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Field observations

On a visit to Shapfell Quarry, Hardendale (NY 585 145) in February 2019, members of Cumbria GeoConservation discovered a suite of small gour pools in a stream on the east side of the quarry entrance road (Figure 1). The pools represent deposition of tufa in such a way that it builds up a barrier leaving behind a pool of water. The tufa deposits are a startlingly clear light cream/white colour, and result from an unusual set of circumstances which have arisen within the quarry since blasting ceased in 2009 and restoration began.



Figure 1 Small gour pools near former entrance to Shapfell quarry, 13 Feb 2019

In August 2019, when members of the Cumberland Geological Society visited Shapfell quarry, we were directed to a much larger area of these gour pools in the south western corner of the quarry, by Chris Queen, Shapfell Manager (see excursion report). A small spring or seepage emerges from a bedding plane about halfway down the quarried rock face, a 2m cliff of Lower Carboniferous Knipe Scar Limestone (KSL). The bedding plane may have been widened by previous blasting (Figure 2). Where the spring emerges into the quarry, it has deposited a large area of fresh, light-coloured flowstone; a deposit of considerable complexity and beauty (Figure 3). At the foot of the cliff, the emerging stream spreads out over an area of calcite pools,



Figure 2 Lime rich water issuing from a bedding plane, Shapfell quarry 17 Aug 2019

each with a small dam over which a thin film of water flows (Figure 4). Small cave pearls were seen in some of the pools. The features are fresh, actively forming, having formed within the last ten years. Their area, speed of formation and pristine nature are notable. They may represent the fastest rate of present day tufa deposition so far recorded.

Terminology: tufa or travertine?

Despite an extensive literature (only a sample of which is referred to here) there appears to be little agreement over the use of the terms tufa or travertine, which are often used interchangeably, as discussed by Ford & Pedley (1996), Golubic (2008),



Figure 3 Tufa/ flowstone deposition on quarry face, Shapfell quarry 17 Aug 2019



Figure 4 Extent of gour pool deposition in Shapfell quarry 17 Aug 2019

Banks et al (2012a) and Farr et al (2014). Similarly despite many classifications of tufa types, none appear to cover the features observed in Shapfell Quarry.

The term travertine, a deposit which may be siliceous or calcareous, is usually reserved for hot spring deposits, though the term is widely used in the USA. The large open air travertine pools of Yellowstone National Park are well known. In classic karst areas, and in thermal systems, gour pools may be up to metre scale, arranged stepwise down a slope. The Plitvice Lakes in Croatia have massive travertine (or tufa) dams (Kresic N., and Stevanovic, Z. 2010). Pentecost (1993 & 2005) uses the term travertine in his seminal works. He defines travertine as chemically precipitated limestone formed around seepages and springs in cave environments. He outlines three criteria for tufa classification; water temperature, fabric and morphology, noting that tufa deposits are characteristic of karst environments and, unusually are formed by constructive land surface processes. His classification includes tufa deposited on vegetation, on steep slopes, as stream barrages and crusts and in lakes, notably Malham Tarn. Many of these processes involve bryophytes and algae. None appears to apply to the pools in Shapfell quarry. Farr et al 2014 consider Pentecost's classification of tufa deposits to be the most applicable to Britain; however they do not adopt the term travertine. The BGS opts for the term tufa, as used by the European Union and Joint Nature Conservation Committee, UK.

Tufa is usually defined as limestone deposited from ambient temperature water. It has long been known from 'petrifying well' sites, such as Mother Shipton's at Knaresborough and Matlock Bath, (Wolverson Cope 1978). There are many studies of tufa deposits in the White Peak (Banks et al 2012b). Tufa is also seen at waterfall sites, such as Janet's Foss, Malham, where the depositional process is considered to be aided by moss. Brumhead (1979) describes 'tufa screens' in Gordale Scar where the deposits have preserved leaves and twigs, similar to the petrifying wells. Studies in China (Chen et al 2004) confirm that tufa deposition at waterfall sites is due to CO_2 outgassing, low pressure and jet flow effects, and not to the effects of vegetation. The gour pools in Shapfell Quarry appear to

be unrelated to either vegetation effects or to waterfalls. Baker & Simms (1998), in a study into a possible decline in tufa deposition in the mid Holocene in Wessex, SW England, suggest a significant underreporting of contemporary tufa deposition. This may be particularly the case for features in quarries.

I use the term gour pools to describe the landforms in Shapfell Quarry, as these tufa terraces resemble features seen in caves in NW England, in their size, extent, appearance and absence of vegetation. The name gour is a caving term, possibly not widely recognised elsewhere. Gour pools are considered a common feature in caves, and are referred to, though not explained, in caving guides (Brook et al 1974 for example): they are rare and unusual above ground, and especially in a quarry. Gour pools form on a gently sloping surface. Gour is defined as a flowstone deposit of calcite or tufa built up along the edge of a pool due to precipitation from a thin film of water. Inside the pool more calcite may be precipitated as crystals or pearls.

How gour pools form in general

Gour pools form by solution of limestone followed by chemical precipitation or redeposition, according to the reversible equation

$CaCO_3 + H_2O + CO_2 \leftrightarrow Ca(HCO_3)_2$

Limestone readily dissolves in acidulated rain water, to form the soluble calcium hydrogen carbonate. When water supersaturated with $Ca(HCO_3)_2$ reaches the surface, or a large underground cavity, the reaction is reversed, CO_2 is released to the atmosphere and $CaCO_3$ is redeposited as tufa, leaving lime-rich water to flow away.

Underground deposition

Inside caves, this process forms the familiar formations, (speleothems), of stalactites from the ceiling, stalagmites on the ground, pillars where they join, and flowstone on the walls. Deposition begins at the air/water/rock interface. Banks & Jones (2012) report that speleothems can occur outside caves and cite an example of flowstone from lime-rich mortar at Lindisfarne. Straw stalactite speleothems are also reported from under railway bridges (Smith,2016), and in Smardale NNR (personal observation).

In certain circumstances where $CaCO_3$ rich water flows over a gentle slope, gour pools may result. These build up as cascades of redeposited tufa, with wavy edges, often tinged with colours from trace amounts of chemicals. Turbulence over the gour pool dam outgasses the CO_2 from the water resulting in mineral precipitation on the edge (Figure 5).

Specific formation in Shapfell Quarry

Solution of limestone depends on the nature of the limestone, overlying rocks and soil and/or plants, the type of water flow and variations in temperature and pressure. The following section examines the extent to which these factors are operating in Shapfell Quarry.

For the rapid formation of gour pools, limestone of great purity and water flow, through joints and across bedding planes, are needed. The KSL is classed as 'high purity limestone' with over 97**%** $CaCO_3$. Thin layers of impermeable shales may help direct the water out of the quarry rock face, essentially as a spring. Cantonati et al (2016) term these Limestone Precipitating Springs (LPS). They identify six types, and have developed a conceptual model to predict where LPS may occur, based on evidence from northern Italy. Their model does not appear to include the type of gour pools seen in Shapfell Quarry. They consider such springs to be threatened features despite their protection in the EU Habitats Directive.

As part of the quarry restoration process, 'fines', that is less than millimetre-sized lime dust, from the quarry washing plant, have been returned to the quarry base above the lowest levels. This has provided readily soluble limestone dust. Percolation water can be in intimate contact with the fines, which has resulted in very rapid dissolution and redeposition. Interestingly, tufa deposition in drains has been the subject of research in north-east Ohio from the 1980s where it is regarded as a problem leachate, from iron and steel slag. Research suggests that certain types of slag show a high tufa generating potential, (Gupta et al 1994). Like limestone fines, the slags show a high surface area and are reactive with CO_2 charged water. Similarly Banks & Jones (2012) note that anthropogenic materials, such as lime processing waste, can have a greater propensity for dissolution. They cite a tufa barrage along a stream in Derbyshire, but do not mention gour pools.

The precise water source for the Shap Quarry gour pools is not known. It appears to be only a small water flow. It is likely that the water source is rainfall, seeping through the fines, and flowing underground for a short distance through joints widened by blasting. 'Aggressive' rain water (that is water with a high CO_2 content) will become totally saturated with limestone at only a short distance below the surface. The role of mixed-water corrosion which renders the water aggressive again, is not known at present as



Figure 5 Rimstone edge to gour pools 17 Aug 2019

details of water flow within the KSL are not understood.

The solubility of CO_2 in water reduces as temperature increases: the cool ambient temperatures at 300m altitude at Shapfell may aid the limestone redeposition.Changing pressure may not be a relevant factor here.

Overlying glacial deposits, soil and vegetation were removed during quarrying of the KSL. Their absence is unusual in the processes of acidifying rainfall, and in tufa deposition. Despite the on-going restoration, the area of Shapfell Quarry restored with limestone fines is not yet vegetated, and unusually plants appear to have had no role in forming the gour pools. Further research is needed into these questions.

Plans for research and conservation

The wide range of unanswered questions suggests the need for a research project, which is planned for summer 2020. This project will aim to record the gour pools, their size and extent, shape, slope angle and location. Measurements of rainfall, water pH, Ca content and flow rates, together with deposition rates and other factors will need to be made. A more thorough literature review may also prove beneficial.

As far as has been ascertained no other similar gour pools have been reported above ground in Britain. Therefore steps are planned to protect these rare and beautiful features in Shapfell Quarry with protective fencing, and possibly boardwalks to permit continuing observations and on-going research studies. Cantonati et al (2016) consider the threats to Limestone Precipitating Springs to be 'water diversion, nutrient enrichment and lack of awareness by non-specialist persons and administrators'. It is vital that the significance of these fragile and unusual features is adequately recognised and that measures are put into place for their protection. It is important that the rainfall receiving area for the gour pools is not re-vegetated. The case for conservation is very strong.

We are indebted to Chris Queen, Shapfell manager, for making Society members aware of these gour pools. Note that Shapfell quarry is private. Geological groups may visit by prior arrangement with Tata Steel.

References

Baker, A., & Simms, M.J. (1998). Active deposition of calcareous tufa in Wessex, UK and its implications for the 'late-Holocene tufa decline'. *The Holocene* 8 (3) 359-365

Banks, VJ., & Jones P.F. (2012a). Hydrological significance of secondary terrestrial carbonate deposition in karst environments in *Hydrogeology: A Global Perspective* ed by Kazemi, GA. http://nora.nerc.ac.uk/id/eprint/16794/1/Banks__final.pdf

Banks, V.J., Jones, PF., Lowe, D., Lee, J.R., Rushton, J. & Ellis, M.A. (2012b). Review of tufa deposition and palaeohydrological conditions in the White Peak, Derbyshire , UK: implications for Quaternary landscape evolution, *Proceedings of the Geologists Association*, 123, 117-129.

Brook, D., Davies, GM., Long, MH., Ryder, P.F. (1974). *Northern Caves V 5 The Northern Dales*, p98 & 101. (This caving guide reports that Lower Pate Hole NY 678125 (near Great Asby) involves 'crawling over gours and rock floor quickly becoming too low'. For West Pate Hole NY 678121 the instructions are 'flat crawling through muddy gours'. (These cave formations will not be pristine with cavers crawling over them))

Brumhead, D. (1979). *Geology explained in the Yorkshire Dales and on the Yorkshire Coast.* David Charles

Cantonati, M., Segadelli, S., Ogata, K., Tran, H., Sanders, D., Gerecke, R., Rott, E., Filipppini, M., Gargini, A., Celico, F. et al. (2016). A global review on ambient Limestone-Precipitating Springs LPS: Hydrogeological setting, ecology and conservation. *Science of the Total Environment* 568, 624-637

Chen, J., Zhang D., Wang, S., Xiao T & Huang, R. et al. (2004) Factors controlling tufa deposition in natural waters at waterfall sites. *Sedimentary Geology* 166, 353-366

Farr, G, Graham, J, and Stratford, C. (2014). Survey, characterisation and condition assessment of *Palustriella* dominated springs 'H7220 Petrifying springs with tufa formation (Cratoneurion) in Wales. *British Geological Survey Internal Report*, OR/14/043

Ford, T.D., & Pedley, H.M. (1996) A review of tufa and travertine deposits of the world. *Earth Science Reviews* 41, 117-175

Golubic, S., Crescenzo, V., Andelika, P-M,. Tonci, G. et al. (2008) Travertines and calcareous tufa deposits: an insight into diagenesis *Geologia Croatica* 61/2-3, 363-378

Gupta, J.D. (1994). Characterization of Base and Subbase Iron and Steel Slag Aggregates Causing Deposition of Calcareous Tufa in Drains. *Transportation Research Record* No 1434 National Academy of Sciences (US)

Pentecost, A. (1993). British Travertines: a review. *Proceedings of the Geologists Association* 104 23-39

Pentecost, A. (2005). *Travertines* Berlin Heidelburg

Smith, G.K. (2016). *Cave & Karst Science* 43 (1) 4-10 (reports that calcite straws grow from concrete structures).

Waltham, A.C. (1974) *Limestones & Caves of North West England* David & Charles (This classic, site-specific, text does not extend to the Shap area and does not mention gours).

Waltham, A.C., Simms, M.J., Farrar, A.R. and Goldie H.S. (1997). *Karst and Caves of Great Britain*, *GCR Review Series No 12*. (This publication lists karst landforms, including dolines, dry valleys, limestone pavement and karren, karst types and the evolution of caves. P12 lists gour dams, as part of a flowstone cave floor. The research section refers mainly to the dating of cave sediments).

White, W.B. (2010). Springwater geochemistry of Springs, Groundwater hydrology of springs: Engineering, theory, management and sustainability, edited Kresic, N. and Stevanovic, Z. , Butterworth-heinemann, 231-268.

Wolverson Cope, F. (1978). *Geology Explained in the Peak District* David & Charles