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The strangeness of Stump Cross Caverns, North Yorkshire, UK – is the answer from below? Possible hypogene speleogenesis in the eastern Yorkshire Dales

Phillip J MURPHY
School of Earth and Environment, University of Leeds, LS2 9JT, UK

Abstract: The Stump Cross Caverns cave system is formed in folded and faulted limestone strata situated in the transition zone between the Askrigg Block high and the Craven Basin. It consists of large tubular passages connected by smaller passages or rifts, and has a distinctive multi-level maze-like plan, unlike that of any other cave in the region. A re-evaluation of the morphology and a review of the previous studies undertaken in and around the cave system suggest a possible origin linked to hypogene karstification.

Keywords: Askrigg Block; Craven Basin; Craven Fault Zone; Last Glacial Maximum; lead mining; Morphological Sequence of Rising Flow; thermal groundwater.

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Introduction

The Stump Cross Caverns cave system is a network of more than 6 kilometres of passages positioned beneath the interfluve between Wharfedale and Nidderdale, the two most easterly glaciated valleys of the Yorkshire Dales (Fig.1) in northern England. The area lies within the Craven Fault Zone, which is a structural feature of regional extent, forming the boundary between the Askrigg Block horst to the north and the Craven Basin to the south.

During Early Carboniferous times, this area – along with neighbouring districts to the west, north and probably the east – was characterized by repeated cycles of shallow-water carbonate deposition, punctuated by shorter episodes of emergence, erosion and karstification. This led to the formation of the rocks comprising the regionally recognized Great Scar Limestone Group (formerly known simply as the "Great Scar Limestone"). Concurrently, to the south, sedimentation in the Craven Basin was dominated by deposition of clastic sediments in deeper water.

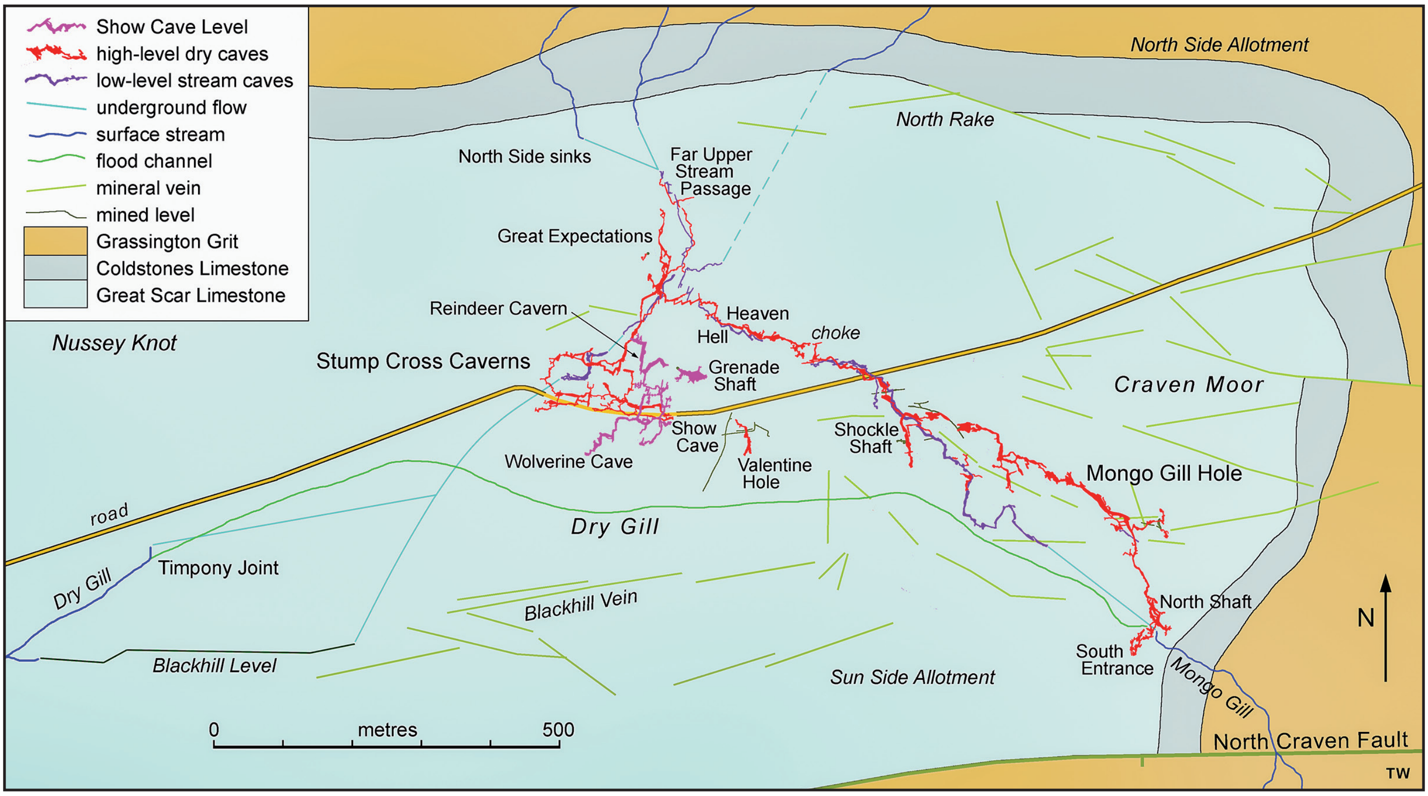

***Figure 1**: The main caves and geology of the Stump Cross Caverns area.*
[Compiled by Tony Waltham, after surveys by the Craven Pothole Club and others; edited version: reproduced, with permission, from Long, 2017, Fig.28.4.]

Figure 2*: Reindeer Cavern. A typical large tube floored by sediment overlain by extensive speleothem deposits.*

A series of roughly northeast–southwest-orientated periclinal folds and associated faulting, termed the Ribblesdale Fold Belt (Arthurton, 1984) or (in its regional context) part of the Môn–Deemster–Ribblesdale fold–thrust belt (Pharaoh *et al*., 2020), occurs to the south of the Craven Fault Zone. These folds provide evidence of a Variscan inversion of the Craven Basin and are interpreted as having formed in response to regional dextral shear (Arthurton, 1984). Stump Cross Caverns and the surrounding area lie at the easterly limit of the fold belt, where the Craven Fault Zone cuts across the anticlinal structure, truncating the northeasterly fold closure. Long and complex interplay between faulting and folding has resulted in significant structural complications to the local geology. As a result, the form of the cave system is unlike that of most caves in the Yorkshire Dales karst, because it is formed within relatively steeply dipping limestone beds (15–30°), now recognized as being part of the Great Scar Limestone Group (see below), that lie within the northern limb of the Stump Cross/Greenhow Anticline.

Historically, the area was a lead-mining field of some significance (Dunham and Stubblefield, 1944; Dunham and Wilson, 1985) and the miners made use of the natural caverns that they encountered. Access to the known caves is mainly through mined shafts, and evidence of the past mining activity is seen throughout the area, both above and below ground. Miners who broke into parts of Stump Cross Caverns recognized the site's potential value as a visitor attraction, which led to the subsequent opening of the highest-level passages to visitors (Halliwell, 2022a, b).

Until recently, an additional factor complicated the understanding of the wider contexts of the geology and cave development around Stump Cross when compared with those in adjacent and more distant areas. Detailed geological mapping that was undertaken as part of wartime mineral resource investigations (Dunham and Stubblefield, 1944), had supported the local establishment of a more specific stratigraphical terminology than that then in use elsewhere across the Yorkshire Dales (which was essentially covered by use of the broad term "Great Scar Limestone"). Whereas younger and older formations were defined (see, for example, Waters and Lowe, 2013, Figure 2.9), according to the local (1944) nomenclature, the Greenhow caves were considered to have developed within beds of the Stump Cross, Greenhow and Hargate End limestones – rock units that could not readily be recognized elsewhere in the Yorkshire Dales.

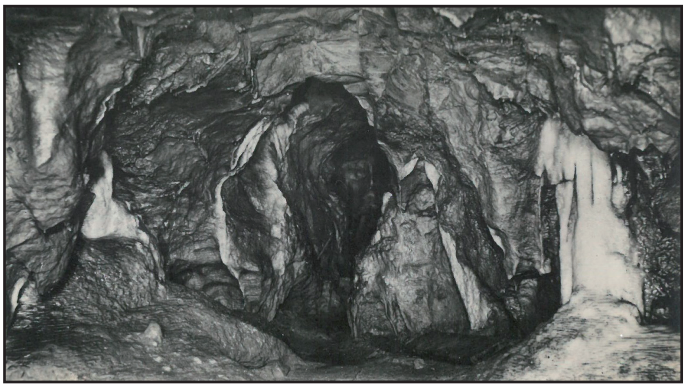

Figure 3*: A hall to narrows transition located at the southern end of the Chamber of Pillars – Show-cave level. [Image from the British Speleological Association records: kindly provided by the BCRA online archive.*

As more-recent mapping took place across districts to the west and north, mappable limestone-dominated rock units, mostly belonging within the Great Scar Limestone Group (see for example Waters and Lowe, 2013, Table 2.3 and Figure 2.9), were recognized and defined, based upon different criteria. Nonetheless, it was many years before a widely accepted correlation of these units with those defined at Greenhow (also within the Great Scar Limestone Group) was achieved and accepted. Recent understanding is that the Stump Cross, Greenhow and Hargate End limestones correlate with the upper part of the Malham Formation (Arthurton *et al*., 1988) or with the Malham Formation and the upper part of the underlying Kilnsey Formation and/or their correlatives in other districts to the west and north, as considered and described in detail by Waters *et al*. (2016).

Observation of the width of the interfluve between the glaciated Wharfedale and Nidderdale valleys has resulted in some debate as to whether the area was ice-covered during the Last Glacial Maximum (LGM). The area shows glacial landforms typical of the wider region, such as glacially transported boulders and glacially scoured rock surfaces, and the hill of Nussey Knott west of the Caverns (Fig.1) shows the classic shape of a roche moutonnée. Arguably, some of these could, however, be products of glacial episodes older than the LGM. Nevertheless, terrestrial cosmogenic nuclide dates from transported boulders and from a glacially scoured surface (Wilson *et al*., 2017) confirm that both sediment transport and deposition by ice occurred during the LGM, though the absence in the cave of significant clastic deposits dating from the LGM suggests that sub-glacial drainage was locally limited.

Site description

The system is formed on three main levels, the upper of which has been operated as a show cave since 1860 (Long, 2017). This level is characterized by short sections of large, tubular, passage containing extensive clastic and speleothem deposits (Fig.2). The near-horizontal passages are aligned along the strike of the dipping beds and are connected vertically by joint-aligned rifts. Many of these sections of passage in the show cave area end at major collapses, some of which have evidence of surface materials being brought into the cave. The large tubular passages are commonly interconnected by smaller passages, giving an overall "hall and narrows" (Osborne, 2001) feel to the system (Fig.3). Much of the system's speleothem was deposited as a complex and extensive layer, capping beds of coarse-grained clastic sediment.

The middle level is a far more extensive abandoned network of rifts, developed along joints and mineral veins, with some sections of bedding-guided passage. Commonly, larger passages are linked by smaller ones, imparting a maze-like complexity to parts of the system. This level contains deep fills of clastic sediments, covered in places by, and locally interlayered with, speleothem. Again, generally, the cave passages are aligned along strike, so the system curves around the northern limb of the fold.

The lowest explored level consists of constricted, active, vadose stream passages containing short water-filled sections. These carry water, gathered on the overlying, impermeable, clastic sedimentary rocks of Namurian-age, from the north and east towards resurgences in the Dry Gill valley to the west. The former natural hydrology has been compromised by the mining activity, especially by the targeted driving of levels to lower the water table. Base flow now emerges from the portal of Blackhill Level (Fig.1), and the normally inactive resurgence of Timpony Joint discharges large volumes of water during times of elevated flow. In many parts of the system, miners removed speleothem to be sold to visitors.

Faunal remains associated with surface fissures that are now impenetrably choked have been recovered from locations in the upper level of the system (O'Connor and Lord, 2013). In 1956, parts of four reindeer skeletons were found in a narrow rift adjacent to the show cave (Collins, 1959). Wolverine bones, including a skull embedded in flowstone, were found at the base of the rift by which the show cave is entered. In 1980 a reindeer bone and bones of wolverine and wolf were discovered when a cutting was made in the sediment fill to facilitate visitor access. More wolverine bones and remains of both fox and bison were recovered during systematic excavation of this site (Sutcliffe *et al*., 1985). The bones were part of a clastic horizon containing abundant speleothem fragments. Except for a single wolverine skeleton discovered in the middle levels of the system, all faunal remains recovered are from the upper-level passages.

Several dating studies have been carried out on speleothem samples from the cave, presumably in view of its intriguing geological and geographical setting and the ease of access provided by the show cave operation. The upper (show cave) level is one of the most intensively dated cave sites in the British Isles, with 68 published U-series dates (see Lundberg *et al*., 2020, for a summary, critique and reassessment of this work). Dates obtained to help constrain the age of the clastic horizon, placed the faunal remains within MIS 5b at 90–84ka (Sutcliffe *et al*., 1985).

Re-study of the speleothem deposits in the upper levels, using more precise dating techniques, showed that a bison–reindeer–wolverine fauna was present in northern England at least as early as 91.9 ± 0.5 ka BP, and that the Banwell Bone Cave fauna probably occupied the Yorkshire Dales from soon after ~100 ka to 80 ka BP (late MIS 5c–early MIS 5a). The latter study also identified an older bone bed, dating from 175 to 172 ka, MIS 6d. This is only the second reported occurrence in the Yorkshire Dales of a fauna that pre-dates the Last Interglacial (Lundberg *et al*., 2010). The results of this study confirmed that calcite deposition in this cave was precluded by local flooding during interglacial peaks, but at other times was comparable with that recorded in other caves of northwestern Europe. The oldest dates obtained were based on calcite samples from the uppermost levels in the cave, and they show that dewatering had occurred by at least ~430 ka BP (early MIS 11).

The extensive clastic deposits within the system have received relatively little attention in the scientific literature. A sequence in the Bowling Alley Passage of the show-cave level was described by Sutcliffe *et al*. (1985). It comprises sandy gravels overlain by a sand/silt complex, overlain in turn by current-bedded sand/silt, all overlain by extensive speleothem development. Radiometric dating of the speleothem deposits has constrained the deposition of the sandy gravels to MIS 8–10 and the sand/silt complex to MIS 6e-7c. Local development of a sandy breccia/conglomerate termed the 'clastic horizon' has been interpreted as being emplaced as the result of high-energy flooding events (O'Connor and Lord, 2013; Lundberg *et al*., 2020). Analysis by x-ray diffraction of grab samples of sediment, recovered during cave digging activity and considered to be the lateral equivalent of the sandy gravels, has shown a mineralogy consisting mainly of calcite, quartz, muscovite and feldspar (Fig.4), which is consistent with being derived from the local glacigenic surface deposits.

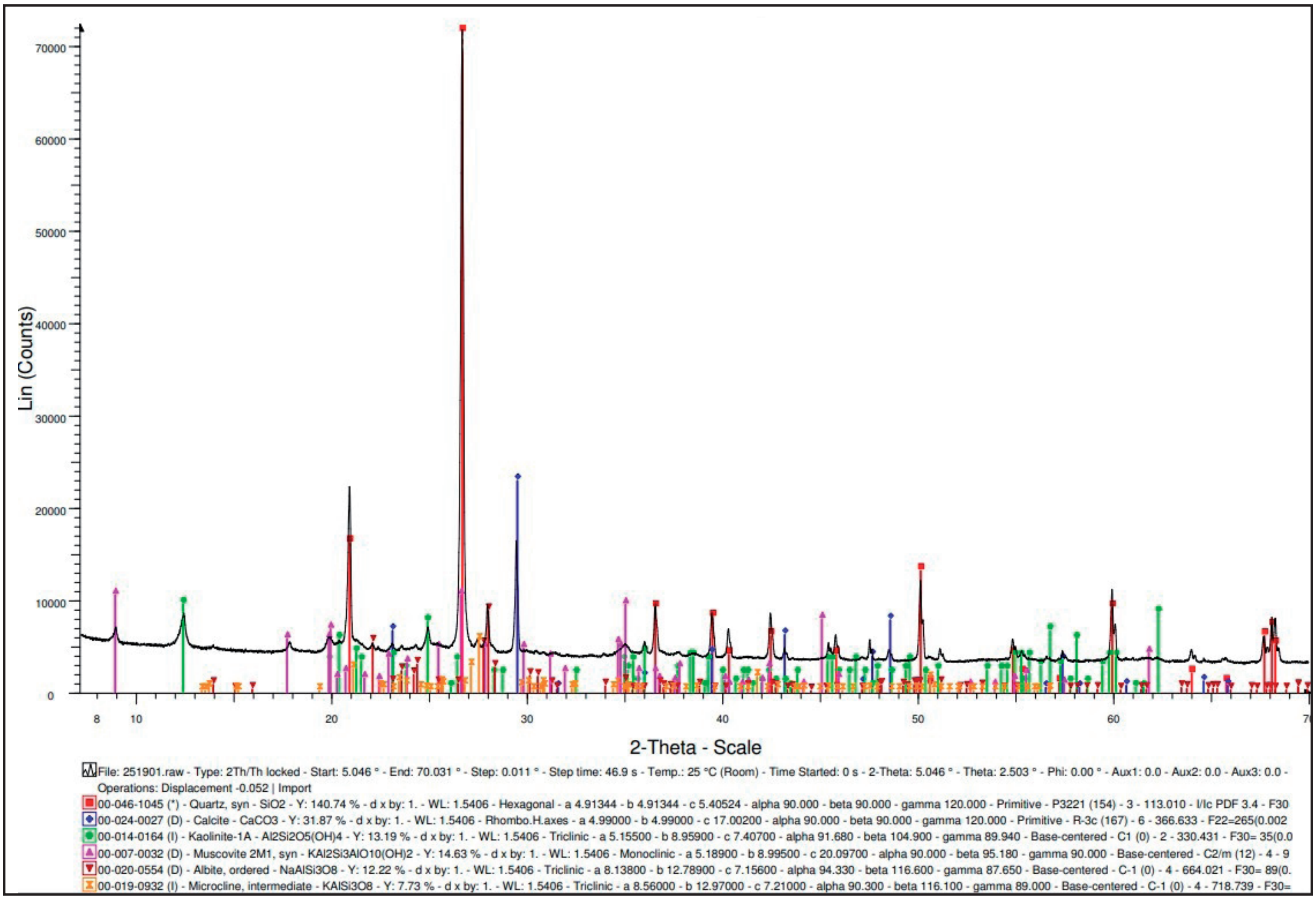

***Figure 4**: XRD analysis of sediment considered to be the lateral equivalent of the Sandy Gravels of Sutcliffe* et al. *(1985).*

Inclusion of kaolinite – a breakdown product of feldspar-group minerals – might, however, indicate that the source sediments were subject to weathering during a warm, moist, interglacial phase. Presence of kaolinite in the Stump Cross sediments contrasts with the mineralogy of sediments from Victoria Cave, 25km west of Stump Cross Caverns, deposition of which has been constrained to glacial periods by U-series dating of interglacial speleothem layers within which no such material was identified (Lord *et al*., 2017).

Discussion

Considering the system's accessibility, known history, and importance as a Pleistocene pit-fall trap site, little has been written about its origins. Present-day water flow passes beneath the complex of large tubular passages, whereas recent caver exploration of an active water sink into the system has shown a typical Yorkshire Dales cave morphology. Initially the drainage follows the dip until reaching the water-filled levels, at which point the flow direction reverses towards the resurgence (Thompson, 2024). Whereas occasionally the hydrologically active passages are overwhelmed by back-flooding during high-discharge events, at other times they are decoupled hydrologically from the higher-level development.

Passages forming the higher levels of development in the cave display rounded and tube-like morphologies, with no readily observable evidence of a vadose phase having been a part of their development history. In the higher (including the show cave) levels, profuse speleothem deposits obscure details of the passage morphology. In contrast, the far more limited speleothem deposits in the middle levels allow more-detailed morphological study. Linking of tubular passages has created a maze-like void-conduit system of chambers that merge into one another both horizontally and vertically. This has resulted in a cave system where, especially in the show cave area, the plan view presents a maze-like pattern. This complexity stands out as being virtually unique within the Askrigg Block, where most passages are developed in sub-horizontally bedded limestone and their inter-relationships are relatively simple.

A possible explanation of the greater complexity present within the Stump Cross Caverns system is that its mode of development differed from that which dominates elsewhere in the region. Rather than the typical epigene karst of the region, which reflects the actions of surface-derived (meteoric) and shallow groundwater, the Stump Cross system was formed by hypogene karstification, related to the activity of deep groundwater that was initially decoupled from surface processes. Hypogene speleogenesis involves development of dissolutionally enlarged permeability structures by acidic water that ascends from deep-seated sources into a zone of potentially soluble rocks under leaky confined conditions. In such cases, flow from deeper groundwater systems can interact with the flow in shallower and more local groundwater systems. This contrasts with the more visible and hence more familiar epigene speleogenesis, which is dominated by the effects of shallow groundwater systems receiving aggressive-water recharge from the overlying or immediately adjacent land surface.

Studies during the last two decades have indicated that hypogene speleogenesis is a far more common phenomenon than had previously been supposed. In large part, this change of view reflects recognition of the distinctive morphological suites that result from hypogene processes. Previously in the UK, complex maze-cave systems within the confined karst aquifers of the Northern Pennines had been considered to have formed under hypogene conditions (e.g. Harrison, 2016), as had mineralized cavities such as Pen Park Hole in the karst of southwestern England (e.g. Knight, 2016; Farrant and Mullan, 2008). Recent reconsideration of an isolated cave chamber beneath Pembroke Castle in western Wales has indicated a possible hypogene origin (Gunn *et al*., 2022a), and the early development of a range of distinctive underground features in the Peak District of Derbyshire has also been proposed as being hypogenic (e.g. Gunn *et al*., 2022b).

It was proposed by Long (2017) that large rifts in caves formed in limestones of knoll-reef facies within the Great Scar Limestone Group along the southern margins of the Askrigg Block were developed by non-epigenetic processes. Here a possible syngenetic origin associated with lead-zinc mineralization has been suggested for north–south-aligned vertical development. Towards the east of the Stump Cross Caverns system, within the Greenhow mining area, large sediment-filled sub-vertical karstic cavities, known locally as gulfs or gulphs were encountered by miners. Based upon study of limited historical records of the mine workings, subsequent publications, and examination of the few gulfs still accessible, it appears that the main phase of gulf development post-dated late Permian mineral emplacement, because their sediment fill contains materials reworked from the epigene mineralization. The presence of chlorite-group minerals within the sediment fill suggests a possible source from beyond the Askrigg Block indicating a pre-LGM age for the sediment. This is supported by the presence of kaolinite, a weathering product of feldspar group minerals, most prominently associated with warm climates, suggesting that the fill was emplaced during an interglacial warm phase older than the LGM (Murphy and Everett, 2013; Murphy *et al*., 2018). These two examples support a view that karstification in the area has a long and complex history.

It has been shown that confined settings provide the principal hydrogeological environment for hypogene speleogenesis. There is, however, a general evolutionary trend for hypogene karst systems to lose their confinement due to the ongoing effects of uplift and denudation, as well as due to changed relationships reflecting their own expansion. Confined hypogene caves may experience substantial modification, or be partially or largely overprinted, during subsequent unconfined (vadose) stages. If the development of the Stump Cross Caverns system was, at least in part, driven by hypogene processes, then comparisons of features at macro- and meso- scales with Klimchouk's (2007) *Morphological Sequence of Rising Flow* (MSRF) model should provide at least some support for the attribution of such an origin.

The MSRF model identifies three major components: 1) feeders (inlets); 2) transitional wall and ceiling features; and 3) outlet features. At Stump Cross Caverns evidence for the feeder component is heavily obscured because extensive clastic deposits obscure the nature of the bedrock floor of the passages. Excavation of sediment from a below-floor rift in the Wolverine Cave part of the show cave level as part of a palaeontological excavation showed that rift features, which might have functioned as conduits for rising fluids, do exist in the floors of the large tubular passages (Sutcliffe *et al*., 1985). Transitional wall and ceiling features include rising wall channels, ceiling cupola complexes and ceiling channels. Wall morphologies of tubular passages have received hardly any comment in literature relating to the Stump Cross system. Generally, cavers have interpreted the visible wall sculpting as large scallops, typical of large, drained, phreatic passages observed in other parts of the Yorkshire Dales karst. Re-examination and review of the Stump Cross features indicates that many are not asymmetrical in the direction of stream flow, as would be the case with scallop hollows formed by phreatic flows. Instead, the Stump Cross features are far more symmetrical, and they merge into the tubular passage walls and ceilings, as would be expected with a convectional origin. Outlet features (*sensu* Klimchouk, 2007) are vertical tubes connecting either from the ceiling of passages to higher levels, or to the fluid outlet. In the Stump Cross System such vertical connectivity between the passage levels does exist. There are also examples of connections, possibly including ones of the same type, between the cave and the present-day land surface. These include not only the open passageways used both by cavers and the former miners to enter the system, but also sediment-filled features that have been traced both below ground and on the surface. The presence of these morphological forms and their relationships suggest that at least some of the observable cave features in Stump Cross Caverns do align broadly with the constraints of the MSRF model for the recognition of a hypogene origin.Considering the regional setting, potential sources and transfer mechanisms for the fluids required to initiate hypogene speleogenesis must be considered. One possibility could involve expulsion of fluids from the adjacent Craven Basin. This was an area of crustal subsidence during much of the early Carboniferous, and its rock sequences include carbonate strata that pre-date the deposition of the better known carbonates of the Askrigg Block to the north. Whereas, as described above, younger deposits in the basin consist largely of clastic sedimentary rocks, interbedded carbonate horizons and Waulsortian mud-mound deposits are also present. Sulphurous springs have long been known emerging from beds within the Craven Basin sequence, with the source of the contained sulphur generally believed to be via surface oxidation of pyritic mud rocks (Armstrong *et al*. 2023). Nevertheless, isotopic evidence has been recorded for a deep-seated, petroleum-related, source for at least one such spring (Murphy *et al*., 2014). Additionally, the Craven Basin contains the only example yet known from the British Isles of a cave carrying a sulphur-rich stream (Murphy *et al*., 2015).

Another possible source of fluids is suggested by the presence of thermal groundwaters in the area. With the intention of draining the Greenhow mines at depth, driving of Eagle Level (portal SE14506530) southwestwards from the grounds of Eagle Hall near Pateley Bridge in Nidderdale was begun in 1825. Tunnelling was abandoned sometime around 1874 after a drivage of 7020 feet (about 2140m) had been achieved. A warm spring was encountered where the advancing level intersected the North Craven Fault (Dickinson and Gill, 1983, p50). Thermal springs are relatively uncommon in the British Isles, with significant examples being those at Bath, Hotwells (Bristol), Taff's Well (Cardiff), Buxton and Matlock Bath (Peak District), and Mallow (Eire). Thermal springs at the localities named above emerge from – but are not necessarily restricted to – the Carboniferous Limestone, in structural settings that allow meteoric water to descend to sufficient depth for it to be heated by the geothermal gradient and then return to the surface without a significant drop in temperature (e.g. Gallois, 2006). The record of a thermal spring where the North Craven Fault intersects the Ribblesdale Fold Belt is a further example of such a geological setting. Eagle Level was entered on behalf of Yorkshire Water in 1990 and explored for approximately 350m to a collapse, so the location of the reported thermal spring is no longer accessible (Riley, L – pers. com.).

Possible outlets for such fluids, prior to erosion exposing the cave-bearing rocks and, eventually, actual cave passages to surface must also be considered. Across much of the Greenhow area a regional unconformity at the base of the Millstone Grit Group has cut out the Wensleydale Group strata and brought the sandstones and mudstones of the Millstone Grit Group into direct contact with the carbonate sequence, at least as far down as the beds formerly considered as the Greenhow Limestone (see Waters and Lowe, 2013, Figure 2.9). Such connectivity may have provided an outlets mechanism for the dissolving fluids. A similar situation also prevailed farther west in the Grassington Moor mining field, where rising mineralizing fluids were not trapped within the carbonate sequence by an overlying aquiclude, as is typical of Mississippi Valley Type (MVT) mineralization, but entered beds of sandstone facies within the overlying Millstone Grit Group strata. The lowermost sandstone unit in the area, the Grassington Grit, was therefore mineralized and was known to the miners as the "Bearing Grits" (Gill, 1993). Mines in the Hebden Gill area, 6km west of Stump Cross Caverns, provide an example of this type of mineralization and host rock, with siliceous dust providing a health hazard for the miners (Gill, 1994, pp 99–108).

Conclusions

Despite Stump Cross Caverns being both a regional tourist attraction and a significant Pleistocene palaeontological site, surprisingly little consideration has been given in the speleological literature to the mode of formation of the cave system. This review suggests that many features of the system, including system plan, passage morphology and passage wall features, are consistent with an origin, at least in part, by hypogene rather than epigene karstification. Additional support for a possible hypogene origin is revealed by consideration of its regional hydrostratigraphical setting.

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