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A uranium-series date and stable-isotope record from Fairy Hole, Warton Crag, Lancashire, UK; implications for speleogenesis and palaeoclimate

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Abstract

A uranium series date from Warton Crags confirms a pre-last glacial maximum age for the draining of a phreatic cave fragment in the Morecambe Bay Karst of North West England. Preliminary stable isotope data appears to record millennial scale climate variability.

Introduction

Warton Crag is one of a series of fault blocks of Carboniferous Great Scar limestone that form the Morecambe Bay karst (Fig 1). The eastern part of the area is well known for outstanding examples of limestone pavement and other karst landforms (Waltham et al. 1997 p 101 – 112, Gale 2000, Webb 2013), but there are relatively few explored caves (Holland 1967, Ashmead 1974, Brook et al. 1994 p 264-281). The limestone escarpments that have formed on the fault blocks lack cappings of impermeable rocks, thus 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 implies integration of the diffuse-flow inputs within the aquifers.

Fragments of inactive and largely sediment-chocked cave passage survive in places in the Morecambe Bay karst. The bulk of these consist of short, isolated remnants of phreatic passage, with evidence of later vadose activity, if it exists, obscured beneath sedimentary fill (Gale 1984, Moseley 2010, Murphy and Moseley 2015), though Ashmead (1974b p.33) states that some vadose development can be seen in the Dog Holes on Warton Crag.

The known inactive cave fragments do not show any obvious relationship to the present-day topography or hydrology of the area, and it is also difficult to establish former hydrological relationships between any of them. In an attempt to explain the location of these caves within the modern landscape, Ashmead (1969, 1974a, 1974b) related the altitudes of cave development in the area to a succession of regional water tables controlled by the series of falling Pleistocene eustatic sea-levels proposed by Parry (1958, 1960). Gale (1981a), however, showed that the distribution of the caves is essentially random, implying the absence of a simple altitudinal control on cave occurrence, and he was also unable to find any morphological or sedimentary evidence of the sea-levels postulated by Parry.

Measurements of scallop assemblages in three of the Morecambe Bay caves enabled Gale (1984) to calculate former discharge velocities, and by extrapolation, to estimate the catchment areas of each cave at the time the scallops were formed. In all three examples (Roudsea Wood Cave SD33358255, Capeshead Cave SD 33337814, and Fairy Cave, Witherslack SD 43408265), the calculated former catchment is much larger than the present-day area, implying, if correct, that the formation of the scallops pre-dates the dissection and reduction of the catchment areas of the limestone blocks in which the caves occur (Gale, 1984, p. 189-190). However, in the absence of an understanding of the Quaternary and late-Neogene denudation history of the area, Gale was only able to propose a pre-last glacial chronology.

Caves of Warton Crag

There are several fragments of abandoned cave on the Crag. The largest, Dog Holes (SD 4833.7304 alt. 55m above sea level (a.s.l.)), is a mainly phreatic cave situated on the southwest side. Also on the southwest, in the vicinity of Barrow Scout Quarry and on or near the line of the Warton Crag Fault, there is a group of small caves: Badger Hole (SD 4821 7283 alt 29m a.s.l.), Barrow Scout Cave No. 2 (SD 48207283 alt. 23m a.s.l.) and No. 1 (SD 48197282 alt. 15m a.s.l.). Harry Hest Hole (SD 49467286 alt. 114m a.s.l.) and Fairy Hole (SD 49697296 alt. 82m a.s.l.) are situated on the eastern flank of the Crag.

Fairy Hole

Fairy Hole (Figs 1 & 2) consists of a chamber with a maximum width of c.5m and a depth of c.15m. A number of small joints are visible, and there is a passage heading south beneath the entrance (Ashmead 1973, 1974). Most of the present cave has been uncovered as a result of early archaeological work and extensive later excavations by local cavers.

The cave was excavated archaeologically before the First World War producing remains of at least two human skeletons, flint flakes, pottery, iron artefacts, and animal bones (Jackson 191).

Extensive excavations by local cavers were carried out over a nine year period ending during the severe winter of 1962/63 and not resumed. The dig completely cleared out the fill to an estimated depth of 10m, uncovering the passage beneath the entrance (Ashmead 1973). The fill was dumped outside the entrance where it now forms a prominent vegetated spoil heap.

Unfortunately no record was made of the sedimentary sequence but it is reported that two layers of boulder clay separated by a sandy layer were exposed (Holland, 1967 p. 86). Fragments of “limestone, Silurian and Borrowdale Volcanics” lithologies were included in the fill. The presence of a calcareous sand layer occurring beneath boulder clay was also reported by Ashmead (1974a).

There is no significant *in situ* speleothem exposed in Fairy Hole, but numerous broken pieces of dripstone were found at a considerable depth in the fill during the excavations. The specimens are an average of 3-4 cm thick and composed of closely-packed acicular crystals. They show three (sometimes four) brown-stained horizons, marking interruptions in deposition of calcite, with the present surface being stained in the same way and showing evidence of re-solution (Anon 1963). The specimens are angular but with some rounding suggesting a degree of mechanical abrasion following breakage.

Further caver activity in the late 1990s resulted in a deepening of the site to its present depth with the previously discovered passage being filled with plastic bags of dig spoil. This was presumably intended to conceal evidence of digging activity because prior activity in the nearby Harry Hest Hole (Holland 1967 p 84 – no corresponding entry in Brook et al. 1994) had come to the attention of the authorities (Fig 3).

Scalloping on the walls of the excavated shaft shows it was a phreatic riser, i.e., water moved up the shaft towards the present cave entrance (Fig 4). Amongst the fill at the base of the shaft are highly rounded and highly spherical pebbles and cobbles, many of chlorite-bearing Windermere Supergroup lithologies (the "Silurian" of Holland 1967). The occurrence of cobbles with a very high sphericity have been recorded previously at and near the base of active phreatic risers (Murphy and Cordingley 2013).

Intriguingly, broken mineral vein material consisting of calcite and aematite is included in the digging debris now slumping down the excavated shaft. There is evidence of hematite mineralisation in the vicinity of Fairy Hole. A square infilled shaft in hematite-stained limestone at SD 49697295 (referred to as Fairy Hole Mine by Moseley [1969]) is probably an unsuccessful trial pit. There are traces of two further shafts on a parallel fault to the northeast at SD 497 729 and another infilled shaft on a minor fault at SD 495 734 (Moseley 2010).

Speleothem dating results

In order to understand the age of karstification in the area, a stalagmite sample attached to bedrock and calcified sediment (FHW-1) was recovered from the 1950s-1960s spoil heap deposited outside the cave (Fig 5). The sample was obtained from near the surface at the furthest extent of the heap and so may be from the latter stages of the excavations. A sub-sample from the middle of the speleothem-part of FHW-1 (Fig 5) was dated by U-Th multi-collector inductively coupled plasma mass spectrometric methods (MC-ICPMS) (Shen et al 2011; Cheng et al 2013). Unfortunately the sample is low in U (c.130 ppb) and high in detrital Th ($^{230}Th/^{232}Th_{atomic} = 45 \times 10^{-6}$), however, it yielded a corrected age of 54,760 ± 3,246 years. Note, the datum is 1950 C.E. (Table 1).

Stable-isotope analyses

Powders for stable-isotope ($\delta^{18}O$ and $\delta^{13}C$) analysis were hand drilled at a spatial resolution of 1mm along the 32mm-long central axis of FHW-1 and measured on a Thermo Fischer DeltaPlusXL isotope ratio mass spectrometer linked to a Gasbench II at the University of Innsbruck. Additional powders were drilled from the bedrock attached to the speleothem (Fig 5). All isotopic results are reported relative to the Vienna PeeDee Belemnite standard. Analytical precisions are 0.08‰ for $\delta^{18}O$ and 0.06‰ for $\delta^{13}C$ (1σ)(Spötl 2011).

The results for the speleothem show that $\delta^{18}O$ varies between a maximum of -2.36 and minimum of -3.91‰ (range 1.55‰), whilst $\delta^{13}C$ varies between -8.63 and -11.14‰ (range 2.51‰) respectively (Fig 6). $\delta^{18}O$ and $\delta^{13}C$ values are moderately correlated ($r^2 = 0.49$). Bedrock values are c.0 to 2‰ for $\delta^{13}C$, and -6 to -7 for $\delta^{18}O$ (Table 2).

Discussion

Direct geological evidence of the age of the remnant cave fragments of the Morecambe Bay karst has until now been entirely lacking. Gale's results relating the time of scallop formation in three of these caves to landscape denudation are interesting, but seem to do little more than support the observation that the absence of apparent relationships between the locations of these caves and the modern topography, together with their highly fragmented nature and distribution, points to their being hydrologically active prior to the later stages of denudation. The chronology of surface lowering, landscape dissection and valley incision in the area remains disputed, particularly the extent to which Pleistocene glacial activity contributed to these processes.

The U-Th speleothem date of 54760 ± 3246 years is the first available absolute dating evidence from the Morecambe Bay karst that we are aware of, and shows that Fairy Hole was drained and no longer functioning as a phreatic riser before the Last Glacial Maximum. Specifically, it places speleothem growth within Marine Isotope Stage (MIS) 3, and during a time of enhanced secondary calcite deposition in the northwest of Europe during the last glacial period (Baker et al. 1993).

The stable isotopes appear to record millennial-scale climate variability (Fig 6), though in the absence of an age model these results are at present preliminary. We interpret less(more)-depleted δ^{18}O to reflect warmer(colder) and wetter(drier) conditions associated with interstadials in the North-Atlantic realm (Dansgaard et al. 1993; Meerbeeck et al. 2011; Moseley et al. 2014). δ^{13}C values fall within the range for secondary carbonate deposited in equilibrium with CO_2 respired from C3 plants (Baker et al. 1997; McDermott et al. 2004), though variation in δ^{13}C could also be controlled by moisture availability (McDermott et al. 2004). The U-Th age is coincident with a period of less-depleted δ^{18}O between 18-26 mm from the top of the growth axis (Fig 6) that, within dating uncertainty, could be associated the long and relatively mild interstadial 14 (Dansgaard et al. 1993; Meerbeeck et al. 2011; Moseley et al. 2014). In comparison to δ^{18}O speleothem records from Central Europe (Moseley et al. 2014), the δ^{18}O signal of FHW-1 is enriched by c. 5.5 to 7 ‰ reflecting the closer proximity to the North Atlantic ocean and the lower elevation of Fairy Hole.

The nearest cave system where a programme of uranium-series dating has taken place is the Lancaster Hole/Ease Gill Caverns system on Casterton Fell (Brook et al. 1994 pp118-170), 18 km to the north east of Warton Crag. As part of a major alpha-spectrometric dating study by Gascoyne et al. (1983a &b), four samples from Colonnade Passage and Bridge Hall in Lancaster Hole gave dates within the range of 52 to 58ka. A later study in the system using thermal ionisation mass spectrometric methods (Baker et al. 1995) identified a period of active speleothem growth between 55.6 ± 4.3 and 58.8 ± 1.1 ka in another flowstone sample from Colonnade Passage. A compilation of 325 uranium-series dates from previous work across the Yorkshire Dales karst by Latham and Ford (2013) records 20 dates between 50-60 ka, the most dates recorded for any 10 ka period predating the Holocene. The date obtained from Fairy Hole therefore falls within a period of very active speleothem growth in the north of England.

Conclusions

A U-Th MC-ICPMS date obtained from speleothem material recovered from excavation debris outside Fairy Hole, Warton Crag, shows the relict phreatic lift was drained by MIS 3. This confirms a suspected pre-Last Glacial Maximum age for the relict phreatic cave fragments that are found across the Morecambe Bay karst. The study shows datable speleothem material does exist in the area. This preliminary work should hopefully lead to further detailed studies to elucidate the chronology of the intriguing lowland karst surrounding Morecambe Bay.

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Fig 1. Location map. Reproduced from Waltham and Lowe 2013 with permission.

Fig 2. Fairy Hole entrance. The photographer is stood on the grassed over spoil heap from the 1950/60s caver excavation.

Fig 3. The instruction notice to cease digging in Harry Hest Hole.

Fig 4. Fairy Hole. The view from the 1990s excavated shaft back towards the entrance.

Fig 5. Speleothem sample FHW-1 collected from Fairy Hole, Warton Crag. The black line on the sample indicates the position of the U-Th sub-sample. The scale bar is 2 cm.

Fig 6 Stable isotope results relative to distance along growth axis with the position of the U-Th sample highlighted

Table 1 U-Th dating results

Table 2 Bedrock stable isotope results