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Sediment-filled cavities in the Morecambe Bay karst (UK): examples from the Warton and Silverdale area

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Abstract: Various types of sediment-filled natural cavities are exposed in abandoned haematite and copper mines in Carboniferous limestones around Morecambe Bay, northwest England. They range in age from pre-mineralization through to Pleistocene though, because the date of the mineralization is disputed, it has been impossible to propose a confident chronology for many of them. Re-examination of two sites in the eastern part of the district, together with recently published results that point to a Mid Triassic age for the mineralization episode, now make it possible to propose a Neogene age for at least one example. Other, pre-mineralization, cavities and infill sediments probably date from the period of denudation that removed Carboniferous strata in this area prior to deposition of Permo-Triassic red beds. Some unconsolidated sediments are assigned on lithological evidence to being Pleistocene glacial deposits.

Key words: Morecambe Bay, palaeokarst, chronology, Carboniferous, Permo-Triassic, Neogene, Pleistocene

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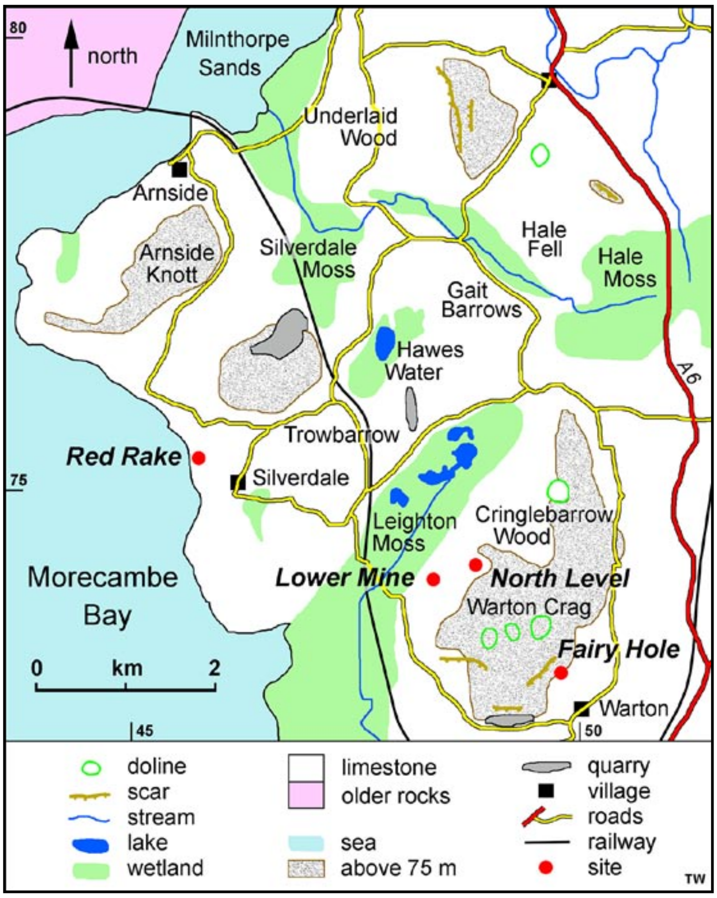

***Figure 1:** The extent of the Carboniferous (Great Scar) limestone outcrops in the eastern part of the Morecambe Bay area, showing locations of sites discussed in the text.*

The Morecambe Bay karst (Fig.1) is developed on a series of discontinuous outcrops of Great Scar Limestone. The eastern part of the area is well known for outstanding examples of limestone pavement and other karst landforms (Waltham *et al*., 1997, 101–112; Gale, 2000; Webb, 2013, especially Fig. 5.26) but there are few explored caves (Holland, 1967; Ashmead, 1974; Brook *et al*., 1994, 264–281). Local fragments of relict and largely sediment-choked cave passage survive.

Escarpments formed on the limestone now lack impermeable caprocks; drainage is wholly subterranean with little integration of surface flow. Recharge to the limestone aquifers is largely by diffuse flow, but the existence of discrete risings and some restricted active cave development around the bases of the escarpments implies integration of the diffuse-flow inputs within the aquifers.

Haematite ore-bodies emplaced within the limestone strata of the western part of the district were mined extensively from early times until the 20th century, and Furness became the most productive iron-orefield in the world for a time during the second half of the 19th century. The eastern part of the district was much less important as a source of ore but it is known that deposits of haematite and copper carbonate ores were also prospected and mined on a relatively small scale here during the 18th and 19th centuries, and likely earlier. Explorations of abandoned workings in this district found that the miners had intercepted natural cavities at a number of sites. Brief accounts of the known mine workings, natural cavities and infill sediments were given by Moseley (1969, 2010).

The most extensive mine workings are on Warton Crag (Fig.1), a 163m-high limestone escarpment lying between Silverdale and Warton village. There are a number of abandoned metalliferous mines on the Crag, mostly concentrated in the vicinity of Crag Foot in the northwest, and various types of natural cavities and cave sediments have been reported during investigations of these mines. Palaeokarstic cavities and sediments were also encountered in mines at Silverdale and elsewhere in the district.

Some of the more important of the known exposures of natural cavities and infill sediments have become inaccessible due to sealing of the mines, but several sites (Fig.1) remain open. Exposures in two of the still-accessible sites, North Level on Warton Crag and Red Rake at Silverdale, have been re-examined and the findings are reported here.

North Level

North Level (Fig.2) of the Crag Foot mine complex is a 100m-long level (NGR SD 48257409) driven through Dinantian limestone, presumably in an abandoned attempt to intersect and de-water mines higher up the Crag. It has been referred to as *'Grizedale Wood Drainage Level'* by several authors including Holland (1967), Griffiths (1981), Gale (1984), Monico (1995) and Hill and Hall (2015). Calcareous sand, a haematite-bearing conglomerate overlain by laminated argillaceous sediments, and coarse-grained fills containing chlorite-bearing lithologies are exposed in the level.

Calcareous sand

The adit forehead is at a point where water wells up from a narrow partly-choked natural rift, which has so far proved impenetrable for cave divers (Hill and Hall, 2015). The stream carries a well-sorted bed load of fine-grained, well-rounded calcareous sand grains with a minor component of both black and yellow iron oxide grains. The textural maturity and the presence of the iron oxide grains suggest that this material is being re-eroded from concealed natural cavities beyond the explored limit of the level; iron oxide being usually found as crusts on cave sediments deposited under phreatic conditions.

Coarse fills with chlorite-bearing lithologies

At two points North Level intersects fragments of cave passage characterized by coarse-grade fills that contain pebbles (defined as 2–64mm) and cobbles (64–256mm) of fine-grained chloritized lithologies (points D and A on Fig.2). The nearest sources of such lithologies are outcrops of Silurian Windermere Supergroup strata to the north. Considering that glacial ice cover in this area was sourced from areas to the north, including the Lake District massif (Brandon *et al*., 1998), these deposits are probably of Pleistocene age.

Haematite-bearing conglomerate and laminated clays

Approximately midway along the level (point C on Fig.2), another sediment-filled palaeokarstic cavity, which differs from the previous examples, is encountered. The deposits are described briefly in Moseley (1969, p.10; 2010, pp 15 and 85, fig.5). The sedimentary sequence is unlithified and consists of a conglomeratic layer 1–2m in thickness overlain by up to 35cm of partly-consolidated red and grey laminated silts and clays that fill the cavity entirely (Fig.3). The junction between the two units is abrupt. The conglomeratic layer contains both well-rounded and angular fragments, up to cobble grade, within a silty matrix. Clasts consist predominately of limestone and micaceous sandstone along with some haematite. Many of the rounded clasts are composed of a soft, clay-grade material that XRD analysis reveals to be mainly quartz with subordinate microcline feldspar and muscovite mica. No clasts of chlorite-bearing lithologies have been identified. The overlying banded clays display approximately twenty red–grey alternations and are distorted by slumping and faulting. XRD analysis of this material, both red and grey layers, shows the presence of quartz, microcline, muscovite and haematite, but again no chlorite.

Gale (1984) conjectured that the conglomerate layer was deposited under torrential fluvial conditions. The mixture of clast morphologies in the conglomerate does suggest that some material has been subjected to significant fluvial transportation over a significant distance, resulting in high degrees of roundness and sphericity, but the angular nature of some other clasts indicates a more local origin. Such varied morphology is consistent with involvement of mass movement processes ('slumping'), which are well documented as being responsible for the emplacement of some coarse-grained material into caves (Murphy and Cordingley, 2013). Both of these possible processes imply rapid deposition. This material is overlain by laminated, quiet-water sediments with an abrupt or interrupted chronological hiatus between the two. If the red–grey layers represent annual deposition it is possible that the whole conglomerate and banded clay sequence accumulated very rapidly in just a few years.

These conglomerate and banded clay fills have been interpreted as being derived from surface glacial materials (Gale, 1984), but the suite of lithologies represented does not support this proposal. Glacially-transported materials in the area are sourced from the varied igneous and sedimentary Lake District strata and typically display a diversity of rock types, with the chloritized lithologies that are common among Lower Palaeozoic strata particularly in evidence. As mentioned above, clasts and fine-grained material from such lithologies are absent in the North Level conglomerate and banded clay deposits. The small suite of component rock types and mineralogies that are represented is instead consistent with derivation from younger strata that formerly overlay the area, and they were probably deposited during or soon after denudation of these parent rocks. However, as no strata younger than the Lower Carboniferous limestones now survive on Warton Crag, it is difficult to identify the specific source reliably.

The micaceous sandstone clasts and mineralogy of the argillaceous deposits might be consistent with an origin from Millstone Grit Group strata. Sandstones believed to be mid to late Carboniferous, probably Namurian, in age were formerly exposed a little over a kilometre south of Crag Foot at Ings Point. Alternatively the presence of haematite in the clays points to a possible derivation from the younger Permo-Triassic red sandstones, in which case the source might have been the equivalent of the Permian Collyhurst Sandstone Formation. These iron-bearing strata crop out beneath a thick cover of till in the Morecambe area (Brandon *et al*., 1998, p.103) and are suggested as being the probable source of haematite that has resulted in the reddening of Namurian Millstone Grit Group strata in the western part of the Lancaster region (Brandon *et al*., 1998, pp106–107). However, the occurrence of haematite clasts in the North Level conglomerate indicates that the iron content of the banded clays could have been derived from pre-existing emplaced iron-ore deposits rather than from Permo-Triassic red beds.

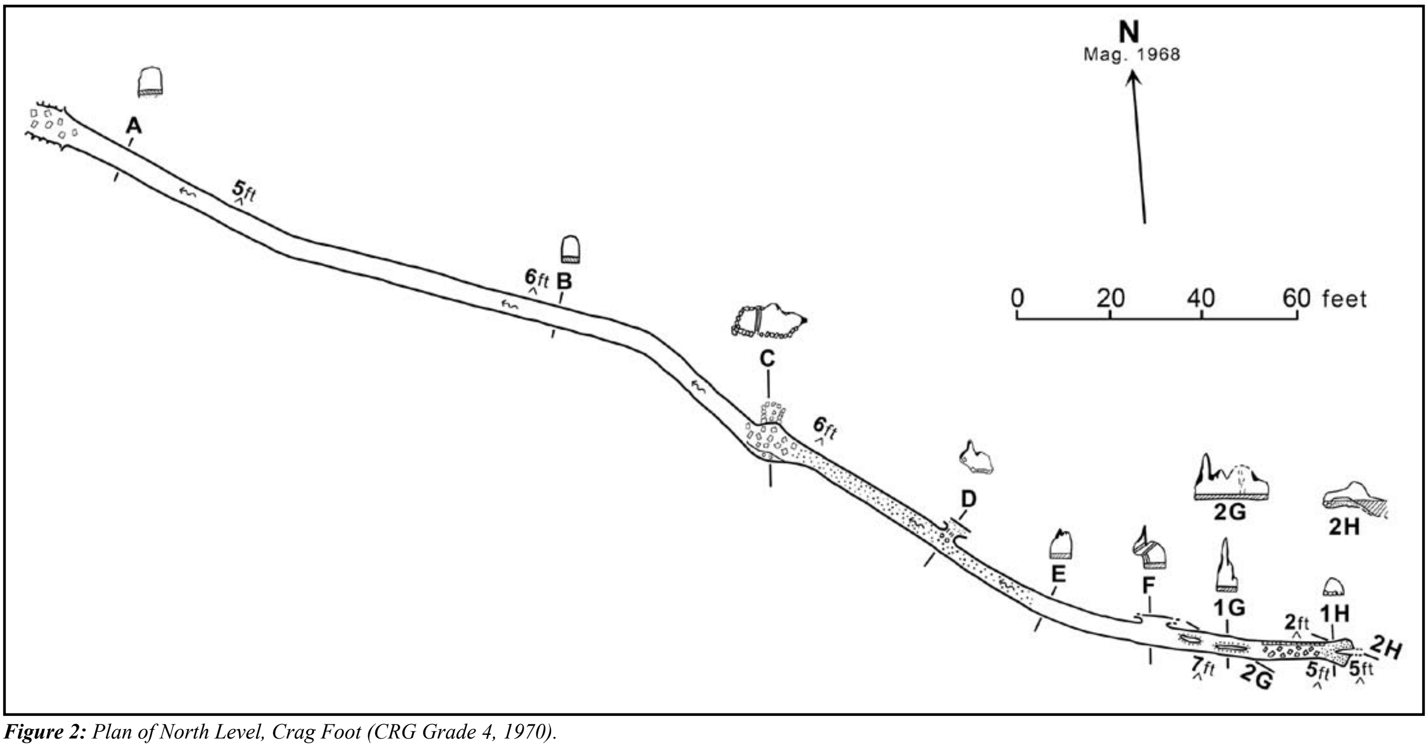

Figure 2: *Plan of North Level, Crag Foot (CRG Grade 4, 1970).*

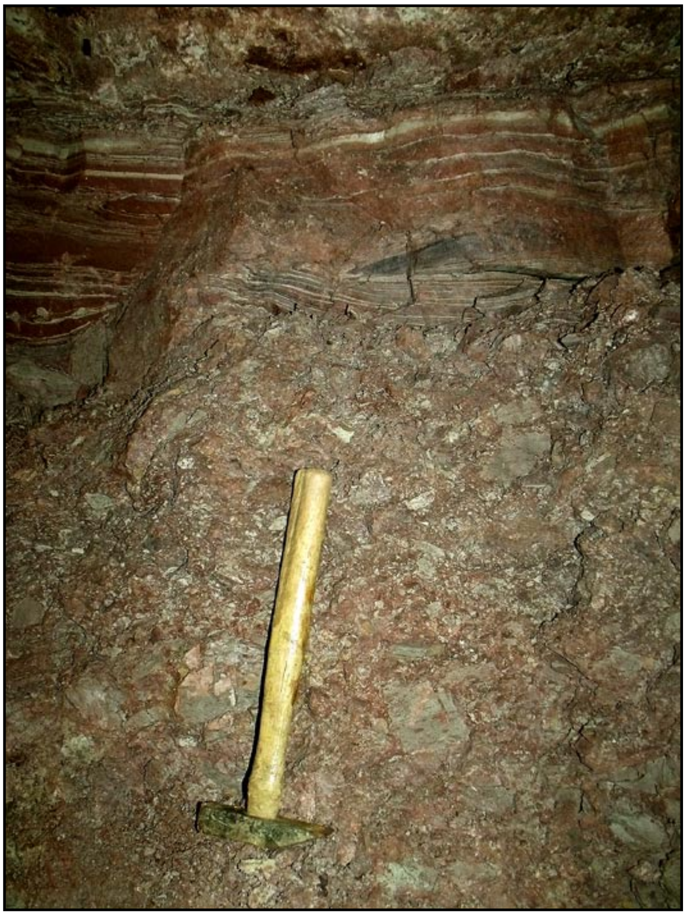

Figure 3: *Detailed view of sediment fill in North Level (Warton Crag) showing contact between conglomerate and banded clays. Note the angular and rounded clasts in the conglomerate. Hammer (handle length = 32cm) for scale.*

Any attempt to date the timing of deposition of the conglomerate-banded clay sediments involves speculation. Based on palaeomagnetic evidence from the laminated deposits and other observations, Gale (1984) suggested a Pleistocene date older than 100 ka BP. However, no methodology or data are presented and a re-study using modern techniques would be needed before any validity could be given to this result. As explained above, the lithology and mineralogy of the deposits, especially the lack of chlorite, suggests they are not derived from the Lower Palaeozoic terrains of the Lake District or the Southern Uplands of Scotland to the north, appearing to rule out a Quaternary glacial origin.

Arguing on the basis of the presence of sandstone clasts in the conglomerate and the geological history of the area, Moseley (1969, 2010) favoured an early, possibly Carboniferous or Permian origin during the period of erosion that is known to have preceded deposition of the Permo-Triassic red beds. However, haematite clasts in the conglomerate unit show that it must post-date the mineralization. The age of the mineralizing episode has been a subject of contention for many years but a recent re-study has provided a Mid Triassic age (Crowley *et al*., 2013). If confirmed, this result negates the possibility of a Carboniferous or Permian date for the North Level deposits.

It is generally accepted that at the end of the Triassic there was a widespread marine transgression across the region, which remained submerged throughout the Jurassic and Cretaceous (Brandon *et al.,* 1998). Any resultant Mesozoic strata were eroded during the Cenozoic and it is probable that the North Level deposits were laid down during this period of erosion, presumably towards its end, whilst denudation was re-exposing the Carboniferous strata. This suggests a possible Neogene (Miocene or Pliocene) age for the sediments.

Red Rake

Red Rake (NGR SD 45667539) is a small mine-working for haematite in Dinantian limestone, situated in low coastal cliffs at The Cove, Silverdale, Lancashire, close to the Lancashire–Cumbria border (Fig.1). Haematite-stained horizons formerly exposed in the saltmarsh soil profile by marine erosion showed two separate attempts to exploit the deposit. These can be correlated with an opencast working (probably dating from early 18th century) and a later (probably late 19th century) underground adit (Moseley, 2010).

The mine was excavated on a small northwest–southeast-trending fault plane that can be traced on the surface farther towards the southeast as a shallow valley. The level appears to have been driven at least in part along a cave passage. Mineralized veins and sand-filled and open natural cavities are exposed in the underground workings.

Unconsolidated stratified red haematite-bearing and yellow-brown sand is deposited in natural cavities in the roof and walls of the level. The well-sorted and highly rounded coarse sand consists mainly of quartz with subordinate lithic grains. Sporadic pebbles of water-worn limestone occur in the sand deposit, including some showing the presence of haematite mineralization. The origin of such a texturally mature sand deposit could have been the Permo-Triassic deposits since eroded away. The lack of chloritized grains in the deposits suggests that it is not sourced from the glacial deposits and thus pre-dates the Pleistocene.

Other examples of natural cavities and sediments

Other workings of the Crag Foot mine group exposed a variety of sediment-filled cavities. The fills include lithified argillaceous and arenaceous bedded sediments intimately associated with iron and copper carbonates, oxides and gangue minerals; unconsolidated yellow clays; well-sorted deposits of sand; and gravels and coarse sands containing chloritized lithologies (Moseley, 1969, 2010). Some of the best exposures were in the now inaccessible Crag Foot Mine (NGR SD 48377355) (Fig.2). One section here revealed a sequence consisting of arenaceous haematite-bearing bedded sediments overlain by alternating fine and coarse sand. A sample of the coarse sand showed it to comprise mainly quartz and grains of a chloritized lithology (Moseley, pers. obs.). The succession was capped by speleothem overlain in turn by a deposit of clay with rounded clasts including chloritized lithologies. This sequence implies that the main cavity-fill was deposited before the arrival of material sourced and transported from Lower Palaeozoic rocks by Pleistocene ice. Elsewhere in the mine examples of haematite ore emplaced within lithified cavity-fill sediments imply a pre-mineralization date (i.e. probably pre-Mid Triassic) for the earliest stage of the sequence, suggesting an origin during the period of denudation that removed Carboniferous strata in this area prior to deposition of Permo-Triassic red beds.

The workings of the Lower Mine at Crag Foot, referred to as *'Moss House Mine'* (NGR SD 48067380) and *'Aragonite Band Mine'* (NGR SD 48157380) by Holland (1967) (Fig.1) are still physically accessible and contain some natural cavities and cavity-fill exposures that offer potential for further research in the area.

Calcareous sand is reported to underlie boulder clay in Fairy Hole (Fig.1), a natural cave fragment at NGR SD 49697296 on the eastern side of Warton Crag (Ashmead, 1974, p.221). This material might be similar in origin to calcareous sand carried by the stream in North Level (see above).

Outside the immediate study area, Ashmead (1974, p.207) reports dissolution pipes filled by *"Millstone Grit and sandstone boulders"* to the southeast of the study region at Swantley Reef Knoll, near Kellet. Brandon *et al*. (1998, p.129) describe a sediment-filled cave in a quarry near Nether Kellet, which contained 6m of unfossiliferous sediment consisting of brown stony clay with reddish brown and orange-brown clay overlain by brown stony clay, which was overlain in turn by finely laminated grey and pale brown clay. The authors suggested derivation of the cave fill from a temperate interglacial palaeosol for the lowest deposits in the sequence and that the whole sequence might span the last interglacial/glacial cycle. Moseley (2010) reported a surface exposure of yellow sand that appears to be a cavity infill at NGR SD 47338074 near Storth.

Conclusions

There are many examples of sediment-filled palaeokarstic cavities recorded from the mines of Warton Crag and district. These preserve portions of the local stratigraphical record, from pre-mineralization through to Pleistocene, that have been removed in the surface environment by subsequent erosion. Further study to elucidate the stratigraphy and origins of these sediments could therefore provide important information on both the erosional history of northwestern England and also the still-controversial process of mineralization of the Morecambe Bay haematite ores. The sediment-filled cavity exposed in the North Level of the Crag Foot mine group shows a fill sequence that postdates the emplacement of haematite mineralization and probably pre-dates the glaciation of the region. It might be Miocene or Pliocene (Neogene) in age and, if so, is the only Cenozoic sediment so far known in this vicinity.

Scalloping associated with haematite mineralization at Hodbarrow (West Cumbria) is ascribed on geological grounds to late-Carboniferous or early-Permian karst processes (Murphy and Moseley, 2012). Radiometric dating has shown that by the Mid Pleistocene, clastic and carbonate material was being deposited in caves in the Yorkshire Dales (Lundberg *et al*., 2010), so there is direct dating evidence that at least some cave formation in northern England pre-dates this. Elsewhere, karst cavity fill deposits of the Brassington Formation of the southern Pennines have also been shown to pre-date the Pleistocene. This latter sequence of sands, gravels and clays contain a Late Miocene (Tortonian) palynoflora (Pound *et al*., 2012).

Reports of palaeokarstic caves and fill sediments are rare in the British context. Thus, in the future these features merit full consideration when geoconservation measures are being reviewed for the area, which is renowned for its limestone pavements but possesses little known underground karst development. It is unfortunate that some of the most important exposures have already become inaccessible due to the sealing of mines.

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