

# Old mines and new sinkholes along the Hucklow Edge vein, Derbyshire

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**Abstract:** A major, near-vertical mineral vein hosted by faulted Lower Carboniferous limestone is concealed beneath the Namurian mudstone forming the southern slope of Hucklow and Eyam Edges. It has been mined underground from numerous localities in several phases during a period of three centuries. The depth of working increased progressively as more options became available to drain water out of the mines. Prior to the 20th century, these operations were limited to the selective extraction of higher-grade zones of galena. Miners left the gangue minerals largely intact, albeit honeycombed with a network of narrow tunnels and stopes. The overlying mudstone was also penetrated by shafts and tunnels. The modern Milldam Mine recovers the unworked, in-situ vein minerals (mainly fluorite, barite and calcite) by open stoping of the vein across its full width. Mined-out voids are backfilled with waste rock to provide long-term ground stability. The legacy of historical underground mining and the particular local geology has created situations where unsupported, weak roof zones above open cavities are vulnerable to sudden collapse, enabling voids to migrate through the overlying mudstone to form sinkholes at the ground surface.

On Christmas Day, 2013, a small group of walkers who were enjoying a ramble below Hucklow Edge, near the village of Foolow in the Peak District, were surprised to be confronted by a very large open hole in the ground. This conical-shaped crater was located within a cluster of abandoned lead mine shafts sunk in previous centuries through a thick bed of mudstone to work a large mineral vein system in the limestone beneath. The immediate interest in this event focused on its most likely cause, as a crown hole from the collapse of an underlying mine. Of greater interest however is the process by which a collapsed underground void at a depth of approximately 100 m was able to migrate vertically through the overlying rock sequence to break through to the land surface.

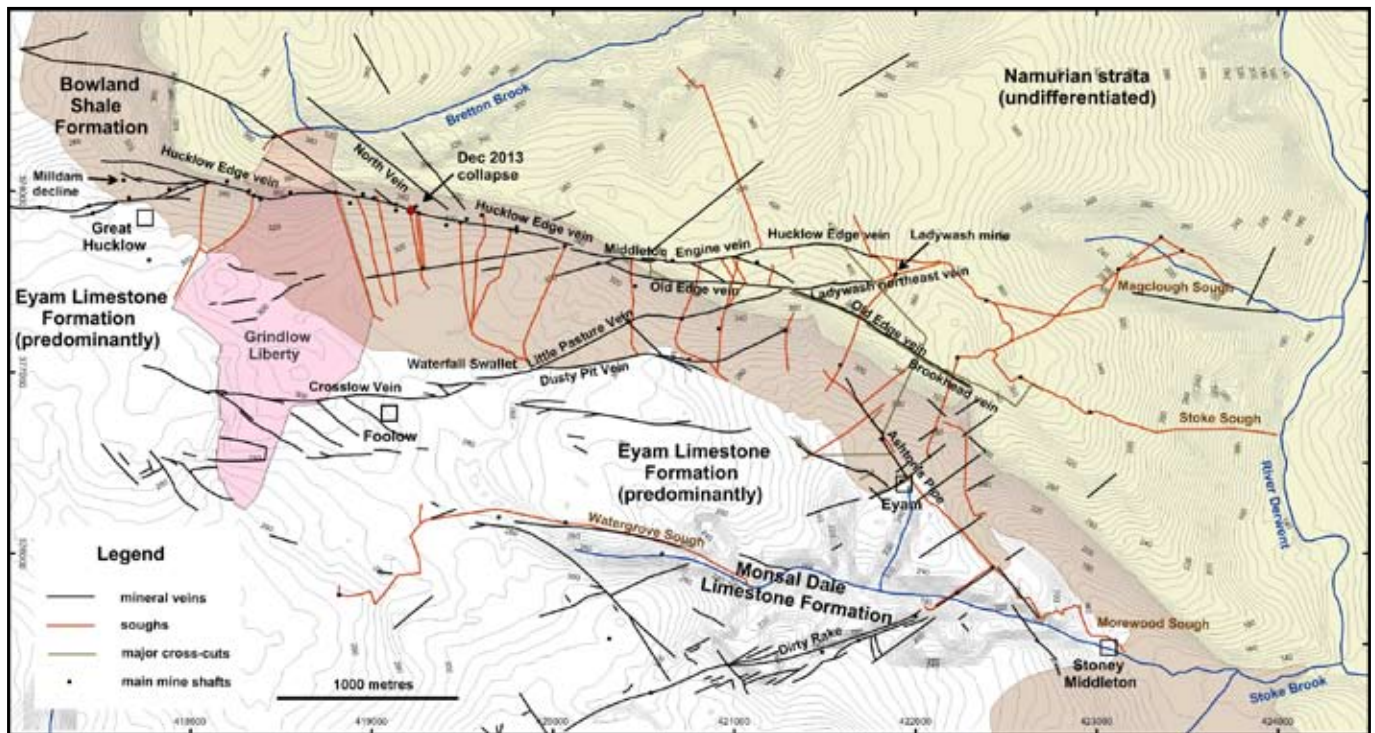
The new crater at Slater's Engine lead mine appears to be the surface expression of a deep, columnar, collapse structure that can be known as a rubble chimney or as a collapse-breccia pipe. This type of structure is characterised by the failure of the roof above an underground cavity in solid rock, followed by the spontaneous, upward migration of its zone of failure through weak overlying beds, sometimes reaching a vertical extent of several hundred metres. The loose debris falling from the continuously collapsing roof accumulates at the base of the migrating void space, gradually filling the entire column with material. The 2013 collapse event near Foolow was, at that time, the most recent of at least four such events that are known to

have occurred in the Hucklow-Eyam Edge area during the last 130 years. The process by which a surface crater formed at each of these events is analogous with that forming natural caprock sinkholes (Waltham et al., 2005), except that the underground voids initiating the collapses beneath Hucklow Edge are all man-made.

Both naturally occurring and human-induced rubble chimneys are widespread. Examples of the former include active sinkholes and breccia pipes containing unconsolidated fill in sequences overlying dissolution cavities in Permian gypsum beds around Ripon in Yorkshire (on a small scale) and in the Delaware Basin of New Mexico (on a larger scale). Clusters of older, cemented breccia pipes along both rims of the Grand Canyon in Arizona, some of which have been mineralised with uranium and other metals, demonstrate that the process has occurred in earlier geological time periods. These breccia pipes developed above collapsed caves in the Carboniferous Redwall Limestone, although dissolution of gypsum beds in the overlying Permian strata may have assisted the upward stoping of the pipes to the extreme penetration of up to 1000 m into overlying strata. Examples of human-induced, columnar, collapse structures include the large-scale rubble chimneys that formed during the catastrophic failure in 1994 of the Retsof salt mine, New York State (Yager, 2013) and multiple breccia pipes that disrupt currently-working coal mines in the Shanxi coalfield in China (Lu and Cooper, 1997).



*Figure 1. Hucklow Edge, viewed from the south, with the 2013 sinkhole in the centre on the lower slope of the edge (photo: PDNPA).*



**Figure 2.** Outline geology with the mineral veins, mine shafts and drainage soughs along Hucklow and Eyam Edges.

## Geological setting

Hucklow-Eyam Edge lies along the eastern margin of the White Peak area of the Derbyshire Peak District, where the uppermost Lower Carboniferous (Brigantian) limestones dip gently northeastwards beneath the escarpment formed by the overlying Namurian mudstone and gritstone beds. The local stratigraphical succession consists of thickly-bedded Monsal Dale Limestone Formation overlain by the thinly-bedded Eyam Limestone Formation containing mudstone intercalations and thin black chert bands. The latter is followed by a thin bed of dark mudstone previously identified as the Longstone Mudstone Formation but now incorporated within the Widmerpool Formation. These units are succeeded by a thick mudstone sequence belonging to the Bowland Shale Formation (previously the Edale Shales), of Pendleian age, above which the first gritstone unit of the Namurian Millstone Grit Group occurs. The Eyam Limestone Formation also contains locally-developed, more massive and fossil-rich reef facies. Depending upon their form and dimensions, these are described as either flat reefs or knoll reefs.

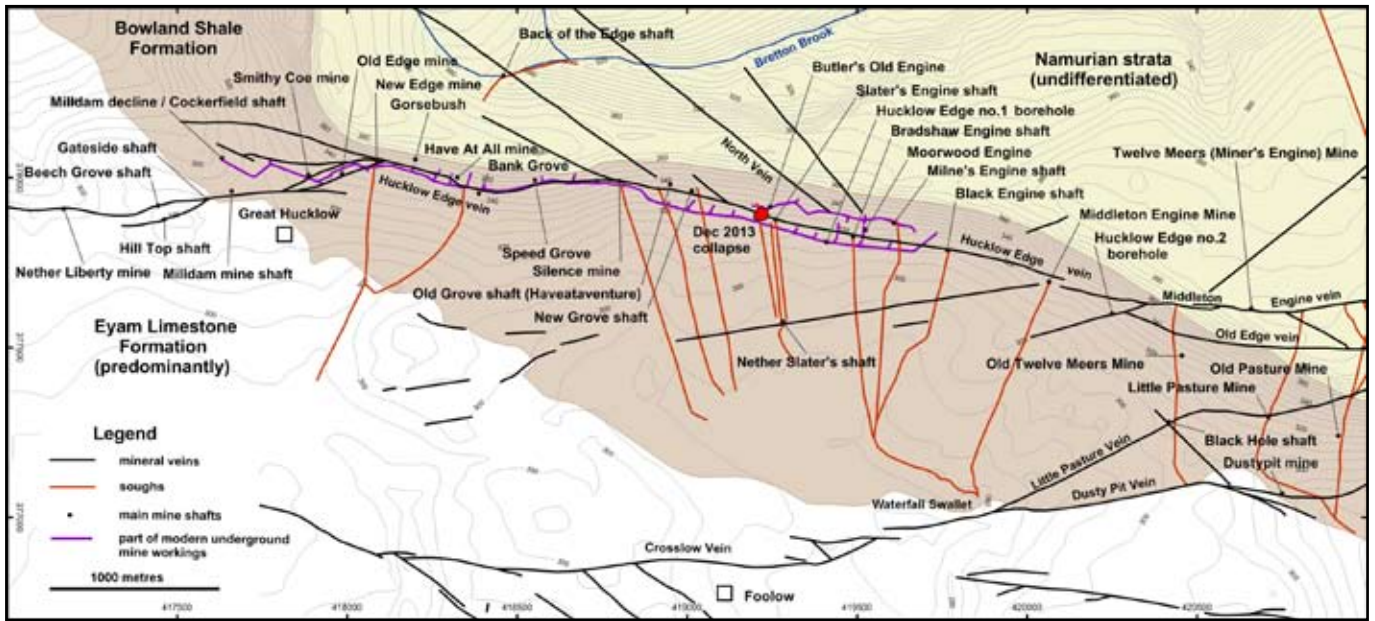
Concealed at depth within the Monsal Dale Limestone Formation and present beneath Hucklow and Eyam Edges and much of the surrounding area is the Cressbrook Dale Lava Member of the Fallgate Volcanic Formation. The volcanoclastic Litton Tuff Member also occurs within the Monsal Dale Limestone Formation above the Cressbrook Dale Lava, but it is less than 1 m thick beneath the Hucklow and Eyam Edges and is indistinguishable from other clay wayboards of decomposed volcanic ash that occur in the limestone. Repeated episodes of wrench faulting in the closing

phases of the Variscan orogeny created a network of narrow open fractures in which calcite, barite, fluorite and other minerals precipitated from hydrothermal fluids. These mineral veins along faults in the limestone occur at a variety of scales, and generally do not persist into the volcanic rocks or the Namurian mudstones.

## High Rake and Hucklow Edge vein

One of the largest mineral veins in the White Peak can be traced across the limestone from Tideslow, eastwards to Great Hucklow, from where it continues in the same direction beneath the entire length of the Hucklow and Eyam Edges, a total length of about 9 km. The mineral vein is not a single wrench-fault structure, but it is an extended zone of multiple, interconnected and en-echelon faults, many of which are mineralised. A cumulative sinistral displacement of approximately 150 m can be estimated from the offset of the outcrop of the Litton Tuff where it is cut by the fault zone at Tideslow. The effect of this lateral displacement upon the northeasterly-dipping beds causes a vertical offset across the fault, with a downthrow on the northern side.

The vertical extent of the mineral infilling of fracture cavities beneath Hucklow and Eyam Edges is restricted to the upper half of the Monsal Dale Limestone Formation and the full thickness of the overlying Eyam Limestone Formation. The mineral veins deteriorate and disappear where the faults pass upwards into the Namurian cover rocks and also downwards into the Cressbrook Dale Lava. Thus the mudstones and the lava form, respectively, the ‘roof’ and ‘floor’ of the mineral vein. The progressive increase in thickness of the Cressbrook Dale Lava eastwards from Great Hucklow to the area around Eyam (Hunter and Shaw, 2011) is accompanied by a corresponding reduction in thickness

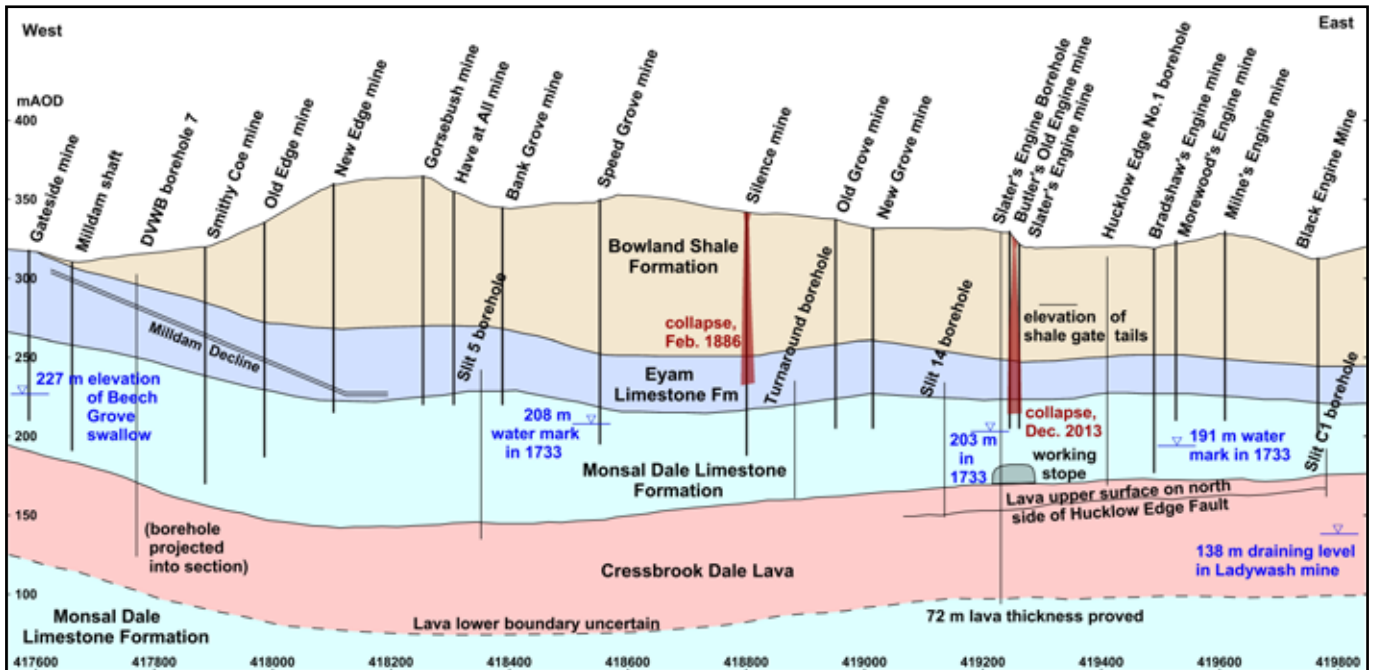


**Figure 3.** Some of the major mines, shafts and workings along Hucklow Edge.

**Figure 4.** Mineral vein exposed in the roof of a sub-level in Milldam Mine; it consists of banded and brecciated fluorite with a central core of late-stage calcite and barite (photo: Paul Deakin).



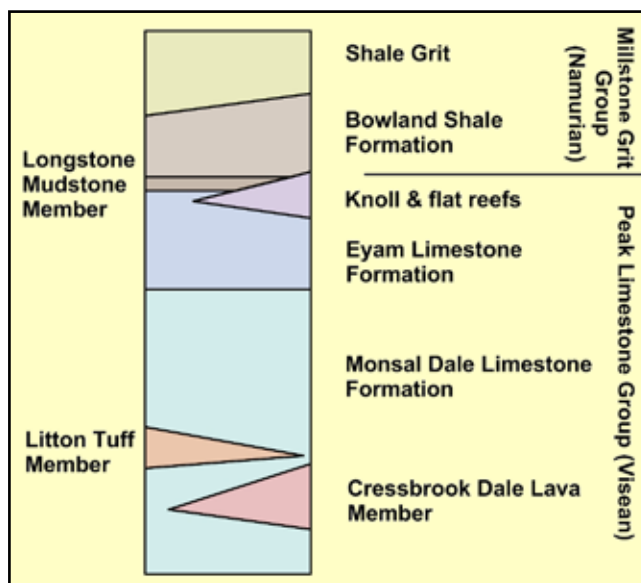
**Figure 5.** Longitudinal section along the line of the Hucklow Edge mineral vein; most shaft depths are uncertain, and details of the mine workings are omitted. Vertical scale exaggeration = 2.66.





**Figure 6.** Worked-out stope on the Old Edge vein in Ladywash Mine, typical of the earlier phases of 'in-vein' workings.

**Figure 7.** Lithostratigraphy for the Hucklow Edge area.



### Early mining west of Great Hucklow

Evidence from inscribed Roman-era lead ingots and rare references to Derbyshire lead in Anglo-Saxon deeds and the Domesday Book confirm that small-scale mining and smelting of lead from mineral veins in the White Peak continued intermittently throughout the first millennium. It would seem likely that a major mineral vein exposed in limestone at outcrop along White Rake, Tideslow Rake and High Rake would have been discovered during this period, but this assumption cannot be verified by any unequivocal evidence.

The earliest known surviving document referring to mining on Tideslow Rake dates from the year 1195 and a few more accounts are known from the early part of the 13th century (Rieuwerts, 2007). A lead mine near Great Hucklow mentioned in an Inquisition Post Mortem dating from 1299 (Sharp & Stamp, 1912) indicates that the entire length of exposed mineral vein was probably being worked by that time. The scale of these workings may not have been large and they would have been limited by their ability to manage the water inflows. Surviving documents relating to leasing, financial agreements or legal disputes in the Duchy of Lancaster or Barmote courts demonstrate that intermittent working of the exposed mineral vein continued throughout the next three centuries, but it is unlikely that miners were able to penetrate very far eastwards beneath the cover of Namurian mudstone where its outcrop begins at the village of Great Hucklow. The earliest written references to lead mining on the east side of Great Hucklow date from the 1670s (DRO, Bag C/549).

of the Monsal Dale Limestone Formation above it. Therefore the vertical extent of the Hucklow Edge mineral vein also decreases from west to east. The fault system dislocated all of the Namurian sequence above the Brigantian limestone and was a factor controlling the orientation of the linear escarpment formed by the Shale Grit and known as Hucklow and Eyam Edges. It is possible that the fault system penetrates vertically downwards through the Cressbrook Dale Lava and becomes mineralised again in the limestone beneath, but despite historical attempts to investigate this possibility, the concept has never been proved.

Individual sections of this major mineral vein system are known by different names at different locations along its length. The western half of the vein system, where it traverses the limestone outcrop is known sequentially, from west to east, as White Rake, Tideslow Rake and High Rake, where a hidden intrusive igneous body defeated the deep shaft-sinking ventures at Black Hillock and High Rake mines in the 19th century (Hunter, 2011). Beneath the Hucklow and Eyam Edges it is known as the Hucklow Edge vein. The concealed section of the Hucklow Edge vein has been worked intermittently along its entire length, from Great Hucklow to the eastern side of Eyam, by numerous different mining partnerships for almost three centuries. Today, a single company operates underground at Milldam Mine, with its decline entrance at Great Hucklow, extracting the fluorite-rich mineral left untouched by previous generations of lead miners.

*Acronyms of reference sources:*

- PDNPA = Peak District National Park Authority
- SA = Sheffield Archives
- DRO = Derbyshire Record Office

## Mining at Hucklow and Eyam in the 1700s

Two technical factors that limited early exploration of the mineral vein east of Great Hucklow were uncertainty about its position within the limestone concealed beneath thickening cover, and the problem of draining water from mine workings at increasing depths.

The combination of the steep escarpment behind Great Hucklow and the easterly dip of the limestone meant that the mudstone covering it very quickly reached a thickness of about 100 m. However, this was not the impediment to mineral exploration that it might first appear to be. The miners would have known from mine workings at the western edge of the mudstone cover that the faults hosting mineral veins in the limestone continued upwards through the mudstone as a zone of brecciation that contained indications of mineralisation, most likely consisting of iron-stained calcite veinlets. The miners called these features *mudds* or *symptoms* (Rieuwerts, 1998). They would have soon realised that the main vein was likely to be parallel to and downslope from the gritstone edge. They explored for symptoms by driving levels known as *shale gates* from localities near the base of the mudstone, downslope from Hucklow Edge, hoping to intersect them just above where the vein existed in the limestone below. For example, in October 1721, a miner stated that “*a firm vene with mud and cavil and oare about a hand ful thick*” had been discovered in a “*shale drift*” near Milnes’ Engine shaft (DRO, D3304/1/1). When symptoms were discovered, a vertical shaft was sunk from the surface through the mudstone to facilitate mine development in the limestone.



**Figure 8.** Brecciated mudstone associated with Hucklow Edge fault, exposed in the highest sub-level in Milldam Mine.

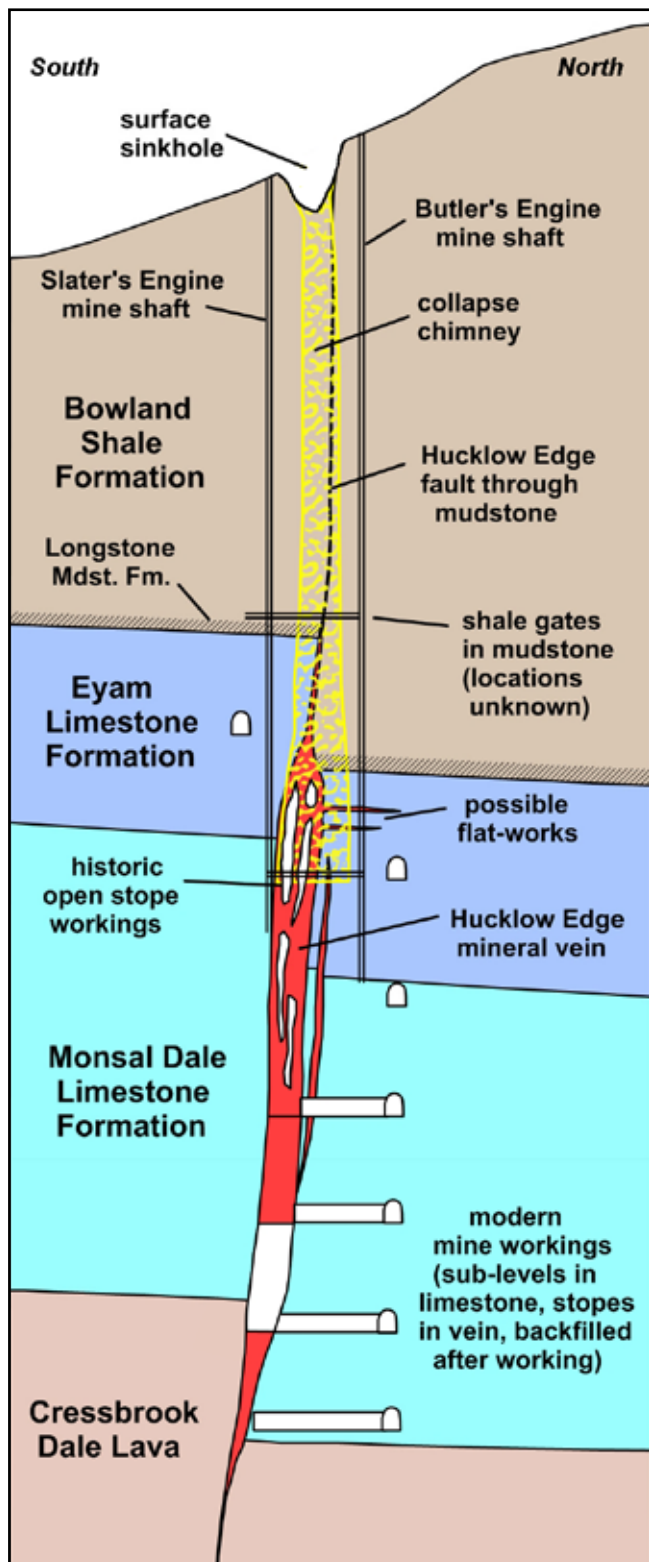


**Figure 9.** Slickensides on a stope wall in the Ladywash Mine.

Driving levels through the softer mudstone was considerably easier than driving through the limestone, particularly where the uppermost beds of limestone contained abundant chert. In some later underground mine workings in the vicinity of Eyam, miners considered making deviations out of the limestone into the mudstone to avoid having to drive tunnels through exceptionally hard rock (e.g. SA, OD/1392(a)/31, dated 1741 and OD/1392(c)/115, dated 1769). However, driving levels through the mudstone brought its own problems. The laminated mudstones have low rock mass strength, so the tunnel roofs, and occasionally the side walls, required timber support. The mudstone also depleted the oxygen from the mine air, and probably emitted methane and carbon dioxide, necessitating the sinking of ventilation shafts at intervals along the levels.

The entrances to the shale gates along the southern flank of Hucklow Edge have all collapsed. It is no longer possible to enter any of them and most are untraceable across the ground surface. Therefore it cannot be determined with certainty whether they were driven horizontally or inclined downwards to follow the dip of the upper surface of the limestone. Kirkham (1964) describes shale gates as having been used as drainage levels (driven nearly horizontally into the hillside and operated in conjunction with pumping shafts). This arrangement would have required small underground chambers to have been excavated inside the mudstone where the levels and shafts intersected. If the group of shale gates driven towards the section of the mineral vein between Silence Mine and Slater’s Engine Mine were driven near-horizontally, then they would not intersect their respective shafts below an altitude of 290-285 m. The next group of shale gates, from Bradshaw’s Engine Mine to Middleton Engine Mine all radiated from a single site near Waterfall Swallet, at the slightly lower elevation of 280 m. The altitude of the base of the mudstone along the mineral vein between Bank Grove and Slater’s Engine mines is around 250 m on the southern (upthrown) side of the fault, at least 30 m lower than the shale gate tails.

Other evidence, however, suggests that at least some of the shale gates were inclined downwards, following the dip of the beds, and may have been used for man-access and for ventilation purposes, with occasional references in records to a *firehouse* (e.g. DRO, Bag C/377/2, dated c1790). All of these cavities excavated in the Namurian mudstone cover created zones of weakness in and around the fault breccia; very few of them are shown on maps and plans with any degree of accuracy.



The drainage of early underground mines along Tideslow Rake and High Rake was assisted by the presence of natural, deep, karst conduits within the cavernous limestone. The mineral vein follows a ridge of high ground between Tideslow and Great Hucklow, and groundwater that may have been trapped in isolated mine workings by thin, impervious clay wayboards could be drained away by extending levels (*soughs*) to connect with small, narrow, natural caves into which the water conveniently disappeared (termed *swallows* by the miners). These conduits trend northwards, down-gradient, and a recent dye-trace from the south side of Hucklow Edge vein demonstrated that some of this water flows underground in a northerly direction as far as Bradwell, where it rises inside Bagshawe Cavern (J. Gunn, unpubl.). The underground drainage of this area was greatly modified in the 19th century when long *soughs* were driven from the Derwent valley into the eastern end of Eyam Edge at a lower elevation.

Underground mining operations in the Hucklow Edge vein eastwards from Great Hucklow increased significantly in the early 18th century. Subdivided into a succession of short lengths called *meers*, the mineral vein was leased by a number of separate partnerships which each sank their own individual mine shafts through the mudstone cover. Shaft sinking probably began in Great Hucklow parish and progressed westwards through the parishes of Grindlow, Foolow and Eyam. The Grindlow liberty had been granted to Lilleshall Priory in 1199 as an outlying grange and it remained under monastic control until the dissolution of the monasteries under Thomas Cromwell, when it was acquired by Sir William Cavendish. The manor was confiscated from Sir William's grandson in the 1640s during the Civil War and was not returned after compounding, the ownership then being transferred to the Harpur family. One of the consequences of this particular example of Peak District land title history is that the customary rights of unrestricted exploration by lead miners did not apply there and mining could only occur with the consent of the Lord of the Manor. For reasons not yet understood, no shale gates were apparently driven to the Hucklow Edge vein through Grindlow parish and the closest shale gates carefully follow its eastern and western boundaries. As a result, there may be fewer tunnels and cavities in the mudstone beneath Hucklow Edge within Grindlow parish.

Surviving documentary records contain useful data on lead production, but there is insufficient information to reconstruct a detailed chronology for the development of the shafts and shale gates of the individual mines along Hucklow Edge. Similarly, the surviving historic plans for these mines are simplified, schematic and show few details of levels and stopes within the

**Figure 10.** Transverse section through the Hucklow Edge mineral vein, with a conceptual model of features probably associated with the chimney collapse near Slater's Engine Mine; the height on the north side is about 250 m.



**Figure 11.** Typical gallery, with stacked 'deads' left by the 'old man' in the upper parts of the vein (photo: Rob Eavis).

Hucklow Edge vein (e.g. SA, OD/1232, OD/1233). It is known that the Bank Mine was open and working by 1712 and Speed Mine in 1713. The Silence Mine section of the vein was named in ore accounts in the same year and significant production was recorded in 1714 from that mine for its first decade of operation (SA, OD/1505). No dates have been found for shaft sinking at Butler's Engine and Slater's Engine mines, but they were in operation by the 1720s. Exploration beneath the mudstone further east along Hucklow and Eyam Edges was occurring simultaneously from the exposed veins in the limestone around Eyam (Ford, 2010, 2012). Brookhead Sough was begun near Eyam in the summer of 1714, driven northwards to its vein from an elevation of 240 m. The soughers discovered *symptoms* on Old Edge Vein in Sept 1718. Sometime prior to the 1740s, northwest-trending branch veins were also discovered splitting away from the north side of the Hucklow Edge vein (Rieuwert, 1994).

It is apparent from the earliest production records, covering the period from 1712 to the 1740s, that the mining partnerships were usually able to recover significant quantities of lead ore in the first two to three years after intersecting the mineral vein in the uppermost limestone beds within their meers. Thereafter the annual ore production usually diminished. One possible explanation for this pattern is that some of the first lead ore to be encountered at the shaft bottom occurred in high-grade flats (thin, strata-bound, bedding-replacement orebodies) in the Eyam Limestone (SA, OD/1505). These flats extended laterally from the sides of the near-vertical veins and the process of extracting lead ore from them

would have created wide but low, sub-horizontal stopes-cavities in the thin limestone beds immediately beneath the fault breccia in the mudstone. The empty stopes would have been partially backfilled with packs of waste rock (*deads*) for temporary roof support, but integrity of the roof would have been disturbed and weakened.

The rock mass strength of the Eyam Limestone is higher than that of the overlying mudstone strata, but the thin, poorly-bonded limestone beds with intercalations of mudstone are fractured and disrupted close to the fault zone hosting the Hucklow Edge mineral vein. Slabs of rock easily become detached from the roof zones of wide stopes in the flats workings. However, the Hucklow Edge vein may be not be susceptible to these conditions along its entire length. Where flat reefs (which are not related to ore flats) and knoll reefs exist as lateral facies variations within the Eyam Limestone, the rock has a more massive character that may have provided greater stability for the historical mine workings. Similarly, zones of silicification associated with the mineral vein may have increased the rock mass strength on a local scale.

As the miners excavated downwards through the Eyam Limestone they would have encountered the more regular, near-vertical mineral vein system hosted by the massive beds of the Monsal Dale Limestone. However, the continued development of separate mining operations working from their own isolated mine shafts could not be sustained for long, as the miners struggled to drain away the inflowing water and also suffered from insufficient ventilation. These problems and other practical mining issues, such as underground haulage distances, were ameliorated by the consolidation of separate mining titles and by collaborative agreements between partnerships that enabled the interconnection of their separate mine workings. By the 1750s, Butler's, Slater's and Bradshaw's Engines mines were consolidated into a single title (SA, OD/1232(b)). Mine reckoning books also show that many of these operations were working at an annual loss in a number of years, and were effectively being subsidised by annual profits from other mines owned by the major partners, particularly Odin Mine, near Castleton (SA, OD/1499).

### Contemporary drainage of the mines

Interconnections between mines may have alleviated the problem of water drainage for some of the partnerships by enabling water to flow between the workings. Additional tunnelling may have also intersected more karst fissures. This may either have improved the drainage through natural swallows, or it may have exacerbated the problem by encountering more inflows of water. The natural swallows inside the limestone west of Great Hucklow all lie at about the same altitude. Poynton Cross swallow is at 46 fathoms deep, equivalent to an elevation of 238 m, while another swallow in Beech Grove mine is 48 fathoms deep, at 227 m altitude, which is close the level of the Litton Tuff at that locality. The dimensions of Beech Grove swallow was small (21



**Figure 12.** Stone arching that supports the roof in Morewood Sough, west of Stoney Middleton (photo: Rob Eavis).

inches high by 7 inches wide) and its shared use became the cause of a legal dispute in 1862 (Derby Mercury, 26 March 1862). The court depositions described routine mining operations several fathoms below the elevation of the swallow, with drainage water lifted up to that level for disposal. However, during periods of heavy seasonal rainfall the swallow was overwhelmed by increased flows of underground water, and the deeper mine workings were regularly flooded to levels at least 10 m above the swallow.

Historical documents include a few unspecific references to swallows in the limestone east of Great Hucklow, and some natural karst drainage must have existed there. Interconnections between the mines in Great Hucklow, Grindlow and Foolow parishes may have enabled water to be drained westwards to the swallows or possibly northwestwards through a sough to Stanlow Dale (at the head of Bradwell Dale), although the latter cannot be verified (Rieuwerts, 2007). By the mid-1720s however, groundwater problems were inhibiting the development of these ambitious underground workings beneath Hucklow Edge. Long distance, deep-level soughs were needed to drain the mineral vein to a lower elevation, but these were major capital investments and required syndicates of wealthy investors. In the late-1720s such a partnership was eventually formed to drive the Stoke Sough westwards from the River Derwent into the eastern end of Hucklow and Eyam Edges, a distance of 6 km from Great Hucklow (Rieuwerts, 1994, 2007). Beginning from an altitude of 125 m, its objective was to dewater all of the intersecting mineral veins above that level along the whole length of the escarpment. A second, competing partnership began to drive Magclough Sough from a more northerly starting point at an elevation of 154 m.

Farey (1811) wrote that the soughers in Stoke Sough encountered significant quantities of inflammable rock-oil while driving their tunnel through the Namurian mudstone. A zone of oil-impregnated mudstone was also intersected by the sinkers in Ladywash shaft (Carruthers, 1923). Lighted candles ignited liquid oil floating on the surface of the water inside Stoke Sough. Bitumen was recorded as being encountered among *boulder stones* at the base of the mudstone (DRO, Bag C/391, 1761).

Strong flows of water were met, sometimes associated with outbursts of carbon dioxide, which caused sections of the tunnel to collapse. Methane explosions killed several soughers. The ventilation shaft above Stoke Sough is now run-in and blocked above sough level, and the sough itself is blocked by squeezed mudstone a few hundred metres from the entrance, although some water still flows out. Magclough Sough and its air shafts have also collapsed.

In 1733, in anticipation of the benefit of lowering the water level in their meers by drainage through Stoke Sough, marks were made in the mine shafts between Great Hucklow and Eyam to record the baseline water depth for the purpose of calculating future compensation payments. At Speed Grove Mine the mark was made 498 feet below the surface and at Old Edge Mine it was set at 486 feet (DRO, Bag C/730). These depths equate to elevations of 208 and 187 m respectively, indicating that even before any potential benefits were achieved from the long-distance soughs, miners were able to reach lead ore at depths well inside the Monsal Dale Limestone. The shaft water mark at Speed Grove Mine indicates that the miners had been able to reach a depth equivalent to the upper 40% of the total vertical extent of the mineral vein at that locality. At Slater's Engine, the water mark was at 203 m, representing penetration through more than 50% of its vertical extent. It is not known if the water marks recorded the natural stable groundwater surface at that time or the lowest level to which the miners could keep the workings drained by using their own primitive methods of lifting water to the surface. The 208 m elevation is still a substantial depth and it is possible that the upper part of the limestone was already partially drained through natural deep karst conduits, or that miners had discovered and connected their workings to such swallows.

By the middle of the 18th century Stoke Sough had reached the workings at Ladywash mine and, through interconnections with many other mines, was able to provide some mine drainage at the eastern end of Hucklow and Eyam Edges. A third drainage level, Morewood Sough, was also started in the 1780s and driven beneath Eyam from Middleton Dale at an altitude of 142 m. No written evidence exists suggesting that any of these soughs were able to lower the water levels in mines at the western end of the escarpment in the parishes of Great Hucklow, Grindlow and Foolow. The hydrogeological barrier formed by the large mound of Cressbrook Dale Lava located beneath the village of Eyam, with its clayey, impervious upper boundary, may have been one reason for this.

In 1755 the first recorded ground failure in the mudstone of the Bowland Shale Formation probably occurred. The unexpected cause was the earthquake that devastated Lisbon, Portugal, in November of that year (Musson, 2013). Tremors from this earthquake were felt as far away as Scotland and Scandinavia. Miners working underground in Peak District lead mines that day experienced the ground movement, and



the narrow escape suffered by two miners working beneath Hucklow and Eyam Edges was reported by a mine agent called Francis Mason (Bullock, 1755). He described a linear 'chasm', 150 yards long, opening in a field above a mineral vein where the miners were working 60 fathoms underground. The miners were too terrified to climb out of their shaft in case it ran in on them. Four more shocks were felt, each accompanied by a loud rumbling noise, over an interval of about 20 minutes. All the shafts remained intact, but quantities of rock and mineral were dislodged from the sides and roof. The exact location of this surface chasm cannot be determined, but it is known that Francis Mason was working at Miners' Engine mine in the 1730s.

Without a direct connection to any of the eastern soughs, which eventually drained the Ladywash workings to an elevation around 138 m, the miners in Great Hucklow, Grindlow and Foolow parishes could apparently not work any deeper than about 203 m, and production ceased sometime in the second half of the 18th century. Speed Grove Mine was recorded as producing small amounts of ore up to the early 1770s. For a few decades from the late 1770s, shares in these mining properties were advertised for sale intermittently in newspapers (e.g. Derby Mercury, Jan 17, 1778). No records of lead production have been found from then until almost the 1850s, when mining resumed.

### Mining at greater depth in the 1800s

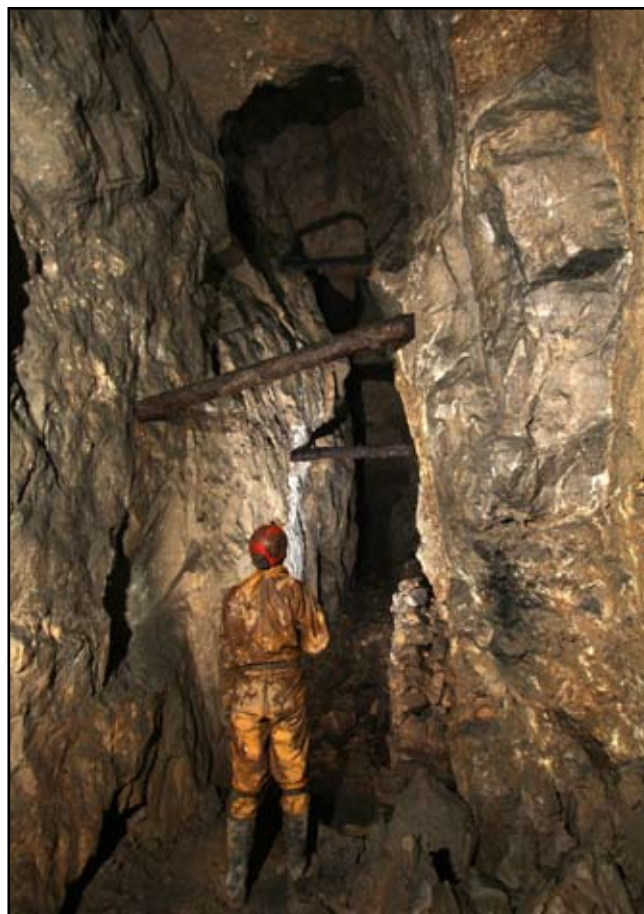
The formation of the Mill Dam Mining Company in August 1857 represented the third major phase of historical mining activity along the section of the mineral vein near Great Hucklow. The objective of the new group of investing partners was to acquire rights to and reopen some of the old lead mines in the vicinity of the village. They intended to utilise new technology, notably steam pumping engines, to drain the limestone more effectively and so gain access to deeper, previously unworked parts of the mineral vein. Mining activity was hindered in the first few years by a dispute with the neighbouring (and also recently-formed) Great Hucklow Mining Company, although the latter company closed down in 1873 after it failed to sink below the Cressbrook Dale Lava. The dispute arose over access rights to the Beech Grove swallow (at 227 m). Both companies sought to dispose of some of their water through the swallow to help reduce the burden of lifting it all to the surface. At first it was not realised that the water being discharged at the surface into a nearby swallet was probably draining back into the workings (along with normal runoff), and even with the assistance of the steam-driven pumps the mine would flood during periods of heavy rain. Eventually, improved surface drainage was engineered and the mine was able to work throughout the year.

The Eyam Mining Company was formed in 1848 with the object of reopening and extending Morewood Sough to drain and work additional ground. It also worked the Dusty Pit vein. Later it expanded its activity

to work other veins around Eyam, driving a branch level in Magclough Sough and clearing out and extending Stoke Sough. Glebe shaft was started after Morewood Sough was extended beneath Eyam village in 1848. By 1861 the company was sinking the New Engine Shaft on the eastern end of Hucklow Edge vein (Sheffield Independent, 30 November 1861). The Black Hole Mining Company was floated in late 1860, based on Old Pasture, New Little Pasture, Broadlow and Black Hole Mines. This company was probably acquired by Eyam Mining Company.

In the late 1850s the Mill Dam Company leased rights to lead ore in the Smithy Coe section of the vein contained in the ground below the flooding level of 50 fathoms depth. This is equivalent to an elevation of 228 m, effectively the same as at the Beech Grove swallow, demonstrating the control exerted over the local water table by the karst drainage system. Reports in newspapers in 1866 stated that a level was in the process of being driven to connect Milldam Mine with Smithy Coe Mine (Sheffield Independent, 26 March 1866). The Derby Mercury of 1 August 1866 stated that the Mill Dam Mines were nearly exhausted.

Litigation hindered production from Mill Dam Mine for a few years, but significant quantities of ore were raised each year during the period between 1868 and 1878. Stopping reached a depth of 65 fathoms (elevation approximately 190 m) and the workings must have been



*Figure 13. Timber stemples in an abandoned stope within the higher part of the vein (photo: Rob Eavis).*



**Figure 14.** A cross-cut slit into an open stope in Milldam Mine, with brecciated fluorite in the stope wall (photo: Paul Deakin).



**Figure 15.** A short slit into a large stope that was worked many years ago in Milldam Mine (photo: Rob Eavis).

close to the lower boundary of the limestone where it lies in contact with the lava. By 1880 the mines became unprofitable to operate and eventually closed. The property and equipment was sold by auction in August 1895 (Sheffield Independent, 6 July 1895), after which the shaft eventually collapsed.

The Mill Dam Mining Co had continued to extend its operations eastwards, and in 1873 it leased a section of the vein at Silence Mine (*aka* Grindlow Mine), where a steam engine was erected. It is not known if the company acquired the title to work the ground between Smithy Coe and Silence Mine and it is also not clear whether the miners repaired and reinstated an old shaft or sank their own new shaft. They soon discovered that old mine workings dating from the previous century in Silence Mine had reached a depth of 148 m from the surface, at an elevation of about 195 m (Barnatt, 2012). These old workings were described as being on a small scale but the operators may have been hiding the truth. The mine produced a small quantity of ore in 1877, but the company did not find the rich mineral they had hoped for in the upper half of the vein, and the partners were forced to deepen the shaft to 87 fathoms and 2 feet (160 m depth, reaching an altitude of 185 m), a level inaccessible in the previous century because it was permanently flooded. The vein at that depth consisted of at least three parallel and interconnecting sub-veins. By 1881 a replacement steam engine (presumably larger) was helping to control the water inflow and some ore was raised from the deep level in 1882. Exceptional rainfall in the winter of 1882-1883 increased the water flow underground, overwhelming the pumps and flooding the workings. These problems continued until 1884, when the persistent low lead prices forced the closure of Silence Mine. By that time the orefield had entered a period of terminal decline, unable to compete with cheaper imported lead

On February 11, 1886, a major collapse of the ground surrounding the shaft top at Silence Mine swallowed the winding head-frame and some nearby sheds. The eventual size of the surface crater is not known, but it was not sufficiently large to engulf the stone-built engine and winding house, the ruined foundations of which still survive. Contemporary newspaper reports stated that the cause of the collapse was the decay of some shaft timbers, made worse by *a severe frost followed by a heavy thaw* (Derby Daily Telegraph, February 11, 1886). The shaft was oval in cross-section and its dimensions are shown on a plan (DRO, D1738/10/8) as 3.5 x 2.7 m. The total volume of the shaft would therefore have been 2,417 m<sup>3</sup>, equivalent to a conical void at the surface about 19 m across and 25 m deep. This seems insufficient to have swallowed a head-frame with its associated sheds and plant, described in newspaper accounts as having been *precipitated down the abyss, which is over 100 fathoms deep*. There may have been some exaggeration in the newspaper story, but when the bulking factor (volume increase) of a mass of broken mudstone is taken into account, it seems more likely that the collapse was the result of roof failure above old stopes, shale gates and other underground cavities close to the shaft. This would increase the available void space for infilling and create conditions for upwards propagation of a continuously collapsing cavity through 95-100 m of overburden.

### Mining in the twentieth century

At the beginning of the 20th century, abandoned lead mines in the Peak District were being re-examined for potential resources of fluorite (*aka* spar). The most easily won fluorite was contained in hillocks of waste gangue minerals stored on the surface near old mine shafts. William Robinson promoted awareness of the value of the spar in the waste hillocks as a useful

primary product. Between 1899 and 1910 he temporarily improved the local economy by expanding the recovery of this mineral and developing its markets (James and Foster, 2001). Almost all the mine shaft hillocks along Hucklow and Eyam Edges were re-worked for spar until this resource was exhausted (Carruthers & Pocock, 1916). Surface tips at Glebe Mine were also re-worked, and underground mining for fluorite was attempted in Black Hole and Little Pasture mines until water inflows forced abandonment. At Silence Mine a large mound of mine waste remained next to the collapsed shaft hollow and the ruined engine house; this was gradually re-worked to recover its spar content, with work probably ending in the 1950s. Hillocks at Old Grove mine were re-processed in the 1970s.

In 1920, Blackwell & Sons leased Ladywash mine even though the surface dumps had already been reworked. Ladywash and nearby New Engine Mines were eventually reopened by Ashover Mines Ltd, which worked underground until their combined operation ceased around 1937. In 1936, Glebe Mine in Eyam had been reopened to extract vein fluorite from underground. The following year, W. Braithwaite, the Glebe Mines agent, explored and reopened the Ladywash shaft for English Lead Mines Exploration Ltd. Glebe Mines drove a new cross cut from Glebe Mine to Ladywash, reaching Old Edge vein in 1945 at a depth of 160 m within Ladywash. This persistence paid off with the discovery of an unworked section of Old Edge Vein, 760 m long, which provided the bulk of production until 1948. Ladywash became the main haulage shaft and its diameter was enlarged in 1949.



**Figure 16.** A large stope in Milldam Mine, worked 'in vein' before slits were used to reach the stopes(photo: Paul Deakin).

By then the main crosscut level had been extended northwestwards to connect to Ladywash shaft and also to cut the Crosslow and Hucklow Edge veins. Laporte Minerals Ltd acquired Glebe Mines in 1959 and a new fluorite processing facility at Cavendish Mill was opened in 1965, replacing the old plant at Eyam. Ladywash Mine finally closed in March 1979, having been in existence (although not continuous production) for 262 years. The shaft remained open as part of the mine ventilation system.

Operations at Ladywash Mine ceased because of the limited winding capacity of the shaft and the increasing distance for underground haulage as mining proceeded westwards along the Hucklow Edge vein. Another factor was because *the in-vein sub-level stoping method then in use had become unsafe, due the incompetence of the mineral* (Bramley, 1991). The mudstone forming the roof over the stopes was weak and had collapsed in a number of places, causing surface craters and contaminating the ore with material that adversely affected the froth flotation ore processing in the mill. No specific dates or exact locations of these craters were given by Bramley. A more detailed account of another similar collapse, as experienced by a miner from inside the mine, is given in *Lead in the Veins*, a book published by the parishoners of Great Hucklow village (2009, p.130). The writer describes how the floor of an upper level (near the top of the limestone) gave way into a worked-out, open stope, followed shortly afterwards by failure of the mudstone roof, including the support rings. This was a single collapse event that propagated upwards through the entire thickness of overlying strata within a matter of seconds. It sent a blast of air through the workings, infilled the empty stope with debris and formed a large crater on the surface. Fortunately, only a single tree was swallowed by the new hole. The location of this collapse was near the old Miners' Engine mine and the event occurred in the 1980s. The solution to these problems was to develop an alternative mine entrance at the western end of Hucklow Edge, in Great Hucklow village. This is the modern Milldam Mine.

The post-WWII history of underground mining operations beneath Hucklow and Eyam Edges can be followed from the planning records. The first Ministerial Planning Permission was granted in 1952 to work vein minerals in the central part of Hucklow Edge from Black Hole Mine, followed in 1955 by another permission to work fluorite, galena and associated vein minerals from Glebe Mines in Eyam and at Ladywash Mine. In March 1986, a new planning permission was granted for the extraction of fluorite and associated vein mineralisation from the Glebe and Black Hole permission areas and also from an additional area to the north west of Black Hole Mine. This consolidated and superseded the earlier permissions and included the area now known as Milldam Mine, where a new mine compound was developed on the site of a former scrap yard. An inclined access and the main haulage level were driven eastwards from the compound and



**Figure 17.** The sinkhole that developed over the chimney collapse in December 2013 (photo: The Independent).

**Figure 18.** Thin-bedded Eyam Limestone overlying the more massive Monsal Dale Limestone, exposed in Furness Quarry, above Stoney Middleton.

eventually linked up with the old Ladywash workings in September 1991. Limited extraction of ore started in 1992, followed by full production in 1994. This planning consent, allowing extraction of fluorite and associated minerals, expired on 31 December 1998.

The 1 in 8 decline into Milldam Mine utilises trackless vehicles with no winding shafts. Mining operations no longer take place inside the mineral vein, relying instead on tunnels (*sub-levels*) driven through the host limestone adjacent and parallel to the vein, which is then worked from a series of short cross-cuts (*slits*) connecting with it. Tunnels wide enough and high enough to accommodate large vehicles require no artificial roof support where they are driven through the thickly-bedded Monsal Dale Limestone. Fans of shot holes are drilled into the vein from each slit and the vein mineral is fragmented by blasting and excavated safely as it pours through the slits. The width of the vein is variable and exceeds 11 m in places, although this is usually where multiple, individual veins separated by faulted slices (*riders*) of limestone are extracted as a bulk orebody, leaving a large empty underground void. The mining scheme requires the empty stopes to be backfilled with the broken rock generated from the sub-levels as they are developed in the limestone.

Renewal of the planning consent for a further 15 year period was granted in November 1999, to expire on 31 December 2013. The approved plans associated with this permission identified that working of the mineral vein would begin on the west side of the Black Hole Mine shaft and progress from there in a westerly direction to a point about 520 m east of the Milldam Mine compound. Some extraction was also proposed within offshoot veins branching off the main vein to the northwest. One month later, Laporte Minerals sold the company to Glebe Mines Ltd and after a brief period of activity the operations at Milldam Mine were curtailed in response to a fall in the price of the refined spar product. The mine remained in care and maintenance status for more than a decade until October 2012, when the new owners, British Fluorspar Limited (BFL), restarted works to bring the mine back into production.



The Hucklow Edge mineral vein being worked in Milldam Mine is the same vein that has been worked for lead ore since the early 1700s. These historical mining operations only extracted galena and the minimum quantity of the other vein material sufficient to gain physical access to it. The average galena content of typical Peak District mineral veins is estimated to be 5% and the thick zones of banded and massive fluorite, calcite and barite were of no interest to the miners at that time. It is evident from the descriptions above that the historical mining activity penetrated through much of the vertical extent of the mineral vein and would have left it punctured by a network of small tunnels and narrow stopes. A few of these small 'old man' holes can be seen where they are occasionally intersected by the modern sub-levels inside Milldam Mine, but most of the old in-vein workings are inaccessible.

### The collapse in December 2013

Three months before the 1999 planning permission was due to expire on 31 December 2013, an application was submitted by BFL to renew the consent for Milldam Mine for an additional period of 15 years. On December 23, while this application was being considered by the planning authority, another collapse occurred at the mine. Like the previous events, the failure of the roof area over historical underground voids caused a rapid chimney-like collapse to propagate upwards through the mudstone cover to form a surface crater near to the old Slater's Engine shaft. The cause of the collapse was stated to have been the consequence of weakening of

the mudstone from persistent heavy rainfall (Derbyshire Times, 31 December 2013). A subsequent inspection of the underground workings by the HSE (the Health and Safety Executive of the HM Inspectorate of Mines) in January 2014 led them to conclude in a letter to the planning authority that the historic mine workings presented a hazard and that modern mining activity at Milldam Mine was a contributory factor. No further technical details relating to the collapse have been released by the company. It is likely that this area is either too dangerous to enter or is completely inaccessible from the modern sub-levels.

The Hucklow Edge No.1 borehole, drilled in 1965 between Slater's Engine and Bradshaw's Engine mine shafts, records the uppermost 22 m of limestone as consisting of Eyam Limestone. It is characterised by a succession of individual beds of grey to pale-grey limestone, frequently fossiliferous and varying in thickness from 0.75 to 4.3 m, with no significant intercalations of mudstone and no lost core (Stevenson & Gaunt, 1971, p.370). It is possible that this lithology represents a local development of reef limestone facies. Further east, between Middleton Engine and Miner's Engine shafts, the Hucklow Edge No.2 borehole intersected 24 m of Eyam Limestone. This also consisted of several beds of limestone of varying thickness but with few fossils, some irregular silicification, minor fluorite replacement and two zones of no core recovery (Stevenson & Gaunt, 1971, p.101). The latter description may be indicative of the character of the Eyam Limestone where it is less capable of supporting a load above a cavity.

The dimensions of the previously existing cavity into which the mudstone rubble collapsed are unknown, but it is possible that the chimney above it has a wide, elongated base aligned over an old open vein stope or flat (or both), tapering upwards to a narrower circular shape, before flaring out to the sinkhole in the shape of an inverted open cone formed in weathered mudstone.



**Figure 19.** A run-in of mud and debris where a high-level cross-cut within an early phase of the mine had encountered even older workings left by the 'old man' (photo: Rob Eavis).



**Figure 20.** A line of stemples across a slope in "old man" workings in a higher part of the vein (photo: Rob Eavis).

The surface area of the sinkhole was measured as 1150 m<sup>2</sup> and its maximum depth was 19 m; giving it a volume of about 7280 m<sup>3</sup>. A bulking factor around 35% may be expected in broken material falling out of the roof of a collapsed underground void; this means that upwards failure reaches only about three times the original void height before it stabilises when the fallen debris meets the roof. For a collapse-chimney to propagate through about 100 m of cover and also to leave a surface crater exceeding 7000 m<sup>3</sup> suggests that some of the historic mine workings may be larger than previously thought. Slater's Engine shaft, located close to the collapse crater, was unaffected by the disturbance and it remains open down to a known blockage at a depth of 54m.

In the spring of 2014, BFL submitted a scheme for the backfilling and remediation of the sinkhole at Slater's Engine, while the planning authority continued to deliberate the application for renewal of consent. This included a revision of the proposed working scheme to improve awareness of the risk posed by the historic workings and the methods required to mitigate against future ground failure. Backfilling of the crater with waste rock from the mine was undertaken during the year, with no enforcement action taken by the planning authority (PDNPA, Delegated enforcement report, Milldam Mine, September 15, 2014) and renewal of the consent was eventually granted in January 2015, extending the potential operating life of the mine until the end of 2028. The remaining ore reserves are estimated to be 2.45M t, not counting any branch veins that may be found, and planned annual output is 150,000 t.



**Figure 21.** Backfilling the sinkhole in 2014, when the Bowland Shale mudrocks were exposed on the left side (photo: PDNPA).

The working scheme (Wardell Armstrong, DOC171063, rev C, August 2013, submitted to PDNPA) predicts that where the roof of a stope is formed from massive limestone beds it will perform as a coherent beam, capable of supporting the superimposed load, except where it is badly fractured, in which case it will be rock-bolted. In situations where the mineral vein is worked close to the overlying mudstone, an artificial crown pillar (ACP) will consist of roof and rib bolting with steel mesh, oversprayed with shotcrete, and will be installed from a dedicated ACP tunnel. New stopes are mined in panels with a maximum height of 25 m and a strike length of 9 m. Empty open stopes are backfilled with heading rock before extracting the next panel.

In April 2015, a tree on Hucklow Edge blown down by high winds was found to have been capping the historic Have At All mine shaft, which was then revealed as an open hole. A further visit from the Mines Inspector determined that there was no direct connection with the current operations in this instance. This minor incident is interesting however, in demonstrating that not all of the historic mine shafts sunk through the mudstone of the Bowland Shale along Hucklow and Eyam Edges have run in and formed small craters at the surface. The sides of this shaft, originally 100 m deep and sunk through mudstone, appear to have remained self-supporting for three centuries. The December 2013 collapse event near Foolow, like similar previous events below Hucklow Edge, was ultimately a mine roof failure. A combination of complicated and weak roof rock together with the unknown extent of old mine workings created a situation where a collapsing void was able to migrate rapidly upwards through the overlying beds and through to the surface. Further slumping of weathered mudstone around the sides of the crater enlarged it into a sinkhole.

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