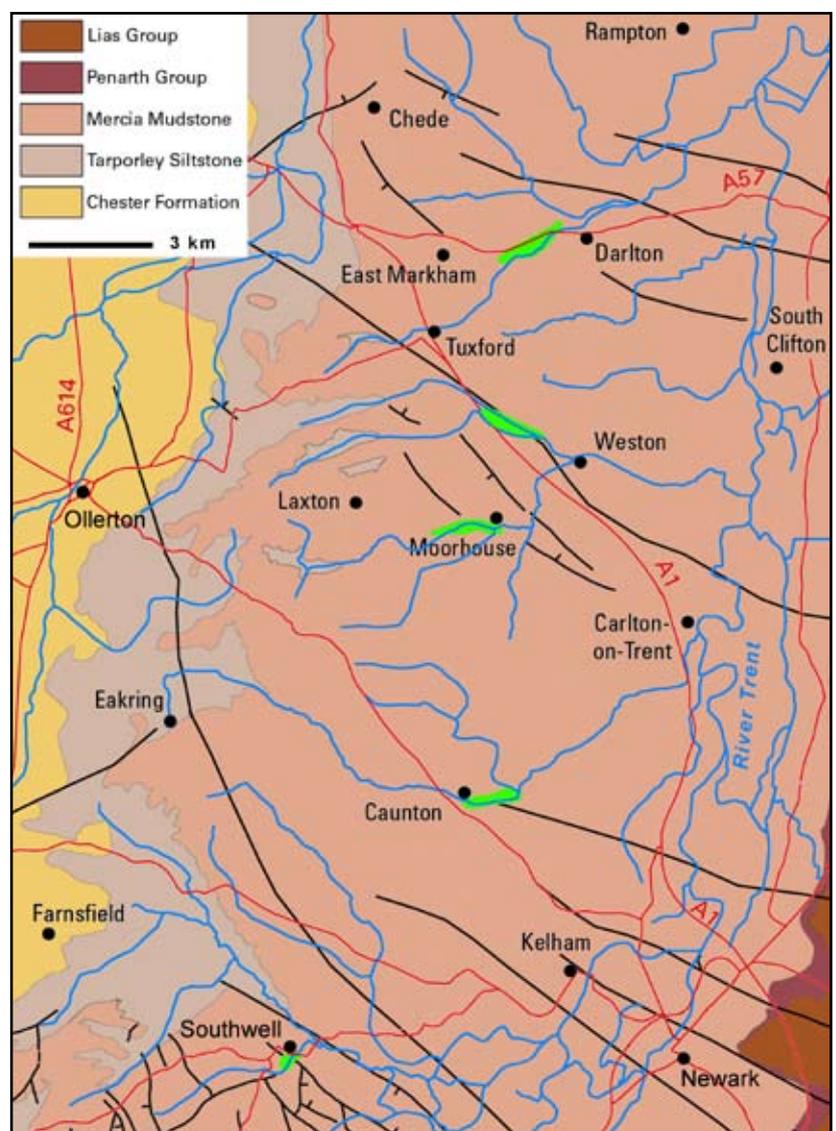# Riverine tufa deposits
# on the Mercia Mudstone Group of Nottinghamshire

## Albert Horton, Keith Ambrose and Keith Ball

**Abstract:** The argillaceous Mercia Mudstone Group is an unlikely source for the deposition of tufa. Calcite is rare, but traces of dolomite, usually as cement, are present throughout the sequence. Calcium sulphate, as gypsum or anhydrite, occurs as cement, nodules, veins and thin beds and is an important source of calcium for ground and surface waters. Thin fine to medium grained sandstones and siltstones provide potential low-grade aquifers. Historical records of water quality show that there are two chemically distinct groundwater hydrogeological units within the Group. The tufa deposits are found in areas that have high bicarbonate contents in spring and well water, occurring near the base and in the middle of the Group (Cotgrave Sandstone). Tufa exists in the region as proto-sinter, sinter, phytoclast (including.reed-bed), and intraclast varieties. The major tufa occurrences lie between Southwell and East Retford. Large tufa deposits are no longer being formed because of land use changes, especially the draining of boggy areas during mediaeval times to the present. Tufa is still being deposited in streams and drainage ditches.

There are several deposits of calcareous tufa in northeastern Nottinghamshire (Edwards, 1967; Smith *et al* 1973) and it was recognised during the original geological surveys of the area (IGS, 1966, 1967; BGS, 1996). Many of the deposits have been used as a building stone in several churches. Tufa has also been recognised (Horton & Harrold, 2012) in three buildings in Leicestershire. Small fragments of tufa, possibly of local origin, have been used in the old Rectory adjacent to the Horninghold Church [SP807971]. Large dressed blocks of tufa and Lincolnshire Limestone were used in Knaptoft church [SP627896] and small fragments were used to fill gaps between the inner and outer walls. Tufa is a very minor component of the Roman 'Jewry Wall' in Leicester. The sources of these tufas are unknown.

Typically, calcareous tufa is a freshwater carbonate deposited from groundwater issuing usually as springs. It is precipitated when water that has high levels of calcium bicarbonate becomes super-saturated due to degassing of carbon dioxide. The carbon dioxide may initially have been absorbed from the atmosphere, and occurs in soil gases as a by-product of the decay of the organic debris (Atkinson, 1977). Loss of carbon dioxide from a solution with calcium bicarbonate can result from equilibriation with the lower levels in the atmosphere, decrease in atmospheric pressure or increase in temperature. Degassing can occur as low flow-rate groundwater emerges at the surface, or subsequently as a result of increased turbulence along proximal stream courses.



***Figure 1***. *Tufa localities identified in Nottinghamshire, marked in bright green, with the unconventional colour used merely to distinguish them more clearly on this map (extracted from mapping by British Geological Survey).*

Tufa deposits in the East Midlands commonly occur in limestone areas. There are several developments in the White Peak District of Derbyshire, notably in Monsal Dale between Cressbrook Mill and Lees Bottom (Aitkenhead *et al.,* 1985) and in the Via Gellia valley (Columbu *et al.,* 2013). However, within Nottinghamshire tufa deposits have not been described from the dolostones of the Permian Cadeby Formation, although further north there is abundant tufa associated with the same formation at Knaresborough in Yorkshire (Cooper & Burgess, 1993). To the northeast, in the Brigg district of Lincolnshire, tufa deposits are associated with springs issuing from both the Middle Jurassic Lincolnshire Limestone and the younger Cretaceous carbonates (Ussher *et al.*, 1888).

## Local geology

The area where the tufa deposits occur in Nottinghamshire is underlain by the Triassic Mercia Mudstone Group (Fig. 1). To the west lies the outcrop of the Chester Formation (Ambrose *et al,* 2014) of the underlying Sherwood Sandstone Group. To the east, it is progressively overlain by the late Triassic Penarth Group and Jurassic Lias Group rocks. Over most of this area the geological mapping predates the latest changes to the stratigraphy and, with the exception of the Tarporley Siltstone Formation (the former Keuper Waterstones and Sneinton Formation), the new members and formations are not delineated on the older maps.

The Tarporley Siltstone Formation forms the lowest unit of the Mercia Mudstone Group (Table 1). It crops out in a narrow belt from Nottingham to Retford, comprising a sequence of red brown and greenish grey, mainly thinly inter-bedded, mudstones, siltstones and fine-grained sandstones with several thicker beds of coarser sandstone and some structureless mudstone. Calcite nodules occur in some of the sandstone beds and gypsum occurs as primary nodules and secondary veins. The Formation is 60–80 m thick. It was thought to have accumulated on a broad alluvial plain washed by rivers that deposited the sands. The laminated beds were deposited in bodies of standing water. There is very rare evidence of marine influence with the occurrence of the brachiopod *Lingula tenuissima* in the Ollerton district (Rose & Kent, 1955). Episodes of wind-blown dust deposition resulted in deposition of the structureless mudstones.

The succeeding Sidmouth Mudstone Formation and its component members (Table 1) comprises about 125 m of red-brown, blocky, structureless mudstones with thin (0.1–0.2 m) beds of greenish grey, dolomitic or siliceous siltstone and fine-grained sandstone (formerly referred to as 'skerries'), and some thin sequences of laminated mudstones. It has been suggested that the structureless red mudstones were deposited as desert dust on a saline playa mudflat (Mader, 1992). Infrequent episodes of heavy rain resulted in sheet floods that formed the interbeds of siltstone and sandstone; the residual water gave rise to playa lakes in which laminated mudstones were deposited. Small quantities of gypsum occur throughout the formation as primary nodules and secondary veins.

The basal Radcliffe Member comprises about 10 m of finely interlaminated mudstone, siltstone and fine-grained sandstone. This has been interpreted as a subaqueous environment with a very limited fauna, suggesting near shore marine or brackish water (estuarine) conditions (Wills, 1970). Madar (1992) concluded the environment consisted of alluvial mudflats and brackish lakes in a semi-arid climatic setting.

The overlying Gunthorpe Member shows the typical Sidmouth Mudstone lithologies with common beds of green siltstone and fine grained sandstone; these include the 'Plains Skerry' (Elliott, 1961) that is weakly calcareous. Higher in the sequence, the Cotgrave Sandstone Member is a persistent bed of a weakly calcareous sandstone up to 3 m thick. This represents the establishment of a widespread weakly braided fluvial system (Howard *et al,* 2009). The uppermost Edwalton Member (about 45 m thick) includes beds of green siltstones with a siliceous cement.

In the Ollerton district, two lithological divisions within the Keuper Marl, a lower dolomitic 'skerry belt' and a younger siliceous 'skerry belt', have been recognized (Edwards, 1967). These correspond roughly to the Gunthorpe and Edwalton members respectively. During a resurvey of the East Retford district (Smith *et al,* 1973), the Clarborough Beds were defined as a distinctive division within the lower part of their Keuper Marl; 3–12 m of 'mudstones and silty mudstones have much gypsum and a higher than normal proportion of skerries'. A lithologically similar unit occurs within the Gunthorpe Member of the Nottingham district, but the correlation is tenuous and the term has not been retained.

| Current names | | | Former names |
|---|---|---|---|
| Branscombe Mudstone Formation | | | Cropwell Bishop Formation |
| Arden Sandstone Formation | | | Hollygate Sandstone Member |
| Sidmouth Mudstone Formation | Edwalton Member | Edwalton Formation |
| | Cotgrave Sandstone Member | Cotgave Sandstone |
| | Gunthorpe Member | Gunthorpe Formation |
| | Radcliffe Member | Radcliffe Formation |
| Tarporley Siltstone Formation | | | Sneinton Formation |

*Table 1. The stratigraphy of the Mercia Mudstone Group, and its current terminology within the Nottinghamshire area.*

## Geological structure

The Mercia Mudstone Group dips gently eastwards. Very few surface faults are shown on the published maps, but borehole and seismic data indicate the occurrence of faults within the underlying basement. Recent gravity, magnetic and seismic surveys of the East Midlands (Pharaoh *et al.,* 2011) confirmed the presence of two main deep-seated faults within the pre-Triassic strata, the Eakring-Foston Fault and the Bothamstall Fault. In the absence of a detailed Triassic stratigraphy it is impossible to determine whether the discontinuous outcrops of many siltstone beds in the study area are the result of limited sedimentation or subsequent faulting.

Surface faults with an approximate NW–SE trend occur between Caunton and Clarborough. Only the faults in the Moorhouses and Southwell areas crop out close to a tufa deposit. Other tufa deposits at Caunton and that between Egmanton and Weston crop out close to basement faults. These faults may be present at the surface but have not been mapped.

## Tufa types in Nottinghamshire

The main tufa deposits in Nottinghamshire are an integral part of the alluvial sequence in which they occur. To some extent this controls the internal structure and the morphology of the deposits. At many sites deposition on a small scale continues to the present time. The Nottinghamshire tufas are all composed predominantly of calcium carbonate. No significant amounts of gypsum have been noted.

There is a plethora of terminology and many classifications associated with tufa (Buccino *et al.*, 1978; Pedley, 1990; Pentecost and Viles, 1994; Schneider et al., 1983; Viles and Pentecost, 2007; Banks *et al*, 2012; Pentecost, 2013). Broadly, tufa classifications have followed four approaches: biological, petrographical, physiochemical, and geomorphological. Here we have adopted a classification based on field observations, using the classification of Pedley (1990) and Pentecost and Viles (1994) where applicable.

## Proto-sinter tufa

This is deposited directly from fast-flowing streams on to the surface of sandstone and siltstone pebbles from the Mercia Mudstone Group. Initially deposition occurs as minor crystalline specks on the pebble surfaces and continues to form snow-flake-like, micro-crystalline aggregates. With continued precipitation, the initial flat cones may develop into blanket-like coatings. Many pebbles show growth only on the upper surfaces, unless overturned during flood conditions, resulting in varying degrees of overgrowth on all faces.

## Sinter tufa

At the ground surface the deposit is extremely porous with very low density, here referred to as sinter tufa (Pentecost & Viles, 1994). It has a characteristic pale ochreous hue, possibly reflecting absorbed iron minerals from the Mercia Mudstone Group. This feature is not seen in the tufas derived from the Carboniferous limestones. It occurs as infill to land drains and may coat or infill open ditches. Where such drainage spills into deeply dissected stream beds, it can create partly conical tufa aprons around the outfall, against the bank, and also low barrages across the stream bed (Fig. 2). Initially these deposits are relatively soft and crumble easily. When dry, they become harder and stronger, producing rock-like material.

There are extensive outcrops, of much older, lithologically identical deposits, probably of early Holocene age. These consist of pale to ginger coloured cryptocrystalline, extremely porous and apparently structureless tufa. Very rarely they contain mollusc shells. The tufa gives rise to slightly raised areas in valley floors but exposed sections have not been seen.

Reworked fragments of sinter tufa are, in places, the dominant pebble constituent of basal alluvial gravel. They are associated with pebbles of siltstone and sandstone, glacially derived pebbles (mostly quartzite), wood, loam and rarely thin peat debris and animal bones. This lag-gravel is sometimes overlain by a plant-rich layer of peaty clay or peat. It is suspected



***Figure 2****. Tufa barrier that has incorporated plastic bags and twigs, in a cut-off trench north of Laxton [SK717677].*

*Figure 3. Detail of reed tufa (Phragmites sp.) with tubes that are about 7 mm across; from a field stone collected on the alluvial flat near Darlton [SK768741] (photo: Carole Jones).*

that the pebbles of sinter tufa are fragments from former spring aprons or were derived from contemporaneous barrages of sinter tufa. It is possible that the barrages and associated peat bogs could have created the lagoons in which reed-beds developed. Sadly, no barrier structures or exposures of *in-situ* reed-bed tufa have been observed.

## Phytoclast tufa

These comprise erect and less-commonly inclined, cylindrical casts of plants, mostly the common reed *Phragmites australis* (Pedley, 1990). Their casts generally range up to 10 mm in diameter but some show plants up to 20 mm in diameter. These show traces of concentric banding, but are characterised by an outer nodal, pimply surface of small hemispherical masses of calcite (proto-sinter tufa), probably microbially mediated. Fragments may be re-worked and deposited as clasts in pea gravels.

As precipitation continues, the reeds die, but carbonate precipitation continues, and individual casts become cemented together creating an open framework rock structure, with high porosity and permeability (Fig. 3). Rarely the deposit contains shells of freshwater gastropods and bivalves. In one example, a fine-grained cemented detrital parting preserved an oak leaf impression. Thin sections show that the material consists of microcrystalline to cryptocrystalline calcite with a little fine quartz and cryptocrystalline silica (Edwards, 1967). Despite its open texture and low density, cross-cementation between stems means this lithology is sufficiently strong to be used as a building stone in several local churches.

## Intraclast tufa

This comprises loose coarse silt to sand grade, non-ooidal, white, calcareous particles (Pedley, 1990). They may have been directly precipitated in quiet-water lagoonal environments, or could be detritus from reed-bed lagoons, but they now occur as reworked sediment (beds and lenses) within the alluvial sequence (Fig. 4).
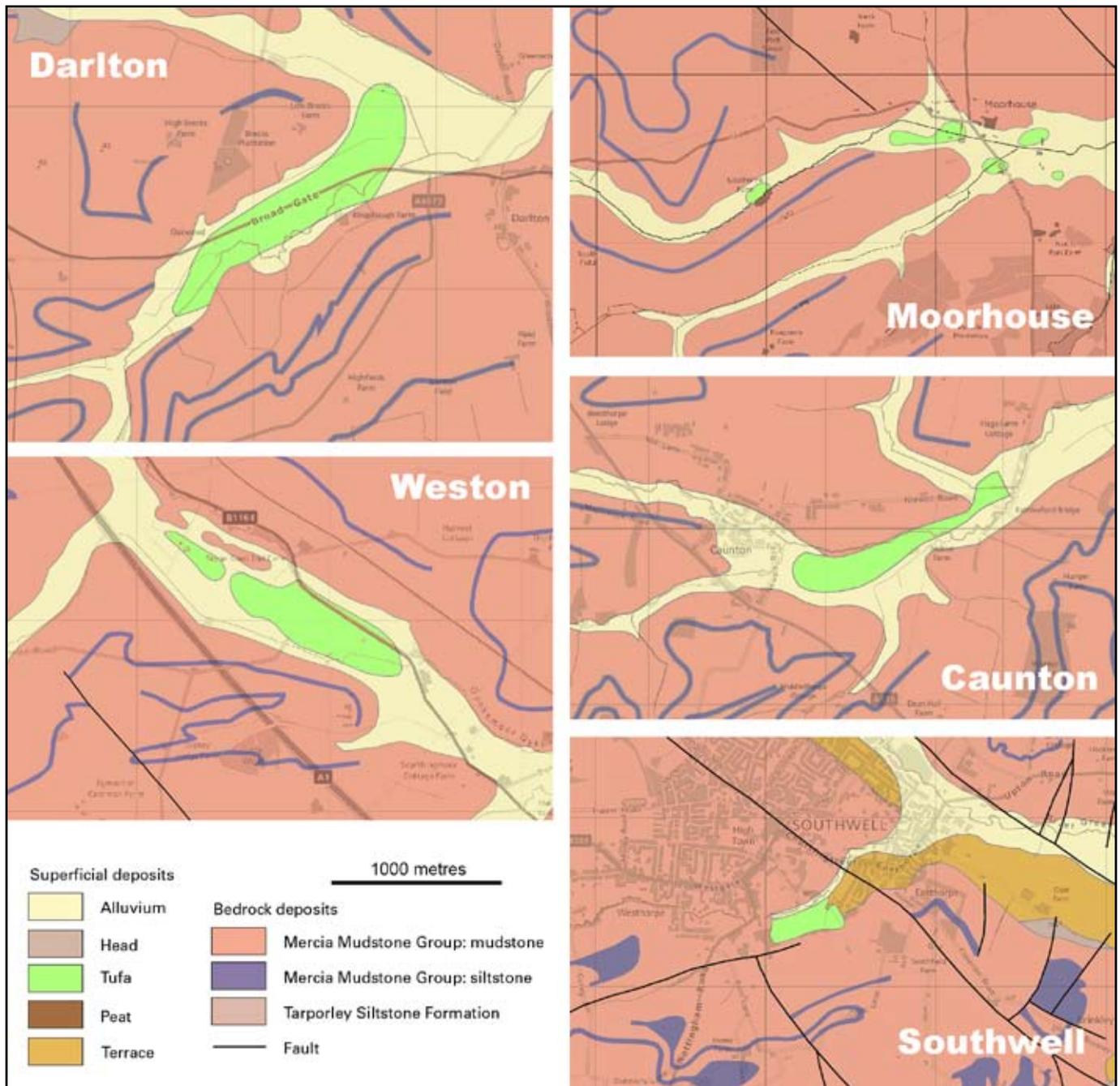


*Figure 4. Intraclast tufa from Moorhouse Beck [SK763667]. The upper layer of tufa is about 40 cm thick, and is overlain by silty alluvium; it is separated from the thicker tufa beneath by a layer of organic-rich alluvium.*

## The Nottinghamshire tufa deposits

All the main deposits were formed by groundwater issuing from the Triassic Sidmouth Mudstone Formation of the Mercia Mudstone Group, a sequence dominated by blocky, structureless mudstones, with many thin beds of siltstone and fine-grained sandstone. It may be significant that three of the tufa deposits, at Caunton, Weston and Darlton, lie on or very close to the outcrop of the Cotgrave Sandstone Member, a 2–3 m bed of fine-grained sandstone that is prominent and persistent within the sequence. Many of the thin siltstones and sandstones form aquifers, and numerous springs.

### Southwell

This site contains all the different types of tufa, and is larger than the other deposits. A variety of tufa lithologies are largely the result of direct precipitation, but minor reworking of tufa is also present. The lacustrine deposit is larger than shown on the published geological maps (Fig. 5). It extends from the eastern edge of Bishop's Drive south of the Minster and is confined to the south bank of Potwell Dyke. Traces of reworked tufa occur in the thin gravel beneath the alluvium. Fragments of sinter tufa have been found in a short narrow gorge-like depression [SK701533]. Gravel beneath thin alluvial clay includes several fragments of sinter tufa. This site

*Figure 5*. Geology of the five main tufa sites in Nottinghamshire (extracted from mapping by British Geological Survey).

lies on the Radcliffe Member of the Mercia Mudstone Group. The upper part of the drainage basin is underlain by the Gunthorpe Member. Both members may have contributed to the formation of the tufa.

An extension of the eastern edge of the school has been built on tufa, and unconfirmed reports suggest that the foundations are built on massive blocks of tufa. The tufa outcrop is marked by a bench showing debris of sinter tufa. The bench is dissected by small streams fed by a line of springs, probably along a fault. A deep drainage channel near the northwestern corner of the cemetery of the Reserve proved at least 1.5 metres of white granular tufa. The outcrop continues eastwards where foundation problems have been encountered in several buildings. Debris in the gardens included white loam, reed-bed and sinter tufa.

## Caunton

Tufa-rich sediments constitute part of the alluvial sequence along The Beck, and can be traced from the bridge near Kersall downstream to Bathleyford Bridge [SK760600] and Norwell (Fig. 5). As a result of differential compaction between alluvium and tufa, the tufa rock deposits now stand out as very low terrace forms, with 0.5 m of humic loam over the white granular tufa. Debris from a recently deepened pond at Beesthorpe Hall showed tufa framestone and tufa sand. A 0.4m-thick stone band, part enclosed in gypsum, is one of several siltstones that crop out in a field immediately to the west. A strong spring [SK729620] originally at the edge of the alluvial flat has recently been diverted into The Beck, and another spring occurs on the flood plain immediately above the village [SK739620].

*Figure 6. Block of tufa within the exterior wall of Caunton church [SK745600]; coin is 26 mm across.*

The church is partly built from tufa (Fig. 6), and tufa has been exposed in the graveyard. There is a small roadside outcrop to the west of the Church. Granular white tufa was proven to about 1.4m in a posthole in the village [SK748599]; a nearby septic tank is said to have been dug into about 3m of 'white muck' that is likely to be tufa. Sinter tufa fragments occur in the ditch below Caunton Manor House [SK745598] and have been noted in the basal alluvial gravel. Framestone tufa was dug from a shallow quarry, 370m west of Bathleyford Bridge. Bernard Smith's fieldslips of 1907 (archived at the National Geoscience Records Centre, British Geological Survey, Nottingham) indicate tufa at Norwell [SK771611]. The tufa deposit overlies beds 130m above the base of the Mercia Mudstone, putting this outcrop at around the horizon of the Cotgrave Sandstone.

## Moorhouse and Laxton

A stream originally flowed to the north of the Motte and Bailey at Laxton. The original stream has been diverted into a cut-off trench along the northern boundary of the site. Small rosettes of calcite are being deposited on pebbles in the stream bed. Tufa cascades and barriers in this trench were recorded by Bernard Smith in 1907; these features are still forming, and incorporate plastic bags along with twigs and branches.

Granular white tufa occurs at the base of the alluvium downstream of Laxton, in the Moorhouse area (Fig. 5). The site was thought to be on an inlier of the Tarporley Siltstone, but recent boreholes have shown that it lies in the Gunthorpe Member, around 90 m above the base of the Mercia Mudstone. This is close to the level of the Plains Skerry (Elliott, 1961).

## Weston and Goosemoor Dyke

Between Tuxford and Weston, tufa has been mapped along Goosemoor Dyke, a stream that rises on the Tarporley Siltstone west of Kirton. Southwest of Tuxford, two possible traces of tufa in the alluvium have been noted, in the village of Egmanton and on the Egmanton tributary to the main Dyke. At a lower level to the east, large blocks of reed tufa, up to 0.8 m x 0.3 m thick, crop out at the edge of the deposit. Extensive outcrops of similar rock have been worked near Stone Pits Farm [SK753693], and due to differential compaction these now form benches above the alluvium. A temporary section [SK765687] near Goosemoor House exposed at least a metre of white granular detrital tufa above a thin bed of peat. A drainage ditch [SK768683] at Scarthingmoor Farm exposed gravel composed mostly of angular sinter tufa pebbles at the base of the alluvium. At the confluence of Moorhouse Brook and Goosemoor Dyke near Weston, alluvium overlies white granular tufa. The height of the tufa deposit above the base of the Mercia Mudstone, varies from about 120 m in Stone Road End Farm to 140 m in Weston village. This places it around the level of the Cotgrave Sandstone.

## Darlton

A tufa deposit occurs at the confluence of two streams that drain the Gunthorpe Member (Fig. 5) between two major deep-seated faults, neither of which has been recognised at outcrop. Sinter tufa is present in the ditch west of Kingshaugh Farm [SK764733], and field debris of reed tufa and granular tufa occurs further west. To the north of the house, the original stream may coincide with debris from excavations that include fragments of reed and granular tufa. To the east, the northern tributary now flows in a cut-off trench that exposes an alluvial sequence with a poorly sorted gravel containing sinter tufa fragments at the base. Upstream at Kingshaugh Plantation [SK760732], a ditch reveals up to 0.9 m of alluvial clay on white granular tufa above peaty loam. Sinter tufa crops out at the edge of the alluvial flat to the south.

This tufa occurs at about 120–130 m above the base of the Mercia Mudstone. This is around the level of the Cotgrave Sandstone, which is a possible source of the springs that formed this deposit.



*Figure 7. Siltstone containing a vein of gypsum vein; from Beesthorpe Farm [SK728606].*

## Factors controlling deposition of the tufa

Tufa is generally deposited by groundwater issuing at springs draining limestone terrains. The local deposits are unusual in that they are associated with the predominantly argillaceous Mercia Mudstone which only contains very small amounts of dolomite and calcite cements. Its minor lithologies are thin dolomitic and calcareous sandstones and siltstones. Exceptionally these may be up to 3.0 m thick but are generally reach less than 0.3 m. Gypsum is disseminated throughout.

The deposition of tufa requires interaction between a variety of topographic, lithological, biological and hydrogeological factors. The source rock must have a suitable lithological composition, preferably limestone or calcareous sandstone, and has a large area of outcrop to capture rain water that may be weakly acidic due to atmospheric carbon dioxide. Tufa is also known to grow faster in fast-flowing water and in the presence of biogenic material (Gradzinski, 2010).

Initially the resulting ground water becomes more acidic, due to the presence of humic and carbonic acids from the decay of vegetation. At some horizons within the sequence there is a chemical source with significant quantities of primary and secondary gypsum and minor quantities of calcite, the dissolution of which yields carbonate, calcium and sulphate ions. Together these acidic fluids facilitate the dissolution of dolomite, further enhancing the concentration of calcium ions.

Individual siltstones may be relatively thin, compact, well-cemented and minimally porous, and occur as isolated thin beds within the mudstone sequence. However, at some horizons, they may have closely spaced joints and be sufficiently close together vertically to constitute a single aquifer.

The geological structure and topography must be such that in valley floors the ground surface intersects the aquifer to create a spring. There must be a quiet water environment at the outfall, and downstream barrages and backwaters that impede the flow and thus facilitate deposition of calcium carbonate as tufa.

Old topographic maps reveal the unexpectedly widespread occurrence of springs, issues and isolated field wells, all occurring at diverse heights throughout the outcrop of the Mercia Mudstone Group. The scattered field wells are shallow, and were presumably dug as sumps to capture and store the small output of water-bearing horizons. The two 1:10,000 Ordnance Survey maps (SK76SW and SK75NW) for the country south and west of Caunton show 34 and 42 issues respectively. This evidence suggests the presence of many minor aquifers within the Mercia Mudstone Group. The numerous farms with 'spring' in the name probably used emergent ground-water, and other farms were dependent upon shallow wells and boreholes. Generally the water yields were low and the quality was poor.

Lamplugh *et al.,* (1914) noted that the water from the lower dolomitic siltstones was totally different from that of the younger siliceous beds. Water from the first group was "loaded with mineral water, frequent deposits of calcareous tufa when flowing in the open in shallow streams". Locally the groundwater is very hard and variable with 50–200 mg/l $CaHCO_3$ (Downing *et al.,* 1970). This variation in quality is attributed to the high value of non-carbonate hardness due to the dissolution of gypsum. Water from the younger siliceous beds is significantly less hard. This is confirmed by contrasting the Caunton tufa deposit, sourced from springs within the dolomitic beds outcrop, with the absence of tufa in the area immediately to the southeast where the younger siliceous beds crop out and feed numerous springs.

## Age of the tufa

The alluvial sequence has a basal lag gravel composed largely of rounded platy fragments of siltstone and pebbles, mostly quartzite derived from Pleistocene glacial deposits, with animal bones and partly carbonised wood fragments. This bed is generally less than 30 cm thick, but partly infills shallow depressions; in places it contains fragments of sinter tufa. It is overlain by peaty detrital sediment locally with large plant fragments. These lenses may in turn be overlain by medium to fine-grained detrital white calcareous tufa sand or angular tufa pebbles. The period of calcareous sedimentation was abruptly terminated by the influx of reddish brown silty clay with small pebbles and rare shells at the base. This is probably hill wash or head.

No age dates have been obtained from the tufa deposits. They are thought to have been initiated in Late Devensian times, between 15,000 and 10,000 years BP, when they were formed by the excessive runoff from meltwater of the retreating ice sheet. However, the bulk of dated tufa deposits in England, and in Europe, are much younger, as they were formed in Boreal–Atlantic times within the Holocene, so postulated Devensian ages for the Nottinghamshire tufas must be regarded as tentative. Very-small-scale precipitation of tufa continues today as tufa aprons at stream and land-drain outfalls into deeply incised streams, as small lime-cemented calcareous barrages, and as deposition on pebbles eroded from the siltstones and sandstones.



***Figure 8**. Phytoclastic tufa forming field stones at Beesthorpe Farm [SK728607].*

## Origins of the tufa

Modern observations confirm the records of earlier workers who mapped and recorded deposits of tufa in Nottinghamshire. Although a predominantly argillaceous formation, the Mercia Mudstone includes a significant number of minor aquifers. Conditions are optimal for the deposition of tufa around the outcrop of the Cotgrave Sandstone.

The common dolomitic siltstones, weakly calcareous sandstones and concentrations of gypsum were such that the ground water is enriched in calcium and bicarbonate ions that are required for the formation of tufa. Springs occur where minor aquifers are intersected by the valleys. In areas of softer water underlain by siliceous siltstones, no tufa has formed below the numerous springs. Faults may provide pathways for groundwater flows that feed springs above some of the tufa deposits, but the extent of this influence remains uncertain.

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