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# Cave and karst development in the Craven Basin, UK

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***Abstract:*** The Craven Basin, which was an area of crustal subsidence during much of the Carboniferous, contains carbonate strata that pre-date the deposition of the better known carbonates of the Askrigg Block to the north. Later basin-fill deposits consist mainly of clastic sedimentary rocks. However, interbedded carbonate horizons and Waulsortian mud-mounds are also present. Karst development has taken place locally on the exposed carbonate strata. including establishment of the only example of a sulphurous cave stream currently known in the British Isles. The caves so far examined in the area are described, alongside an account of their geological setting.

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The Craven Basin (Hudson, 1933) or Bowland Basin (Ramsbottom, 1974) covers a broad geographical area that extends into the eastern Irish Sea. In the Craven lowlands it is defined by the Southern Lake District High and the Askrigg Block to the north, and by the Central Lancashire High to the south. It is one of a number of fault-controlled extensional basins of Carboniferous age in the UK developed between upraised fault bocks (Fig.1). The Craven Basin has also been divided into two principal sub-basins; the Lancaster Fells Sub-Basin to the north, and the Bowland Sub-Basin to the south. The two basins are partly separated by a high point known as the Bowland High. It is the southerly of the two, the Bowland Sub-Basin, that is the subject of this report.

The Bowland Sub-Basin is a northeast-trending half-graben bounded to the south by the Pendle Fault, to the north by the faults of the Bowland Line (Arthurton *et al.,* 1988), and to the northeast by the Craven Fault system. The early part of the sedimentary fill of the sub-basin during Tournaisian (Early Mississippian) times is characterized by widespread, shallow-water marine shelf and platform carbonates. The basin floor subsequently fractured and rifted into a series of intra-basin highs and lows. Initial rifting of the basement floor produced a varied basin floor topography in which deeper water Waulsortian limestones accumulated. Waulsortian mud-mounds, previously referred to widely as reef knolls, are developed at two horizons in the Tournaisian Clitheroe Limestone Formation. These enigmatic features crop out in the Ribble Valley in the east and in the Hodder Valley in the west. They formed under an appreciable depth of water, perhaps as deep as 200m or more, where sunlight barely penetrates.

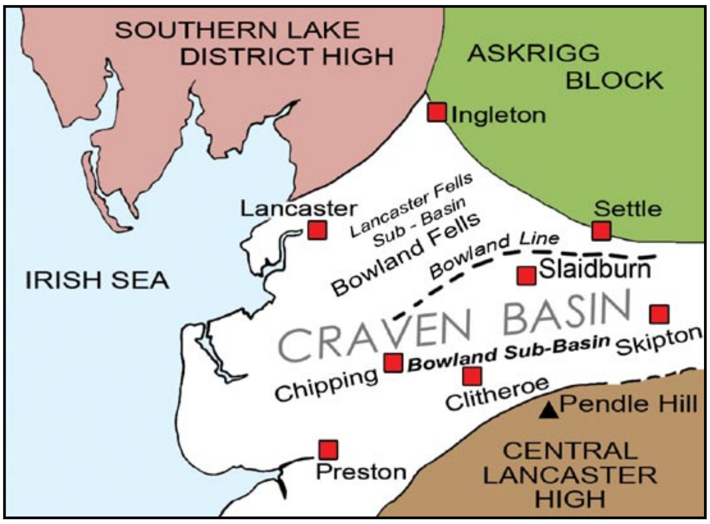


***Figure 1:*** *Tectonic setting of the Craven Basin. Reproduced from Kabrna (2011) with permission.*

Further rupturing of the basin floor resulted in a widespread change in depositional regime as pelagic mudstone and limestone turbidites were deposited throughout Visean (Mid Mississippian) times (Fig.2) making the basin far deeper and more anoxic. Increasing pulses of sand into the basin set the scene for yet another major change in depositional style, this time with advancing river deltas that deposited the Millstone Grit Group. The first major Millstone Grit sandstone within the Craven Basin is the Pendle Grit. The deep-water turbidite fan that constitutes the Pendle Grit marks the onset of the Namurian (Late Mississippian to Early Pennsylvanian) Regional Stage (Arthurton *et al.,* 1988), which was dominated by the deposition of siliciclastic material, i.e. quartz-rich sediments, which formed the Millstone Grit Group.

Towards the end of the Carboniferous Period, the tectonic forces were reversed and the formerly extensional regime became one of compression during the Variscan Orogeny. The basin-fill was folded and faulted during the orogeny, resulting in a series of northeast–southwest-trending anticlines (the Ribblesdale Fold Belt: Phillips, 1836; Kirby *et al.,* 2000), which are cut by a series of northwesterly-trending faults. Subsequent erosion of these folds resulted in the creation of a series of inliers, where the more carbonate-rich rocks of the early basin-fill sequence now crop out. The detailed geology of part of the area is described by Brandon *et al.* (1998) and a broad account of the area's geology is given by Kabrna (2011).

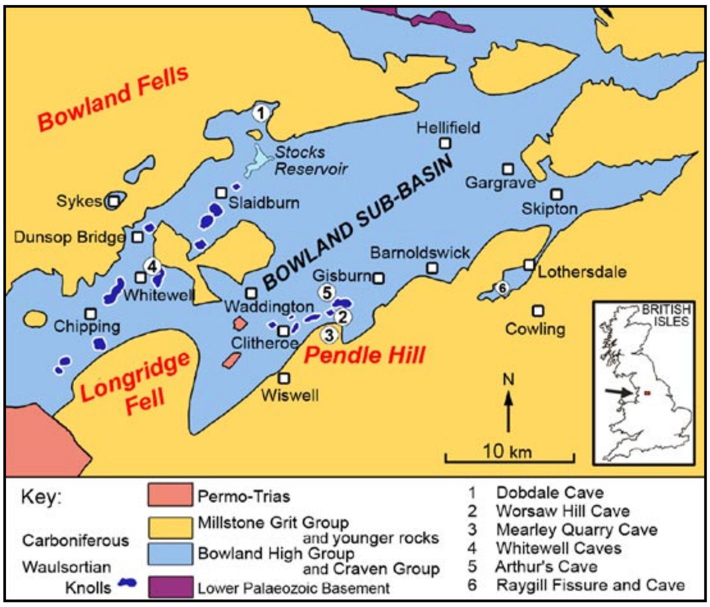


***Figure 2:*** *Geology of the Bowland Sub-basin and surrounding area. Reproduced from Kabrna (2011) with permission.*

## Caves

Limited cave development has been recorded in the area (Fig.2). Dobdale Cave, comprising 40m of low passage including a 10m-long sump, is in an isolated block of limestone in Gisburn Forest (Ryall, 2009a and 2009b). Worsaw Hill Cave, a sediment-filled tube near the summit of the Waulsortian mud-mound of Worsaw Hill, 1.5km southwest of Downham, can be explored for 5m (Mullan, 1991; Warren, 2001). Mearley Quarry Cave is a 12m-long phreatic cave fragment in the upper part of the Pendleside Limestone at 235m altitude on the northwestern slope of Pendle Hill (Mullan, 1991). The area is covered by glacial deposits though an active stream sink occurs at 300m altitude above Barkerfield Farm.

A number of active and relict caves occur in the Waulsortian mud-mound limestone around Whitewell in the Forest of Bowland (Dugdale, 1949; Brook *et al.,* 1994; Brown, 2007). Active stream sinks on the eastern side of the Hodder valley feed water to the Whitewell Resurgence, explored for 36m and to a depth of 16m by Cave Diving Group members (Monico, 1995). Hell Hole is an open shaft that contains two pitches reaching a terminal depth of 38m. Whitewell Cave comprises 81m of mainly steeply descending passage that can be explored without tackle to a depth of 33m (Nicholls, 1987). Whitewell Pot is the longest (137m) and most complex cave in the area, containing two pitches and a series of climbs reaching a depth of 41m (Crompton, 1964; Brown, 2007, 2009). An active stream sink has been excavated to a depth of 18m on the western side of the valley (Whitmore Pot), and natural passages encountered during mining for calamine have been referred to as Dinkling Green Mine Cavern by Brook *et al.* (1994) and as the Calamine Pit by Brown (2007). Also on the western side of the valley, on the slope of New Laud Hill, there are three short fragments of cave passage, referred to as Fairy Holes. One cave was investigated archaeologically in the 1940s, revealing Bronze Age artefacts (Musson, 1947). The caves and surrounding area were reinvestigated in 2011 and 2013 by archaeologists from the University of Central Lancashire, resulting in the discovery and excavation of more caves and a reinvestigation of the deposits in Fairy Hole (web references 1 and 2). The new excavations showed a far more complex prehistoric record from the caves than did the original work by Musson.

Arthur's Cave is situated on the steep, wooded slope of the northern bank of the River Ribble, 300m southwest of Fooden Hall Farm near Bolton-by-Bowland. The cave is blocked by sediment a short way beyond its large entrance. Various caver-excavated routes can be followed through the fill, including a short (30m) length of passage carrying a stream. Hunt (2004) reported the occurrence of sulphurous waters in the cave. Lofthouse (1946) and Dixon (1988) had reported that sulphurous waters in the cave originated from a stream sinking above the cave, supposedly sourced from the Fooden Sulphur Spring, situated in a shallow valley to the south of the historic Fooden Hall Farm. Brook *et al.* (1994, p.260) refer to a *"probable sink 0.4km N"* as being a potential source for the stream in the cave. At Fooden Sulphur Spring the water emerges from limestone bedrock (Chatburn Limestone Formation) but Brown (2007) reports that the sulphur spring waters do not sink but stay on the surface and flow into a tributary of the Ribble; thus the sulphurous waters of Arthur's Cave must be sourced elsewhere. On a still day the smell of rotten eggs can be detected tens of metres away from the Fooden Sulphur Spring, whereas the smell is far less strong in the cave. The Arthur's Cave water and Fooden Sulphur Spring rise from rocks of the Chatburn Limestone Formation on the northern limb of the Gisburn Anticline, which is cut by a northerly-trending fault, the effects of which can be seen in the heavily deformed strata exposed in the cliff to the east of Arthur's Cave. Arthur's Cave is on the western side of the fault, Fooden Sulphur Spring is on its eastern side. Away from the fault zone the dips are generally around 12 degrees towards the north.

Sampling and analysis were undertaken to investigate the origin of the sulphur water. Detailed analyses of spring waters from around the area are given in Murphy *et al.* (2014). All the waters display elevated Na, Cl and $SO_4$ compared to other springs sampled in the area, concentrations that indicate a component of more heavily mineralized brine to these groundwaters. Also the Sr:Ca ratio is elevated compared to the less mineralized waters (0.010 to 0.048), consistent with the presence of a longer residence time component to these groundwaters. However, both of the springs sampled (Fooden Sulphur Spring and Arthur's Cave) yielded temperatures (10 to 11°C), consistent with shallow groundwater in this area. Thus there is no evidence of any significant deep thermal groundwater contribution to these springs. Nitrate concentration is below detection at Fooden Sulphur Spring and may indicate minimal mixing with shallow, agriculturally-contaminated groundwater. At Arthur's Cave nitrate concentrations are higher and the water might represent a mixture of mineralized and shallow groundwater. The results suggest that the Arthur's Cave stream is not derived from water that originated from Fooden Sulphur Spring as suggested by Lofthouse (1946) and Dixon (1988). Further details, including sulphur and carbon isotope analyses, are given by Murphy *et al.* (2014).

The Embsay Limestone is exposed in Raygill Quarry, Lothersdale, at the core of the Lothersdale Anticline, one of the structures within the Ribblesdale Fold Belt. Quarrying in late Victorian times encountered a sediment-filled pothole from which an Ipswichian (MIS 5e) interglacial fauna was recovered (Davis, 1880). This has recently been re-evaluated (O'Connor and Lord, 2013) and it might have acted as a waterhole trap rather like the cenotes of Central America. What appear to be sediment-filled shafts or fissures can still be seen in the southern quarry wall, but the fossiliferous shaft has been quarried away. Warren (1983) describes a 5m-deep sediment-floored rift entered by scrambling 30m up the southern face of the quarry, but this site is believed to be no longer accessible.

## Conclusions

The limestone strata forming part of the basin-fill of the Bowland sub-basin do show karst development on a number of horizons, and contain the only sulphurous cave stream known in the North of England. Perhaps closer investigation and exploration within this relatively rarely prospected area will reveal other speleological gems.

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Our interest in this area was stimulated by a report of the cave waters of Arthur's Cave by Brian Hunt, who also greatly assisted the work.

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