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THE HABITAT AND ORIGIN OF LEAD ORE IN GREBE SWALLET MINE, CHARTERHOUSE-ON-MENDIP, SOMERSET

by

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ABSTRACT

Undisturbed deposits of lead ore were found when Grebe Swallet, an old mine at Charterhouse, was reopened in 1982. Abraded lumps of galena are present in a variety of sedimentary matrices filling voids in the Carboniferous Limestone. The deposits are residual orebodies derived from primary galena veins that once existed at levels above the present limestone plateau of the Mendip Hills. Formed in association with neptunian dykes, the primary lead veins were fragmented and concentrated as the plateau surface was lowered 90 metres or more by dissolution over a very long period of time. It is argued that all the lead orefields of the Mendip high plateau are likely to have consisted of secondary residual deposits similar to those at Charterhouse.

INTRODUCTION

In AD 49, within 6 years of their occupation of Britain, the Romans were exporting lead from Charterhouse, and it is assumed that they took over mines that had long been worked by the native Britons (Gough, 1967, p. 19). The mines were probably shallow surface workings that developed into what are now the Charterhouse and Ubley Rakes (Stanton and Clarke, 1984; Stanton, 1985). The ore, concentrated in a shallow residual deposit, would have been easily won, which accords with Pliny's observation that in Roman Britain lead ore "was found at the surface of the ground so abundantly that a law was spontaneously passed to limit production" (Gough, 1967, p. 35). The Roman occupation of Charterhouse probably lasted for some three and a half centuries and the mining was, for much of the time, intense. In the Dark and Middle Ages mining was desultory at best (Gough, 1967, p. 48-49), and the renewed activity of the 16th, 17th and 18th centuries, when narrower, poorer lodes were worked in deeper mines, may well have produced less lead than was extracted by the Romans. By the mid-18th century the metal had become scarce and the local men had proved that "the ore on Mendip . . . does not lies deep", few mines having been deeper than about 50 metres (Gough, 1967, p. 141). The Cornish miners who came to Charterhouse in the 1840s were sure that their superior technology would reveal rich ore below the workings of the "old men" but their 6 trial shafts and galleries, reaching depths as great as 108 m, proved again that the deeper levels were barren (Stanton and Clarke, 1984, p. 33). They recouped their losses by resmelting the slags and slimes of earlier days.

The early writers seldom say much about the ore itself. Gough (1967, p. 3-4) quotes a variety of names applied by 17th and 18th century Mendip miners to the lead ore: *common*, *honeycomb*, *naked*, *blue* or *popinjay green*. Probably all but the last, which was certainly pyromorphite (Kingsbury, 1941, p. 74), were galena in different forms or circumstances. In the Mendip mines galena occurred sometimes as "loose separate stones", sometimes adhering to the rock walls of the lode. One "stone of lead" from the Cornish shafts was recorded as weighing between 500 and 600 kg. Gough (1967, p. 137-141) quotes 17th and 18th century accounts which show that a Mendip miner's *gruff* or *rake* normally went down between two "cliffs" of limestone rock. These were evidently much harder than the lode itself, which sometimes consisted of "sparre" (vein calcite), sometimes of earth, clay or rubble. In two deep shafts the Cornish miners proved that the lodes they were following downwards gradually shrank to "nothing more than a small vein or division of the rock, with spots of lead in places". Charles Moore, the Bath geologist, examined the "Charter House Mine" in one of the rakes about 1860 (Moore, 1862, p. 735; 1867, p. 491-493). He found a neptunian dyke of Lower Liassic "blue marl", 2.5 m thick, 53 m below ground, that yielded about 7% galena as disseminations that sometimes replaced fossils.

In 1981 in the Blackmoor Valley, Charterhouse on Mendip (ST504555) a group of cavers including myself began to excavate Grebe Swallet hoping that it would bypass the impenetrable sump at the end of Waterwheel Swallet (Stanton, 1987). We soon realised, from the abundance of galena and the many stemple holes in the rift walls, that the 'cave' was in fact an old lead mine. Gravel washed into it in the floods of 1968 (Hanwell and Newson, 1970) had completely filled some of the upper galleries and shafts, but most of the lower workings, including some natural cave passages, were still open. By 1982 we had reached the limits of the mine workings except where they had collapsed on a massive scale. Subsequently, digging to extend the cave passages had only minor success. The survey (Figure 1) shows the whole system as known in 1990. The passage length is 310 m and the vertical range 54 m.

The natural cave passages of Grebe Swallet mine are insignificant, but the 18th century miners had left diverse relics of their activities in them. In the mine, they had not cleaned out all the mineral lodes. Lead ore was encountered *in situ* at several places. This paper describes the re-opening of the mine, the methods of working used by the miners and the nature of the mineral lodes, drawing particular attention to their association with neptunian dykes. Finally, this evidence is brought to bear on the problems of the origin and emplacement of lead ores in the Mendip Hills.

THE RE-OPENING OF GREBE SWALLET MINE

Intense storms on July 10, 1968, caused about 160 mm of rain to fall in 24 hours at Charterhouse-on-Mendip (Hanwell and Newson, 1970). The normally dry Blackmoor Valley was flooded to a depth of several metres and three new swallet holes opened in its floor. One of them, called Grebe Swallet, led down into 45 m of narrow rifts ending in a boulder choke. The first explorers found many lumps of lead ore lying on the floor. By 1970, falls of earth had blocked the swallet entrance. Air photographs taken before the 1968 floods showed a flat featureless valley floor at the position of the present entrance which is a vertical shaft at the bottom of a funnel-shaped depression 12 m wide at ground level and 4 m deep. The void volume of the sinkhole represents about 150 m^3 of unconsolidated sediment that was washed underground by the 1968 floods.

Our first job in 1981 was to clear the collapsed entrance shaft, which took 7 days. The fill included tipped rubbish and a live rifle cartridge. Beyond were the rifts of the mine, floored with 1968 sand and gravel and roofed with unstable boulders. To make a commodious passage we removed the gravel to a depth of c. 2 m (which revealed the original miners' floor in a few places) and stacked it over our heads on a base made of large rocks jammed across the rift and secured with cement. By this means the boulder roof was supported and made safe. The 1968 gravels were found to contain tin cans, branches, turf, lumps of black mud tailings, rocks, pieces of galena, Roman pottery and part of a Roman bronze manicure set. In the rift walls we found the opposing "egg" and "slot" hollows battered into the limestone by the miners to hold wooden stemples.

The open rifts ended where the mine had sloped down to a shaft. Gravel deposits more than 3 m thick filled these passages to the roof, burying a miners' dump of lead-rich mud. Beyond the shaft was a mass of huge boulders, the Galena Ruckles. Gaps between boulders had been packed with deads and walled off by the miners. As we dug out the gravel that plugged the shaft we uncovered a giant stemple hollow, the size of an adult boot, that must have accommodated one end of a young tree-trunk. Obviously, the opposite wall must have worried the miners, and we soon realised that it was a huge, undercut, tottering rock mass. We quickly backfilled the shaft and worked forward into the ruckle, following the route taken by the waning 1968 stream, as shown by battered rock faces and pebbles of slag and other surface material. Key boulders were chemically removed and the remaining ones stabilized using a 1 : 3 mix of cement and the local gravel. In June 1982 on the 104th working day we unexpectedly broke into a small neighbouring mine (The Other Side) with rifts and boulder ruckles, that led after about 20 m to the foot of a choked entrance shaft.

In the main ruckle, where the miners never penetrated, we found large slabs of galena. The biggest weighed 23 kg. The 1968 stream route through the ruckles turned vertically downwards, the gaps between boulders often being empty of gravel. Below, open rifts in solid rock took us forward several metres at a time. In August 1982, on day 122, we hammered the last boulder into bits — and re-entered the mine. A roomy rift with stemple hollows (the "12 Metre Climb") dropped vertically to the back of a heap of deads nearly touching the roof. Over them we could peer into a level gallery extending to left and right, with heaped deads on both sides. Pushing over the deads we followed the gallery to the right. Theorizing that a small man could have wheeled a barrow along it we named it, probably wrongly, the Barrow Run. After a few metres a gravel choke showed where the 1968 stream had sunk in the floor. Ahead, up a slope, we entered a high natural rift chamber (Sidcot Chamber) with stalactites, two mined shafts in the floor, heaps of deads and a variety of mining relics. Some 30 m of natural phreatic passages, with more mining relics, led off the chamber to end in chokes (Young Clark's Passages and Bootprint Chamber).

In the other direction (left) the Barrow Run ended at a collapse cone that we stabilized and dug through into a frighteningly unstable chamber that was the miners' way in, probably from the gravel-filled shaft in the upper cave. Dozens of stemple hollows, thick rotting oak stemples, and the remains of shaft walling showed how the miners had tried, and eventually failed, to support this treacherous area. It had collapsed before they had finishing extracting the lead ore. Two lodes remain, so we called it Lode Chamber and spent many days stabilizing it with masonry and cement.

We now attempted to open up the stream sink below the Barrow Run. Working down through miners' tipstuff and then boulders and mud in a wide rift, we gave up at 11 m depth on working day 194. We had proved that only a small part of the 1968 stream had sunk into this rabbit-sized hole, which through the ages had been kept open by sudden uprushes of muddy water during floods. The Barrow Run follows the roof of a boulder chamber, now mostly full of miners' tip, and the 1968 stream must have found many different routes down through the boulders, of which Deep Dig, as we called it, is the furthest one.

A choked rift in Young Clark's Passages, sloping downwards and draughting, was our next objective (June 1983). The rift varied in width from nearly a metre to less than 50 mm. Progress was achieved by digging out the stony mud deposits (two mudflows, studied in some detail but not described here) and by hand-drilling and blasting the left wall of the rift. By day 256 we had advanced 11 m and could see ahead into a chamber beyond a barrier of 4 large stalactites. To avoid damage we bypassed them via a mud-filled bedding plane on the right and entered the chamber on day 260 (January 1984). It led nowhere, and, reacting to our concentrated effort in the Blasted Rifts, we took a breather and went caving elsewhere.

A month later we attacked the boulder choke at the end of Breather Chamber, which led into another narrow rift that we widened by drilling and blasting, this time descending almost vertically. On day 315 (September 1984) we broke out of a muddy ruckle into open passage, which was blocked after a few metres by a sagged rock rib. This removed, we continued horizontally along a narrow phreatic rift, blocked by rocks here and there, to a point where the cave totally changed character. Our rift broke into the side of a much larger rift that converged onto it from the right at an acute angle. The larger rift is choked with boulders (Semicostatum Ruckle) and is so wide that we have never seen the far wall. According to the survey it probably corresponds to the important fault along which the most southerly of the Charterhouse Rakes was excavated (Stanton and Clarke, 1984, Figure 13). Purposeful digging ceased at this point (day 337) because we didn't know which way to go; but some progress has been made using methods described in Appendix A. Miners never entered the known cave below Young Clark's Passages, indeed most of the extractive mining occurred in the ruckles and rifts above the Barrow Run, although the miners used the natural void space in the latter for disposal of deads.

GREBE SWALLET MINE AND ITS MINERS

The mine consists of a maze of natural rifts and larger cavities that, before mining began, were partly or completely full of unconsolidated sediments. These consisted of a usually unsorted mixture of mud, silt, sand, gravel, stones and rocks, and were excavated by the miners for the grains and lumps of galena ('the stones of lead') which formed an integral part of the mixture. The miners worked systematically along and down the rifts. Their lighting was dim and the sediment muddy, so that although they could identify large lumps of galena by their weight, small lumps (walnut size and smaller) escaped their vigilance. The mud, sand and small stones were therefore carried out of the mine and the galena separated, probably by washing in trough buddles (Gough, 1967, p. 147). The larger stones and rocks were easily recognized as worthless "deads" and were dumped in worked-out parts of the mine.

The miners made extensive use of wooden stemples to support unsafe places. They appear to have known that the "stones of lead" tended to gravitate towards the base of a deposit (at least in the upper galleries), so the initial passage was often driven at a low level following a rock floor if there was one. The roof of loose sediment had therefore to be supported. In rifts this was easy; matched 'egg and slot' hollows were chipped in the opposing walls, horizontal stemples were hammered into them, and poles or boards were pushed forward to fill the gap between stemples and roof. In the upper galleries, level or sloping lines of stemple hollows mark the initial passage roofs. Later, if the deposit was payable, the stemples were removed and the deposit picked down or allowed to fall. This eventful procedure, termed "overhead stoping", was continued upwards until the ore, or the miners' nerves, failed. It seems that the latter eventuality was not unknown where the deposit occupied a large cavity and contained many boulders. In such conditions, wooden stemples and props are unreliable supports. For instance the North Shaft in Lode Chamber leads up into the base of a boulder ruckle 2-3 m wide, which the miners hardly penetrated although it is rich in galena, nor did they penetrate the Galena Ruckles, where we found much galena *in situ* including slabs of 19 and 23 kg weight.

Lode Chamber itself must have severely tested the miners. The stemple hollows that crowd its walls include, among the normal circular hollows, rectangular ones carefully shaped to accept sawn beams of about 7 × 15 cm (3 × 6 inches) cross section (Figure 2). The chamber nevertheless suffered major collapse. Rectangular stemple hollows are also found in the 8 fathom shaft (14.5 m deep) beyond Sidcot Chamber, but nowhere else in the mine. Shotholes for blasting are also restricted to the Sidcot Chamber shafts and the North Shaft in Lode Chamber. Thus, shotholes and shaped stemples may together characterise the final stages of working in the 1750s.

The mine entrance was probably, but not certainly, within a few metres of the present entrance. The upper galleries, with simple stemple hollows and no shotholes, could have been worked long before the shaft down to Lode Chamber, bypassing the Galena Ruckles, was sunk. Lode Chamber must have been a key point in the mine. The massive heaps of deads alongside and under the Barrow

Figure 2. *Three stemple hollows in Lode Chamber, two rectangular (the biggest 15 cm high) and one round.* (Photo A. Griffin)

Run did not derive from Sidcot Chamber and are best explained as having come from a deep trial shaft, now filled or covered, beneath Lode Chamber. They contain much rubble of Triassic and Liassic neptunian dykes similar to those still visible in Lode Chamber, and many galena granules. Indeed, another possible explanation for the special rectangular stemples used in Lode Chamber is that they could have supported headworks and winding gear above the deep shaft, where the rubble was offloaded and tipped beside the Barrow Run.

Ore must have been hard to find in the 1750s. The 8 fathom and 2.5 fathom shafts in Sidcot Chamber were sunk by laborious shothole drilling and blasting that widened fissures containing mud with galena granules that were only c. 15 cm wide at the top of the shaft and shrank to a width of 3 cm width or less at the bottom. The miners were adept at drilling shotholes 23 mm in diameter and as much as 48 cm deep, using a borer with a single, chisel-like edge, and blasting them with gunpowder tamped by a mixture of lime and grit (Stanton, 1983). As each shaft deepened they maintained its regular shape by dry stone walling, each section of wall being founded on a wooden stemple and built up to reach the previous stemple 1-2 m higher (Figure 3). Now the stemples are largely decayed and the stone walling has sagged or collapsed. The miners used picks with a rectangular chisel edge about 15 mm wide, as shown by occasional pickmarks preserved in clay. For prising galena-bearing mud out of narrow fissures they employed a "spud", an 18th century agricultural tool (used in heavy weeding, as of docks or thistles) like a spear whose iron head had not a point but a chisel edge. We found the rusted head of a spud above the 12 m climb. Stemple hollows were battered into the limestone by a pointed pick or hammer. Our experiments with a lump hammer showed that a simple stemple hollow could be formed in little more than 5 minutes.

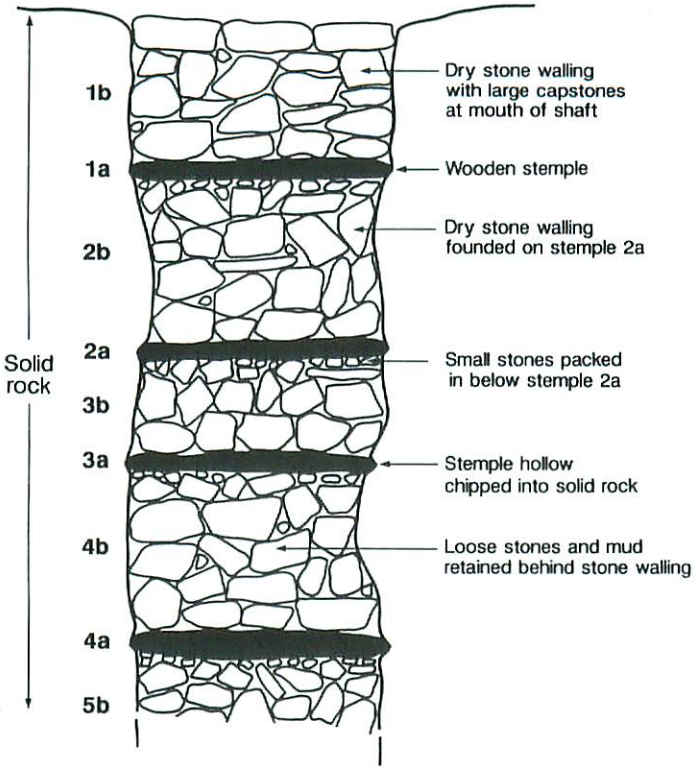


Figure 3. *Diagram of a vertical retaining wall as constructed by 18th century miners in shafts about 1 m wide. Wooden stemples and dry stone walling were emplaced in the numbered sequence indicated.*

The miners left other relics. On the floor in Sidcot Chamber are the rotting remains of a pair of boots with ironshod leather soles and heels. A print made by these or other boots in the mud floor of Young Clark's Passage was destroyed by a careless visitor. On the lip of the 2.5 fathom shaft is a stone-built work bench upon which rest two flat slabs of sandstone, possibly roof tiles of Pennant stone (Figure 4). In one of them are 3 deep grooves formed by sharpening a flat implement, probably a shothole borer. The other slab was, presumably, a spare. The miners had chipped a long groove across the stalagmited wall above the work bench to collect water and drip it onto the sharpening stone. A similar sandstone slab was found amongst the deads in the Barrow Run.

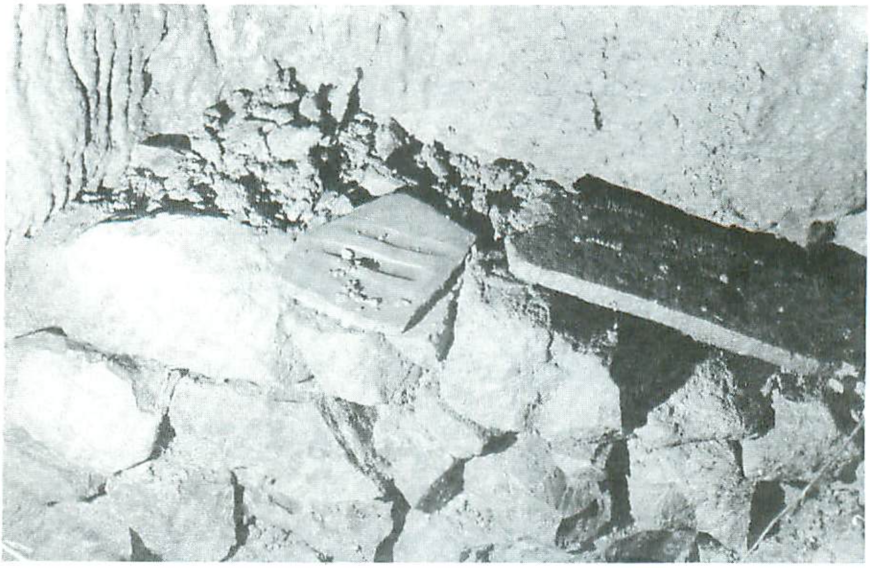


Figure 4. *The miners' work bench in Sidcot Chamber. On it are two sandstone slabs, one used for sharpening borers.* (Photo A. Griffin)

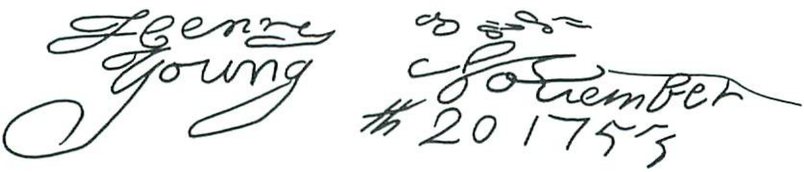
Figure 5. *A cryptic symbol in Young Clark's Passage, scratched on mud using a stalactite, crossed by many thin trails; on the left are a child's finger marks and on the right are holes stabbed into the mud using a stalactite.* (Photo A. Griffin)

a) Enigmatic symbols, scratched with a stalactite, crossed by many thin trails.

b) John Clark, scratched with a stalactite, dated 1753.

c) Another symbol, close to a), scratched with a stalactite. The curious similarity to a) may indicate illiteracy.

d) Henry Young, signed with a fingertip and smudged. Hen.... ran out of space at a corner.



e) Henry Young, scratched with a stalactite, unconventionally dated, crossed by one thin trail (distant from the working faces, unlike a) and c)).

Figure 6. *Signatures and cryptic symbols left on muddy ledges by 18th-century miners (traced from photographs).*

On muddy ledges in Young Clark's Passage two of the miners stabbed holes with a broken stalactite, scrawled cryptic symbols (Figure 5), and used fingers and stalactites to sign their names (Figure 6). Henry Young and John Clark were down the mine on 20 November 1753, and judging by the small size of their fingermarks they were children, able to write their names with plenty of flourishes but not otherwise very literate. This inscription almost certainly dates the last phase of mining activity and the November visit accords with the possibility that some mines were worked by farmers who went underground in the slack winter season. The miners appear to have introduced a population of small creatures that left thin trails crossing muddy ledges near the main working areas but not elsewhere (Figure 5). They broke off and removed many stalactites but missed those 5 m up in Sidcot Chamber; possibly their lights were too dim to reveal them. One thing is certain; they would have surfaced at the end of each day plastered with sticky mud!

THE LEAD ORE

Green (1958) reported that galena "is widespread both as specks and as small crystals scattered in calcite and barite" on mine spoil dumps throughout the Mendips. However, nowhere in Grebe Swallet Mine has lead ore been found as a vein in the solid rock. Veins of coarsely crystalline calcite are present in a few places, but are barren. The galena occurs exclusively as detrital fragments forming part of the unconsolidated sedimentary infilling of rifts and other cavities. The composition of the infilling varies widely from place to place; from ruckles of mainly limestone blocks, to jumbled rocks and stones (of limestone, vein calcite, neptunian dyke fragments and insoluble chert, sandstone and galena) with some clay, to structureless clay carrying dispersed sand, silt and stones of the types already mentioned.

The lumps of galena vary in size from slabs up to 80 mm thick and up to 23 kg weight down to granules (Figure 7) and sand-size particles. Small pebbles and granules are often smoothly rounded (Figure 8). The large galena lumps are almost always slabs of roughly uniform thickness, with a pattern of gentle convexities on one side and irregular hollows on the other (Figure 9). Most lumps and slabs

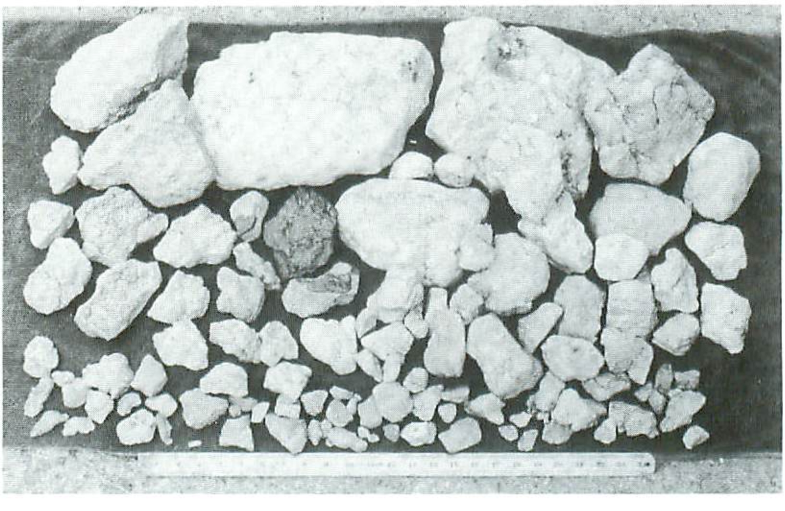


Figure 7. *Some of the larger "stones of lead" found while reopening the mine. The dark stone near the centre is limonite; two clasts beside it have partial limonite coatings. The scale bar is 62 cm (2 feet) long.*

Figure 8. *Small "stones of lead", showing degrees of rounding. The coin is 22 mm wide.* (Photo A. Griffin)

are worn smooth, but on one relatively unabraded slab the convexities have rough surfaces formed by innumerable crystal terminations. In section the slabs are seen to consist of massive crystalline galena in crystals that are often elongated normal to the surface. The lumps and slabs, which are also described by Green (1958) from mine dumps, are without doubt, broken pieces of encrusting galena veins, the convexities marking the growing face and the hollows the attachment face. These mammilated forms are typical of some hydrothermal deposits, and are remarkably similar in appearance to the encrustations of iron hydroxides that have developed on Roman masonry in the Hot Springs of Bath.

The largest slabs of galena were found trapped between limestone boulders in the Galena Ruckles. Lumps of 1-5 kg weight, such as could easily trickle out of the boulder ruckles, are locally common in the stony rubble filling rifts like the lode in Lode Chamber (Figure 10), but they also occur here and there in the ruckles and in the stony clay deposits of other rifts. The sedimentary fill of the narrowest rifts (up to 20 cm wide) usually consists of small, often rounded, stones and granules, typically composed of insoluble material such as chert, sandstone and galena, set in brown clay. There is thus a clear similarity in clast size between the galena and its associated sedimentary particles, resulting, probably, from the greater mobility of the smaller particles, irrespective of their composition, in the confining environment of the rifts and boulder ruckles.

Some of the galena lumps have thin patchy coatings of whitish to translucent cerussite (lead carbonate) as observed by Green (1958, pp. 80-81). Brown

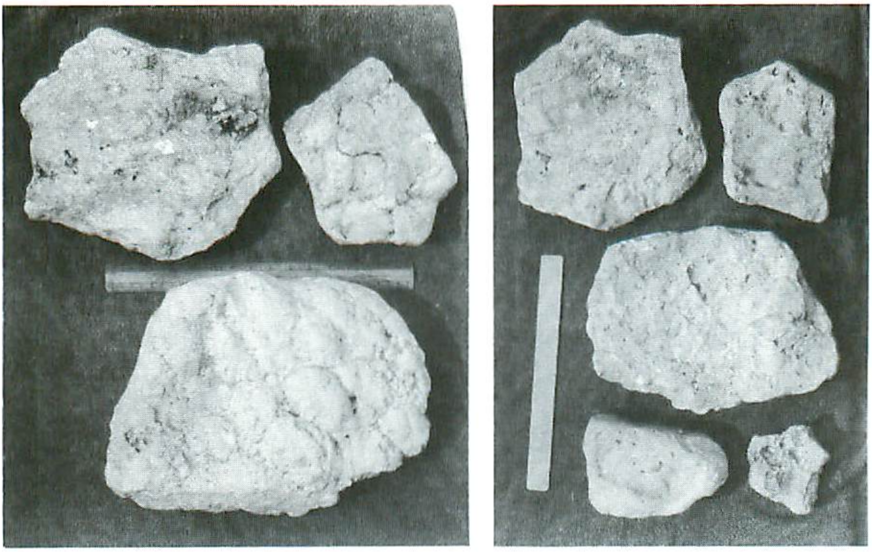


Figure 9. *Some of the large galena slabs that are broken pieces of encrusting veins.* **A:** *growing faces.* **B:** *attachment faces. The scale bars are 32 cm long.*

limonitic iron hydroxides occur in significant quantities encrusting lumps of galena, and also, less commonly, as separate fragments, usually angular, in the sedimentary deposits (Figure 7). No other ore minerals have been found in the mine.

The smooth rounded surfaces that characterise the galena lumps must result from weathering of originally angular broken fragments of vein (Figure 11). Physical abrasion, suffered as the fragments moved downwards with or through (by virtue of their greater density) the other sediments, must have played some part. The big slabs in particular are deeply indented in a few places where adjacent rocks or stones pressed against them. However, the fact that the small pebbles and granules are as smoothly rounded as the slabs suggests that chemical corrosion such as rounds limestone surfaces in the subsoil, has been at work. The conversion of galena to cerussite is perhaps a stage in this process, which requires, occasionally, a chemical environment different to the present one.

THE NEPTUNIAN DYKES

There is a common association in the Mendips between lead deposits and neptunian dykes, and it is well seen in Grebe Swallet Mine. At several places in the upper passages from near the entrance down to Lode Chamber, dykes of red marly limestone or marl not more than 80 mm thick adhere to the vertical walls of the rifts (and ruckles). They sometimes show sedimentary lamination varying from sub-horizontal to vertical. Because of their colour, and because similar dykes are frequently seen in Mendip quarries to be transected by later dykes that are demonstrably of Lower Liassic age, they are assumed to be of Triassic age.

Figure 10. *A lode in Lode Chamber, with fines partly removed by tricklewater. Stones of limestone (large), chert (mostly dark coloured), galena (light coloured), ironstone (very small, black) and sandstone are present. The label is 8 cm long.* (Photo A. Griffin)

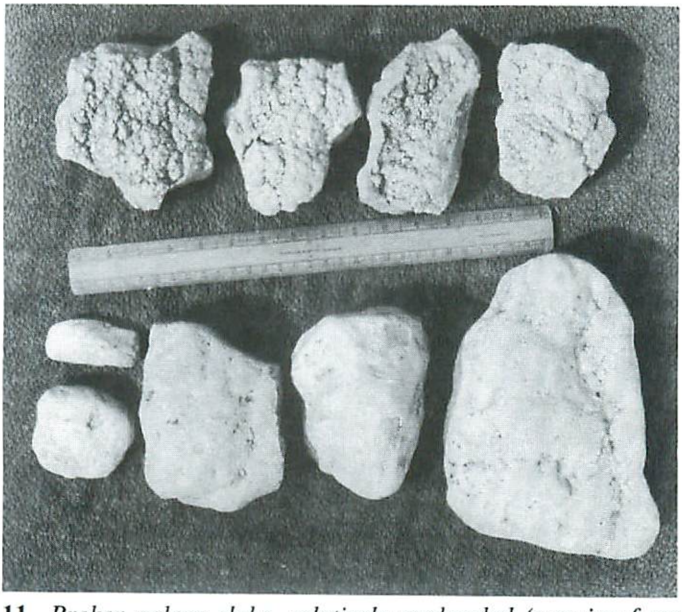


Figure 11. *Broken galena slabs, relatively unabraded (growing faces) above, heavily abreaded and rounded below. The scale car is 32 cm long.*

In Grebe Swallet Mine Liassic dykes are seldom seen *in situ*, but are evidently present in two areas, the Semicostatum Ruckle and Lode Chamber. The Semicostatum Ruckle at the south end of the cave includes many boulders up to 0.5 m across of a limestone that is visibly different to the prevalent Carboniferous Limestone. It is a lighter grey, often with yellowish or greenish tints, is softer (the fragments being usually edge- or sub-rounded), breaks relatively easily, and tends to develop a brownish weathered crust. Fossils, especially *Rhynchonellids*, are locally present in it, and good specimens have been collected which Professor D.T. Donovan has kindly examined. He has identified *Piarorhynchia juvenis* (Quenstedt) (common in *Bucklandi* and *Semicostatum* zones, rare later), *Arnioceras sp.* (*Semicostatum* zone or a bit later), *Euagassiceras sp.* (*Semicostatum* zone) and *Plagiostoma sp.* He comments that the fossil assemblage "could all have come from the *Semicostatum* zone of the Lower Lias, though of course adjacent horizons could also be represented". It is interesting that the mineshaft in which Charles Moore recovered a large number of Lower Liassic fossils from a neptunian dyke was almost certainly situated in the southernmost Charterhouse Rake, in the same fault as the Semicostatum Ruckle but about 250 m further east-southeast.

Below the North Shaft of Lode Chamber, vertical dykes of very soft grey and brown clay, apparently deformed by rock movement are present. Nearby, on the east wall is a thin dyke of grey granular material consisting almost entirely of tiny double pointed calcite crystals. Its relationship to an adjacent Triassic dyke indicates that it is younger (probably Liassic). On one wall of Lode Chamber there is a thin dyke comprising angular clasts of Carboniferous and Triassic limestone, in a matrix of bright yellow ochreous Liassic limestone with patches of calcite crystals. Finally, the miners' deads from Lode Chamber dumped in the Barrow Run include pieces of soft grey limestone like that described above from the Semicostatum Ruckle, together with harder pale grey to cream porcellanous limestone (not unlike the White Lias), hard coarse-grained grey to brownish limestone packed with crinoid and shell fragments, and dark grey to black mudstone. The latter contains dispersed cubes of galena up to 6 mm in width. All these rock types are assumed to derive from Liassic dykes, the mudstone (some pieces of which contain clasts of crinoidal limestone) possibly being the youngest.

The big Liassic dyke whose breakdown products characterise the Semicostatum Ruckle is thought to underlie, and to have determined the east-southeast to southeast trend of the southernmost Charterhouse Rake. In the mine, the small visible dykes of Trias and Lias age follow similar trends except for three that trend east or slightly north of east. All are vertical or nearly so. None are seen to contain galena.

EMPLACEMENT AND DERIVATION OF THE LEAD LODES

I have already shown that the ore in Grebe Swallet Mine consists of broken fragments of encrusting galena veins, most of which are worn smooth and to varying degrees of roundness. It must be assumed that they originated at levels much higher than their present ones, and have been smoothed and rounded as they gradually worked their way downwards, under gravity, with and through the sediments enclosing them. An extremely long period of downward transport is indicated.

Several mechanisms of downward transport are possible. We found clear evidence of one in the entrance passages. The rainstorms of July 10 1968 saturated the unconsolidated materials of the lodes to the point that deposits of galena-bearing stony mud became mobile and sludged downwards through rifts and boulder ruckles. Our excavations revealed at several places an irregular layer up to 100 mm thick of mud with galena and other stones resting on the stratified sands and gravels washed in by the 1968 stream. The mud had fallen in soft dollops from the overhead ruckle, after stream flow had ceased.

A similar process operated on two occasions when vertical faces that we had excavated in the stony mud collapsed during or just after heavy rain, forming debris fans sloping at 35° to 40° to the horizontal. Pebbles and granules of galena tended to separate out and concentrate at the foot of the slope. Similar but ancient fans, sometimes stalagmite-coated, are common debouching from gaps between boulders in the Semicostatum Ruckle. They bear no galena.

Limestone boulders in the ruckles are gradually wasted by infiltrating water (which, because the stones in the mud fill at higher levels are mostly insoluble, may remain aggressive to considerable depths) so that they and the overlying materials occasionally subside and the whole mass slowly works its way downwards.

The soft mudstones, marls and limestones of the Liassic neptunian dykes that hosted the galena veins are more readily weathered and eroded by percolating water than the Carboniferous Limestone wall rocks. A special factor is also at work. The various dyke materials, as demonstrated by the debris dug from below Lode Chamber and tipped in the Barrow Run, contain a small proportion of finely disseminated pyrite, which oxidises in contact with cave air and/or infiltrating oxygenated water to form a brownish weathering crust. The initial reaction liberates sulphuric acid:

$$2FeS_2 + 2H_2O + 7O_2 = 2Fe^{2+} + SO_4^{2-} + 4H^+ \qquad (1)$$

The ferrous iron is further oxidised to limonitic iron hydroxides and ochres, generating additional acidity:

$$4Fe^{2+} + O_2 + 10H_2O = 4Fe(OH)_{3(S)} + 8H^+ \qquad (2)$$

As already mentioned, limonite often encrusts or penetrates the galena pebbles and it must be assumed that sulphuric acid formed by the oxidation of primary pyrite has played an important part in:
1) breaking down and mobilizing the dyke material,
2) widening and deepening the rifts and other voids that had contained the dykes,
3) leaching out the soluble fraction (mainly calcite) of the dyke material,
4) promoting subsidence, to great depths, of the residual insoluble fill of the rifts.

In recent papers (Stanton, 1981, 1985) I described field evidence, mainly from East Mendip quarries and boreholes, that primary galena veins commonly transect

Triassic and Liassic neptunian dykes. Galena, with sphalerite, pyrite, barite and silica, locally replaces Upper Inferior Oolite limestone in the Egford area of East Mendip. Evidently, from the Late Triassic to at least the Middle Jurassic, the Mendip area was subject to crustal tension. From Banwell in West Mendip to Nunney near Frome, steep to vertical neptunian dykes are locally common in quarries and orefields, the majority trending roughly parallel to the Mendip axis, i.e. between southeast and east, but with a significant number orientated north or north-northwest, parallel to major wrench faults. In places, e.g. Torr Quarry (ST 695.445) in East Mendip, the total thickness of dykes corresponds to a crustal extension approaching 5%.

During the period of crustal tension, sporadic seismic events formed deep open fissures in the Carboniferous Limestone that, in the late Triassic, gaped open at the ground surface and quickly filled with reddish fine-grained sediment. In the early Jurassic, when they opened on the sea bed, they filled with fossiliferous marine calcareous ooze or mud. The *Semicostatum* zone of the Lower Lias probably saw peak seismic activity. By the middle Jurassic the Carboniferous Limestone was buried, in most places, beneath Liassic and later clays, which stretched under tension instead of cracking open like the brittle limestone. Thus, seismic events in the later Jurassic were able to open fissures in the Carboniferous Limestone and Dolomitic Conglomerate that did not extend up to the sea bed. They remained open, affording easy passage to circulating groundwaters that eventually filled them with crystalline calcite, or, when other mineral solutions passed through them, with galena, sphalerite, pyrite or barite. In some parts of Mendip, permeable rocks capping the Carboniferous Limestone were extensively silicified, forming the Harptree beds (Stanton, 1981, pp. 28-29).

The primary galena veins accompanying the neptunian dykes, that by their breakdown have formed the residual ore deposits described above, must have existed at a level well above the present limestone plateau surface, which is 250-260 m AOD in the Charterhouse area. This conclusion is based on two reasonable but unprovable assumptions:

1) that the Charterhouse Rakes were the Roman lead mines,
2) the Rakes originally contained shallow residual galena deposits similar, to but larger and richer than those of Grebe Swallet mine, at the level of the present plateau surface.

The age and development of the Mendip plateau surface has been debated at length (see Donovan, 1969, p. 64; and Ford and Stanton, 1969, p. 408). Whatever the earlier history, there is some agreement that subaerial weathering in the late Tertiary and perhaps the early Pleistocene developed a peneplain at a level slightly higher than the present Old Red Sandstone summits, i.e. at about 325-350 m AOD. Then, through the rest of the Pleistocene, falling sea levels permitted renewed subaerial degradation of the peneplain. The Mendip horst of Paleozoic rocks resisted erosion and became a plateau. Upon it, the limestone areas have been lowered by dissolution at rates controlled by climatic factors, sometimes as much as 0.1 mm per year (Atkinson, 1971), while the insoluble sandstones have suffered only slight erosion. This is why the sandstone summits now stand 80-90 m higher than the limestone plateau.

At Charterhouse, therefore, the original galena veins could have extended up to 90 m above the present land surface. Being virtually insoluble in rainwater, they collapsed and broke into pieces as the dykes and calcite veins that enclosed them wasted away. The pieces accumulated, with other insoluble material, at or just below ground level, and subsided in step with, or slightly faster than, the owering Carboniferous Limestone surface (Figure 12). It is not impossible, of course, that the original galena veins extended even higher, and that the first residual deposits accumulated on the end-Tertiary peneplain.

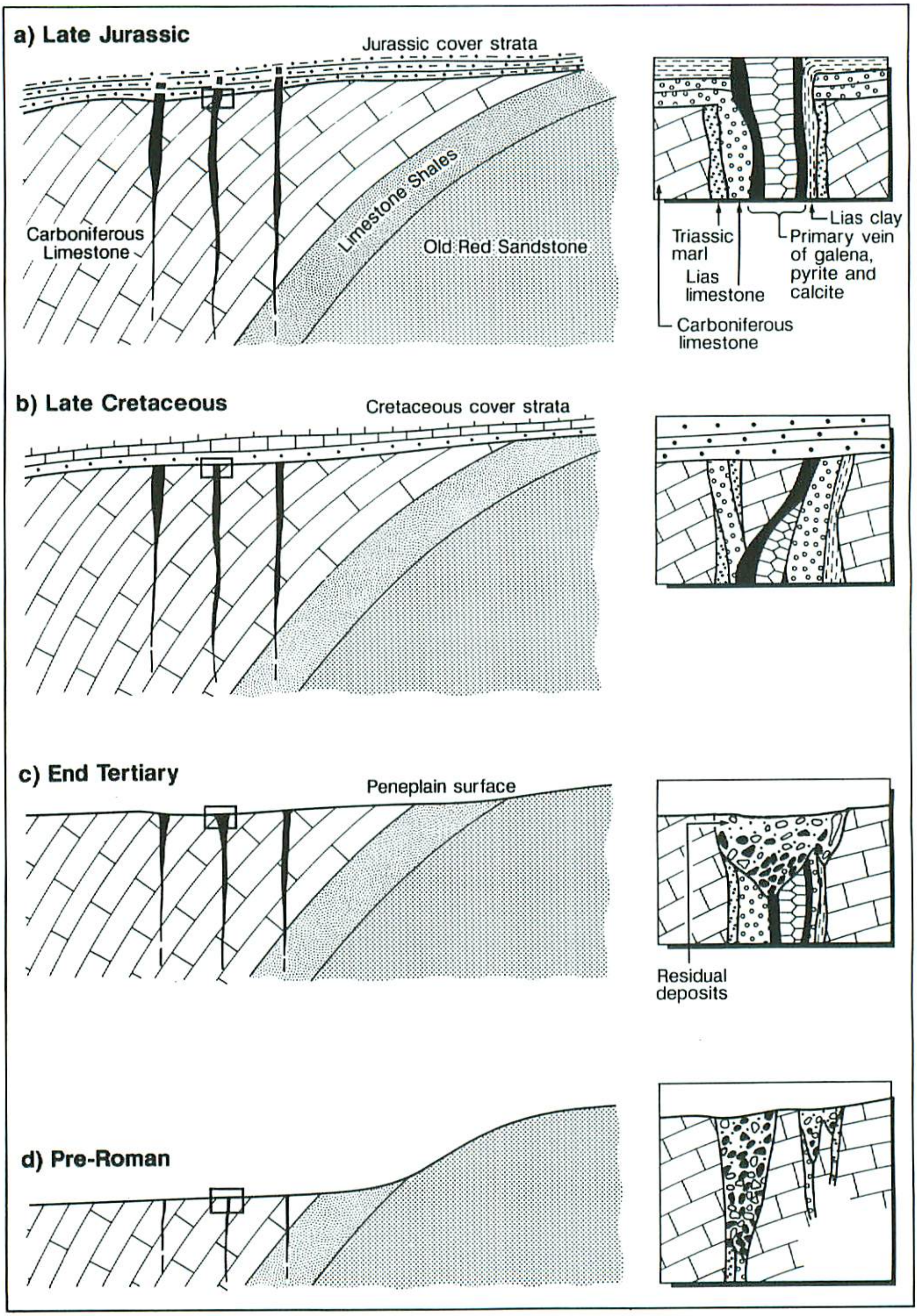
To summarise, the new and unexpected evidence from Grebe Swallet Mine is that the lead deposits of the Charterhouse orefield were not classic veins, but were residual deposits formed by weathering and breakdown of such veins over at least the greater part of the Pleistocene period.

THE CHARTERHOUSE OREFIELD COMPARED TO OTHER MENDIP OREFIELDS

The major lead orefields of Mendip (Charterhouse-Lamb Leer, Chancellor's Farm, Chewton Warren, West End, Rookham-Green Ore; Stanton, 1981, Figure 2) are all on the high plateau at altitudes exceeding 250 m AOD. The only exception is the northeast part of the Rookham-Green Ore orefield which falls to 230 m AOD in the dry valley system at Green Ore. All the orefields except West End and the Green Ore low level area are dominated by rakes: linear rocky trenches that on the Geological Survey maps are interpreted as mineral veins and in the Charterhouse area are now known to have contained shallow residual orebodies. At Charterhouse, some rakes definitely, and others presumably, are the surface expression of major neptunian dykes or dyke swarms. I have mapped plentiful Triassic and Liassic dyke material, with vein calcite, on mine tips in the Chancellor's Farm and West End orefields, and Liassic material in the Chewton Warren orefield (which is entirely in Triassic conglomerate). In all the orefields Green (1958, p. 80) evidently found abundant Triassic and Jurassic fissure material, sometimes veined by calcite, barite and galena, among the debris thrown out from the old workings. Even the minor orefield adjacent to and east of GB Cave (ST 476562) has Liassic dyke material on its tips.

Green (1958, pp. 80-81) found lumps and slabs of galena similar to those of Grebe Swallet Mine on mine tips throughout the Central Mendips, but he also noted small galena crystals *in situ* in vein calcite and barite and in dyke material. Like the Cornish miners at Charterhouse, miners in other orefields must have reached the unweathered primary veins and dykes at depth, below the enriched residual ore deposits characterised by "stones of lead".

Elsewhere in the Mendips and on adjacent Carboniferous Limestone hills, primary galena veins with calcite gangue, often accompanying Liassic dykes (e.g. Stanton, 1981, pp. 26-27) are not uncommon, but are, of course, at altitudes well below the Mendip high plateau. On Broadfield Down near Bristol airport at ST 487657, 140 m AOD, two mine shafts were temporarily opened in 1984 and I recorded that they were 25 m deep in stopes roughly 50 m long, at least 20 m


a) Late Jurassic
Jurassic cover strata
Carboniferous Limestone
Limestone Shales
Old Red Sandstone
Triassic marl
Lias limestone
Carboniferous limestone
Lias clay
Primary vein of galena, pyrite and calcite
b) Late Cretaceous
Cretaceous cover strata
c) End Tertiary
Peneplain surface
Residual deposits
d) Pre-Roman

high and 0.5 m to 1.5 m wide, following a thick calcite vein and an impersistent dyke of Lias limestone. The galena had apparently been present in pockets of brown clay. In Simonds Mine (ST 570478, 180 m AOD) near Wells a vertical vein 150 mm wide consists of clay with dispersed galena granules on both sides of a central calcite vein. In Whatley Quarry (ST 730485, 130 m AOD), East Mendip, extensive Triassic and Liassic dykes are occasionally cut by calcite veins with thin stringers of galena, and the laminated muddy sediments filling a phreatic cave passage are locally silicified and replaced by galena. Pearl Mine (ST 428592, 100 m AOD) on Sandford Hill is an extensive stope on a bedding-controlled vein that is expressed as a shallow rake on the ground surface. In general, the richest lead orebodies appear to have been the residual deposits of the rakes on the high plateau, indicating that the primary veins reached maximum development above the present plateau surface.

The nineteenth-century industrialists who reworked the slags and slimes left by Roman and later miners in the Charterhouse and Priddy mineries (the dressing and smelting stations that between them processed most of the produce of all the Mendip lead orefields) piled up huge heaps of waste sand, gravel and stones on the valley floors near their buddles. In both mineries a large proportion of the waste stones on view consists of sub-angular to well rounded sandstone and chert. This would be surprising if the lead had been won from primary veins, but it is now explained by the fact, observed in Grebe Swallet Mine, that the residual orebodies contained much insoluble material that was left behind after dissolution of the limestone.

Sandstone and chert occur on Mendip in the Old Red Sandstone, the Carboniferous Limestone and the Harptree Beds, but three factors suggest that other sources also provided stones. First, a wide variety of both rock types is represented, including tough quartzites and possibly Lower Cretaceous cherts. Second, the high degree of sphericity and/or polishing exhibited by some very hard stones is not likely to have developed during stream transport over the short

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Figure 12 (opposite). *Schematic sections illustrating the development of residual lead ore deposits at Charterhouse-on-Mendip.* **a)** *Neptunian dykes of marl, limestone and clay occupy Carboniferous Limestone fissures that gaped open to the ground surface during Triassic and Liassic seismic events. Post-Liassic gaping formed roofed cavities through which mineralizing solutions flowed, depositing primary veins of galena, pyrite and calcite.* **b)** *Early Cretaceous erosion removed Jurassic cover, some Carboniferous Limestone and the tops of the mineral veins and dykes, before deposition of Upper Greensand and Chalk.* **c)** *Exhumation of Mendip begins in the late Tertiary and a peneplain develops. Accelerated decomposition of dyke and vein material by sulphuric acid from oxidising pyrite forms shallow surface depressions that trap insoluble residues.* **d)** *Pleistocene dissolution lowers the limestone plateau surface until only the roots of the primary veins remain beneath masses of insoluble residues including much galena. Roman miners removed these rich secondary orebodies, forming the Charterhouse and Ubley Rakes.*

distances available on the Mendip plateau. (Rounded pebbles occur in the Old Red Sandstone conglomerates, but they mostly consist of vein quartz which has not been found, so far, in the mine.) Third, highly polished, usually rounded granules of hard limonitic ironstone not known in any of the local rock types are invariably present in the stony clays of the mine, even as far down as the Semicostatum Ruckle.

The mode of formation proposed for the residual orebodies implies that the rakes of the Mendip plateau were often slightly depressed below the general level. Throughout the Pleistocene and possibly the late Pliocene they would have trapped and retained material from the plateau surface that resisted physical and chemical degradation. Some of the most rounded sandstone and chert pebbles and ironstone granules accompanying the galena may, therefore, have come from valley gravels on the end-Tertiary peneplain, or even from Tertiary or Cretaceous conglomerates that could well have extended beyond their present outcrops in south Somerset and East Devon as far as Mendip. This is a promising field for further detailed studies.

ORIGIN OF THE MENDIP LEAD

In 1981 I reviewed the succession of proposed origins of Mendip lead, from emanations given off by a Hercynian igneous mass (Buckland and Conybeare, 1824; Dewey, 1921) to Mississippi Valley type (Ford, 1976). I questioned Ford's suggestion that the ore-bearing fluids migrated laterally from distant sources under a cap of impermeable Keuper Marl (Mercia Mudstone) because the proposed sources, Culm Measures and Carboniferous Limestone on the south side of the central Somerset rift valley (Whittaker, 1975) would have lost their potentially ore-bearing formation waters in the Hercynian orogeny, long before lead mineralisation began to affect the Mendips in the Middle Jurassic. I suggested then that the ore fluids rose up faults associated with late stages of rift valley formation.

Further consideration leads me towards a modified Mississippi Valley hypothesis. Lead ores are not confined to the main Mendip range, but occur on Carboniferous Limestone outcrops at Worlebury, Broadfield Down, Clifton and elsewhere. Even the small isolated limestone hill of Nyland, south of Cheddar, has residual galena on its summit. The galena deposits are undoubtedly shallow. The 18th century "old men" knew it and the 19th century Cornish miners at Charterhouse re-proved it. In the 1830s the long tunnel now known as Sandford Levvy (ST 429594) was driven through Sandford Hill at a low level (56 m AOD) beneath many shallow workings, without striking ore. Deep quarries such as Stancombe Quarry near Flax Bourton have galena at high but not at low levels, and inclined boreholes sunk by a mining firm about 25 years ago on the Stock Hill Fault in the Chewton Warren orefield and beneath Lodge Hill at Westbury sub Mendip found hardly any lead at depth.

All the Carboniferous Limestone outcrops mentioned above are buried hills that have been exhumed from the Triassic marls and mudstones that surrounded them on all sides. As the deeper Triassic sediments compacted, the formation waters in them would initially have escaped upwards, but by the Middle Jurassic when thick Liassic clays covered most of the region the formation waters were forced to move sideways into escape routes provided by the Carboniferous Limestone hills. These would have stood higher than they do now, because they have lost height by dissolution since they were exhumed. As the formation waters rose through the fissured limestone towards the land surface (or sea bed) they cooled, degassed at the reduced pressure, reacted with shallow meteoric waters, and deposited dissolved minerals including galena. Many of the fissures were, of course, rejuvenated neptunian dykes.

This hypothesis can explain the concentration of galena veins at the tops of buried hills, the position of the richest orebodies on the main Mendip range (the highest limestone hill, adjacent to the largest Triassic basin in the rift valley) and the relative sparsity of ore on the smaller, lower hills northwest of Mendip, where the volume of Triassic and Lower Jurassic sediments in the intervening basins (the source of formation waters) was relatively small.

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REFERENCES

ATKINSON, T.C. 1971. *Hydrology and Erosion in a Limestone Terrain*. Unpublished Ph.D. thesis, University of Bristol.

BUCKLAND, W. and CONYBEARE, W.D. 1824. Observations on the south-western coal district of England. *Transactions of the Geological Society of London, Series 2*, **1**, 210-316.

DEWEY, H. 1921. Lead, silver-lead and zinc ores of Cornwall, Devon and Somerset. *Geological Survey Special Report on Mineral Resources of Great Britain*, **21**.

DONOVAN, D.T. 1969. Geomorphology and hydrology of the Central Mendips. *Proceedings of the University of Bristol Spelaeological Society*, **12**, 63-74.

FORD, D.C. and STANTON, W.I. 1969. The geomorphology of the south-central Mendip Hills. *Proceedings of the Geologists' Association*, **79**, 401-427.

FORD, T.D. 1976. The ores of the South Pennines and Mendip Hills, England — a comparative study. In *Handbook of Strata-bound and Stratiform Ore Deposits*, **5**, (ed. Wolf, K.H.), Elsevier, Amsterdam, 161-195.

GOUGH, J.W. 1967. *The Mines of Mendip*, David and Charles, Newton Abbot, pp. 270.

GREEN, G.W. 1958. The Central Mendip lead-zinc orefield. *Bulletin of the Geological Survey of Great Britain*, **14**, 70-90.

HANWELL, J.D. and NEWSON, M.D. 1970. The great storms and floods of July 1968 on Mendip. *Wessex Cave Club Occasional Publication*, **1**, pp. 72.

KINGSBURY, A.W.G. 1941. Mineral localities on the Mendip Hills, Somerset. *Mineralogical Magazine*, **26**, 67-80.

MOORE, C. 1862. On the palaeontology of mineral veins. *Mining Journal*, **32**, 735.

MOORE, C. 1867. On abnormal conditions of secondary deposits. *Quarterly Journal of the Geological Society of London*, **23**, 449-568.

STANTON, W.I. 1981. Further field evidence of the age and origin of the lead-zinc-silica mineralisation of the Mendip region. *Proceedings of the Bristol Naturalists Society*, **41**, 25-34.

STANTON, W.I. 1983. Shotholes containing lime in a Mendip lead mine. *Proceedings of the University of Bristol Spelaeological Society*, **16**, 185-189.

STANTON, W.I. and CLARKE, A.G. 1984. Cornish miners at Charterhouse-on-Mendip. *Proceedings of the University of Bristol Spelaeological Society*, **17**, 29-54.

STANTON, W.I. 1985. Mendip lead mining — the Charterhouse lead orefield. *Earth Science Conservation*, **22**, 42-43.

STANTON, W.I. 1987. Waterwheel Swallet, Charterhouse-on-Mendip. *Proceedings of the University of Bristol Spelaeological Society*, **18**, 3-19.

WHITTAKER, A. 1975. A postulated post-Hercynian rift valley system in southern Britain. *Geological Magazine*, **112**, 137-149.

APPENDIX A. TECHNIQUES USED FOR EXCAVATION OF THE SEMICOSTATUM BOULDER RUCKLE

The challenge was to advance horizontally through a boulder ruckle consisting of about 6 parts rock, 2 parts mud and 1 part void. Negative factors were the total lack of conventional tipping space and our wish to create a walking-height passage. Positive factors were the availability of water, the easy access to the face, the advanced age (hence acquired patience) of the digging team and the technical fascination of the challenge. We attacked the ruckle as a pastime, because it was there.

A reservoir was made by damming a passage leading off Breather Chamber (Figure 1). The more active drips and wet-weather trickles throughout the system were tapped and led through hosepipes to the reservoir. An automatic flushing system was devised that, installed at the reservoir, emptied it at full hosepipe capacity when the water reached a chosen level. This produced a short-lived but powerful spray that, directed onto a heap of mud at the end, converted it to slightly muddy water that conveniently vanished. A sandy residue, excellent for cementing, remained.

To make forward progress into the ruckle we sort out the mud and wash it away. Rocks and stones are stowed in voids, carried to daylight or used as supporting masonry. The face is advanced at about 2 m height and 1.5 m width and is immediately surrounded by cemented masonry and stony backfill that reduces the width to just under one metre. About 15 m has been gained to date. The main function of the mud washing, however, has been to produce sand for cementing works back in the mine to support and replace miners' walls (where wooden stemples have decayed) and for a variety of conservation measures. March 14th 1990 was working day 733.

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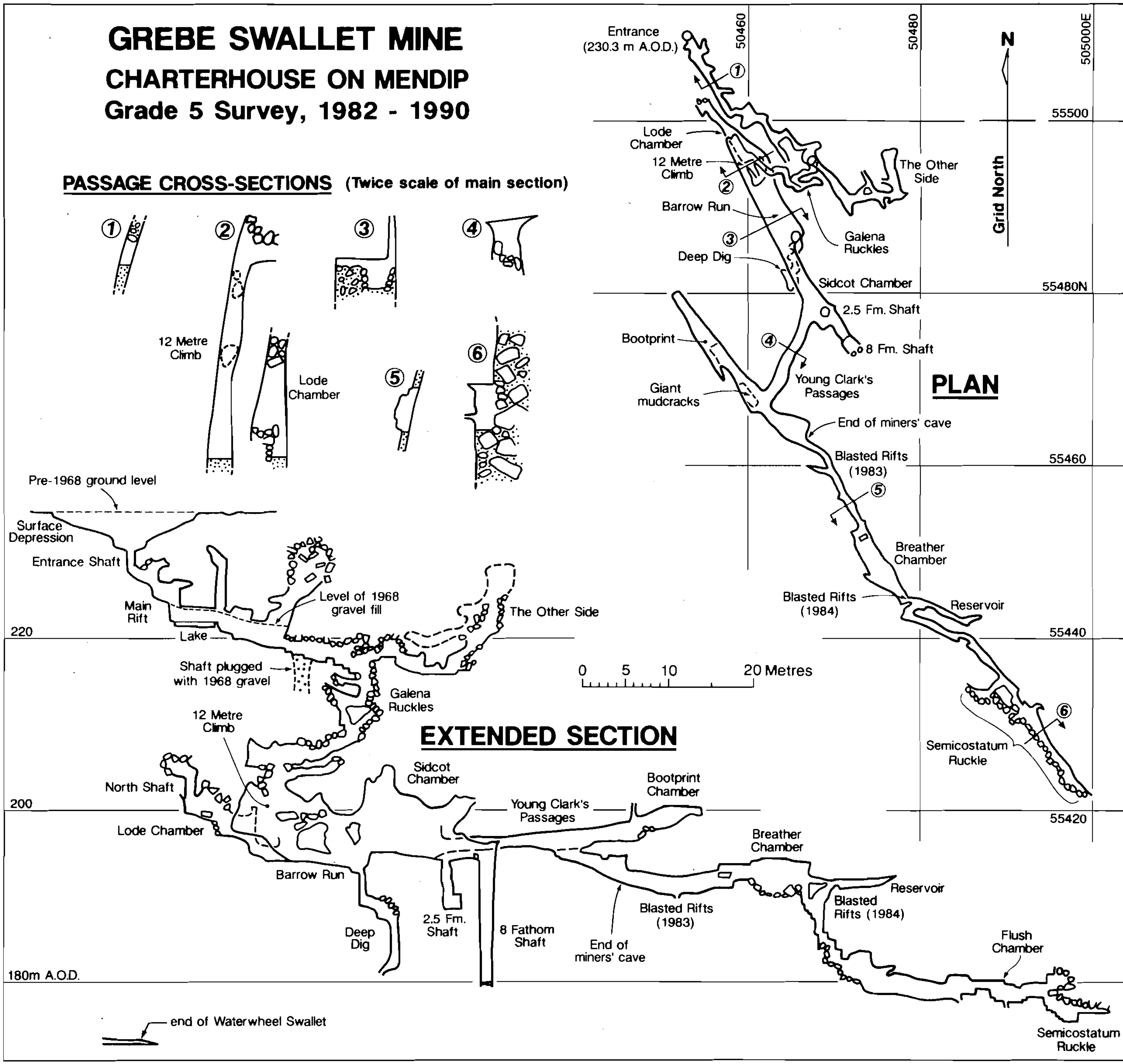

Figure 1. *Plan and section of Grebe Swallet Mine.*