CAVE ARCHAEOLOGY AND KARST GEOMORPHOLOGY OF NORTH WEST ENGLAND

Field Guide

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THE YORKSHIRE DALES KARST

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Introduction

The main part of the Yorkshire Dales karst lies on the largest outcrop of the Great Scar Limestone across the southern dales. The finest of the karst landscapes are around Ingleborough and Malham, but many of the major caves lie to the east and west, and the karst is continuous from the Dent Fault, in the west, to the eastern watershed of Wharfedale - a distance of 40 km. The topography is dominated by the massive unit of nearly horizontal limestone, whose top surface forms a series of plateaus and benches at around the 400 m level. Outliers, formed largely of shale, rise to summits at around 700 m, and the glaciated troughs of the Dales cut through the limestone to expose basement inliers. An important westward extension of the Dales karst is presented by the lowland fault blocks around Morecambe Bay, which contain some of the finest limestone pavements in the country (see Standing, this volume; Goldie, this volume). The limestone landscapes of the Dales are the most spectacular in Britain, and have the country's finest glaciokarst landforms, while the geology has proved ideal for the development of large caves.

The Great Scar Limestone Group is the unit of strong Dinantian carbonates so conspicuous in the topography of the Yorkshire Dales karst. It consists of limestone beds of massive facies, formed through the Arundian, Holkerian and Asbian stages, locally sub-divided into the Kilnsey, Cove and Gordale Formations (Fig 1.; Arthurton *et al.*, 1988). The facies includes the Hawes Limestone of the lower Brigantian. The Great Scar Limestone is mainly formed of very pure, cream or pale grey, thickly bedded, bioclastic, sparites and micrites; these were a shallow water facies formed on the Askrigg Block, a shelf area partly bounded by faults and surrounded by deep water in the Dinantian sea. Thin shale beds throughout the limestone succession greatly influence the cave development, but reef facies at Malham and in lower Wharfedale are of little significance to the wider karst geomorphology. The limestone is 160-220 m thick, and the variation is almost entirely due to transgression across over 50 m of local relief on the basal unconformity. Beneath the limestone, Lower Palaeozoic greywackes and slates are totally impermeable, and are exposed in the floors of most of the dales; their buried ridges provided the clastic debris for the discontinuous conglomerates at and near the base of the limestone.

The basement inliers in the dale floors are truncated to the south by the North Craven Fault. The southern limit of the karst is along the South and Middle Craven Faults, which down-throw to the south by many hundreds of metres. The slice of limestone between the faults is widest where it forms the splendid karst above Malham. The Dent Fault bounds basement rocks to the west, and forms the western edge of the main Craven karst. The pavements around

Morecambe Bay are formed on fault blocks of carbonate that is laterally equivalent to the Great Scar Limestone and is of similar lithology. Both the northern and eastern limits of the main karst are formed where the Great Scar Limestone dips gently beneath its cover rocks. The regional dip on the Askrigg Block is just a few degrees north, splaying to northwest and northeast off the axis of the Pennine anticline. Minor faults, mostly with horizontal displacements, occur all across the limestone outcrop.

Above the Great Scar Limestone, an alternating series of thin shales, limestones and sandstones forms the Brigantian Yoredale Group. This is up to 300 m thick, and has considerable lateral variation; all the limestones have some karstic features, mostly on a small scale. The clastic units between the five lower limestones are locally absent, and the Gayle and Hawes Limestones are inseparable from the Great Scar across much of the Dales area. The entrance bedding passages of some of the major caves are within the Hawes Limestone, and east of Wharfedale, the Mossdale and Langcliffe caves in the Middle Limestone drain underground right through to the Great Scar. More significant to the karst than the local stratigraphy is the ubiquitous situation where the higher slopes of the Yoredale shales provide surface streams that drain onto the main limestone benches.

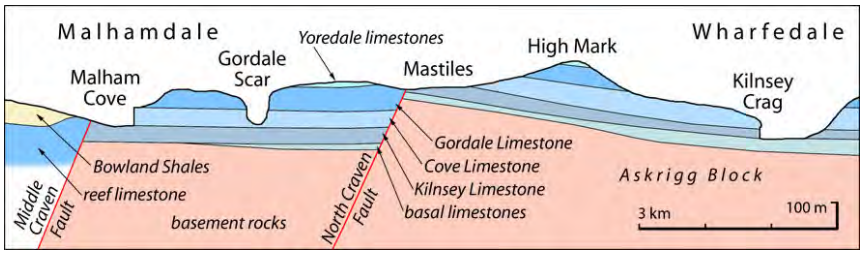

Fig 1. Semi-diagrammatic and curved profile across the type localities of the units within the Great Scar Limestone on the Askrigg Block.

The karst

Based on dated stalagmites in de-watered caves adjacent to the western dales, a current best estimate of the mean rate of valley incision on the Askrigg Block is about 0.15 m/ka. From this, it may be interpreted that widespread karst development in the Yorkshire Dales started with the first exposure of the Great Scar Limestone at about 1.3 Ma ago (Waltham, 2012). At about that time, limestone was exposed in the floor of Chapel-le-Dale and also across part of the area around the present site of Malham Tarn. This was probably preceded for an unknown interval by karst in lower Ribblesdale where structurally high limestone was exposed between the flanks of Fountains Fell and the site of Settle.

Subsequent erosion, both fluvial and glacial, entrenched the dales through the entire thickness of the Great Scar Limestone, and also stripped back the cover of Yoredale rocks on the interfluves. The effect was the expansion of the high limestone plateau surfaces, which may be described as structural benches or stratimorphs (Waltham and Long, 2011). It is these that now support the finest of the glaciokarst, notably on the wider plateaus around Ingleborough and north of Malham. The bare outcrops of limestone have great expanses of pavement, deeply incised by solution runnels. Where the fissured limestone is veneered with glacial till, doline fields with thousands of subsidence dolines (locally known as shakeholes) have formed, and are still active.

Ice sheets scoured the entire Yorkshire Dales karst, during at least four of the Pleistocene cold stages. Sediments and landforms are mainly from the Devensian ice retreat, and large dolines on the Malham High Country are among the few features of earlier genesis that can now be recognised. Glacial till plasters much of the terrain, forms significant moraines in only a few of the dales, and is moulded into large drumlin fields around Ribblehead (see Mitchell, this volume), in the lower Ribble Valley and across the Lancashire Lowlands between the limestone hills towards Morecambe Bay.

The glacial interludes interrupted the karstic processes of warmer interglacial climates, and their phases of glacial erosion alternated with those of fluvial erosion to impose a sequence of rejuvenations on the pattern of geomorphic evolution. The effects of the Devensian glaciation are most conspicuous within the present landforms. At its maximum, Devensian ice covered the entire area; during its wane, summit nunataks appeared while the ice still swept over the limestone plateaus, and the final retreat stage saw only shrinking valley glaciers in the dales beneath the limestone benches. Ice flowed from the north, and its impact on the dales varied with the ice catchment as defined by the topography; Wharfedale and Ribblesdale carried the largest glaciers, but the Ease Gill and Malham valleys were both sheltered from major ice scour. Except for those two valleys, all the dales are deep glaciated troughs flanked by limestone scars.

All the streams and rivers have dry sections in their surface courses across the limestone. The Ribble and Wharfe maintain their surface flows in all but very dry weather, while most small streams off the shale outliers sink into caves and potholes under all conditions. The limestone high ground is therefore normally streamless in the present environment. Fluvial erosion of the mature karst has been limited to short periods of periglacial conditions, particularly during the Devensian ice retreat. There are few dry valleys, but some were formed by subglacial and proglacial meltwater, and include the spectacular gorges of Gordale and Trow Gill. Malham Cove has a more complex origin (Waltham, 2012), but the evolution and survival of its great limestone cliff are further consequences of the changing karstic processes.

The Yorkshire Dales karst owes its spectacular geomorphology to the

combination of so many landforms: the sinks which take all the drainage, the expanses of pavement, the long scars, the deep gorges and the innumerable dolines. The area is strictly a glaciokarst, but Ingleborough and Malham provide the finest limestone landscapes in Britain.

The plateau surface

The wide benches that are conspicuous features above most of the main valleys have been described as a 1300-foot erosion surface across the Dales (Sweeting, 1950), but this concept is no longer accepted (Waltham and Long, 2011). It was found impossible to fit a widespread erosion surface on to the more accurate topographical maps now available, and those authors agreed with others that most of the plateau surfaces at about 400m a.s.l. are largely a structural stratimorph formed on the top of near-horizontal Great Scar Limestone. This had been created by the denudation of higher and less competent rocks until strong beds close the top of the Great Scar succession formed a resistant surface. The original concept of "cave levels" associated with the "erosion surface" (Sweeting, 1950) is better explained as cave passage development focussed at key horizons and shale beds within the limestone (Waltham, 1970).

A consequence of recognition of the stratimorphic origin of the plateaus, was an estimate of the first exposure of the Great Scar Limestone along the southern edge of the Askrigg Block (Waltham and Long, 2011). Based on assumed surface erosion rates and consequent isostatic uplift rates, the Great Scar Limestone (and therefore also the "1300-foot erosion surface") was just below sea-level, and ~300m below the contemporary land surface, 3 Ma ago. During uplift, the limestone became exposed in valley floors roughly 1.3 Ma ago, and this would therefore be the earliest time that significant caves could form in the Dales from pre-existing proto-conduits. Subsequent glacial and fluvial erosion enabled deepening of the valleys and removal and retreat of overlying Yoredale rocks to widen the adjacent plateaus. With the steeper hydraulic gradients, meltwater during deglaciations and rainwater during interglacials, cave passages could rapidly enlarge over long path lengths. Successive stages of cave passages were broadly synchronous with the glaciations that followed the exposure of the limestone, but many or most of the early caves were lost during subsequent enlargement of the valley profiles; only fragments of the older caves survive within the larger and younger cave systems.

The caves

Nearly half of all Britain's known caves lie in the Yorkshire Dales karst. This is because the geology presents an ideal cavernous environment: allogenic streams from the shale cover provide input to the top of the limestone, draining through to resurgences at or near the base of the limestone exposed in the dale floors. Therefore most underground stream routes have a simple staircase profile. Shafts are formed on joints or faults which are close to vertical, and nearly horizontal caves lie along the bedding planes and shale horizons within

the limestone. Vadose canyons follow the bedding down the gentle dips, while phreatic routes are directed towards the available resurgence sites, regardless of geological structure. Looping cave plans are created where passage directions change in response to the hydrology, and patterns are further complicated where faults divert the underground drainage by overriding the bedding influence.

The geology imposes local detail on cave profiles, mainly because vadose water descends the first available tectonic fracture. The deep daylight shafts, such as Gaping Gill, therefore drain into long sub-horizontal conduits at depth. Many other sinking streams find and follow shale horizons high in the limestone sequence, and therefore drain through long caves at shallow depth; Mossdale Caverns above Wharfedale provide the extreme case, but their water does eventually descend to depth, and the Birkwith caves in Ribblesdale provide the grandest exception by draining out of a perched resurgence.

Vadose flow in the caves is mainly down-dip to the north. Phreatic flow is then up-dip to the south, towards the lower surface levels. This accounts for the long flooded zones in the lower levels of nearly all the Yorkshire Dales caves; Keld Head is the finest example with more than 7 km of flooded cave behind the resurgence. The phreatic conduits can also loop up and down between submerged bedding horizons; the route from Ireby Fell Cavern to Leck Beck Head has at least five phreatic lifts, the highest carries water more than 60 m up a vertical shaft on a joint or minor fault. The only long vadose streamway out to its resurgence is White Scar Cave, draining down-dip into Chapel-le-Dale.

Prior to successive rejuvenations and surface lowering during the Pleistocene, higher levels of phreatic caves developed where the aquifer was impounded behind the impermeable rocks south of the Craven Faults. These caves were then abandoned as the entrenching dales created new resurgence sites, close to where they breached the fault barrier. The old phreatic caves also developed largely along the bedding, and now form the high-levels, abandoned, invaded or intercepted by the modern, rejuvenated stream caves. The Gaping Gill Cave System has a long system of old sub-horizontal caves at depth beneath the famous daylight shaft, and Sleets Gill Cave has the best examples of abandoned phreatic lifts. These old caves contain extensive calcite and clastic sediment sequences, that record the Pleistocene environments and rejuvenations, but dating of the material has been on a modest scale, and much remains to be evaluated (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1983a; Latham and Ford, 2012).

The combination of large dendritic systems of active cave passages and intercepted networks of abandoned conduits produces very long caves. Beneath the southern flanks of Gragareth, the Three Counties Cave System is the longest in Britain, with nearly 90 km of mapped passages extending beneath Casterton, Leck and Ireby Fells; links through to the Kingsdale caves are known to exist but await exploration. There is still much to learn from the underground geomorphology, cave sediments and surface landforms within the Dales karst.