REPORT

Malham Cove

Perhaps the most conspicuous single landform in the Yorkshire Dales, the white limestone cliff of Malham Cove is a focal point within Britain's finest karst terrain. Well known but not well understood, there is still no consensus on how the Cove was actually formed. Geomorphologists have tended to avoid the issue whenever they can, but Malham has attracted a little more attention over the last few years.

Underground waters at Malham

The underground drainage between and beyond Malham Tarn and Malham Cove is a classic of karst hydrology. Out-flow from the Tarn normally sinks at various points collectively known as the Water Sinks, which lie just downstream of the North Craven Fault where the stream crosses onto the limestone outcrop. And the valley below has significant risings at the foot of Malham Cove and also at Aire Head, which lies another 2 km to the south and just beyond a synclinal outcrop of the cover shales. A cave at Malham Cove Rising is entirely underwater; its main passages follows bedding planes with a cross-section mostly around 5 metres wide and about a metre high (Murphy, 2017). The water flows up the gentle dip, so the passage is 15 metres below resurgence level at the furthest point yet reached by cave divers, more than 650 metres from the entrance, and directly beneath the dry valley of Watlowes. There is no accessible cave at Aire Head.

Malham's underground drainage is almost infamous for its crossing flow-paths, though such is actually fairly normal in a 3-D network of karstic fissures, conduits and caves, A suite of dye-tests and pulse-tests in 2016 (Gunn and Kelly, 2017) improved understanding of a mature karst aquifer that is more complex than just having crossing flow-paths.

Figure 2. The limestone cliff of Malham Cove; it is about 80 metres high, though the lip of the central, ephemeral waterfall is only 70 metres above the pool hidden behind the trees.

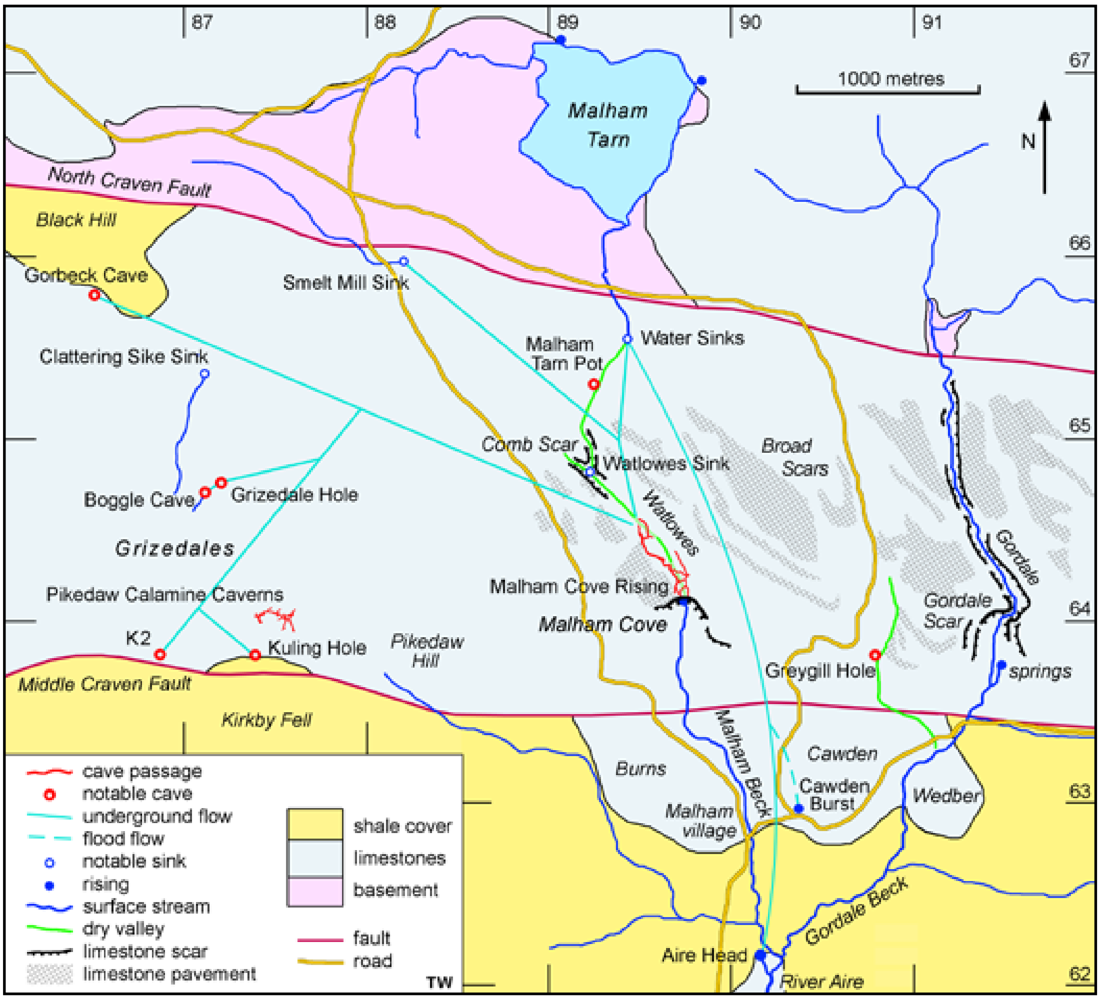

Figure 1. Main features of the geology and geomorphology of the area around Malham Cove, compiled from various sources. The indicated underground flows, from Water Sinks to Aire Head and from the various Grizedales sinks to Malham Cove Rising are active in all conditions; not shown are the complex and multiple links whereby water from most or all of the sinks emerges at all the risings in flood conditions, as these are not known in detail,

In dry to normal weather, the Tarn water sinking at Water Sinks emerges at the double rising of Aire Head, except for about 5% of its flow that crosses into the conduit feeding to the Malham Cove Rising. In the same conditions the area around Pikedaw Hill and Grizedales, including the Smelt Mill Sink (Fig. 1), drains entirely to the Cove rising. However, flow-paths change in flood conditions, when flows at Aire Head increase only slightly, restricted by the size of its feeder conduit, while Malham Cove Rising can emit massive flood flows. It appears that most of the flood flow from Water Sinks resurges at the foot of the Cove. And in major flood events, water also emerges from Cawden Burst, where a powerful stream emerges from a bank of scree above Malham village, before flowing down the road to join Malham Beck; typically this happens just once or twice a year.

Figure 3. *Malham Cove waterfall in its brief interlude of activity on December 6th, 2015 (photo: Barry Holgate).*

The Cove waterfall

In centuries gone by, the dry waterfall of Malham Cove was recorded as briefly resuming activity after heavy rainfall, though such events were declining in frequency. Then, for the first time since 1824, the Cove waterfall flowed twice in December 2015. A temporary waterfall existed for most of the day of December 6th (Fig. 3) and again for most of the night of December 26th to 27th. On each occasion, an exceptionally large flood flow from Malham Tarn overcame the normal Water Sinks. A torrent continued on down the valley, formed a waterfall at Comb Scar and lost some of its flow into the boulder-choked sink at its foot. But for some hours on each occasion flow was sufficient to continue along the normally dry Watlowes valley. It then formed the Cove waterfall, with a perfect free drop about 4 metres wide and exactly 70 metres high (Murphy, 2017).

Each waterfall event followed exceptionally heavy rainfalls totalling around 90 mm within about 48 hours, though the rain had stopped for most of December 6th when the waterfall was actually flowing. Both events were late within a period of two months when the Tarn catchment had been saturated with more than double the normal rainfall. The waterfall on December 6th featured widely with photographs in the national media, but the Boxing Day event was barely recorded, as it was seen by few and photographed by no-one during the night. When the Cove waterfall will flow again is anybody's guess.

The origins of Malham Cove

Malham Cove and the nearby Gordale Scar can both be described as steps in their respective valleys, formed where they pass off the edge of the limestone plateau. That edge is defined by the Middle Craven Fault, which separates the limestone of the Craven Uplands in the north from the softer sedimentary sequence beneath the Craven Lowlands to their south. Each valley-floor step has retreated about 600 metres from the fault outcrop. The two, long, feeder valleys, Watlowes and Gordale, are essentially fluvial features. They are now recognised as meltwater channels, formed quite rapidly by powerful rivers, largely or entirely when the ground was frozen and therefore less permeable during cold stages of the Quaternary.

Figure 4. *Malham Tarn, the wide and shallow lake that appears to lie on a limestone plateau but actually sits on an inlier of impermeable rock beneath the karst limestone.*

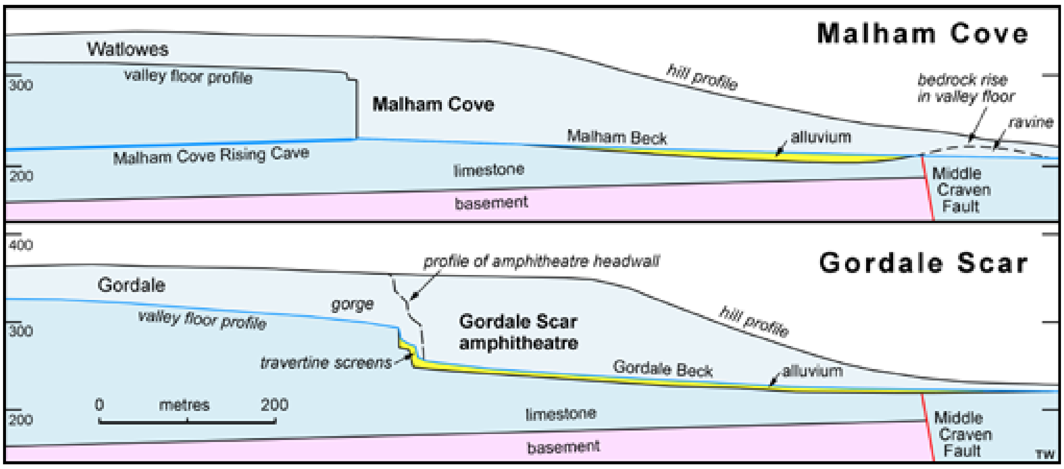

***Figure 5**. Long profiles that show the similarities between Malham Cove and the amphitheatre at Gordale Scar.*

At Gordale Scar, the Hole in the Wall has been claimed as a remnant of a collapsed cavern, but it was formed only in 1730 when the stream broke through a thin rib of limestone between two faults. Collapsed caverns are extremely rare, and the deep, narrow gorge of Gordale Scar is clearly a fluvial feature (though this does not apply to the wider bowl into which the gorge opens).

Malham Cove remains the debatable landform. Commonly described just as a dry waterfall, its origins are complex, with four suites of processes (fluvial, glaciofluvial, glacial and karstic) active during parts of the Quaternary. Debate continues over how much each process has been responsible for the Cove's evolution (Waltham, 2017).

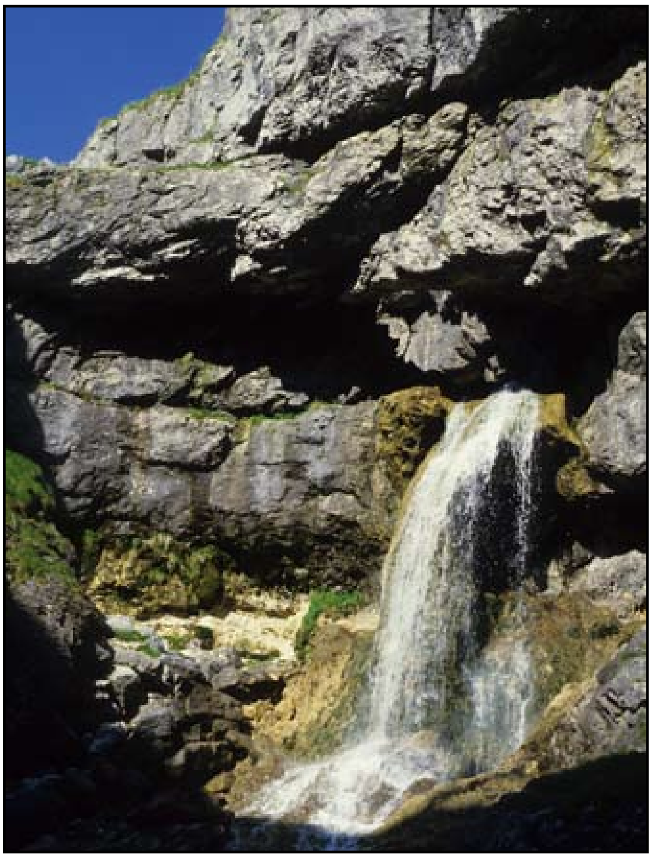

***Figure 6**. The Hole in the Wall at Gordale Scar; not a remnant of a collapsed cavern, but the site of a fluvial breakthrough in 1730; the earlier stream channel was out of view to the left.*

***Figure 7**. Malham Cove and Malham Tarn, with the Watlowes valley in between; Quaternary ice sheets had moved towards the camera position (photo: Anthony Raithby).*

Fluvial erosion. A simple history as a dry waterfall is supported by the dry, fluvial valley of Watlowes feeding to the head of the Cove. But in the 200-metre-width of the Cove far exceeds the 50-metre-width of the Watlowes valley (Fig. 7). Niagara-style waterfall retreat typically forms a gorge with a cliff at its head, with both gorge and cliff little wider than the river channel. The narrow gorge of Gordale Scar, upstream of its lower amphitheatre, is a fluvial feature, and its shape is totally unlike that of Malham Cove.

Figure 8. The dry fluvial valley of Watlowes, looking downstream towards the lip of Malham Cove, which is out of sight beyond a slight curve.

Undoubtedly, Watlowes and the Cove have carried significant streams in the past. These could have been long-lived features active on the limestone plateau when underground drainage was inhibited by ground ice developed under periglacial conditions during phases of the Quaternary. Or they might have been features of short-lived, pro-glacial drainage from remnants of Quaternary ice on the Malham High Country. Any such processes are likely to have contributed to the deepening of the valley and the shaping of the waterfall cliff, but simple fluvial erosion alone cannot account for the entire morphology of the Cove.

Glaciofluvial erosion. Any consideration of fluvial erosion at Malham Cove has to rely heavily on flows of meltwater, from or beneath Quaternary ice sheets, especially during their retreat phases. Erosion of the limestone surface then occurred when the capacity of any contemporary sinks was temporarily exceeded by meltwater flows. And these could well have included periodic, massive, sub-glacial floods, known as jökulhlaups, named after the floods in Iceland that are generated by sub-glacial volcanic eruptions. Events only slightly smaller than those can develop where meltwater accumulates beneath warm-based glaciers to a point where the covering ice is floated and uplifted enough to allow the water to escape laterally between a rock floor and an ice roof. Waters from limestone springs around Malham Tarn currently have temperatures around 7°C. A typical Devensian temperature decline of around 6°C then suggests that these karst springs could have continued to flow during at least parts of the Last Glaciation. It is not a new idea that karstic spring water could then accumulate within the Malham Tarn basin, until it lifted the ice and escaped southwards down a sub-glacial or pro-glacial Watlowes (Pitty *et al*., 1986). Such self-dumping of an ice-dammed or sub-glacial pond within the Tarn basin could produce flows of 25-50 cubic metres per second over periods of a few days.

Very large, short-lived flows of this style could account for the scale of the Watlowes valley more easily than could steady streamflows from the rather small Tarn catchment. But they are still a long way short of the scale of floods that could be expected to create Malham Cove as an ephemeral waterfall. Not only is Watlowes much narrower than the Cove, but there is minimal evidence of tributary channels contributing to a single large flow over the Cove, and flow through conduits entirely within the ice (thereby eroding no valley in the bedrock) are unlikely to be large or long-lived. Glaciofluvial processes could have been significant at Malham, but they too cannot account for all the landforms that survive today.

Glacial erosion. The site of Malham Cove lay beneath the ice during each of the Pleistocene glaciations. The well-known limestone pavements around the crest of the Cove (Fig. 11) are the clearest indicators of ice erosion, but there is no specific evidence of ice action on the walls of the Cove itself. However, over-deepening of the valley below the Cove (Fig. 9) indicates a history of glacial excavation. For 600 metres downstream from the Cove, Malham Beck runs across an alluviated valley floor, before entering a ravine cut through a ridge of limestone bedrock immediately south of the Middle Craven Fault.

Figure 9. The over-deepened basin in front of Malham Cove, viewed from the crest of the limestone ridge that was its confining barrier, the ravine that later drained it contains the trees on the extreme right.

***Figure 10**. Aerial view over the lip of Malham Cove (with the Watlowes valley lower left); the rounded, glacially over-deepened basin below the Cove is floored by dark green grass and is traversed by the footpath that then rises over the confining ridge with the paler grass (photo: Anthony Raithby).*

The role of ice erosion is also indicated by the Cove's width of about 200 metres being so much greater than that of the Watlowes valley at its head. This gross imbalance suggests that much of the Cove's morphology could derive from origins as a sub-glacial step, where Quaternary ice sheets moving southwards from the Craven Uplands and descended over the fault scarp along the Middle Craven Fault. Through much of the Quaternary glacial episodes, ice was probably cold-based and therefore had little impact on the landscape of the high fells. But, at critical times during the climatic oscillations, a change to warm-based conditions at lower altitudes would have given the ice significant erosive power at Malham Cove. Ultimately derived from the Littondale ice stream, the ice flowed symmetrically over the Cove amphitheatre, whereas the fluvial Watlowes valley enters obliquely from the northwest. Vertical joints within the limestone, and the weakness of the bedding plane (and its caves) at the foot of the Cove facilitated development of a steep back-wall by glacial plucking (now described as ice quarrying).

***Figure 11**. Limestone pavements at the top of Malham Cove; these are true features of glaciokarst, with their bare rock surfaces scoured, plucked and swept clean by over-riding glaciers, before drainage runnels were formed by dissolution.*

The rock-walled amphitheatre that is the lower, outer part of Gordale Scar is a landform of comparable size to that of Malham Cove, except that is more deeply recessed into the limestone plateau (Fig. 5). Its origins are probably similar to those of Malham Cove, except that subsequent flows of meltwater cut the narrow gorge into the headwall of the larger and older amphitheatre.

Stalagmite at least 27,000 years old, now below water level inside the Cove's cave, indicates that the valley in front of Malham Cove had been eroded to close to its present depth prior to the main Devensian glaciation (Murphy, 2017). However, the scale and morphology of any ancestral landform at Malham Cove also remains unknown.

Karstic erosion. The Cove has often been described as a pocket or headless valley that evolved by some combination of spring sapping, cavern collapse and river erosion. Water emerging from the cave at the foot of Malham Cove does contribute to shaping of the cliff by dissolutional erosion, removal of rock debris and some undercutting of the limestone wall. The cave on the bedding plane just below water level at the foot of the Cove has guided and aided surface retreat of the Cove wall, but it is orders of magnitude smaller than the Cove, and it can only have been contributory to the Cove's evolution. It is also possible that the over-deepened basin in front of the Cove developed as a karstic depression with an underground exit for its drainage, however, there is no evidence for any cave outlet buried beneath the sediment, and the concept of glacial over-deepening better fits the overall morphology of the valley.

The debate continues. It is likely that all four of the above processes have contributed to the distinctive and unusual morphology of Malham Cove, but it is far from certain as to which processes were dominant. Whether or not enhanced by proglacial or subglacial meltwater, and with or without jökulhlaup floods, the Watlowes valley is largely fluvial, and its water must have contributed to shaping the Cove. There is no doubt that Malham Cove was occupied and covered by ice during the Quaternary cold stages, and it is difficult to explain the width of the Cove without some element of glacial erosion. Karstic processes played only a minor role. The origins of Malham Cove remain open to debate.

Tony Waltham

References

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