SUBTERRANEAN GLACIAL SPILLWAYS: AN EXAMPLE FROM THE KARST OF SOUTH WALES, UK

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Many karst areas in the UK have been glaciated one or more times during the last 0.5 Ma, yet there are few documented examples of caves in these regions being affected by glacial processes other than erosion. The karst of South Wales is one area where sub or pro-glacial modification of pre-existing caves is thought to occur. Evidence from the Ogof Draenen cave system suggests that caves can sometimes act as subterranean glacial 'underspill' channels for melt-water. This cave, one of the longest in Britain with a surveyed length of over 70 km, underlies the interfluve between two glaciated valleys. Sediment fills and speleo-morphological observations indicate that melt-water from a high level glacier in the Afon Lwyd valley (>340m asl) filled part of the cave and over-spilled into the neighbouring Usk valley, temporarily reversing non-glacial groundwater flow directions in the cave. It is suggested that this may have occurred during a Middle Pleistocene glaciation.

(Note: Welsh terms used in this paper: Ogof = Cave, Afon = River, Cwm = Valley, Mynydd = Mountain).

1. Introduction

Most of the upland karst areas in the north and west of the UK have been glaciated several times during the past 0.5 Ma, particularly during the Marine Isotope Stage (MIS) 12 Anglian glaciation (equivalent to the Elsterian of northwest Europe) and the MIS 2-4 Devensian glaciation (equivalent to the Weichselian), but also during Middle Pleistocene glaciations. Glaciations can have profound and complex effects upon karst landforms and their underlying aquifers, and may destroy, inhibit, preserve, or stimulate karst development (Ford, 1987). Sub-glacial water flow can be considerable, especially in active, warm based glaciers, and at the margins of glaciers and ice sheets. Where these are in contact with karstified aquifers, there is scope for significant input of allogenic melt water into pre-existing cave systems (Lauritzen 1984; 1986).

The impact of glaciations on caves in the UK is poorly understood, with few documented examples of caves being affected by glacial activity except through valley incision and erosion. One example of a cave system being affected by glacial activity is Dale Barn Cave in the Yorkshire Dales karst of northwest England, which is thought to have been reactivated by sub glacial melt waters (Murphy et al., 2001). This largely phreatic system connects two adjacent glacial valleys, Chapel-le-Dale and Kingsdale near Ingleton, Yorkshire. Speleothems dated to 343.4 (+86.0/-47.7) ka within the Illusion Pot section of the cave suggest that the conduit was drained during or prior to Marine Isotope Stage 10. However, scalloping on these speleothems suggest it underwent a second, later phreatic episode, with water forced uphill from Chapel-le-Dale to Kingsdale, a distance of approximately 1.5 km. Sediments preserved within the conduit contain distinctive lithologies derived from the Chapel-le-Dale end of the cave, and resemble those described from sub-glacial eskers. The reactivation of the conduit is most plausibly explained by sub-glacial drainage near the snout of the Chapel-le-Dale glacier flowing through to the higher, but unglaciated Kingsdale valley.

In the karst of South Wales, there is further evidence for glacial modification of pre-existing cave systems through melt water recharge. Copious amounts of sediment have been introduced into some caves by glacial melt-water, notably those under Mynydd Llangattock (Smart and Gardner, 1988). This has led to ponding and localized paragenesis; blocking some passages, reactivating others and in some cases, facilitating the development of new conduits (Farrant and Smart, 2011). In Ogof Agen Allwedd, Simms and Hunt (2007) provide evidence of sediment influx, glacial flooding and impoundment and suggest that glacial damming and recharge from melt-water might have been a significant factor in its development. The discovery of a major new cave system Ogof Draenen in 1994 (Farrant and Simms, 2011) a few kilometers to the southeast of Mynydd Llangattock has provided additional evidence for the utilization of caves by glacial melt water.

2. Ogof Draenen

Ogof Draenen [National Grid Reference SO 24631 1179] is a complex multiphase intrastratal cave system located six kilometres south-west of Abergavenny, South Wales (Figure 1). It is currently one of the longest cave systems in the UK at more than 70 km in length and spanning over 150 m in elevation (Chelsea Speleological Society and Stevens, 1997; Waltham et al., 1997). The cave is developed within Lower Carboniferous limestones on the north-eastern margin of the South Wales coalfield. The limestones are overlain by Upper Carboniferous siliciclastics including the Twrch Sandstone Formation ('Millstone Grit') and the 'Coal Measures', a cyclical sequence of sandstones and mudstones with some coal seams (Barclay, 1989). The geological structure is relatively simple, with dips to the south-west at between 5° and 20°. Ogof Draenen underlies the interfluve between the deeply incised Usk valley and its tributaries to the north and east, and the smaller Afon Lwyd valley to the west.

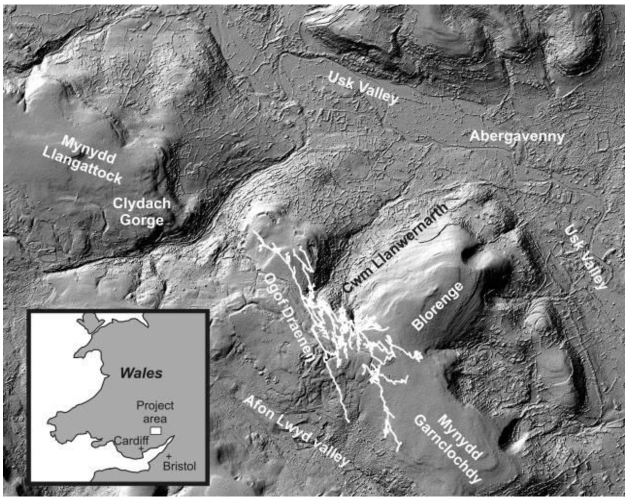

Figure 1. Nextmap hill-shaded surface model image of the north-eastern part of the South Wales coalfield and the Usk valley, showing the location of Ogof Draenen.

The cave has had a long and complex evolutionary history (Farrant and Simms, 2011; Simms and Farrant, 2011). It essentially comprises three vertically stacked, genetically separate, cave systems linked by phreatic under-captures, shaft drains, chance passage intersections and invasive vadose inlets.

The present autogenic catchment is very small as the limestone forms only a relatively narrow outcrop along the steep scarp of the Usk valley. Consequently, recharge throughout the cave's history has been predominantly allogenic, derived largely from numerous small streams draining the Upper Carboniferous clastics that cap the escarpment above the cave.

The higher level passages in the cave system (those that lie up dip to the east of the Score-Gilwern Passage conduit) are considered to have drained south, initially to resurgences at c. 360 m above sea-level (asl) in the Usk valley (Farrant and Simms, 2011), and then to progressively lower resurgences in the Afon Lwyd valley at 360-320 m asl. Subsequent cave development occurred in response to valley incision in the Clydach Gorge to the north, effectively reversing the hydraulic gradient. This change facilitated the development of a lower level series of passages (the Score-Gilwern Passage conduit) that flowed northwest to a former resurgence in the Clydach Gorge at 320 – 300 m asl (Figure 2). Subsequent valley incision in the Afon Lwyd valley caused a second reversal in flow direction, this time to the south, creating the present Beyond a Choke stream-way, which resurges 10 km to the south near Pontypool at 120 m asl. This streamway is fed by a series of small inlets and stream sinks along the margin of the overlying sandstone cover.

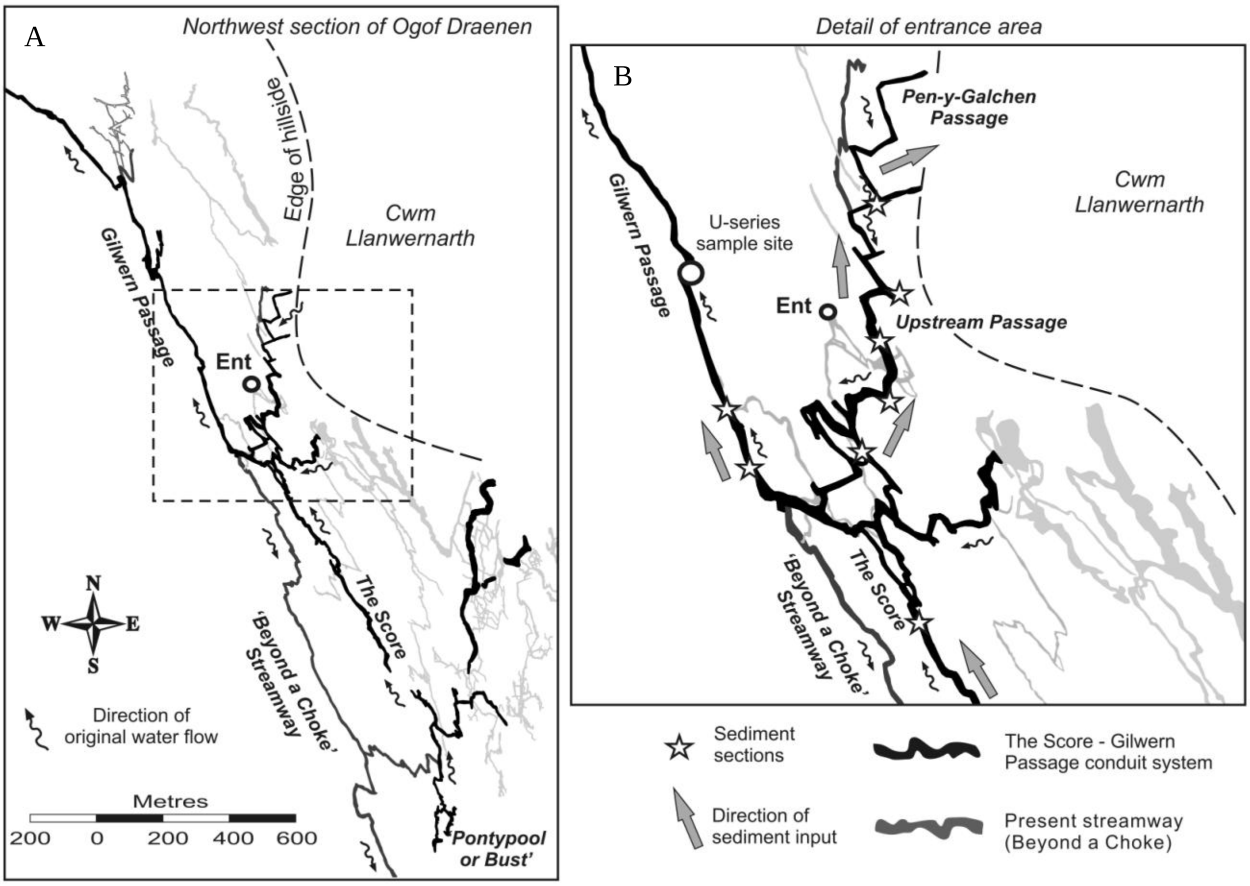

Figure 2. Outline centre-line survey of Ogof Draenen, adapted from surveys by Chelsea Speleological Society and Stevens (1997). A. The northwestern part of the cave. B. Inset of area around the cave entrance. The black passages are those developed during the Score-Gilwern Passage conduit phase of development, whilst the Beyond a Choke streamway (dark grey) represents the final phase of cave development. Directions of water flow are those when the passage was formed. The rest of the cave is shaded pale grey.

3. Cave sediments

Observation of the sediment fills in and around the northern end of the main streamway and its tributaries

(Gilwern Passage, Upstream Passage, The Score and Pen-y-Galchen Passages; Figure 2) suggested that two distinct sediment facies occur in this area. These comprise coarse, poorly sorted sands and gravels in the active streamway; and relict, finer-grained, silt, sand and sandy gravel preserved at higher levels. To characterize these sediments, samples were collected from over 30 sites and subjected to clast size, lithology and facies analyses (Pash, 2003; Trowbridge, 2003). Clast lithology data, together with two surface streams for comparison is shown in Table 1, and particle size cumulative frequency graphs in Figure 3.

Table 1. Clast lithologies for the 2000 – 3350 mm particle size range (Mean %) for the present streamway, Gilwern Passage and two surface sites. The 'Total Sandstone' is a combination of 'Millstone Grit' and Sandstone. The glacial till samples were collected from Forgeside, near Blaenavon [NGR SO 2471 0876], whilst the Coal Measures sample was taken from a tributary feeding the River Clydach at [NGR SO 2156 1254]. Data from Pash, (2003).

Lithology (Mean %)	Beyond a Choke Stream-	Gilwern Passage	Glacial Till (surface)	Coal Measures (surface)
Mudstone (Shale)	67.4	58.9	28	100
Sandstone	16.2	20.7	38.4	0
'Millstone Grit'	7.1	11.5	25.1	0
Quartz	6.7	7.5	6.5	0
Limestone	1.1	0.7	0	0
Total Sandstone	*23.3*	*32.2*	*63.5*	*0*
Carbonaceous clasts	1.4	0.7	2	0

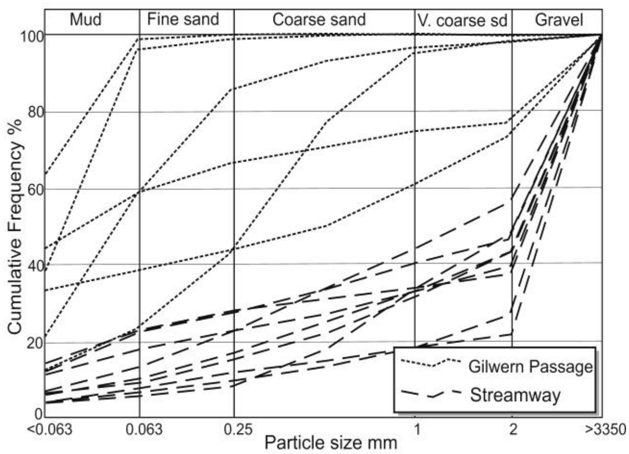

Figure 3. Cumulative frequency plots for the streamway and Gilwern Passage sediments.

Sediments in the active streamway are dominated by poorly sorted, sandy gravels comprising mostly allogenic mudstone and sandstone clasts, often with a dark grey manganese patina. Most of the clasts are angular to sub rounded. Angular clasts of limestone, derived from passage collapse and breakdown (largely caused by vadose incision and secondary gypsum growth in fractures) are common, but not appear to be undergoing significant transport. These are typical of the thalweg facies of Bosch and White (2007). A second distinct facies occurs as sediment banks and remnant fills preserved up to 22 m above the present stream-way and in neighbouring relict passages. This consists of fine- to medium-grained, moderately sorted, pale grey, brown and black, cross-bedded sand, silty sand and laminated clays. Minor amounts of coarse sand and gravel comprising mudstone and quartz occur in places, but few large clasts are present. Remnants of this once extensive fill can be observed throughout the upper reaches of the streamway (Upstream Passage) and surrounding passages. Sedimentary structures are often picked out by conspicuous, very distinctive, dark grey or black laminae, comprised of coal, carbonaceous or manganese stained material. These cross-bedded sands are more typical of the channel deposits of Bosch and White (2007), but locally are capped by laminated sediments of the slack-water facies.

Excellent exposures occur in Gilwern, Upstream and Pen-y-Galchen passages. At the southern end of Gilwern Passage (307 m asl), >2 m of fine- to medium-, locally coarse-grained, cross-bedded sand with coal-rich laminae overlain by a few centimetres of fine grained, laminated silts can be seen. Cross bedding here and ripple marks 200 m farther downstream indicate northward flow. Significantly, no other deposits are known in the rest of Gilwern Passage and its northerly continuation. A similar sequence can be seen in Upstream Passage, 50 m north of Cairn Junction at 321 m asl. Here up to two metres of fine- to medium-grained dark grey sands overlying boulders are capped by 1 m of laminated silts (Figure 4).

Figure 4. Desiccated, cracked laminated silts overlying fine-grained silty sand, draped over breakdown, Upstream Passage (photo M J Simms).

Another 100 m upstream at the same elevation, plaques of cross bedded sands (Figure 5) can be seen high up on the walls, at least 4-5 m above the current floor and within a couple of metres of the roof. The 0.5 m high northerly dipping foresets are picked out by the dark grey and black carbonaceous or manganiferous laminae.

A short distance further on the large passage ends in a sediment choke, again comprised of fine-grained dark grey sands with ripple cross-lamination showing northward flow. Remnants of similar, but coarser sand again with northerly dipping cross beds, and sometimes cemented by calcite can be seen on the walls of Pen-y-Galchen Passage. Similar coal-rich sediments occur further south in ‘The Score’, an inlet passage off White Arch Passage, at 313 m asl. This passage is the upstream continuation of the Gilwern Passage conduit (Farrant and Simms, 2011), and contains an abundant sandy fill throughout, as does its southerly continuation ('Crystal Mole' passage and 'Pontypool or Bust'). In the Entrance Series, a conspicuous tide-mark is present on the passage walls up to an elevation of c. 325 m, indicating the maximum sediment fill level.

Figure 5. Cemented remnants of cross-bedded coaly sands preserved several metres above the floor of Upstream Passage. Cross bedding indicates flow to the left (‘upstream’). Height of face shown is about three metres. Photo M J Simms.

It is clear that these passages were largely filled with sediment in the past. The sedimentary structures preserved in the deposits within Upstream Passage and its tributaries indicate flow ‘upstream’ into progressively smaller vadose inlet passages. This is in the opposite direction to the present stream and the regional hydraulic gradient. Moreover, these sediments overlie extensive breakdown indicating they were deposited after considerable vadose incision and collapse. The sands bear no resemblance to the poorly sorted, manganese stained, fine-medium grained fluvial sand and gravel currently in transport. Today, even in extreme flood conditions, water levels in Upstream Passage rarely exceed a metre in depth, barely enough for the stream to be visible above the boulder floor and 4-6 m below the relict cross bedded sands observed on the passage walls. Very little sediment is transported during these floods; indeed, many of the gravel banks in the inlet streams are cemented with a manganese and iron oxide coating.

Significantly, no relict sediment deposits occur in the southerly continuation of the streamway downstream of the junction with Gilwern Passage. This part of the streamway (‘Beyond a Choke’) is a late-stage under-capture off the relict MS&D-Score-Gilwern Passage conduit (Farrant and Simms, 2011), and only carries a small amount of sandy gravel in the active stream. Unlike Upstream Passage, no sediments are preserved above stream level. The point of capture is clearly marked at the southern end of Gilwern Passage where the stream that flows down Upstream Passage swings south into a smaller, lower level passage, whilst the roof tube swings north into Gilwern Passage.

It is clear that these finer grained, carbonaceous and manganiferous sands seen in Gilwern Passage, The Score and Upstream Passage are genetically distinct from those currently in transport in the active stream. Although both are fluvial sediments, there is a striking difference between them in composition, fabric and volume of sediment in transport. As such they must have been brought into the cave system under very different hydrological conditions. The presence of fine fragments of sandstone and mudstone, together with abundant quartz clearly indicates an allogenic source, most probably from the overlying Upper Carboniferous Coal Measure sandstones and the Twrch Sandstone Formation. The cross bedding preserved within these relict sediments indicate that when they were emplaced, hydraulic gradients were locally reversed to that of the stream that formed the passage. This must have been a temporary reversal, as these sediments have since been largely flushed out and the former hydraulic gradients restored. Moreover, the time during which the sediment was emplaced must have been short lived as there is no significant evidence for dissolution, scalloping or paragenetic modification of the passage morphology (Farrant and Smart, 2011). No pendants, notches, wall anastomoses or half tubes have been identified in Upstream Passage or in Gilwern Passage. Clearly, fluvial transport under present climatic conditions cannot account for these anomalous sediments. An alternative explanation is that the sediments were emplaced during glacial or pro-glacial conditions when glacial melt water was able to transport significant amounts of sediment into the cave. This hypothesis has been invoked for the extensive sediment fills in the Mynydd Llangattock caves, notably Ogof Agen Allwedd (Smart and Gardner, 1989; Simms and Hunt, 2007), a few km to the north across the Clydach Gorge (Figure 1).

4. Discussion

4.1 Age of the sediments.

Although these relict cave sediments have not been dated directly, two strands of evidence suggest that they are of considerable antiquity and predate the last Devensian (MIS 2-4) glaciation. Firstly, the lack of fine-grained relict sediments in the ‘Beyond a Choke’ streamway is in marked contrast to the abundant sediment fills in the passages associated with the relict MS&D-Score-Gilwern Passage conduit. This suggests that the finer grained sediments were deposited prior to the development of the streamway. This passage, which is up to 30 m high in places, is too large to have developed since the end of the last glaciation. It currently flows south to resurgences in the Afon Lwyd valley and probably developed during and subsequent to the last interglacial (MIS 5). Secondly, much of the sediment fill has been flushed out, leaving remnants preserved up to 6 m above the floor. Whilst sediment removal can be a very efficacious process, it is hard to imagine this amount of sediment being removed since the end of the last glaciation.

A speleothem in Gilwern Passage was taken for Uranium series dating at the NERC Isotope Geosciences laboratory, at the British Geological Survey, Keyworth. The sample (OD-07-96E) was dissolved in hydrochloric acid, and the uranium and thorium were co-precipitated with Fe-hydroxide and separated by ion exchange (AG1x8 and UTEVA). Uranium isotopes were measured by TIMS (Triton) and Thorium by MC-ICP-MS (Nu HR). The sample yielded an age of 302.9 ± 2.8 ka (Table 2) which suggests the passage was vadose by this time. However, it is not clear whether the sediment fill predates speleothem deposition or represents a later stage reactivation of the passage. Either way, it is probable that the sediments predate the last interglacial (the most likely period when the present streamway developed), and possibly as old as the Anglian (Elsterian) glaciation (MIS 12). Further U-series dating work is currently in progress to constrain the age better.

Table 2. U-series data. U and Th total procedural blanks were <26 pg and <8 pg, respectively. Data reduced using an in-house spreadsheet and Isoplot with decay constants from Cheng et al. (2000).

Sample	**U ppm**	**^{232}Th ppm**	**[^{230}Th/^{232}Th]**
OD-07-96E	25.9	0.0014	9.088E+04
[^{230}Th/^{238}U]	**2σ%**	**[^{234}U/^{238}U]**	**2σ%**
1.637	0.22	1.566	0.04
ρ 08-48	**Age (ka)**		**[^{234}U/^{238}U]$_{initial}$**
0.000	302.9±2.8		2.335±0.010

4.2 Glacial geomorphology

Mid and South Wales was glaciated on at least two occasions during the Pleistocene; during the Anglian (Elsterian) and more recently during the Devensian (Weichselian) glaciation (Barclay, 1989). A further three Middle Pleistocene glaciations have been postulated, during MIS 16, 10 and 6 (Saalian glaciations) (Lee et al., 2012). Whilst the extent of some of these Middle Pleistocene glaciations across Britain may be controversial, it seems likely that upland parts of Wales would have been at least partially glaciated during these events. During any of these glaciations, it is probable that Ogof Draenen would have lain at or close to the southern margin of the ice sheet at various times (Ehlers and Gibbard, 2004).

These ice caps probably had several spreading centres, principally in mid and north Wales, but a local dispersion centre was also likely over the Brecon Beacons. These reconstructions are supported by the presence of till up to elevations of 445 m asl on the flanks of the Usk valley and its tributaries (Barclay 1989), and glacial striae on the Llangattock plateau. The uplands of Mynydd Llangattock, Gilwern Hill and Mynydd Garnclochdy were probably occupied by ice caps (as they were during the Late Glacial Maximum where glacial till forms an extensive sheet at c. 350 - 400 m around Brynmawr). To the south the ice was funneled into a series of valley glaciers, including the Afon Lwyd glacier. Locally derived gravelly till (of presumed Devensian (MIS 2-4) age) over 10 m thick is present in the Forgeside borehole [SO 2504 0828; 345 m asl], and thin pre-Devensian tills extend south as far as Pontypool. To the north, the major glacier in the Usk valley was largely confined to the present valley (Barclay, 1989). During the Devensian, the ice surface was not much above 250 m in the Abergavenny area, terminating in a complex series of moraines around Kemys Commander [SO 340 040] south of Abergavenny. Patches of morainic material demonstrate that the small north-east facing cirques on The Blorenge contained small glaciers or snow patches, but there is little evidence for a major glacier in Cwm Llanwernarth during this time. We suggest that during either the Anglian (Elsterian) glaciation, or possibly during MIS 10 and 6, similar conditions prevailed (Figure 6). It is possible that a comparable glacial setting may have occurred during the early Devensian (MIS 4), but the size and maturity of the Beyond a Choke streamway suggests that the sediments were deposited prior to this time.

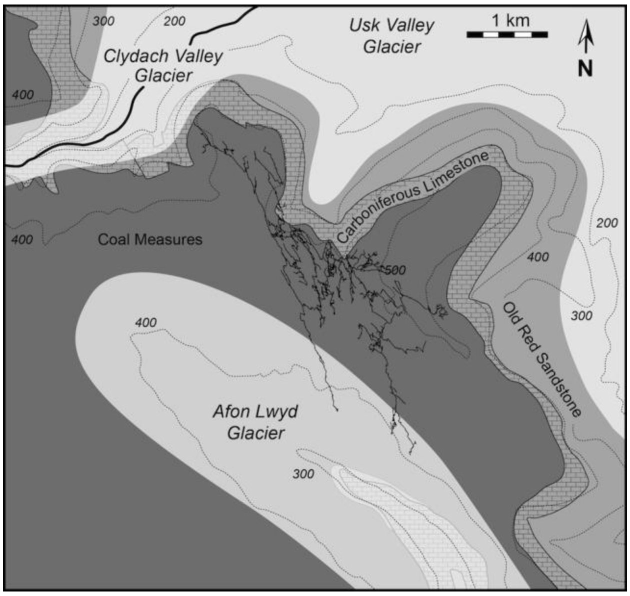

Figure 6. Proposed glacial setting during periods of subterranean glacial under-spill through Ogof Draenen. Contours at 100 m intervals. Glaciated areas are pale grey.

The presence of a glacier in the Afon Lwyd valley at elevations above 350 m, and an ice surface less than 250 m in the lower Usk valley, coupled with open, relict cave passages extending through the intervening mountain provided suitable conditions for the reactivation of these passages by glacial melt-water. Sediment laden melt water flowed into the cave via inlets along the eastern margin of the Afon Lwyd valley around Blaenavon (>320 m asl). From these and other inlets, water flowed north via a currently sediment choked passage (‘Pontypool or Bust’) into ‘The Score’ and then into the start of Gilwern Passage and the surrounding area. In doing so, it deposited fine-grained sand and silt up to an elevation of c. 320-325 m asl. With outlets to the north (the Clydach Gorge) blocked by glacial ice, sediment or collapse, and the present streamway not yet in existence, the only available outlet was into Cwm Llanwernarth, a small tributary valley to the Usk.

Although this valley probably contained a small cirque glacier, the glacier surface was considerably lower than the Afon Lwyd (Figure 7). Consequently, the water then flowed out ‘upstream’, via a series of passages at the eastern end of Upstream Passage, including Pen-y-Galchen Passage. These former inlet passages had previously been truncated by valley incision at the head of Cwm Llanwernarth, but because they form the lowest overspill point in the cave system, they were subsequently reactivated as series of temporary resurgences.

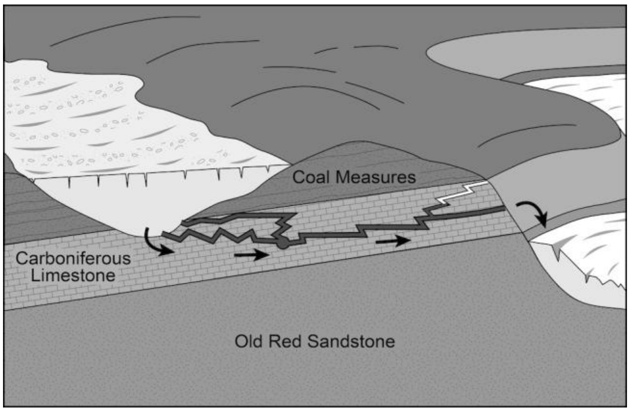

Figure 7. Schematic cross section between the Afon Lwyd valley to the west (left) and the Cwm Llanwernarth valley to the east.

6. Conclusions

Within Ogof Draenen, several distinct sediment facies can be observed in the network of passages around Gilwern Passage, Upstream Passage, The Score and the present streamway. In particular, the deposition of a distinctive suite of fine grained sediments that infilled parts of the cave to depths of over 20 m is ascribed to the influx of sediment laden glacial melt water, either during the Anglian (Elsterian) glaciation or possibly during MIS 10 or 6. This melt water, derived from the base of a glacier in the Afon Lwyd valley flowed into the lower part of Ogof Draenen via many pre-existing inlets. As the level of glacial ice in the neighbouring Usk valley was significantly lower, this melt-water was able to flow north through the cave (in the opposite direction to normal interglacial drainage), over spilling through various truncated inlet passages in the headwall of the Cwm Llanwernarth cirque to form a series of temporary springs at c. 320 m. The cave thus acted as a subterranean glacial spillway, transferring water from one catchment to another.

Acknowledgements

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