Peter's Stone, Cressbrook Dale, Derbyshire: landslide or paraglacial feature?

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Abstract: Peter's Stone is a conspicuous landslide block of Carboniferous limestone within the upper reaches of Cressbrook Dale in the White Peak. It appears to have a complex origin where the sliding movement was largely translational, but included horizontal rotation and was initiated after tilting due to undercutting.

The best known landslides in the Derbyshire Peak District are those in Edale and on the adjacent Mam Tor (Waltham, 1999). These are formed in the interbedded sandstones and mudstones of the Mam Tor Beds that overlie the Bowland Shale Formation of the Millstone Grit Group. Less common, are reports of landslides on the Carboniferous carbonate platform limestones of the White Peak. Of the 44 landslides recorded in the British Geological Survey's National Landslide Database (Foster et al., 2012) for this area, 20% are related to volcanic horizons and 80% are in the limestones (59% the Monsal Dale, and 16% in the Bee Low). Two of the larger landslides on the platform limestones of the White Peak are those of Hobbs House (Aitkenhead *et al*., 1985) and Peter's Stone. The latter stands about 35 m from the valley side, and is one of the more photogenic features of the White Peak, particularly when viewed from the northeast, looking down Cressbrook Dale (Fig. 1).

Both those landslides have been described as rotational in the BGS Database. However, previous authors (Dalton *et al*., 1999; Ford, 1977; Stevenson & Gaunt, 1971) have suggested that Peter's Stone has moved along a slip-surface developed in the Litton Tuff Member, so it is debatable whether it is a rotational or translational landslide. Movement has been attributed to weathering and water softening of the upper surface of the tuff together with the angle of dip of the bedding. Debate concerns the relative importance of the various factors involved in the landslide, namely shear failure within the underlying tuff, any cambering over the incompetent beds beneath, and stress relief due to loss of support during deglaciation.

Geomorphology of Peter's Stone

Cressbrook Dale is a southward draining tributary of the River Wye, Derbyshire. Disrupting the otherwise straight line of the valley, the positions of three meanders correspond with zones of east-west, fault-guided mineralisation. The undulating valley floor lies at 220 to 240 m OD with the sides rising to the plateau surface at 300 m. The dale is seasonally dry with migrating, ephemeral springs, including Peter's Spring, which discharge during periods of higher groundwater levels. The valley floor is around 10 m wide and is incised by about 3 m below the landslide.

The landslide block known as Peter's Stone lies on the eastern side of the dale inside the northernmost meander (Fig. 2). Bedrock is Carboniferous Brigantian limestone of the Monsal Dale Limestone Formation (Stephenson & Gaunt, 1971). These comprise pale limestones that are thickly bedded and also a darker facies that is thinly bedded with argillaceous partings; chert occurs as nodules. Peter's Stone immediately overlies the airfall volcanic ash known as the Litton

***Figure 1**. Peter's Stone seen from the northeast, looking down Cressbrook Dale, with its source head scar just out of sight beyond the scar profile top left, and with the lower block of the landslide only in profile against the distant valley side.*

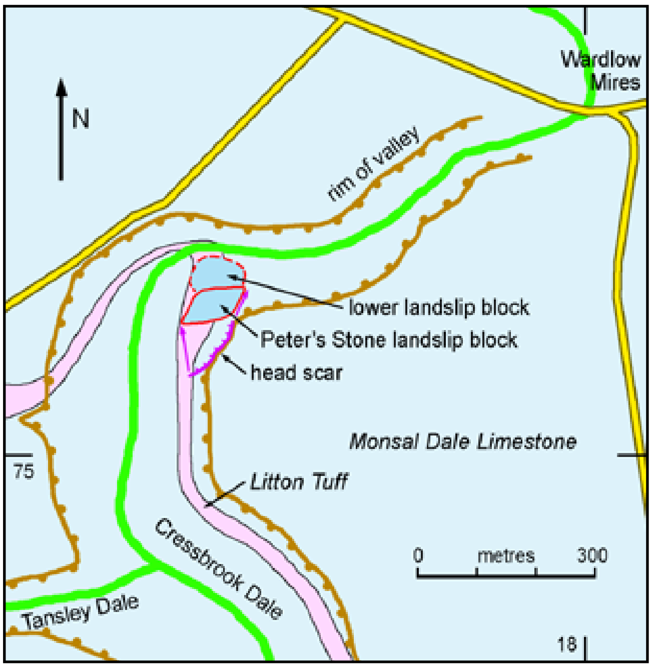

Figure 2*. Sketch map of the main features at and around Peter's Stone and upper Cressbrook Dale.*

Tuff (Hunter & Shaw, 2011), which is about 13 m thick; it is underlain by some 5 m of limestone that overlies the basaltic Cressbrook Lava. Two coral beds with *Siphonodendron junceum* (Fig. 4) form marker horizons 15 and 16 m above the lava (Stephenson & Gaunt, 1971). Tansley Dale lies along one of the mineralised faults, and enters the main valley from the west 430 m south of Peter's Stone (Fig. 2).

Geology of the landslide

The morphology of Peter's Stone suggests that the rock mass is part of an extensive translational landslide that has broken and spread in its movement. The main block has an irregular shape about 45 m by 15 m in plan extent. A conspicuous scar within the valley rim, about 55 m to the south, appears to be the position site from which the Peter's Stone landslide block has moved (Fig. 3). The grass cover on the lower parts of the slipped mass masks the morphology of the lower part of the landslide. However,

Figure 4*. The coral band exposed in Peter's Stone.*

where exposed, the orientation of the bedding in the slipped material points to at least two slipped masses; the crag referred to as Peter's Stone has been divided, with part of it having slipped lower down the slope (Figs 1, 2). Aprons of scree lie on the front of the main slipped block (Fig. 5) and also against the crag that appears to be the head scar of the landslide. As elsewhere, it is likely that the screes are largely the product of periglacial activity following the landslide event.

The limestone dips roughly to the north, at an angle of about 20° in the valley sides and just over 10° within Peter's Stone. This might suggest that the landslide was rotational, over a curved slip surface. However the change in dip may equally be attributed largely to rotation whereby the block spun round as it moved down an almost planar slip surface, thereby more in the nature of a translational landslide. A thin mineral vein within Peter's Stone has opened to a fissure nearly a metre wide that is now conspicuous within its south face (Fig. 5). Alignment of the vein is significantly different from that of all the veins recorded nearby, suggesting that the detached crag has been subject to clockwise rotation of about 30–40°. The coral band noted by Stevenson and Gaunt (1971) was identified in logged sections, and its position within Peter's Stone is 15 m below its original elevation in front of the surviving

Figure 3*. The limestone crags along the east side of Cressbrook Dale, which appear to be the head scar from where the landslide blocks originated.*

***Table 1**. Index properties of weathered volcanic clays. The first four samples are from ground adjacent to Peter's Stone; Miller's Dale is 4 km south-west of Peter's Stone, and Aldwark is 18 km to the south-south-west.*

material	*#*	*Liquid Limit*	*Plastic Limit*	*Activity*	*grading %*			
					clay	*silt*	*sand*	*gravel*
Litton Tuff, toe of landslide	1	53	34	2.04	9.3	18.4	53.4	18.9
Litton Tuff from 0.70 m depth	4A				4.5	4.2	87.8	3.5
Litton Tuff from 0.90 m depth	5A	81	47	0.77	43.9	32.0	20.3	3.8
Weathered Cressbrook Lava	1A				81.8	16.0	2.1	0.1
Weathered lava at Aldwark	6	92	30	1.20	76.4	16.7	6.2	0.7
Clay wayboard at Miller's Dale		51	30					

head scar. It was also identified in the lower landslide block that became detached from Peter's Stone, where it is another 23 m below.

Though the mineralogy of the volcanic deposits and the significance of the palaeokarstic surfaces that underlie them are well documented (Walkden, 1974), a short programme of laboratory index testing was required to provide data on the engineering properties of the weathered clays associated with them (Table 1).

It might be anticipated that slope failure has occurred where limestone that is underlain by the weathered Litton Tuff dips into the valley at an angle exceeding the residual shear angle of the clay. The effective shear angle of the Litton Tuff, as determined from Atterberg limits (using the empirically derived chart of Skempton, 1964), ranges between 13° and 28°. However, the dip of the top of the Litton Tuff is 7.4° (Hunter & Shaw, 2011), and is in a direction almost parallel to the crag from which the landslide originated. This indicates that a simple sliding process is unlikely, and suggests that disturbing forces for this slide were more than gravitational sliding on the clay.

Mechanism and process in the landslide

The field evidence suggests that Peter's Stone is a translational landslide. Though its joints are more open than those in the valley sides, it has retained much of its original form, suggesting limited lateral movement; this is compatible with the short distance between the landslide block and is source position in front of the surviving head scar. Given that the landslide is not considered to be the consequence of simple sliding over an outward dipping bed of clay, four other potential driving processes are considered.

Paraglacial cambering. Unstable conditions can derive from gull formation associated with cambering where less competent material is squeezed towards the valley. Overlying competent beds then spread over the less competent material towards the valley side when joints are widened to form the crevices known as gulls. Such features are well known in the Jurassic limestones of the Cotswolds (Farrant *et al*., 2015). Whereas the open joints on the eastern side of Cressbrook Dale (Fig. 6) might suggest a related process, cambering is considered unlikely because of the shape of the slipped crag. Furthermore, it is difficult to see how this process might account for its clockwise rotation.

Paraglacial stress relief. This would have occurred along the dale sides due to loss of support by ice as a consequence of deglaciation at some stage during the Quaternary. However, the extent of the screes associated with the de-stressing of the detached crag and of the valley side head scar indicates that debuttressing would be more likely to result in rock fragmentation than detachment of large and relatively intact blocks.

Tectonic uplift. Differential uplift, which may be glacio-tectonic due to isostatic rebound, could induce landsliding (Walsh *et al*., 1972), but there is no evidence to support this at Peter's Stone.

Undercutting of the valley side. Undercutting as a part of fluvial incision might induce sliding or toppling. Were Peter's Stone reconstructed on the eastern side of

***Figure 5**. The south and east faces of Peter's Stone, with screes below, and with the mineral vein in the shadowed fissure.*

***Figure 6**. Widened joint within the crags along the eastern side of Cressbrook Dale.*

the valley, the weak Litton Tuff beneath it would have been exposed to erosion at some stage during valley incision, probably by glacial meltwater. Undercutting of the limestone is likely to have been initiated, but the geometry and morphology of Peter's Stone suggests that this alone is insufficient to account for the landslide.

It appears that the landslide developed by a combination of processes. Initiation was by undercutting and local, outward tilting of the limestone and the Litton Tuff on the inside of a high-level meander. This induced joint opening within the valley side, facilitating groundwater entry at the base of the overlying limestone, enabling saturation and weathering of the Litton Tuff, which eventually triggered outward sliding along the tuff. Association of the landslide with incision of the high-level limestone plateau points to this being an ancient landslide with its inception likely to date back to the Anglian. The relatively intact nature of the detached block, and the duration implicit in the suspected processes, suggests that this was a slow-moving landslide that significantly impacted on fluvial development of Cressbrook Dale.

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