

**LANDMARK OF GEOLOGY
IN THE EAST MIDLANDS**

The reef at High Tor

Impossible to miss where it looms over the A6 highway into the Peak District, High Tor is well known as a fine example of a Carboniferous reef - known more precisely as a carbonate mud mound. This splendid structure is cleanly exposed in the vertical limestone cliff above the east bank of the Derwent Gorge between Matlock and Cromford. High Tor forms the highest part of the cliff at SK306589, about 1 km downstream of Matlock.

The structure of High Tor is best seen from the footpath between Matlock and the Heights of Abraham, at SK292589 above the west side of the Derwent Gorge looking down the easterly dip slope of the limestone (Fig. 1). The main cliff is made up of bedded limestones of the Monsal Dale and overlying Eyam Limestone Formations of Brigantian age that enclose a lens-shaped mass of pale unbedded limestone (Fig. 2). The Great Rake, a mineralised fault previously worked for fluorspar, cuts the southern edge of High Tor is marked by a line of old mine workings and High Tor Rake emerges on to cliff face immediately to the north of

the carbonate mud mound (Ford, 2001). The ground behind High Tor is formed by late Brigantian and early Namurian shale, with Riber Castle built on the escarpment of Ashover Grit forming the skyline (Smith *et al*, 1967).

The lens-shaped mass of pale unbedded limestone at High Tor is an excellent example of a carbonate mud mound; the main type of reef found in limestones of Carboniferous age around the world. Reefs were constructed by communities of organisms that formed a rigid structure on the sea floor supported by their calcareous skeletons. Modern reefs are constructed by corals, sponges and calcareous algae that grow in tropical conditions found around Florida, the Red Sea and the Great Barrier Reef of Australia. Reefs were built by different communities as organisms evolved through geological time; corals, sponges, bivalved molluscs and calcareous algae were responsible for many Mesozoic and Tertiary reefs, while corals and stromatoporoids were important reef-builders during the Palaeozoic and blue-green algal reefs occur in late Pre-Cambrian carbonate successions. However, the Carboniferous was an unusual period in geological history because no dominant reef-building community was present and it is not known how carbonate mud mounds, including the one at High Tor, grew.

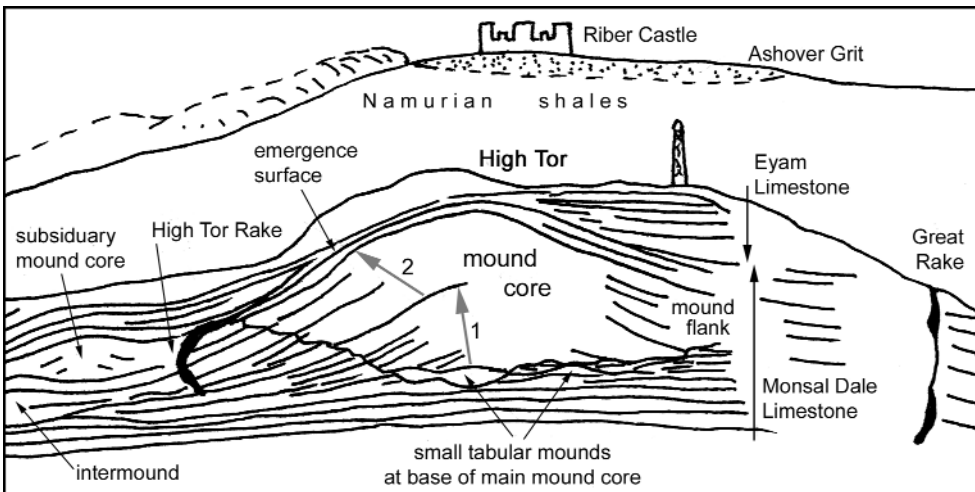


Figure 1. Panorama of High Tor looking due east across the Derwent Gorge from the footpath up to the Heights of Abraham. The length of the cliff section is about 650 m, seen in this down-dip view. Mineral workings of the Great Rake lie in the trees to the right of the main cliff.

Figure 2. Internal structure of the carbonate mud mound, sketched from the same viewpoint as in Figure 1. The mound core initially grew vertically (1) followed by a phase of lateral growth (2).

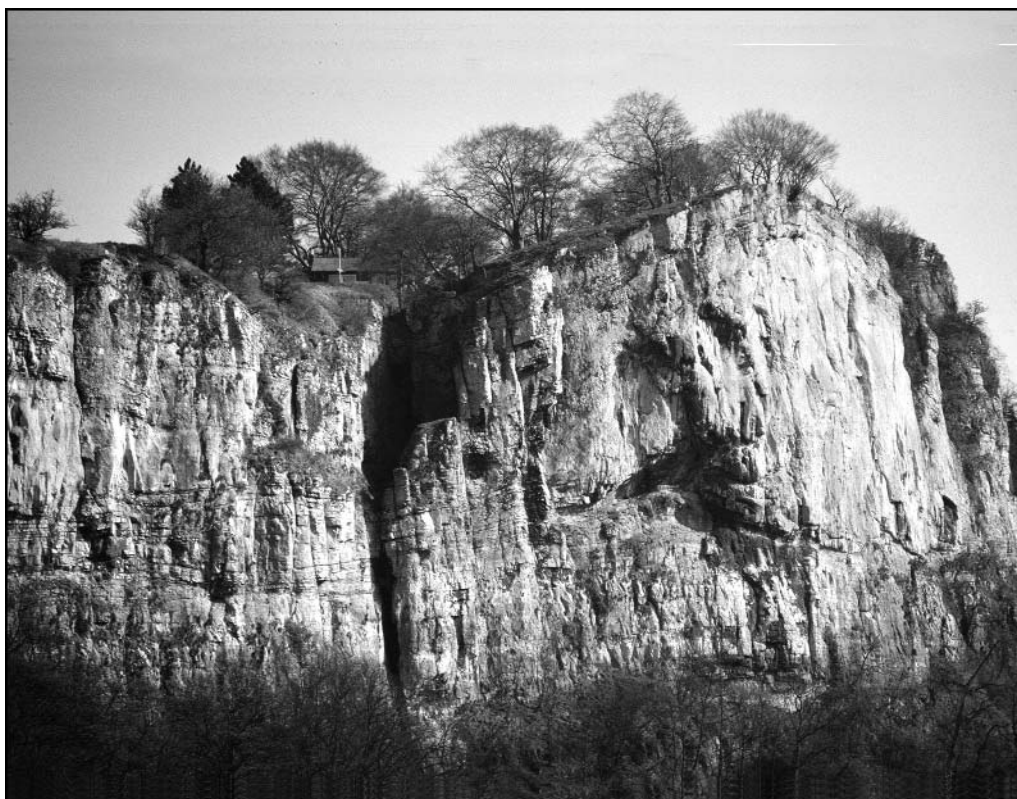


Figure 3. High Tor seen across the Derwent from Shining Cliff. The unbedded lens of the carbonate mud mound on the right passes left into bedded limestones of the mound flank and intermount areas. Part of a second, smaller tabular mound core is present at the left edge of the photograph. The shadowed cleft in the centre is High Tor Rake, a mineralised fault that emerges from behind the cliff.

The lens of unbedded limestone represents the core of a dome-like mound that probably stood some 10-20 m above the surrounding sea floor at its maximum development. It is composed almost entirely of carbonate mud; fossils are scarce but include brachiopods, fenestrate (fan-like) bryozoans, bivalves and crinoids. The brachiopods and bivalves often occur as clusters (Gutteridge, 1990) while the fenestrate bryozoans and crinoids are scattered through the mound core. Unlike modern reefs, no organisms with large calcareous skeletons capable of constructing a supporting framework are present.

The main mound grew by the amalgamation of smaller mounds that can be seen around the base of the mound core (Fig. 2). Bedding planes that dip away from the mound core become more prominent towards the margins of the mound core. These are the mound flank beds that represent the original surface of the carbonate mud mound, with depositional slopes that may have been as steep as 30-40°. Like the mound core, the mound flank beds are composed mainly of carbonate mud, but with fewer brachiopods and more abundant crinoids (Gutteridge, 1995). The disposition of the mound flank beds shows that the carbonate mud mound had a two-stage development. An initial phase of vertical growth was followed by the development of much thicker mound flank beds as the carbonate mud mound spread out across the surrounding sea floor. It was during this second phase of growth that a separate, smaller tabular mound core was initiated a few hundred metres north of the main mound core. The internal structure and the final form of the

carbonate mud mound seen on Figure 2 represent different stages of mound growth. There is no evidence that the High Tor mud mound was modified by erosion.

Further away from the mound core, the mound flank beds merge with the flat-bedded limestones that were deposited in the shallow water of the surrounding flat-topped Derbyshire carbonate platform (Biggins, 1969). The contact between the top of the carbonate mud mound and the overlying bedded limestones represents an episode of subaerial exposure killing the community that built the carbonate mud mound (Biggins, 1969; Gutteridge, 1991). The carbonate mud mound failed to re-establish after sea level rose, and the now-dead carbonate mud mound was buried by limestone and then shale.

The mud mound debate

A number of questions about how carbonate mud mounds grew are unanswered:

- Where did the carbonate mud come from?
- How was the carbonate mud able to support such steep depositional slopes?
- Many carbonate mud mounds grew in shallow water high energy conditions, so why are erosional features within carbonate mud mounds rare, even though the carbonate mud should be easily eroded?
- There is no evidence of a frame-building community of calcareous organisms, so what type of organisms built these carbonate mud mounds?

It is possible that carbonate mud carried in suspension was trapped by fenestrate bryozoans or crinoids to form a carbonate mud mound. However, fenestrate bryozoans are too sparsely distributed to have any baffling effect. The case for trapping of carbonate mud by crinoids is more compelling because many carbonate mud mounds are surrounded by what must have been a submarine forest of crinoids. But field relationships show the crinoids colonised the flanks of the carbonate mud mound only after the mound core was fully established. This shows the crinoids therefore played no rôle in the initiation of carbonate mud mounds. In thin section, the evidence against a detrital origin of the carbonate mud is clearer. The texture of the carbonate mud in the mounds is quite distinct from that in the surrounding limestones. The source of the carbonate mud appears to have been on the mound core itself.

The lack of erosional features in carbonate mud mounds and the steep mound flanks suggest there was some means of stabilising the surface of the carbonate mud mound. Organisms adapted to, or forming hard substrates are very rare and the brachiopods and bivalves found in mound cores were suited to soft or firm sediment (Gutteridge, 1990, 1995). Production of carbonate mud by communities of algae and bacteria offer the best explanation for the origin of carbonate mud mounds. Under the microscope, the carbonate mud resembles the biological precipitates of bacteria and blue green algae (Pickard, 1996). Microbial communities occur as rubbery mats that bind modern carbonate sediments. It is likely that similar mats, probably about 50 to 100 mm thick, bound the surface of carbonate mud mounds protecting them against erosion and supporting the steep depositional slopes. The mat was breached by small erosional hollows that were colonised by brachiopods and bivalves which were preserved in clusters (Gutteridge, 1990). If you could stand on the surface of a carbonate mud mound, it would probably have supported your weight up to a point. The rubbery mat may have broken and you would have sunk into the soft carbonate mud. Your legs would probably penetrate to knee depth with your feet feeling firmer sediment a few tens of centimetres beneath the surface.

Carbonate mud mounds are only common in the geological record immediately after mass extinctions when the main reef building organisms were wiped out. This allowed algal-bacterial communities to diversify and expand into ecological niches that were otherwise occupied by framework reefs. A mass extinction during the late Devonian cleared the marine ecosystem of reef-building communities and allowed carbonate mud mounds to become the main reef type during the Carboniferous (Bridges *et al.*

1995). There are many more carbonate mud mounds exposed in Derbyshire, including those near the National Stone Centre and in the western end of Lathkill Dale (described on page 254 in this *Mercian Geologist*), but the one at High Tor is one of the best exposed examples.

Half an exhumed reef knoll

The present day topography over the back of High Tor may be partly controlled by the Dinantian sea floor topography, as the High Tor hill mimics the shape of the carbonate mud mound. It may be considered as a partially exhumed reef knoll that was then fortuitously cut through by the Derwent.

The origin of the Derwent Gorge may itself be related to the carbonate mud mound at High Tor. Ford and Burek (1976) suggested the River Derwent previously flowed at the level of the limestone plateau to the west of the Derwent Gorge. The river migrated eastwards by uniclinal shift, down the dip slope of the limestone, by eroding the shale cover faster than the limestone. The carbonate mud mound at High Tor interrupted this erosion because it projected upwards into the shale and diverted the course of the River Derwent vertically downwards to form the Derwent Gorge. However, it may be questioned that an isolated feature of the limestone outcrop could cause a major diversion in drainage. An alternative view suggested by Smith *et al.* (1967) is that the Derwent Gorge represents a glacial diversion from an older course along the limestone/shale boundary.

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