

THE SULPHIDE MINERALOGY AND PARAGENESIS OF THE
SOUTH PENNINE OREFIELD, ENGLAND

by

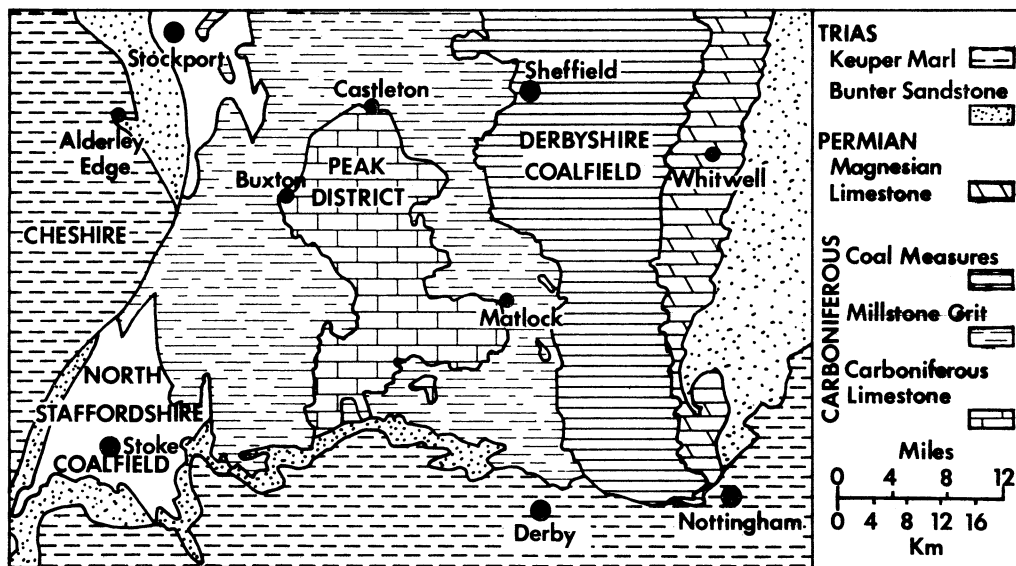
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Summary

Throughout the South Pennine Orefield, the primary sulphide mineralogy is remarkably uniform and simple, and displays a consistent paragenetic sequence. The main sulphides, in their generalized paragenetic sequence are bravoite, nickel-rich and nickel-poor pyrite and marcasite, chalcopyrite, galena and sphalerite. There is no systematic variation in the abundance, presence or absence of any sulphide mineral except for an overall increase towards the more mineralized eastern margin of the orfield. The widespread occurrence of nickel bearing sulphides throughout the orfield, and their appearance in similar deposits elsewhere, suggests that nickel is an important and characteristic minor element of the ore-fluids that produce Mississippi Valley style mineralization.

Introduction

The South Pennine orfield is composed of the galena-sphalerite-baryte-fluorite deposits occurring within the Carboniferous Limestone outcrop of the Derbyshire Dome and its associated outliers of Ashover and Crich, (text-fig.1). The anomalous copper-rich district



Text-fig.1. An outline geological map of the South Pennine Orefield.

of Ecton, Staffordshire is not considered to be part of the orfield. Together with the North Pennine orfields, that of the south has been classified as belonging to the Mississippi Valley type of deposit by Dunham (1966), and Worley and Ford (1977), although Emblin (1978) has proposed a new classification for them both, namely the Pennine type.

The mineralization consists of small vein deposits, metasomatic replacements, or cavern infillings with a simple primary mineralogy. This comprises calcite, baryte, fluorite and occasionally quartz 'gangue' together with much smaller amounts of galena and sphalerite and very minor amounts of iron, nickel and copper sulphides. The sulphides have two main styles of crystallisation, either as small inclusions within the 'gangue', or, less commonly, as mixed sulphide ore. Subsequent oxidation has resulted in numerous secondary sulphides, carbonates, sulphates and hydrated oxides.

The orefield was formerly mined for galena with minor exploitation of cerussite, sphalerite, smithsonite, wad and ochre (Ford and Ineson, 1971). The orefield is now a major producer of fluorspar; with minor barytes, and galena often extracted as by-products of the fluorspar mining. A little calcite is also mined producing some by-product galena.

The economic importance of the fluorspar deposits has meant that recent mineralogical studies of the orefield have concentrated on the minerals excepting the sulphides, to the virtual exclusion of these sulphides. There is now, however, enough information to allow detailed discussion of the mineralogy, paragenesis and distribution of the sulphides within the orefield for the first time.

Previous mineralisation investigations in the South Pennines

General aspects of the South Pennine orefield have been discussed by Wedd and Drabble (1908), Varvill (1959), Ford and Ineson (1971) and Ford (1976).

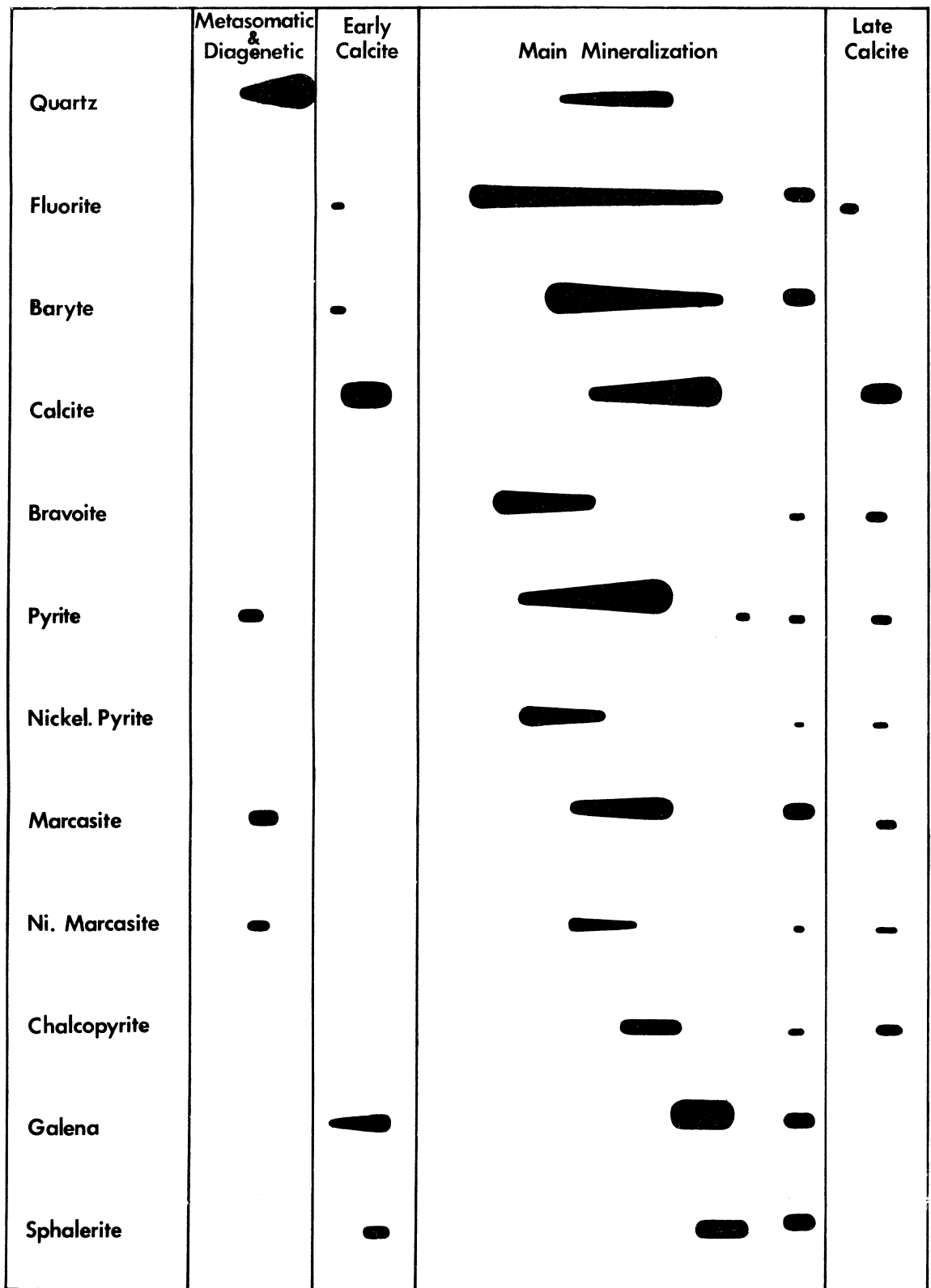
Regional zoning of the non-sulphides was described by Wedd and Drabble (1908), Dunham (1952) and especially by Mueller (1951, 1954a) who delineated three temperature controlled zones. The zones are an eastern fluorite zone passing westwards into a cooler baryte zone and finally a calcite zone. Additionally, Mueller (1951) defined a pyritic calcite zone and subdivided the fluorite zone into three, the easternmost of which consisted of fluorite with sulphide inclusions. Varvill (1959) suggested the existence of two northwest to southeast trending 'lead-belts'. More recently, Firman and Bagshaw (1974), in an extensive re-examination of both the mine records and field evidence, found that Mueller's concept of a fluorite zone succeeded westward by baryte is broadly true but the junctions are by no means clear cut.

Table 1 shows Mueller's (1954a) table for the concentration of minerals in his three zones, which is the only quantitative estimate of the amounts of sulphide present in the orefield. Ford (1976) has amended this assessment by noting the restriction of sphalerite to the eastern margin, and the more widely spread occurrence of pyrite and chalcocopyrite. Townley (1976) qualitatively investigated the regional distribution of the sulphides as briefly discussed by Ixer (1978).

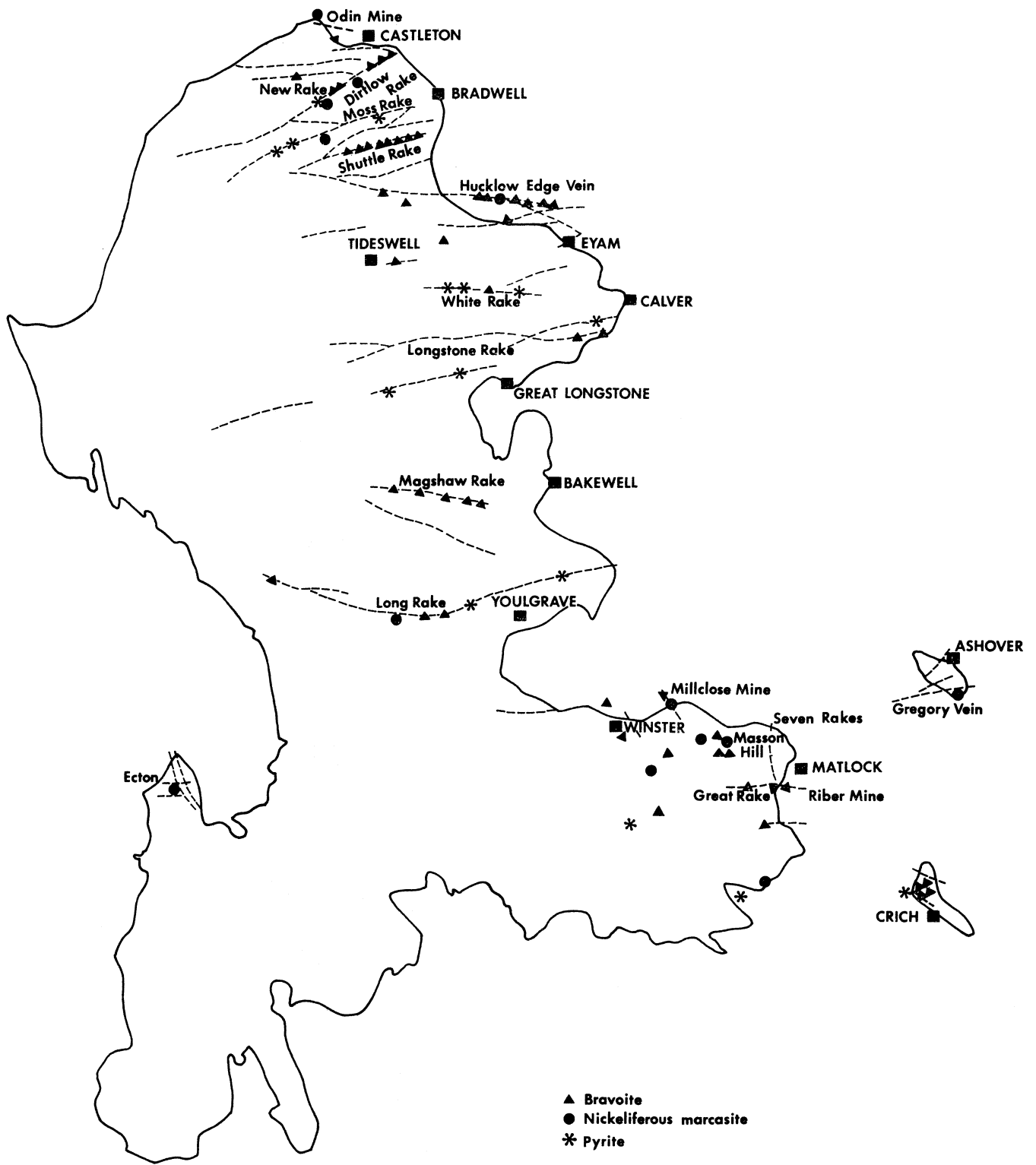
Table 1 Zonal Distribution of Hydrothermal Minerals (Mueller, 1954a)

	CaF ₂	BaSO ₄	CaCO ₃	PbS	ZnS	CuFeS ₂	FeS ₂
Fluorite Zone	10-50%	2-10%	40-85%	1-5%	0.5-3%	0-10%	0-5%
Baryte Zone	1-10%	10-40%	55-85%	0.5-3%	0-1%	-	-
Calcite Zone	0-1%	0-10%	80-99%	0-3%	0-0.5%	-	-

Few detailed mineralogical and paragenetic studies of individual deposits have been published. These include bravoite and other sulphides from Millclose Mine, Wensley Dale (Bannister, 1940); Vaughan, 1969); the baryte-galena deposit of Golconda Mine, Brassington (Ford and King, 1965) and the fluorite-calcite-sulphide mineralization of a pipe deposit in the Blende Vein, at Sheldon near Bakewell (Worley, 1976). Ford (1976) correlated the paragenetic sequences from four other individual deposits, those of the multiphase baryte-fluorite vein



Text-fig. 2. A generalized paragenesis for the South Pennine Orefield. The diagram gives no information as to the relative proportions of the minerals; the quantities of sulphides are far less than those of the non-sulphides.



Text-fig. 3 Distribution of bravoite, nickeliferous marcasite and pyrite in the South Pennine Orefield.

deposits of Raper Mine (Ineson and Al-Kufaishi, 1970); the essentially single phase fluorite-baryte-calcite-sulphide replacement deposit of Masson Hill (Ixer, 1974) and two vein deposits from Ashover, (White, 1968). Although the four deposits show some differences in their detailed paragenesis, in that the rakes show repetitive phases of mineralization whilst the flats show a more continuous mineralization sequence, this is largely due to differences in mineralization styles. Rake deposits being more susceptible to tectonic movements than metasomatic flats will show a number of generations of mineralization as they open and close to the mineralizing fluids, whereas unmineralized portions of a flat deposit are always receptive to the fluids. However, all four deposits show an early silicification followed by an extensive phase of fluorite, baryte and sulphide mineralization and, finally, late calcite. Firman and Bagshaw (1974) proposed a similar generalized paragenesis comprising an early rhombohedral/columnar calcite phase with galena and rare sphalerite, the main fluorite-baryte and sulphide mineralization and a final scalenohedral calcite phase.

Similar studies have been carried out on the North Pennine Orefield which is mainly situated over two basement highs, the Alston and Askrigg Blocks. The mineralisation of the Alston Block shows clear concentric zoning of both sulphides and non-sulphides but no clear paragenetic sequence, except that fluorite is earlier than baryte (Dunham, 1948, 1966). Similarly, the Askrigg block has been shown to contain mineral zoning (Small, 1978). Recently, Hagni and Trancynger (1977) have described a detailed paragenetic sequence from the Magmont Mine, Missouri, which may be used as a model for the 'typical' Mississippi Valley ores, and Ixer (1978) has noted the mineralogical similarity between the sulphides of this type of deposit and certain red-bed deposits, including that of Alderley Edge, Cheshire.

Method of study

Representative mineralized specimens were collected from 80 sites throughout the ore-field, mainly from small outcrops within open old mine workings or their accompanying dumps. The location of the collecting sites and description of the material collected at them is given in Townley (1976). Three distinct types of mineralized specimen were found; large single crystals of calcite, fluorite or baryte carrying sulphide inclusions; mixed sulphide-gangue or banded sulphide and non-sulphide ores: mineralized lavas and agglomerates.

Multiple polished sections were made of material from three richly mineralized areas, namely Masson Hill-Oxclose Mine (28 sections), Millclose Mine (12 sections) and Odin Mine (12 sections), and the paragenesis established from the textural relationships of the sulphides. Additionally, 94 sections were made, one or more from each site, and these were used to investigate the full sulphide mineralogy of the ores and to search for any evidence of regional zoning.

Paragenesis

Investigation of the ore material shows the sulphides to have three distinct modes of formation. The most common mode is as bands of inclusions in fluorite, calcite, baryte or, more rarely, quartz. This has been discussed by Mueller (1954b), Ford (1976), Firman and Bagshaw (1974) and Ixer (1974). Less commonly galena, sphalerite and marcasite form a banded ore with baryte and fluorite, the good terminations of the crystals indicating that this ore-type is due to open void infilling; or even rarer, the sulphides and non-sulphides are randomly intergrown producing a non-banded mixed ore. All three modes of occurrence are largely contemporaneous.

The sulphides will now be discussed in greater detail, both as inclusions and as non-inclusions.

Sulphide inclusions

Bravoite, marcasite and chalcopyrite are the most common inclusions, with nickeliferous pyrite and marcasite, and pyrite being less common; galena, sphalerite and haematite are rare.

Typically the inclusions occur in bands which are up to 500 μm wide and are sub-parallel to each other and to the growth zones of the enclosing host mineral. The sulphides are especially concentrated at the junction of two host minerals which are usually baryte, fluorite or calcite. The bands can be mono-mineralic chalcopyrite or marcasite, or comprise bravoite with successive pyrite and marcasite overgrowths. Each band, however, is comprised of one type of inclusion with its own modal size, although adjacent bands may have different modal sizes and mineralogies. Alternating bands of chalcopyrite and marcasite are common.

Bravoite inclusions have a pentagonal dodecahedral habit and mainly belong to the zoning types II, IV and V of El Baz and Amstutz (1963) and have two modal sizes of 30 μm and 5 μm . Larger crystals up to 150 μm are rare, having been found at Crich and near Winster. They show a variety of colours from brown, purple, lilac to steel-grey and within one crystal colour zoning (up to 10 μm wide) is usual. The colouration varies between successive bands and even within one band there are variations in colour, successive order of colours, and the width and arrangement of zoning. Partial overgrowths of pyrite (10 μm) and marcasite (15 μm), both often nickeliferous, form aggregates up to 80 μm in size. The overgrowth is characteristically in the growth direction of the enclosing host mineral.

Euhedral to subhedral nickeliferous pyrite up to 50 μm is typical, as are marcasite laths, up to 200 x 10 μm , although small marcasite mosaics are also common. Nickel-rich zones in the marcasite are of the order of 5 μm wide. Chalcopyrite is found as anhedral or rare subhedral crystals up to 450 μm enclosing iron-nickel sulphides, or as isolated grains. Sphalerite and galena are rare forming 100 μm anhedral and 30-60 μm rounded grains respectively. Very fine haematite dust, far smaller than 1 μm , has been found in calcite and fluorite crystals near Bradwell and in quartz near Bonsall and Calton Hill. Fine haematite inclusions are common in vesicular calcite from the altered lavas of the orefield (Ixer, 1972).

Other inclusions are native copper and bornite identified in hand specimen within late stage calcite from Riber Mine (Varvill, 1959). Mueller (1954b) stated that the sequence of inclusion bands in crystals could be correlated between different veins and over some distance. The present study has shown that the crystallization sequences can be quite complex and therefore the correlation of crystals between veins would be difficult, using recognition of these bands as the sole criterion. In one instance a limited correlation was found to be practicable. The very rare and hence distinctive band of haematite inclusions in fluorite crystals found in the Bradwell Pipe could be correlated across the many smaller pockets of vug infilling or metasomatic replacements that make up the pipe over a distance of approximately 100 m.

Non-inclusion sulphides

These will be discussed in the order of their paragenetic sequence during the main fluorite-baryte-sulphide mineralization, as shown by their textural relationships. A more complete paragenesis is depicted in text-fig. 2.

Iron-nickel sulphides

Bravoite was identified optically by its zoning and/or deep colouration. Its occurrence in the South Pennine orefield has been reviewed in Lunn *et al.*, (1974) and Ixer (1978), who has also summarized the available chemical analyses. The two major textures, first recognised from Oxclose Mine (Ixer, 1974) are constant throughout the orefield:

- (a) Brown to pink-brown euhedral to subhedral crystals (20-60 μm) occur and reach 1000x250 μm at Oxclose and approximately 3.5 cms at Millclose Mine (Bannister, 1940). Zoning is broad but sharply defined, although within each zone fainter and more diffuse zones can be seen. Colouration is usually darker towards the centre of the grain but as was shown by Vaughan (1969) there is no precise correlation between colour and nickel, cobalt and iron content of the grain. Most of the eight zoning types described by El Baz and Amstutz (1963) are represented. Pyrite and marcasite enclose or are intergrown with this bravoite (Plate 7, figs. 1 and 2). This is especially true at Oxclose Mine where a pseudomymekitic texture has resulted, (Plate 7, figs 3 and 4).
- (b) Less common are small (5-10 μm) very euhedral, lilac, zoned bravoite crystals enclosed within 200 μm pyrite aggregates.

Both types of bravoite, as with all the iron-nickel sulphides, are oxidized to goethite.

Nickeliferous pyrite was distinguished from pyrite by its pink/brown colour, faint zoning and lower reflectivity. It has a more restricted paragenesis than pyrite as it only crystallized within the main mineralization phase.

The earliest pyrite is present as diagenetic framboids (10-35 μm) within shale or limestone host rocks, and is associated with poorly crystalline 'spongy' pyrite, (Plate 8, figs 1 and 2). It is surrounded by radiating twinned marcasite euhedral crystals (Plate 8, fig.3) or enclosed by chalcopyrite anhedral crystals as at Odin Mine, (Plate 8, fig.4). The pyrite and nickeliferous pyrite found with the main mineralization typically form rims and overgrowths (10-20 μm) around bravoite, or as independent anhedral or subhedral crystals (70 μm) associated with it, (Plate 9, figs. 1 and 2). At the end of the main mineralization, large pyrite grains, often up to several centimetres in size, are associated with baryte and calcite crystals. These pyrite crystals contain relict marcasite laths (400x100 μm). The final phase comprises veinlets (5-10 μm) of poorly polished brown pyrite that forms as rims around all other primary sulphides. This is the 'melnickovite' pyrite of Ramdohr, (1969) although a less mineralogically ambiguous term would be colloidal pyrite.

Within the altered and mineralized lavas, there are also a number of pyrite generations. The earliest is a poorly crystalline spongy pyrite that encloses and replaces titanium dioxide pseudomorphs after ilmenite laths. Later subhedral pyrite, introduced with calcite veining, contains thin (2-5 μm) faint nickeliferous zones. Angular pyrrhotite (up to 70 μm), showing patchy alteration to marcasite and haematite, is found within this pyrite but is not associated with the nickeliferous areas. Pyrrhotite is recorded elsewhere, notably from the Tansley borehole (Ramsbottom *et al.*, 1962) and from Eyam and Longstone Edge (Ford and Sarjeant, 1964).

Nickeliferous marcasite was distinguished optically from marcasite by its green-white to blue-lilac reflection pleochroism and lower reflectivity. Its presence was first recorded from the orefield by Townley (1976) and Ixer (1978) who also gave confirmatory electron microprobe analyses.

As with the other iron-nickel sulphides, there are a number of generations of marcasite crystallization. The earliest marcasites are the small framboids and radiating marcasite crystals associated with the pyrite framboids (Plate 10, fig.1) and of diagenetic origin. Some of the marcasite is nickeliferous. Most of the nickeliferous marcasite is associated with the main mineralization. The marcasite crystallizes both as overgrowths and intergrowths with bravoite and pyrite. Small (10 μm) nickeliferous areas and 1-3 μm lilac-brown nickeliferous zones can be observed throughout the marcasite in a similar manner to zoning type VIII of El Baz and Amstutz (1963). The zones are sinuous, cutting anisotropic boundaries and are often the continuations of zoning within enclosed bravoite. Euhedral bladed marcasites commonly carry repeated 5 μm wide nickeliferous zones parallel to the crystal outline, (Plate 9, figs. 3 and 4). Later generations of marcasite include the relict marcasite crystals within large pyrite crystals and large radiating marcasites associated with alternating baryte, fluorite, sphalerite and galena within the rhythmically banded ore.

Chalcopyrite

Chalcopyrite is less common than the iron-nickel sulphides but encloses them, seen especially in samples from Odin Mine (Plate 7, fig.4). Chalcopyrite forms twinned anhedral crystals reaching a maximum size of approximately 0.5 cms. Smaller euhedral to subhedral crystals (30-50 μm) occur along growth zones in sphalerite and are concentrated at the margins (Plate 10, fig.3). Chalcopyrite is variously altered to bornite, covellite, chalcocite, cuprite and green carbonates; the alteration forming successive concentric rims 4-10 μm wide (Plate 10, fig.4).

Galena

Galena is seen as subhedral to euhedral crystals up to 10 cms across independently of whether it is an early or late generation. It commonly encloses other sulphides, and rarely, native silver at Odin Mine. Native silver has been reported from the South Pennine orefield (Ford and Sarjeant, 1964) but generally the galena has a low silver content (< 50 ppm) (El Shazly *et al.*, 1957). Alteration to cerussite and anglesite is common, accompanied by framboidal secondary galena.

Sphalerite

Sphalerite is rarer than galena. It is iron-poor with less than 5 mol % Fe, normally with yellow-white internal reflections, but some have a deep purple colouration along twin planes. El Shazly, *et al.*, (1957) report a restricted trace element content for sphalerites from Millclose Mine with only cadmium (3000 ppm) and silver (200 ppm) being of significant concentration. Higher cadmium values, up to 0.88 wt % are reported from Oxclose Mine (Iyer, 1972). Smithsonite containing relict sphalerite and greenockite flecks (5 μm) also suggests locally higher cadmium at Oxclose Mine. Alteration of sphalerite is extensive, with rims of covellite and goethite and replacement by hemimorphite, smithsonite and goethite, (Plate 10, fig.2).

Other sulphides

A few other sulphides have been reported, including millerite, in association with pyrite; pyrrhotite, chalcopyrite and sphalerite from the Tansley borehole (Ramsbottom *et al.*, 1962) and from Ashover; cinnabar in smithsonite from the Matlock area (Braithwaite and Greenland, 1963); tetrahedrite from Millclose Mine (Bannister, 1940) and arsenopyrite from Eyam and Longstone Edge (Ford and Sarjeant, 1964).

Regional distribution

The iron-nickel sulphides were the most widely distributed phases within the ore material studied, generally as bravoite accompanied by pyrite and marcasite. Both zoned and unzoned bravoites were identified from 50 sites, unzoned bravoite from a further 8 and optically identifiable nickeliferous marcasite from 12. The distribution of bravoite and nickeliferous marcasite is shown in text-fig.3. At only 16 sites were no nickeliferous minerals recognised and these sites were randomly distributed and often closely surrounded by others containing a high proportion of nickel minerals. Galena was almost as widespread but chalcopyrite and sphalerite were less common.

There was a general increase in the occurrence of sulphides towards the more intensely mineralized eastern margin of the orefield, but no other regional variation could be detected in either the presence or absence of phases or their relative amounts.

Insufficient material was collected for any quantitative discussion on the relative abundances of the sulphides, but a visual estimation, using all the sections, gave the following relative modal proportions: galena very much greater than sphalerite > marcasite > pyrite very much greater than bravoite > chalcopyrite.

Summary and conclusions

The primary sulphide mineralogy of the ores is simple and uniform throughout the orefield and consists of iron-nickel sulphides, chalcopyrite, galena and sphalerite. Most of the sulphide mineralization is epigenetic, the contribution of diagenetic processes is slight, unlike at Magmont Mine, Missouri where much of the sulphide is thought to be diagenetic, especially the early generations of pyrite and bravoite (Hagni and Trancynger, 1977). Both field and textural evidence suggests that the ores have resulted from the three main episodes of mineralization discussed by Firman and Bagshaw (1974); namely an early calcite-galena-sphalerite episode followed by the main fluorite-baryte-calcite-sulphide mineralization, and finally calcite again. The repetitive nature of the mineralization, which is typical of the Mississippi Valley type of deposit, is most clearly demonstrated by the sulphide inclusions. Throughout the mineralization there is a constant sequence of bravoite with successive pyrite, marcasite and chalcopyrite overgrowths. This repetition is also shown by the three major generations of galena and sphalerite, and the two generations of pyrite and marcasite. However, significant bravoite and chalcopyrite crystallization only occurred once and this within the main mineralization. This restricted paragenetic position largely accounts for the relative paucity of the two sulphides.

The distribution of the sulphides shows no evidence for any east-west variation or zoning, other than a general increase of all sulphides eastwards, nor is there any evidence of lead-belts. This supports the view of Firman and Bagshaw (1974) who found a similar increase in intensity of mineralization towards the eastern margin of the orefield. However a more subtle regional zoning may be present, and if so, a systematic investigation of the trace element contents of sphalerite, galena and chalcopyrite would seem to provide the best chance in recognising it. At present, there are virtually no published trace element analyses for the sulphides from the South Pennines Orefield. Chemical analyses of the nickel minerals show that the nickel content within one specimen can vary widely, for example between 0.15 - 6.40 wt. % in nickeliferous marcasite and between 8.0 - 24.0 wt. % for bravoite, Ixer (1978). This variation in chemistry, which reflects the extreme sensitivity of the iron-nickel sulphides to changes in the local mineralizing fluids, means that its use would be severely limited in investigating regional variations.

The widespread distribution of sulphides containing nickel in the South Pennine orefield is indicative of nickel as a characteristic minor element in the ore fluids, of at least equal importance with copper. Bravoite is known from similar deposits found in the Askrigg Block and Mendip Hills in England (Townley, 1976) and accompanies vaesite in the Cave-in-Rock district Illinois (Park, 1967) and siegenite from Magmont Mine, Missouri (Hagni and Trancynger, 1977) suggesting that nickel is characteristic of Mississippi Valley style deposits generally.

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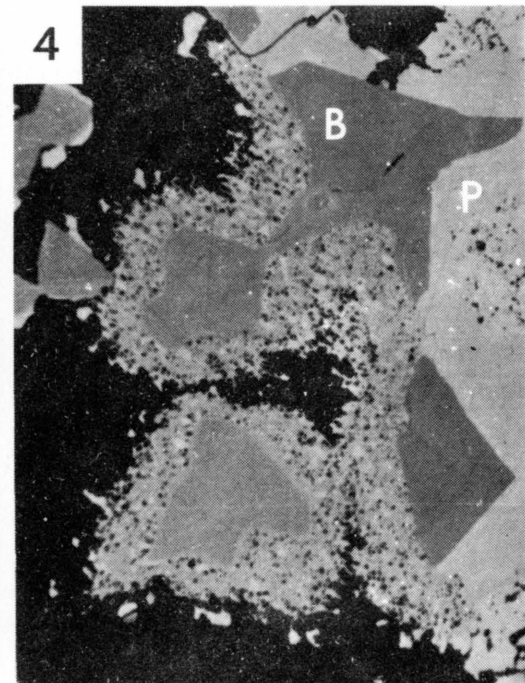
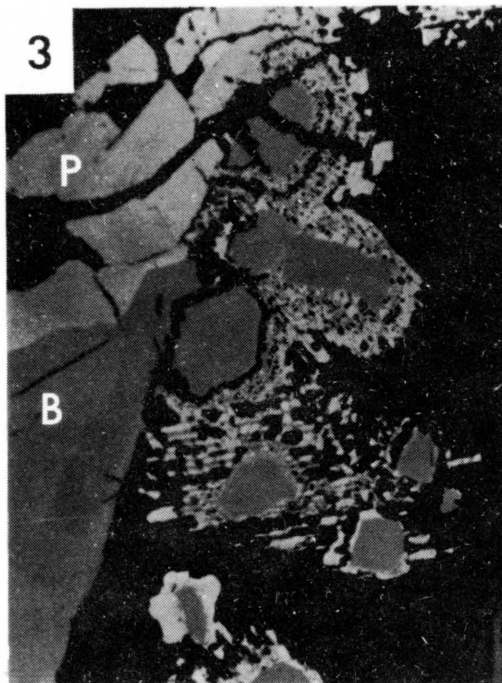
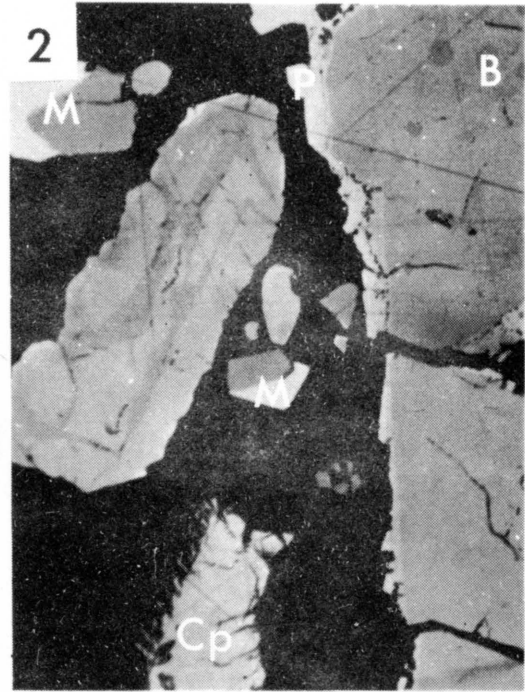
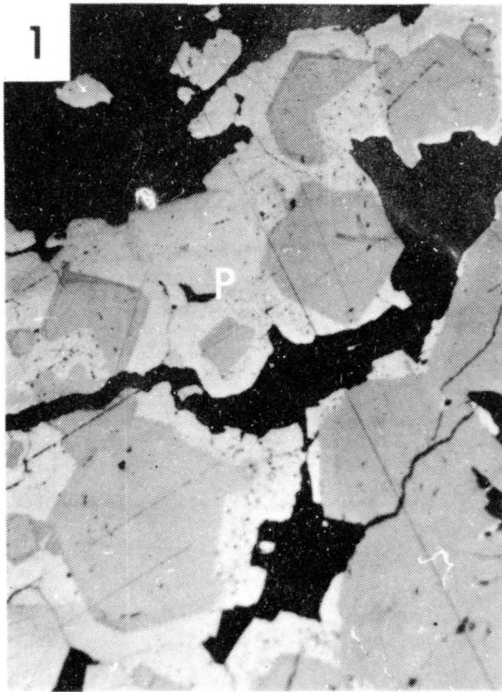
EXPLANATION FOR PLATES 7 and 8

- Plate 7, fig.1 Euhedral zoned bravoite (dark greys) enclosed in zoned nickeliferous pyrite (P) and pyrite. Later fracturing of the sulphides have been healed by fluorite x 180.
- Plate 7, fig.2 Irregularly zoned bravoite is associated with unzoned bravoite (B) which is enclosed in pyrite (P) and euhedral marcasite (M). Chalcopyrite (Cp) that is altering along its cleavage to covellite and goethite is also present x 250.
- Plate 7, fig.3 Zoned bravoite (B) is enclosed in nickeliferous pyrite (P). Bravoite and pyrite are intergrown in a coarse pseudomyrmekitic texture. Later fracturing is cemented by fluorite x 400.
- Plate 7, fig.4 Zoned bravoite (B) is partially enclosed by nickeliferous pyrite (P) and partially surrounded by a fine-grained pseudomyrmekitic intergrowth of bravoite and pyrite x 500.

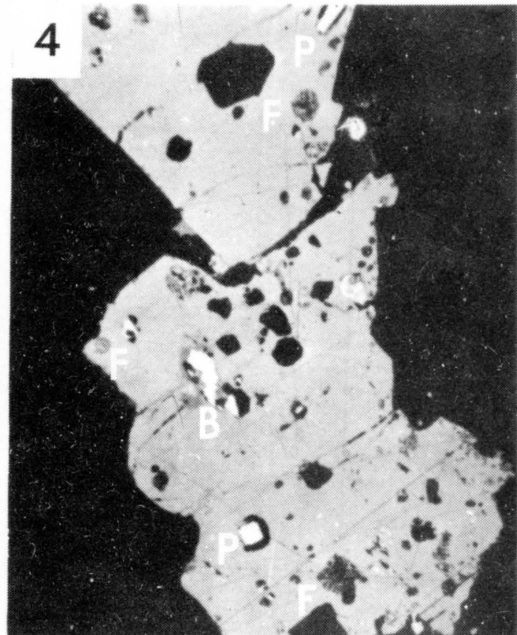
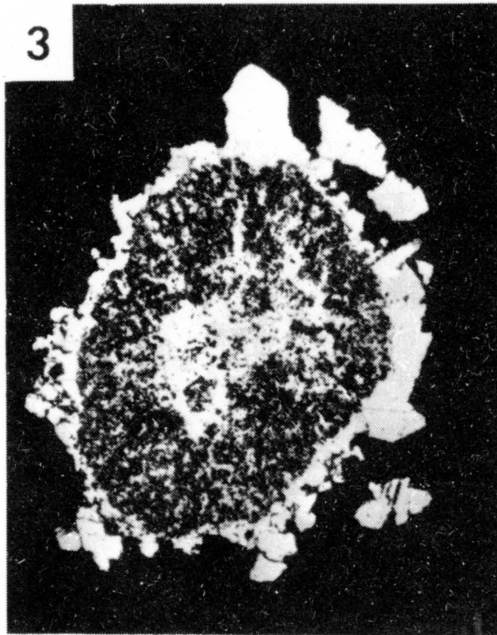
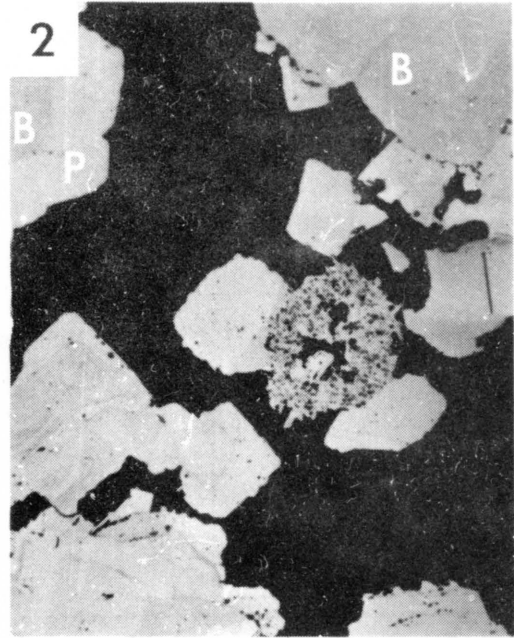
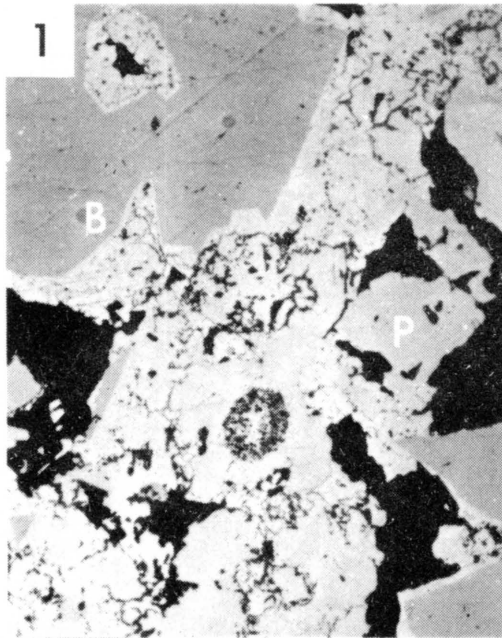
All specimens are from Oxclose Mine, reflected light, plane polarised light, oil immersion.

- Plate 8, fig.1 Rounded spongy pyrite (centre) enclosed in nickeliferous pyrite (P), marcasite and coarse-grained bravoite (B). Oxclose Mine, x 120.
- Plate 8, fig.2 Diagenetic pyrite (centre) with a rim of acicular marcasite. Irregularly zoned and unzoned bravoite (B) and pyrite (P) is associated. Oxclose Mine, x 250.
- Plate 8, fig.3 Oxidized spongy diagenetic pyrite together with the accompanying rim of radiating euhedral marcasite crystals. Oxclose Mine, x 600.
- Plate 8, fig.4 Anhedral chalcopyrite enclosing euhedral pyrite cubes (P), bladed marcasite (white) with bornite rims (B) and oxidized pyrite frambooids (F). Odin Mine, x 150.

All photomicrographs are in reflected light, plane polarised light and oil immersion.



Ixer & Townley S. Pennine Sulphate mineralogy (For explanation see p. 62).



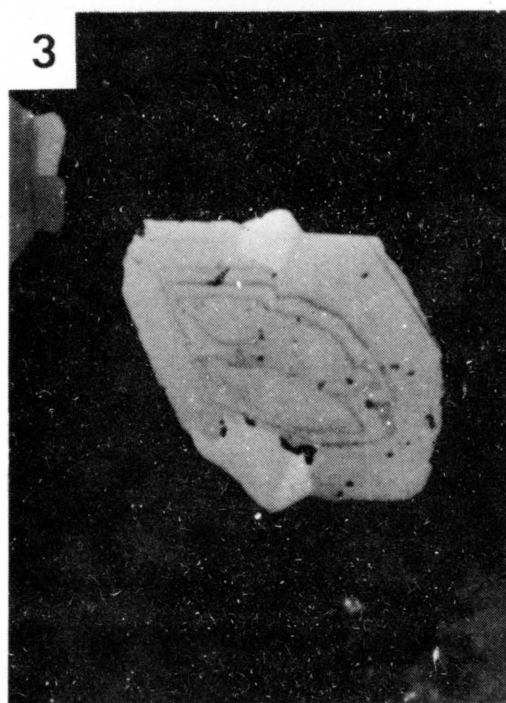
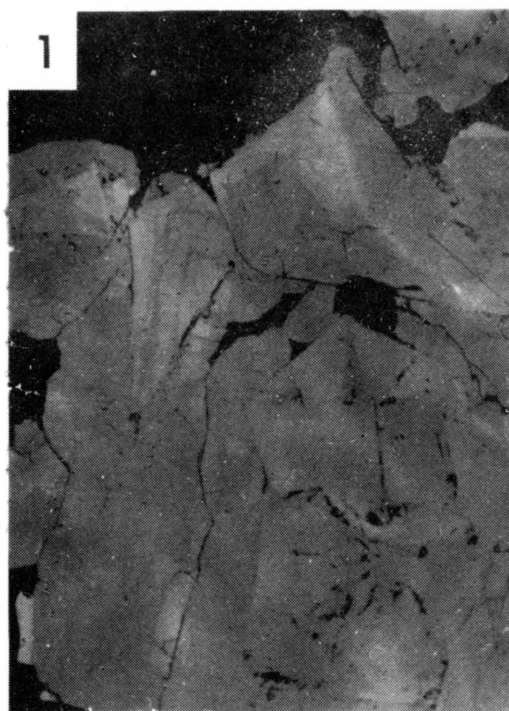
Ixer & Townley S. Pennine sulphide mineralisation
(For explanation see p. 62).

EXPLANATIONS FOR PLATES 9 and 10

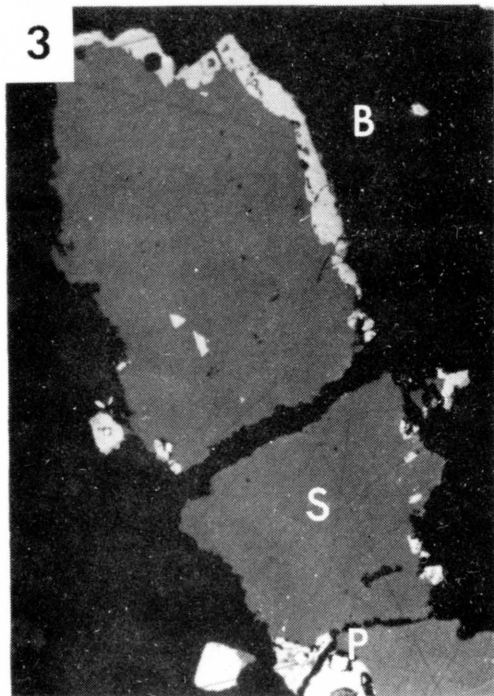
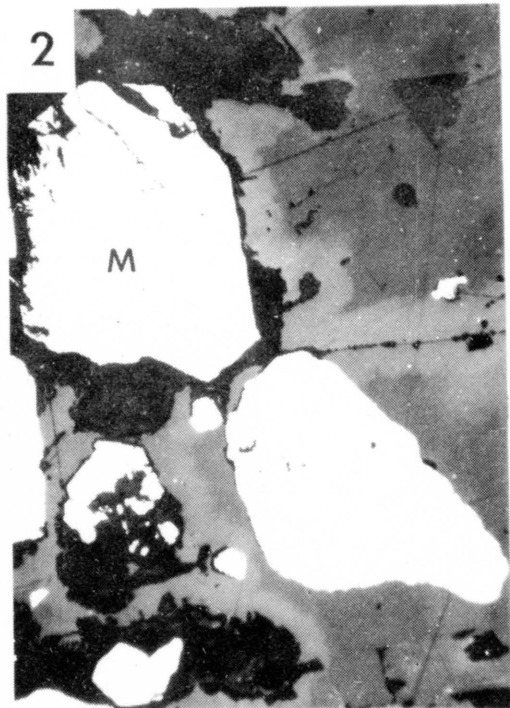
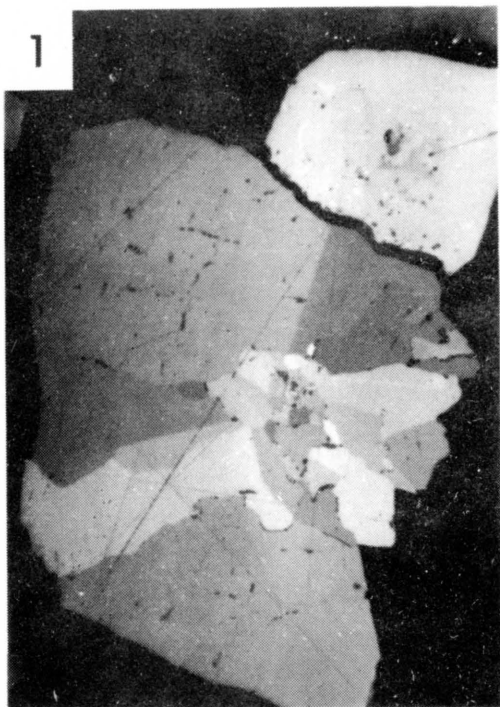
- Plate 9, fig.1 Nickeliferous pyrite showing faint but characteristic zoning. Oxclose Mine, x 200, plane polarised light.
- Plate 9, fig.2 Zoned nickeliferous pyrite subhedra with pyrite overgrowths (P). Later fracturing is cemented by calcite. Hucklow Edge, x 300, plane polarised light.
- Plate 9, fig.3 Euhedral and zoned marcasites. Different shades of grey show grains in slightly different anisotropy positions. Odin Mine, x 1400, partially crossed polars.
- Plate 9, fig.4 Fractured zoned marcasite. Odin Mine, x 400, partially crossed polars.

All photomicrographs are in reflected light, oil immersion.

- Plate 10, fig.1 Radiating aggregate of late generation marcasite with crystals in differing anisotropy positions. Odin Mine, x 450, partially crossed polars, oil immersion.
- Plate 10, fig.2 Euhedral marcasite (M) associated with sphalerite. The sphalerite shows the characteristically lighter coloured rim associated with its alteration. Oxclose Mine, x 250, plane polarised light, oil immersion.
- Plate 10, fig.3 Anhedral sphalerite (S) with triangular chalcopyrite inclusions and a chalcopyrite rim. The chalcopyrite encloses pyrite cubes (P) and framboidal pyrite. Calcite (dark grey) and baryte (lighter grey B) are the 'gangue' minerals. Odin Mine, x 100, plane polarised light.
- Plate 10, fig.4 Anhedral chalcopyrite altering to covellite about its margin and along its cleavage. Oxclose Mine, x 250, plane polarised light, oil immersion.



Ixer & Townley S. Pennine sulphide mineralisation
(For explanation see p. 64).



Ixer & Townley S. Pennine sulphide mineralisation
(For explanation see p. 64).