The sediments of Illusion Pot, Kingsdale, UK: Evidence for sub-glacial utilisation of a karst conduit in the Yorkshire Dales?

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Abstract: Analysis of the sedimentary fill preserved within the Illusion Pot section of the Dale Barn Cave system indicates that the sediments were derived from the Chapel-le-Dale end of the cave. The sedimentary sequence exposed in the conduit is very similar to those described from sub-glacial eskers, and a possible hydrological connection with the sub-glacial drainage system of the Chapel-le-Dale glacier is proposed. Scalloping superimposed upon speleothems in relict conduits within the system confirms that a second phreatic episode occurred during the cave's development. Speleothem uranium series dates constrain the second phreatic episode to post-date 343,400 BP (+86.0/-47.7ka).

INTRODUCTION

Dale Barn Cave is a remarkable linear cave system orientated approximately southeast-northwest below Scales Moor, passing beneath the southwesterly nose of Whernside from Chapel-le-Dale to Kingsdale (Figs 1 and 2). An account of karst features of the area and of the cave's setting is given by Waltham *et al.* (1997). The cave was explored from Chapel-le-Dale (Crossland, 1975a, 1975b). However, due to the arduous nature of the caving required to reach the far end of the system a new entrance (Illusion Pot) was engineered on the southern side of Kingsdale. As well as facilitating further exploration in the cave, the opening of the new entrance has enabled the study of relatively undisturbed sediments in otherwise highly remote cave passages.

Currently, active cave passages carry streamways from both the Chapel-le-Dale and Kingsdale ends of the cave to a confluence almost directly beneath the topographic divide, before draining to the resurgence of Dry Gill Cave in Chapel-le-Dale. Above the active levels lie a series of abandoned passages. Sediments contained in the northwestern end of the relict high level passages (named Vandals Passage by the original explorers but referred to as the Expressway by Brook *et al.*, 1994) are the main topic of this paper.

Vandals Passage is oriented southeast-northwest and is up to 15m in diameter (Fig.3). It is aligned along a minor sub-vertical fault showing calcite mineralisation, and it terminates to the northwest in a calcite
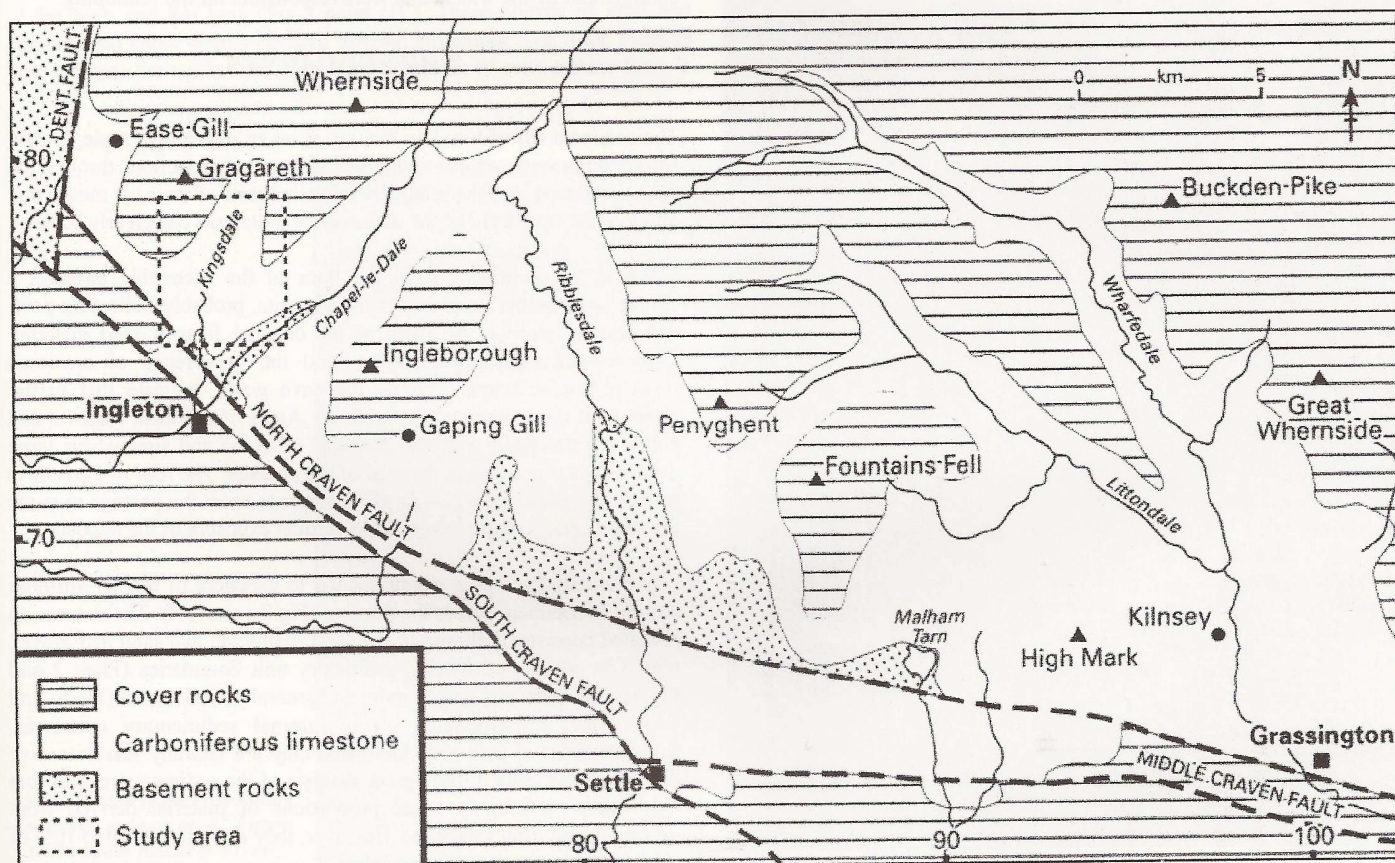

Figure 1. Map of the Yorkshire Dales Karst showing the location of the study area. Reproduced from Waltham et al. 1997 with permission.
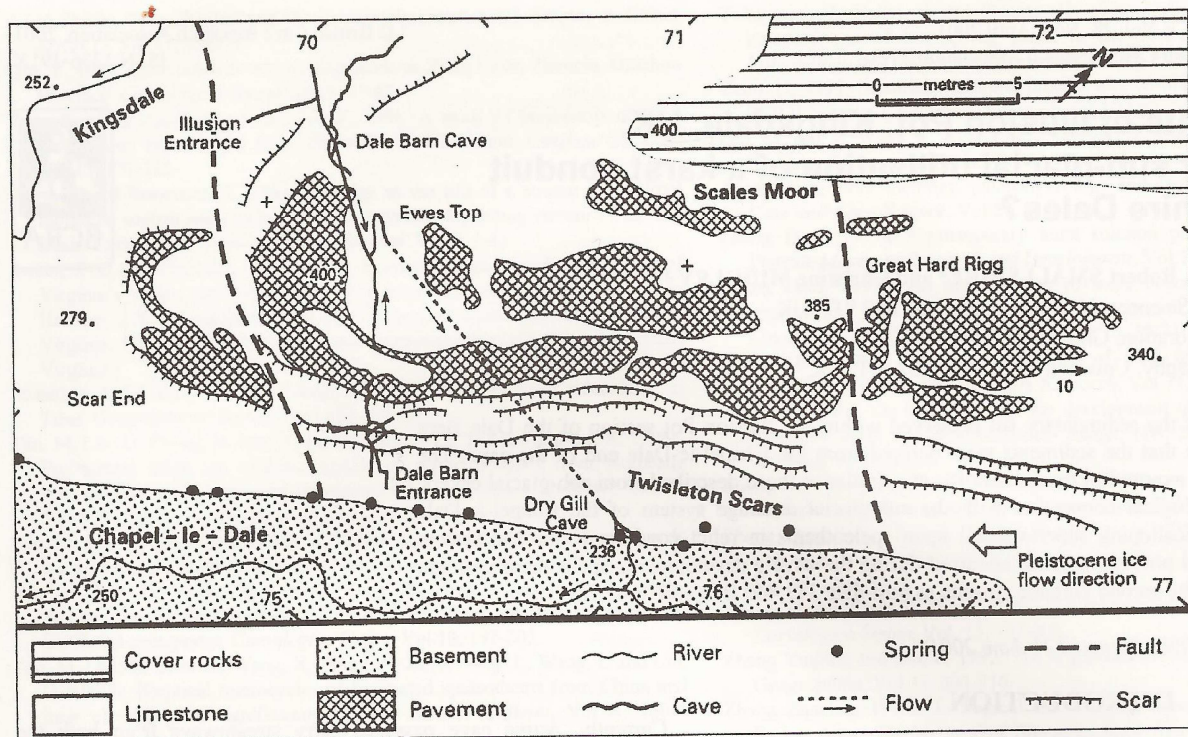
Figure 2. Geological map of Scales Moor. Reproduced from Waltham et al. 1997 with permission.

Legend:
- Cover rocks
- Limestone
- Basement
- Pavement
- River
- Cave
- Spring
- Flow
- Fault
- Scar

blockage beneath the southern flank of Kingsdale, where radio-location data indicate a depth of only 6m beneath the surface. To the southeast the passage terminates in the block collapse of Rushton Chamber. Relict high-level development can be followed across Rushton Chamber in a low crawl named Perfidia, which is believed to be in the top of the almost totally filled 15m-diameter passage. These relict high-level passages have counterpart relict levels in the Dale Barn Cave end of the system in Chapel-le-Dale. The Illusion Pot entrance enters Vandals Passage from the southeast by a more modest 2 to 3m-diameter passage.

Plate 1. Scalloped speleothem on the upper southwest wall of Vandals Passage

SCALLOPED SPELEOTHEMS

Large speleothems with superimposed phreatic scalloping (signifying a northwesterly flow direction) occur in the roof of Vandals Passage (Plate 1). This indicates that the initially water-filled high-level passages in the Dale Barn Cave were drained, allowing the growth of extensive speleothem deposits prior to resumption of flooded conditions during the second phreatic episode in the cave's history. It appears clear that the overall dimensions of the conduit suffered relatively little enlargement by the waters that were responsible for the scalloping.

THE SEDIMENTS

The sediment fill of Vandals Passage is on an impressive scale, locally filling the passage almost to the roof. A number of sections through the fill are exposed, and the relatively unvisited state of the cave means that much of the fine detail of the undisturbed sediments can clearly be seen.

Where the sediments form the floor of the accessible passage, a cobble and boulder layer masks the deposits, probably indicating post-depositional removal of much of the original finer-grained material. Evidence of sediment slumping, and the occurrence of erosional remnants of sediment high on the cave walls, indicate that partial removal of the sediments has occurred. Areas of sediment removal and collapse correspond with the positions of avens and sites where large drips of water enter from the roof of the passage. The roof of Perfidia is remarkably uniform; no avens allow water to enter the passage to erode the sediments, so there is very little vertical exposure of the deposits.

In Vandals Passage a slump has led to exposure of a clear 4m-high section of sediment across the passage (Fig.3 point 'A'). The succession revealed consists of alternating units of diamicton and sand and gravel, with very sharp and locally undulatory unit boundaries (Plate 2 and Fig.4). The sand and gravel units are generally well-sorted (Fig.5) and show either cross-bedding or no internal sedimentary structures. Sporadic units of pale grey laminated clay are laterally less extensive than the other units. Lithological analysis of the sediments reveals that they comprise roughly equal proportions of material derived from limestone and from sandstone. However, they also contain up to 10% of chloritised slate and mudstone debris.
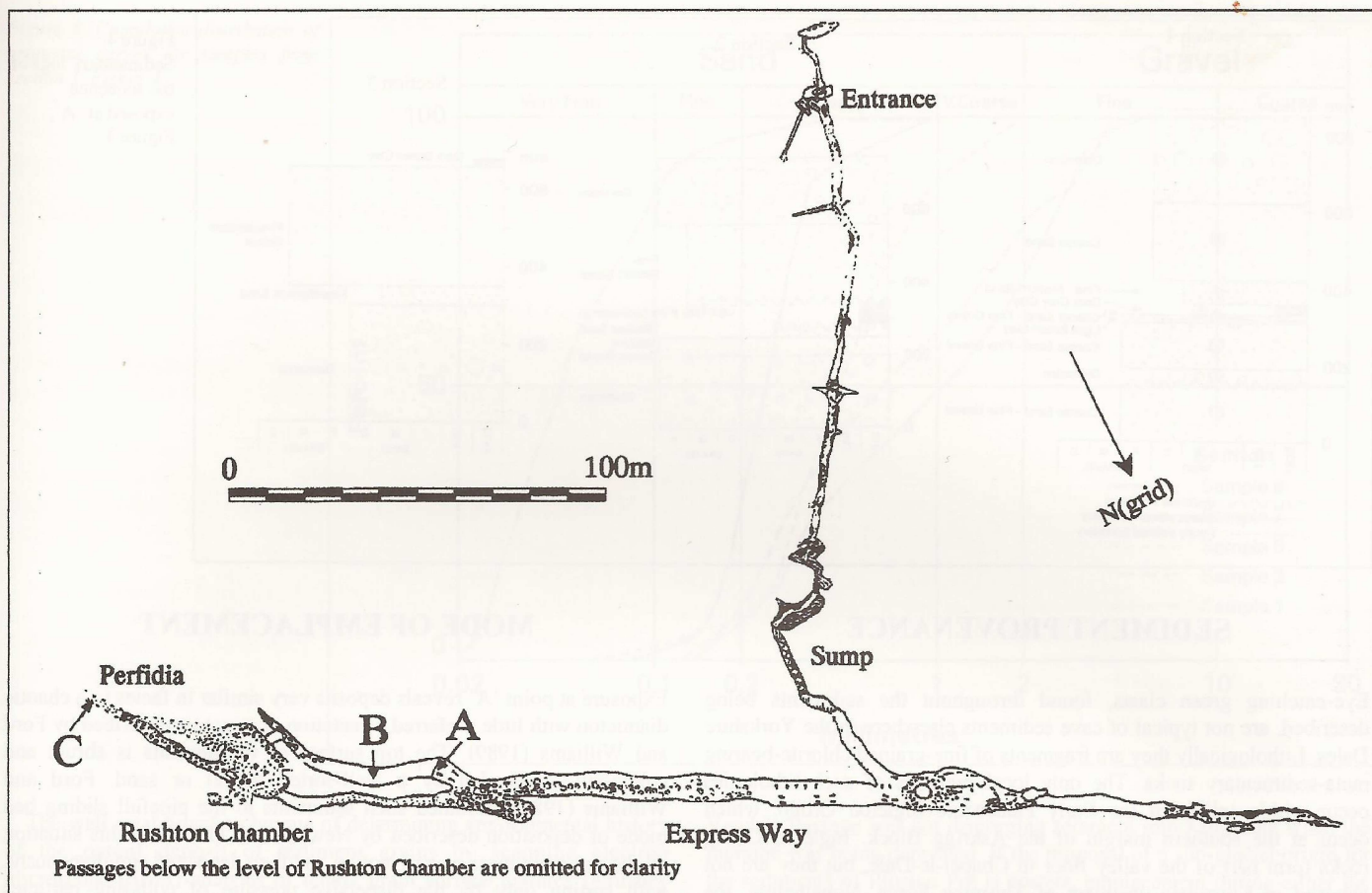
Figure 3. Illusion Pot Series, Dale Barn Cave. Reproduced from the Northern Cave Club Survey. (BCRA grade 5e) by permission.

Overlying the vertical exposure are several large dune forms up to 1.5m high and 8m long (Fig.3 point 'B'). These consist of sand and gravel, and show clearly-defined internal structures. The dune foresets dip towards the northwest. A dissected remnant of such a dune form is exposed on the northeastern wall of Perfidia (Fig.3 point 'C'), where the foresets dip towards the northwest. The lithological content of the sands and gravels exposed in the dune forms differs little from that of the units described at point 'A'. Typically, all the sediments analysed contain a relatively small percentage of fine-grained chloritised clasts.
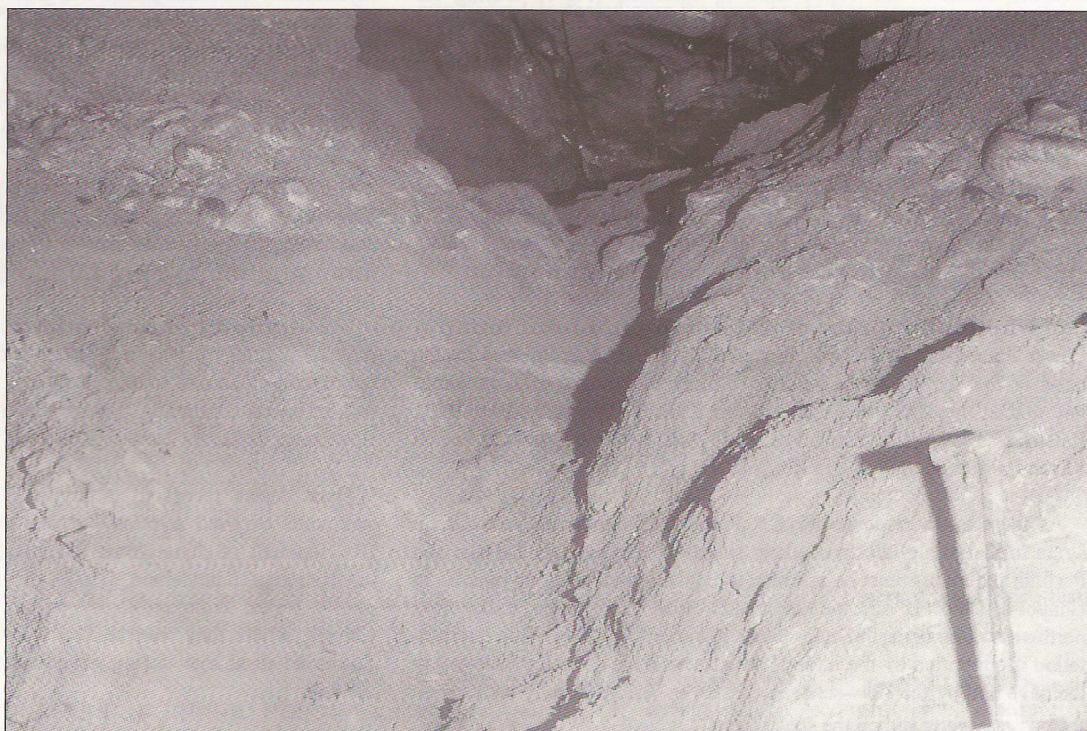

Plate 2. View of the sedimentary sequence exposed at 'A', Figure 3, The Spade handle is 80 cm long.
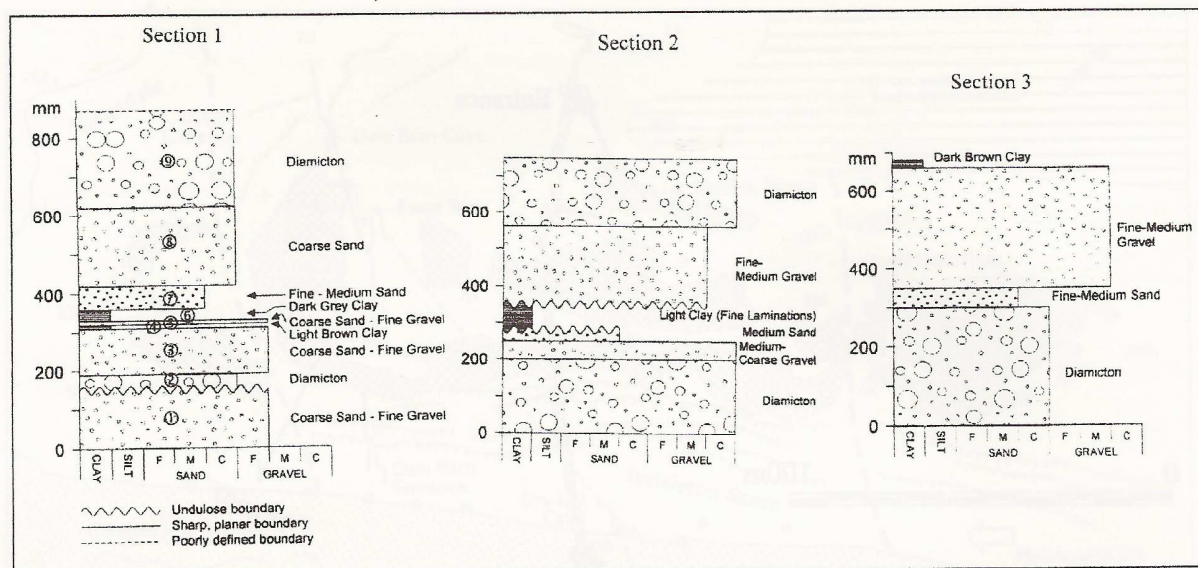
Figure 4. Sedimentary logs of the sequence exposed at 'A', Figure 3

SEDIMENT PROVENANCE

Eye-catching green clasts, found throughout the sediments being described, are not typical of cave sediments elsewhere in the Yorkshire Dales. Lithologically they are fragments of fine-grained chlorite-bearing meta-sedimentary rocks. The only local outcrops of such lithologies occur within inliers of the Early Palaeozoic Ingleton Group, which occur at the southern margin of the Askrigg Block. Ingleton Group rocks form part of the valley floor in Chapel-le-Dale, but they are not exposed in Kingsdale upstream of Thornton Force. Nonetheless, the possibility that Ingleton Group strata might crop out beneath the superficial deposits forming the valley floor in Kingsdale must be considered.

In the early 1990s cave divers found and explored a connection between the cave systems on the east and west sides of Kingsdale. This connection follows a bedding-guided passage (East Kingsdale Branch), which reaches a maximum depth of 34.5m (Monico, 1995) and is aligned northwest-southeast for much of its length. The presence of cave passage beneath Kingsdale indicates that, beneath the superficial deposits, much of the valley floor is limestone (Fig.6). During the diving explorations no Ingleton Group strata were seen in the floor of the East Kingdale Branch (J N Cordingley, pers. com.).

Thus, the possibility that Ingleton Group strata could form the floor of Kingsdale is limited to the area northeast of Valley Exit Cave and southwest of Kingsdale Head hamlet where rocks of the Great Scar Limestone Group crop out in the bed of Kingsdale Beck (Fig.6). Under conditions of low discharge, Kingsdale Beck sinks into the superficial deposits at a number of points downstream of Kingsdale Head, suggesting that the superficial material is underlain by limestone.

In Wharfedale, 30km east of Kingsdale (Fig.1), a buried outcrop of Lower Palaeozoic strata beneath superficial deposits is inferred on the basis of the occurrence of chloritised metasedimentary erratics within late glacial deposits down valley from Kilnsey (Dakyns, 1890, 1893; Raistrick, 1931). No such erratics are found in the Late Devensian Raven Ray retreat moraine in Kingsdale (Fig.6).

As there is no evidence for the presence of buried Ingleton Group strata in Kingsdale, the most likely source of the Vandals Passage and Perfidia sediments must be assumed to be the Ingleton Group outcrop in Chapel-le-Dale. If so, the sediments must have been transported northwestwards beneath Scales Moor towards Kingsdale. This interpretation is supported by the internal structures of the dune-forms found in the cave and by the flow-sense suggested by the scalloping patterns on the passage walls and on the speleothem.

MODE OF EMPLACEMENT

Exposure at point 'A' reveals deposits very similar in facies to a chaotic diamicton with little preferred orientation or structure described by Ford and Williams (1989). The top surface of the deposits is abrupt and commonly succeeded by a well-sorted gravel or sand. Ford and Williams (1989) attributed such sediments to the pipefull sliding bed mode of deposition described by Newitt et al. (1955). In this situation all the sediment mass was in motion and then deposited simultaneously, with sorting only by the dispersive pressure of colliding particles (McDonald and Vincent, 1972). Similar sediments have been described from sub-glacial eskers (a flow situation analogous to that in phreatic cave conduits) and attributed to the sliding bed mode of deposition (McDonald and Vincent, 1972; Saunderson, 1977). Saunderson (1977) takes the occurrence of such deposits to be diagnostic of water-filled sub-glacial tunnels.

Brennand (1994) studied a number of extensive and well-exposed sub-glacial eskers in Ontario, Canada, and described a sequence dominated by gravels and diamictons with a secondary assemblage of rhythmically alternating sand and gravel units. The internal structure of the units showed significant variation, whereas contacts between the units were commonly very sharp. Brennand (1994) considered the sediments to be the result of deposition from fluidal flow or hyperconcentrated dispersions, and the rhythmicity of the sand/gravel alternations is interpreted as being a response to episodic flood flows.

Brennand (2000) reviewed the sedimentology of the eskers of the Laurentide ice sheet in Canada. Vertically stacked gravel-sand couplets and large gravel dunes, as seen in Illusion Pot, are observed in many of the eskers described.

The clay layers recorded in the exposed sections at Illusion Pot indicate periods of relative quiescence between stronger flows, and the laminations recorded within them may be analogous to varves. Their lack of lateral continuity suggests that they were eroded by the stronger flows responsible for overlying deposits of gravel, sand and diamicton.

Dune forms recorded at points 'B' and 'C' (Fig.3) overlie the sediments exposed at point 'A' and are therefore a younger feature. Development of dune forms is indicative of a relatively low-energy environment. Saunderson (1977) described dune forms overlying a poorly sorted sediment facies within the Guelph esker in Ontario, Canada, where they were related to the energy change accompanying decreased discharge during abandonment of the sub-glacial drainage conduit.

Figure 5. Cumulative distribution of grainsize curves for samples from section 1, Figure 4.
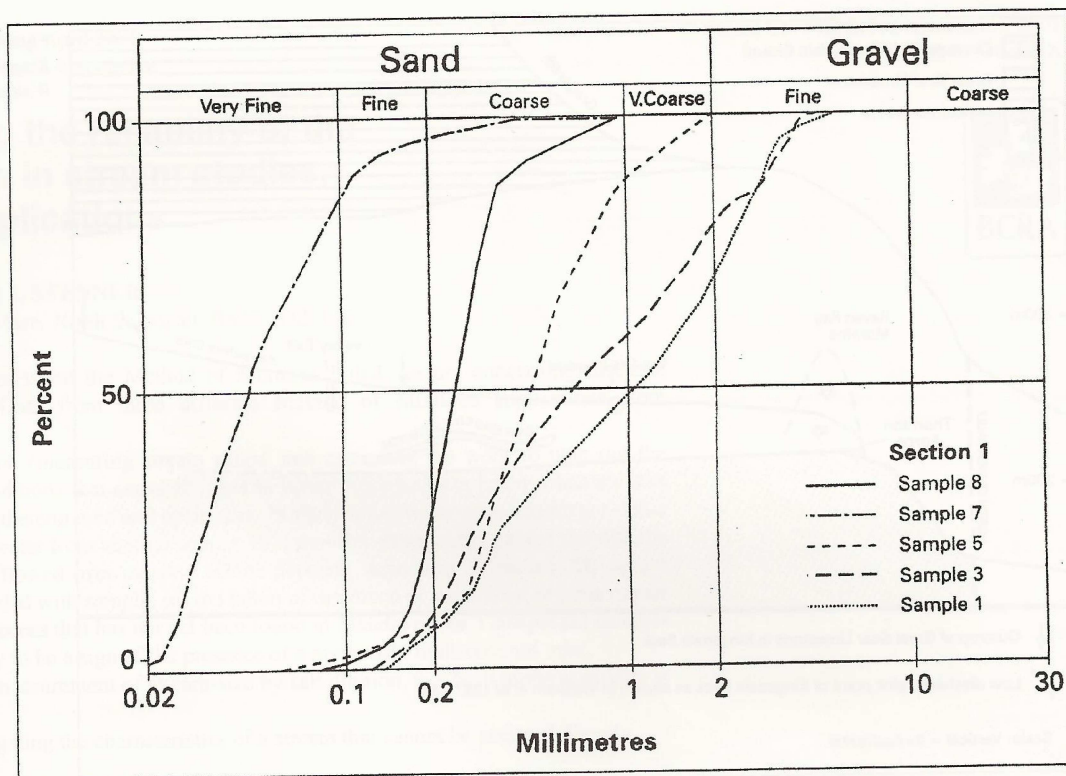
The well established technique of determining environmental history of the parent deposit of sediment grains by scanning electron microscope (SEM) analysis of quartz grain surface textures (Krinsley and Dornkamp, 1973) has been used successfully on cave sediments (e.g. Bull, 1989). SEM analysis of the Illusion Pot sediments was undertaken on samples from Unit 9, section 1 (Fig.4). The 0.15 to 0.25mm sieve fraction was used, and the samples were washed in distilled water to remove any adhering clay particles. Brittle fracture facets, typical of glacial deposits, dominated the grain surface textures.

X-ray diffraction analysis of the laminated clay units in Illusion Pot showed that they consisted only of calcite and quartz. This composition is typical of underground clay and silt deposits in glaciated karst regions and such deposits are interpreted as reworked "glacial flour", produced by basal, sub-glacial, ice erosion (Ford and Williams, 1989).

The apparently limited effect of the waters responsible for scalloping the speleothems in Vandals Passage (Plate 1) in enlarging the overall size of the conduit could be due to the depleted aggressiveness of glacial meltwaters (Smart, 1984). Alternatively it is possible that the connection of the conduit to the highly dynamic sub-glacial drainage network was only for a limited time.

TIMING OF SEDIMENT EMPLACEMENT

Waltham (1990) considered that the Chapel-le-Dale inlier did not exist in pre-Anglian times. If this is so the sedimentary fill of Illusion Pot must be Anglian or younger in age. The scalloped speleothem shown in Plate 1 has a three layer internal stratigraphy. A sample from the middle layer was assayed by standard uranium series disequilibrium alpha counting methods, yielding an age of 343,400 years +86.0/-47.7ka (corresponding to the 'Hoxnian' interglacial of Waltham *et al.*, 1997). This age is consistent with dates obtained from speleothems in relict phreatic tunnels in the Gaping Gill system to the east and the Easegill system to the west (Gascoyne *et al.*, 1983; Gascoyne and Ford, 1984). Vandals Passage was drained prior to this date, and the second phreatic episode post-dates this time.

The lack of clasts derived from rocks of the Ingleton Group within the Late Devensian deposits of the Raven Ray moraine indicates that

Vandals Passage was not disgorging sediment into Kingsdale when the moraine was being deposited. If the proposal of a sub-glacial origin for the sediments of Illusion Pot is correct, emplacement during either the Early Devensian or the 'Wolstonian' (Oxygen Isotope Stage 6) is indicated.

INTERPRETATION

A mechanism that could account for the establishment of a second phreatic episode, and the related sedimentary features described here, is that the Dale Barn Cave system functioned as a sub-glacial conduit. Chapel-le-Dale is a classic example of a glacial trough valley, whereas Kingsdale is much less well incised. This is because the ice flow route into Kingsdale passed over the high divide from Dentdale to the north, possibly leading to a situation where Kingsdale was ice-free while Chapel-le-Dale was carrying a major ice stream from the local ice centre to the north (Mitchell, 1991). This would account for the sediments exposed at point 'A' (Fig.3) having been deposited in the pipefull, sliding bed, mode as described by Ford and Williams (1989). The layered clay deposits would have formed during periods of ponding, when the cave system was not in hydrological continuity with the dynamic drainage system beneath the Chapel-le-Dale glacier. Dune forms, as exposed at the top of the sediment fill, record a decrease in discharge during the final stages of utilisation of the cave by the sub-glacial waters.

A similar case of the utilisation of a pre-existing karst conduit resulting in reversed phreatic flow is described from Storbekkgrotta, Glomdal in Norway by Lauritzen (1983,1984), though no emplacement of sediment by the sub-glacial water is described.

CONCLUSIONS

The high-level relict passages of Illusion Pot were drained more than 343,400 (+86.0/-47.7ka) years ago.

Subsequently the relict passages were subjected to a renewal of phreatic conditions, during which sediment was transported northwestwards from Chapel-le-Dale towards Kingsdale. The sediments
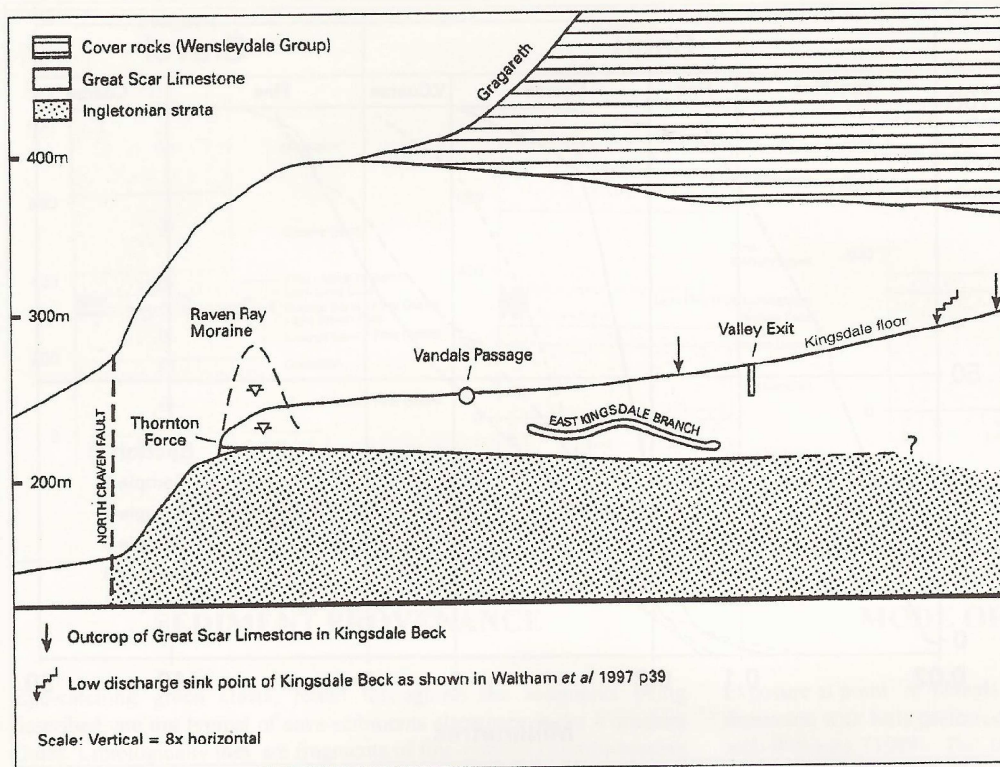
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Figure 6. Section along the course of Kingsdale Beck. Based on Figure 28.3 of Waltham 1986 with permission.

are analogous to those seen elsewhere, deposited within sub-glacial drainage conduits and preserved as eskers. Thus, the second phreatic episode may have been a result of the utilisation of the pre-existing cave as a drainage channel for the sub-glacial waters of the Chapel-le-Dale glacier.

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