REPORT

An unusual sedimentary bentonite from Castlemorton Common, Malvern

A bentonite deposit, of a type previously unknown in this area, was formed by the alteration of eroded basalt rock from the Malvern Hills, in Worcestershire. It results from the locally unique proximity of exposed and readily erodible volcanic rocks to a low-lying area of relatively weak and easily eroded mudstone.

Bentonite clay is commonly formed by the decomposition of volcanic ash, emitted from remote volcanoes and widely dispersed, falling into water with subsequent alteration of the ash to bentonite. Such clays are common in the Silurian rocks of the west Midlands and elsewhere. A less common method of formation is from the weathering products of other rocks, usually granite or basalt, transported to another location and undergoing chemical alteration in water (Grim & Güven, 1978). Such deposits have been called 'sedimentary bentonites' (e.g. Naish *et al.*, 1993). One such case has been found in an area of Triassic mudstones east of and adjacent to the Malvern Hills.

The Malvern Hills are composed mainly of plutonic and metamorphic rocks. A separate series, the Warren House Formation, forms a section of the ridge, at around SO765395, in an area of about a square kilometre. These volcanic rocks include spilitic basalts, keratophyres, rhyolitic lavas and felsic pyroclastic rocks plus dolerite intrusions.

Bentonite horizons occur throughout the Silurian sequence west of the Malvern ridge (Ray *et al.*, 2013). These bentonites were formed from dispersed volcanic ash. Such deposits are unknown in the Triassic mudstone to the east in the Severn Valley.

Much of the ground near and east of the Malvern Hills is covered by solifluction deposits. Superficial deposits of other types are minor. Bentonite lies within a small area of structureless grey clay a few hundred metres from the exposure of the Warren House rocks.

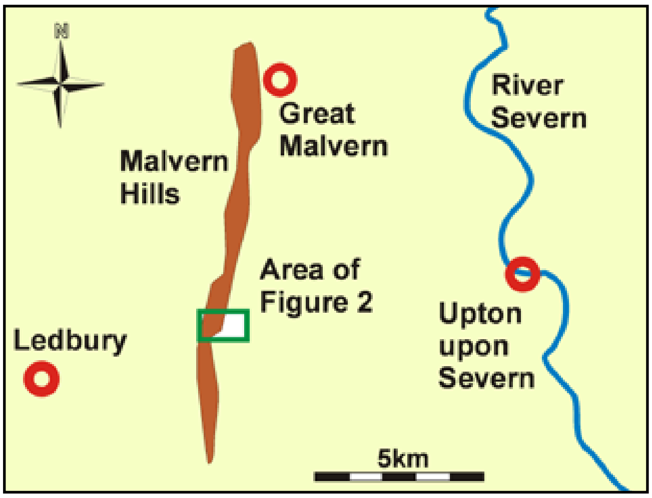

***Figure 1.** The Malvern Hills.*

Locations of the clays

At Dales Hall, at the northwest end of Castlemorton Common, a grey clay underlies a thin layer of topsoil (Fig. 2). It lies near the junction of the Warren House volcanic rocks and the Triassic Mercia Mudstone of the Severn Valley (Fig. 3). The site lies on sloping marshy ground about 300 m from the steep eastern edge of the Malvern Hills. Its known area is about 20x70 m^2, but it may be larger. The ground slopes roughly 4% to the east. A small stream runs along the north side of the site, issuing from a steep valley uphill to the northwest. The valley is a couple of hundred metres long before broadening to a small but wider valley. This is believed to be a late Quaternary channel that carried a greater discharge in periglacial conditions. The valley is cut into the Mercia Mudstone, which also underlies the clay deposits. The adjacent hill, Hangman's Hill, has Warren House rocks at outcrop.

Clay samples, designated A and E, were taken from each of two locations, both at elevation close to 100 m OD. The sample of clay A was retrieved from a digging at SO77063887, altitude 94 m OD. The site of clay E [SO77083895, 86 m OD] is in an area of rough vegetation on marshy ground a little to the north. Further east is a separate marshy area (X in Fig.3), also with a grey clay [SO77183891, 78 m OD]. It is not known whether these areas of clay are connected.

At the clay E location, excavation to 170 cm depth did not reach the base of the grey clay. This clay at certain levels contains angular fragments of rock of sizes up to about 40 mm in a matrix of the grey clay. At the location of clay A, beneath a 16 cm layer of soil cover is medium grey clay (pink in places) about 30 cm thick, resting on one metre of weathered Mercia Mudstone which, in turn, lies upon the unweathered Triassic mudstone at a depth of 165 cm. This clay contains no inclusions of size greater than 1 mm.

An apparently similar clay is reported (T Cameron, *pers. comm.*) from Fir Tree Cottage [SO766386], extending to 4 m below the surface.

A bentonite (clay B) of known volcanic origin within the Silurian Coalbrookdale Formation was sampled at SO75753929 to allow comparison.

Mineralogy and petrology

X-ray diffraction showed each Dales Hall sample to consist of a substantial fraction of montmorillonite (24–57%), similar to the Silurian bentonite (34%). Other constituents were also similar, except for a lack of illite in the Silurian material. On this basis, the Dales Hall clays may be classed as bentonites. Results from optical microscopy, differential thermal analysis, infrared absorption spectra, electron microscopy and x-ray fluorescence elemental analyses support this.

A major difference between the Dales Hall and the Silurian clays is the proportion in the former of quartz crystal grains and larger clasts up to about 40 mm in

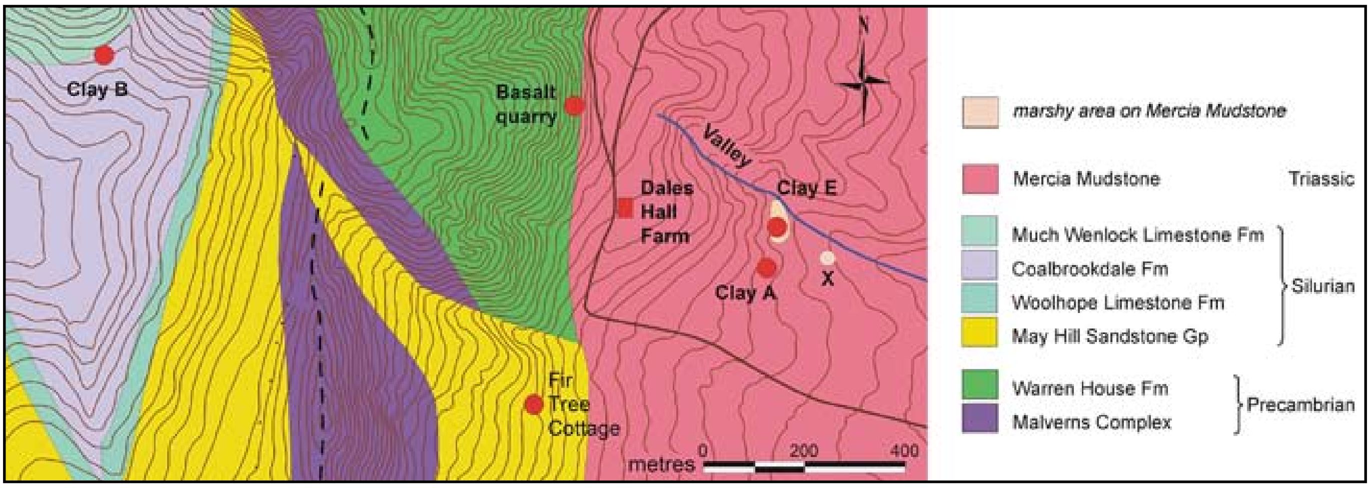

Figure 3. Topography and geology of the Dales Hall area, with locations of the clay samples. The dashed black line is the crest of the Malvern ridge, and contour lines are at 5 m intervals (contains OS and BGS data).

size (12% in the clay E sample). The larger clasts are mostly of rhyolite tuff, containing much quartz and hence resistant to weathering. The tuff, as well as basalt, is found in the Warren House rocks and was gravity- or water-transported to the clay site along with some other Warren House clasts. These large clasts were matrix-supported in the clay, indicating that both clasts and clay were transported together from the same source and at the same time. Such coarse inclusions are absent in the originally wind-blown material of the Silurian bentonites.

Obvious is the great difference in the thickness of the deposits, typically a few centimetres for the local Silurian clays but, for the Dales Hall material, almost two metres directly observed and possibly originally 15m (inferred from the altitude range of the clay deposits).

The Dales Hall clay is mineralogically distinct from the surrounding Mercia Mudstone. The latter contains much sepiolite and little montmorillonite (Jeans, 2006; Dumbleton & West, 1966). The strong difference in colour confirms that major interaction between the two clays has not occurred.

***Figure 2.** The site where the Sample E bentonite was collected, as it appeared in 2005. Since then, many alder trees have grown across the open land.*

Origins of the bentonite

The origins of material from the two sites appear to be quite different. The Silurian clay was interbedded with siltstones. This is typical for bentonites derived from altered, wind-blown volcanic ash.

The Dales Hall clays are also derived from the alteration of volcanic material, in this case from the washout of the fine erosion products from the weathering of the rocks, particularly basalts, within the nearby Warren House rocks. The present topography is consistent with the outwash being deposited as mud in a hollow where alteration to bentonite has occurred.

Complete geological mapping has never been achieved for the Warren House rocks; their exposures are too sparse (Platt, 1933). The amount of basalt exposure and its location on the hill is not known in detail but an outcrop occurs just above the junction with the Triassic mudstone and close to the top of the valley leading to the deposit site (Fig. 3). This may be part of a much larger basalt outcrop.

The clay samples contain large proportions of illite. This is usually derived from the weathering of feldspar, which is a component of the Warren House rhyolites, and the presence of rhyolitic tuff clasts within the clay shows that other weathering products could be transported to the deposit site.

The Dales Hall bentonite is very likely to have been formed in either Triassic or Quaternary times. Only at these times has this level in the local Mercia Mudstone been exposed at the surface, that is, at its formation in the Triassic and after recent exhumation in the Quaternary following its burial beneath about 170 m of the upper Mercia Mudstone and, probably, very thick layers of Jurassic and Cretaceous strata (Pharaoh, 2019). There was no local or regional volcanicity in these intervals of exposure so deposition as a volcanic ash cannot have occurred.

Apart from ash-fall deposition, two other, less common, modes of bentonite formation are recognised (Christidis *et al*., 2009). These are the hydrothermal alteration of volcanic glass, and the formation of smectite-rich sediments in salt lakes and sabkha environments. There is no suggestion of hydrothermal activity at the site, so some form of the second mechanism appears to be pertinent at Dales Hall.

Bentonite can form by weathering of epiclastic deposits derived from igneous (usually pyroclastic) rocks (Kadir *et al*., 2017; Naish *et al*., 1993; Grim & Güven, 1978), and appears to be relevant here. No other such deposits have been found locally (Barclay *et al*., 1997; Worssam *et al*., 1989).

Age of the bentonite

The bentonite was formed probably during and since the Devensian glaciation but perhaps in the late Triassic. There is currently no firm evidence to confirm or eliminate either possibility.

The ground lies on a fan gravel correlated with, and grading into, a Severn river terrace (Worssam *et al*., 1989), which is dated between to 18–13ka (Maddy & Lewis, 2005), during the Devensian cold stage, when the lower Severn valley was subject to periglacial conditions. This period, or later, appears to be the likely date of the deposit if it is of Holocene origin since only from this time was the Mercia Mudstone on which the clay rests exposed at the surface following erosion through the fan gravel cover.

The conversion of the eroded basalt into bentonite probably did not occur in the cold climate of the Devensian but in the more recent warmer conditions. Naish *et al.* (1993) found Holocene bentonites in which the alteration occurred in a few thousand years in a climate with average temperature only a few degrees above that of Worcestershire today.

The topography of the Dales Hall site makes Quaternary deposition a strong possibility. The clay minerals and frost-eroded clasts were transported to the deposition location by solifluction or water flow via a channel which started close to the outcrop of the volcanic rock.

The quite different possibility exists that the clay stems from erosion in Triassic times with long-term burial and subsequent exhumation. During the late Triassic, the Malvern ridge formed the western side of a sabkha in which the Mercia Mudstone was deposited (Barclay *et al*., 1997). Marine incursions provided the saline environment noted by Naish *et al.* (1993) and others as important for bentonite formation. Hollows generated by flash floods allowed the accumulation of the observed metres-thick deposits. The conditions for the formation of smectite-rich sediments in salt lakes and sabkha environments (Christidis *et al.,* 2009) were satisfied here, viz. a large water/rock ratio and a ready supply of magnesium.

However, a conclusive proof of a Triassic origin, such as the observation of Mercia Mudstone *in situ* above the bentonite, has not been found (nor sought).

References

Barclay, W J *et al*., 1997. Geology of the country around Worcester. *Mem. Geol. Surv. GB*, Sheet 199, 156pp.

Christidis, G E & Huff, W D, 2009. Geological aspects and genesis of bentonites. *Elements*, **5**, 93-98.

Dumbleton, M J & West, G, 1966. Studies of the Keuper Marl: mineralogy. *Road Research Lab. Rept*, 40, 25pp.

Grim, R E & Güven, N, 1978 *Bentonites, geology, mineralogy, properties and uses.* Developments in Sedimentology, **24**, Elsevier: Amsterdam (pp 131-135).

Jeans, C V, 2006. Clay mineralogy of the Permo-Triassic strata of the British Isles: onshore and offshore. *Clay Minerals*, **41**, 309-354.

Kadir, S *et al.,* 2017. Mineralogy, geochemistry and genesis of bentonites in the Miocene volcanic-sedimentary units of the Ankara-Cankiri Basin, Central Anatolia, Turkey. *Clays Clay Minerals*, **65**, 64-91.

Maddy, D & Lewis, S G, 2005. *The lower Severn valley*. In Lewis, C A and Richards, A E (eds), *The glaciations of Wales and adjacent regions,* Logaston: Hereford, 73-84.

Naish, T R *et al*., 1993. Evolution of Holocene sedimentary bentonite in a shallow marine embayment, Firth of Thames, New Zealand. *Marine Geology*, **109**, 267-278.

Pharaoh, T. 2019. The complex tectonic evolution of the Malvern region: crustal accretion followed by multiple extensional and compressional reactivation. *Proc. Open Univ. Geol. Soc.*, **5,** 35-50.

Platt, J I, 1933. The petrology of the Warren House series. *Geol. Mag.*, **70**, 423-429.

Ray, D C *et al.* (2013). Late Wenlock sequence and bentonite stratigraphy in the Malvern, Suckley and Abberley Hills, England. *Palaeogeography, Palaeoclimatology Palaeoecology*, **389**, 115–127.

Worssam, B C *et al.,* 1989. Geology of the country around Tewkesbury. *Mem. Geol. Surv. GB*, Sheet 216, 57pp.

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