Malham Cove and Gordale Scar

[SD 89 64]–[SD 91 64]

Highlights

Malham Cove and Gordale Scar are two of Britain's best known karst landforms. Malham Cove is a spectacular amphitheatre of limestone cliffs which in part represents a dry waterfall, while the neighbouring Gordale Scar is a fine gorge still carrying a small stream. The area is also renowned for its dry valleys, limestone pavements, tufa deposits and underground drainage patterns.

Introduction

The spectacular, concave, crescentic limestone cliff of Malham Cove and the impressive limestone gorge of Gordale Scar are located on the southern margins of the Yorkshire Dales karst plateau (Figure 2.33). Both are impressive examples of fluviokarstic landforms which demonstrate the intertwining of fluvial knick point retreat, glacial scour and meltwater excavation with karstic processes. The area has many other features of note including the fine Watlowes dry valley above Malham Cove, the stream sinks at the southern end of Malham Tarn, which feed to the Malham Cove and Aire Head risings, and the massive tufa deposits in Gordale Scar. Limestone pavements are prominent features of the plateau landscape, and those at the top of Malham Cove are especially well known for their fine morphology. The underground drainage of the area is a classic demonstration of the complex nature of limestone hydrology, with convergent and divergent flow patterns. The area contains some of Britain's finest glaciokarst, much of which is clearly related to the local geological structure.

The geomorphology of the area is summarized by Sweeting (1974) and Clayton (1981) and features in numerous textbooks. The denudation chronology of the area was deduced by Sweeting (1950), while regional denudation studies were carried out by Hudson (1933) and King (1969). Moisley (1955) describes many of the other karstic feature in the area while Pitty *et al.* (1986) discuss the formation of Malham Cove and Gordale Scar. A descriptive account of the geology of the Malham area is outlined by Arthurton *et al.* (1988), O'Connor (1964) and Shaw, J. (1983). The hydrogeology of the area was investigated by dye tracing (Smith and Atkinson, 1977) and by stable isotope analysis (Brown *et al.,* 1986). The Malham area has been the focus for limestone surface solution studies, such as those of Sweeting (1966) and Trudgill (1985b), while its many glacial features were studied by Clark (1967). The tufa deposits of Gordale Scar were discussed by Pentecost (1981).

Description

The limestone geology at Malham is complicated by the major facies variations across the line of the Middle Craven Fault, which was active in Carboniferous times when it formed the boundary between a shallow submarine shelf to the north and a subsiding basin to the south. The central outcrop of massive limestone belongs to the Malham Formation, the upper part of the Great Scar Limestone; it is bounded by the North and Middle Craven Faults. The same beds form the higher ground north of the North Craven Fault, where erosion levels have reached just low enough to expose the basement of impermeable Silurian siltstones, on which most of Malham Tarn lies. A block of reef limestone, contemporaneous with the bedded Malham Formation, lies just south of the Middle Craven Fault and is overlain unconformably by the Upper Bowland Shales (Arthurton *et al.,* 1988). Within the shale sequence, a thin basinal limestone crops out at Aire Head (Figure 2.33) and has a buried contact with the reef limestones to provide a routeway for the unseen, underground karst drainage. Glacial till is significant only on the lowland areas to the south, and there is an extensive glaciofluvial kame complex across the limestone plateau along the line of the North Craven Fault (Clayton, 1981). Malham Cove and Gordale Scar both lie about 500 m north of the Middle Craven Fault.

Malham Cove

The Cove is a massive, concave crescentic, vertical cliff cut into the Great Scar Limestone (Figure 2.34). Its rim is 80 m above the Malham Cove Rising, where water resurges at the foot of the cliff, and the curved walls extend over 100 m on each side of the resurgence. Above the Cove, the Watlowes dry valley extends up past Comb Scar, but loses most of its depth before its head zone on the plateau below Malham Tarn. The valley is entrenched up to 50 m deep into the massive horizontal limestone, more resistant bands of which form scars along the valley sides. Malham Tarn covers 62 ha, most of which is less than 3 m in depth, and owes its existence to the small inlier of impermeable Silurian rocks to the north of the North Craven Fault (Figure 2.33). Water from the Tarn flows out at its southern end and sinks shortly after crossing the fault onto the limestone; a number of choked fissures lie along the streambed, various of which are active at different times and stages. After exceptional rainfall, the sinks may overflow so that the dry waterfall at Comb Scar becomes temporarily active; the water then soaks away in the floor of Watlowes. On rare occasions, water gathered from seepage springs and direct rainfall in the lower Watlowes can cascade over the Cove. Continuous surface flow, from Tarn to Cove, is recorded in the past, but not in this century (Halliwell, 1979a). West of the Tarn, Smelt Mill Beck also sinks shortly after crossing the fault.

The hydrology of the Malham area is commonly regarded as a fine example of the unseen complexities of underground drainage in limestone. There are two major sinks: Water Sinks fed by the outflow of Malham Tarn, and the smaller Smelt Mill Beck sink to the west. There are two resurgences: Malham Cove Rising at the foot of the Cove, and Aire Head Rising south of Malham village. Dye tracing has proved that water from both sinks flows to both resurgences (O'Connor *et al.,* 1974; Smith and Atkinson, 1977). Most of the water from Malham Tarn resurges at Aire Head, taking 13–24 hours, while a smaller amount resurges at Malham Cove, taking 24–29 hours to arrive. The waters of Smelt Mill Beck arrive at the Cove in 2–7 hours, and at Aire Head in 6–10 hours. Both the sinks and Aire head are choked by boulders that prevent any access. At the Cove Rising, the water flows up the very gentle dip in low, wide and totally flooded bedding plane caves, which have been mapped for 600 m behind the Cove (Figure 2.33). Somewhere in the unexplored zone beneath Comb Scar, a complex of caves and partially choked fissures allows the waters to merge, diverge and overflow into separate flood routes.

Gordale Scar

Two kilometres east of Malham Cove, Gordale Scar is a deep and narrow gorge emerging through the headwall of a massive limestone amphitheatre (Figure 2.35). The cliffs are higher than those of Malham Cove, though they are more broken and less vertical. The gorge cut into them is the most spectacular feature, and it descends steeply from the foot of Gordale via two waterfalls; the upper fall emerges from beneath a rock arch, effectively a short cave passage breaching a high rib of limestone bounded by minor faults. This route through the eyehole has only existed since 1730. Before then, the thin rock rib may have been intact, or the eyehole may have been blocked by coarse debris; the ravine behind was choked with sediment, and the stream cascaded through a slot just north-west of its present route. Gordale is entrenched across the limestone plateau parallel, and in similar style, to the Watlowes valley, but it has a narrower, box canyon profile, and, unlike the Watlowes, it always carries a surface stream. The waters of Gordale Beck rise between Great Close Scar and High Mark, and then flow across the impermeable Silurian inlier, across the North Craven Fault, through the box canyon and into the gorge.

Gordale Beck is saturated with calcium carbonate, and deposits a considerable amount of tufa, especially in the lower reaches. Here, there are extensive tufa banks and terraces, many a little way above the present stream level. The upper waterfall within the Scar gorge is actively building an apron of algae-shrouded tufa where it lands below its hole in the rock rib. A similar apron of tufa stands on the right bank of the cascade, where the stream landed from the slot through the rock rib until the change of course in 1730. The lower falls, formed over a partially re-eroded bed of strongly banded tufa, cascade onto a flatter gravel floored section, where the flow is augmented by a number of springs fed by percolation and also by small sinks higher in Gordale. Downstream of the Scar, Janet's Foss is another small waterfall over a fine, moss-covered, screen of massive tufa (Figure 2.33).

The interfluves between Gordale and Watlowes have areas of excellent limestone pavements. Rundkarren and kluftkarren are well developed on many beds separated by low ice-plucked scars. The single best known pavement is that at the top of Malham Cove. It is a classic of its type, even though it is now unnaturally polished by the passage of boots and shoes. Kluftkarren grykes form a rectilinear grid, and the clints are scored by deep rundkarren runnels which are deeper and more rounded close to where they can be traced beneath a cover of organic soil.

Interpretation

The origins of both Malham Cove and Gordale Scar have long histories of debate and speculation, widely mentioned in textbooks but little documented in research literature. Popular concepts of the Cove as a dry waterfall and the Scar as a collapsed cave contain only fragments of the more complex histories of development (Clayton, 1981; Pitty *et al.,* 1986; Waltham and Davies, 1987).

The morphologies of Malham Cove and Gordale Scar have many similarities (Figure 2.33) and (Figure 2.36); both have large rock amphitheatres upstream of the Middle Craven Fault and downstream of gently graded, narrow, fluvial valleys. The main contrast lies in the steeper gradient of Gordale, its permanent stream, and the incision of its gorge at the Scar. At each site, the amphitheatre and the valley appear to have separate origins.

Malham Cove is conspicuously wider than the Watlowes valley at its head. It was excavated largely beneath an ice sheet moving south over the scarp of the Middle Craven Fault. A concentration of ice flow in an iceway, probably guided by an earlier and smaller fluvial feature, formed much of the Cove by locally enhanced plucking and wall retreat. The iceway has no expression on the plateau above the Cove; the Watlowes arrives obliquely from the north-west. Ice overaeepened the wide valley below the Cove to leave a reverse gradient on the bedrock floor (Figure 2.36); the rock hump has now been entrenched by the post-glacial stream, but is clearly recognizable where the stream turns briefly to the east. The Gordale amphitheatre was formed by similar glacial headwall retreat, and it too has no valley on the plateau above.

Both the Watlowes valley and Gordale, above the Scar, are clearly fluvial features. Their excavation was largely by seasonal meltwater when ground ice reduced the permeability of the cavernous limestone. This took place subglacially at first, and then downstream of glacier snouts as the ice retreated; it is difficult to estimate the relative contributions of the subglacial and proglacial flow phases. Gordale is Britain's finest example of a meltwater channel cut into limestone under periglacial conditions, with a morphology closely comparable to modern examples in Arctic Canada (Smith, D.I., 1972); Watlowes is more degraded due to its more complete abandonment following underground capture of its drainage (Figure 2.37).

Pitty *et al.* (1986) suggested that Watlowes valley and the Cove were cut by repeated jökulhlaup outbursts of subglacial waters draining from the Malham Tarn basin; current groundwater temperatures and documented Devensian cooling indicate the likelihood of water ponding beneath a melting ice sheet in the Malham basin until it was released in the style of the jökulhlaup floods seen in Iceland today. They also suggested that these floods may have contributed to the scale of excavation at the site of a Cove waterfall. Alternatively, jökulhlaup events may have enhanced wall retreat at the Cove beneath an ice cover. In Holocene times, the steepness of the Cove cliffs has been maintained and assisted by spring sapping at the base, with associated undercutting and periodic collapse.

The meltwater incision of the Gordale Scar gorge may be ascribed to more rapid excavation along the line of minor faults, which are not pre sent at Malham Cove. Solution of the limestone along and between fissures beneath the ravine bed created cavities which were subsequently exposed, and thereby accelerated downcutting in advance of wall retreat. One cave survives to form the eyehole above the top waterfall; cavern collapse is only a minor contributory feature in the gorge excavation by waterfall retreat. Pitty *et al.* (1986) point out that abrasive scour by sediment particles would have accelerated incision and knick point retreat at Gordale Scar, but was lacking in the Watlowes, where the Tarn basin was an effective sediment trap.

Grey Gill is a steep narrow limestone gorge in the slope between Malham and Gordale (Figure 2.33). It demonstrates the form of a gorge cut by meltwater into the fault scarp away from any larger, glacially excavated headscar.

The surface stream in Gordale is something of an enigma. Moisley (1955) surmised that carbonate precipitation may be more important here than solution, and drift deposits may have blocked former sinks. Springs at the foot of the Scar are fed largely by percolation water, and there are no cave passages comparable in size with those beneath the Watlowes. Moisley (1955) drew attention to a series of lacustrine deposits upstream of the Scar, through which the stream has cut leaving a series of terraces. He suggests that they were laid down in lakes held back by tufa dams or moraine barriers. The unusually extensive tufa dams and screens of Gordale Scar were described by Pentecost (1981) as 'probably the best example of a tufa depositing stream in the British Isles'. The formation of tufa is aided by the presence of certain mosses and algae, which extract carbon dioxide and therefore cause precipitation from spring water saturated with calcite. This is aided by an increase in water turbulence, which is why many active tufa screens in Gordale are situated in the lower steeper section.

Dye-tracing in the Malham area has had a long history. The first unsuccessful attempts were made around 1870 (Tate, 1879) using a variety of crude tracers, and successful flood pulse traces were conducted in about 1879. Further traces in 1899, used both flood pulse methods and chemical tracers (Howarth *et al.,* 1900) to demonstrate the major links between Smelt Mill Beck and Malham Cove, and between Malham Tarn and the Aire Head Risings (Figure 2.33). A review of these early experiments is presented in Smith and Atkinson (1977), who then conducted rigorous dye-tracing experiments using *Lycopodium* spores, Rhodamine WT and flood pulse methods. These confirmed the underground links, and indicated that the two sinking streams joined before bifurcating to go to the two risings. The high velocity of underground flow suggested that a conduit drainage system existed, as opposed to a diffuse fissure network. Analysis of the flood pulses implied that most of the passage between Water Sinks and Aire Head is phreatic. Dye budgeting at varying discharges established that a greater proportion of the Tarn water emerges at the Cove risings under low flow than under high flow conditions; this suggests that a bottleneck in the cave system behind the Cove restricts the discharge at high flow thus diverting a greater percentage of the flood water to Aire Head. The waters of Malham Tarn also have a distinctive label in their stable oxygen isotope profile, which can be clearly identified in the Aire Head springwaters (Brown *et al.,* 1986).

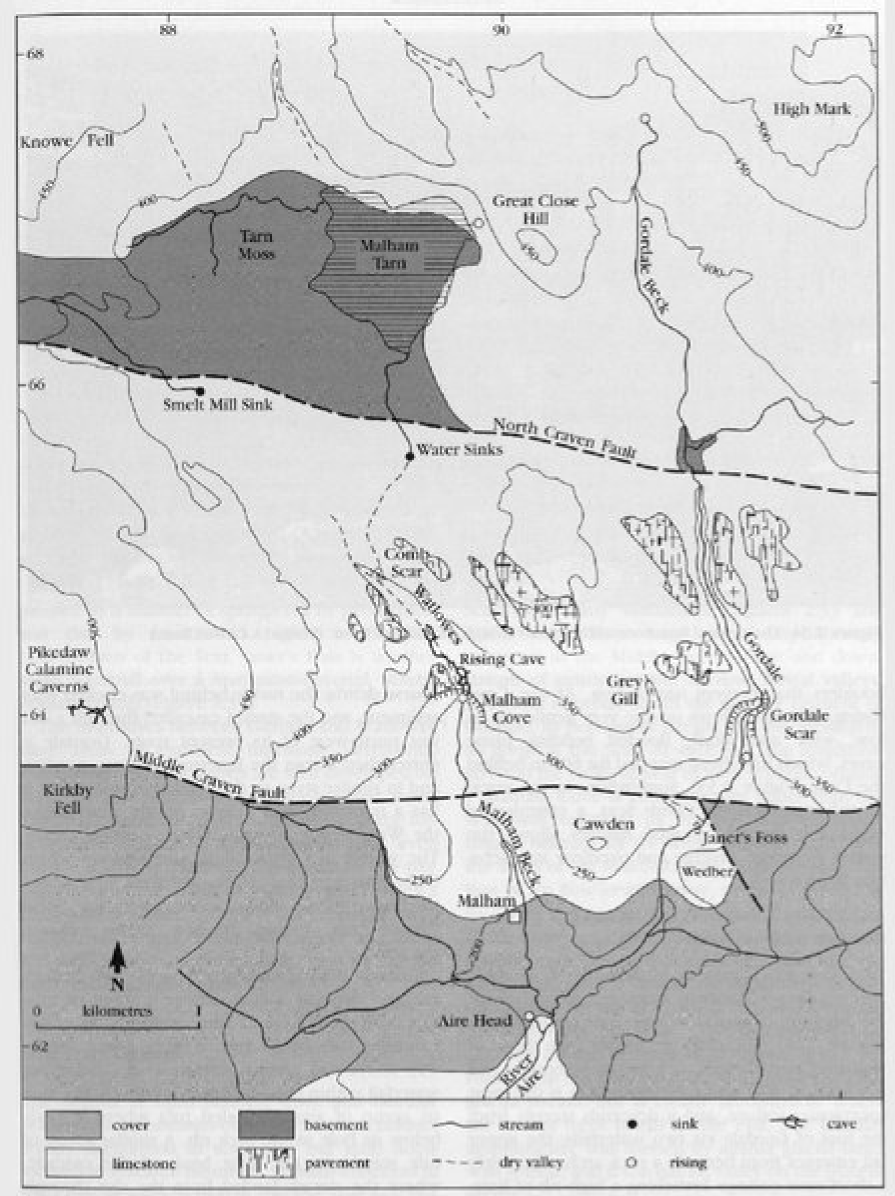
The geochronology of the Malham area is poorly constrained. The broad relief was probably established during the late Tertiary, either by differential erosion or differential uplift across the Craven Fault system (Clayton, 1981). Both Clayton (1987) and Sweeting (1950) recognized erosion surfaces at 600 and 400 m, although in many places these erosion levels may be confused with stratimorphic surfaces (Waltham, 1970, 1990). Clayton '(1981) advocated a Miocene age for his 600 m surface and an early Quaternary age for his 400 m surface. Glaciation has since modified the landscape, although when most of the valley incision took place is unclear. Short-term erosion rates of 0.1–0.6 m/ka were calculated for the Malham area by Trudgill (1985b) using limestone pill data; he showed that the composition of the soils and drift influences differential erosion, as the most rapid erosion occurs under acid soils. Many of the landforms seen today were probably formed during the Devensian glaciation (Clark, 1967; Clayton, 1981).

The valleys of Watlowes and Gordale were cut by meltwater, probably first beneath and then beyond the snout of a waning Devensian glacier (Waltham and Davies, 1987). The tufa deposits are all almost certainly Holocene in age (Pentecost, 1981).

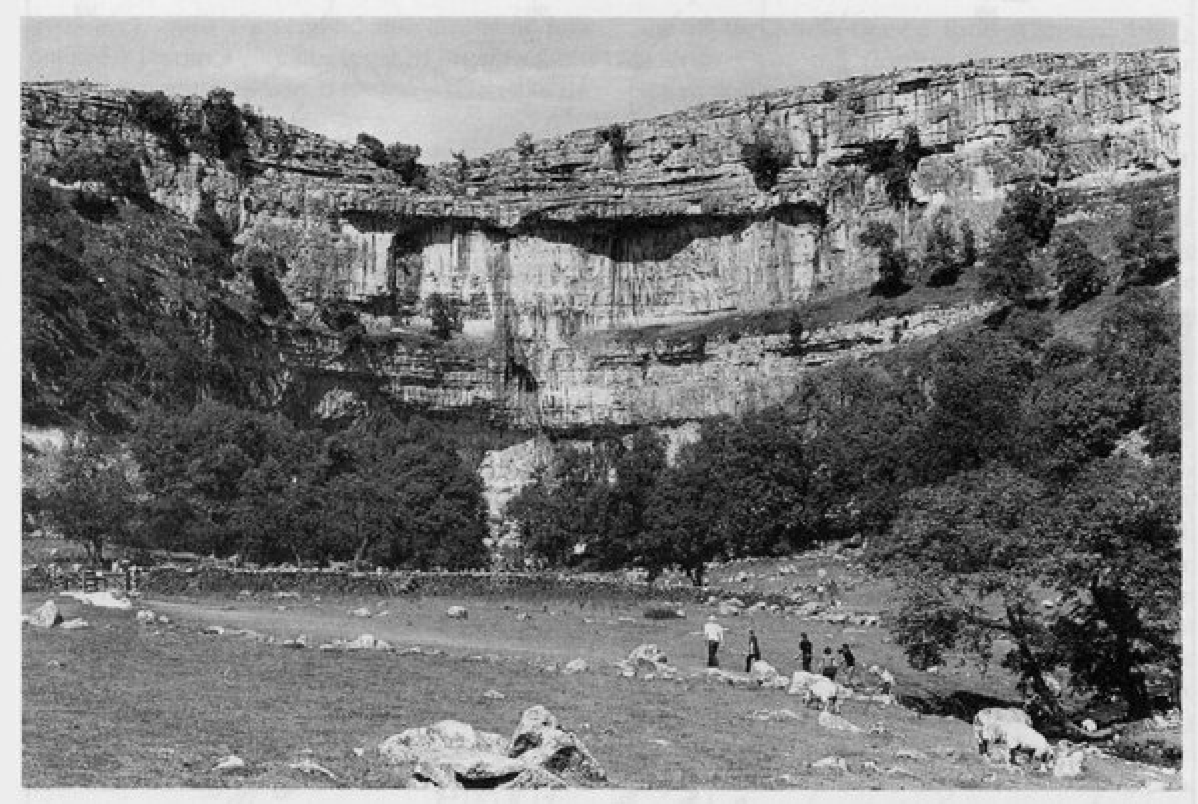
Conclusions

The area bounded by the Middle and North Craven Faults of the Malham district has long been recognized to include some of the country's best developed glaciokarst landforms and shows a spectacular relationship to the regional geological structure. Malham Cove and Gordale Scar especially provide two excellent examples of glaciokarstic landforms, both formed in part by erosional retreat from a fault scarp. Malham Cove is a unique feature, partly an old waterfall, partly a glacial step, whose origins are complex and highly debated. Gordale Scar is a spectacular karst gorge entrenched between very high limestone cliffs. It was cut largely by meltwater; its active and fossil tufa deposits are the best exposed and among the most massive in Britain. The karst also contains many other impressive features, including the Watlowes dry valley and several expanses of well developed limestone pavement. The Malham drainage system is a classic example of the complexity of karstic hydrogeology.

References

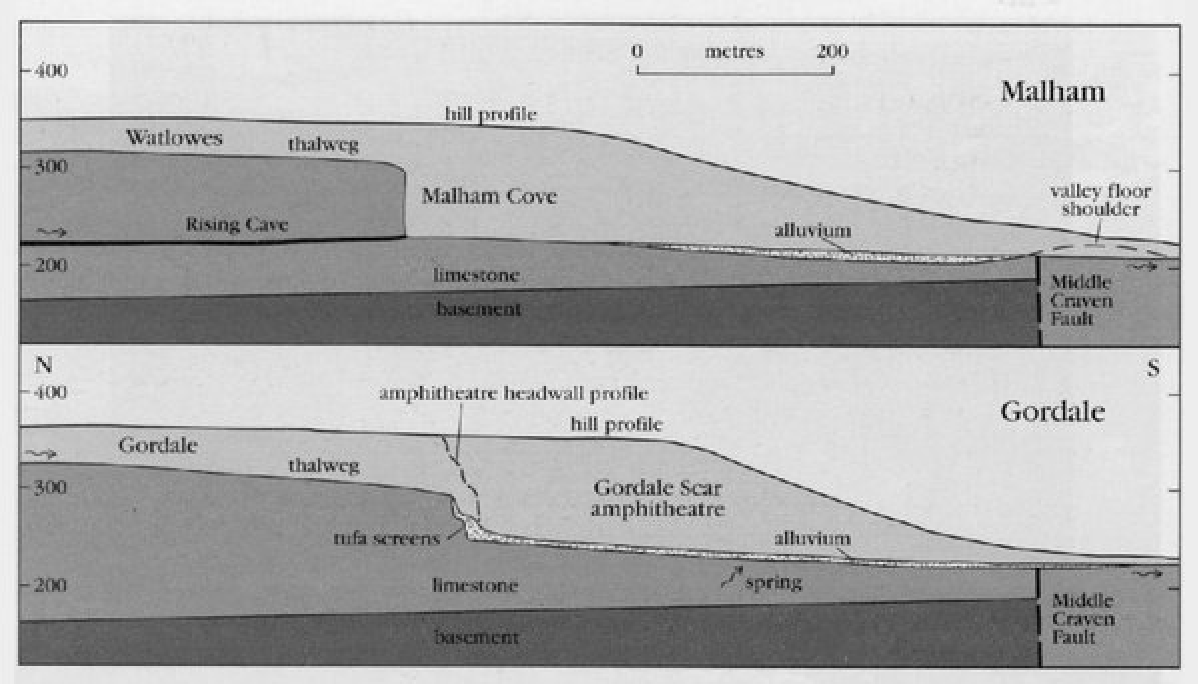


(Figure 2.33) Geological map of the area around Malham Cove and Gordale Scar. The limestone at Aire Head is a thin basinal facies, distinct from the reef and shelf limestones north of Malham village. Cover rocks are Bowland Shales. Basement rocks are Silurian siltstones. There are many minor faults, mostly orientated NW–SE between the North and Middle Craven Faults. Only the main areas of well formed limestone pavement are marked.



(Figure 2.34) The vertical limestone cliffs, 70–80 m high, of Malham Cove. (Photo: A.C. Waltham.)

(Figure 2.35) The limestone cliffs of Gordale Scar. The tufa waterfalls are lost in the shadows in the meltwater gorge which opens into the glacially excavated amphitheatre. (Photo: A.C. Waltham.)



(Figure 2.36) Long profiles through Malham Cove and Gordale Scar showing the prominent thalweg steps which have retreated from the Middle Craven Fault scarp.

(Figure 2.37) Watlowes, the dry valley excavated by meltwater which leads down to the top of Malham Cove. (Photo: A.C. Waltham.)