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New uranium-series dates from Keld Head, Kingsdale, North Yorkshire, UK.

Phil MURPHY [1], John CORDINGLEY [2] and **Tony WALTHAM [3]**
[1] School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK.
e-mail: P.J.Murphy@leeds.ac.uk
[2] Ingleborough Cave, Clapham, Lancaster, LA2 8EE, UK.
e-mail: jncordingley@aol.com
[3] 11 Selby Road, Nottingham, NG2 7BP, UK.
e-mail: tony@geophotos.co.uk

Abstract: Dated stalagmite flowstone from the underwater passages in Keld Head indicates that the cave was partially drained about 89,000 years ago. This implies that the cave was draining into a Kingsdale valley that had a lower floor profile prior to deposition of the Raven Ray moraine and subsequent alluviation of the main valley floor.

Key words: Kingsdale, stalagmite, uranium-series dates, glaciation, alluviation

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KELD HEAD

The large spring of Keld Head in Kingsdale has been a magnet for cave divers from the earliest days (Fig.1) and was the site of pioneering cave dives by Graham Balcombe in 1945 (Farr, 1991; Balcombe, 2007). To date, about 8km of submerged passage have been mapped, making it the longest flooded cave system yet explored in Britain. The majority of the passages are at depths of 9m or shallower, relative to the water surface at the Keld Head resurgence pool, but the deepest reaches to just over 30m in depth. The flooded cave is the downstream portion of the multiphase West Kingsdale System, which drains benchlands above both flanks of Kingsdale (Brook, 1974). The bulk of the emergent water derives from both the east and west sides of Kingsdale, with additional input from the Marble Steps area further to the west. A description of the site intended for visiting divers is given in Monico (1995). Combined with the descending vadose passages through from Swinsto Hole, just one of its influent cave systems, Keld Head has been proposed as the type example of cave development in the Yorkshire Dales (Waltham *et al*., 1981). The Kingsdale valley floor is a glaciated trough with a low long gradient and a relatively shallow aggradation of alluvial and other deposits. The retreat moraine ridge of Raven Ray lies across the mouth of the dale, downstream and south of the entrance to Keld Head.

THE UNDERWATER SPELEOTHEMS

The presence of calcite speleothem deposits now under water in the Keld Head cave passages has been recorded by various divers exploring the system (Yeadon, 1978; Hryndyj, 1978; Cordingley, 2000). These recorded speleothems fall into two groups (Fig.2). Those in the entrance area (in the First Airbell and the adjacent High Road) lie at depths of 20–30cm below the water level at present minimum discharge; they are adjacent to stalactites that are above the normal water level within the airbells (Fig.3). Only one date has previously been published for this material and that was from a stalactite in the entrance area 18cm below the present water level (Murphy *et al*., 2004). A date of 2489 ±31 years BP was interpreted as suggesting that the present water level might have been raised artificially as a result of human activity in the valley. A further sample, KH2, was obtained on this project; this was obtained from calcite wall deposits 11cm below water level in the First Airbell of the entrance complex (Fig.2).

The second group of speleothems extends to 4.5m below water level on the west wall of a side passage at 517m from the Keld Head resurgence along the Marble Steps Branch of the cave (Fig.2). During diving exploration in February 2008 two samples (MS1 & MS2) from this site were recovered from a depth of 4.0m (Cordingley, 2008). This material takes the form of a calcite flowstone forming a thin veneer with a mean estimated thickness of 20mm down the cave wall. The location is off the main flow of the cave, above deep deposits of silt that are easily disturbed causing visibility to deteriorate rapidly. The precise location of the sampling point had been carefully identified on a previous dive, allowing collection to be made quickly and efficiently before visibility was reduced to zero. The samples were sent for uranium-series disequilibrium dating by thermal ionisation mass spectrometry at Bristol University, along with the KH2 sample. They were dated using standard protocols (Hoffman *et al*., 2007) and the results are shown in Table 1.

CHRONOLOGY OF THE CAVES

The date of 4500 years BP for the sample KH2, taken from shallow depth in the First Airbell, confirms that the water level was significantly lower in the Holocene than it is at present. Though its date is older than the 2489 years BP recorded for the previously gathered material (Murphy *et al*., 2004), the two dated samples suggest that Keld Head drained at a slightly lower level in post-glacial times before the level of Kingsdale Beck was raised either by intended artificial works, by natural aggradation, or by sedimentation consequent on other modifications to the river hydrology.

The dates of 87.8 and 89.4 ka BP for the two samples, MS1 and MS2, collected from greater depth upstream in the Marble Steps Branch, appear to fall into Marine Isotope Stage 5c. This was a time

Figure 1. *Keld Head, with the rock wall across its back above the entrances to the flooded caves.*

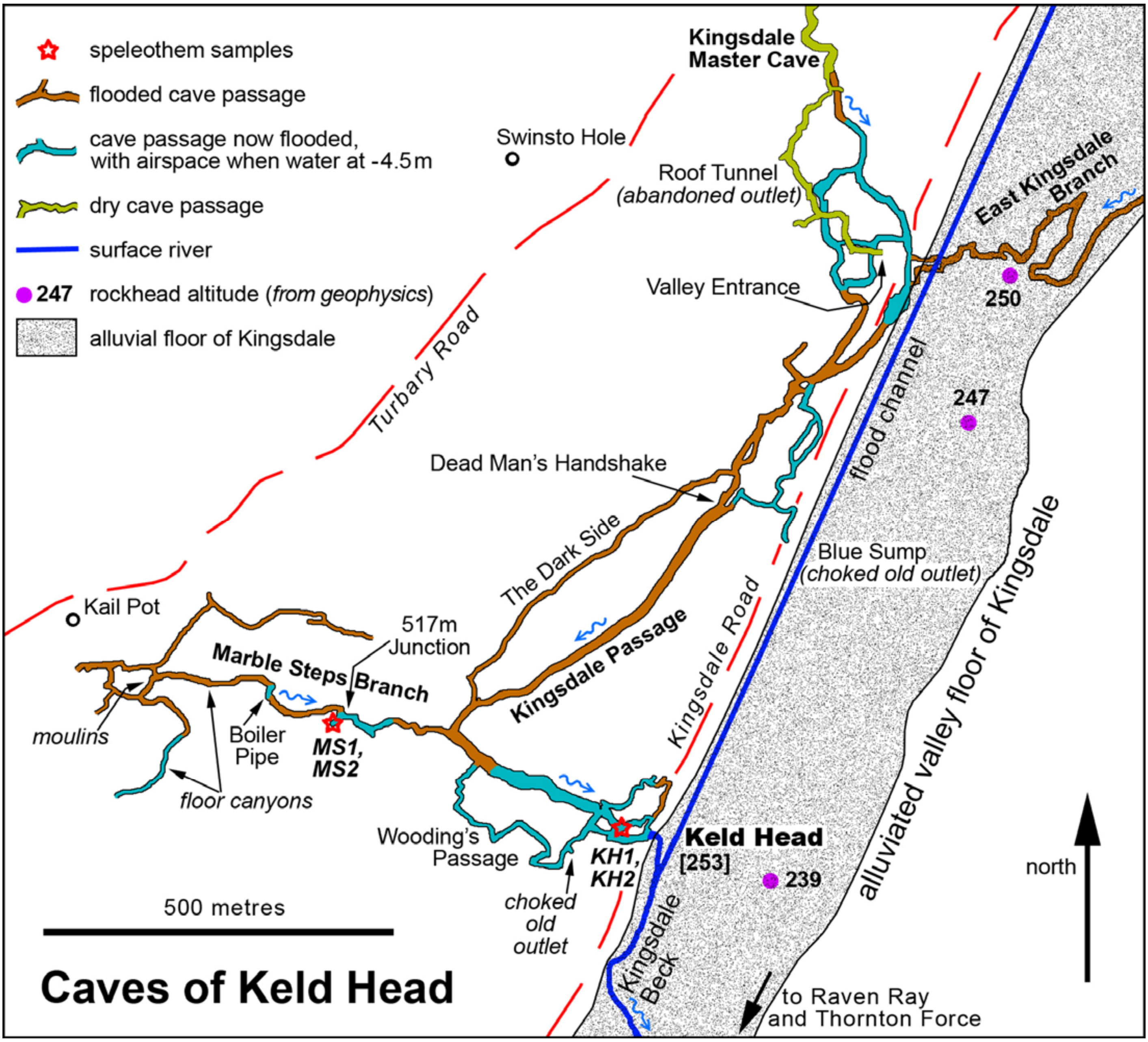

Figure 2. *Outline map of Keld Head and just some of its underwater passages adjacent to the floor of Kingsdale (this version is a compilation of new survey data gathered by John Cordingley and Rupert Skorupka, and plotted by Ray Duffy, combined with older data from various surveys by members of the CDG).*

of slightly increased temperatures within a period of modest climatic fluctuations after the end of the main Ipswichian interglacial (Stage 5e) but well before the main advance of the Devensian ice. These speleothems in the flooded passage are broadly coeval with a number of stalagmite samples dated by Gascoyne *et al*. (1983, 1984) and Atkinson *et al*. (1978), which together indicate a time of widespread calcite deposition within the Yorkshire Dales caves.

The important feature of these speleothems from the Marble Steps Branch is their confirmation of a water level within the Keld Head caves prior to the onset of the Devensian glaciation that was significantly lower than it is today. With a water level at 4.5m below the present level, well over 1200m of the known flooded cave passage would have had air space; the resurgence entrance would have led after 100m into a spectacularly long, and perhaps rather gloomy, lake, while farther in the passages would have alternated between lakes, sumps and sections of free flowing streamway (Fig.2). It appears that the water level could never have been any lower in these passages, as it has always had to flow over a rock lip where the cave floor rises to −4.5m just inside Keld Head. This relies on the very reasonable assumption that there is no other lower outlet buried by sediments in the lower slopes of Kingsdale; none has been found by divers within the flooded cave.

This drained level within Keld Head would have been active throughout the Ipswichian interglacial and the minor interstadials prior to the Devensian ice occupying Kingsdale. There are several long sections of the underwater passages with floors at or close to the 4.5m depth, which might have been graded to a local water table at that level. At nearly 725m up the Marble Steps Branch, beyond

Sample code	Age (KaBP)	U conc (ppm)	Th conc (ppm)	$^{230}Th/^{238}U$	$^{234}U/^{238}U$	$^{230}Th/^{232}Th$	Initial $^{234}U/^{236}U$
KH2	**4.5 ±0.9**	134.5	9.14	0.061 ±0.001	1.073 ±0.003	2.73 ±0.03	1.075 ±0.003
MS1	**87.8 ±11.8**	340.0	344.6	0.771 ±0.003	1.162 ±0.002	2.33 ±0.01	1.282 ±0.004
MS2	**89.4 ±1.0**	311.2	27.26	0.678 ±0.003	1.175 ±0.002	23.66 ±0.07	1.230 ±0.004

Table 1. *Stalagmite samples from Keld Head, with analytical data and interpreted ages. A correction for detrital thorium of 232Th/238U = 1.25±0.625 has been adopted. All errors are 2σ.*

the stalagmite location, the Boiler Pipe is a keyhole passage only negotiable by divers in its upper tube section. The floor of the narrow canyon section below lies at an estimated depth of about 4m, so this could be a short section of interglacial vadose canyon immediately above the contemporary water level. The same applies to at least the shallower parts of the flooded canyon in the long southern inlet to the Marble Steps Branch (Fig.2).

There are sections of canyon observed at depths as great as 8m elsewhere within the flooded passages of Keld Head. These might well be features developed by corrosion, where bedload of clastic sediment is carried through the phreatic passages and therefore only mimic their vadose counterparts. Evidence of this corrasion comes from moulins (rock mills) that puncture the flooded passage floors where pebbles are swirled around by turbulent flow. Particularly fine examples of these have been seen in the downstream sump of Speedwell Cavern in Derbyshire and there are similar features in the further reaches of the Marble Steps Branch of Keld Head. Canyons and moulins between the Boiler Pipe and the inner junction area (Fig.2) lie behind and deeper than the rock lip near the entrance of Keld Head, so they do not appear to be true vadose features.

GEOMORPHOLOGY OF THE VALLEY

The current water level in Keld Head is maintained by sediments on the floor of Kingsdale that post-date the growth of the underwater speleothems at about 89 ka. The Raven Ray ridge is a barrier of glacial till across the mouth of Kingsdale, and is clearly a very fine retreat moraine created during an interruption to the wasting of the Kingsdale glacier at the end of the Devensian glaciation (Fig.4). When first deposited, it created a barrier to meltwater that was still emerging from the glacier and a lake was formed behind it. The moraine dam was subsequently overtopped towards its eastern end when a post-glacial trench was cut through to rejoin the main valley at Thornton Force and thereby drain the lake (Waltham, 2008). Lacustrine sediments had already accumulated behind the moraine, and these form the small area of flat valley floor between Raven Ray and Keld Head. Upstream of this flat section, the Kingsdale floor has a very distinct low gradient on the strictly alluvial sediments that were deposited first as glacial outwash from the waning glacier and then by post-glacial streams.

Unpublished seismic refraction surveys in the fields in front of Keld Head (in 1971 by N G Fox, a student at Lancaster University, and in 1982 by geologists from Trent Polytechnic) both indicated depths of about 15m to rockhead, though these profiles could have missed a slightly deeper centreline of the valley. The surveys showed some steady increase in seismic velocity with depth, as might be expected from burial consolidation, but there was no recognisable boundary to any layer of till between the alluvial sediments and bedrock. The rock floor (rockhead) beneath the sediments of Kingsdale appears to slope gently downstream from an altitude of about 239m at Keld Head, to about 210m where it is exposed immediately downstream of Thornton Force; there the glacial fill within the buried valley reaches down to stream level about 70m west of the waterfall (Waltham, 2008). Between these points the buried valley has its floor at an altitude of about 225m beneath Raven Ray, as indicated by resistivity (Bruckshaw, 1948) and

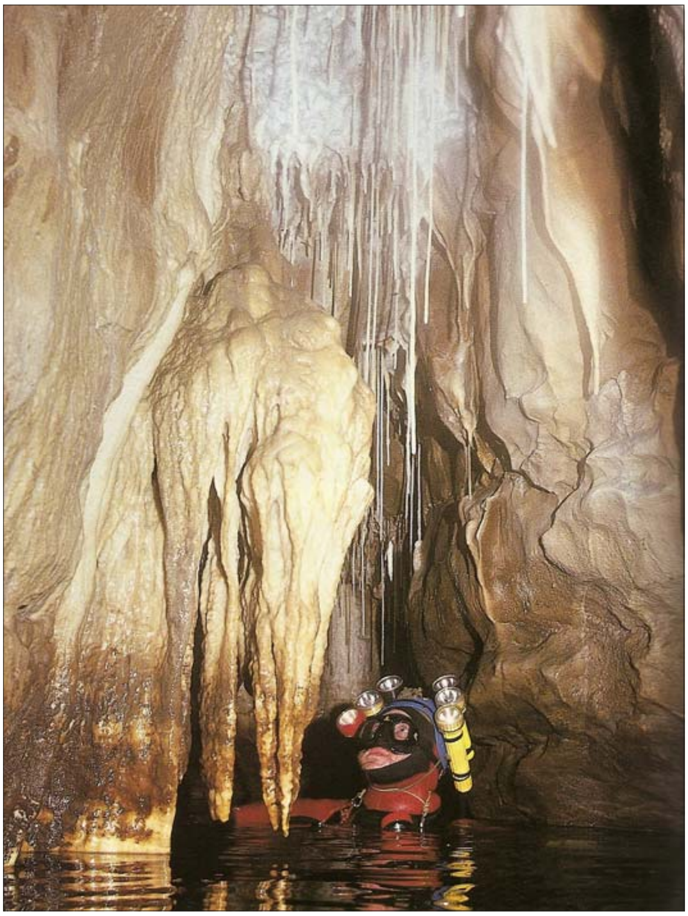

__Figure 3.__ Stalactites in the airbell not far inside the Keld Head cave; the speleothems sampled as KH1 and KH2 lie out of sight beneath the water level (photo: Russell Carter).

__Figure 4.__ Looking downstream at the lower end of Kingsdale, with the Raven Ray terminal moraine across the skyline; Keld Head is recessed into the grassy moraine bank between the two groups of sheep, and is ponded by the alluvial sediments that extend to Raven Ray; water entering on the left is flood flow in the surface channel that runs the length of Kingsdale.

seismic (Wilson, 1980) surveys. The floor of the limestone, resting unconformably on basement rocks, dips gently northwards from an altitude of about 220m where it is exposed at Thornton Force. By inference from the structure of the exposed limestone, the base is probably at about 212m at Keld Head, and close to 205m beneath Braida Garth. It would appear that the flooded passages of the East Kingsdale Branch cross beneath the valley with at least 10m of solid rock above the cave roof and around 18m of limestone between their lowest point and the basal unconformity; divers in Keld Head have found neither any outcrop of the basement rock (as in White Scar Cave) nor any pebbles of the same material (as in Dale Barn Cave).

It therefore appears that prior to the Devensian glaciation the water from Keld Head cascaded to a valley floor perhaps 10m below the level of the cave mouth. The passages inside Keld Head, from both the Kingsdale Master Cave and from King Pot, are almost entirely phreatic, and yet are perched above both the main valley floor and the base of the limestone. This implies that they were developed at an earlier stage when the valley floor was even higher, prior to either the Wolstonian or the Anglian glaciations. The passage was then truncated by the glaciers at the position of Keld Head, but most of the passages remained flooded because they were still below the level of their truncated outlet. The subsequent Devensian glaciation did not lower the outlet, but raised the water level slightly by ponding behind the new valley floor sediments. A later and additional small rise in the valley floor level is indicated by the Holocene deposition of the stalactites of sample KH2 that also now lie underwater.

The Keld Head resurgence is only one of a number of passages under West Kingsdale that were truncated by deepening and/or widening of the main glacial trough (Fig.2). Down-valley, a relict outlet off from Wooding's Passage reaches to a choke close to water level and just below the hillside (Cordingley, 1999). Up-valley, the Blue Sump is a large distributary passage that might once have carried the main flow and now ends at a choke where it rises almost to water level and very close to a shakehole just below the road between Keld Head and the Braida Garth junction (Cordingley, 1998). This appears to pre-date both the passages that now continue down the valley, and is the truncated remnant of the route to an older resurgence in the valley floor, intermediate in age between the Roof Tunnel and the present flow routes to Keld Head.

The major predecessor to Keld Head's flooded passages now forms the Roof Tunnel out of the Kingsdale Master Cave. This too was truncated by Pleistocene glaciers, but was left dry when the drainage took the lower route to Keld Head (Brook, 1969, 1974). Stalagmites and flowstone from Roof Tunnel have produced dates both around 200 ka and more than 300 ka (Gascoyne *et al*., 1983, 1984; Atkinson *et al*., 1978). The older dates have elements of uncertainty because they have considerable error margins at close to the limits of the uranium-series method. The fact that the Keld Head passages are now shown to be at least 89,000 years old, and probably pre-date the Ipswichian, implies that the greater ages for the Roof Tunnel stalagmites might be reasonably reliable. As more becomes known about the chronology of the Yorkshire Dales caves, their evolution and development appears to be reaching ever farther back into time.

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