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RINGING RAKE, OLD JANT MINE AND GENTLEWOMEN'S PIPES AND THE GENESIS OF THE MASSON DEPOSITS, MATLOCK BATH, DERBYSHIRE

by

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Summary

This paper comprises part of the evidence for a new theory on the formation of the South Pennine orefield and demonstrates that individual ore deposits display unusual textures and structures which, although not previously described, are of key importance in understanding the processes of mineralisation. From a detailed study of the geology and mineral paragenesis of the pipe-cavities at the NE end of Masson Hill and comparison with the large fluorite flats further up-dip in Masson Cavern, it is concluded that orefluid migrated downwards from the top of the hill through a zone of jointed, dolomitised limestone and continued down-dip and along strike at the base of the dolomite (towards Ringing Rake and Great Rake respectively). Hydrothermal dissolution during mineralisation allowed fissure veins and stratiform orebodies to develop. Orefluid was probably derived from the Namurian shales that directly overlay the limestone during deep burial in the Upper Carboniferous.

MASSON HILL

Introduction

The exposed limestone in the South Pennines consists of an uplifted area of about 400km^2 of Middle to Upper Dinantian carbonates and volcanics. About 225km^2 of this limestone is mineralised on the eastern side. The orefield has been mined for lead since Roman times, but in this century North Derbyshire has become a major producer of fluorite. The mineralogy in the orefield consists of fluorite, barite, calcite, galena, sphalerite, and minor iron sulphides, with a complicated and variable paragenetic sequence (Quirk, 1985).

The Upper Dinantian strata in the Masson Hill area can be divided into limestone units below, between and above two basalt horizons known as the Matlock Lower Lava and Matlock Upper Lava which are 80m and 22m thick respectively (see Fig.2). Beneath the Lower Lava lie the Bee Low Limestones and above these the Matlock Group, comprising the Matlock Lower Lava, the Monsal Dale Lower Limestone Formation, 36m thick between the two basalts, the Matlock Upper Lava, and the Monsal Dale Upper Limestone Formation above the Upper Lava (Ixer, 1975; Aitkenhead and Chisholm, 1982). The massive limestones of the Matlock Group are generally pale grey micrites with a bioclastic component, and contain many thin clay bands of altered tuff known locally as clay wayboards (Smith et al, 1967). The Monsal Dale Lower Limestones, in particular, are frequently dolomitised (Ixer, 1975). A thin sequence of dark limestones and shales, known as the Eyam Limestones lie non-sequentially above the Monsal Dale Upper Limestones, and are in turn overlain by up to 210m of black Namurian shales, whilst to the east 360m of deltaic Millstone Grit shales and sandstones, and nearly 1300m of Westphalian Coal Measures dip away from the limestone outcrop (Weaver, 1974).

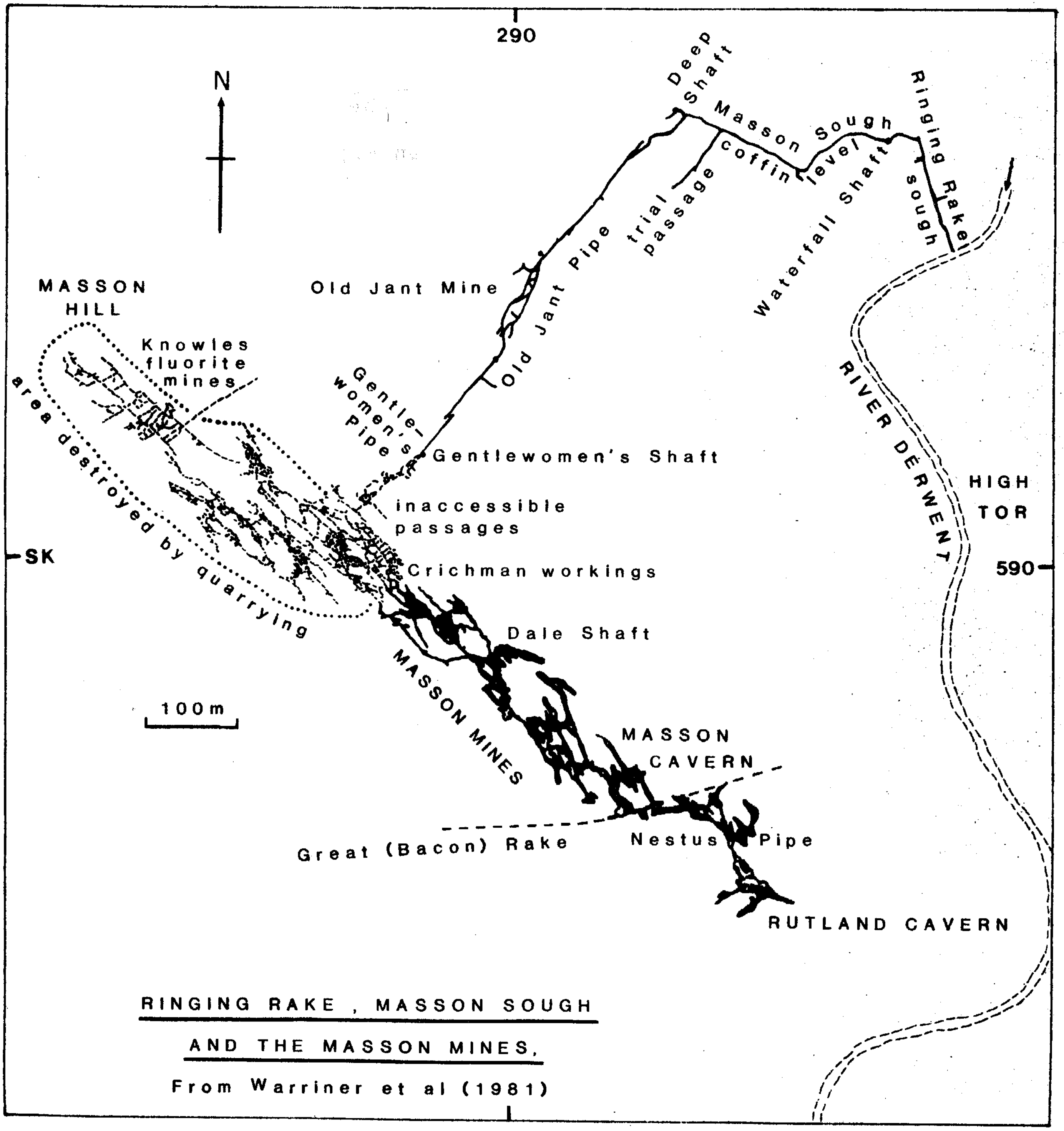


Fig.1. Underground workings in the east side of Masson Hill.

The beds in the NE flank of Masson Hill dip 12°-19° to the NE (Dunham, 1952), and contain mineralised joints and veins both parallel and perpendicular to the NW-SE direction of strike. An undulating anticlinal axis heads WNW from a culmination lying just to the SW of the top of the hill (Butcher, 1976), where there is an intrusion of dolerite.

Stratabound mineralisation has long been exploited on the NE side of Masson Hill, Matlock Bath, at the south-east end of the orefield (Dunham, 1952). Stratiform orebodies known as flats, formed by metasomatic replacement and cavity-fill, occur for a strike length of up to 1.5km but generally the fluorite content decreases down-dip (Ixer, 1978). These were worked for lead since before the fifteenth century (Flindall & Hayes, 1976) and for fluorite, the major component of the Masson flats towards the top of the hill, since 1910 (Dunham, 1952).

Masson Hill Quarry, a disused opencast fluorite mine at the summit of the hill (SK 284 591), was recently extended SE along strike following the stratiform orebody but destroying some of the underground passages known as the Crichman workings (Flindall et al, 1981). Fluorite content generally decreases down-dip (Ixer, 1978).

The aim of this paper is to relate the morphology, structure and paragenesis of the smaller mineral bodies in the east side of Masson Hill to the origin and genesis of the main Masson deposits.

Previous Research

Earlier workers have only described the Masson fluorite deposits towards the top of the hill.

Butcher (1976) noted that the "Masson flat", a term he used for the whole stratabound deposit, is developed along a NW-SE series of mineralised joints, many of which occur as "minor fault monoclines" downthrowing to the NE. NE-SW cross-joints also occur, and pipe-like cavity-lining mineral bodies extend further down-dip (Butcher, 1976). The main flat generally lies 3-6m above the Matlock Lower Lava on top of a zone of unaltered limestone. Some of the joints in the dolomite above the flat have fluorite replaced walls with chimney-like developments at vein intersections (Butcher, 1976). Metasomatised joints rise up to 12m above the flat to just beneath the 30cm thick tuff called "Clay Wayboard 4" by Ixer (1975). This tuff is thought to split into three thin beds known as the "Three Clays" further down-dip (Willies, in Warriner et al, 1981).

Jointing is well developed in the dolomite above the flats, but the limestones beneath are only poorly jointed (Ixer, 1978). Ixer described 134° trending master joints, vertical or steeply dipping to the SW, and a subsidiary 049° vertical set (Fig.1). His diagrams of "dominant mineral present in the joints" suggest a slight preference for fluorite in the NW-SE joints and calcite in the NE-SW cross joints. This is similar to the dominance of fluorite in the NW-SE veins above the flats and calcite in the NE-SW veins above the pipes further down-dip and described herein.

Weaver (1974) found that the main mineralised joints in the Matlock area trend 125° with a subsidiary 045° set and a minor N-S set. He suggested that the joints were a result of Variscan deformation; hence, according to Ixer (1978) dolomitisation must be of late Carboniferous age, as had been claimed for other areas of Carboniferous limestone (eg. Bhatt, 1976).

Ixer (1978) showed that carbonate diagenesis, dolomitisation, and clay alteration all occurred prior to mineralisation. He described fluorite mineralisation as dying out NE, down-dip, and claimed that this was due to ponding of upwardly migrating fluids by an

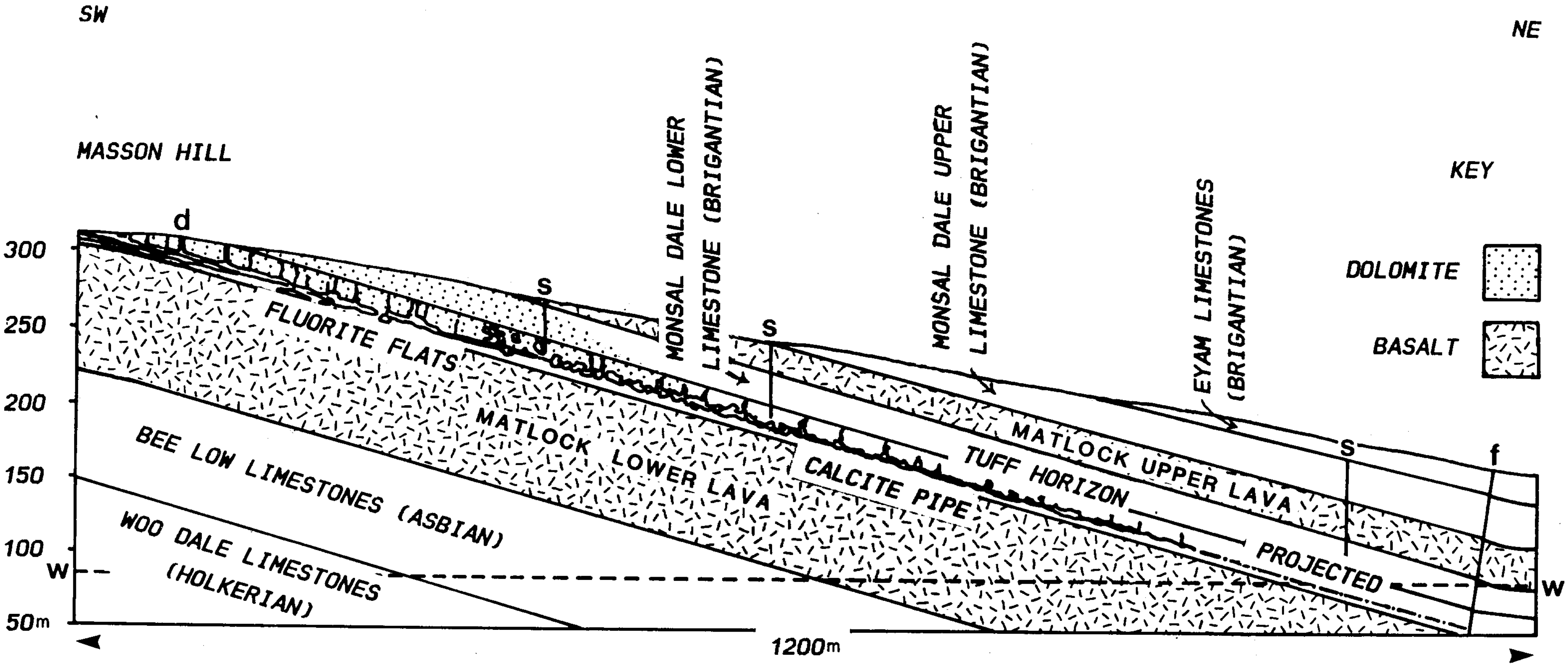
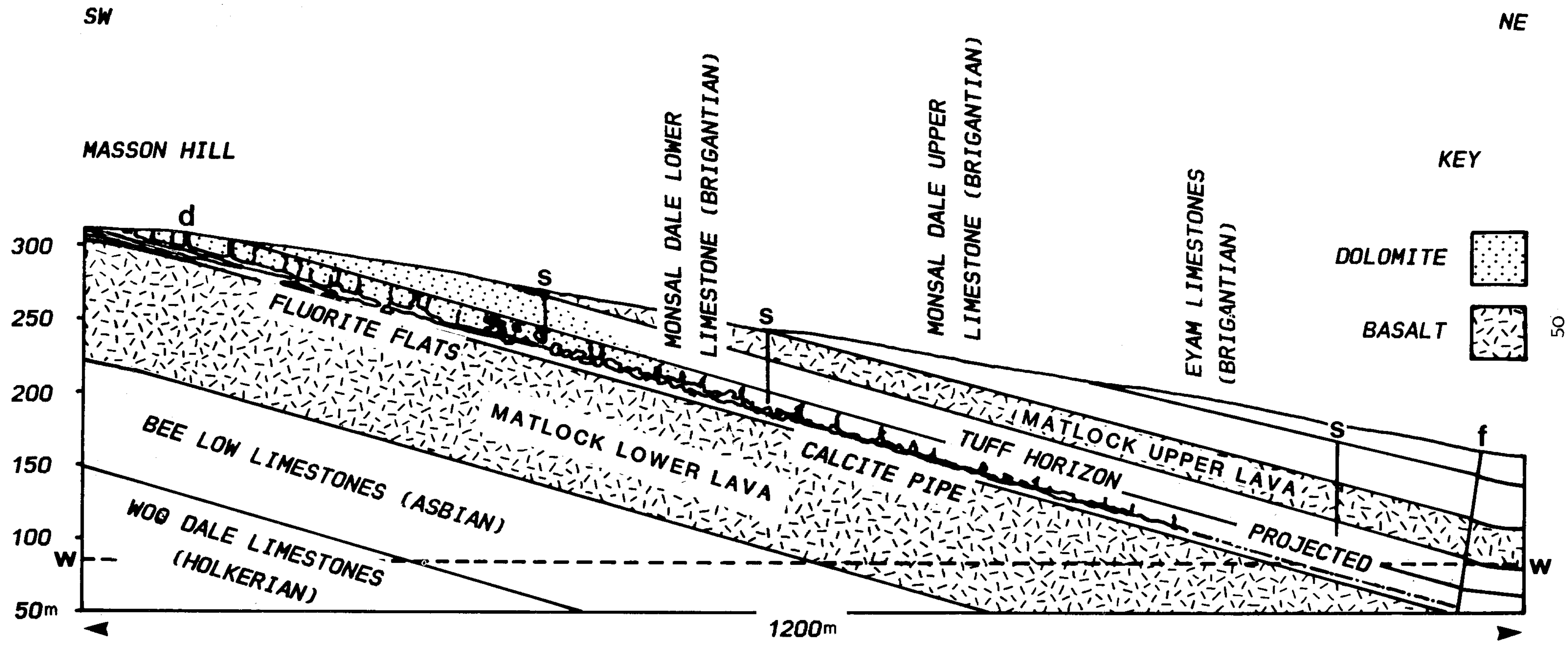


Fig.2. Cross-section through Masson Hill showing the position of dissolution veins and fluorite flats near the base of the Monsal Dale (or Matlock) Lower Limestone towards the top of the hill and calcite pipes further down-dip.
The tuff horizon was known as the "Three Clays" by old lead miners.
d = dissolution vein; f = projected location of Ringing Rake;
s = mine shaft; w = river level. No vertical exaggeration.


SW
NE
MASSON HILL
KEY
DOLOMITE
BASALT
d
s
S
S
S
f
MONSAL DALE LOWER LIMESTONE (BRIGANTIAN)
MONSAL DALE UPPER LIMESTONE (BRIGANTIAN)
EYAM LIMESTONES (BRIGANTIAN)
FLUORITE FLATS
MATLOCK LOWER LAVA
CALCITE PIPE
TUFF HORIZON
MATLOCK UPPER LAVA
PROJECTED
BEE LOW LIMESTONES (ASBIAN)
WOO DALE LIMESTONES (HOLKERIAN)
300
250
200
150
100
50m
W
W
1200m

unmineralised, clay-filled, fault further up-dip, for which there is now little evidence.

Worley (1978) presented a diagram illustrating the evolution of the caves in the Matlock area. The earliest stage involved formation of irregular mineralised cavities, known as pipes, in Permo-Triassic to Early Jurassic times due to a process he called "phreatic hydrothermal cavernisation" during early circulation of acidic orefluid. Later they became lined with concentric mineral layers. The location of these pipes was controlled by the base of dolomitisation, volcanic horizons and vertical joints (Worley, 1978).

Butcher (1976) suggested that the flat was fed from Great Rake, a major ENE-WSW vein at the south-east end of the deposit, but here the flat is more intermittent and irregular and calcite is more common than fluorite. Flindall and Hayes (1976) show Great Rake as down-faulting the SE end of the Masson deposit which they claimed occurs as the Nestus Pipe in Rutland Cavern (Fig.1). The BGS geological map (Sheet SK 25 NE) also depicts Great Rake with southerly throw near Derwent River (Fig.1).

Ixer (1975), Worley (1978), and Mostaghel (1984) presented generalised paragenetic tables which bear little resemblance to the complicated sequences determined by the present author. At most they indicated a tendency for certain minerals to predominate during early or late mineralisation (although there is little agreement between the authors even on this point) but they did not give specific examples and no textures were described in detail.

Fluorite from Masson Hill and from the SE end of the underground workings contains fluid inclusions typical of the main phase of mineralisation in the orefield. They yield mean homogenisation temperatures of 84°C and 92°C respectively (Atkinson, 1983) which possibly indicate an increase in temperature with depth. Correction for pressure during crystallisation may indicate temperatures of formation nearer 130°C (Quirk, 1987). The inclusions contain NaCl brines approaching 20% salinity (Atkinson, 1983) which may show evidence of mixing between a shale-derived orefluid and a local CaCl-rich formational fluid (Quirk, 1987).

Galena from Masson Cavern contains approximately 16ppm nickel, compared with an average of 11ppm for Derbyshire galenas (Mostaghel, 1984). This excess nickel may be related to the widespread occurrence of microscopic bravoite reported by Ixer (1974). Silver content of the galena is low (about 10ppm), typical of the orefield generally (Mostaghel, 1984).

Lead isotope ratios in galenas from the South Pennine orefield are very homogeneous even though they are enriched in a radiogenic component similar to Mississippi Valley type carbonate-hosted lead-zinc deposits (Coomer and Ford, 1975). Mineralisation in MVT areas is generally regarded as shale-derived, with a broad spread in lead values attributed to distant migration from a dewatering sedimentary basin, whereas the restricted range in isotopes from Derbyshire suggests that the orefluids moved only a short distance from a uranium-enriched shale and precludes the introduction of lead from other sources (Quirk, 1987).

Atkinson (1983) also found rare earth element and strontium isotope evidence for a local shale-derived orefluid in fluorite and calcite from Derbyshire.

The nearest potential shale source in the Matlock area occurs in the Namurian strata that directly overlay the limestone in Upper Carboniferous times. In the basal marine shales of the Tansley borehole 3km to the east of Matlock, Spears and Amin (1981) reported high contents of lead (155ppm, an eight-fold increase from an average black shale), barium (415ppm), zinc (103ppm), copper (140ppm), and nickel (125ppm). Harrison et al (1982) found values of 810ppm and 650ppm fluorine in Namurian mudstones although they did not indicate from where the samples were collected. Also, the Namurian shales were found to be enriched in uranium by Ponsford (1955).

Ineson and Mitchell (1972) attempted to date altered volcanic clays from mineralised areas by the potassium-argon method after assuming that hydrothermal circulation caused complete resetting of the clay mineral age. However, they obtained a broad spread in dates ranging from Late Carboniferous to Mid Jurassic which is incompatible with the limited variance in lead isotope values if these K-Ar results are regarded as representing periods of mineralisation. Langley (1980) called into question the significance of the K-Ar technique when she showed that different results could be obtained from different clay mineral fractions in the same specimen. The uniform homogenisation temperatures (of around 84°C) recorded in fluid inclusions from the orefield (Atkinson, 1983) suggest that the heat during mineralisation was due to depth of burial rather than an external source. Mineralisation is therefore unlikely to have produced a strong age signature in the volcanic rocks that were analysed by Ineson and Mitchell (1972). In fact, meteoric water circulation around the mineralised zones might be expected to have a far greater effect on clay development than a short episode of veining; argon loss is also likely. Ineson and Mitchell's (1972) concept of prolonged episodes of mineralisation is not supported by the precise period of mineral formation determined by the present author from structural and paragenetic research in the orefield. In contrast, strontium isotope ratios in fluorite and calcite determined by Atkinson (1983) provide evidence for an Upper Carboniferous age of mineralisation (Quirk,1987).

The idea of orefluid being derived from the Namurian shales in the Upper Carboniferous is discussed in more detail by Quirk (1987) but this paper provides part of the evidence for a new theory on genesis of the South Pennine orefield.

RINGING RAKE, OLD JANT MINE AND GENTLEWOMEN'S PIPE

The mine workings and drainage adit described here were inaccessible to previous investigators although they are in fact connected with the Masson flats further up-dip to the SW.

Ringing Rake and Masson Sough

The drainage adit known as Ringing Rake Sough was rediscovered in 1977 (Warriner et al, 1981). The passage extends from the Derwent River along a vein known as Ringing Rake and then heads in a westerly direction as Masson Sough to the lower end of Old Jant and Gentlewomen's Mines (Fig.1). These abandoned lead workings continue SW up towards the Masson fluorite deposit. Gentlewomen's Pipe was worked from the Crichman workings in Masson Cavern from about 1630, producing 3 to 7 tonnes of galena per week (Flindall and Hayes, 1976). The lower pipe workings in Old Jant Mine were worked from a separate shaft until the 19th century where less than 200 tonnes of galena were produced between 1817 and 1864 (Warriner et al, 1981).

At present the workings are wet and confined making fieldwork difficult and arduous.

Entrance to Ringing Rake Sough is gained via a manhole on the north-west bank of the River Derwent, between Matlock and Matlock Bath, at O.S. grid reference SK 2956 5942, or else by descent of an old mine shaft on the hillside above the Derwent at SK 2921 5959 (**Deep** Shaft, Fig.1).

A walled passage heads NNW from the manhole at the river entrance and after 50m enters solid rock and the start of mine workings.

The adit follows Ringing Rake, a vein trending 175°, with a steep dip varying from vertical to 70°W, that cuts through the base of the Matlock Upper Lava in the roof of the passage (see Fig.2). The beds strike roughly 150°/13°NE and are downthrown on the east side of the vein by about 1.5m, making Ringing Rake a reverse fault. No strike slip movement is evident. The irregular vein occurs within a 1m wide zone of altered basalt (containing much clay, calcite, quartz, pyrite, and some epidote), and consists of rarely more than 10cm of pale pink, coarsely crystalline calcite, surrounded by many minor veinlets and tension gashes filled with fibrous calcite. Abundant sphalerite was reported in the lava by Willies (in Warriner et al, 1981) but none was discovered in this present study. The base of the amygdaloidal basalt is marked by a 0.5m thick bedded tuff that contains numerous, sub-horizontal en echelon tension gashes, indicating variable directions of planar slip.

The vein was only worked below river level for a length of about 30m, in the floor of the sough, presumably where the vein widened out below the Matlock Upper Lava. These workings are now flooded and it is not known how much galena was obtained.

However, the main passage was driven primarily as a drainage adit for lead mines several hundred metres to the SW and higher up in Masson Hill (Fig.1). Ringing Rake and the basal tuff provided an inherent weakness for tunneling operations which was exploited by the miners in preference to the hard limestone or basalt in other areas.

Further north the base of the lava dips beneath the passage and the calcite vein becomes thinner. 160m from the entrance, the passage, which is still in basalt, turns off and heads west, cutting into lower beds of limestone (Figs.1 and 2).

The adit passes through a short section of nodular limestone below the lava, where lenses of grey micrite, about 3cm long, are rimmed by stringers of volcanic clay.

Above where the nodular horizon is intersected, a vertical shaft in the roof of the passage, known as Waterfall Shaft (Fig.1), allows a stream that runs along the Matlock Upper Lava to descend as a waterfall to sough level. Here the lava is about 24m thick (Willies, in Warriner et al, 1981). The shaft allows access to upper workings which show little evidence of Ringing Rake continuing above the lava.

30m from Ringing Rake Sough, a narrow passage, coffin-shaped in section, enters massive limestone more typical of the Monsal Dale Lower Limestone encountered in the rest of the mine (Fig.2).

The sough continues through progressively older beds of hard grey micrite with occasional thin clay bands of volcanic tuff. Three prominent tuff horizons, 2 or 3cm thick and dipping about 10°ENE, in limestone 0.5m thick, are intersected at a distance of about 100m west of the Waterfall Shaft (Figs.1 and 2). These are probably the split equivalent of the 30cm thick tuff in Masson Hill Quarry named "Clay Wayboard 4" by Ixer (1975). This horizon occurs about 22m above the Matlock Lower lava. Stratabound mineralisation throughout the Masson Hill area generally occurs beneath these beds which were known as the "Three Clays" by later miners (Willies, in Warriner et al, 1981).

The passage continues to cut down through the limestone in a WNW direction, oblique to strike trend. After 300m of tortuous coffin level, Masson Sough intersects Deep Shaft which was sunk from surface 82m above (**Figs**.1 and 2).

In the roof of the chamber the porcellanous limestone contains a horizon rich in Productid shells, concave up. The limestone has a strike and dip of 146°/10°NE. A 7mm wide, straight-sided vein of clear cubic fluorite, with calcite crystals in the centre, trends 011° towards the shaft but soon dies out. However, a more irregular vein of fluorite cuts across the full length of the roof for several metres, roughly in an 044° direction.

65m ESE of Deep Shaft, a trial passage heads off SW from Masson Sough (Fig.1) along similar porcellanous limestone, following a thin vein of coarse calcite. This vein also contains small amounts of cubic fluorite on the walls of the fissure. On the SE side of the vein porous smithsonite (after sphalerite) occurs within the early fluorite. A simple paragenetic sequence of joint dilation; inward growth of fluorite (+ sphalerite); and slow growth of calcite, is typical of many of the areas of mineralisation at the lower end of Masson Hill (see Table 1). Also the fissure has the same general NE-SW trend as the mineral bodies further to the west.

Gentlewomen's and Old Jant Mines

The main passage turns to the SW several metres before Deep Shaft and continues for 25m along a NE-SW joint until a NW-SE joint is intersected. The sough follows for a short distance until the coffin level swings to the SW again. After a slight bend to the west the passage then enters the lower workings of Old Jant Mine (Fig.1).

The mine follows a calcite-lined pipe cavity up-dip to the SW towards similar mineralisation in Gentlewomen's Pipe (Fig.3). The lower end of Old Jant Mine is over 600m down-dip from the deepest flats in the Crichman workings which form part of the Masson deposit. Altered basalt is piled in the main passage in Old Jant Mine, derived from the top of the Matlock Lower Lava that occurs only metres below the mineralised horizon.

At the NE end of the mine, red silt obscures the walls of the passage but because the passage has dimensions similar to mineralised sections in the lower part of the mine (4m wide by 3m high) the pipe-cavity probably continues on down-dip as calcite only and hence remained unworked.

The mineral bodies in Gentlewomen's and Old Jant mines are simple mineral-lined pipes, elongated NE-SW, which occur as continuous but irregular cavities 2m or more in width and generally less than 2m in height. In some places the passage is heightened by up to 20m following an irregular vein of galena and calcite which is only seen in the roofs of the pipes (Fig.3).

The wallrock is pale grey bioclastic Lower Matlock Limestone which is partially silicified in a few areas. Stylolite seams, containing prismatic crystals of quartz less than 0.5mm long, run irregularly through the limestone in some places.

The pipe cavities themselves are lined with a layer of inward-pointing, white, comb-textured or "columnar" calcite, several centimetres thick, displaying closely-spaced scalenohedral terminations (Fig.3). Each columnar crystal widens upwards, to a width of about 1cm, because some of the early crystals at the base of the layer have been crowded out during competitive growth (see Quirk, 1986). The walls of the pipes are generally highly undulatory. In some places small blocks of limestone are entirely surrounded by columnar calcite as if stranded by dissolution and crystal growth (see Fig.3). In other areas columnar calcite extends into the wallrock forming small lenticular protruberances. The calcite usually contains two zones of fluorite and galena towards the top of the layer. The columnar calcite is overgrown by large white scalenohedra, known as

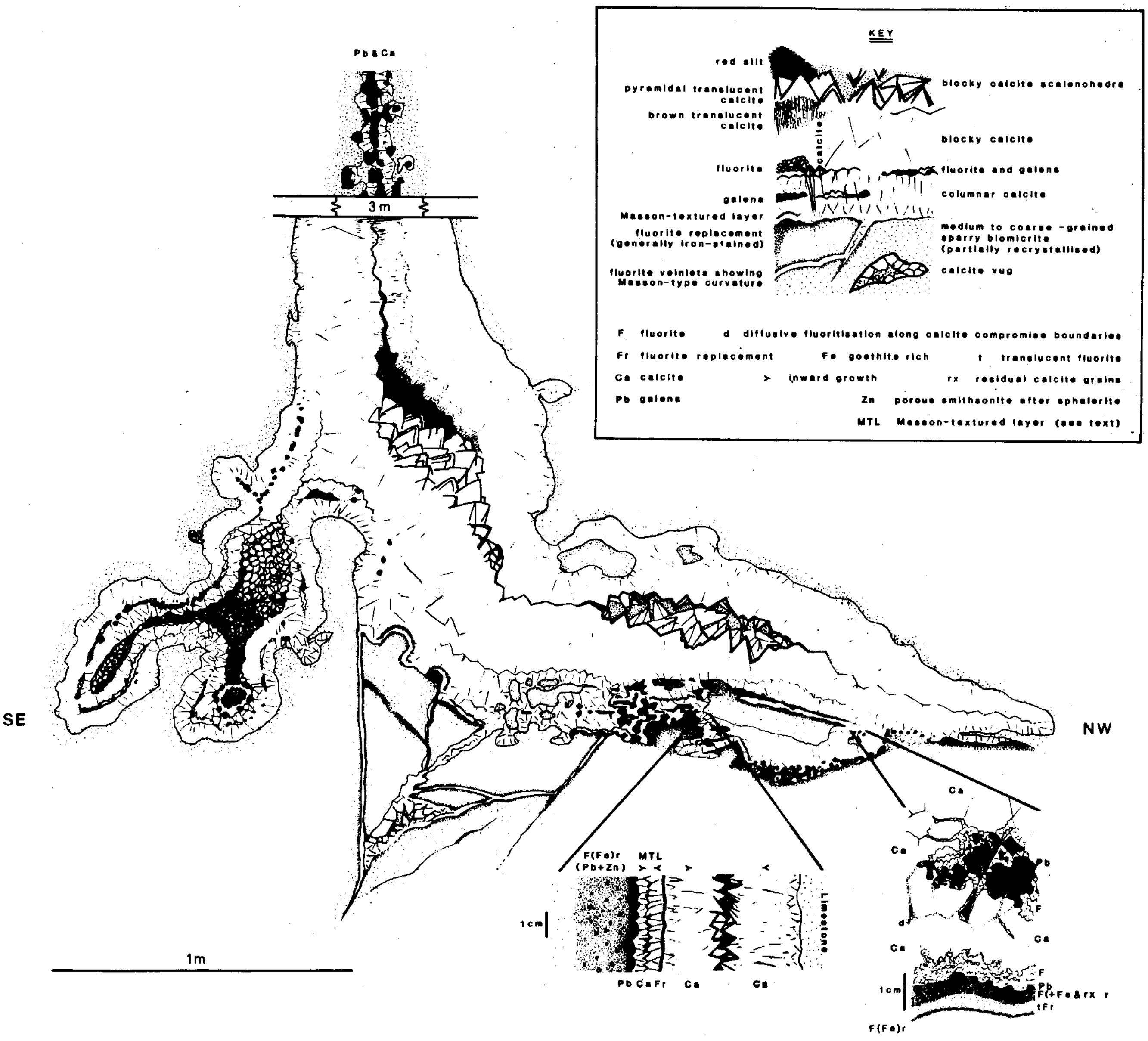


Fig.3. Typical appearance of small calcite pipe in Old Jant or Gentlewomen's Mines. The earliest phase of mineralisation occurs as fluorite replacement, irregular veinlets and Masson-textured layers at the base of the pipe. The main cavity was formed during subsequent hydrothermal dissolution by orefluid that appears to have been fed from a NE-SW trending fissure in the roof of the pipe. The orefluid probably moved on down-dip and escaped into Ringing Rake.

"blocky" calcite, that occur towards the centre of the cavities. In turn these blocky crystals are usually encrusted by translucent calcite in the form of (I) epitaxial overgrowths, (II) blocky scalenohedra, or (III) columnar layers. This translucent calcite often displays pyramidal rather than scalenohedral terminations with Miller Indices of $2\bar{2}01$.

Relict patches of red silt indicate that cave sediment filled many of the mineral cavities after cavernisation when a natural stream flowed through the passages. There is some evidence that this sediment was extracted by the old lead miners (Willies,in Warriner et al, 1981) suggesting that alluvial galena may have been present in the silt after being washed down from higher and richer pipes.

At the top end of Old Jant Mine, a few metres north of Gentlewomen's Pipe, the only strong bedding plane observed in the mine has a strike and dip of 150°/19°NE, indicating that the pipe cavities run parallel to dip.

The lower end of Gentlewomen's Pipe appears to begin several metres south of the mineral bodies in Old Jant Mine and the two pipes can be regarded as similar but separate. The narrow passage that works through Gentlewomen's Pipe exposes broadly similar but slightly more complicated mineralisation.

Detailed Paragenesis

Old Jant Mine

In some areas, mainly in the upper parts of Old Jant Mine, the base of the calcite pipe consists of a 1-3cm thickness of metasomatic fluorite. This fine-grained fluorite usually has a sharply defined lower margin and a crystalline upper surface which forms the base to the pipe. In some cases the metasomatic fluorite has been embayed or surrounded by later columnar calcite. The replaced zone is sometimes faintly layered and may contain diffuse bands of unreplaced calcite which represent residual grains of recrystallised wallrock. Other layers are rich in microscopic pyrite partially altered to goethite. The layers appear to represent fronts of metasomatism advancing up through limestone, prior to the major phase of dissolution during pipe cavity formation. Galena is sometimes found within the replaced zone and occasionally these crystals are embayed by clear cubic fluorite due to later corrosion and encrustation. Small areas of clear vuggy fluorite or veinlets of fluorite and galena within the replaced wallrock suggest that fluorite also grew in small cavities and solution joints that were forming during metasomatism. Prismatic crystals of microscopic doubly-terminated quartz (ca. 0.1mm) are also present within the replaced zone and adjacent wallrock. These seem to have grown during the earliest phase of metasomatism prior to fluorite mineralisation (Table 1).

Hydrothermal dissolution appears to have become established towards the end of the main phase of fluorite replacement and led to formation of flask-shaped cavities between the metasomatised zone at the base of the pipe and NE-SW fissures in the roof (Fig.3).

The columnar calcite that lines the pipe cavities consists of two concentric layers, in total about 6cm thick, separated by an intermittent zone of fluorite and galena that becomes more strongly developed in the mineral bodies to the SW further up the mine. This fluorite can occur as a fine-grained, iron-rich replacement along compromise boundaries near the top of the columnar layer or as clear cubic crystals, 1 to 3mm in width, encrusting the partially corroded upper surface of the calcite (Fig.3). The galena consists of subhedral to anhedral crystals, up to 1cm across, associated with the fluorite.

Campylite crystals were discovered on the surface of one specimen.

The second layer of columnar calcite above the fluorite is generally only 1 or 2cm thick and individual crystals are poorly formed relative to the closely-spaced, downward tapering columns of the underlying calcite. The upper layer is itself overgrown or intergrown by a second layer of fluorite and galena.

Very coarse-grained blocky calcite usually occurs on top of the columnar calcite. These crystals often display twinned terminations which are seen as multiple points towards the ends of each scalenohedron (see Fig.3). The C-axes of individual crystals within a group of blocky calcite are generally unaligned.

The latest mineral phase in the pipes is a translucent form of calcite that contrasts with the opaque white of earlier calcites. This is thought to reflect a slower rate of growth (Quirk, 1986). The crystals are frequently stained brown by iron which was probably derived from the red silt that smothered the crystal surfaces during cave sedimentation (Fig.3). In fact in some areas large pyramidal translucent crystals (type II), which may be up to 10cm wide, have thin syntaxial overgrowths of very late calcite on top of earlier ragged and silt-covered surfaces. Therefore the growth of these crystals was temporarily halted during an influx of cave sediment suggesting that they were formed relatively recently. The columnar variety of translucent calcite (type III), which also has pyramidal terminations, usually encrusts blocky calcite with an embayed and recrystallised surface, indicating that some dissolution also took place (during cave formation?) before the final phase of translucent calcite.

Rounded and widened passages and avens containing eroded calcite and cave sediment provide more obvious evidence of recent cave processes.

Gentlewomen's Pipe

The mineralisation becomes more complicated further up-dip in Gentlewomen's Pipe where greater amounts of fluorite, galena and sphalerite are present.

Irregular zones of wallrock towards the base of the pipe have been replaced by fine-grained fluorite rich in goethite (after microscopic pyrite and some chalcopyrite). Some areas also contain grains of sphalerite (now smithsonite) and more commonly galena (Fig.3). The fluorite often displays metasomatic layers of slightly differing composition and these "fronts" may be curved, convex up, similar to the zones of replacement at the base of the stratiform mineral bodies in Masson Cavern (see later).

In rare cases the limestone beneath the fluoritised zones contains sub-horizontal "veins" of metasomatic fluorite (+ galena and sphalerite), less than 1cm wide (Fig.3). Of an equivalent size are small dissolution veins which consist of irregular fissures encrusted on both walls by cubic fluorite (plus sulphides) or filled with early columnar-phase calcite. The fine-grained fissure walls often contain metasomatic fluorite with goethite and pyrite inclusions. Both types of veinlet have probably exploited pre-existing weaknesses such as bedding plane surfaces and fractures.

Dissolution veins are also found within the pipe cavities themselves, entirely surrounded by later calcite, after having been stranded by complete removal of the adjacent host-rock. Therefore, these veins appear to represent early feeder channels for corrosive orefluid and are rather similar to the sub-horizontal vuggy layers found at the base of the mineral flats in Masson Cavern (see later).

Relationship to the Masson Deposits

The mineralisation in the upper sections of Old Jant Mine and Gentlewomen's Pipe shows a strong similarity with the irregular stratabound bodies down-dip of the main flats in Masson Cavern. These also consist of mostly calcite with some brown metasomatic fluorite, clear cubic fluorite, galena and sphalerite. In fact Gentlewomen's Pipe represents an elongate extension of the Masson deposit at approximately the same stratigraphic level (Figs.1 and 2). Ore minerals other than calcite have mostly died out towards the bottom end of Old Jant Mine, about 185m below the top of Masson Hill and 750m to the NE of the summit (Fig.2).

Economic Significance

It is possible that other NE trending pipes extend down-dip from the Masson deposit to the NW or SE of the Gentlewomen's-Old Jant pipe system. For example, further extension of the trial adit near Deep Shaft (Fig.1), which follows a SW trending mineralised joint, may encounter another pipe system within a short distance as similar veinlets also occur in the vicinity of Old Jant Pipe. However, by analogy the fluorite, zinc and lead content is likely to be very small at this depth. Also, the linear nature of these mineral bodies might make targeting of pipes quite difficult.

Mine workings extend for short distances above the Matlock Upper Lava from shafts in Masson and Ringing Rake Sough but little mineralisation was found. Therefore, it appears that the lower part of the Monsal Dale Lower Limestone represents the chief host-rock in the lower part of Masson Hill.

GENESIS OF THE MASSON DEPOSITS

Dolomitisation

In Masson Hill Quarry approximately 30m of secondary dolomite overlie 5.5m of unaltered, coarse-grained crinoidal limestone above the Matlock Lower Lava (Ixer, 1975). This zone of dolomitisation dies out immediately to the NW, although it reappears intermittently at the same stratigraphic level for several kilometres further west. The dolomite is medium-grained, pale brown to grey and usually occurs in beds in the order of a metre thick that are notably porous. Except for strong, sometimes mineralised jointing, these beds are generally featureless. However, occasionally an unaltered raft of limestone occurs within the dolomite near the base of the Upper Lava and this may be rimmed by several centimetres of metasomatic fluorite (Ixer, 1975). The dolomite is uniform in composition containing about 18.5 % MgO, 31.0 % CaO and 2.5 % SiO_2, compared with 1.1 %, 54.0 %, and 1.5 % respectively in the limestone (Ixer, 1978). The dolomite is silicified at its base with approximately 8 % SiO_2 (Ixer, 1978), and fluorite and galena sometimes fill microscopic pore spaces.

Two generations of epigenetic dolomite appear to be present: 0.05mm-sized dolomite rhombs surrounded by coarse-grained poikilitic crystals (Ixer, 1975). A similar petrology also occurs in epigenetic dolomite from the Woo Dale area which is now thought to have developed during late diagenesis in magnesium-enriched fluid derived from adjacent shales (Schofield and Adams, 1986).

Dolomite from Masson Hill contains prismatic quartz crystals, about 0.1mm in length, which often replace relict calcite grains (Ixer, 1975). Calcium and silica proportions increase in the dolomite up to a few centimetres above and below clay tuff beds which therefore appear to have inhibited dolomitisation as have also the lavas (Ixer, 1978).

Ixer also described the transition from almost totally dolomitised rock to limestone as occurring within 15mm, but the present author has found rhombic dolomite crystals (the early generation), 0.1mmlong, dispersed in the limestone well below the main dolomitised zone throughout Masson Cavern. XRD analysis of wallrock below the thin flats and irregular pipes at the SE end of the deposit also usually shows some dolomite present for a few centimetres beneath the mineralised horizons. Therefore, at least underground the dolomite/limestone transition is often difficult to locate and is probably gradational.

The zone of dolomitised limestone is often roughly parallel to bedding which possibly partly reflects primary lithological differences in the original limestones (Ixer, 1978) such as grain-size or chemistry. It is thought here that the porcellanous variety of limestone encountered in Masson Sough is the rock-type that is easily dolomitised towards the top of Masson Hill. The basal coarse crinoidal limestone has remained unaltered throughout because of impermeability, lack of jointing, the presence of stable sparry calcite and the proximity to the Matlock Lower Lava which probably had some hydro-geochemical effect that helped prevent dolomitisation.

In some areas a thin tuff band marks the base of the dolomite or the mineralisation and this horizon possibly represents "Clay Wayboard 1" of Ixer (1975).

During initial mineralisation it appears as though undolomitised calcite crystals were replaced in preference to secondary dolomite, especially by early metasomatic quartz.

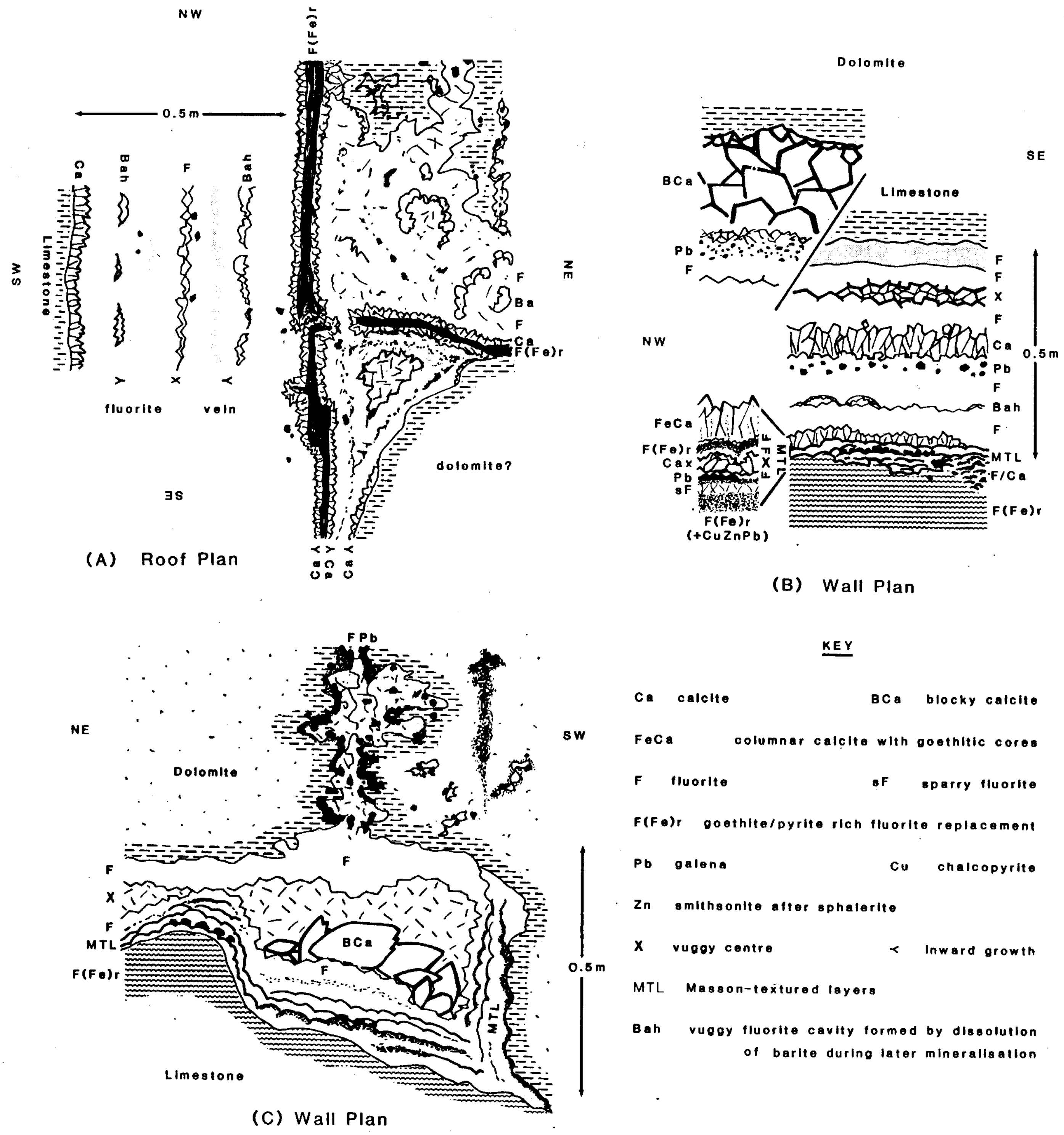
The Masson Flats

A fluorite flat is here considered as an individual stratiform orebody, rather than the whole stratabound Masson deposit as has been the case with some previous authors (eg. Dunham, 1952; Ford & Ineson, 1971; Ixer, 1974 & 1978; Butcher, 1976).

The limestone at the base of a typical flat is often replaced by fine-grained fluorite which usually appears layered due to slight differences in coloration (from brown to grey) and crystal size. These differences probably arose from slight variations in orefluid conditions during gradual metasomatic advancement. The replaced zone may also contain inclusions of sphalerite, microscopic iron sulphides and euhedral quartz. Galena usually only occurs towards the top of the zone.

The zone of replacement beneath a typical flat may be many centimetres thick. Above this, the cavity-fill mineralisation is normally less than 1m thick and built up of crustiform horizons of vuggy fluorite, calcite, and sulphides. Barite is occasionally present but may show evidence of corrosion by later mineralising events.

The basal part of the crustiform zone consists of vuggy horizons of mostly fluorite and calcite which are usually about 1cm thick and display sharply-defined upper and lower margins. The upper margin or "roof" usually consists of a thin zone of metasomatic fluorite which is catenary or "scalloped" in shape with upwardly-convex embayments and downward-pointing cusps (Figs.4b and 4c). Fluorite or calcite crystals often appear to hang down from the roof and may or may not quite meet with similar crystals that have grown upwards from the lower margin, thus forming a central suture or "toothy grin" (respectively). These inward-grown crustified horizons are herein called "Masson-textured layers" and are known to occur at the base of other stratiform orebodies in the South Pennine orefield (Quirk,



(A) Roof Plan

(B) Wall Plan

(C) Wall Plan

Fig.4. Mineral bodies in Masson Cavern near Dale Shaft (Fig.1).
a) Dissolution vein in roof of passage formed around an early NW-SE joint abutted by an irregular 030° trending cross-joint.
b) Mineral flat consisting of metasomatic fluorite at the base of the orebody followed by thin Masson-textured layers, convex-up, above this and finally thick upward-grown layers of crustiform fluorite and calcite comprising most of the flat. Late blocky calcite (top left) lies above the final fluorite cavity in some places.
c) More irregular fluorite orebody along strike towards Great Rake. Note the Masson-textured base (convex-up layers) and irregular veinlets in the dolomite above the cavity.

1987).

The lower part of a flat is therefore built up of discrete horizons of encrusted mineral which appear to represent thin cavities formed during early mineralisation (Fig.4). These horizons were therefore produced by intermittent solutional stoping in the roof of the developing flat followed by progressive inward growth of crystals from the upper and lower surfaces of the cavity after the roof had been replaced by fluorite. Dissolution became re-established in the partially dolomitised limestone above the preceding Masson-textured layer probably because through-flow of orefluid became inhibited by crystal growth.

The thicker mineral layers that overlie the Masson-textured horizons in the main part of the deposit consist of mostly coarse-grained, upward-pointing crystals of fluorite and calcite (eg. Fig.4b). At the edges of a flat younger layers may appear to overstep the older horizons and so "on-lap" the limestone wall directly.

The thicker layers probably reflect a period of more prolonged dissolution following the formation of Masson-textured layers. Most of this zone consists of single upward-grown layers. The absence, very often, of a corresponding downward-grown layer in the main part of the flat suggests that crystal growth may have occurred at the base of the cavity whilst dissolution continued in the roof (Quirk, 1987).

The upper layer of a flat is perhaps 10cm thick and usually consists of coarse vuggy fluorite (or calcite in the more irregular mineral bodies towards the SE and NE ends of the deposit) which lines the roof and floor of the final elongate cavity overlying the rest of the flat.

In conclusion, early stratiform mineralisation began to develop beneath a zone of porous and pervious dolomite. Initial metasomatism was followed by repeated dissolution and mineralisation in the roof of the flat. Thin mineral-lined cavities continued to form in an upwardly developing sequence until overhead dissolution became well established; from then on thicker mineral layers started to build-up at the base of the enlarging cavity until limestone dissolution ceased and late crystals grew on the walls of the cavity.

Towards Great Rake, at the SE end of the deposit, the basal Masson-textured layers decrease in number to one prominent layer of calcite with an upper and lower margin of brown metasomatic fluorite narrowly encrusted with clear cubic fluorite (eg. Fig.4b). Galena often occurs in an intermittent zone at the base of this layer, above the replaced footwall, but mostly the flats consist of calcite only.

It appears that the Masson flats were fed by large NW-SE-trending fluorite veins that occur in the dolomite above the flats at the top end of the deposit (Fig.4a). These veins are sub-parallel to strike and are similar in appearance to the flats except that the mineral layers are vertical rather than horizontal.

Often two similar "sub-veins", up to 0.5m in width, occur either side of a thin central wall of iron-rich fluorite replacement (Fig.4a). These veins developed by dissolution on either side of a central joint which had been strengthened by early metasomatic replacement. Crustiform mineralisation occurred during the main phase of ore formation that is also recorded in the flats beneath the veins.

Minor NE-SW mineralised joints run into the main feeder veins suggesting that they originally abutted the major NW-SE fractures prior to dissolution and mineralisation. The NE-SW fractures are therefore younger than the NW-SE structures.

The important flats in the Masson deposit are located in the lower 6m of the Monsal Dale Lower Limestone towards the top of Masson Hill around SK 285 592 (Ixer, 1978). For example, Dunham (1952) described one area of fluorite mineralisation at this position that measured 500m by 240m.

The flats mainly occur within the dolomite/limestone transition, an undulating zone of perhaps a metre thickness where rhombic dolomite crystals, about 0.1mm in diameter, are dispersed in a fine-grained matrix of limestone. Some of the dolomite crystals have been replaced by later calcite (Ixer, 1975). This zone is about 5.5m above the top of the Matlock Lower Lava at surface but the base of the dolomite may rise gradually up-section further down-dip. In Masson Hill Quarry, a few flats also directly overlie the top of the lava. Dunham (1952) noted the importance of the "Little Toadstone", a 60cm thick tuff which he said occurred 5.5m above the Matlock Lower Lava, in determining the base of dolomitisation and the roof of the mineral flats. However, Ixer (1975) and the present author were unable to locate this, either because the tuff has been removed by opencast mining operations or perhaps because mineralisation and hence exposure only occurs in places where the Little Toadstone is absent.

Similar stratabound mineralisation near the base of the Matlock Lower Limestone occurs below epigenetic dolomite at Jugholes Mine, SK 2793 5971 (eg. Ixer, 1974) and Tearsall Farm Quarry (SK 263 600) 3km to the NNW. Calcite is the dominant mineral in the Tearsall deposit.

DISCUSSION

The vein system in Masson Hill comprises three fracture trends that occur throughout the South Pennine orefield. These are an early NW-SE set of long straight joints, an important set of sinuous ENE-WSW dextral wrench faults and a late NE-SW set of short irregular joints (Quirk, 1987). The formation of these fractures is related to the overall stress history of North Derbyshire in the Carboniferous which involves (1) NE-SW extension in the Dinantian during development of the limestone shelf; (2) WNW-ESE compression, uplift and erosion in end-Dinantian times; (3) NW-SE extension during burial in the Namurian (Fig.5). In late Westphalian times extension rotated to a N-S direction allowing dilation and the main phase of mineralisation to occur (Quirk, 1987).

Some folding of Masson Hill had probably occurred prior to burial in the Upper Carboniferous. This helps explain the apparent downward flow of orefluid through Masson Hill, especially if the Matlock Upper Lava had been removed by erosion further up-dip. The fluid appears to have moved down the main NW-SE joints (which became enlarged by dissolution) and through the porous dolomite. The "Three Clays" tuff horizon and the late NE-SW joints appear to have played an important rôle in channeling orefluid further down-dip towards Ringing Rake. Orefluid also moved along strike towards Great Rake which was probably opening tectonically at this time. It is thought that both Ringing Rake and Great Rake may have formed hydraulic "sinks" for exhausted orefluid. In fact, dilation of Great Rake may have been sufficient to draw orefluid through Masson Hill from the overlying Namurian Shales, the main source of mineralising fluid in the South Pennine orefield (Quirk, 1986; 1987).

Therefore, during the Upper Carboniferous late diagenetic brine, rich in fluorine, barium, metals and sulphur, was expelled from the Namurian shales mainly to the NE of Matlock Bath (Quirk, 1987). Due to compaction this dense orefluid migrated up-dip at the base of the shales but then descended into the highly fractured and dolomitised

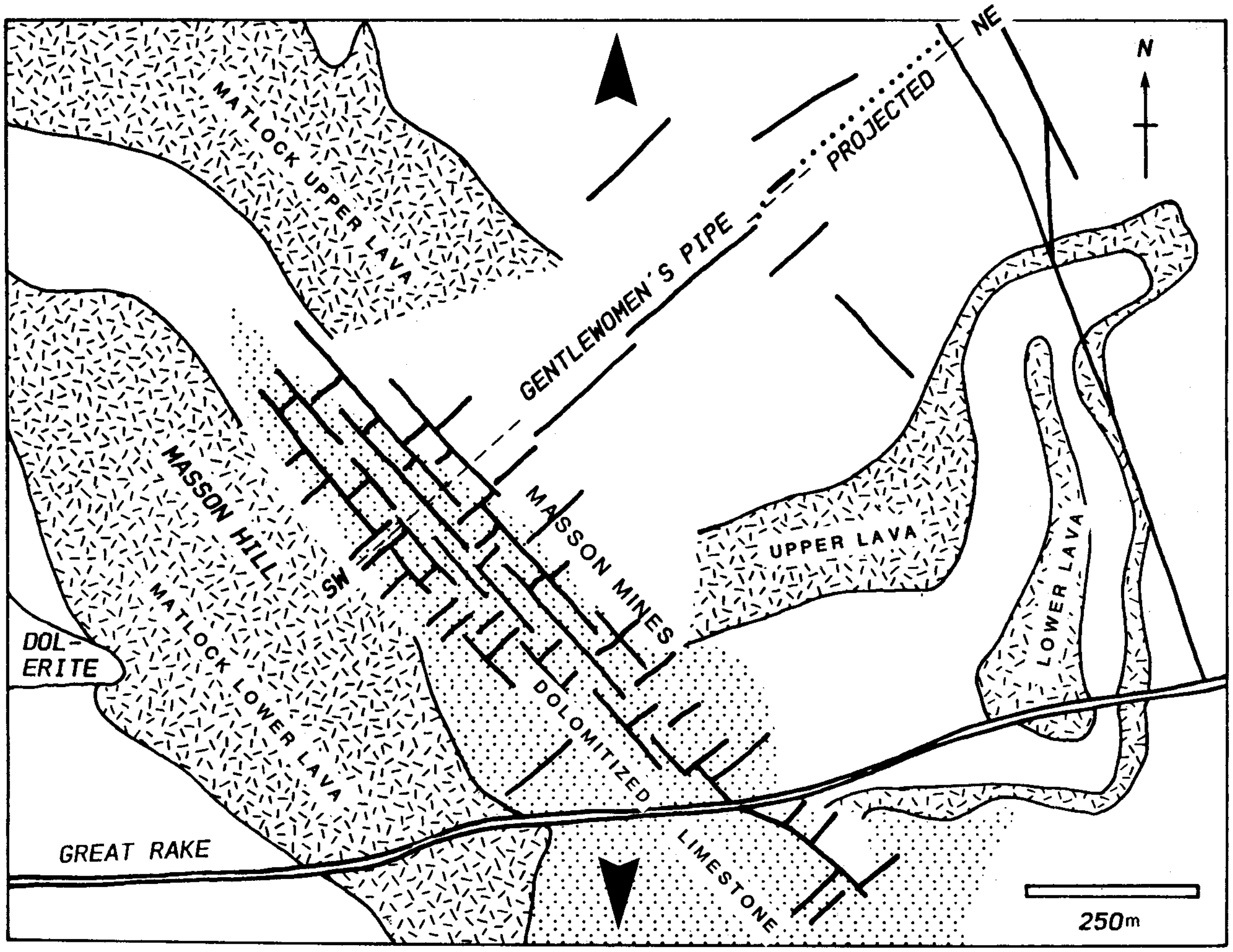


Fig.5. Representative vein pattern in Masson Hill with surface geology partially removed. The closely-spaced NW-SE fractures were formed as master joints and minor faults during NE-SW extension in the Dinantian; the long ENE-WSW and NNW-SSE fractures were formed as wrench faults during end-Dinantian compression (in a WNW-ESE direction); and the short NE-SW fractures were formed as joints during NW-SE extension in the Upper Carboniferous. During mineralisation the direction of extension rotated to a N-S direction and stress conditions were probably hydrostatic.

limestone at the top of Masson Hill. A large contrast in pH and ion content led to metasomatism and dissolution at the base of the dolomite where unaltered limestone was encountered. The dolomite remained mostly unreplaced during orefluid migration as this had already equilibriated with shale-derived magnesium-rich fluid prior to mineralisation (Quirk, 1987).

Ore content and the effects of metasomatism and dissolution decrease towards Ringing Rake and Great Rake as orefluid became gradually buffered by wallrock alteration.

CONCLUSION

A detailed paragenetic, structural and morphological study of the cavity-fill stratabound mineralisation in Gentlewomen's and Old Jant Pipes, Matlock Bath, Derbyshire, and comparison with the Masson stratiform deposit further up-dip of the pipe cavities have led to the conclusion that all mineralisation above the Matlock Lower Lava, in the NE side of Masson Hill, is contemporaneous and occurs at the base of a zone of dolomitisation. The mineralisation dies out down-dip. The vertical fissures that now host vein mineralisation were formed in separate fracture events involving (1) NE-SW extension during sedimentation and early lithification; (2) WNW-ESE compression and wrench faulting at the end of the Dinantian, associated with uplift and erosion; (3) NW-SE extension and burial in the Upper Carboniferous when some of the limestone became dolomitised; and (4) rotation to a N-S extension during mineralisation in late Carboniferous times. Both the dolomitising fluid [during episode (3)] and orefluid [during episode (4)] were probably derived from overlying Namurian shales. Highly corrosive and fluorine rich orefluid migrated down the main NW-SE joints [formed during episode (1)], along subsidiary NE-SW joints [from episode (3)] and through the permeable dolomite. Orefluid probably moved further down-dip along a clay tuff horizon and down NE-SW joints that became enlarged by dissolution. Thus the pipe cavities in Gentlewomen's and Old Jant Mines may lie beneath irregular NE-SW fissures filled with calcite and galena.

The detailed paragenetic sequence in the pipes can be simplified to (i) limited fluorite metasomatism + dissolution along thin fissures; (ii) development of cavities by hydrothermal dissolution above the metasomatised areas; (iii) inward growth of comb-textured calcite, including two layers of fluorite and galena within and on top of the calcite; (iv) growth of very coarse-grained scalenohedra of "blocky" calcite; and (v) formation of translucent calcite with three-sided pyramidal terminations in the centres of some of the cavities (probably during later meteoric circulation). At the down-dip end of the pipes, Ringing Rake, which intersects the Matlock Upper Lava, consists entirely of coarse pink calcite and shows evidence of reverse faulting, with downthrow to the east.

The stratiform orebodies in Masson Cavern consist of vuggy fluorite layers built up by progressive overhead dissolution. Metasomatic replacement at the base of the dolomitised limestone was followed by the formation of one or more thin crustiform horizons herein called Masson-textured layers. The composite fluorite veins in the roof of the Masson deposit are similar to the flats and the fissures were formed by dissolution around the replaced walls of NW-SE master joints. These veins appear to have been the main feeders to the flats which spread out down-dip. Along strike, towards Great Rake, calcite becomes predominant and the mineral bodies have a similar appearance to the pipes in the Gentlewomen's/Old Jant system. Great Rake appears to show a component of normal movement with southerly downthrow. However, both Great Rake and Ringing Rake were probably originally wrench faults formed as a result of end-Dinantian compression [(2) above]. During mineralisation they are thought to have acted as "sinks" for exhausted orefluid as it moved down and along highly permeable wall-rock from the Namurian shales directly above the deposit.

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