meanders, incised perhaps hundreds of metres into plateau surfaces, are a common feature of upland Europe. Meanders may have been developed on the original plateau surface, and then been vertically incised into bedrock. Commonly, however, bedrock meanders have continued to develop their loops during the process of incision such that outer bends are cliff-like, whereas inner bends are ramped, mirroring the direction of channel lateral migration while erosion was proceeding. Meanders may also be dismembered during this process, leaving high-level abandoned curving valleys. Such features are well preserved on hard, permeable rocks, such as on the River Dee limestones.

These features would appear to be pre-glacial, possibly relating to warmer Tertiary conditions and the block uplift of present plateau areas. Incised loops were over-run by glaciation, involving deposition and partial blocking of some sections. However, it also has been suggested that much higher glacially-related discharges could have been responsible for the bedrock excavation of large-scale meanders, the discharges necessary being much larger than ones available to present-day rivers. The examples found on the River Dee, which bear comparison with those on the lower Wye, are best developed along a 15 km section of the valley around Llangollen.

Description

The River Dee upstream of Llangollen has examples of incised meanders of the ingrown type which are amongst the most well studied of such features in Wales (Figure 3.12). The river meanders across a broad floodplain upstream of Corwen, but at Glyndyfrdwy is rejuvenated and enters a deep gorge. Lateral erosion as well as vertical erosion has taken place such that the river valley is asymmetrical in cross-profile. Thus, for example, at Rhewl (183448), on the northern side of the river, the valley side is steep, whereas on the inside of the meander loop there is a much gentler slope, suggesting that rejuvenation was progressive. On the inside of the bend, gravel deposits have been built up, whereas there are 2 – 3 m bank scars on the outside. There are also local examples of abandoned channel loops at Llantysilio and just south of Llangollen. The section provides a direct contrast to those entrenched meanders of the Lower Wye.

Interpretation

Mention was made of river sections in the Vale of Llangollen in early papers regarding the evolution

Figure 3.12 General view of the River Dee at Llangollen. (Photo: S. Campbell.)

of the River Dee (Ramsay, 1876; Lake, 1900; Wills, 1912; Embleton, 1957). However, the most detailed fieldwork in the area between Llanrwst and Llangollen was done by Wilkinson and Gregory (1956). They investigated a series of remnant surfaces in the area and concluded that between Corwen and Llangollen a flight of four series of terrace remnants may be distinguished, at *c*. 300, 350, 400 and 430 m (although there is a west–east gradation in heights). It was suggested that the various levels corresponded to periods of standstill of the Dee. Lateral erosion in the form of the meandering river was still taking place such that all protuberances within the valley were eroded. In addition, there were periods of vertical incision corresponding to lowerings of base level, which Wilkinson and Gregory (1956) suggested could possibly be the result of river capture further downstream, namely that of the 'Proto-Trent' by the Lower Dee. It was also suggested that the incision since the formation of the 300 m terrace remnant (their Stage 4) must have been rapid since '... the river has become incised *in situ* and there has been insufficient time since the incision to remove the protuberances between' (Wilkinson and Gregory, 1956). This has resulted in the abandonment of incised meanders at a higher level than the present river; three upstream of Llangollen and one downstream. The 300 m surface is associated with the summits of the cores of such meanders. Wilkinson and Gregory suggest that these four stages of terrace remnants are best preserved in the section of the Dee, between Glyndyfrdwy and Llangollen.

The superficial deposits in two of the abandoned meanders of the Dee have been examined by Kelly (1976), namely those of the Llantysilio abandoned meander (to the north-west of Llangollen) and the Pengwen abandoned meander (to the south-east of the town). The former meander is over 30 m, and the latter approximately 45 m above the present river level. They were developed in the softer beds of the Lower Ludlow (Silurian) series. Wills (1912) also investigated the deposits within these meanders and discussed their mode of origin, and suggested that the material was glacial drift with patches of alluvium and gravel filling in the pre-glacial valley. Kelly (1976), however, suggested that the preferred stone orientation of deposits in the meanders indicated that the majority of the exposures were deposits of solifluction and they therefore did not comply with the ideas of Wills. However, much of Wills' analysis was of deposits at greater depths using boreholes, and included more sites.

With regard to the origin of these abandoned meanders, there is evidence for a glacial interference. During glaciation of the middle Dee gorge, ice was channelled along the valley and carved troughs across the necks of four meanders. When this ice melted, the post-glacial River Dee followed the course of these deepened troughs, so abandoning the old meander beds at a higher level, (*c*. 300 m) than the present valley.

The River Dee between Glyndyfrdwy and Llangollen provides the best examples of ingrown incised meanders in Wales. The present-day meander upstream of the Horseshoe Falls presents an excellent example of such a feature, with a typical asymmetrical valley. Such a landform is also preserved as two abandoned incised meanders found to the north and south of Llangollen, at a level 300 m above that of the present day, formed by the short-circuiting of spurs during the last glaciation. It is suggested that the periods of vertical incision creating such features may have resulted from the lowering of base level corresponding to the capture of the Proto-Trent by the Dee during the last glaciation rather than a lowering of sea level.

Conclusion

These are spectacular incised meanders cut approximately 300 m into bedrock. They are classic examples of this type of feature and were the subject of much study in the early 20th century. They were affected by glaciation, and related to previous large-scale changes in the regional drainage system.

RIVER WYE AT LANCAUT, GWENT (ST 532965)

G. Higgs

Highlights

This is a site with incised meanders which exhibits evidence of staged incision during the development of this major river system. Although not recently researched, this area provides valuable evidence for long-term landscape development as well as being a notable example of a type of river landscape.

Introduction

The lower Wye between Ross and Chepstow has the best examples of entrenched incised meanders in Wales. The river has eroded through tilted layers of Carboniferous rock laid upon Devonian sandstones such that outcrops of Carboniferous Limestone formed cliffs in the gorges, such as the Piercefield Cliffs (532958).

The origin of the meanders was discussed by Miller (1935, 1937), who suggested that the Wye has entrenched through an original meander plain at 1000 ft (300 m) through rejuvenation. This meander plain was at a higher level than that of the present plateau surface of the highland of the Forest of Dean. It was during a period of peneplanation that the latter surface was formed. The 500 ft (150 m) plateau was, in turn, entrenched very rapidly. Finally, Miller hypothesized, entrenchment was interrupted at a base level 200 ft (60 m) above that of the present day, producing extensive peneplains around Ross-on-Wye. Subsequent submergence of the lower reaches of the river led to a widening of the valley.

Description

The large meander loop at Lancaut is an excellent example of the features produced by the rejuvenation that has taken place on the lower Wye. On the outside of the meander loop the river has tended to undercut the steep slopes, creating rocky precipices (e.g. at Wyndcliff, Piercehead Cliffs and at Wintours Leap). It was suggested by Dreghorn (1968) that the river initially meandered across a broad plain approximately 600 ft (190 m) higher than the present level. A subsequent uplift of the Forest of Dean plateau forced the river to cut down more vigorously, thus creating the gorge and its incised meander loops. However, there were intermittent pauses and it was during such periods that the river deposited sands and gravels on the inside of the meander, building up terraces — the remains of these can be seen in the Lancaut peninsula — thus creating an asymmetrical-shaped valley. This bench is approximately 250 ft (80 m) above the present valley bottom and can be correlated with the Liveoaks bench to the north (5397). Thus flatter land, more than 60 m above river level (250 and 300 ft contours), occurs inside each bend between Tintern and Chepstow, with steeper slopes on the north than on the south side of each spur. A cross-section through the Liveoaks meander, for example, shows that the west side of the valley has a marked break of slope at 90 m (300 ft contour) with the steep slopes of Wyndcliff rising above the more gently inclined spur within the meander curve. In addition to such terrace remnants, there is also evidence of the earlier evolution of the Wye in the form of two abandoned meander loops — one at Newland (5408) which is 370 ft (115 m) above the present level of the Wye at Redbrook and which has a meander core at 500 to

600 ft (150 – 190 m) representing the Forest of Dean plateau, and the other at St Briavels (5404) which is at a height of only 100 ft (30 m) above the river at Bigsweir, indicating a much more recent formation.

Interpretation

The earlier detailed investigation of the formation of such entrenched meanders on the lower Wye was carried out by Miller (1935, 1937). It was proposed that there was evidence of three and perhaps four cycles of development in the lower Wye Valley (with stages at 450 – 500 ft, 400 ft, 200 – 250 ft and the present level). It was suggested that the Wye provides an excellent example of superimposed drainage whereby the courses of the river and the tributaries show virtually no adjustment to the geological outcrops shown on the present-day map. The river system has evolved on a cover of more recent rocks (Jurassic or Cretaceous) which have subsequently been removed by erosion. Thus it was suggested that: 'The uplift at the close of the Carboniferous initiated a prolonged episode of erosion during which thousands of feet of sediments were removed. By Triassic times an irregular surface had been produced on which patches of Triassic sands and breccias can be seen resting today' (Miller, 1935).

Miller suggested that the present plateau surface of the Forest of Dean could not have been the original meander plain, since such a surface would need to be more extensive. It was thus hypothesized that the original surface was of Mesozoic deposits at a higher level than the existing plateaux of the Forest of Dean, although not much of this 900 ft stage was preserved. Entrenchment, leading to the formation of the gorge-like sections of the lower Wye, was into the 500 ft peneplain, which is well-preserved on Tidenham Chase as well as in most of the high land of the Forest of Dean. Miller (1935) also suggested that the abrupt break in slope at the 500 ft level between Ross and Chepstow indicated that such a rejuvenation was rapid. This was particularly marked in the longitudinal profiles of tributaries entering this section of the Wye, with such streams becoming entrenched in gorges themselves. The third stage of derivation noted by Miller is represented in the Liveoaks and Lancaut meander core 'benches' at the 200 – 250 ft level and in the longitudinal profiles of tributaries. The last stage in the process occurred with the melting of the ice caps and the subsequent rise in sea level, resulting in the submergence of the lower Wye, thus causing the tides to extend up to Bigsweir. Vertical erosion has been reduced, whereas the widening of the valley has been accelerated.

Little work has been carried out on the entrenched meanders of the Lower Wye in recent times. However, there is evidence of at least three stages of erosion in this section of the river, namely: (1) the 900 ft plateau, of which today only a few small patches remain; (2) the 500 ft stage in which the river entrenched; (3) the 250 ft stage represented in the meander core at Lancaut.

The Lancaut meander of the Wye is an excellent site demonstrating the rejuvenated nature of the river, with rocky scarps on both banks. The river flows independently of the main controls of structural geology, suggesting that the pattern is a good example of superimposed drainage.

Conclusion

The large valley meanders of the River Wye are spectacular features which have developed in a complex manner over a long period of geological time. Clues as to their origin are provided by their relationship to the surrounding relief, their relationship to the bedrock and the nature of their morphology and deposits, including high-level abandoned meander loops. The features are a fine example of superimposed drainage and incision due to rejuvenation of the river system.

AFON HEPSTE, POWYS (SN 931133 – SN 924098 – SN 942109)

G. Higgs

Highlights

Unusually well-developed waterfalls and dry river courses are related here to the outcrop of limestone and adjacent rock types. Detailed relationships between lithology and structure and landforms are evident along this short river reach.

Introduction

The Afon Hepste downstream of Hepste Bridge provides an excellent example of the geological controls on river development. It is characterized in its upper reaches by a dry stream course over areas of Carboniferous limestone and in the lower part by waterfalls.

The Hepste drains southwards from the Brecon Beacons. It rises on the Old Red Sandstone and crosses outcrops of the Carboniferous Limestone and the Millstone Grit. On the limestone, water enters well-developed joints and bedding planes such that during times of low flow, the river upstream of the Penderyn–Ystradfellte road bridge is dry-bedded. The area to the east of the Hepste is characterized by swallow or sink holes caused by the collapse of the roofs. North (1962) presented aerial photographs illustrating the relationships of such features to the underground passages of the area. The river re-emerges 0.5 km downstream of the bridge through joints in the Millstone Grit. This re-emergence, after the stream had previously entered fissures in the limestone at the base of a small waterfall subsequent to flowing over rocks of the Millstone Grit Series, is illustrated in Figure 3.14.

Immediately downstream of this point, the river flows over Upper Carboniferous rocks of the Millstone Grit and Coal Measures. It is the influence of three factors, namely the alternation of soft and hard rock beds, the influence of faults, and the increasing erosive power of the captured (and thus rejuvenated) Hepste, that accounts for the features of this section of the river, notably those of waterfalls and cascades. Such features have been described as 'more numerous and varied than in any other area of similar size in the whole of the country' (North, 1962).

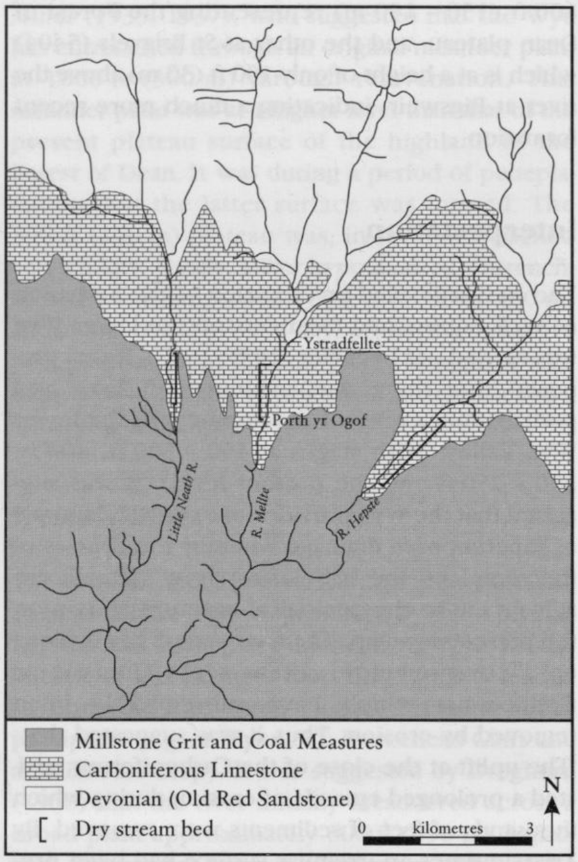


Figure 3.13 A diagrammatic geological map of the neighbourhood of Ystradfellte. The 'solid' rock outcrops are shown. They are largely and irregularly covered by superficial deposits.

Description

The course of the Afon Hepste flows over limestone for approximately 5 km. The bed seldom carries water, so that grass and other vegetation has become established amongst the pebbles. Below the bridge (945113) the Hepste Valley is floored by the conglomerates and sandstones of the Millstone Grit that overlies the Carboniferous Limestone (Figure 3.13). The rejuvenated and downcutting Hepste has penetrated the sandstones to reveal a small exposure of Carboniferous limestone (938097). The river at this point, 1 km upstream of Scwd-yr-Eira, flows underground beneath a vegetation-covered dry river bed for approximately 50 m. It re-appears through joints in the Millstone Grit (Figure 3.14).

The first description of the features of the lower Hepste was made by Malkin (1807), who suggested that the most important fall was at Scwd-yr-Eira (Malkin's Upper Hepste Fall), in contrast to the series of cascades further downstream. Scwd-yr-Eira was initiated by a fault which caused the stream to flow from hard sandstones to soft shales (Figure 3.15). A band of more resistant shale below the sandstone is exposed at the base of the cliff. Downstream of the fall, the river enters an 80 m gorge caused by the upstream retreat of Scwd-yr-Eira and another fault. Between these falls and the junction of the Hepste and Mellte is a series of smaller falls first described in detail by Young (1835) and known as the Lower Hepste falls. Here two plunge pools are separated by a series of rapids, followed by a 10 m fall in a gorge section of approximately 100 m in length.

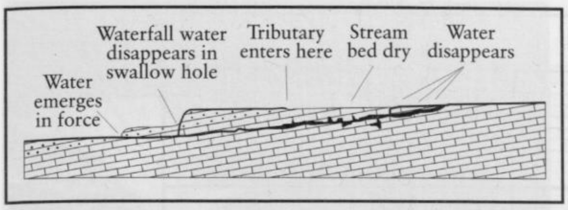


Figure 3.14 The disappearance and reappearance of the Afon Hepste near Penderyn.

Interpretation

The Hepste, like the nearby Mellte and Nedd Fechan, illustrates features of river evolution unique to karstic environments. Early works concentrated on a basic description of the area (e.g. Atkinson 1890; Thomas, 1902; Malkin, 1907). The first major attempt at the interpretation of such features was made by North (1930) in a National Museum of Wales publication, which was subsequently updated in 1938, 1949 and 1962. Mention was also made of such features in a National Museum of Wales publication (1979) describing aspects of the Brecon Beacons National Park scenery. Thomas (1974) has described some of the features of the South Wales interstratal karst, namely beneath the Millstone Grit fringing the South Wales Coalfield including dry river valleys, which, it was suggested, extend to a maximum individual length of 3 km. Many of the features of the upper Neath were attributed to the active downward erosion of the tributaries as a result of the capture by the River Neath of streams that previously entered the Taff. The results of this rejuvenation, however, are not consistent because of the nature of the rocks over which the streams flow.

The Scwd-yr-Eira Fall (928099) was initiated where a fault caused the stream to flow from hard sandstones on to soft shales. The backwash of the water has brought about the disintegration and removal of the shale near the base of the fall, so that the sandstone tends to be overhanging. Sandstone blocks periodically fall away, so that the waterfall is receding away from the original fault zone. There is a deep plunge pool at the base of the falls, which has formed because of the erosional influence of entrained pebbles. This, it has also been suggested, has led to the deepening of the gorge immediately downstream of the falls (North, 1962). Below Scwd-yr-Eira the bed of the Afon Hepste falls rapidly, and for the last 0.5 km down to the junction with the Mellte at the base of a 75 m gorge, the river descends in a succession of waterfalls. This is partly due to another fault and also because the relation of the Hepste to that of the Mellte is that of a 'hanging valley'.

Conclusion

The Afon Hepste GCR site includes features that are peculiar to karstic scenery, including dry river beds and underground passages. These features provide excellent examples of the response of a river to geological control coupled with the results of rejuvenation following river capture. The river is exceptional in having a range of such features within a small area.

AFON MELLTE DOWNSTREAM OF YSTRADFELLTE, POWYS (SN 931133 – SN 924098 – SN 942109)

G. Higgs

Highlights

This is a partially dry limestone river, with a notable associated cave system. Valley rejuvenation is also in evidence, so that the influence of

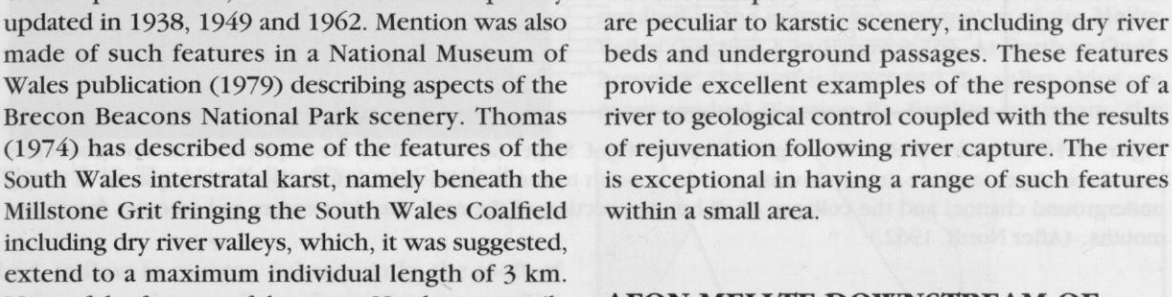


Figure 3.15 Sequential diagrams illustrating stages in the formation of Scwd-yr-Eira. This fall owes its origin to a fault, which has retreated upstream as a result of the erosion of some beds of shale that occur near its base. (After North, 1962.)

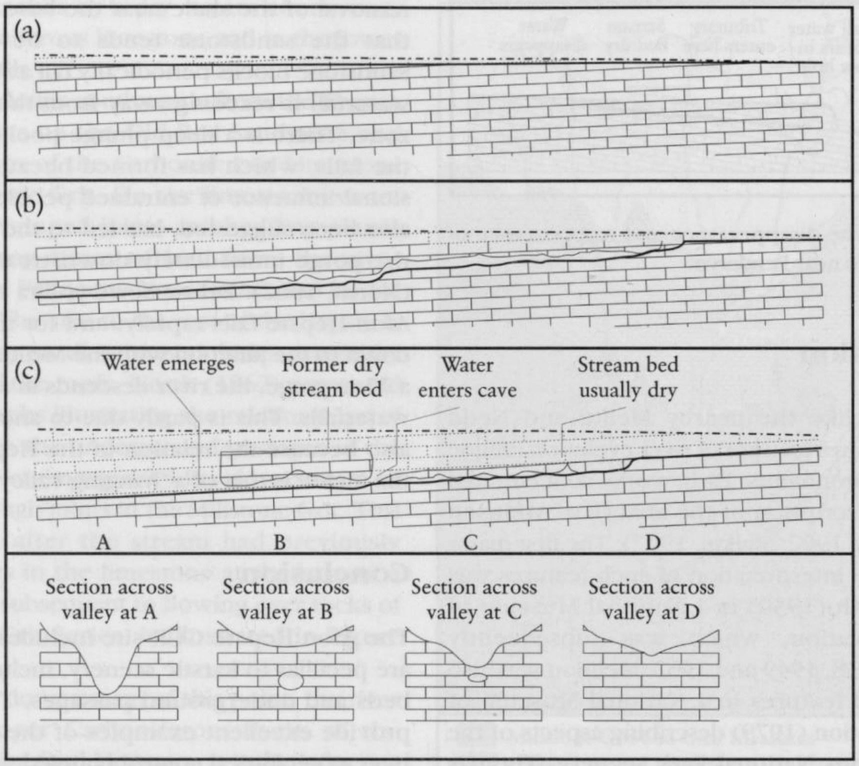


Figure 3.16 The Afon Mellte: the origin of Porth-yr-Ogof. Stages (a), (b) and (c) are sequential. The sections represent three stages, and are drawn downstream from north to south (from right to left). By the occupation of a long underground channel and the collapse of all but one section of the roof, the river enters and emerges from cave mouths. (After North, 1962.)

lithology and karstic development on such sites can be assessed.

Introduction

The Afon Mellte near Ystradfellte flows for the majority of the time in subterranean channels in Carboniferous Limestone, with the result that for 1 km or so the river bed is more often than not dry. The section has features unique to rivers in karstic environments, as well as waterfalls formed under a range of different conditions (Figure 3.16 and 3.17). Many of these features have, it has been suggested, arisen from the rejuvenation of the Mellte (along with neighbouring tributaries) following capture by the River Neath (North, 1962). There is a strong geological control, since the rocks of the region vary in degrees of hardness and resistance to river erosion. Thus 'the features produced as a result of rejuvenation in the district drained by the River Neath vary according to the nature of the rocks over which the streams flow in successive parts of their courses' (North, 1962).

Description

The Afon Mellte is formed by the junction of the Afon Llia and Afon Dringarth, approximately 1 km NNE of Ystradfellte, and for the first part of its course flows over erosion-resistant Old Red Sandstone. On reaching an outcrop of Carboniferous Limestone near Ystradfellte, the water passes underground such that the river bed is usually dry (933135). Downstream, the Mellte enters the Porth-yr-Ogof cave approximately 1.5 km SSE of Ystradfellte (927122), where it crosses the outcrop of the Carboniferous Limestone. The river emerges a little over 300 m downstream. A few metres outside Porth-yr-Ogof there are fissures communicating with a subterranean channel.

The Mellte once flowed at a higher level than at present but over time it has completely deserted its

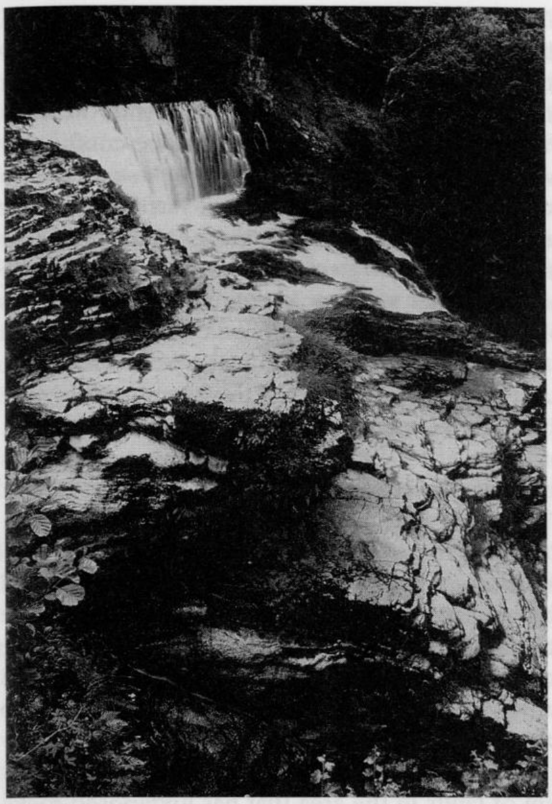


Figure 3.17 The Afon Mellte. (Photo: S. Campbell.)

bed, to flow in caverns. Subsequently, the roofs of such caverns have collapsed, creating a gorge-like valley downstream of Porth-yr-Ogof. North suggested that the cave system itself was not a single unit. The shape is seen to vary according to the jointing system of the limestone such that '... the cave is deep and narrow where it is due to the widening of vertical joints, but where it has been developed along bedding planes it is very extensive and has a low flat roof' (North, 1962).

Downstream of the cave system, the narrow gorge rapidly widens out to form a flat shelf on the west bank, with a limestone cliff forming the east bank. The river then flows over Millstone Grit before entering the River Neath at Pontneddfechan (903075).

Between Porth-yr-Ogof and the confluence of the Mellte and Hepste (925098) there are three main sets of waterfalls — the Upper Clyngwyn Falls, the Scŵd Isaf Clyngwyn (= Lower) and the Scŵd y Pannwr Falls. Each has been formed as a result of differential erosion of shale and sandstone, and their detailed morphology is influenced by the structure of faults and fall migration. For 0.5 km below these falls the river flows over shale and has cut deeper into the sides of the ravine to produce a fairly wide valley with an alluvium-covered floor, only to be confined once more by the vertical sandstone walls of the gorge.

Interpretation

North (1962) discusses the origin of Porth-yr-Ogof. He suggests that the original Mellte flowed at a much higher level than at present, but that subsequent erosion and solution had led to the downcutting of the river. This is supported by the potholes visible at varying levels in the present-day gorge. Such a process was, it is suggested, dependent on the characteristics of different limestone bands. Thus water was able to pass more rapidly through resistant bituminous limestone and resulted in the formation of caverns beneath stretches of dry bed (Figure 3.16). The subsequent collapse of the roofs of such underground channels resulted in the gorge-like appearance of the Mellte Valley (Section A in Figure 3.16). At Porth-yr-Ogof, however, the roof is intact and the valley sides are more gradual (Section B). Farther upstream, the

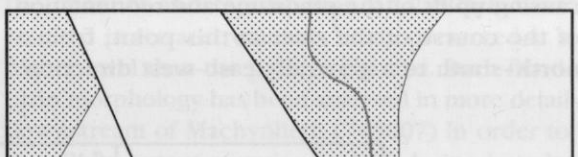


Figure 3.18 The Afon Mellte: waterfalls and their relation to faults.

downcutting process continues to occur and the bed of the Mellte is normally dry (Section C).

The Upper Clyngwyn Falls were developed at a point at which the river passes over a fault that juxtaposed hard Millstone Grit sandstones against soft shales (Figure 3.18). The particular section of fault with which the falls are associated can be clearly discerned and has resulted in the formation of a two-step waterfall, with an initial 5 m fall on to a rocky ledge and then a 15 m descent. Owing to the inclination of the rock strata, there has been a lateral concentration of flow such that more erosion has occurred on the steeper southeasterly cliffs of the gorge (Figure 3.19). Thus there is a wide sandstone pavement on the right bank of the river and steeper cliffs on the opposite bank of the Mellte.

The waterfall at Scŵd Isaf Clyngwyn, downstream of the Upper Clyngwyn, is also the result of differential erosion on the downthrow side of a fault (Figure 3.20). However, in this case the morphology is complicated by the fact that there are two parallel faults, and two falls separated by a pool at different angles to the main flow direction. The complex nature of the falls was discussed by North (1962), and explained on the basis of a fault causing uplift of the sandstone and reorientation of the course of the river at this point, from a north–south to a generally east–west direction. These falls, it was suggested, had receded such that they were now at the head of a deep and narrow gorge. Where sandstone forms the bed of the river, the third major Mellte waterfall (Scŵd y Pannwr) was formed 0.5 km from the confluence with the Hepste. The tilt of the rock strata of the so-called Twelve Foot Sandstone has resulted in a lateral migration of the waterfall as in the upstream waterfalls. The waterfall is again of a composite nature, with two rock ledges separated by a plunge pool.

Although the Afon Mellte displays excellent karst-environment features, the geomorphology of the area has been complicated by the rejuvenation of the river following capture of those tributaries that once flowed into the Taff by the River Neath. This event is thought to have occurred in Late Tertiary times (National Museum of Wales, 1979) and it accentuated the already irregular nature of the river. It has also led to downcutting by water through joints in the limestone and thence to the formation of underground passages and caverns which are still preserved at Porth-yr-Ogof but which have largely collapsed, creating a gorge.

The picture is yet further complicated by the system of faults in the area that has juxtaposed rocks that have significantly different degrees of resistance to erosion. Thus within the Millstone Grits of

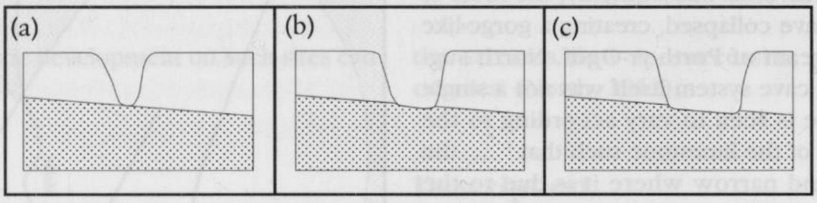


Figure 3.19 Diagrams illustrating the lateral migration of a waterfall. The water tends to collect on one side of the gorge owing to the inclination of the hard rocks over which it flows, and the valley grows wider, principally by erosion of the softer shales on one side. (After North, 1962.)

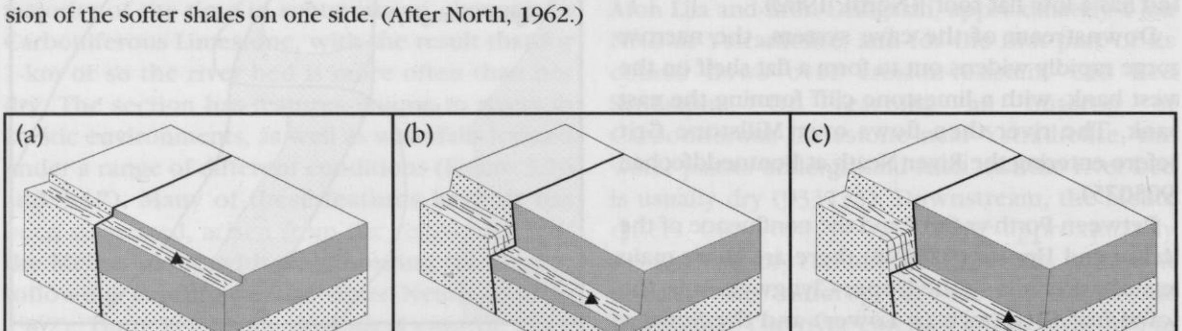


Figure 3.20 Diagrams illustrating stages in the formation of Scŵd Clyngwyn. The fall has resulted from the removal of comparatively soft shale. (After North, 1962.)

the area there are alternate beds of sandstone and less resistant shale. Water enters joints and bedding planes in the rock, resulting in the formation of fractures. Subsequently, the river erodes the underlying shales of the series, which leads to the formation of waterfalls. These falls, it is suggested, have gradually receded upstream, as is the case with Scwd-yr-Eira on the Hepste. This site is therefore exceptional in showing the combined influence of karst processes, geology and rejuvenation. It is the combined assemblage of features — as well as the individual features themselves — that is exceptional.

Conclusion

This site comprises a normally dry river bed, where the flow disappears into limestone, an associated cave system, and then a series of waterfalls and gorges downstream, where the river re-emerges. In the downstream section, shale and sandstone are juxtaposed by faults. The fluvial features have resulted from rejuvenation of the system, but are controlled by the geology.

AFON DYFI BETWEEN DINAS MAWDDWY AND MALLWYD, CAERNARFONSHIRE AND MERIONETHSHIRE (SN 860139 – SH 862116)

G. Higgs

Highlights

The upper Dyfi valley floor has a well-preserved terrace sequence cut into Devensian glacial materials. The present river is actively migrating, and the site is a representation of the recent sequence of Welsh valley floor development.

Introduction

The section of the Dyfi between Dinas Mawddwy and Mallwyd is unusual in Wales in that rejuvenation of the river (which in some cases leads to the formation of rocky gorges) has preserved well-developed terrace sequences. Three main terraces were identified by Thomas *et al.* (1982) (see Figure 3.22). Underlying them are sequences of glacial, glaciofluvial and glacio-lacustrine sediments identified in river bank sections. These deposits in turn overlie glacial till (as revealed in a seismic profile at Cemmaes (839062)). The till was deposited by ice which subsequently retreated, producing these glacigenic sequences of Devensian age (Thomas *et al.*, 1982). The glacigenic material was then reworked by the Afon Dyfi to form terraces at progressively lower levels. These are especially well-preserved in this section of the Dyfi.

The Dyfi upstream of Dinas Mawddwy (958149) is deeply entrenched with a narrow floodplain, and the present channel shows little evidence of lateral mobility. However, downstream reaches of the river (e.g. at Llanwrin, 785030) exhibit rapid rates of movement (Lewin and Hughes, 1976; Lewin, 1983). Thus a meander loop was seen to have developed in this location within 90 years. The lateral movement has involved the reworking of an estimated 10.78×10^4 m^2 of agricultural land, and led to the creation of such features as abandoned channels and gravel deposits on the floodplain of the lower and middle Dyfi. Present-day channel deposits in the Dyfi catchment, such as point bars, have been studied in greater detail by Blacknell (1982) at Penegoes (765008) on the Afon Crewi. Lateral movement of the channel and rejuvenation of the Dyfi have resulted in terrace remnants being preserved at a higher level than the present channel. Such floodplain morphology has been analysed in more detail downstream of Machynlleth (745007) in order to map flood extent at various stages during inundation (Lewin and Hughes, 1980).

Description

In places, river bank sections reveal the relationship between terrace gravels and glaciofluvial and glacial deposits. Five such sections have been analysed for the middle Dyfi by Thomas *et al.* (1982), including two between Dinas Mawddwy and Mallwyd. Evidence for the rejuvenation of the Dyfi at this point occurs in the form of a rocky gorge immediately upstream and downstream of Pont Mallwyd (857122). The channel is rock lined and has a steeper gradient than that of upstream reaches, culminating in a series of rapids. Upstream of Pont Mallwyd, a number of distinct terraces are evident (Figure 3.21). Thomas *et al.* (1982) suggest that three main terrace levels exist but that ' … a considerable number of minor forms intervene and up to five terraces occur in some areas'. Such terraces are well-preserved on the left bank of the Dyfi, but appear to have been largely removed on

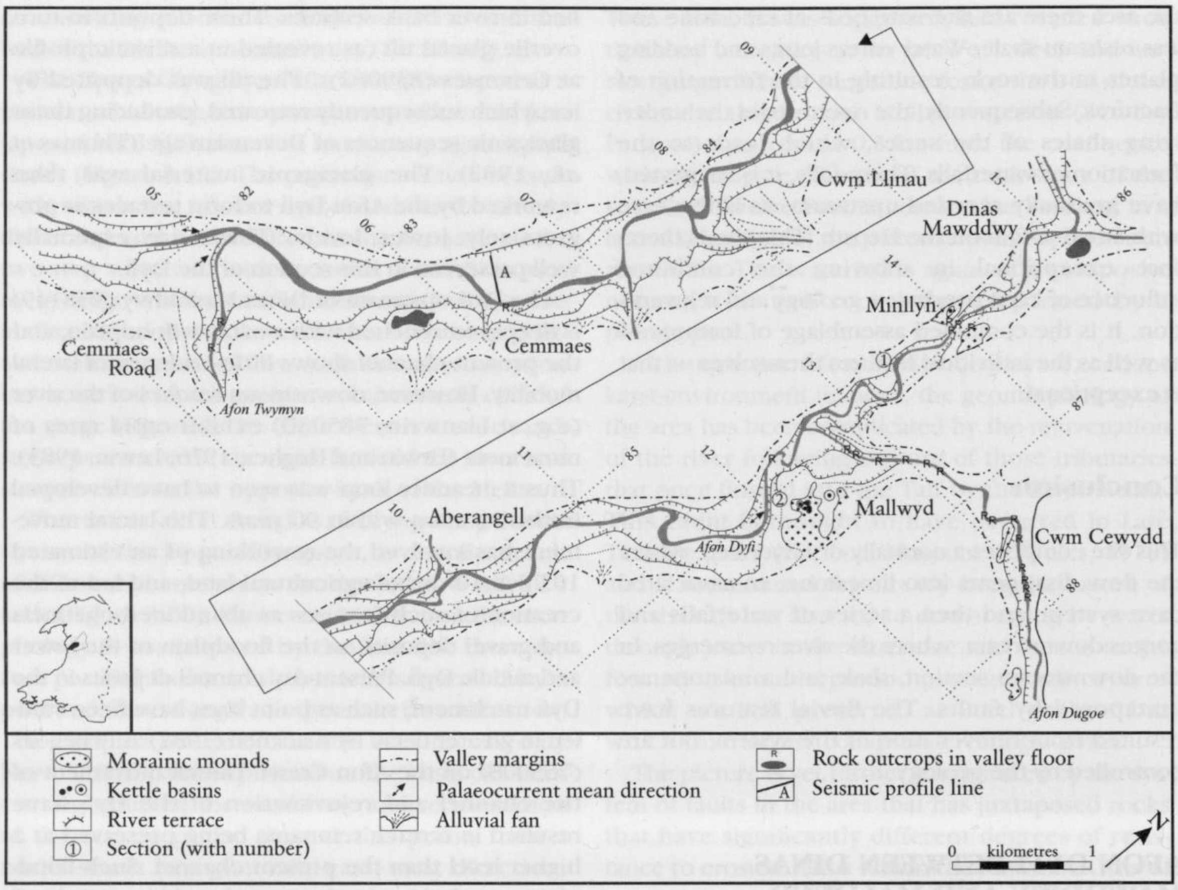


Figure 3.21 A geomorphological map of the Afon Dyfi: see Figure 3.22 for sections. (After Thomas *et al*., 1982.)

the right bank. Exceptions to this occur opposite Maes-y-camlan (859133) on the inside of a meander loop, where the lowermost of the terraces (Thomas *et al*. 'Flood Plain Terrace') is approximately 2 m above the present channel level. Two sections of the Dyfi between Dinas Mawddwy and Mallwyd have especially well-preserved terraces due, it is suggested, to 'the confining of the river to its rock channel and its consequent inability to meander across the valley floor' (Thomas *et al*., 1982). Individual terrace levels cannot be traced downstream as a continuous feature, but tend to

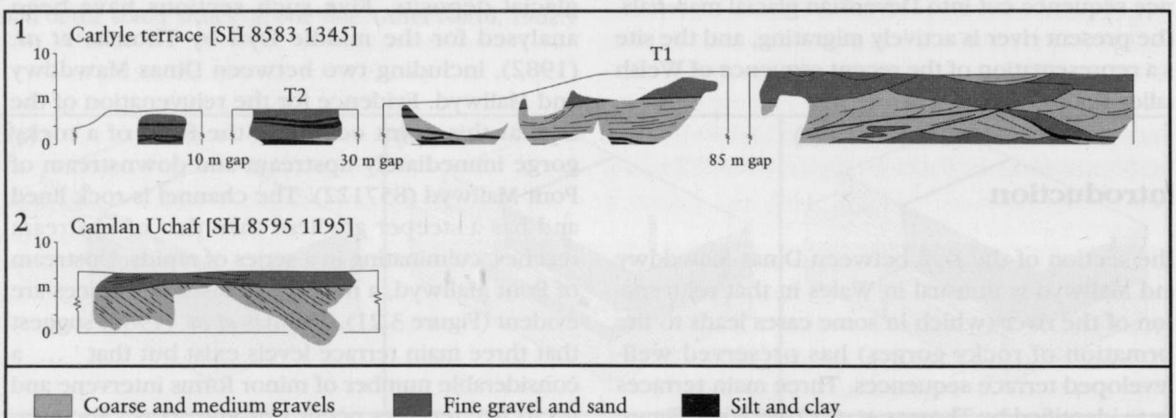


Figure 3.22 The Afon Dyfi: cross-sections through the terrace. (After Thomas *et al*., 1982.)

grade into lower terraces. Three such levels can be identified at Mallwyd (863124), with two immediately upstream of the confluence of the Dyfi with the Dugoed (856125). The form of these terraces is clearly outlined by the 70 m and 80 m contours on the 1 : 10 000 map (Sheet SH 81 SE) and they have dissected a low-angle alluvial fan deposited by the Afon Dugoed which grades into the uppermost level.

Bank sections at Carlyle Terrace and Camlan Uchaf (sections 1 and 2 on Figure 3.22) reveal the relationships of terrace gravels to the glaciofluvial deposits which underlie them. Three main facies have been identified between the two sections: terrace deposits consisting largely of coarse and medium gravels (facies A in Figure 3.22); sandur deposits (facies C) which represent a braided outwash environment and consist of fine gravel and sand underlying the terrace gravels at Carlyle Terrace; and facies B, which Thomas *et al.* (1982) suggested was of deltaic origin and consists largely of 'repeated tabular bed sets of fine to medium gravel dipping steeply down-valley' (Thomas *et al.*, 1982). These last deposits were present at the 7 m bank section opposite Camlan Uchaf (859119) downstream of Pont Mallwyd on the left bank of the Dyfi, where a distinct 'break' occurs between the terrace gravels, representing a meandering channel environment (2 m of coarse gravel deposits) and sediments of deltaic origin which consist of a 5 – 6 m deposit of finer gravel and coarse sand (facies B). This has been complicated in the area of Pont Mallwyd (857123) by ancient alluvial fan deposits originating from the Dugoed Valley. The deltaic deposits of facies B have fining upwards sets and represent deposition in a meltwater environment controlled largely by seasonal variations in flow.

Interpretation

Thomas *et al.* (1982) used these sections, together with three more at Cwm Llinau (844082) and Cemmaes Road (821050 and 819049) and a seismic profile at Cemmaes (839062 — section A in Figure 3.21), to suggest a sequence of glacial deposits concealed by terrace deposits of coarse gravels similar to those that characterize the present Dyfi, and showing many of the features common to the present rivers of Mid-Wales; that is, gravel beds, composite banks and high rates of lateral mobility. The seismic profile revealed deposits of till up to 50 m thick in places that accumulated during a period of glacial advance, which in turn are overlain by glaciofluvial and glacio-lacustrine deposits that ' ... probably represent a late stage in the waste of this ice' (Thomas *et al.*, 1982). Such a retreat was not continuous (as indicated by moraines at Mallwyd and Minllyn – Figure 3.21) so that a range of proglacial deposits are seen in bank sections in the reach. Alluvial fans were also formed during this stage of retreat from deposits brought down tributary valleys. These glacial sequences, it was suggested, were of Devensian age (as indicated by the freshness of the moraine deposits) and subsequent river development has served only to cut through this valley infill of glacial deposits. These deposits have in turn been reworked and redeposited as river terraces at progressively lower levels. As these terraces have been eroded in the Holocene, only in a few locations are many terrace levels preserved. Confinement of the river in the reach between Dinas Mawddwy and Mallwyd has led to such features being especially well-preserved in this area.

Conclusion

The floodplain of the Afon Dyfi downstream of Dinas Mawddwy is notable for a range of terraces up to 20 m above present level. These are seen to consist of medium to coarse gravels, and overlie glacial sequences which can be identified in several sections of the middle Dyfi but which are especially well-preserved in the reach between Dinas Mawddwy and Mallwyd. Two of these bank sections were studied in more detail by Thomas *et al.* (1982) and these show deposits characteristic of a wandering gravel river environment. Although no study has yet concentrated on the relationship of such terraces to each other, it was suggested that three main terrace levels are present (the so-called Upper, Mid and Flood Plain terraces) and that these were formed by the reworking of the glacial deposits and their subsequent re-deposition.

AFON RHEIDOL, CEREDIGION (SN 650800)

J. Lewin

Highlights

A well-studied sequence of post-glacial terraces characterize this site, where active erosion by a

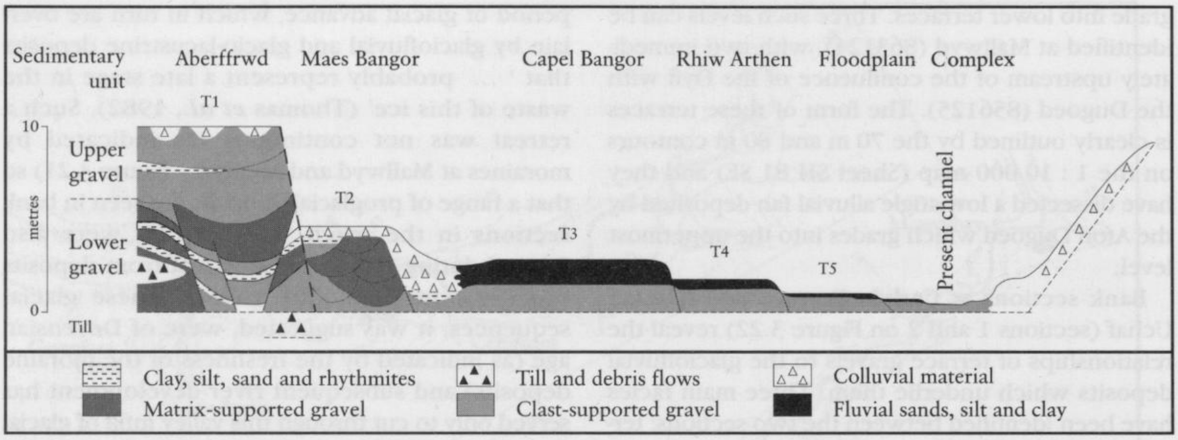


Figure 3.23 The Afon Rheidol: the sedimentology of the Rheidol terraces. (After Macklin and Lewin, 1986.)

confined meandering channel creates good riverbank exposures. Historical metal mining has involved the incorporation of metals into alluvial deposits, and interrelationships between mining activity and floodplain development can be identified.

Introduction

Holocene river terraces are attracting considerable academic attention: it is appreciated that alluvial sediments may record periods of landscape instability resulting both from climatic change and the intensity of human activities. Analysis of sites at which sequences of terrace sediments record such fluctuations, coupled with an understanding gained from contemporary observations as to how alluvial materials are deposited, may provide a good understanding of sediment dynamics under fluctuating controls.

The Rheidol has a small (182 km^2) catchment of relatively steep gradient draining westwards to Cardigan Bay. In its lower 10 km the river is actively meandering and has incised itself some 10 m into glacial outwash deposits, at the same time producing a series of incision terraces and alluvial sediment units of contrasting types. While such sequences are known to exist in part in other valleys (e.g. Ystwyth), exposures are rare and much of the preserved record has clearly been removed by later erosion. The Rheidol Valley in particular does, however, contain a very good set of terrace features and sediment exposures along the river bank within a reach of a few kilometres near Capel Bangor. These have been studied in detail recently (Macklin and Lewin, 1986). In addition, historical river-channel changes (Lewin and Brindle, 1977) and the influence of historical metal mining (Wolfenden and Lewin, 1977; Lewin and Macklin, 1987) have also been examined. The site therefore represents one at which both the evidence available and the research analysis undertaken merit careful attention to site conservation.

Description

At Capel Bangor, a flight of five morphological terraces, underlain by seven distinct sedimentary units, can be seen adjacent to the present river channel. Some channel engineering works have taken place, but for the most part the exceptionally fine river-cut bank exposures allow examination of the sedimentary features in great detail, while the river erosion itself (which keeps the bank exposures 'clean') is a valuable example of confined meander development.

The terrace and alluvial sequence is summarized in Figure 3.23 (after Macklin and Lewin, 1986). The Aberffrwd unit, underlying the highest terrace, T1, is composed of till and gravels which are interpreted as ice marginal outwash and later gravels of Devensian age. The Maes Bangor unit (underlying T2) is a comparatively minor feature but with interesting sedimentary structures, probably laid down in a braided river. The Capel Bangor unit (T3) is the largest feature on the valley floor. It is interpreted as the deposit of a meandering stream, with an exceptionally thick upper fine unit which can be related to the influx of pedogenic material following forest clearance. The remaining units (Rhiw Arthen and the Floodplain Complex; T4 and T5)

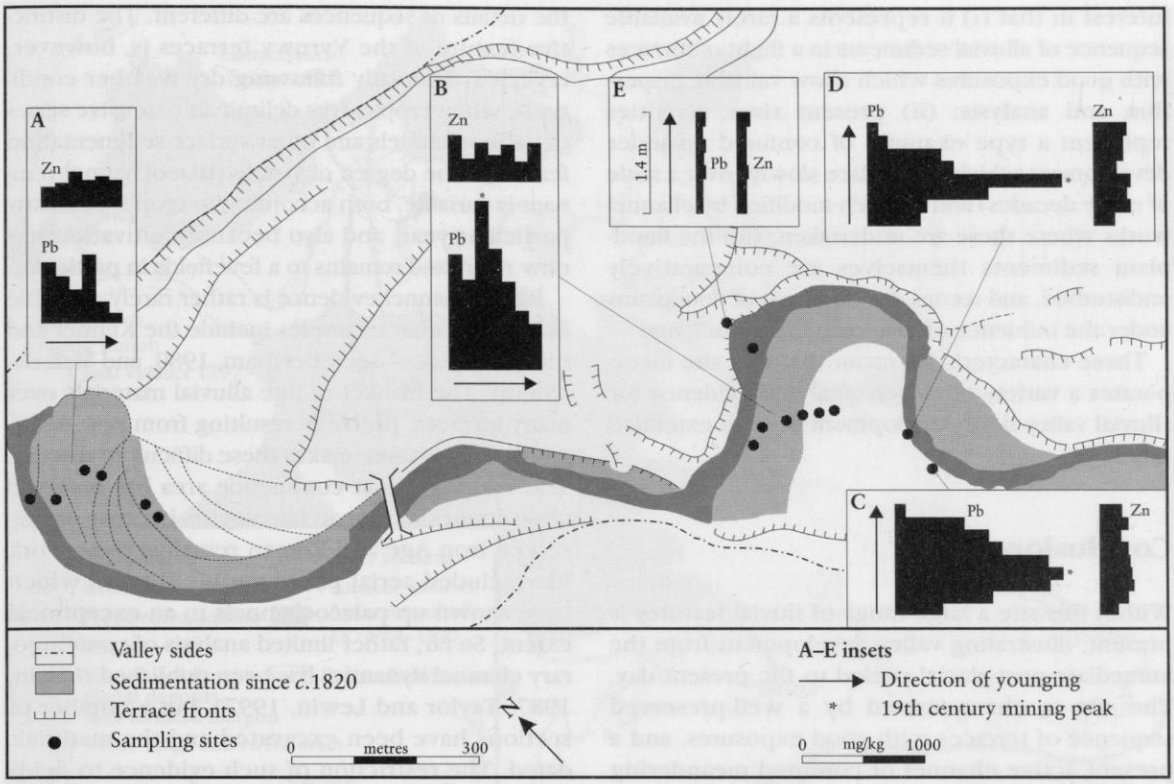


Figure 3.24 The Afon Rheidol: metals (lead and zinc) in river sediments. (After Macklin and Lewin, 1986.)

are again river sediments; the Floodplain Complex contains mining aggradation materials from the 19th century.

Interpretation

Analysis of floodplain sediments (Wolfenden and Lewin, 1977) reveals both their high metal content and the fact that age sequences may be identified in which pre-mining sites of sedimentation (pre-19th century mining was restricted in intensity) and post-mining materials (mining effectively ceased at the beginning of the 20th century) have relatively low metal (Pb, Zn) contents, with a mining era peak and subsequent fall off (Figure 3.24). It is thus possible to derive a detailed picture of metal pollution in both space (fall-off in concentrations down-valley, and concentration in fine sediment zones in particular) and time (in relation to mining activity). The results of this analysis have been widely used as a basis for understanding mining impact in other areas worldwide, and the relatively undisturbed nature of the valley floor (deep ploughing is limited) does contribute to the preservation of alluvial sediments which are of considerable scientific interest.

Finally, the river channel is cut into both terraces and the floodplain itself: this leads to the formation of confined meanders (Lewin and Brindle, 1977), the mode of development of which is somewhat different from 'free' meanders developed on open floodplains. The former tend to develop more slowly than the latter, eventually producing cutoffs adjacent to the scalloped fringe of the terrace itself. During development, the river can become orientated towards the upstream end of cut-bank arcs, with braiding of the material derived from the erosion of the high terrace within the channel. This illustrates both the singular nature of channel developments in such locations, and the role of available sediment supply in channel pattern development. It should be appreciated that the land loss/transfer involved does lead farmers and the water authority to undertake *ad hoc* channelization and bank protection measures. These have been partially, but not completely, successful in decreasing mobility, and they do of course modify future natural trends in channel development.

This river reach is of exceptional scientific interest in that (i) it represents a rarely available sequence of alluvial sediments in a flight of terraces with good exposures which allow valuable inspection and analysis; (ii) present river activities represent a type example of confined meander development which takes place slowly (over a scale of many decades) and is much modified by channel works where these are undertaken; (iii) the floodplain sediments themselves are comparatively undisturbed, and record development of floodplains under the influence of historical mining activity.

These characteristics mean that this site incorporates a variety of closely analysed evidence for alluvial valley floor development over an extended timescale.

Conclusion

Within this site a large range of fluvial features is present, illustrating valley development from the immediate post-glacial period to the present day. The site is characterized by a well-preserved sequence of terraces with good exposures, and a present active channel of confined meandering type. Deposits within the valley floor record the influence of mining activity. All of these aspects have been thoroughly researched, establishing an international significance for the site.

AFON VYRNWY, POWYS (SJ 250207 AND SJ 279206)

J. Lewin

Highlights

At this GCR site, terraces cut into Devensian materials are characterized by exceptionally preserved palaeochannels, revealed especially as crop marks in aerial photography. These are probably the best preserved in Wales, and show the complex changes in channel patterns that have occurred since deglaciation.

Introduction

In the vicinity of its junction with the Tanat, the Vyrnwy Valley contains a flight of terraces up to around 10 m above present river level. These features are not unlike those preserved on the Rheidol (*q.v.*) although section exposures are not good and the details of sequences are different. The distinctive feature of the Vyrnwy terraces is, however, revealed especially following dry weather conditions, when crop marks delimit an extensive series of palaeochannels and other surface sedimentation features. The degree of visible palaeochannel remnant is variable, both according to crop type in any particular year, and also because cultivation has now restricted remains to a few fields in particular.

Palaeochannel evidence is rather rarely available in Britain (other examples include the Kennet and the North Esk — see Cheetham, 1980, and Maizels, 1983b). The blanket of fine alluvial materials over many terraces, probably resulting from post-deforestation alluviation, makes these difficult to discern. The Vyrnwy–Tanat confluence area has received close attention from archaeologists because of preserved Iron Age and Roman remains; their work has included aerial photographic surveys which have shown up palaeochannels to an exceptional extent. So far, rather limited analysis of contemporary channel dynamics has been published (Lewin, 1987; Taylor and Lewin, 1997), but a number of sections have been excavated and the materials dated. The restriction of such evidence to fields that have not been deep-ploughed, points to the fragility of palaeochannel remains, and the site merits careful conservation so that these remnants are not eradicated altogether in the future.

Description

The site comprises a set of fields, on several terrace levels, within which palaeochannel remains are well-preserved. These terraces relate to the Tanat and to the main Vyrnwy between the Tanat–Vyrnwy junction and the eastern extremity of terrace features near the Morda junction (Figure 3.25). Gradients are somewhat steeper than that of the present river. The highest terrace level (*c.* 10 m above present river) contains closed depressions with ponds and has a 'mottled' appearance on aerial photography (Lewin, 1992, fig. 10.3). Such features suggest kame terrace morphology and ice marginal deposition. At Carreghofa there is also evidence of a large palaeomeander at the same altitude, this probably representing the earliest 'post-glacial' alluvial channel.

Three main terrace levels occur in an incision sequence before the contemporary floodplain is reached. Again, these have preserved palaeomeander channels, although along the Tanat there is some evidence of braided channels. These are dated

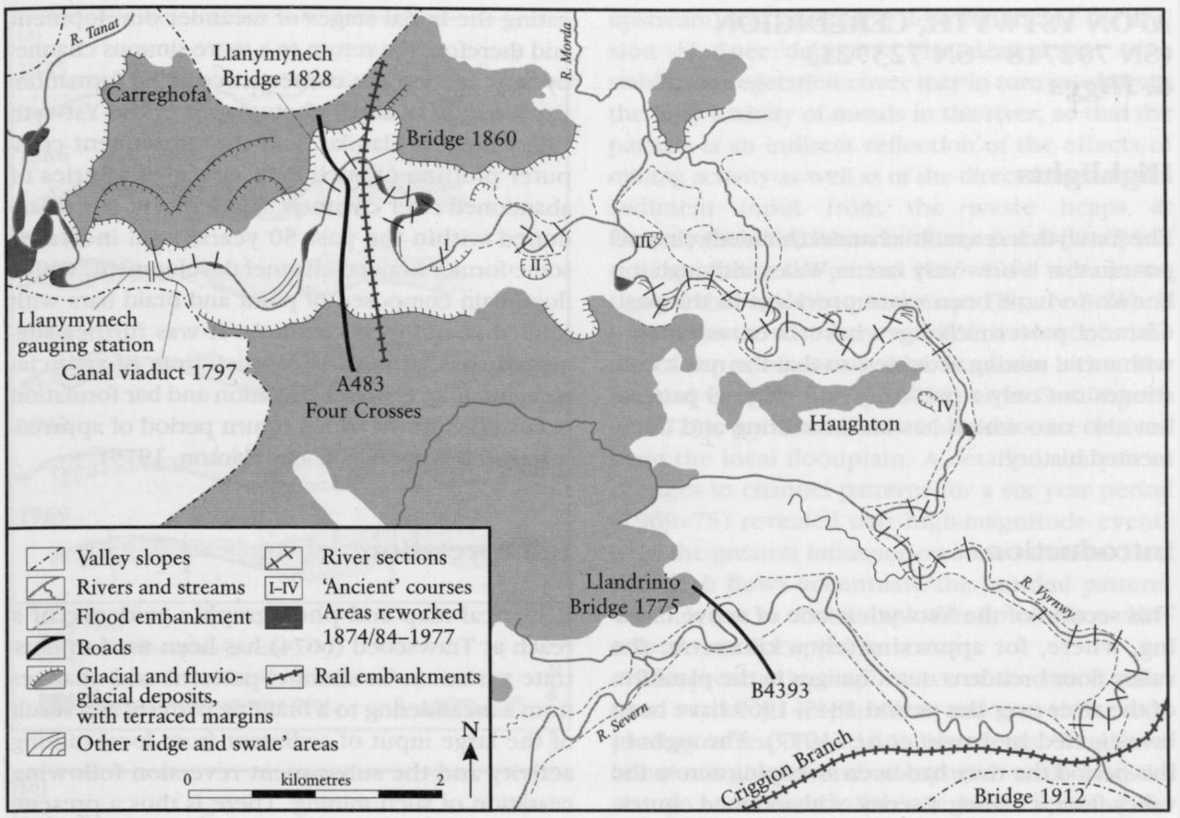


Figure 3.25 The Afon Vyrnwy: a geomorphological map. (After Lewin, 1992.)

as mid-Holocene, and there are remains of a probably briefly occupied Roman camp on the lowest terrace surface, with evidence of near-contemporaneous fluvial infilling in a Roman ditch some metres higher than the present channel.

The present Tanat has been artificially straightened and is incised; the Vyrnwy, above its junction with the Morda, remains a laterally mobile river, producing point bar sediments and, following an extreme flood in 1947, a cutoff immediately downvalley of the Tanat junction (Lewin 1992, fig. 10.4). Downstream of the Morda, the channel is laterally stable and of very low gradient on what is believed to be a former lake floor (Thompson, 1982). Here, medieval ridge-and-furrow features closely approach the present channel, which is now embanked for flood protection purposes (Lewin 1992, fig. 10.5). Terrace features are absent here (Taylor, 1993; Taylor and Lewin, 1997).

Interpretation

The terrace surface features at this site, visible especially under dry weather conditions rather than necessarily constituting marked topographical features, are little known and studied in Britain. They may, however, be more widespread than realized, though concealed, and their finer details can and have been eliminated by cultivation. They provide very useful information on palaeohydrology in the Holocene (especially about river channel size and hence discharges) and could prove to be key features in this respect. Survey and dating of the fluvial sediment provide a timescale for terrace development and channel pattern evolution; it is important that such a site, where evidence is known to be available, is not inadvertently destroyed.

Conclusion

A flight of terraces is present within the Vyrnwy Valley but their distinctive features are the unusually well-preserved palaeochannels in their surfaces. These are particularly revealed in crop patterns on aerial photographs. They have the potential to provide valuable information on past hydrological conditions.

AFON YSTWYTH, CEREDIGION (SN 702718 – SN 723721)

G. Higgs

Highlights

The Ystwyth has a multi-channel (braided) channel pattern that is now very rare in Wales, although it is known to have been more prevalent in the past. Channel pattern changes have been associated with metal mining activities, so that the reach constitutes not only a presently rare channel pattern, but also one which has an interesting and documented history.

Introduction

This section of the Ystwyth is one of active braiding, where, for approximately a kilometre, the valley floor broadens out. Changes in the planform of the river over the period 1845–1969 have been investigated by Lewin *et al.* (1977). Throughout this period the river had been sweeping across the valley floor, creating a series of abandoned chutes. It has been suggested that the impact of mining in the catchment has led to the high toxicity of derived sediments, leading to a lack of vegetation and therefore to more rapid erosion of banks and floodplain, rather than mining resulting in the input of coarse sediment to the system. Work currently being undertaken suggests that the channel section is rapidly changing in response to high-magnitude floods, but that rates of movement tend to be otherwise slow for braided rivers in general.

Description

The section of the Ystwyth at Grogwynion is unusual in that it represents one of the very few braided reaches in Wales (Passmore *et al.*, 1993). Studies on downstream sections of the river reveal high rates of lateral channel shift, largely as a result of human activity. Thus, for example, Lewin (1976) noted a return to a sinuous pattern of the Ystwyth at Llanilar following artificial straightening firstly in 1864 (to protect an adjacent railway track), and subsequently in 1969 by the local water authority. Aerial and ground photography and field survey in the affected reach after the latter channelization revealed that within a year a series of point-bar landforms with lobate bar cores had emerged, indicating the initial stages of meander development and therefore the return to a more sinuous channel by bank erosion as a consequence of bar formation. Examination of aerial photographs of the Ystwyth valley floor at Llanilar, and the subsequent computer plotting of such data, revealed a series of abandoned river channels, some recent (i.e. abandoned within the past 50 years), and indicated some former braided channel development, with a floodplain composed of point and braid bars with infilled abandoned channels. It was further suggested that without the constraints of artificial straightening, channel migration and bar formation occurred at flows with a return period of approximately 0.8 year (Lewin and Manton, 1975).

Interpretation

Historical map and photographic evidence of a reach at Trawscoed (6674) has been used to illustrate variations in channel patterns and changes from a meandering to a braiding pattern, as a result of the large input of sediment from local mining activity and the subsequent reversion following cessation of such mining. There is thus a present-day low-sinuosity channel, and a floodplain with alternations of coarse and fine deposits (Lewin *et al.*, 1983). The highest sedimentation levels were in the 1890s and led to the deposition within the channel of coarse material bars and also of overbank splays of steep gradient. Subsequently, the gaps between such splays have been infilled with 'fines'.

By 1946 the section had reverted to a 'wandering gravel river' type with a single sinuous channel, eroding the 19th century mining sediments within a constricted area between the railway and a higher terrace level. It was suggested that the present channel has a steeper gradient than the pre-mining floodplain and that the '… river is still in the slope discharge class of many braided streams' (Lewin *et al.*, 1983). It appears, therefore, as if there were extensive areas of braiding at the end of the 19th century on the Ystwyth. However, it was suggested that the materials deposited in this reach at Trawscoed (downstream of the braided reach at Grogwynion) were not directly the result of coarse sediment input from the mines, but that they were '… derived from the reworking of upstream alluvial deposits, notably from a pocket of alluvial sediment 5 km upstream in the vicinity of the crushing plant for Frongoch ores' (Lewin *et al.*, 1983).

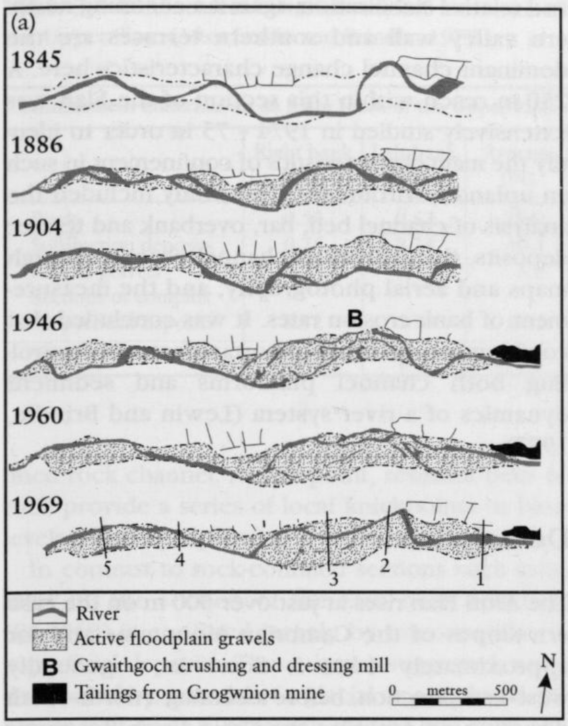


Figure 3.26 The Afon Ystwyth: (a) the channel at various dates; (b) the floodplain profiles at Grogwynion in 1969. (After Lewin *et al.*, 1977.)

Similar conclusions were reached for the Grogwynion reach by Lewin *et al.* (1977), regarding direct input of fines from the mining activity, changes in sedimentation and planform patterns resulting from the reworking of the coarse deposits upstream, and vegetation destruction and the erosion of finer deposits. The destruction of a stabilizing vegetation cover may in turn result from the high toxicity of metals in the river, so that the pattern is an indirect reflection of the effects of mining activity as well as of the direct effects of the sediment input from the waste heaps at Grogwynion. Variations in channel and floodplain profiles during the period 1845–1969 were investigated through historical maps (Figure 3.26). It was suggested that there was little evidence for the direct input of coarse deposits from either the mine at Grogwynion (714723) or at Gwaithgoch (710723), but that the river deposits are derived from the local floodplain. A detailed analysis of changes in channel patterns for a six year period (1969–75) revealed that high-magnitude events have the greatest influence on such variations, and that high flows accentuate the braided pattern, which is not so obvious at lower flows when channels are not occupied by water.

The present-day importance of the reach arises from variations in planform and gravel bar morphology in response to flooding events. These have been monitored and compared with rates of change noted on the River Feshie in Scotland, for example, by Ferguson and Werritty (1983). Despite evidence of more active braiding in the past, there are no comparable sites in Wales that offer such an opportunity for reactivation given a more flood-prone river regime under changing environmental conditions in the future (Passmore *et al.*, 1993).

The reach of the Ystwyth at Grogwynion illustrates the influence of 19th-century metal mining on the sediment and channel characteristics of the river, firstly through the input of toxic metals leading to the destabilization of floodplain vegetation and the subsequent release into the system of coarser material deposited during an earlier phase of activity, and secondly through the direct input from waste and spoil heaps. There is evidence to suggest that other sections of the Ystwyth downstream of this reach, for example at Trawscoed, were formerly braided, but that as a result of the decline in mining activity and of man-made channelization works, the river has returned to a less sinuous pattern.

Conclusion

The Grogwynion GCR site on the Ystwyth is one of the few active, braided reaches of river channel in Wales. Changes have been monitored, with a view to understanding the effect of different-sized flows, allowing comparisons in planform and gravel bar morphology with braided river sites in Scotland to be made.

UPPER ELAN UPSTREAM OF CRAIG GOCH RESERVOIR AT BODTALOG, POWYS (SN 865746)

G. Higgs

Highlights

This upland valley floor displays characteristic infilling of superficial deposits, but has been trenched by an active meandering stream. The site constitutes a type example of confined meandering.

Introduction

The upper Elan upstream of Abergwyngu (871736) provides an excellent example of the response of an upland stream to confinement on a low-relief floodplain. It shows contrasting planform types within a relatively limited area. Lewin and Brindle (1977) suggest that lateral growth, loop expansion and relative stabilization, against a confining northern valley wall and southern terraces are the dominant channel change characteristics here. A 250 m reach within this section of the Elan was extensively studied in 1974 – 75 in order to identify the main characteristics of confinement in such an upland environment. This study included the analysis of channel bed, bar, overbank and terrace deposits, the analysis of channel change through maps and aerial photography, and the measurement of bank erosion rates. It was concluded that confinement can be an important factor in controlling both channel planforms and sediment dynamics of a river system (Lewin and Brindle, 1977).

Description

The Afon Elan rises at just over 500 m on the eastern slopes of the Cambrian Mountains and for approximately 4 km it flows in a generally west–east direction, before assuming a north–south direction on entering the Craig Goch Reservoir downstream of Pont ar Elan (904714). The Elan illustrates a variation in the type and extent of confinement such that, for example, upstream of Pont ar Elan, the river meanders across a 200 – 300 m floodplain before entering the reservoir in a con-

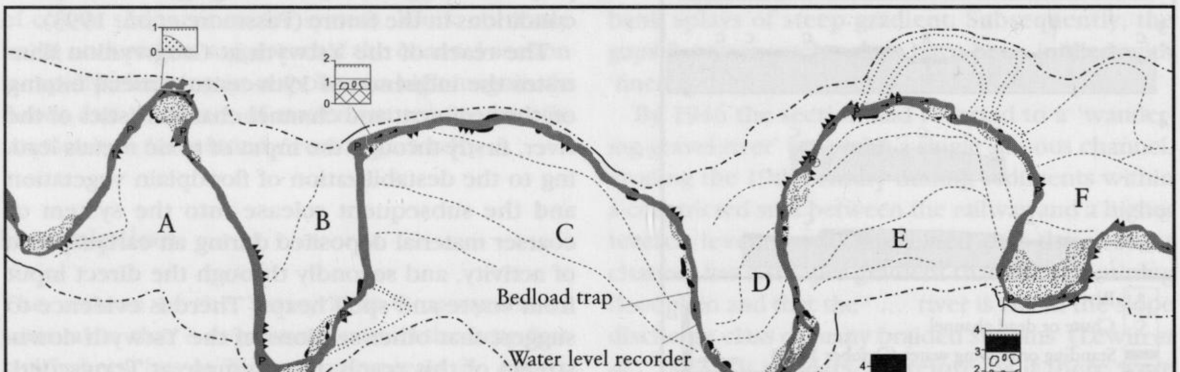


Figure 3.27 The study reach on the Afon Elan (SN 864748). (After Lewin and Brindle, 1977.)

Table 3.1 Confinement materials on an 8 km reach of the Upper Elan. (After Lewin and Brindle, 1977.)

Confinement materials on an 8 km reach of the Upper Elan			
	Right bank (km)	Left bank (km)	Average (%)
Rock	0.53	0.53	29.0
Solifluction deposits	0.75	0.74	40.1
Fluvial gravels	–	0.25	6.8
Sections of complex superficial deposits	0.52	0.34	24.1
Total	1.80	1.86	100.0

fined rock channel. At this point, resistant beds of rock provide a series of local knickpoints or base levels, creating rapids.

In contrast to rock-confined sections such as at 883728, the section of the Elan near Bodtalog (864748) is confined largely by unconsolidated superficial deposits. These, it was suggested, were dominated by material of a glacial or periglacial origin, so that on an 8 km reach studied by Lewin and Brindle (1977), 3.68 km was confined by such deposits and by rock (Table 3.1). This confinement was seen to have important implications for the development of channel planforms, for example, typical meander planforms have been distorted, such as at 863749. There are at least seven points within the section where the present channel impinges on the superficial deposits, and although the degree of erosion varies from bank to bank, these materials form an active input to the system. There is evidence to suggest that some of these deposits remain within the reach as gravel bars, and transport processes are dominantly by bedload, with finer sediment being transported in more extreme events (Lewin and Brindle, 1977). In addition, there are terrace bluffs away from the present channel, which may previously have provided an important source of material. Channel change is evidenced by old channel beds (865747) and channel traces, which are now recognized by boggy conditions and marsh vegetation.

There is evidence of local slumping into the main channel that is aided by the undercutting of banks, which tend to be dominated by coarser materials at the base with finer-grained upper units. The cantilever collapse of such banks, as in lowland sections of major rivers such as the Severn (Thorne and Lewin, 1979), is apparently important for the input of sediment to the system. Such bluffs are 3 - 4 m high in places and are dominated, at least above the level of the main channel, by coarser materials in a fine matrix. The coarse materials are mainly angular and range up to 90 cm in length, and are suggested by Lewin and Brindle (1977) to be largely composed of solifluction material. There are areas of alluvial deposits on the valley floor, including gravel point and side bars and also sheets of overbank gravel in places, which are deposited in flooding events.

Results from bed material sampling (using bedload traps), suspended sediment calculations, and from the measurement of bank erosion rates, suggest that confinement within the reach controls the major source for sediment within the study reach (Figure 3.27) (Lewin and Brindle, 1977). In all, five confined loops and one unconfined loop were studied in this reach. Map evidence suggested that rates of movement of three loops (C, D and E on Figure 3.27) were slow (no major change in position was noted since 1885) suggesting '... relative stabilisation against the confining media' (Lewin and Brindle, 1977). Examination of bank erosion rates revealed a great deal of spatial variation, with an average loss of only 1.4 mm in the study period (April 1974 to May 1975). The highest rates, however, occurred in confined reaches (Figure 3.28), where slumping of material into the main channel — especially during flooding events — was seen to be important (e.g. loop D of Figure 3.27). In the latter case, this has led to the creation of in-channel bars, which in some cases have been colonized by vegetation. The input of finer sediment to the system tends to be spatially and temporally irregular. Thus '... the sediment yield can be highly variable when measured downstream of all but a few active sediment sites' (Lewin and Brindle, 1977). These are generally washed through the system, although there are local deposits of finer silt-sized material. The evidence suggests, therefore, that here the process of confinement has led to meander loops developing within the confining media such that the terrace bluffs, it was calculated, provide 0.02 m^3 of sediment per metre of bank per annum. This has meant that meander loops in such places are not as distorted as, for example, those patterns noted on the Rheidol and Ystwyth (Lewin and Brindle, 1977), Tywi (Lewin and Hughes, 1976; Lewis, 1982) and Dyfi (Lewin and Hughes, 1976), where more complex patterns of meander growth have resulted from the confinement of river channels owing to human activities, such as railway construction. On the Elan, it is suggested that individual confined loops have remained in their position for a century or more.

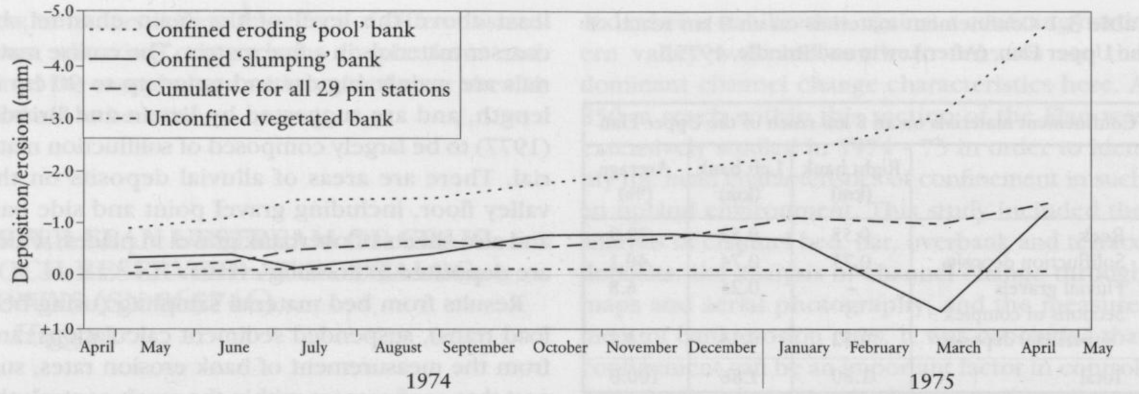


Figure 3.28 Bank deposition (positive values) and erosion (negative values) between April 1974 and May 1975. (After Lewin and Brindle, 1977.)

Interpretation

The Upper Elan provides an excellent example of the response of a river to varying degrees of confinement. This contrasts with those downstream sections of the Elan between Abergwngu and Pont Elan, where the river broadens out across a wider floodplain and creates a range of depositional features characteristic of more lowland streams, and also with the confined rock channels preceding the entry of the river into the Craig Gôch Reservoir. Downstream meanders expand laterally as the degree of confinement decreases. The section also provides an important contrast to meandering sections of confined streams in lowland situations, where such confinement is induced by human activity and where there has been modification to the pattern of meandering. In the case of the Elan, terrace bluffs made up of glacial and periglacial deposits are still providing active inputs of material into the system, resulting in an ensconcement of the meander loop within the confining deposits. There is evidence of cutoffs and abandoned channels on the floodplain. This site thus illustrates the importance of confinement on a river's development through influences on the planform and sediment dynamics.

Conclusion

The upper Elan Valley exhibits a range of channel planform types within a limited reach. It contains especially good examples of confined meandering in which processes of change and sediment dynamics have been measured. The channel is confined by valley-fill deposits of various types.

UPPER RIVER SEVERN BETWEEN DOLWEN AND PENSTROWED, POWYS (SN 996851 – SO 075910)

R.D. Hey

Highlights

This is the epitome of a laterally unstable gravel-bed river in Wales. It is illustrative of the variety of channel forms, sedimentary structures, erosion/deposition processes, and rates and modes of change which occur. Research at this internationally important site relates to sediment transport, bank erosion, flow pattern and meander changes.

Introduction

The River Severn, in the 17.5 km reach between Dolwen (99608512) and Penstrowed (07439103), is a very unstable gravel-bed river which exhibits a wide range of erosional and depositional forms and associated sedimentary features. It represents one of the most unstable sections of natural channel remaining in England and Wales.

The reach is located in the piedmont zone between the relatively steep headwater reaches, which are zones of sediment production, and the less steep alluvial reaches downstream, which have reduced transport capacity. It is the reduced gradient that facilitates rapid bar accumulation, and associated bank erosion and changes in channel planform (Figures 3.29 and 3.30).

At this site the river flows through a wide alluvial valley, which, in part, is a legacy of the last

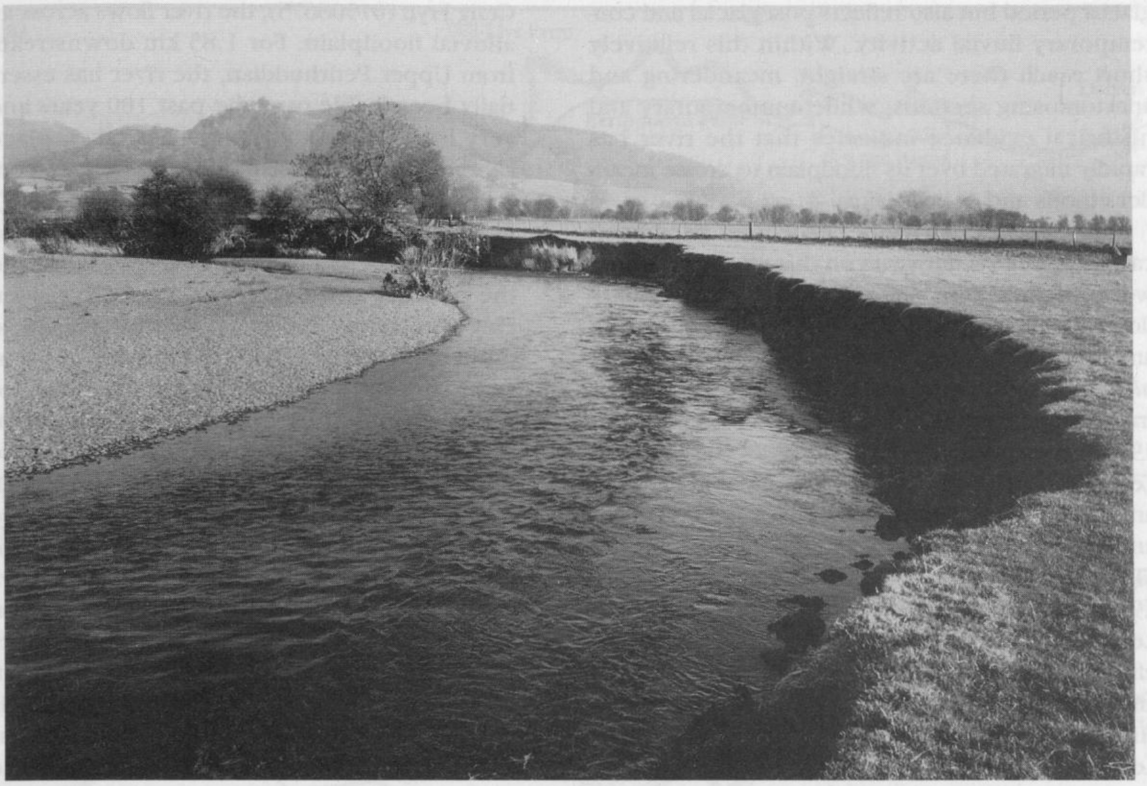


Figure 3.29 The River Severn, at Caersws, showing active erosion of the outer bank of a meander, and deposition on the other. (Photo: S. Campbell.)

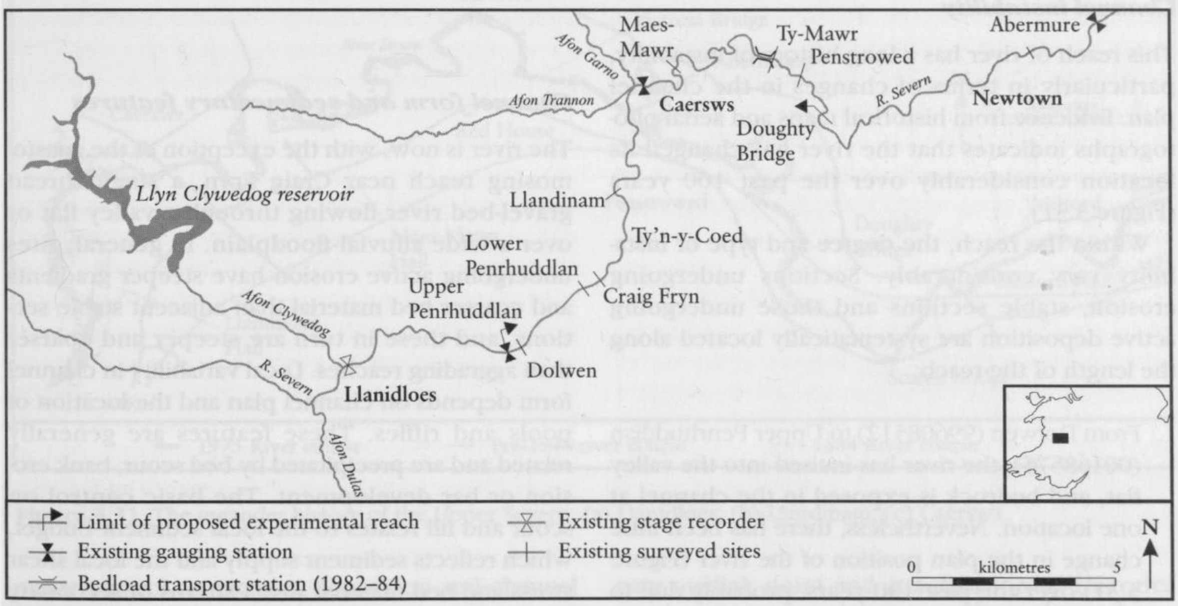


Figure 3.30 A location map of the upper Severn, showing the positions of the measurement stations and survey sections.

glacial period but also reflects post-glacial and contemporary fluvial activity. Within this relatively short reach there are straight, meandering and anastomosing sections, while contemporary and historical evidence indicates that the river has rapidly migrated over its floodplain to create meander cutoffs and oxbow lakes.

Many studies of channel processes have been carried out in recent years on this reach, including work on: flow resistance (Hey, 1979); secondary flows and shear stress distribution in meandering and straight channels (Bathurst, 1979; Bathurst *et al.*, 1977, 1979; Thorne and Hey, 1979); sediment transport (Hey, 1980; Newson, 1980; Arkell *et al.*, 1983; Leeks, 1983, 1986; Hey, 1986; Newson and Leeks, 1987; Meigh, 1987); bank erosion (Thorne and Lewin, 1979; Thorne and Tovey, 1981; Lawler and Leeks, 1992); channel and sedimentary history (Thorne and Lewin, 1979; Hey, 1980; Hey *et al.*, 1981); meander migration and cut-offs (Lewis 1982; Lewis and Lewin, 1983; Lewin, 1987); and the effect of river engineering, flow regulation schemes and environmental change (Hey, 1980; Hey, 1986; Higgs, 1987; Higgs and Petts, 1988; Leeks, 1986; Leeks *et al.*, 1988). The principal geomorphological features of the GCR site and their conservation value are reviewed by Hooke *et al.* (1994).

Description

Channel instability

This reach of river has a long history of instability, particularly in terms of changes in the channel plan. Evidence from historical maps and aerial photographs indicates that the river has changed its location considerably over the past 100 years (Figure 3.31).

Within the reach, the degree and type of instability vary considerably. Sections undergoing erosion, stable sections and those undergoing active deposition are systematically located along the length of the reach:

1. From Dolwen (99608512) to Upper Penrhuddlan (00168575), the river has incised into the valley flat, and bedrock is exposed in the channel at one location. Nevertheless, there has been little change in the plan position of the river (Figure 3.31) over the past 100 years, probably due to the stabilizing influence of the bedrock outcrop and the presence of tree-lined banks.
2. Between Upper Penrhuddlan (00168575) and Craig Fryn (01508675), the river flows across an alluvial floodplain. For 1.85 km downstream from Upper Penrhuddlan, the river has essentially been stable over the past 100 years and very little lateral movement has taken place since it was straightened during railway construction in 1859 (Figure 3.31).
3. From Craig Fryn (01508675) to Ty'n-y-coed (02258780), the channel is very unstable and the position of the river has altered considerably over the last 100 years (Figure 3.31) due to rapid aggradation. The development of transverse bars and associated bank erosion has led to the creation of a braided channel system. Several islands have been formed which have since been vegetated by gorse and other small shrubs.
4. Between Ty'n-y-coed (02258780) and Penstrowed (07439103), the river meanders across its own floodplain. Extensive lateral gravel bars, slumped bank material, meander cutoffs and oxbow lakes all indicate rapid lateral migration of the channel, and this is confirmed by the considerable changes that have occurred in the channel pattern over the past 100 years (Figure 3.31). At Caersws, 9.2 km downstream from Dolwen, two major tributaries, the Trannon and the Garno, join the Severn. Channel sinuosity increased from 1.42 in 1883 to 2.00 in 1967 but has since fluctuated, partly due to artificial as well as natural cutoffs.

Channel form and sedimentary features

The river is now, with the exception of the anastomosing reach near Craig Fryn, a single-thread gravel-bed river flowing through a valley flat or over a wide alluvial floodplain. In general, sites undergoing active erosion have steeper gradients and coarser bed material than adjacent stable sections, and these in turn are steeper and coarser than aggrading reaches. Local variability in channel form depends on channel plan and the location of pools and riffles. These features are generally related and are precipitated by bed scour, bank erosion or bar development. The basic control on scour and fill relates to the local sediment budget, which reflects sediment supply and the local shear stress and bed material size. Patterns of secondary circulation in the channel, which depend on channel geometry and flow levels, significantly affect shear stress distributions and, therefore, have a

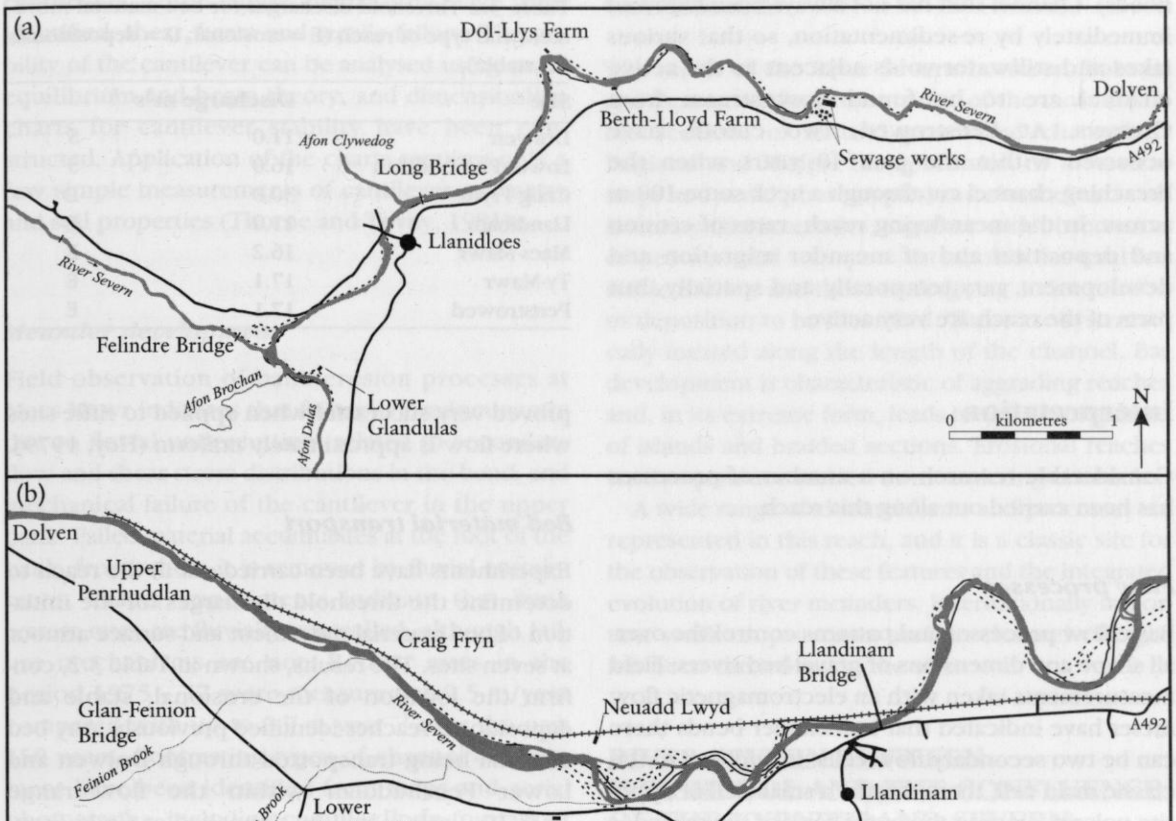


Figure 3.31 The meander history of the Upper Severn: (a) Llanidloes; (b) Llandinam; (c) Caersws.

major control on erosion, deposition and channel change.

A variety of types of bar is to be found along this reach of the River Severn, including lobate, elongate medial, point and attached forms. Historical sources show that these bars often migrate downstream and can cause chute cutoffs and loop abandonment (probably related to high-magnitude floods). Channel shift has not always been followed immediately by re-sedimentation, so that various lakes and stillwater voids adjacent to the active channel are to be found downstream from Caersws. At Penstrowed, two cutoffs have occurred within the past 40 years when the breaching channel cut through a neck some 100 m across. In the meandering reach, rates of erosion and deposition and of meander migration and development vary temporally and spatially, but parts of the reach are very active.

Interpretation

Considerable research on a number of processes has been carried out along this reach.

Flow processes

Basic flow processes and patterns control the overall shape and dimensions of gravel-bed rivers. Field measurements taken with an electromagnetic flow meter have indicated that in meander bends there can be two secondary flow cells. In addition to the classic main cell, there may be a small cell of opposite polarity close to the outer bank of the meander bend, provided that the bank is steep (Bathurst *et al.*, 1979). At the inflexion point between bends, measurements indicate that the old main cell from the upstream bend is displaced by a new cell in the downstream bend. Secondary circulation distorts the primary isovel pattern and thereby affects the position and relative magnitude of the boundary shear stress peaks. High shear stresses are associated with regions of downwelling, and high velocity and low shear stresses with regions of low velocity and upwelling. These shear stress patterns explain local scour-and-fill activity in meander bends. Deposition occurs on the point bar, in spite of high shear stresses during flood discharges, because of the downstream decrease in shear stress. Scour occurs on the outside of the meander bend due to a downwelling where surface flows converge (Bathurst, 1979; Bathurst *et al.*, 1979).

Flow resistance

The resistance to uniform flow in gravel-bed rivers is basically dependent on the flow geometry and the size characteristics of the graded gravel-bed material. An equation has been developed for estimating the friction factor, and thereby the average velocity and discharge in the channel, which has proved very successful when applied to riffle sites where flow is approximately uniform (Hey, 1979).

Table 3.2 Threshold discharges for bed material movement and type of reach (E = erosional; D = depositional; S = stable).

Site	Discharge m^3s^{-1}	
Dolwen	11.0	S
Lower Penrhuddlan	16.0	S
Craig Fryn	30.0	D
Llandinam	11.0	E
Maes-Mawr	16.2	E
Ty-Mawr	17.1	E
Penstrowed	17.1	E

Bed material transport

Experiments have been carried out in the reach to determine the threshold discharges for the initiation of bed material movement and surface armour at seven sites. The results, shown in Table 3.2, confirm the location of the erosional, stable and depositional reaches identified previously. Any bed material being transported through Dolwen and Lower Penrhuddlan within the flow range 16.0–30.0 m^3s^{-1} will be deposited at Craig Fryn. Further downstream erosion will occur because flows will be above transport thresholds (11.0 m^3s^{-1}) and there will be no sediment input from upstream (Hey, 1986). Comparison of the threshold discharges with actual discharge values indicates that bed material transport events are relatively frequent along this stretch of channel.

Bedload transport measurements were made at Victoria Bridge (05799240) in 1982 – 84 with a Helley–Smith bedload sampler (150 mm orifice). Bed material transport was initiated at approximately one third bankfull flow depth and the maximum observed transport rate for high, inbank flows was 3 kgs^{-1}. At higher discharges it was observed that the bed became fluidized and therefore transport rates would have been significantly higher (Meigh, 1987).

Bank erosion

Rivers flowing across gravel often have a composite bank structure, with cohesionless gravel, relict point bar deposits of bedload material, overlain by cohesive fine sandy, silty clay. This structure leads to undercutting and the production of cantilevers in the cohesive material. Upper bank retreat takes place predominantly by the failure of these cantilevers. Three failure mechanisms have been identified: shear, beam and tensile failure. The stability of the cantilever can be analysed using static equilibrium and beam theory, and dimensionless charts for cantilever stability have been constructed. Application of the charts requires only a few simple measurements of cantilever geometry and soil properties (Thorne and Tovey, 1981).

Meander development

Field observation of bank erosion processes at Maes-Mawr indicates that failure is predominantly due to fluvial undercutting, related to secondary flow and shear stress distributions in the bend, and mechanical failure of the cantilever in the upper bank. Failed material accumulates at the foot of the bank, from where it is removed by fluvial entrainment. Tracer experiments indicate that bank retreat rates are fluvially controlled, although failure mechanisms are not. Retreat rates in the period 1975 – 77 were measured at 0.5 m/year compared with up to 0.7 m $year^{-1}$ over the past 150 years. Contrasting types of channel development have been identified from maps and aerial photographs, including complex loop formation, neck and chute cutoff, and the rapid abandonment of lengths of cut bank and deep channel (Thorne and Lewin, 1979). The sequence of development of loops through to cutoff has been traced and the subsequent sedimentary evolution of the abandoned channels has been investigated (Lewis, 1982).

Flow regime

Analysis of hydrological variations in the reach over the period 1963 – 83 led Higgs (1987) and Higgs and Petts (1988) to conclude that although construction of the Clywedog dam and changes in land use in the catchment (mainly afforestation and upland drainage) had major impacts on the flow regime, the effects of climatic variation in rainfall were even greater. This appears to be confirmed by subsequent analysis of flow rates (Hooke *et al.*, 1994). The changes in flow regime have influenced the rates of erosion and amounts of floodplain reworking in the past 20 years (Hooke *et al.*, 1994). Likewise, analysis of variations in channel pattern over the past 200 years, derived from sedimentary and documentary records (Passmore *et al.*, 1993), has shown a relationship to flood incidence.

Conclusion

The reach of the River Severn between Dolwen and Penstrowed represents one of the most unstable sections of natural gravel-bed channel in England and Wales. Interpretation of historical maps and aerial photographs, and channel and sedimentary characteristics, together with observation of bed material transport thresholds has enabled stable reaches and those undergoing active erosion or deposition to be identified. These are systematically located along the length of the channel. Bar development is characteristic of aggrading reaches and, in its extreme form, leads to the development of islands and braided sections. Erosional reaches tend to produce incised or meandering channels.

A wide range of channel forms and processes are represented in this reach, and it is a classic site for the observation of these features and the integrated evolution of river meanders. Internationally important work on processes and on channel changes has been carried out at the site.

RIVER SEVERN BETWEEN WELSHPOOL AND THE CONFLUENCE OF THE VYRNWY AND SEVERN, POWYS (SJ 269127 – SJ 281150)

G. Higgs

Highlights

As a highly sinuous but now laterally stable reach, this part of the Severn has one of the most tortuous multi-loop river reaches in the inland valleys of Britain. The floodplain is dominated by overbank sedimentation, rather than the lateral accretion in evidence at many other sites.

Introduction

The Severn downstream of Welshpool provides an example of a relatively inactive lowland river section. The river at this point is laterally stable and is particularly prone to flooding, although those floods up to a five year return period are contained by flood embankments ('argae'). This contrasts with the section of the Severn upstream of Pool Quay, which historical maps demonstrate has undergone lateral movement (e.g. at Welshpool (237069); Ashworth, 1982). Cross-sections in the confluence areas have low width : depth ratios and occur in silty sediments. The bankfull channel capacity is lower than that farther upstream such that the proportion of high-magnitude discharges flowing outside the channel is larger (Lewin, 1983). A particularly stable meandering reach is known locally as the Roundabout (273129). At this point the channel is narrowly entrenched into alluvium deposits: in places it is 7 m below the floodplain (Humphries, 1979). Sedimentation is predominantly overbank at a rate locally in excess of 1 cm per year (Thompson, 1982). The relatively stable nature of the channel inhibits the erosion of fine deposits, suggesting that there has been a net aggradation in the area (Lewin, 1983).

Description

The Severn between Pool Quay (257116) and Llandrinio (300167) is particularly stable. The floodplain is over 2 km wide in places and is slightly convex in cross-section (Thompson, 1982). The channel itself has a very low gradient (0.0003) and a low width : depth ratio (< 10) (IGCP, 1983), such that in a survey of 14 cross-sections of the Severn between the source and the confluence with the Vyrnwy (95.7 km), sections downstream of Welshpool showed lower bankfull channel capacities, lower width : depth ratios and lower rates of lateral change than those further upstream (Lewis, 1982). Thus, for example, a cross-section

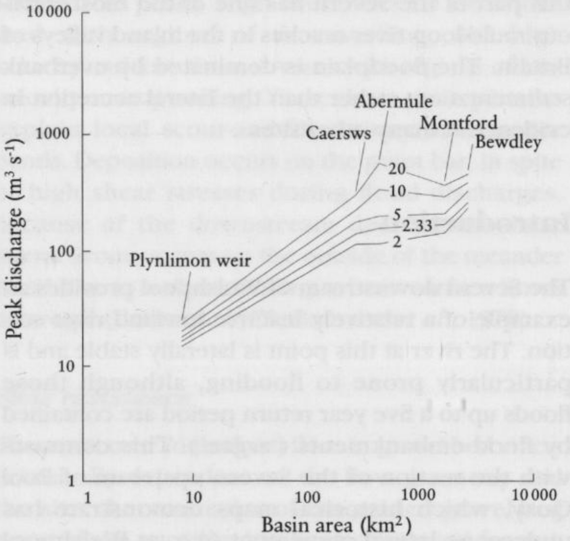


Figure 3.32 The upper Severn catchment: downstream flood frequency variations. (After Hey, 1975.)

surveyed just downstream of Newtown (112914) yielded a bankfull channel capacity of 112 m, a width : depth ratio of 15 and an average lateral rate of change of 0.15 m year^{-1}, as compared with values of 99, 8 and zero respectively for a cross-section downstream of Welshpool upstream of the confluence with the Vyrnwy (Lewin, 1983). In addition, comparisons of channel change for two cross-sections between Welshpool and the confluence for the period 1844 – 1973 with those upstream in the Welshpool area, using historical maps and aerial photography, illustrate that there has been very little lateral change in the former area in historical times (Lewis, 1982), whereas in the Welshpool area (Ashworth, 1982) several cut-offs date from the past 200 years, and zones of sedimentation dating from 1844 onwards exist along the main channel, both in point bar environments and in abandoned channels (IGCP, 1983).

The fact that the channel in this reach of the Severn has entrenched as much as 6 m into its floodplain has meant that in a study of the downstream variation in peak discharges associated with particular return periods in the upper Severn Catchment (Higgs, 1987), flood events of 10 and 20 years return periods had a higher discharge at Abermule than the downstream station at Montford (Figure 3.32), confirming the trend noted by Hey (1975). This was explained by the effect of channel and floodplain storage in the reaches between the two stations, which effectively delays the flood wave and thus reduces the peak discharge. This is particularly the case for the more extreme discharges. It has thus been suggested '... that the floodplain here is naturally adjusted to take a higher proportion of high magnitude flows than upstream where the steeper channel is cut into coarser less cohesive sediment' (Lewin, 1983). In such an environment, overbank sedimentation of fine deposits dominates, since the overbank flows are more frequent (Lewin, 1983). Figures presented by Thompson (1982) for rates based on such deposits burying ditches (e.g. at 268136) and on pottery of Roman origin, suggest net aggradation rates of anything between 0.03 cm per year (outside the Tirymynach embankment) and in excess of 1 cm per year (within such argae), although the tentative nature of such figures is stressed.

The section of the Severn outlined includes a particularly stable reach — the 'Roundabout' — which is a multi-looped meander consisting of two arcs. The neck of this meander is approximately 10 m wide. The river banks in this section are dominated by finer materials, although some gravel deposits exist in the form of bars. The section tends to be tree-lined and this fact, together with the presence of old roots, tends to add to the natural stability of the reach.

Interpretation

The River Severn downstream of Welshpool has features unique to a laterally stable channel where channel migration has not been in evidence (at least since the 1950s; Lewis, 1982). The site provides a direct contrast to those upstream sections of the Severn at Caersws (Thorne and Lewin, 1979) and Welshpool (IGCP, 1983) where channel mobility has involved the lateral translation of meander loops, and sedimentation dominated by in-channel processes (e.g. point bars) and within cutoff environments. The section has low width : depth ratios and lower bankfull capacities compared with those farther upstream owing to the cohesive nature of the sediments. The greater proportion of flows outside the main channel has led to the overbank sedimentation of fines (up to 1 cm a year). It has been suggested that such processes may preserve a record of the flooding history of the Severn at this point (Lewin, 1983), although little work has been done in this area to date. The channel itself has features unique to such an environment, having a low gradient (average of 0.0005) and a low width : depth ratio (generally under 10), since the channel has been cut up to 6 m into its floodplain. The banks are dominated by fines and, for the majority of the section, are tree-lined. At low flows, gravel bars are observed on the inside of the meander loops, which in places are complex multi-loop features. The gravel depositional features, however, are dominated by finer materials than those farther upstream.

Conclusion

This is a site at which the channel has a tortuous but now stable pattern. The channel is relatively deep and narrow, entrenched in fine sediments. It has a lower capacity than reaches upstream and so floods more frequently. This flooding results in a process dominance of overbank deposition on the floodplain.

RIVER DEE, HOLT TO WORTHENBURY, WREXHAM AND CHESHIRE (SJ 402464 – SJ 410534)

A.M. Gurnell

Highlights

This GCR site, known as the 'River Dee meanders', is one of the most tortuous stretches of meandering channel on a major British river. The stretch crosses the fluvial/tidal transition and is a location at which the interaction of river and tidal processes can be observed in a relatively natural setting (Figure 3.33).

Upstream reservoir regulation of the river flow has caused a progressive change in the discharge regime over the past 50 years, and the downstream section of the stretch is also influenced by a backwater from the 11th century Chester Weir.

The restricted amount of management of the channel allows the river's response to these anthropogenic influences to be observed.

Introduction

Little scientific research had been undertaken on this stretch of the River Dee until Gurnell *et al.* (1993) were commissioned to undertake a hydrological and geomorphological study by the Countryside Council for Wales (CCW). Some of the detailed results of this work are summarized in Gurnell *et al.* (1994). A programme of research on the contemporary fluvial–tidal processes on this section of the Dee has subsequently been funded by the Leverhulme Trust (Gurnell, 1996, 1997a,b). The following account of the River Dee meanders site is based on information from the above publications.

The River Dee between Holt and Worthenbury is approximately 18 km in length along the channel centreline, and is located at the transition between the upstream, fluvially influenced river channel and downstream channel sections, that are additionally affected by a freshwater backwater during spring tidal cycles. The most downstream section of the reach also contains a permanent backwater from Chester Weir (located some 20 km downstream of the stretch). The stretch consists of a meandering planform with a highly sinuous course (the sinuosity, expressed as the ratio of total channel centreline length to the length of the axis of the meanders, is approximately 2 : 1). The stretch contains at least

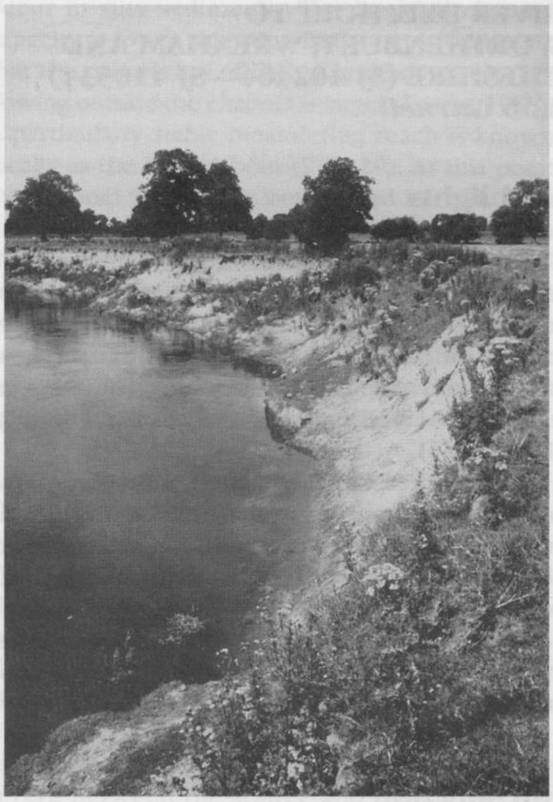


Figure 3.33 The outer bank of a meander of the River Dee, between Holt and Worthenbury. (Photo: S. Campbell.)

16 major meanders with additional changes in direction, giving a major meander wavelength slightly in excess of 500 m. The average channel width is approximately 30 m (limits of normal winter water level) and generalized bedslope ranges from 0.00005 in the most downstream section to 0.00065 at the upstream end of the reach.

The adjacent floodplain contains a number of palaeochannels, indicative of past channel mobility. A comparison of the position of the national boundary between England and Wales in the downstream sector of the stretch, and the county boundary along the upstream sector, is further evidence of movement in the historical position of the channel. A more ancient course of the River Dee has been identified from borehole data, indicating the varying depth from the ground surface to bedrock. These data have been collated by the Environment Agency and can be used to describe a palaeovalley the course of which appears to diverge from the present course of the Dee in a large arc south from Llangollen, crossing the present valley north of Overton, and passing to the east of Holt. At some point in the Devensian late-glacial (estimates vary from 18 000 to 14 000 BP), this course would have migrated towards, or been relocated to adopt, the approximate present position of the channel. Nevertheless, an analysis of Ordnance Survey map (Gurnell *et al.*, 1994) and aerial photograph (Gurnell, 1997a) information suggests that, over the past century, the river channel has been surprisingly stable in its position. Furthermore, sedimentary and archaeological evidence suggests that the recent period of relative channel stability extends back two or three centuries.

Description

Although this stretch of the River Dee is of interest in the context of the long-term evolution of its valley, terraces, floodplain and channel, there are as yet few research results to provide detail with regard to these aspects of the site (Gurnell *et al.*, 1993). Research so far has concentrated upon contemporary processes and adjustments in the river channel over the past century. It has revealed a number of unexpected characteristics of channel morphology and mobility, which are elaborated below.

Detailed analyses of the character and changes in the channel's planform have been undertaken by extracting information from 1 : 10 000 and 1 : 10 560 scale OS maps (Gurnell *et al.*, 1994) and from aerial photographic coverage at approximately 1 : 10 000 scale (Gurnell, 1997a), and by analysing the information within a Geographic Information System (GIS). The use of very careful methods of data extraction and computer-based manipulation have been essential to ensure that subtle changes in the river's planform are separated from errors generated in transcribing and analysing the data (Downward *et al.*, 1994). The changing character of the cross-profile of the river channel has been assessed through the analysis of 122 cross-profile surveys undertaken by the Dee and Clwyd River Authority in 1973, and 36 re-surveys plus an additional 20 new cross-profiles surveyed in 1994 – 95. Field observation of the landforms has been used to confirm the analytical results and to interpret their process significance.

Channel positional mobility

The channel planform has been surprisingly stable over the past century. Channel mobility has been lowest at the downstream end of the reach, increasing steadily in an upstream direction. Where channel movement has occurred, it has been mainly oscillatory in character, rather than indicating the channel migration that might be expected within a meandering river stretch. Where consistent channel migration has been identified, it has been predominantly towards the left bank in the central section of the stretch and towards the right bank in the upstream section. The predominant modes of channel planform change in the lower sections of the reach are either of no identifiable movement or reveal an oscillatory pattern. These spatial trends can be associated with decreasing stream power down the reach as a result of decreasing bed slope, and the increasing influence of the backwater from Chester Weir, and from high tidal levels overtopping the weir crest.

With the exception of six locally active sections, the total width of the floodplain, including the width of the active channel, across which the river has moved in the period 1876 – 92 is in the range 33 – 62 m. Since typical channel widths are in the range 20 – 45 m, total lateral movement beyond the width occupied by the active channel is less than half the present channel width along much of the river. The extent of lateral movement is significantly greater on meander bends (mean extent including the active channel, 55 m) than at points of inflexion (mean extent 46 m).

There appears to be a temporal pattern within the historical planform data, the most notable changes seeming to have occurred since 1949. There appears to have been an initial increase in channel position mobility and then a recent stabilization in channel position since 1979.

Variations in channel width

The active channel width is greater on meander bends than at points of inflexion. When these meander-scale variations in channel width are removed, an unusual spatial trend of downstream narrowing in channel width is identified. In addition, there appears to be a temporal trend whereby the channel has narrowed, particularly since the mid-1960s. The narrowing appears to have propagated downstream to the central portion of the reach by the mid-1970s, and to the downstream portion by 1992. This channel narrowing is thought to result from the closure of Llyn Celyn in 1965, which has resulted in significant changes in the river flow regime (Gurnell *et al.*, 1994).

Variations in the channel cross-profile

Analysis of 122 surveyed cross-sections (Gurnell, 1997b) dating from 1973 has shown that the morphology of the river channel along the 18 km stretch changes in a clearly identifiable manner. Up to three minima in the width : mean depth ratio of the channel at individual cross-sections, identify levels with distinguishable morphologies the geometric properties of which exhibit clear downstream trends. In particular, the highest level (level 1: overtopping level) defines a channel which becomes narrower and deeper in a downstream direction, thus maintaining an approximately constant cross-sectional area. This complements the observations on downstream channel width narrowing from maps and aerial photographs. The lower two levels (levels 2 and 3) define channel cross-sections which increase in area in a downstream direction by maintaining an approximately constant width but an increasing depth. Level 3 is only consistently identified in the downstream sector of the 18 km stretch that is influenced by the Chester Weir backwater. Simple process modelling suggests that level 1 is adjusted to flows within the 1.5 – 2.33 year return period under the present flow regime, and that level 2 may be associated with the dominant discharge for sediment transport and its adjustment as a result of flow regulation. Upstream trends in the geometric properties of cross-sections to level 2 exhibit a distinct change in slope at the limit of the weir backwater, suggesting that the morphological impact of the dominant discharge for sediment transport under flow regulation is moderated by the backwater from Chester Weir.

There are statistically significant differences in the geometry of the river channel cross-sections between the upstream fluvially influenced sector, the central fluvial–tidal sector and the downstream fluvial–tidal–weir backwater sector.

Other spatial and temporal characteristics of channel change identified from aerial photographs, 1946 – 92

Distinct changes in bank vegetation cover have occurred, with an increase in tree- and shrub-lined banks from 31 to 61% in the upstream sector and 3 to 41% in the downstream sector of the stretch over the 1946 – 92 period. The timing of these increases in tree and shrub cover corresponds closely with the timing of observed channel narrowing. Field observations show that the development of willow/sallow/alder cover is associated with high bank sedimentation rates. The association of the development of tree and shrub cover with changing channel width is, therefore, likely to be extremely important in understanding channel change on this stretch of the Dee. Certainly, low-level depositional benches have been observed (in the field and on aerial photographs) to support the development of shrub and tree cover, but the direction of causality is unclear. The development of benches and other less-marked components of the channel cross-sectional morphology may result from a change in the sediment transport and deposition regime as a result of flow regulation, particularly since the mid-1960s. Thus, channel narrowing may result from deposition of sediments, which may then become colonized by shrub vegetation. However, it is possible that a change in bank grazing and management practices has allowed colonization of the banks by shrubs and trees, which has then trapped transported sediment during flood events, thus resulting in a narrowing of the channel.

Analysis of six sets of aerial photographs has also shown differences in the extent of in-channel bars and overbank deposition along the stretch. The central sector, which is not affected by the Chester Weir backwater but is the most upstream sector influenced by tides, has by far the greatest area of exposed depositional bars per unit channel length. This reflects the changing channel form downstream (the downstream channel is deeper and narrower, thus providing a smaller channel area within which bars can be mapped), but it is also probable that the hydraulic disturbance of the tides interrupts sediment transport through this sector and that as a result sediment is deposited. Thus this sector of the study stretch appears to play an important role in the storage and transfer of sediments from the river system to the sea. The extent of post-flood overbank deposition of sediment from one set of photographs also identifies the same central tidally influenced sector as experiencing more extensive bank and floodplain deposition of sediment than the other sectors. There also appears to be a change in bank depositional processes through the study stretch, with a transition from 14% of channel cross-sections experiencing deposition on both banks in the upstream fluvially influenced sector, to over 40% of sections experiencing deposition on both banks in the remainder of the stretch (influenced by hydraulic disturbances as a result of tidal and/or weir influences). Detailed field studies are required to define precisely the processes responsible for the change, but field observations were used by Gurnell *et al.* (1993) to suggest a transition from upstream bank processes dominated by fluvial erosion and deposition, to downstream hydrologically dominated bank failure and backwater-dominated plastering or draping of sediments across the bank face.

It is likely that this transition in bank deposition processes associated with the fluvial–tidal transition and the backwater from Chester Weir, coupled with changing rates of sediment deposition resulting from flow regulation and enhanced sedimentation under the influence of bank vegetation change, are the key factors in explaining spatial and temporal variations in the morphology of the River Dee meanders over the past 100 years.

Interpretation

Although at first sight, the geomorphological attraction of the River Dee meanders focuses on the tortuous planform of the river channel, and the expectation that such a meandering course is likely to be associated with active migration and cut-off processes, detailed research has revealed a far more fascinating and unexpected story. The relatively unmanaged form of the river in this stretch provides numerous clues concerning the interactions between fluvial and tidal processes and the anthropogenic influences of reservoir flow regulation and weirs on river channel form.

In the context of the past 100 years, the decreasing planform mobility and channel narrowing in a downstream direction are unusual observations, which can be explained by the interaction of fluvial–tidal flow regulation and weir influences. The complexity of these interactions is reflected in the cross-sectional form of the channel, and in field observations of the association of properties of channel form with bank sediments, erosion and failure processes. The relatively unmanaged nature of the stretch allows these subtle properties of the channel planform and cross-section to be identified, and also allows the interaction between bank processes and bank vegetation cover to be elucidated.

It is clear from the presence of palaeochannels and the evidence of mismatches between county and national boundaries and the current channel position, that the river has been more mobile in the past. The reconstruction of detailed Holocene fluvial sequences is a major undertaking which has yet to be addressed for this site. However, the preliminary observations presented in Gurnell *et al.* (1993), and based upon archaeological and sedimentary evidence, suggest a period of relative channel stability over the past two or three centuries. If it is the case that significant overbank deposition leading to cutoff infill ceased from some time around 1700 AD, then the possibility arises that the recent historical evolution of the system has been increasingly and significantly influenced by human modification, including progressive flow regulation.

Thus the original conservation interest in this site as an example of lowland tortuous meanders has now been supplemented by its importance as a site influenced by weir-controlled flows in different parts and affected by changes in the discharge regime due to regulation in the catchment. A complex spatial and temporal sequence of morphology and subtle instability has been identified, and is associated with unusual processes of bank adjustment.

Conclusion

This site comprises a tortuous meandering channel and a floodplain with some relict channels, which together with circumstantial evidence of boundary positions imply high mobility of the channel. However, recent research has shown that the channel has become more stable in planform in the past few centuries, but that morphology and stability do vary down through the reach. The behaviour is related to the varying influence of river discharge, tidal flows and weir backwater effects, which result in complex bank erosion and sedimentation processes. Potential exists for further study into the nature of these adjustments, and also into the Holocene evolution of the floodplain.

AFON TEIFI AT CORS CARON, CEREDIGION (SN 684627 – SN 697644)

G. Higgs

Highlights

At this site, the river flows through organic and fine inorganic materials deposited on the site of a former lake, and is a type example of channel development in finer-grade materials. The role of vegetation is evident in channel development, while the lake sediments and longer-term development at this site are also of considerable scientific interest and significance.

Introduction

The Afon Teifi in its upper reaches flows over Cors Caron, an area that was once a shallow lake, and which in post-glacial times became filled by fen peat, over which have developed three large raised peat bogs. The present-day channel of the Teifi is cutting through peat deposits accumulated in this former lake basin. Undercutting of mineral material below the peat results in the collapse of large blocks of peat. There is also an important contrast between the right and left banks of the river, demonstrating the influence of vegetation, with moor-grass roots on the right bank adding extra stability. Part of the reach has been artificially straightened to create shallow pools (flashes). An abandoned course of the river has been left as a marshy environment. Transport processes are dominated by suspended sediment movement, in contrast to upstream and downstream reaches where coarse bedload transport is more significant.

Description

The present-day Teifi originates on the western slopes of the Cambrian Mountains in the Teifi lakes and flows through a V-shaped valley before entering a wide-floored valley 10 km from its source. The evolution of the river pattern owes much to Caledonian folding and faulting movements (Jones, 1949) and there is strong evidence to suggest that the Teifi was once a much longer river before the capture of its headwaters by the proto-Ystwyth (Figure 3.34). Thus the abandoned high-level valley between the present-day watershed of the Ystwyth and that of the Teifi, and capture points on the Ystwyth at Pontrhydygroes (738723) and on the Rheidol at Devil's Bridge (742773), were used as evidence of a two-stage capture of the proto-Teifi by the Ystwyth and then the Rheidol (Howe and Thomas, 1963) This, it was suggested, was aided by excavation along fault lines. Although little work has been done to date the relative ages of this two-stage capture, the capture of the proto-Ystwyth by the Rheidol was probably relatively recent, possibly during an early interglacial or the immediate pre-glacial period (Howe and Thomas, 1963).

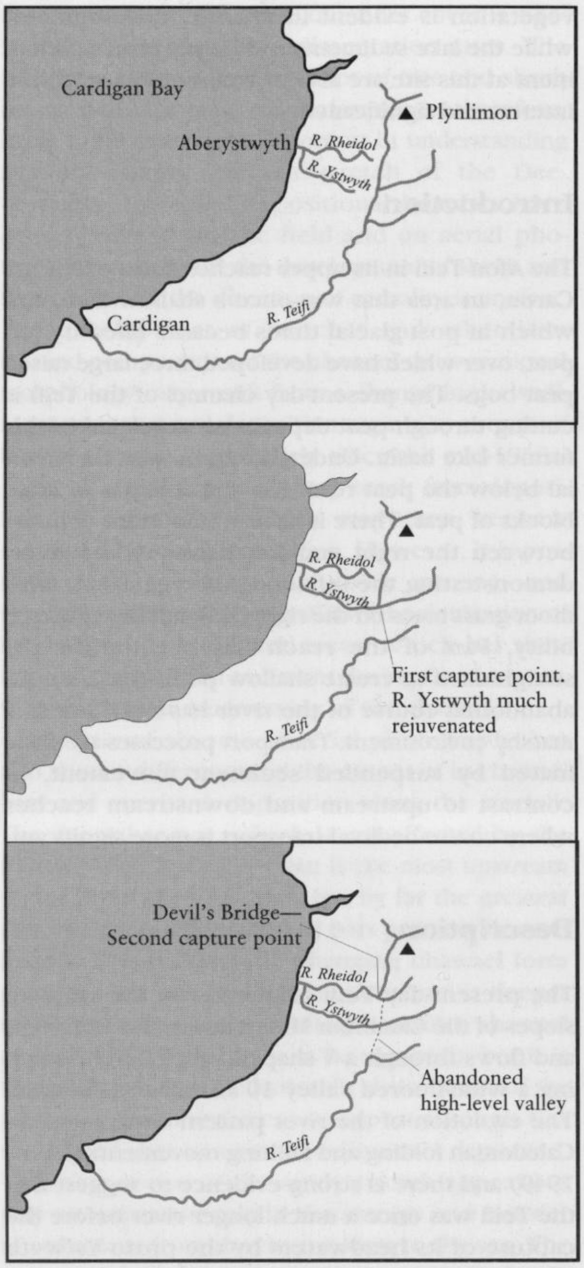


Figure 3.34 The capture of the upper Afon Teifi by the Rheidol and Ystwyth. (After Howe and Thomas, 1963.)

Downstream of Pontrhydfendigaid, the river changes both direction and character, assuming a southwesterly trend following the axis of the Teifi Anticline (Jones, 1949). The river at this point enters a 800 ha valley bog, the origins of which have been discussed in greater detail by Godwin and Mitchell (1938), Turner (1964), the NCC (1968), Godwin (1981) and Campbell and Bowen (1989). The bog owes its origin to the damming of a large lake, occupying several square kilometres, behind a terminal moraine on which the village of Tregaron is located. The lake gradually filled in and drained. The first deposits in such a lake were open-water muds and these were followed subsequently by fen peat and then by ombrogenous *Sphagnum* bog (Figure 3.35). This *Sphagnum* peat has accumulated to form three convex raised bogs (the west, north-east and south-east bogs) that have subsequently been altered to varying degrees by peat cutting and drainage operations. The bogs rise over 10 m above the present river level, and are some of the best developed and best preserved in Britain. Two of these raised bogs were studied in more detail (Godwin and Mitchell, 1938), and pollen analysis was used to illustrate the vegetational history of the area. The development of the *Sphagnum* peat was seen to be related to the prevailing climatic conditions such that rates of peat growth were particularly slow in dry conditions, thus forming a 'retardation layer' of highly humified peat (Turner, 1964).

The Teifi at this point flows over silty alluvium such that the channel itself has features unique to this kind of environment. Between the channel and the raised bogs (particularly that on the right bank of the river) there is a well-developed flood level. Such levels are colonized by *Juncus* and are periodically flooded. They are separated from the domes of the bogs by sloping margins known as 'rands'. Permanent pools of water adjacent to the main stream have been created near the mouths of tributary streams. Such pools are known as 'flashes'. Between the Treflyn and Maesllyn flash, the channel has been artificially straightened (NCC, 1968). The river banks in this section are dominated by silts, which are easily eroded in peak flows such that there is occasional slumping of fines into the main channel. Transport processes are dominantly by sediment in suspension, providing a direct contrast to those upper reaches of the Teifi where bedload transport is more important. In places, the channel is bordered by *Sphagnum* peat and in such sections the width : depth ratios are lower than those farther upstream. Reedgrass occurs in places along the river bank and this adds some stability to the fine sediments. There is thus a contrast between the right bank (dominated by reeds) and the left bank (grass-covered) such that erosion tends to be occurring more rapidly on the latter. In the straightened section (688633), the former channels have been left as marshy environments, which are gradually being recolonized. Soils are predominantly gley and peaty (Rudeforth, 1970). Finer gravels are

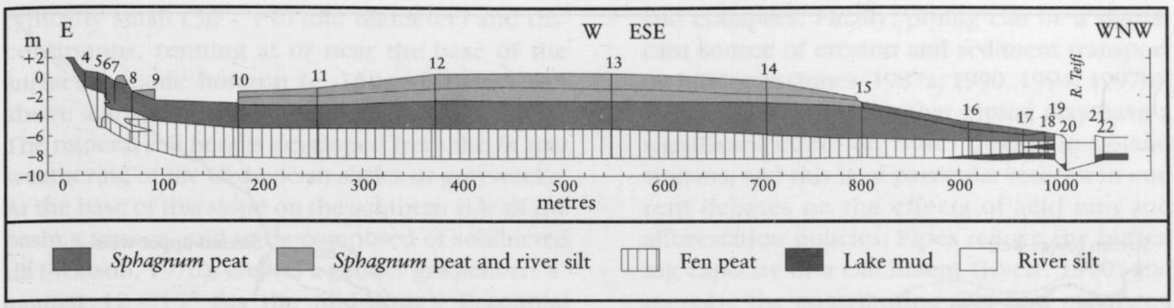


Figure 3.35 The Afon Teifi: the southeastern raised bog at Tregaron, central Wales. Stratigraphic section established by borings between the hillside and Afon Teifi. The division of the peat and the domed shape of the bog are quite distinct. (After Godwin and Mitchell, 1938.)

deposited at the confluence of the main Teifi with smaller tributaries in the reach, and there are occasional patches of such deposits at levels higher than the present channel.

Interpretation

Although work has been carried out into the stratigraphy and vegetation characteristics of the raised bogs and into the hydrological and nutrient status of such features, little work has been done on the geomorphological and sediment characteristics of the Teifi in this reach. However, the reach provides an important contrast to those upstream and downstream sections where the river is more 'typical' of those in the area (gravel-bedded with composite banks), and is unique in being a fine-sediment reach sandwiched between such sections. As such, it provides an opportunity to measure differences in sediment transport and bank erosion between the contrasting reaches.

Conclusion

On the section of the Teifi downstream of Pontrhydfendigaid at Cors Caron, the channel flows through an area of peat bogs which were formed as the result of a developing vegetation succession in a terminal moraine-dammed lake at Tregaron (Godwin and Mitchell, 1938). Transport and sedimentation processes are dominated by the finer lacustrine deposits which are easily eroded from the channel banks, especially where such banks are not protected by coarse vegetation. This unusual reach contrasts with those upstream and downstream, which are dominated by coarse material. Although work has been done on the bog evolution and vegetation succession, little work has yet been carried out on the fluvial geomorphology.

MAESNANT, PUMLUMON (PLYNLIMON), CEREDIGION (SN 785872)

J.A.A. Jones

Highlights

Maesnant contains a particularly good example of extensive natural soil pipe networks. Work on these pipes has made important contributions to hydrological theory, with implications for geomorphology, water quality and land management in the British uplands.

Introduction

The Maesnant Valley (SN 7887) contains an important example of well-developed natural soil pipe networks in an undisturbed upland rough grazing environment. The networks are both extensive and comprehensive, including examples of all the major genetic and generic forms of piping known in the UK, ranging in regime from ephemeral to seasonal and perennial flowing, and in genetic origin from desiccation cracking and mass movement to hydraulic pressure beneath a phreatic surface (Jones, 1982).

Initial work on the piping began here in the early 1970s (Lewin *et al.*, 1974; Jones, 1975, 1978; Cryer, 1978, 1980). An intensive hydrological instrumentation of the catchment upstream of the Environment Agency weir at SH 777876 began in 1979. By the end of 1981 the basin contained 21

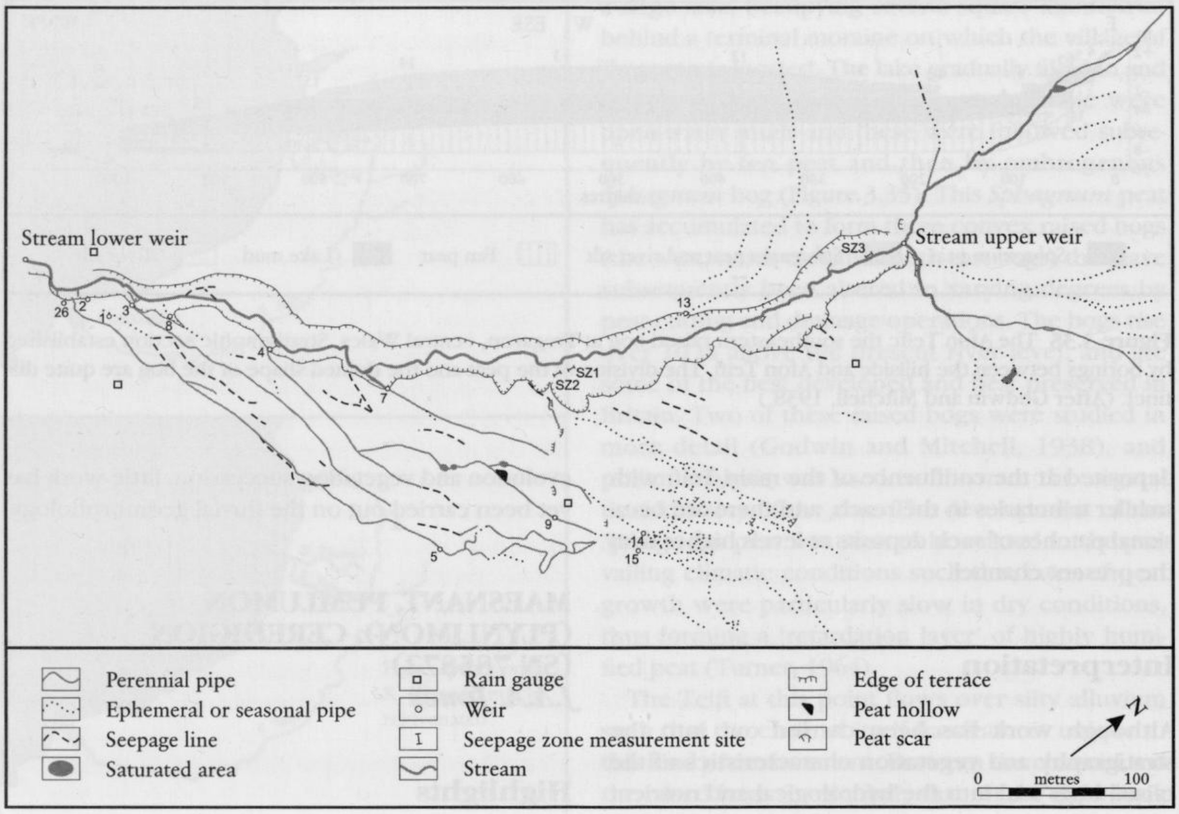


Figure 3.36 Drainage networks in the Maesnant experimental basin.

flow gauges, four rain gauges and four pipe sediment traps, providing a uniquely detailed study of hillslope hydrology (Jones and Crane, 1984; Jones, 1986, 1987a, b). The research indicates that *c.* 50% of storm flow and base flow is derived from pipe flow, a much larger proportion than hitherto considered possible (cf. Ward, 1975, p.255; Rodda *et al.*, 1976), supporting a major extension to the role of subsurface flow in generating storm response in the stream, suggested by Jones (1979) (cf. Ward, 1980, 1982).

Piping features are common in the Welsh uplands, and the site has an important and continuing role as a field laboratory for the investigation of runoff processes and sources of streamwater and their interaction with land management.

Description

The Maesnant catchment drains the western slope of Pumlumon (Plynlimon) in the Cambrian Mountains from the peak of Pumlumon Fawr at 752 m OD to the Nant-y-Moch Reservoir. The experimental basin comprises only the upper part of this catchment, covering an area of 0.54 km^2 upstream from the Environment Agency sharp-crested weir at 470 m OD. The pipe networks lie mainly on the southern side of the valley (left bank) and in the headwater area (Figure 3.36), although the longest single ephemeral pipe in the basin (indeed, the longest yet recorded in the literature) descends for 280 m down the side of Pumlumon Fach on the right bank. Both the headwater arms of the stream begin in pipe systems and are particularly good examples of this form of channel head and process of channel formation (Jones, 1971), with a series of unroofed pipe sections increasing in length downstream until a permanent open channel is formed (Jones, 1994, 1997b).

Piping is present in all the soils of the basin, ranging from peaty gleyed podzols of the Hiraethog Association to undifferentiated peaty soils (Rudeforth, 1970), with the exception of the ranker soils on the upper slopes approaching the crest of Pumlumon, which have an inherently high matrix permeability. The main zone of ephemeral pipes occupies the mid-slopes, where the pipes are typically small (50 - 150 mm diameter) and discontinuous, running at or near the base of the surface organic horizon (*c.* 150 mm thick) and above a shallow mineral soil (< 300 mm thick). The mineral soil here is developed from the *in situ* weathering of the Ordovician shales or greywacke. At the base of this slope on the southern side of the basin a terrace, said to be composed of soliflucted till (Watson, 1970), creates a gentler gradient (*c.* 4° against 12 - 15° for the mid-slope). Perennial groundwater seepage at this inflexion point causes widespread areas of bog. Larger (*c.* 500 mm diameter) and deeper (*c.* 0.5 m) perennially flowing pipes issue from this point. These pipes also tend to flow near the peat/mineral interface and there is a tendency for pipe beds to rest on the parent material, which is clayey and boulder-strewn, with gley (G) or eluvial-gley (E.g.) horizons forming the walls. The stream itself is incised into this terrace 3 - 5 m, and it would appear that the stream rejuvenation that created the terrace was responsible for the initiation of the perennial piping by steepening the hydraulic gradient.

Interpretation

Analysis of the Maesnant data has established pipe flow as a potentially significant source of stream flow where piping is present, with a number of important hydrological and geomorphological corollaries:

1. Piping offers a major extension to the theory of runoff or stream flow generation, because it dramatically increases the effective hydraulic conductivity of the soil, so that storm flow or flood flows in rivers can be generated by this in-soil drainage. It also extends the source of storm flow in streams well beyond the normally accepted bounds in humid areas, potentially to the very top of hillsides (Jones, 1988, 1997a; Connelly, 1993).
2. Piping has a number of geomorphological implications in terms of theories of hillslope development, channel initiation, sources of sediment and methods of monitoring erosion. It introduces a linear element in hillslope erosion similar to rilling and gullying on the surface, although less visible in the early stages. By concentrating flow and erosion it contributes to the selective erosion of certain parts of the hillside. Subsequently, piping may prepare the way for gullying and channel extension as it enlarges and collapses. Finally, piping can be a significant source of erosion and sediment transport on hillslopes (Jones, 1987a, 1990, 1994, 1997b).
3. There is also evidence that piping may have a significant effect on water quality in upland streams, and this is of particular interest in current debates on the effects of acid rain and afforestation policies. Pipes reduce the buffering capacity of a catchment (Hyett, 1990) and increase the contributing area that may need liming (Jones, 1997b). They also affect vegetation patterns (Jones *et al.*, 1991).

The Maesnant features are not unique. Piping is present in most catchments in the Pumlumon area and many others investigated in the southern Cambrian Mountains, the Brecon Beacons and the Black Mountains (Richardson, 1992; Jones *et al.*, in press). What is unique at Maesnant is the amount of research that has been concentrated in the catchment (Walling, 1984, 1991), and the implications from this for both theory and practical land management.

Conclusion

The Maesnant basin contains a particularly good example of natural soil pipe networks. At the present time these are the most extensive and longest yet surveyed worldwide. More importantly, they have been monitored hydrologically for a number of years, and the pipe-flow data collected at Maesnant are the most comprehensive in the world.

BLACK MOUNTAIN SCARP, CARMARTHENSHIRE (SN 810220)
G. Higgs

Highlights

Debris flows occur on high-gradient, high sediment supply mountain streams, and the Black Mountain has some of the best examples in Wales and the best documented to date. Relationships between debris flow activity, surface conditions and climatic factors have been studied in some detail for the site.

Introduction

The northern-facing Old Red Sandstone escarpment of the Black Mountain (Carmarthenshire) provides

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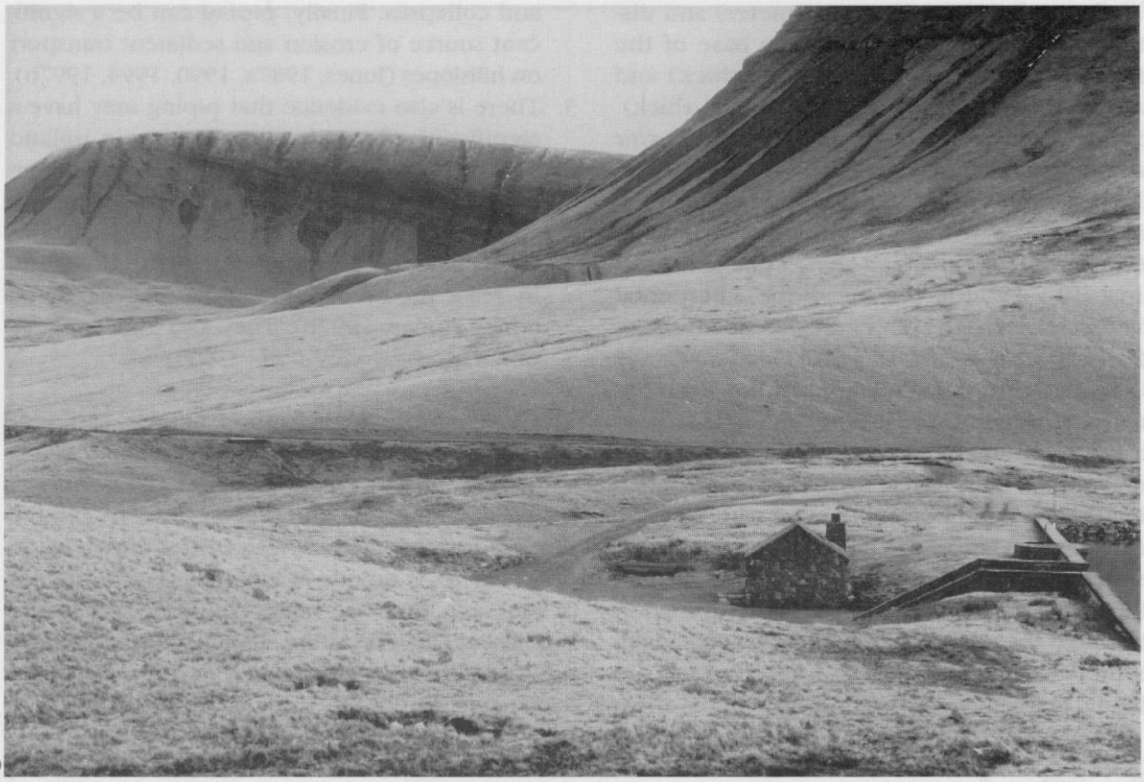


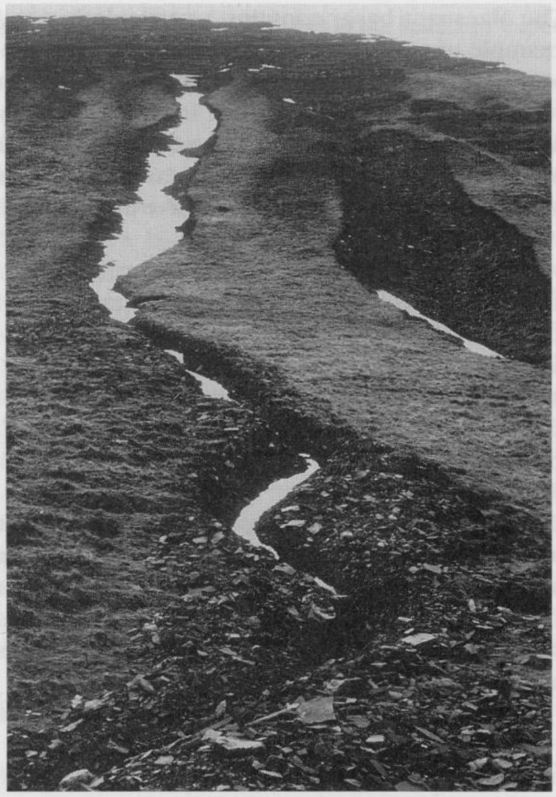
(b)


Figure 3.37 Mynydd Du (Black Mountain): (a) Location of scarp; (b) scars. (Photos: S. Campbell.)

the best examples of debris flows in Wales (Figure 3.37). The escarpment has deep gullies as well as minor mass movement scars. Three such gullies have been extensively studied by Statham (1976), who mapped the dimensions of each of the gullies, together with the extent of debris flow trails downslope of each gully and subsequent debris flow cones. There are well defined levels at the base of the gullies, and it was suggested that debris flow movements tended to be concentrated along similar pathlines, creating well-defined cones of deposition. The gullies have cut into bedrock in the upper parts such that much of the flows consist of bouldery debris. Such flows actively move in response to heavy rainfall events but, it was suggested, only if there is sufficient material within the gullies (Statham, 1976). The sedimentological properties of the flows as well as the yields of such gullies were also studied, and it was suggested that since the gullies were approximately 700 years old, they developed as a response to an environmental change, possibly sheep grazing.

Description

The Black Mountain forms part of the north-facing escarpment of Old Red Sandstone, the geological

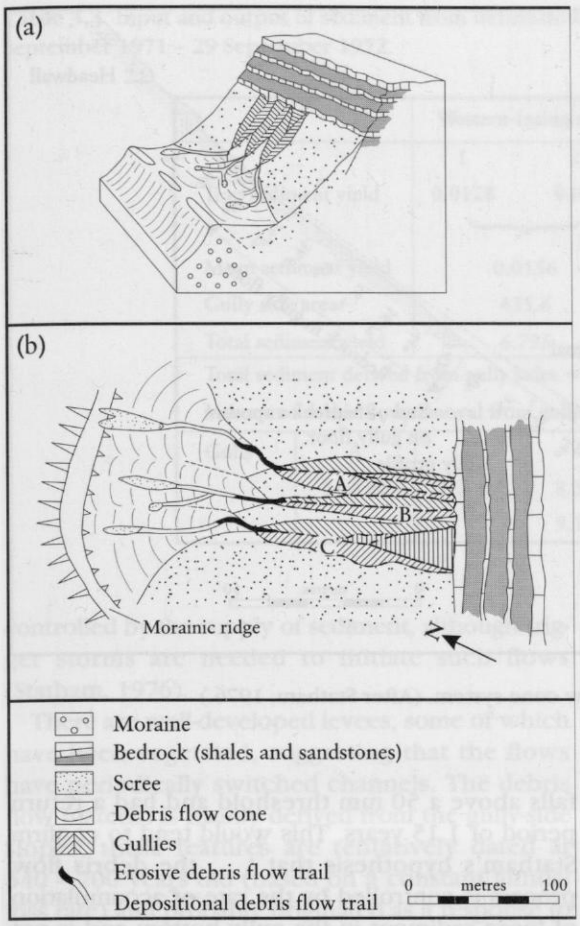


Figure 3.38 Black Mountain: (a) a block diagram of the scarp; (b) a plane table survey of three debris-flow gullies. (After Statham, 1976.)

structure of which has been discussed in great detail by North (1955). The escarpment in this locality is determined by Plateau Beds (conglomerates and sandstones) which overlie Brownstones, up to 450 m thick in places, consisting of red marls, brown sandstones and conglomerates. Locally, the junction between the two beds is marked by a visible discordance in dip (Davies, 1967). At the base of such slopes, scree deposits have built up, it is suggested, through post-glacial erosion processes such as freeze–thaw activity (National Museum of Wales, 1979). Such deposits consist of coarse sandstone material interspersed with finer material (Statham, 1976); in places they are vegetated. The deposits in turn have been cut through by deep gullies, which have reached bedrock in the headwall regions. These gullies have been identified in the Fforest Fawr area of the Brecon Beacons (in some form) in 80% of the area above 450 m (Thomas, 1956). On the slopes of Bannau Sir Gaer, however, debris flows are taking place within the gullies, incorporating bedrock materials together with fines washed down from the gulley sides, leading to the formation of debris flow cones at their bases (Figure 3.38).

Three gullies were studied in great detail by Statham (1976), who examined the form of debris flow trails as well as the active input to such flows from the gullies themselves. It was suggested that debris flows were initiated in the gully system where the angle of the slope ranged from 27 to 37° (Figure 3.39). A survey of one gully profile showed that the slope varied from 40° (where the lowest bedrock layers were present within the gully) to 8° where the debris cones levelled out upslope of a morainic ridge which farther west 'dams' Llyn y Fan Fach (Davies, 1967). This ridge has been 'overtopped' by those deposits from gully C (Figure 3.38) which stem from more recent rainfall events, such that coarse deposits up to 30 cm in diameter lie on the north-facing slopes of the ridge. There is evidence to suggest, therefore, that material is advancing further than those trails plotted by Statham for the early 1970s. There is also evidence that new gullies are being initiated on the slopes to the west of those studied by Statham, and that a gully with an associated debris cone has formed since Statham's work. This would tend to oppose his view that the gullies were all in a similar stage of development. In addition, a number of the gullies do not exhibit debris flows along their courses, suggesting the importance of an optimum slope angle for such features, and the significance of regolith stability and the rates of sediment supply. Thus, for example, Statham suggested that such factors as the stability of the gully sides are important — there is a maximum stable angle of 43.5° when slopes are dry.

Statham also suggested that there was a critical angle which determines whether features of debris trails were governed by erosional or depositional processes, evidenced by levees. Levees were deposited, it was suggested, when the slope fell below 16° at which point the nature of the debris trails changes from erosional to depositional. Thus '… 16 degrees is the transit slope for these flows' (Statham, 1976).

In addition, the input of sediment from the gully sides was measured by traps for gully B in Figure 3.38, and total sediment yields calculated. This amounted to 8.436 m^3 in the year from September 1971 to September 1972, with an estimated 81% of this being eroded from the west-facing slopes

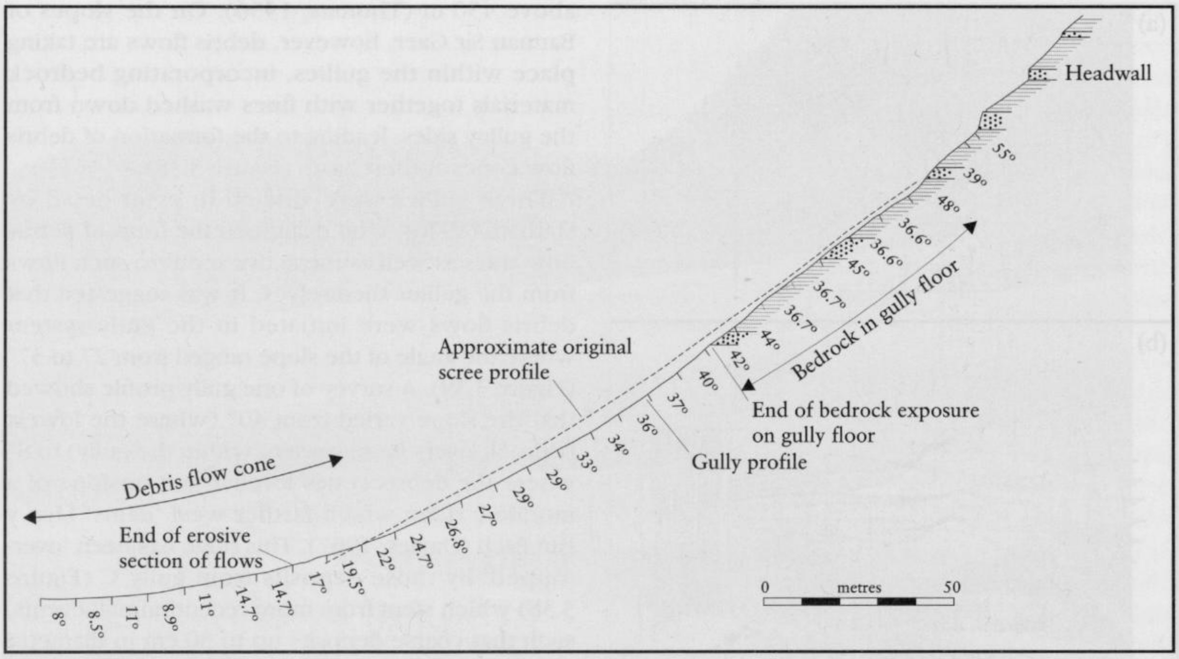


Figure 3.39 Black Mountain: a profile of a typical gully-flow cone system. (After Statham, 1976.)

(Table 3.3); this fact was attributed to the prevailing rainfall from westerly winds, which leads to asymmetrical cross-sections with steeper, less stable westerly slopes. An estimation of the amount of material moved in a debris flow (9.8 m^3) showed a good correlation with that estimated from gully erosion, such that the 'input of sediment to the gully is balanced by output of debris flows, implying that sediment movement by other processes such as streamflow is negligible' (Statham, 1976). However, it was stressed that the observation period (of one year) would need to be extended before such conclusions could be verified. In the upper parts of the gully system, resistant beds of sandstone are evident, although there are suggestions that these are gradually being eroded to add a coarser element to the debris flows. Vegetated areas of scree show evidence of downslope creep of the regolith, especially in gully C. Adjacent slopes show similar features.

Statham also analysed the response of the debris flows to individual rainfall events in the study period and found that a debris flow resulted from a daily rainfall of 54 mm (20 November 1971) but that no flows occurred on those 15 other occasions in the year when rainfall exceeded 30 mm. An analysis of the daily record at Waun Sychlwch (804220) for the period 1971–86 (unpublished) revealed that this event was ranked 103rd in those falls above a 50 mm threshold and had a return period of 1.15 years. This would tend to confirm Statham's hypothesis that '... the debris flow process is controlled by the rate of accumulation of loose sediment in the gully bottom and is not specifically a result of high rainfall intensity' (Statham, 1976). However, rainfall is likely to influence slope instability indirectly through its effect on pore-water conditions in the slope material. Thus the regolith has to be considered in terms of its susceptibility to flow activity and erosivity, particularly with reference to the rainfall regime. Such factors may explain the lack of well-developed flows to the east of those studied by Statham, in particular mid-slope gullies where there is no headwall erosion and where the majority of the sediment is derived from gully sides. There are also small erosion scars along the deposits of Bannau Sir Gaer to Bwich Blaen Twrch with smaller debris flows, some of which are relict features.

Interpretation

The scarp slopes of the Black Mountain provide excellent examples of debris flows originating from gullies developed in scree deposits which, in turn, were eroded from Old Red Sandstone rocks. These have varying degrees of activity, and are seen to be

Table 3.3 Input and output of sediment from debris-flow gullies. Yearly sediment derived from sides of gully B, 30 September 1971 - 29 September 1972.

	Western-facing side		Eastern-facing side		
	1	2	3	4	
Trap sediment yield	0.0128	0.0184	0.0039	0.0028	$m^3 m^{-2} yr^{-1}$
Mean sediment yield	0.0156		0.0033		$m^3 m^{-2} yr^{-1}$
Gully side area	435.6		497.3		m^2
Total sediment yield	6.795		1.641		$m^3 yr^{-1}$
Total sediment derived from gully sides = 8.436 m^3 in one year					
Volume of debris flow removal from gullies					

Gully	**A**	**B**	**C**	
	11.5 m^3	9.8 m^3	8.3 m^3	In observation year
			9.1 m^3	Outside observation year

controlled by the supply of sediment, although trigger storms are needed to initiate such flows (Statham, 1976).

There are well-developed levees, some of which have been vegetated, suggesting that the flows have periodically switched channels. The debris flow material is mainly derived from the gully-side slopes; these features are tentatively dated at 540 - 700 years old (based on a constant annual loss rate) and probably originated as a response to an environmental change, possibly sheep grazing in the area. However, recently, newer gullies have been initiated, which suggests that the picture is more complex than previously thought, and that more work needs to be done, particularly with regard to the thresholds of regolith stability and the rates of sediment supply in relation to heavy rainfall events.

Conclusion

The debris flows of the Black Mountain escarpment are the best documented features of their kind in Wales. The presence of recent erosion scars may suggest that the processes initiating such features are still continuing. Therefore, more work may be needed to establish, for example, how and why such flows are initiated, and also the conditions under which they are activated, such as the importance of antecedent rainfall.