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The demise of a Norber boulder, in the Yorkshire Dales, UK.

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Abstract: There is evidence that one of the iconic erratic boulders at Norber, on the slopes of Ingleborough in the Yorkshire Dales, was toppled from its limestone pedestal by an act of vandalism.

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Spread over the low spur of Norber Brow, on the southeastern flank of Ingleborough, the numerous glacial erratics at Norber, many perched on low limestone pedestals, are among the most widely known of the Yorkshire Dales landforms. They are easily accessible and are an almost essential site within the itinerary of so many field excursions for students of geology and geography. Early in 2009 the most iconic of the Norber boulders toppled from its perch (Fig.1), but this sad event was barely recorded for posterity.

The Norber boulders, each about 1m to 5m across, consist of greywacke (or grit) of the Silurian Austwick Formation, derived from a rocky spur in the western slope of Crummack Dale (Fig.2). This source lies at the head of the well-defined train of erratics extending over Norber Brow and a little further to the south, over a total length of about 1500m (Waltham, 1990, 2013). The erratics were left behind by a tongue of Pleistocene ice that overflowed from Ribblesdale, crossed the limestone benches and deepened Crummack Dale before merging with ice flowing southeastwards along the Craven Lowlands (Mitchell, 2013). Though the erratics now lie on younger Carboniferous Limestone, they were not transported uphill by any significant amount; their train extends almost horizontally from the exposed basement ridge onto the gently down-folded limestone (Waltham, 2005). Isotope dating of the exposure of the boulder surfaces has indicated their emplacement at around 17 or 18 ka, during the glacial retreat of the Devensian Last Glaciation (Vincent *et al*., 2010; Wilson *et al*., 2013).

Figure 1: Before and after photographs of the iconic erratic boulder at Norber, the first image dating from 2005 and the second from 2012.

Norber's erratics are well known for the many of them that are perched on low pedestals of the limestone bedrock. As early as 1886 this situation led to discussion of dissolution rates of the limestone, based on estimates of surface lowering that had not taken place beneath the sheltering umbrellas of the erratic blocks. In truth, the heights of individual pedestals are greatly influenced by the immediate bedrock structure, there is debatable complexity in the role of any rainfall shelter that they provide, and there is much that is variable or remains unknown in the processes of pedestal development that may be in part a consequence of dissolutional lowering of the adjacent surfaces (Hughes, 1886; Sweeting, 1966; Clayton, 1981; Goldie, 2005, 2012; Parry, 2007; Wilson *et al*., 2012). The surface of the limestone newly exposed from where it had been beneath the boulder adds another dimension to debate on the exact details of dissolutional processes on and around the pedestals; it is noticeably smooth except for some small pits (just millimetres across), which are perhaps reminiscent of some marine karst (though sea levels this high are not inferred!).

The boulder that toppled in 2009 was one of the most photographed of all at Norber, and its pre-2009 appearance is still recorded in numerous text books. It does, however, lie away from the main footpath through the boulders, and takes a little finding, out towards the western margin of the erratic field. Part of its fame derived from its position on a very recognisable pedestal, which can be used to demonstrate dissolutional lowering of the limestone surface, even though it may be misleading in the rate implied. There is scope for debate over how and why it toppled.

During a BCRA field meeting in May 2009 (Moseley, 2010), when the boulder was pointed out as having toppled, debate on the cause of the fall, whether natural or artificially induced, was unresolved. Shortly afterwards, following informed discussion, the possibility of restoring the boulder atop its pedestal was ruled out because Natural England found that there was no convincing evidence that the toppling of the boulder was the result of a deliberate act of vandalism (Andrew Hinde, *pers. comm.*). Subsequently, it has been considered that the boulder had been vandalized (Goldie, 2012), and that it had probably fallen due to natural failure (Waltham, 2013). Unfortunately, all of these conclusions fell short because their authors did not have access to all of the available evidence (and it appears that a correction concerning the boulder's demise has won the race to be the first item to render out-of-date the BCRA's new book on the Dales).

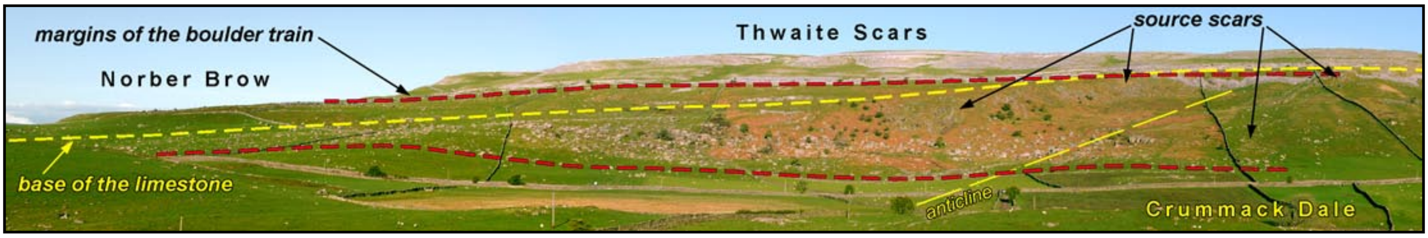

Figure 2: The erratic boulder train extending along the flank of Crummack Dale towards and over Norber Brow, viewed looking westwards across the Dale. Boulder train margins are shown only approximately, because some boulders slipped or rolled downhill after emplacement by the ice sheet; the train extends over the horizon at the far left. Two outcrops of the same strong greywacke bed on opposite limbs of an anticline of weaker siltstones (flooring a hollow) are the source scars. Ice plucked (or "quarried" in modern terminology) most of the erratics from the northern (right) scar where its scarp face was exposed and facing down-ice (towards the left).

Artificial toppling or vandalism

It is sad to record that there is convincing evidence that the toppling of this particular boulder was an event prompted by human intervention, perhaps better described as vandalism. The boulder and its limestone pedestal both bore signs of unnatural processes where a crow-bar or similar lever appears to have been inserted between boulder and pedestal about midway along the northern side (on the other side from that in Figure 1), at an optimum position for tilting the boulder away over its most undercut sector (on the southeastern side, which is the front right of the image in Figure 1).

The effects of inserting the crowbar, probably by hammering it in, were two-fold. Firstly, the underside of the boulder was "bruised" due to its surface being crushed and powdered at the point of impact. In 2009, this was clearly visible (as the pale marks directly above the tape in Figure 3). By 2013, the bruising was barely recognizable due to the effects of natural weathering. Secondly, the edge of the limestone pedestal had been damaged, where a small rectilinear block of rock was broken away (from the shadowed angular recess directly below the tape in Figure 3). This resulted from the crow-bar being levered downwards where the edge of the pedestal became its fulcrum until the rock failed. The missing block limestone block was found wedged into a recess at eye-level in the erratic boulder, but has since disappeared.

An approximation of the boulder's weight puts it at about 6 tonnes. The shape of the boulder and its original position on the pedestal (which was and still is deficient on the southeastern side) suggest that, in 2009, it was already very close to toppling. Insertion of a metre-long crow-bar beneath it, even by just a few centimetres. could lift well over a tonne at its tip by the weight of a person standing and bouncing on its outer end. Based on what could formerly be observed, it appears that such action was adequate to tip the boulder away from the crow-bar's position.

The missing block of limestone on the edge of the pedestal was partly broken away along existing fractures (recognizable by their weathered surfaces), but was partly released along a newly fractured surface. Rough estimates of the area of the new fracture and the shear-strength of the limestone suggest that the rock failure could also have been induced by a loading of about a tonne on the crow-bar's fulcrum, comparable with the loading that displaced the boulder. This tends to confirm that the boulder could have been displaced by one person and a crow-bar, without the aid of any powered machinery.

When the boulder was toppled, a secondary effect was the shearing and detachment of its upper part, thereby leading to the present situation (Fig.1). When the entire boulder hit the ground beside the pedestal, the major bedding-related weakness within it was at a very steep angle, and shear-failure on impact can be deduced as being a mechanically reasonable consequence. Another effect was the development of new vertical fractures through the eastern tip of the limestone pedestal, due to the temporarily increased loading when the boulder rested briefly just on the pedestal's outer edge.

Since the initial event in 2009 (soon after which the photograph in Figure 3 was taken), the site has suffered yet more minor damage. More rock has broken from the edge of the limestone pedestal adjacent to the existing crow-bar damage, and the clean, fresh fracture surfaces suggest that this is also not entirely the result of natural weathering. The western end of the pedestal is also now smaller, where some limestone blocks up to 300mm across are no longer in place. Whereas these blocks were bounded by natural fractures, they have not simply been moved out of position by frost heave or sheep activity. Sadly, vandalism is not new to Norber; some years ago the top of another erratic boulder was levered off using stolen farm equipment.

Natural failure that was pre-empted

The hope that the demise of the boulder might have been a natural event has led to a search for a plausible sequence of events. However, failure due to natural undermining, related to reduction in size of the limestone pedestal, is not a realistic option. The new fractures developed across the eastern tip of the pedestal were clearly a consequence rather than a cause of the boulder's toppling. They appear to be one visible result of instantaneous and localized loading during the toppling event, before further movement transferred part of the boulder's load to the adjacent turf. Furthermore, there are no displacements on the fractures that could have caused lowering of a critical part of the pedestal. Prior to the toppling, there was no known period when the boulder could be rocked, as might have been possible if there had been slow dissolutional removal of the supporting limestone. Though some degree of natural undermining of a pedestal is not impossible, there is no clear evidence for it happening in the case of this boulder.

If it had been left undisturbed, the most likely natural process that could have caused its toppling is shear-failure within the greywacke boulder itself. This erratic block was distinguished by its markedly conspicuous bedding structure, which was inclined at an angle of about 35° in its original position of rest. A penetrative bedding plane that had been greatly indented by weathering around its entire perimeter (Fig.1), appears to have been distinguished by the presence of a thin argillaceous horizon (a clay-rich band of shale, mudstone or slate) of a type that is common within the banded turbidite sequence of the Austwick Formation. Lateral movement could have occurred following shearing along this bedding structure, such that the smaller upper block became detached and slipped outwards. Although the failure is likely to have been an instantaneous event, it could have occurred as a slow creep over a period of hours, days or months.

Figure 3: The bruised underside of the boulder and the damaged edge of its pedestal, in a photograph taken in early 2009 and probably very soon after the toppling event.

***Figure 4:** Some of the many glacial erratics spread over Norber Brow, with the valley of Wharfe Gill beyond.*

Once shear-failure had occurred, the detached upper part of the originally intact boulder would have slipped down the steeply inclined bedding plane, with a component of lateral displacement that carried the centre of gravity of the combined blocks over and beyond the fulcrum provided by the edge of the limestone pedestal. Before the sliding upper block fell over the edge of the lower block, its weight (probably about a quarter that of the entire original boulder) could have been sufficient to rotate the lower block far enough for it to continue over-balancing beyond the fulcrum. Consequently, both blocks would have toppled sideways, to achieve their present positions, with both components toed into the adjacent grass-covered soil.

The angle of friction on the boulder's critical bedding plane is likely to have been marginally less than the 35° at which it was originally inclined. If that was the case, pre-slip stability probably depended upon cohesion within the argillaceous horizon. Such cohesion would have been slowly and steadily reduced by the effects of natural weathering that would eventually have replaced the originally intact mudstone horizon with a weaker mixture of clay particles and detached sand grains. (The angle of friction is a measure of friction expressed as the angular ratio between frictional resistance and the mass or weight of the sliding block, so is close to the angle at which it will slide when tilted; cohesion is the second component of resistance to sliding, and is independent of the tilt angle.)

The precise timing of this type of shear-failure is most commonly a result of climatic factors. A significant rainfall event can raise water pressure within any open micro-fissure or within the weathered material along the bedding plane This would provide partial support for the overlying block, and would therefore reduce the resistance to sliding failure (in the parlance of rock mechanics, it would reduce the effective stress; or in colloquial terms, it would lubricate the sliding surface). An alternative climatic factor would be a frost event, whereby ice growth could reduce cohesion within the rock, and replace it with cohesion by the ice until a thaw allowed failure of the newly weakened material. One or other of these climatic events would probably have triggered the demise of the boulder during some future winter, had they not been pre-empted by human interference.

Evidence for which of these, or perhaps other, processes were involved in the demise of what was one of the best-known of the Norber erratic boulders is not totally conclusive. As described, a potential scenario for the boulder's toppling as a natural event does appear to exist. However, there is also sound evidence that natural processes were overtaken by a deliberate act of vandalism. Whether the toppling of the boulder was humanly induced or was a natural occurrence, the effects of the 2009 event represent the sad loss of one of the more distinctive landforms of the Yorkshire Dales glaciokarst (figs 4 and 5).

References

Clayton, K, 1981. Explanatory description of the landforms of the Malham area. *Field Studies*, Vol.5, 389–423.

Goldie, H S, 2005. Erratic judgements: re-evaluating solutional erosion rates of limestone using erratic-pedestal sites, including Norber, Yorkshire. *Area,* 37, 433–442.

Goldie, H, 2012. *Pedestal studies at Norber, Ingleborough, Yorkshire*. 136–142 *in* O'Regan, H J, Faulkner, T and Smith, I R (eds), *Cave Archaeology and Karst Geomorphology in North West England: Field Guide*. [London: Quaternary Research Association.]

Hughes, T M, 1886. On some perched blocks and associated phenomena. *Quarterly Journal of the Geological Society*, Vol.13, 527–539.

Mitchell, W A, 2013. *Glaciation and Quaternary evolution*. 29–64 *in* Waltham, T and Lowe, D (eds), *Caves and Karst of the Yorkshire Dales.* [Buxton: BCRA.]

Moseley, G, 2010. Taking a closer look at Norber boulders with BCRA. *Speleology*, 15, 20–21.

Parry, B, 2007. Pedestal formation and surface lowering in the Carboniferous Limestone of Norber and Scales Moor, Yorkshire, UK. *Cave and Karst Science*, Vol.34, 61–68.

Sweeting, M M, 1966. *The weathering of limestones*. 177–210 *in* Dury, G H (Ed.), *Essays in Geomorphology*, [London: Heinemann.]

Vincent, P J, Wilson, P, Lord, T C, Schnabel, C and Wilcken, K M, 2010. Cosmogenic isotope (36Cl) surface exposure dating of the Norber erratics, Yorkshire Dales: further constraints on the timing of the LGM glaciation in Britain. *Proceedings of the Geologists' Association*, Vol.121, 24–31.

Waltham, A C, 1990. Geomorphic evolution of the Ingleborough karst. *Cave and Karst Science*, Vol.17, 9–18.

Waltham, T, 2005. Yorkshire Dales excursion. *Mercian Geologist*, Vol.16, 144–147.

Waltham, T, 2013. *Karst geomorphology.* 65–92 *in* Waltham, T and Lowe, D (eds), *Caves and Karst of the Yorkshire Dales.* [Buxton: BCRA.]

Wilson, P, Lord, T C and Vincent, P J, 2012. Origin of the limestone pedestals at Norber Brow, North Yorkshire: a re-assessment and discussion. *Cave and Karst Science*, Vol.39, 5–11.

Wilson, P, Lord, T C, Telfer, M W, Barrows, T T and Vincent, P J, 2013. Dating in the Craven Dales. *Geology Today*, Vol.29, 16–22.

***Figure 5:** One of the Norber erratic boulders that remains in place atop a rather small limestone pedestal.*