Ingleborough karst

[SD 71 73]–[SD 76 78]–[SD 79 70]

Highlights

A broad limestone bench surrounding the summit mass of Ingleborough constitutes Britain's finest single area of glaciokarst. It contains spectacular limestone landscapes, which have an unparalleled scale of surface and underground karstic development. Ingleborough has virtually every type of karst feature, and is one of the best documented and most visited karst areas in Britain.

Introduction

The Ingleborough benches form a triangular block of limestone nearly 10 km across, bounded by the glaciated troughs of Ribblesdale and Chapel-le-Dale and by the Craven Fault scarp across the south-west (Figure 2.1). An outlier of sedimentary rocks dominated by shale forms the summit mass, which rises as one of the well known Three Peaks above the limestone plateau of the Craven Uplands. The summit reaches an altitude of 723 m, the top surface of the gently sloping limestone bench lies at 350–440 m, and base level in the dale floors is at about 220 m. Ingleborough forms a magnificent limestone landscape of wild open country, containing an impressive range of splendid glaciokarstic and fluviokarstic landforms. Its conservation values are regarded as a special case within the Yorkshire Dales National Park, and the whole mountain is designated as a Site of Special Scientific Interest for its geological and biological features.

Ingleborough is remarkable for the excellence of both its surface and underground karst landforms. Within any mature karst landscape, the processes and evolution of the cave drainage systems are totally interrelated with the progressive development of the surface topography, and they should be viewed together. The sheer scale and significance of the geomorphological interest in the Ingleborough karst dictates that its description and interpretation are subdivided, and separate reviews of the surface karst and the caves are more appropriate than a geographical subdivision. The caves are described in the next section.

Geologically, Ingleborough lies on the upstanding southern edge of the Askrigg Block, bounded to the south by the Craven Fault system which separates it from the Craven lowlands. The main karst is formed on the Dinantian Great Scar Limestone, consisting of nearly 200 m of pale grey, fine-grained, bioclastic limestones (Hughes, 1909; Moseley, 1973; Doughty, 1968). There is considerable local variation in the carbonate lithology, and individual beds are mostly 0.5–5.0 m thick, commonly separated by thin partings of shale. The limestone is well jointed, has a high secondary permeability and is well karstified; it generally dips a few degrees to the north. Above. the limestone, the summit outlier consists of the cyclic sequences of interbedded shales, sandstones and thin limestones of the Yoredale facies of the Brigantian Wensleydale Group. Ordovician and Silurian slates, mudstones and greywackes form the basement to the karst aquifer. They lie beneath a strong unconformity, which is exposed in the floors of Chapel-le-Dale, Clapdale, Crummack Dale and Ribblesdale.

The diversity of karst features on Ingleborough has prompted a long history of research, of which the earlier work is reviewed by Halliwell (1974). The geology of the area has been described by Garwood and Goodyear (1924), Dunham *et al.* (1953), Rayner (1953), Wilson (1974), Waltham (1974b), Arthurton *et al.* (1988) and many others. Further research on the Great Scar Limestone includes that by Schwarzacher (1958), Sweeting and Sweeting (1969), and Waltham (1971b), and the Yoredale beds were described by Hicks (1959). The karst geomorphology of Ingleborough is reviewed by Sweeting (1950, 1966, 1974) and Waltham (1970, 1990), Waltham and Davies (1987) and Waltham and Tillotson (1989); the various erosion levels were further described by Trotter (1929), Hudson (1933), King (1969) and Clayton (1966, 1981). Dating of stalagmites from some of the caves has provided limited evidence for the rates of valley entrenchment and the chronology of geomorphic evolution of Ingleborough (Atkinson *et al.,* 1978; Gascoyne *et al.,* 1983a, b; Gascoyne and Ford, 1984; Waltham, 1986).

Description

The diversity of the karst landforms on Ingleborough is due in large part to geomorphic contrasts produced by the patterns of the Pleistocene glaciations; the ice scoured and eroded some of the limestone outcrops, while protecting and burying others beneath till. During each cold stage of the Pleistocene, ice moved from the north, and the main flows diverged around Ingleborough to continue down Chapel-le-Dale and Ribblesdale. During the glacial maxima, ice covered the entire landscape, and the two dales were iceways beneath an ice sheet which spread over and scoured the limestone benches. During advance and retreat phases, the dales were occupied by valley glaciers which deepened the troughs below the limestone benches. A significant distributary ice flow left the Ribblesdale iceway and crossed the eastern benches of Ingleborough to drop into Crummack Dale and Clapdale (Figure 2.13), (Figure 2.14). Areas of lesser ice flow became the main zones of glacial deposition, and the thickest till mantles the limestone outcrop on Newby Moss, lying in the protected lee of the Ingleborough summit mass.

The limestone plateau around Ribblehead now carries a splendid drumlin field, left by Devensian ice on the broad upland before it was constrained southwards between the Three Peaks.

Stream sinks, dolines and shakeholes

Ingleborough is commonly cited as a textbook example of karst landscape, due to the huge number of closed depressions on the limestone benches. These include deep potholes, open cave entrances, active sinkholes, blind valleys, large solutional and collapse dolines, drained structural depressions, and the thousands of shakeholes which are subsidence dolines in the till cover.

Streams draining off the summit slopes of Ingleborough sink into the top of the limestone all around the shale outlier (Figure 2.13). More than 250 cave entrances are known, providing access to over 54 km of mapped caves. Some lead into almost level cave passages formed along shale horizons between the upper beds of limestone. Many are vertical potholes, with fluted limestone walls disappearing out of daylight as they reach depths of 10–100 m; the large open shafts of Gaping Gill, Alum Pot and Meregill Hole are just the better known of many impressive shafts. The cave systems fed by these sinks are described below, but they have developed almost radially to resurgences in the floors of all the adjacent dales (Figure 2.13). Some of the larger potholes, including Great Douk Cave, Alum Pot and Gaping Gill, lie out on the limestone benches, and may be close to past positions of the retreating shale margins (Sweeting, 1974; Waltham, 1990).

The few blind valleys on Ingleborough are cut only into the glacial till where streams have found routes into the buried limestone, so none exceeds a depth of about 10 m; Gaping Gill is the best known example, and there are others along the buried shale boundary to the east and west (Figure 2.14).

Most of the limestone benches were scoured by Devensian ice, and large solutional dolines have not developed in the short period of postglacial time. The only solutional features larger than the main open shafts are some preglacial depressions now wholly or partly filled with clastic sediment. Braithwaite Wife Hole, on the bench north of Meregill (Figure 2.21) is a conical hole 60 m across and 25 m deep, with sides of slumped till which mask most of the rock profile. Wider but not as deep is the partially filled solutional doline above the west side of Clapdale. A group of dolines on the limestone bench north-west of Crummack Dale (Figure 2.14) have almost level grass-covered floors only about a metre below their rims of bedrock limestone. These appear to be preglacial dolines, filled with till and perhaps truncated by surface lowering, but their subsurface structure has not been investigated; shakeholes within them reveal soil fills a few metres deep with no exposure of rock. These and other, similar large depressions are of largely solutional origin, but collapse modification is almost inevitable; it is known to have occurred in Braithwaite Wife Hole where a tributary cave passage gives access to a zone of collapse reaching 30 m below the floor of the surface depression.

Large, shallow closed depressions on Thieves Moss (Figure 2.14) are structural basins within the limestone, each excavated to a single bedding plane by glaciers. They are not karstic, except that they remain dry due to underground drainage.

Where the limestone benches of Ingleborough are covered with glacial till or any other clastic soils, the ubiquitous feature of the karst is the shakehole. This style of subsidence doline is formed by the soil cover ravelling into the fissures in the buried limestone as rainwater filters through and creates small piping failures. There are around 3000 shakeholes on Ingleborough. Most are 1–10 m across, no deeper than the till thickness, and with sides sloping at 10–40°. The deepest are therefore in the thick till blanket on Newby Moss (Figure 2.14), but the greatest densities of shakeholes lie along the strip of till over the shale boundary along the bench above Chapel-le-Dale. Only a small proportion expose limestone in their floors; some have open shafts or cave entrances, and others are blocked so that they now contain small ponds. The shakeholes have formed and enlarged over the 10 000 years of postglacial time, and they continue to evolve today. New shakeholes are occasionally recorded, but many more old shakeholes periodically deepen or widen as their soil fills slump into hidden limestone fissures. In 1980, a massive failure enlarged the shakehole containing Marble Pot when hundreds of tons of soil and debris ran into the chamber below and blocked the outlet cave passage (Waltham, 1989).

Dry valleys and gorges

The largest dry valleys on Ingleborough are all cut into the southern slopes (Figure 2.13). Crina Bottom is the longest and deepest, and has a thin alluvial fill along part of its floor; its headwaters have been captured by White Scar Cave, draining beneath the scars to the north-west, but flood flows reach down the normally dry valley to a series of sinks which feed parallel drainage routes to Chapel-le-Dale. Cote Gill is a smaller dry channel, largely cut into the glacial till which fills a broader valley in the bedrock.

Trow Gill is the finest dry valley feature. It forms a trench across the plateau south of Gaping Gill, and then descends 70 m through a narrow rocky gorge less than 3 m wide at its narrowest point (Figure 2.15). The gorge is incised more than 20 m into the strong limestone, and has vertical walls in its upper section. It descends into Clapdale, where it is joined by a dry valley through the retreat moraine in Clapham Bottoms, and it forms the upper reaches of a fluvial channel that is almost continuous down the floor of the glaciated trough of Clapdale. Trow Gill beheads an older dry valley which is less deeply entrenched on its southern side and ends over the low scars that contain the Foxholes cave.

Apart from these four, the only dry valleys on Ingleborough are shallow rocky ravines which descend through some of the limestone scars. Sulber Nick is the longest of a number aligned on fault zones, and others are associated with caves which have captured their drainage.

Limestone pavements and scars

Glaciation has sculpted many of the landforms present on Ingleborough, and the extensive pavements and long scars of bare white limestone dominate many of the landscape vistas. The spectacular limestone pavements extend over nearly 400 ha (Ward and Evans, 1976), and lie on the plateaus and benches which received the full impact of glacial scour by ice moving down both the west and east sides of the Ingleborough summit mass (Figure 2.13), (Figure 2.14). The very variable quality and morphology of the Ingleborough pavements were assessed in a survey by Waltham and Tillotson (1989). They found that the pavements of the finest quality all lie in two narrow belts, around Scar Close and between Alum Pot and Thieves Moss, both at the cores of the main pavement zones west and east of Ingleborough.

The Ingleborough pavements are extremely varied, presenting suites of pavement landform types, from great undissected sheets of scoured limestone, to closely fractured linear clints. The most massive pavements lie in two smaller areas, on Scar Close and west of Thieves Moss, and these contain the largest clint blocks, with some of nearly 2 ha on Scar Close. In contrast, the linear pavements, with knife-edge clints and larger blocks with length/width ratios greater than 4, lie mostly in the limestone nearer the Craven Faults, on White Scar, above Clapdale and on southern Moughton (Figure 2.13). These broad patterns of pavement distribution are superimposed on a wealth of detail at individual sites.

On the terraces and benches of Raven Scar, overlooking Chapel-le-Dale, many large clints, particularly near the inner edge of the terraces, have centripetal systems of deep runnels. There are also many lamellar clints with bedding planes etched into the walls of the perimeter grikes; smaller clints in flaggy limestone show flakey weathering which produces more loose debris. Scattered sandstone boulders are glacial erratics.

Some of the finest of Ingleborough's pavements lie below Meregill Hole, across the top of the Southerscales Scars and into Scar Close (Figure 2.16). The exposed limestone bedding is horizontal or dips 1–5° north-east, and many of the clints are more than 10 m across. There is an identifiable sequence of variation across the pavements on each terrace, with a tendency for the large clints to be etched by very smoothly rounded rundkarren near the inner boundaries where strips of glacial till survive. Towards the central sections of the terraces, the larger clints still have deep runnels, many of which are individual, sharply edged rillenkarren not forming dendritic systems. The outer edges of the terraces are broken into smaller clint blocks which cannot support large systems of deep runnels. On the larger clints on Southerscales Scar, some of the large single runnels are tadpole-shaped, and each drains downdip from the remains of a kamenitza.

The main pavement in Scar Close has been protected from grazing sheep since 1960; it is therefore developing a new natural plant cover of mosses, heather, juniper, yew, ferns and flowering shrubs. Very large rectangular clints commonly have a central hump down their length, etched by short rundkarren draining to either side. There are also some extensive, undissected surfaces which carry rich vegetation on islands of remnant till and peat (Gosden, 1968). Dissection of the limestone is by dendritic runnels originating from drainage off these islands, and also off the marginal shale cover, as well as by grikes on the rectangular networks of tectonic joints.

At the head of Ribblesdale, Colt Park contains a stretch of pavement retaining a mature, natural vegetation cover; ash dominates a thick woodland which hides a dense undergrowth with deep moss over a massive pavement with very deep grikes. Borrins Moor Rocks, south of Alum Pot, has some excellent, massive clints with deep rounded runnels. Massive pavements continue to the south along the outcrop of the strong beds of limestone near the top of the Great Scar sequence; they extend west of Thieves Moss, where the largest clints occur, and on to the scars east of Clapdale. Extensive pavements are developed on the lower limestone beds which extend over the gently sloping Moughton plateau (Figure 2.14); there is great variety in the karren morphology, but the clints are generally smaller to the south where the Craven Faults are approached.

To the west, the margin of the shale cover is largely obscured by drift, but a small pavement by Long Kin East Cave (Figure 2.18) is notable for its glacial striae. These are preserved on limestone sealed beneath an impermeable till cover which is slowly retreating. Newly exposed striae are removed by rainfall solution within about 10 years, and the limestone is then etched by new solution runnels (Tiddeman, 1872; Sweeting, 1966, 1974). Further south, the Norber ridge is famous for its perched glacial erratics of greywacke (Figure 2.17). These were derived from outcrops in Crummack Dale and carried obliquely upwards onto the limestone outcrop (Figure 2.14). They now stand on pedestals of limestone which have been protected from corrosion by direct rainfall while the surrounding limestone surface has been lowered by subaerial and subsoil solution. As the protected pedestals are mostly 400–500 mm high, the mean rate of lowering of the exposed surface has been about 30–40 mm/ka since the Devensian ice retreat (Sweeting, 1966). The narrowness of the pedestals, and their incision by solution grooves, may be accounted for by dripwater flowing down the underside of the boulders.

The limestone scars are best developed where ice moved obliquely along them or down over them, maximizing the scale of glacial plucking. The scars south of Moughton and Sulber (Figure 2.14) are vertical cliffs, while the Raven Scars along the south side of Chapel-le-Dale form a series of terraces each capped by a stronger bed of limestone. There are few scars along the western side of Ribblesdale, where the ice was moving obliquely up the limestone slope onto the Sulber plateau.

Interpretation

The summit of Ingleborough has been regarded as a remnant of one of a series of old erosion surfaces (Trotter, 1929; Hudson, 1933; King, 1969). The regional drainage pattern was probably initiated on the earliest of these, with rivers originally flowing east, before tectonic warping diverted some of the drainage south. Subsequent denudation was ascribed to four phases by Sweeting (1950); the first was the formation of the 400 m surface, during which the limestone suffered a widespread planation, and this was followed by the 'First Rejuvenation Stage', causing dissection of the 400 m surface, during which underground drainage was initiated; the subsequent 'Dales Stage' was one of relative stability, where the major rivers were able to grade to their base level, after which there was another rejuvenation, forming the master caves of the area. Modern interpretations suggest that large parts of the 400 m surface are stratimorphs, developed on the top of the resistant limestone, and the cave levels ascribed to the successive stages may be a feature of the distribution of inception horizons on shale beds unevenly distributed through the limestone (Waltham, 1970). Though fragments of erosion surfaces can be recognized cutting across the limestone bedding, geological influences on the karstic landforms above and below are strong and tend to mask the effects of past erosion levels. Attempted reconstructions of palaeosurfaces of the late Tertiary and early Quaternary (King, 1969; Clayton, 1981) have little bearing on the modern karst features for which Ingleborough is renowned, other than to outline the broadest geomorphic patterns.

The earliest palaeogeography of Ingleborough for which a tentative reconstruction has been proposed is one with an age of 500 ka, just prior to the Anglian glaciation (Waltham, 1990). The interpreted position of the former shale margin is based on the presence of old cave passages older than 350 ka in Gaping Gill and Newby Moss Cave, and the sites of the major old sinkholes of Alum Pot, Gaping Gill, Braithwaite Wife Hole and Great Douk Cave. The lack of old caves in the Ribblehead area suggests that the limestone was not exposed there in pre-Anglian times.

Stalagmites from White Scar Cave were formed after passages at successive levels were drained in response to the deepening of Chapel-le-Dale, and include material older than 350 ka from the upper levels (Atkinson *et al.,* 1978; Gascoyne *et al.,* 1983a, b; Gascoyne and Ford, 1984); these indicate a maximum mean rate of incision of 0.2 m/ka over this period. Reconstruction of pre-Anglian valley floor profiles for Chapel-le-Dale, based on the stalagmite dates, suggests that 80–100 m of surface lowering has taken place over the last 400–500 ka, both in the glacial trough and around Ribblehead (Waltham, 1986, 1990). Whether the major surface lowering was by fluvial or glacial processes, in their respective climatic stages, is open to debate. The minimal retreat of the shale margin on the steep slopes of Newby Moss (Waltham, 1990) reflects overall low rates of fluvial surface lowering, and also local protection from glacial excavation in the lee of Ingleborough; the implication is that ice erosion accounted for much of the surface lowering over the larger part of the area, which lacked the protection.

Over the last 500 ka, Ingleborough has been subjected to two or three major glaciations, two long interglacial periods of fluvial environments, and several intervening periglacial phases. In each glacial maximum, ice covered the entire area, perhaps reaching thicknesses of 300 m over Ingleborough, and modified the older surface profiles. Few except the largest surface landforms remain from pre-Devensian times, and many of the modern surface features can be attributed to advance and retreat of the Devensian ice.

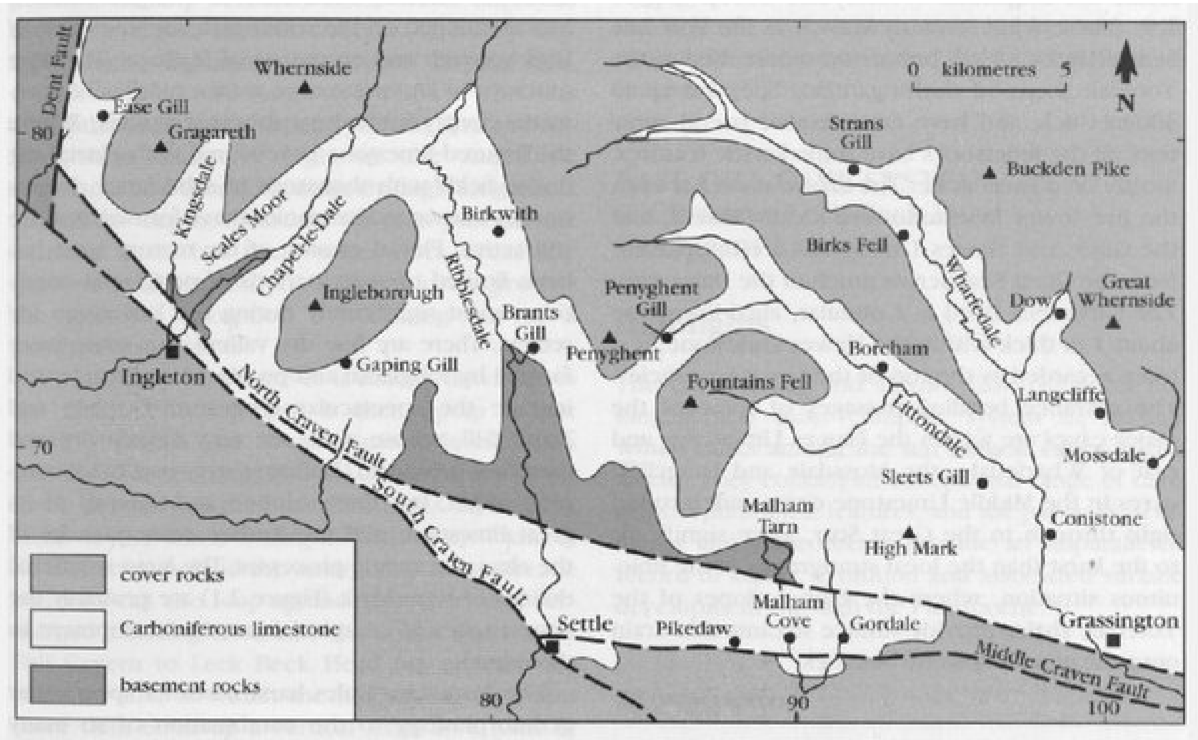
The dry valleys of Ingleborough are essentially the product of meltwater erosion, and probably all date largely to periglacial environments during the retreat phase of the Devensian ice. Crina Bottom may have been a marginal channel carrying snowmelt water off Ingleborough beside the Chapel-le-Dale glacier. The smaller features were probably only active for a short period, carrying surface drainage over the exposed frozen limestone until underground capture caused their abandonment as the climate ameliorated. Trow Gill may have a more complex history. The narrow profile of its gorge section has led to speculation that it may be a collapsed cavern (Waltham, 1970). This concept is now not accepted, as there is no positive evidence of col lapse, and remnants of stream moulins are visible high on the walls of the narrowest section (Figure 2.15); the gorge is merely the steepest, and therefore most entrenched, section of a fluvially excavated subaerial valley (Waltham, 1990). It was cut when the ground was frozen and impermeable, and lost its stream when karstic drainage was re-established. There is scope for debate as to whether the dry valleys and gorges were carved by subglacial or proglacial meltwater (Pitty *et al.,* 1986). Trow Gill is fed by no channel of significant size from the higher slopes of Ingleborough; its source could have been the snout of an ice lobe from the north-east ending on the limestone bench, or could have been crevasses and glacier moulins in a subglacial situation.

Since the Devensian ice retreated, karstic processes have become dominant once more, largely superimposing texture onto the inherited glacial landscape. Underground drainage has been re-established, enlarging the modern stream caves. The limestone pavements have matured on the stronger beds exposed in the bare rock surfaces left by the glacial retreat. Tectonic fractures were widened by solution of their walls to form the grikes around the clints, and karren runnels drained into them. The rounded form of the rund-karren suggest that much of their development took place beneath a permeable, organic soil cover; this may have been of the type now present in Colt Park, or like that now expanding on Scar Close. Most of the original plant cover was then lost due to artificial clearance of the protecting trees, and sheep grazing has precluded regrowth of anything except grass. The lack of rillenkarren may be due largely to the ubiquitous lichen cover which acts as a substitute for a soil cover in facilitating solution over the ridges between the runnels. The preserved ice striae near Long Kin East Cave demonstrate that there has been almost no limestone solution beneath the impermeable mineral soils of glacial till.

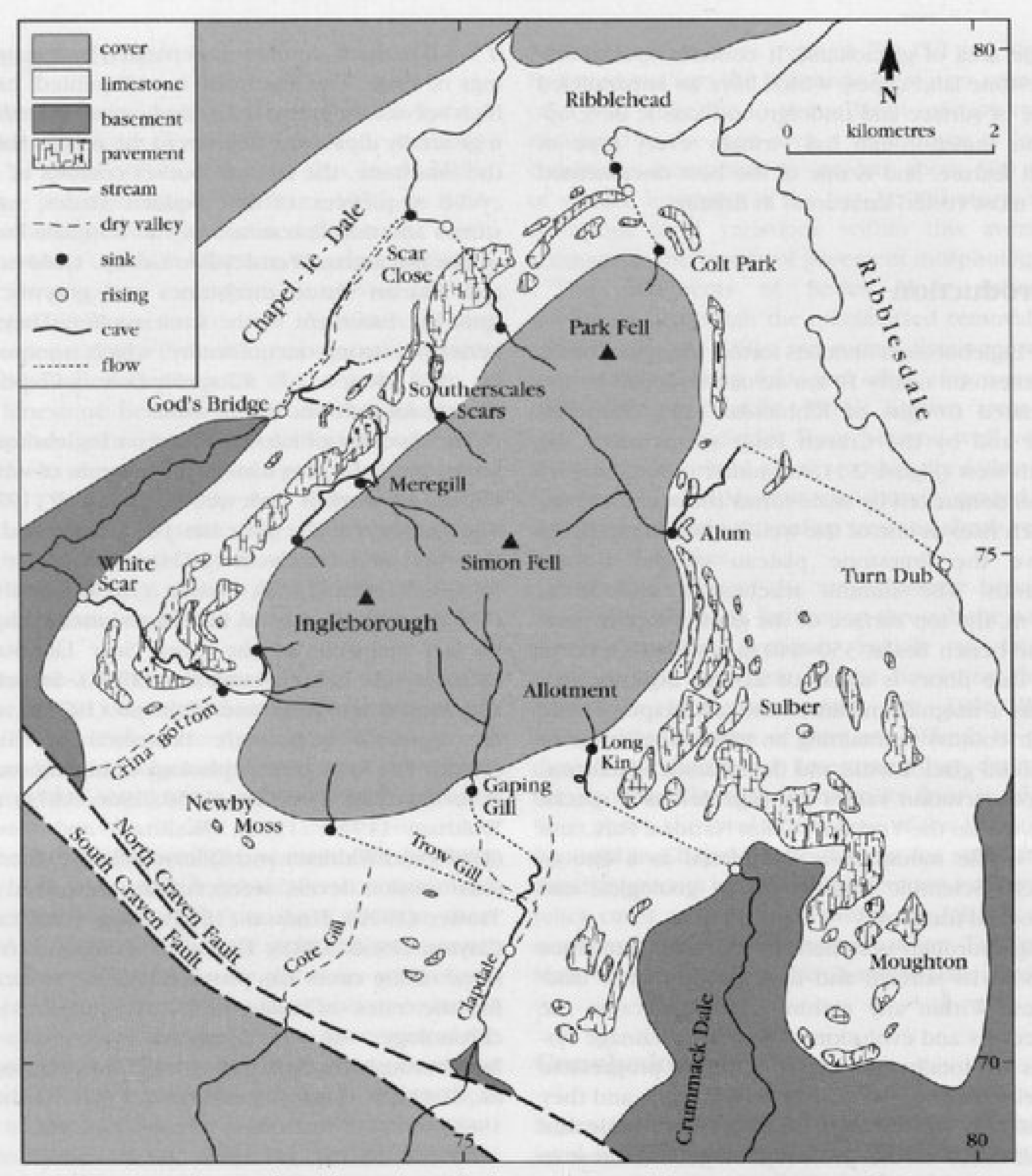
Conclusions

The glaciokarst of Ingleborough constitutes some of Britain's finest limestone landscape. It is of international reputation and importance, and is probably the most used karst teaching example in the country. The dry gorge of Trow Gill, the dry valley of Crina Bottom, the sinkhole of Gaping Gill, the open shaft of Alum Pot, and the perched erratics of Norber are just some of the widely known landforms which are classics of their types. Where the limestone is veneered with glacial till, around 3000 subsidence dolines have formed, and the bare limestone outcrops have nearly 400 ha of spectacular limestone pavements. These include the massive clints of Southerscales Scars and Thieves Moss, and. also the protected area of Scar Close with its new plant colonization. The limestone plateaus scoured by ice, the adjacent glaciated troughs and the potholes around the retreating shale margin combine to provide a record of glacial erosion through the late Pleistocene.

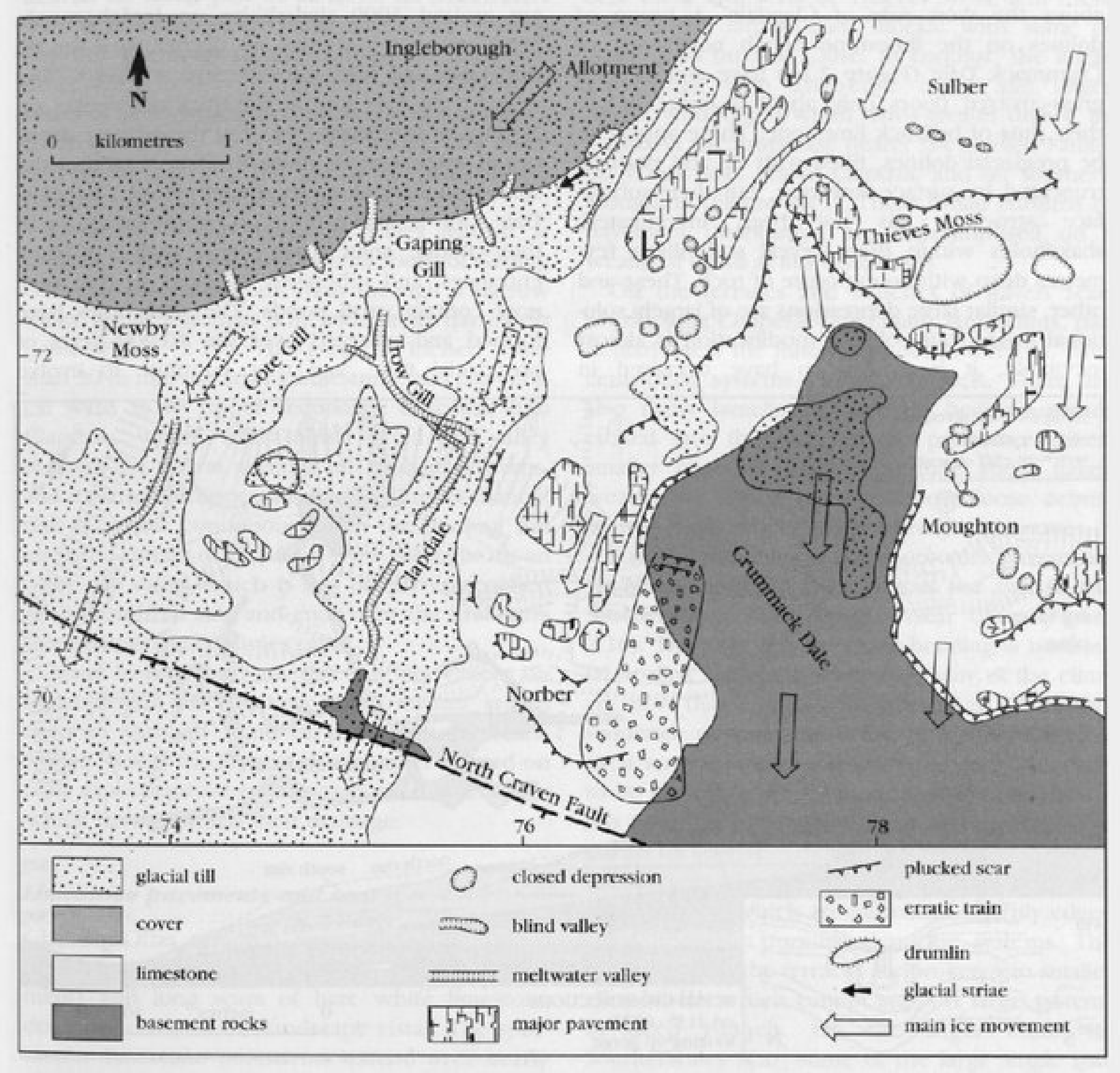
References



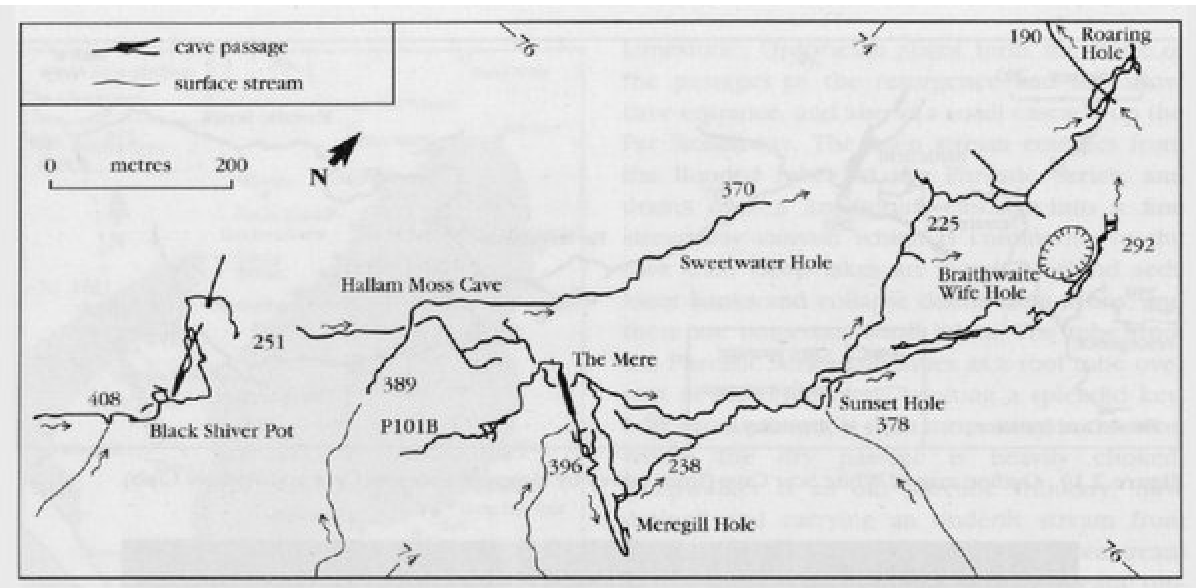
(Figure 2.1) Outline map of the Yorkshire Dales karst, with locations referred to in the text. The Carboniferous limestone shown includes all the Great Scar Limestone (Kilnsey, Cove and Gordale Formations) and also the lower Yoredale limestones (of the Wensleydale Group) where they are hydrologically linked to the Great Scar and are therefore part of the same karst unit. Higher limestones within the Yoredale Series are not marked. Basement rocks are Palaeozoic slates and greywackes. Cover rocks are the Yoredale facies of the middle and late Brigantian Wensleydale Formation and various Upper Carboniferous and Permian clastic formations.



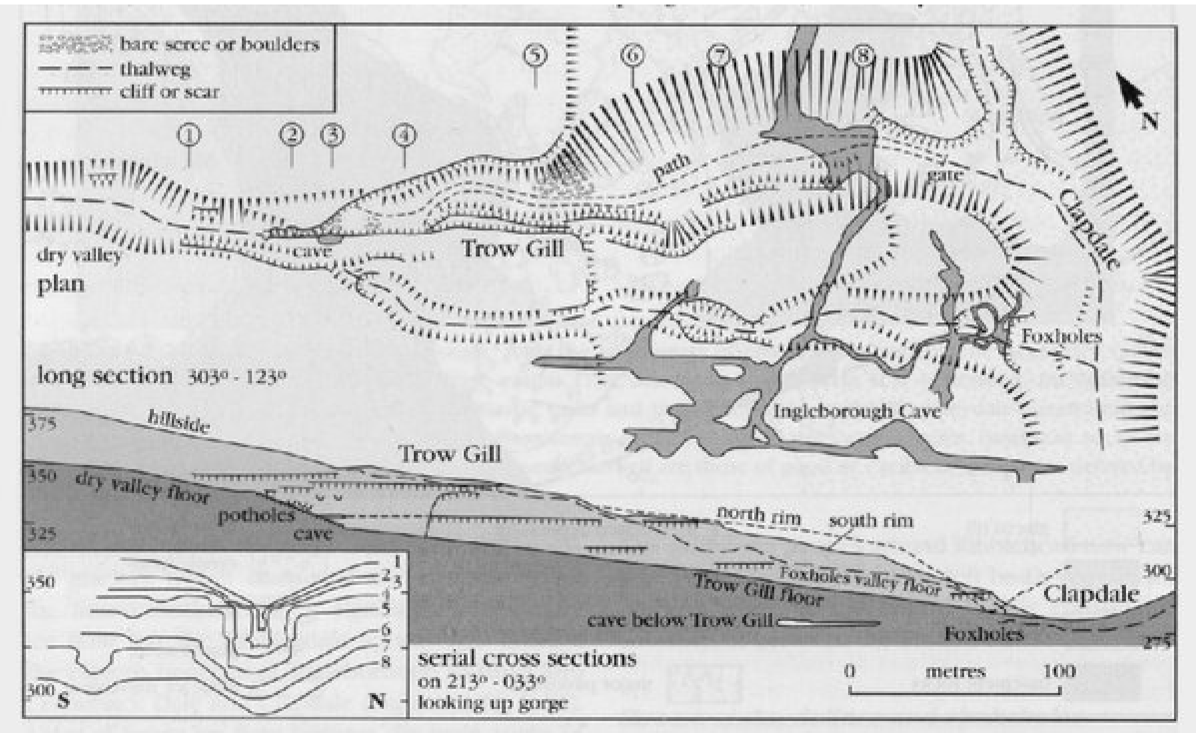
(Figure 2.13) Geological map of Ingleborough, with the main areas of limestone pavement, the larger dry valleys and some of the main underground drainage routes. The limestone is the Great Scar Limestone, including the Hawes Limestone. Cover rocks are various clastic units and thin limestones in the Wensleydale Group and the Namurian Millstone Grit Group, and Upper Carboniferous clastics south of the Craven Faults. Basement rocks are Palaeozoic slates and greywackes. The only pavements marked are those of good or excellent quality (as defined by Waltham and Tillotson, 1989).



(Figure 2.14) Geomorphological map of the southern sector of Ingleborough. The main pavements in the eastern half of the map area were scoured by ice moving down Ribblesdale, while the limestone in the western half is extensively veneered by glacial till deposited in the lee of the Ingleborough summit mass (from Waltham, 1990).

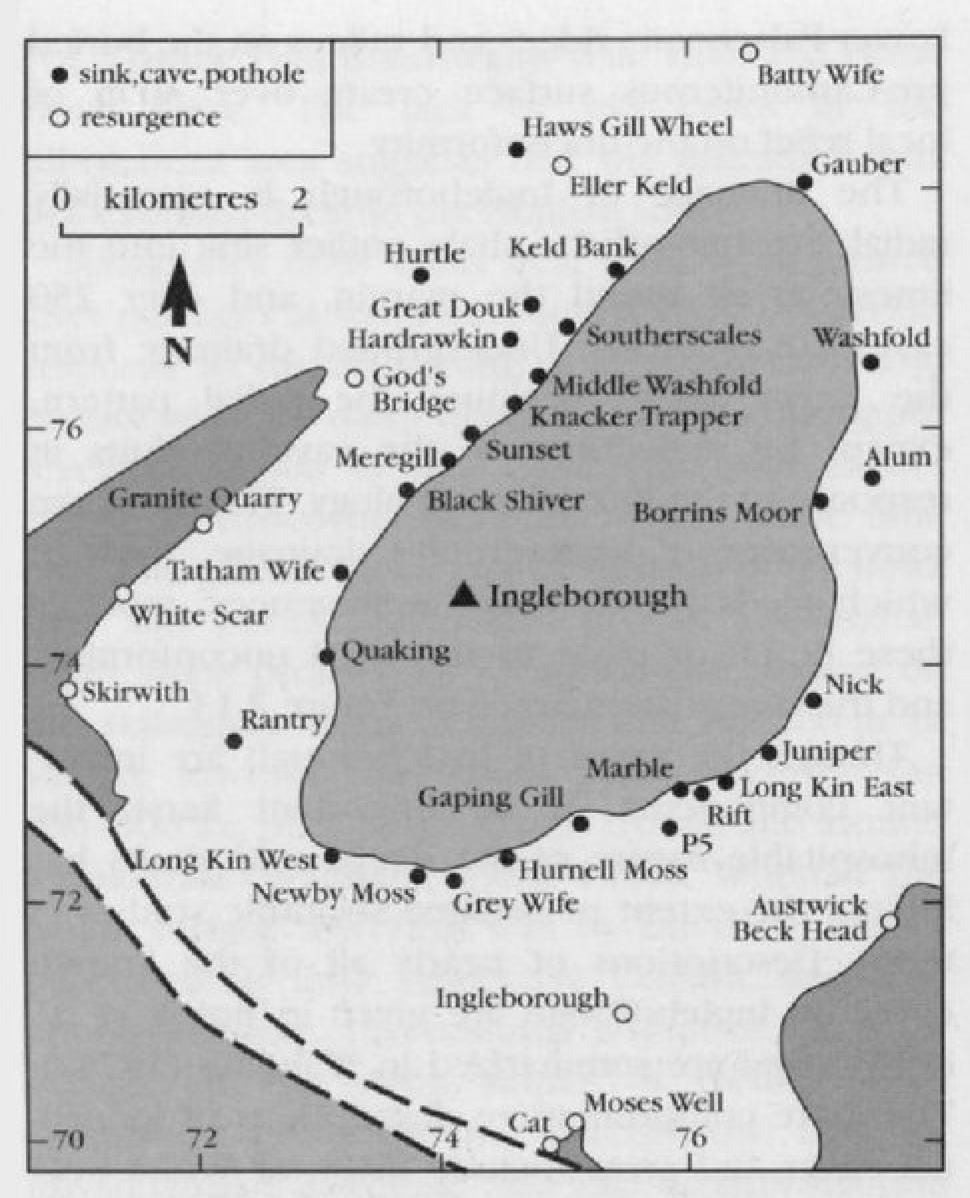


(Figure 2.21) Outline map of the cave systems of Meregill Hole; the flooded passage downstream of Roaring Hole is known to continue for another 300 m. Numbers given refer to elevation in metres (from surveys by University of Leeds Speleological Association).

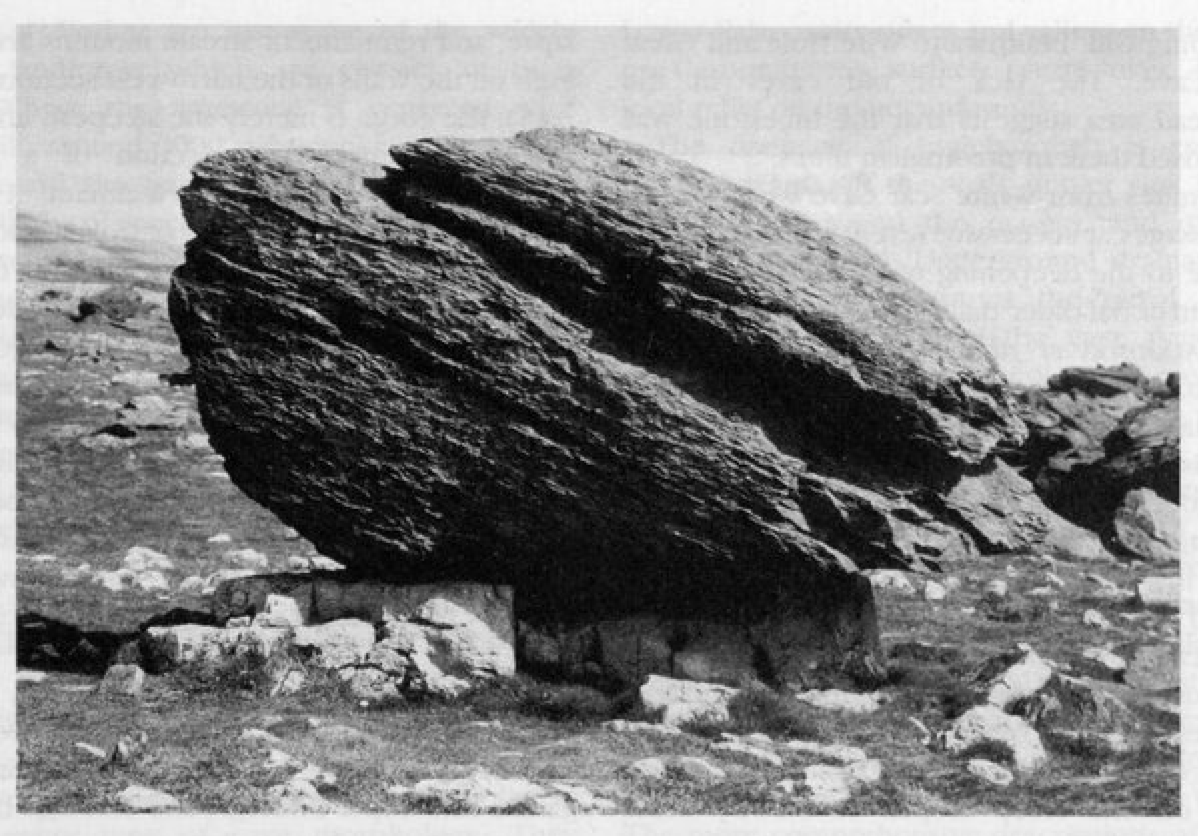


(Figure 2.15) Topographic map and projected long profiles of Trow Gill and the underlying caves. Some cave passages have been omitted to improve clarity, and all the caves lie below the level reached on the serial cross-sections; the thalweg down Trow Gill lies along the centreline of the path (from Waltham, 1990).

(Figure 2.16) The limestone pavements of Southerscales Scars, on the north-western bench of Ingleborough. (Photo: A.C. Waltham.)



(Figure 2.18) Outline map of Ingleborough, with locations of the main caves referred to in the text. Geology as in Figure 2.13.



(Figure 2.17) Glacial erratic of Silurian greywacke on the Norber bench of southern Ingleborough. The erratic is 2 m across and stands on a plinth of limestone which has been protected from solution by direct rainfall. (Photo: A.C. Waltham.)