Tufa deposits in the Via Gellia, Derbyshire

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Abstract: Detailed mapping, sampling and petrological analysis of a tufa deposit in the Via Gellia, above Cromford in Derbyshire, has enabled interpretation of the depositional and post-depositional history of the tufa in context of the geomorphology and hydrogeology of the area.

Holocene deposits of cool-water travertine (also known as tufa or secondary carbonate) are extensive and well-studied in Italy (Buccino *et al*., 1978; Chafetz & Folk, 1984; Conti *et al*., 1979; Ford & Pedley, 1996), where they form an extensive resource that is used for construction (Buccino *et al*., 1978). Although widely distributed, tufa deposits in Britain are generally less extensive (Ford & Pedley, 1996; Viles & Goudie, 1990; Ford, 2006). This makes the thick and once-economically viable deposits of tufa in the Peak District all the more interesting. Examples include the barrage deposits of Lathkill Dale and the Wye in Taddington Dale (Pedley, 1993; Pedley *et al*., 2000) and the perched spring-line deposits in Matlock (Pentecost, 1999).

The exploitation of tufa as a construction material in the Peak District dates back at least to the development of the Peak District thermal waters as Hydros, or Spas, including the opening of Matlock Baths in 1698 (Hey, 2008). A typical example of the use of tufa as a decorative stone has been retained in the grotto of the Winter Gardens at Matlock (Fig. 1). Historically tufa was also exploited for land improvement, and its use as a source of lime predates its use in construction: “the softer parts of the Tufa or deposits made by Springs from the Limestone Rocks at Matlock Bath and some other places are called *marl*, and according to tradition, were formerly used as such, but the practice is quite laid aside I believe” (Farey, 1811, v1, p457). More recently, it was observed that the soil above tufa is very fertile and that “many tons of it are annually sent out of Derbyshire” (Adam, 1851, p33) so its exploitation had not been completely set aside by 1811. Evidence of this exploitation is limited to a small number of abandoned quarry sites, including the roadside Alport Quarry and a small outcrop in the Via Gellia.

Figure 1. *Tufa wall in the Winter Gardens, at County Hall, Matlock (photo: University of Derby).*

Figure 2. *Tufa Cottage in the Via Gellia (photo: Tony Waltham).*

Tufa in the Via Gellia

An old quarry lies close to the south-eastern boundary of the White Peak, in the Via Gellia, above Cromford and south-west of Matlock. Tufa deposits crop out to the west and north-west of Tufa Cottage, a well-known landmark constructed of tufa (Fig. 2). Historic maps indicate that the quarry, which once surrounded the cottage, was in existence by 1884 and was disused by 1938. Tufa Cottage, formerly known as Marl Cottage, was built as a gamekeeper’s cottage in around 1830. The two Dunsley Springs lie at the head of the tufa deposit (Figs. 3 and 4).

Previous references to these deposits suggest that the tufa dates to 9000 to 4000 BP (Ford & Pedley, 1996). Others have recorded the stable isotopes of oxygen and carbon as a means of determining the depositional environment (Thorpe *et al*., 1980; Viles & Goudie, 1990). The aim of the current work was to map the extent of the tufa, establish its relationship with the underlying geology, examine the morphology, macro- and micro- structure of the tufa and monitor the associated spring chemistry to determine whether active deposition or erosion was occurring.

The Via Gellia tufa lies on the Bee Low Limestone Formation (Fig. 4, Table 1), which comprises thickly bedded, shallow-water limestones interbedded with basaltic volcanic rocks (Brossler, 1998; Flindall and Hayes, 1971; Macdonald et al., 1984, and Smith et al., 1967). The tufa is formed on the beds immediately underlying the Matlock Lower Lava, which occurs at a stratigraphically equivalent level to the Miller’s Dale Member around Buxton. The overlying Matlock

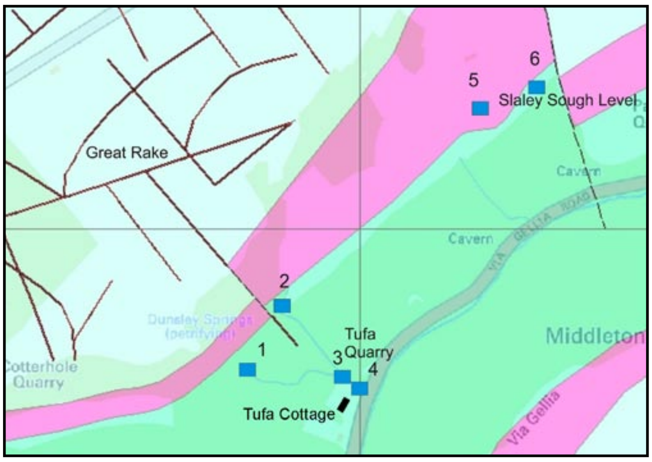

***Figure 3**. Geology around Tufa Cottage and the spring monitoring points; the Dunsley Springs are sites 1 and 2, and the Dunsley Spring Level was not monitored.*

Group comprise dark grey and grey limestones with, locally, much chert. The site lies immediately south of the Cronkston-Bonsall Fault, a significant basement fault associated with dolomitization of the limestones (Gutteridge, 1987). A sporadic cover of superficial deposits includes head on the valley sides, particularly on the southern side of the valley, pockets of glacial till on the plateau surface, tufa on the northern side of the valley (Fig. 4), and alluvium along the valley floors.

A number of NW-SE trending mineral veins cross the area and are intersected by the NE-SW trending Great Rake (Fig. 3). The lead-zinc mineralization was exploited in a number of phases, possibly even dating back to the Roman occupation of the area (Brossler, 1998). Ore minerals include galena and sphalerite, with gangue largely of calcite, barite and fluorite, and with small pockets of secondary ochre, wad and smithsonite. The latter was worked in the Bonsall Leys Liberty for the brass-making industry (Brossler, 1998; Rieuwerts, 2010). Flindall and Hayes (1971) reported on the findings of a survey undertaken on the north side of the Via Gellia by the Mines Survey Group of the Peak District Mines Historical Society (PDMHS). Beneath Bonsall Leys, the Yule Cheese Vein was drained by the Dunsley Spring Level, 150 m south-west of the Dunsley Springs (Flindall and Hayes, 1971). The southern of the Dunsley Springs aligns with the southern end of one of the NW-SE rakes, and the northern spring is close to a parallel rake.

Stage	*Group*	*Formation*
Brigantian	Craven	Longstone Mudstone
	Peak Limestone	Eyam Limestone
		Monsal Dale Limestone
Asbian		Bee Low Limestone *with Lower Matlock Lava*
Holkerian		Woo Dale Limestone

***Table 1**. Stratigraphy of the limestone.*

The Peak District forms the southern part of the Pennines, comprising a dissected upland terrain. Its karst geomorphology includes deep valleys, limestone gorges, scree-clad slopes, a range of dolines, ridges, tors and rock pinnacles (Dalton *et al*., 1999). The area exhibits a complex geomorphology that reflects a long history of uplift and erosion, with response to glacial, glaciofluvial and periglacial processes, and considerable anthropogenic modification.

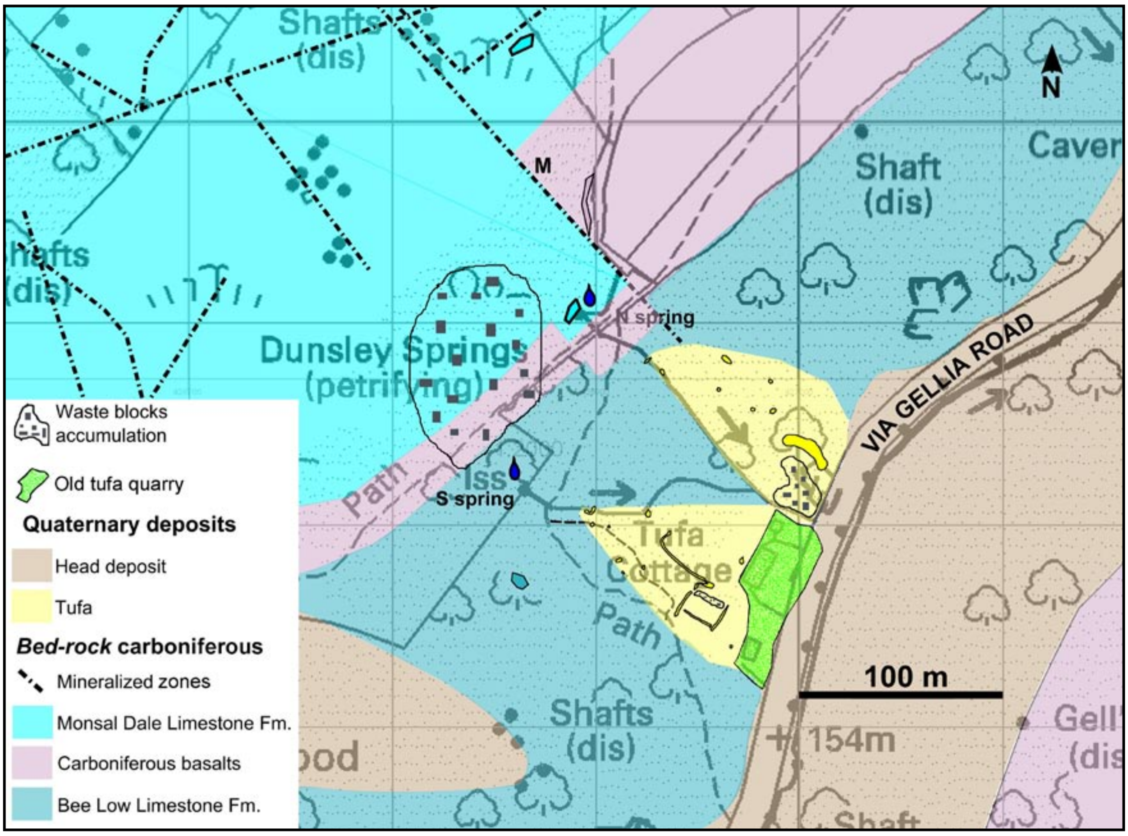

***Figure 4**. Revised geological map of the tufa in the Via Gellia; earlier maps had been generalised to show only a single patch of tufa. Broken material previously mapped as landslide debris is re-interpreted as an accumulation of mine waste derived from the mining in Bonsall Leys Liberty, which extended across the limestone plateau.*

The Via Gellia is a deeply incised, wooded valley, draining eastwards to its confluence with the River Derwent at Cromford, and is around 100 m deep in the vicinity of the tufa deposit. The profile of the valley is steep sided and symmetrically V-shaped, with a meandering thalweg. Tufa Cottage and the associated tufa deposits occupy the northern side of the valley, on the outside of a meander. The valley floor alluvium is currently occupied by an intermittent stream that receives water from both natural sources and mine adits; the stream is perennial downstream of the Dunsley Springs.

At around 325 m OD, the plateau surface above the Via Gellia largely comprises fields of pasture that are bounded by stone walls and are interrupted by scars of the former mining activity. Where they are undeveloped, the valley sides have a thick cover of deciduous woodland. Slopes of 25° or more, attributable to rapid valley incision, have resulted in slope instability and landslides, particularly in areas where beds of limestone are underlain by the basalts. The karst is locally less developed than in other areas of the Peak District; the Good Luck Mine on the south side of the Via Gellia has a long series of narrow adits, crosscuts and small stopes of the early 19th century, which have intersected a number of small solution caverns (Barker & Beck, 2010).

Anthropogenic impacts on the geomorphology of the Via Gellia are dominated by mineral exploitation, quarrying, agricultural modification and industrial development. While quarrying of the tufa has ceased, the more extensive quarrying for limestone continues. Agricultural modification has included enclosure of fields, which have been primarily used for grazing. Modification to springs to facilitate water supply for mining and industry has been widespread. Examples of this lie in documents held in the Derbyshire County Records Office at Matlock (Table 2). Historically, the springs had been used as a source for watering cattle, and during periods of drought the inhabitants of Middleton and elsewhere fetched water from the springs for their own use. Industrial development in the valley was focused on the watercourse, with a water wheel situated in the Via Gellia Mill at the junction of Bonsall Road. In 1936 the mill owner alleged that if the waters were taken from the Dunsley Springs the power and efficiency of the wheel would diminish with a consequential loss of value to the mill. The County Council (in 1934) noted that in the summer the Via Gellia Stream dries about 300 m downstream of Marl Cottage and the loss of this water is at the Whitecliffe Fault, through which it is believed water escapes into the Meerbrook Sough. A thermal spring, known as Middleton Bath, was located opposite Tufa Cottage until it ceased to flow after driving of the Cromford Sough (Ford & Gunn, 2007), but its hydrology may have been totally independent of the Dunsley springs. It is, or was, one among many small springs in the Via Gellia valley.

Date	*Action*
1935	Monitoring of the Dunsley Springs at Marl Cottage. The discharge ranged between 7.53 and 5.18 L/s between April and August 1935.
20.05.1936	Agreement between Thomas Harold Walker of Via Gellia Road, Cromford and the Urban District Council of Wirksworth, which allowed the Council to impound and use water from Dunsley Spring in the Via Gellia in the Parish of Bonsall, in the Urban District of the Matlocks. Given the notice of the Ministry of Health regarding the urgent need for water for the people of Middleton Mr Walker agreed to withdraw his opposition in return for compensation of £127.
14.08.1936	Agreement that with regard to the supply of water to the Marl Cottage the Council shall enclose Spring No.1 and provide a storage tank at Spring No. 2. Mr Key (of Cromford) agreed to the alteration of the line of the pipetrack so as to avoid a newly opened quarry at the line previously intended for the pipeline.

***Table 2**. Records from the Derbyshire Records Office pertaining to the Dunsley Springs (file items # D7017/6/32 and D7167/6/30).*

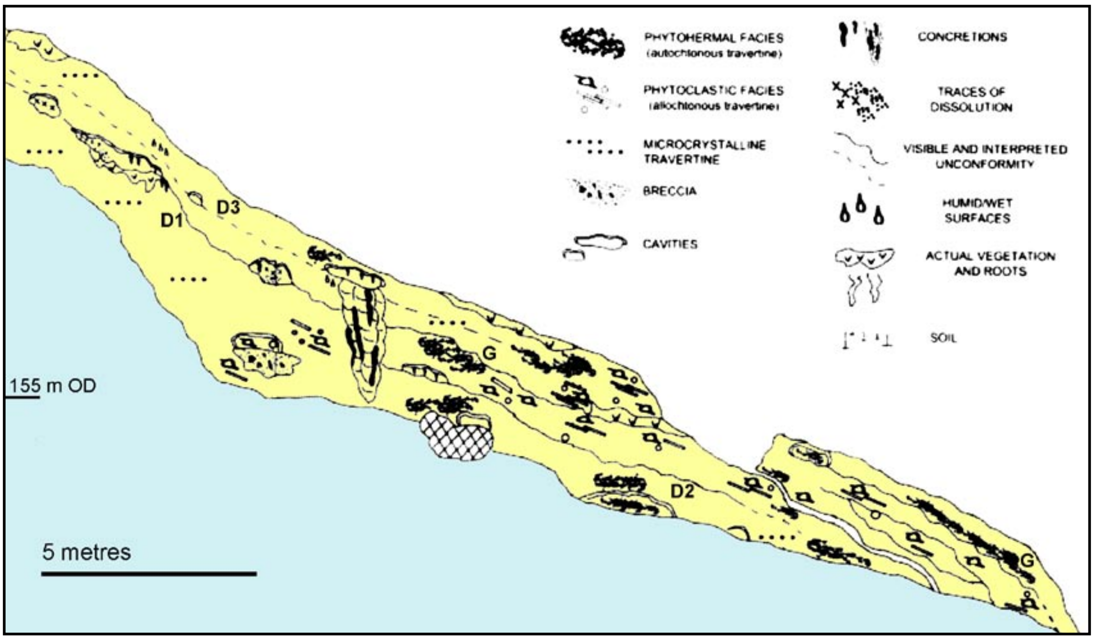

***Figure 5**. Profile of the quarried exposure within the tufa bank at SK 27015 56829. D1, D2 and D3 are unconformities, and G denotes a step in the tufa surface.*

New mapping reveals that the tufa comprises two discrete cones over the carbonate bedrock (Fig. 4). In the dense woodland, slope angles were significant for the mapping. The upper surface of the Lower Matlock Lava forms a low-angle, bedding-parallel surface, whereas the limestones form steep slopes (> 25°) that are modified by the overlying tufa (resting at angles of up to 25°). A quarried face 40 m north-east of Tufa Cottage provides a section through the northern cone of tufa (Fig. 5). This section shows a fan-shaped form, with higher slope angles on the upper valley side giving way to lower slope angles lower down the valley side. Erosional unconformities (D1, D2 and D3) in the quarry section suggests that it comprises at least four beds of tufa. Five exposures of the southern cone reveal comparable features.

Morphology of the tufa

The quarry section (Fig. 5) exposes a variety of depositional and erosional, macroscopic features of the tufa. Zones of developed (*in situ*) phytoherm (Fig. 6) appear to be more extensive higher in the sequence and comprise interwoven stems of a number of different plant species. Typically the plant stems have diameters of 1 to 5 mm and include *Cratoneurom filicinum* and *Eucladium verticillatum*. These zones are better exposed where they are blanketed by actively growing mosses. Phytoclastic (washed in) facies include foliage, stems, tree branches and tree trunks (Fig. 7) and comprise fragments of organic matter that were preserved in the tufa at the time of formation.

Microcrystalline tufa, which is grey in colour, has a sugary texture and is interpreted as reverting from sparry calcite (Fig. 8A). This tufa is generally massive and relatively dense, but with local dissolutional porosity. Speleothems and encrustations (Fig. 8) occur in a number of cavities and fractures and at a variety of sizes. Stalactites are common, with diameters of 2 mm to 2 cm. Encrustation of pre-existing phytoherm reduces the porosity of the tufa. Breccias are either matrix- or carbonate cement- supported. Dissolutional cavities include both primary and secondary cavities associated with speleothems and encrustations. Pinkish brown clayey silt deposits line a number of the dissolution cavities, and would appear to have been introduced by vadose flow.

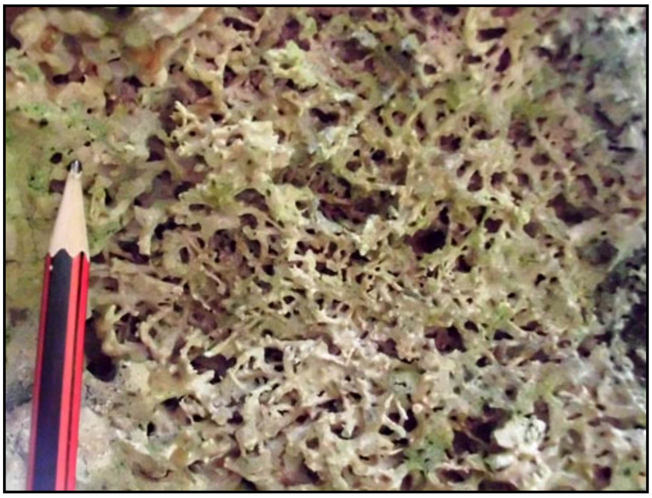

Figure 6 (left)*. Autochthonous tufa with bush-like morphology probably derived from cemented* Cratoneurom filicinum.

Figure *7. A leaf and a tree trunk preserved in the tufa at the Via Gellia; leaf scale is in mm, tree scale is in cm.*

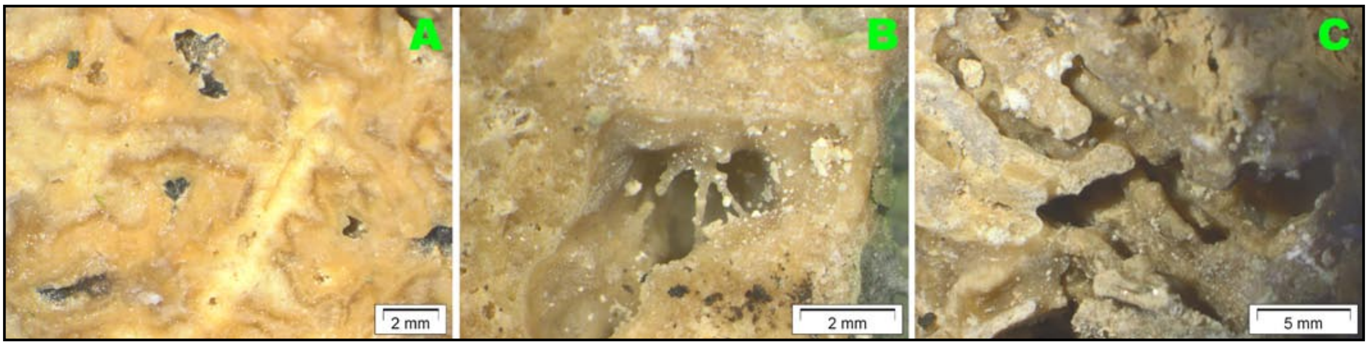

Figure 8*. A : microcrystalline spar. B : speleothem. C : encrustations. All from the Via Gellia tufa.*

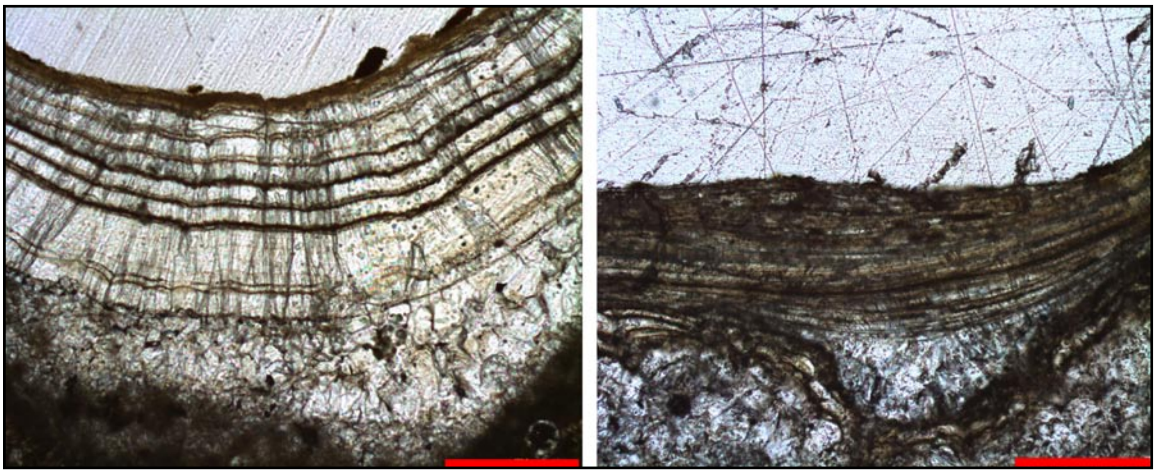

***Figure 9**. Two variations of the banding between the micrite and the sparite in the Via Gellia tufa; bar scales are 250 µm long.*

Petrography of the tufa

Encrustation of the tufa commences with a granular micritic layer that hosts an alternating sequence of sub-millimetre spar and micrite layers of variable thickness and frequency (Fig. 9). The deposits are colour banded with darker bands comprising micrite and lighter bands sparite of mosaic, acicular and palisade forms. The porosity of the darker layers is usually high as a consequence of void formation due to the decay of organic matter and the paucity of diagenetic cementation of the resultant voids.

Cementation of the phytoclastic facies differs from that in the phytohermal facies in that allochthonous (transported) fragments are encrusted with a single, encrusting micritic fringe, rather than a layered sequence. It is suspected that this results from the commencement of cementation during transport of the plant particles, which is followed by further cementation once the particle settles at its point of accumulation. The microcrystalline (Fig. 10) facies is dominated by clotted micrite. The resultant micropeloids (Fig. 10) are globular with low crystalline resolution; under the polarising microscope they appear dark brown with single and crossed nicols, and do not show the normal birefringence colours of micrite, possibly as a consequence of the accumulation of non-carbonate material. Volumetrically less significant is the occurrence of microcrystalline micrite (Fig. 11), in which crystals are distinguishable under crossed nicols. The spar occurs as both cement and debris. The microcrystalline facies appear to be associated with bryophyte cementation, debris accumulation and diagenesis. Diagenetic crystallisation can occur as a consequence of dissolution and re-precipitation, which destroys the original fabric of the tufa.

Porosity types in the tufa can be classified under the microscope (Fig. 12, Table 3). Cementation of both the primary and secondary pores takes a variety of forms that reflect the nature and degree of competition for cementation nuclei. Biological mediation of tufa precipitation is evident in the recent deposits, where diatoms and bacterial colonies are particularly abundant (Fig. 13). Characteristically, cementation commences with a primary rind of dogtooth spar or acicular prismatic crystals that form the nucleus for subsequent, drusy spar growth. Less commonly, botryoidal forms occur. Detrital filling by terrigenous silt, clotted micrite, lithoclasts and organic remains also occurs.

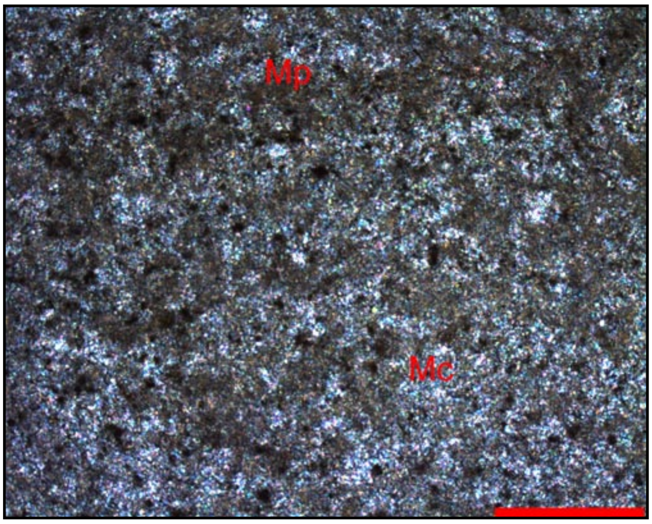

***Figure 10**. Micrite (Mc) and clotted micropeloid (Mp) in micrite tufa; scale bar = 250 µm.*

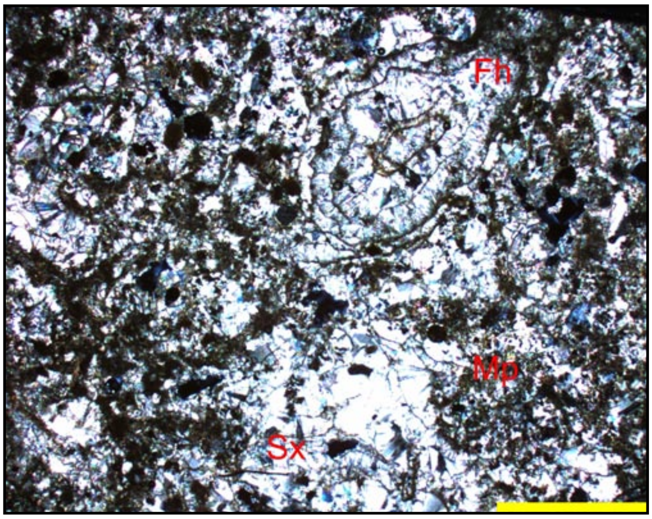

***Figure 11**. Microcrystalline tufa, with micropeloid (Mp), spar (Sx) and phytoherm (Fh); bar scale = 1 mm.*

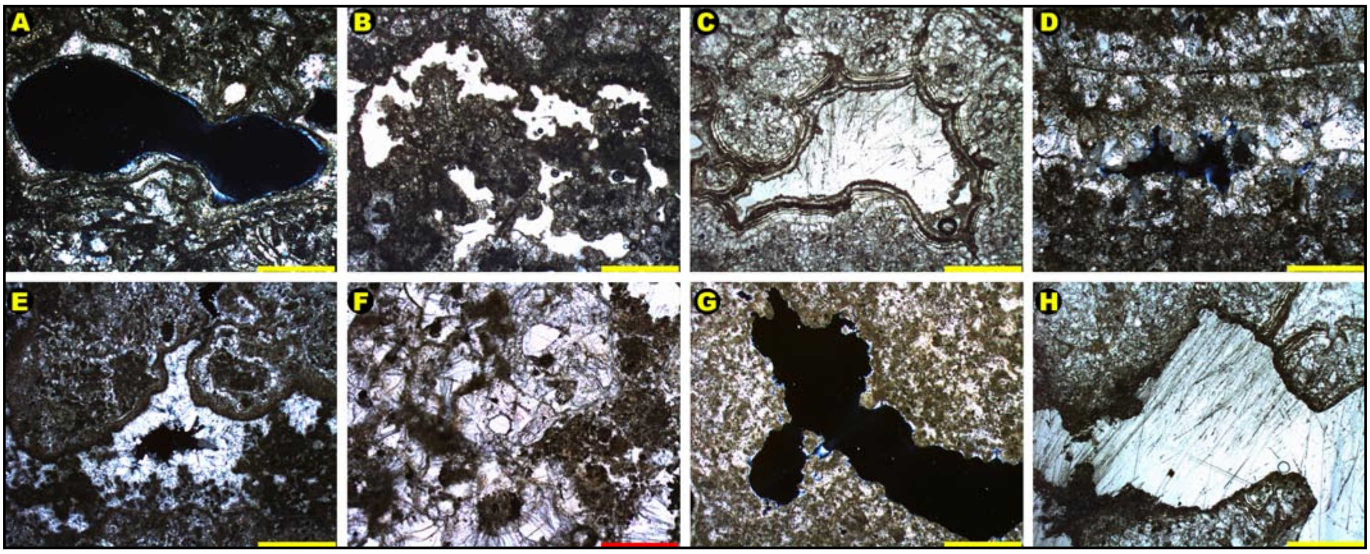

Figure 12. *Microphotographs of various porosity types in the Via Gellia tufa (see Table 3). A – plant decay. B – vuggy. C – intergranular. D – intercrystalline. E – incomplete cementation. F – degassing. G – dissolution. H – biodissolution. Red bar = 250 μm. Yellow bars = 1 mm.*

Porosity type	*Description*
Plant decay	Principal cause of void creation, especially in the phytohermal facies, with rounded to rectilinear pores with voids on mm to cm scale, varying with the organic matter.
Vuggy	Due to encrustation of bryophytes, usually at the millimetre scale.
Intergranular	Voids between the encrusted allochthonous fragments; commonly visible to the naked eye and tending to be flat and linear with irregular and sinuous boundaries.
Intercrystalline	Micrometric porosity between some crystals, maybe due to imperfections in crystal growth
Incomplete cementation	Commonly at the millimetre scale.
Degassing	Resulting from the escape of carbon dioxide gas bubbles leaving rounded or flattened “caries-like” sub millimetre voids occurring commonly in the microcrystalline facies.
Dissolution	Secondary porosity due to weathering and commonly acting on pre-existing pores, leaving irregular voids of mm to cm scale.
Bio-dissolution	Dissolution pores that result from plant etching, by lichens and mosses, commonly by enlargement of pre-existing pores; common in tufa that has a high primary porosity and is characterised by dark residual material on the pore boundaries.

Table 3. *Classification of porosity types in tufa.*

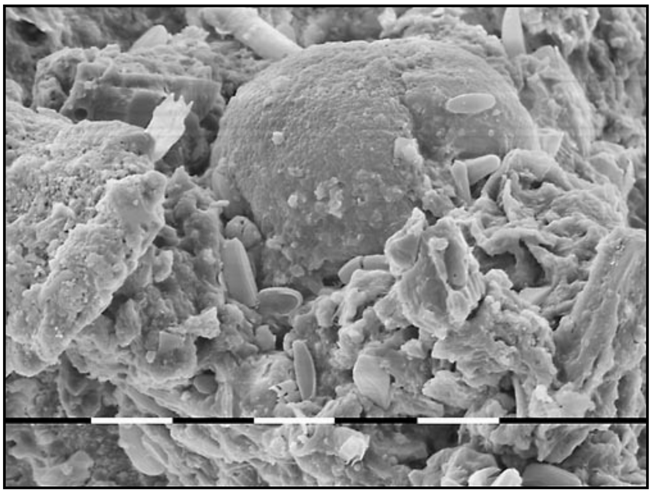

Figure 13. *Tufa with peloids, tubes and diatoms, seen under the electron microscope; white sections on the scale bar are each 10 μm long.*

Hydrogeochemistry of the tufa deposition

Calcium carbonate encrustations of mosses (Fig. 14) indicate active precipitation of tufa downstream in the channels below both springs (Fig. 15). The precipitation of tufa from water that is saturated with calcium carbonate occurs as a consequence of inorganic or organic degassing of carbon dioxide. The former may be due to physical agitation of the water, whereas the latter results from biological removal of carbon dioxide from the water. Plant material commonly forms the nucleus for tufa precipitation. Plants can therefore have either an active (removal of carbon dioxide) or passive (substrate for precipitation) role in tufa precipitation.

Sampling of the spring waters and determinations of discharges were undertaken on four occasions at six sites (Fig. 3, Tables 4, 5). Sites 1 and 2 were the Dunsley Springs, site 3 was immediately downstream of their confluence and site 4 was where the stream discharges to the culvert beneath the Via Gellia road. The headwaters of two additional springs, lying 250 m north-east of Dunsley Springs were also sampled to provide a base-line against which the tufa-precipitating springs could be compared.

Conventional field sampling used a Hanna Instruments portable multi-parameter meter and a Columbia 2 impeller-type flow meter. Laboratory testing comprised ICP-AES (Varian Vista Axial) determinations and ion chromatography in the BGS laboratories, and ionic balances in the range 0.06 to 4.34% were achieved. Geochemical modelling to determine saturation index used SOLMINEQ.GW (Hitchon *et al*., 1999).

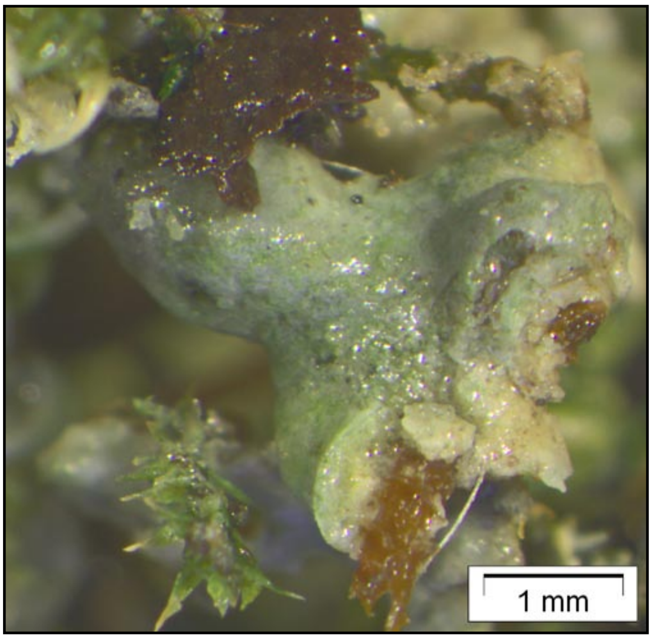

***Figure 14**. Actively precipitating tufa.*

With the exception of some of the nitrate and chloride concentrations, the spring chemistries fell within the range of the groundwater baseline data for the Derbyshire Dome (Abesser & Smedley, 2008). Whereas the chloride concentrations were unusually low, the upper concentrations of nitrate were higher than is usual for the Carboniferous Limestone. It is likely that the elevated nitrate concentrations are derived from cattle silage. In the Peak District fluoride concentrations have been found to be the best indicator of mineralisation (Bertenshaw, 1981). In the Via Gellia data, fluoride concentrations of >1 mg/L in samples 1 to 5 contrast with that of sample 6, with <1 mg/L, suggesting that the water from the Dunsley Springs has been affected by contact with the mineralization. Calcium, zinc, strontium and uranium concentrations appear to discriminate between the Dunsley Springs (>100 mg/L Ca, >120 µg/L Zn, > 100 µg/L Sr and >0.8 µg/L U) and the two springs to the north-east, though they fall within the expected range for the aquifer (Table 5). There are strong correlations between the calcium and strontium and the calcium and zinc concentrations. The Dunsley Springs also differ from those to the north-east by exhibiting lower concentrations of potassium (<1 mg/L), manganese (<1 mg/L), chloride (<6.5 mg/L), sulphate (<18 mg/L) and nitrate (<17 mg/L).

Spring geochemistry provides an indication of the extent and seasonality of water/rock interaction and flow processes in the aquifer. While there are significant changes in the spring discharges, their correlation with calcium concentrations is weak and the spring-water chemistries show little seasonality. Flux (product of discharge and concentration) shows a strong positive correlation with flow. Within the surface watercourses, there is downstream increase in the calcium flux; this suggests overall erosion of the tufa at present, even though observation reveals local deposition.

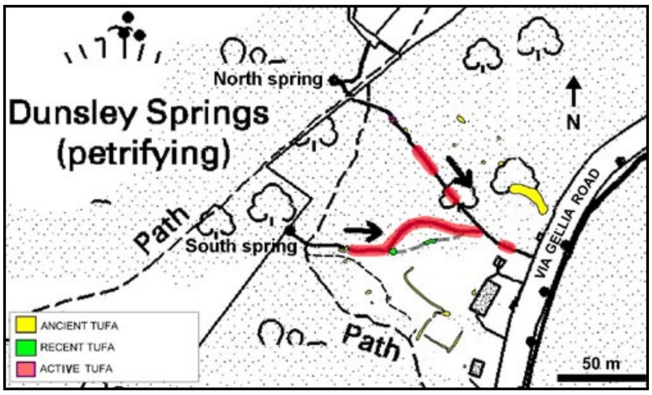

***Figure 15**. Zones of active precipitation of tufa.*

Date	*Site*	*E.C. (uS/cm)*	*Oxygen (ppm)*	*pH*	*°C*	*Flow (L/sec)*
18 June 2011	1	420	10.7	7.72	8.71	16.4
	2	454	9.99	6.97	8.79	8.5
	3	386	12.51	8.73	9.35	29.2
	4	395	10.69	8.35	9.16	39.5
	5	196	9.97	7.26	8.89	n.d.
	6	n.m.				
3 July 2011	1	448	12.57	7.84	10.54	n.d.
	2	484	8.9	7.89	8.81	n.d.
	3	461	10.45	9.00	10.33	n.d.
	4	463	10.33	8.35	10.70	10.0
	5	199	9.51	7.33	14.87	0.1
	6	213	13.4	8.33	18.11	0.1
23 Sept 2011	1	119	9.29	8.77	8.79	0.6
	2	252	6.54	8.42	9.32	0.1
	3	478	8.75	8.41	10.33	0.5
	4	9	9.51	8.57	10.42	1.0
	5	87	8.87	7.47	14.74	0.1
	6	n.m.				
9 January 2012	1	499	10.47	7.07	8.79	57.1
	2	487	10.66	6.99	8.77	21.8
	3	275	14.64	8.49	8.80	108.7
	4	n.d.	12.0	8.33	8.81	137.5
	5	377	10.36	7.09	9.19	0.6
	6	473	9.25	6.91	9.63	0.1

***Table 4**. Field records of sampled waters.*

Deposition and erosion of the tufa

Re-mapping of the tufa has identified two overlapping cones (Fig. 4), which are indicative of point sources for the dissolved carbonate. This supports classification of the deposit as a cascade (spring-line) tufa (Pedley, 1990). The tufa is unusual in that it is the only significant deposit in the Peak District that is on the Bee Low Limestone; most are associated with the Monsal Dale Limestone. However, the hydrogeological properties of the upper part of the Bee Low Limestone are comparable with those of the Monsal Dale Limestone, and have been grouped in the same hydrogeological unit (Banks *et al*., 2009). The Via Gellia tufa is formed immediately beneath the Lower Matlock Lava, towards the top of the Bee Low Limestone, where it is likely to be associated with significant palaeokarstic surfaces and clay wayboards, as in the Hoptonwood Quarry where dissolution pits reach 10 m deep (Waters *et al*., 2006).

Date	Site	pH	Ca	Mg	Na	K	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Sr	F^-	Zn	Mn	U	SIc	Ca Flux
			$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$mg\ l^{-1}$	$\mu g\ l^{-1}$	$mg\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$	$\mu g\ l^{-1}$		$mg\ s^{-1}$
18/05/11	1	8.11	114	1.62	4.9	0.71	295	6.25	17.2	14.9	114	1.27	153	0.9	0.820	1.134	1869.6
18/05/11	2	7.94	103	1.44	4.2	0.66	294	6.27	17.2	14.1	103	1.31	165	0.8	0.853	0.935	875.5
18/05/11	3	7.96	103	1.43	4.1	0.60	276	6.18	17.2	14.7	103	1.27	126	0.2	0.988	0.929	3007.6
18/05/11	4	8.08	103	1.45	4.2	0.64	281	6.15	17.2	14.9	104	1.28	126	<0.2	0.877	1.050	4068.5
18/05/11	5	7.91	80	1.80	5.8	0.92	208	9.58	24.2	15.7	85	1.21	55	10.4	0.718	0.667	
18/05/11	6	7.89	87	2.26	9.3	1.23	222	15.0	24.4	25.5	79	0.95	17	8.8	0.480	0.705	
03/07/11	1	8.24	104	1.44	4.1	0.59	293	6.25	17.4	15.4	103	1.26	160	3.4	0.829	1.218	
03/07/11	2	8.20	104	1.44	4.1	0.63	293	6.25	17.4	15.1	103	1.30	159	<0.2	0.819	1.156	
03/07/11	3	8.31	111	1.55	4.8	0.97	291	6.64	17.5	15.8	112	1.27	120	0.7	0.880	1.303	
03/07/11	4	8.20	104	1.45	4.5	0.98	292	6.78	17.4	17.0	104	1.27	124	0.4	0.866	1.180	1040.0
03/07/11	5	8.09	80	1.81	5.8	1.17	210	10.9	25.0	16.1	85	1.21	57	1.4	0.738	0.847	4.5
03/07/11	6	8.12	85	2.13	8.8	1.37	216	14.8	24.6	25.4	77	0.96	9	2.3	0.493	0.907	0.17
25/09/11	1	7.91	109	1.48	4.2	0.65	295	6.46	17.9	16.1	107	1.25	139	0.6	0.831	0.928	68.1
25/09/11	2	8.09	116	1.54	4.4	0.68	293	6.46	17.9	15.9	113	1.28	151	0.2	0.921	1.119	17.4
25/09/11	3	8.31	102	1.40	3.9	0.70	291	6.48	17.9	15.6	101	1.25	113	0.4	0.877	1.272	56.1
25/09/11	4	8.36	112	1.54	4.3	0.76	290	6.51	18.0	15.8	111	1.25	114	0.7	0.821	1.350	112.0
25/09/11	5	7.99	85	1.93	5.6	0.95	208	9.92	25.9	15.3	90	1.19	52	11.7	0.742	0.770	8.53
09/01/12	1	7.93	114	1.70	4.9	0.68	285	7.01	16.7	17.5	111	1.20	153	1.5	0.871	0.950	6512.8
09/01/12	2	8.02	106	1.59	4.7	0.64	277	7.01	16.8	16.7	107	1.28	142	0.2	0.893	0.998	2308.7
09/01/12	3	8.37	104	1.53	4.5	0.62	283	7.04	16.8	16.7	106	1.24	126	0.5	0.885	1.322	11301.7
09/01/12	4	8.34	108	1.57	4.6	0.64	283	7.13	17.0	17.4	109	1.25	130	0.3	0.886	1.309	14854.3
09/01/12	5	8.00	77	1.86	5.2	1.81	193	8.01	20.5	18.3	82	1.12	52	0.5	0.598	0.713	43.9
09/01/12	6	8.07	88	2.15	7.8	0.94	230	13.7	21.2	30.5	78	0.91	13	0.5	0.467	0.902	7.61
Baseline min max		5.94 9.17	2.36 171	0.27 36.3	3.89 192	<0.5 13.5	21 367	7.32 266	4.96 311	<0.5 12.6	37.1 8440	0.025 1.780	2.2 1840	<0.5 4840	<0.02 5.68		

***Table 5**. Spring-water chemistry; SIc is the saturation index with respect to calcite; max and min baseline values are from Abesser and Smedley, 2008.*

It appears that the Via Gellia valley intercepts south-westerly water flow paths in the limestone immediately beneath the Lower Matlock Lava. The source of carbonate in the spring waters is likely to be related to dissolution in the epikarst, during recharge, and to anastomosing palaeokarst along vadose flow paths (Banks et al., 2009). Concentrations of magnesium and sulphate are low, indicating that the carbonate is less likely to result from the dissolution of dolomite or to be due to sulphate dissolution associated with the weathering of pyrite. The high concentrations of zinc suggest an additional contribution from the dissolution of smithsonite (Brossler, 1998).

The Via Gellia tufa appears to be largely a Holocene deposit (Thorpe et al., 1980; Viles and Goudie, 1990). During this period of post-glacial climatic amelioration the proliferation of vegetation would have facilitated carbon dioxide saturation of recharge water, resulting in increased limestone dissolution in the vadose zone. The banding with dark micrite and light sparite (of mosaic, acicular and palisade forms) is comparable with other tufa deposits in Britain and Europe (Brasier *et al*., 2011). The occurrence of these two types of calcium carbonate can, at least in part, be attributed to the interplay between chemical precipitation of sparite and biologically mediated precipitation of micrite (Brasier *et al*., 2011; Pedley *et al*., 1996). The macro-fauna includes leaves and trunks of deciduous trees, which formed the substrate for tufa precipitation. It comprised a cemented breccia deposit, which together with the local preservation of organic matter suggests rapid deposition of tufa in a relatively unstable environment. It is suspected that high stream flows undercut the banks, thereby triggering tree falls. Such processes may, in part, have been due to rapid incision driven by glacio-isostatic readjustment. Discontinuities in the deposits (Fig. 5) indicate that precipitation of tufa was not continuous. Progradation of the two tufa cones may have been contemporaneous or may represent migration of deposition from one spring to another.

Calculated saturation indices with respect to calcite (Table 5) indicate that the present precipitation of tufa is most likely during the summer months when biological activity is at a maximum, thereby increasing limestone dissolution with higher levels of biogenic carbon dioxide. The saturation indices also confirm active dissolution of the main body of the tufa (sample points 3 and 4). In part this is supported by field evidence, indicating that some cavities in the tufa are primary, representing the voids behind small tufa dams whereas other voids are post-depositional dissolution cavities due to weathering. Some dissolution cavities are lined with speleothems and encrustations that are regarded as third-order deposits with the calcium carbonate being derived from the tufa itself rather than the limestone bedrock. The distribution of these deposits reflects the vadose zone flow paths, which have been modified in the areas that have been quarried.

While the depositional environment of the tufa and its subsequent erosional history is broadly understood, there remain a number of unanswered questions. In particular, the source of the carbonate has not been fully established, the age of the Via Gellia tufa has not been verified, and dating of the unconformities within the tufa has yet to be attempted. More frequent monitoring could determine annual rates of precipitation and erosion of the tufa. The physical appearance of the tufa deposits of the Peak District varies considerably, and the adoption of a descriptive classification would be of value within vernacular architecture, particularly where maintenance works are required.

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