CONTRASTING TEXTURES IN THE SILVER-LEAD-ZINC ORES OF THE MAGNET MINE, TASMANIA

By

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ABSTRACT

The Magnet silver-lead-zinc ore shows two strongly contrasting groups of textures wihch provide a true and a pseudo-paragenesis. The ore group us due to a repeating crustification, appearing as rhythmic banding and as cockade textures, during the early and again during the closing stages of deposition. The other group arises from shearing and partial recrystallization of the the ore at a stage intermediate to the two periods of crustification.

The sulphide minerals, and the associated mangano-siderite of the ore, were deposited at or above 400°C, manganese constituting about 10 per cent of the orebody.

Introduction

It seems appropriate, on this auspicious occasion, to recall that in the immediate post-war years, when living conditions in Berlin were difficult, if not desperate, the opportunity was made by the Australian Government, at the instigation of Dr. F.L. Stillwell and myself, for Professor Ramdohr to migrate to Australia with his family, and join the Mineragraphic Investigations Section of our Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) as a permanent officer, and with full pensions rights. As a result Professor Ramdohr spent the year 1948-1949 with us.

Not surprisingly, at the end of the trial period, the calls of the Old World, and of Heidelberg in particular, proved too strong for the less sophisticated attractions of our part of the New World; and Professor Ramdohr returned to Germany. At least we had the inspiration of working with him, and of seeing "Die Erzmineralien" in its proof stages; and we would like to think that that busy year was not without incident for him, also.

It seems appropriate, too, that I should salute this accasion with a paper dealing with some superb textures in a Tasmanian ore deposit, for from Tasmania came many of the specimens that he worked on, both while he was with us, and subsequently, including the rare heazlewoodite, and the new and even rarer mineral shandite, which he discovered in his period with C.S.I.R.O.

-------XXX-------

The geology of the Magnet orebody has been described by Nye (1923) and by Cottle (1953). The mine is 4 miles west of Waratah, and within a few miles of the famous Mount Bischoff tin deposits in north-west Tasmania (Fig.1), and the orebody is the chief of a series of about 20 small silver-lead-zinc deposits in this part of Tasmania. It was worked from 1895 to 1940 for a production of about 37,400 tons of lead and 7,980,000 oz. silver, from an estimated 620,000 tons of ore raised.

zinc was not recovered, although in the deeper levels assays indicated about 0.4 per cent zinc for each 1 per cent lead.

The lead-zinc deposits occur as a narrow belt trending northeastwards from north of the Meredith Range granite to Mount Bischoff. As first noted by Ward (1902), this lead-zinc zone extends along the north-west "flank" of the tin-bearing Mount Meredith-Mount Ramsay-Wombat Hill granite mass, with its associated cupolas and quartz-porphyry dykes (Fig.2). The larger of the lead-zinc deposits lie at 2 to 3 miles from the edges of the main granite outcrop, but some minor deposits occur within a few hundred feet of the granite; and small granitic or quartz-porphyry dykes lie adjacent to some of the larger deposits.

The narrow north-south trending Mount Cleveland granite mass outcrops at four to five miles west of the lead-zinc belt, so that probably the whole area is underlain by granite at relatively shallow depths.

Rock Formations

The granite, and related porphyries, have intruded Cambrian sediments, and ultrabasic igneous rocks, intrusive into the Cambrian sediments. The ultrabasic igneous rocks, formerly regarded as Devonian (Nye, 1923), are now regarded as Cambrian, on the basis of evidence in other parts of Tasmania (Carey, 1953). The granites are accepted as Devonian, and this finds support in that a group of the silver-lead-zinc deposits, and some associated copper mineralization, occur with a small area of fossiliferous marine Silurian sediments (Eldon Group) in the south-western part of the area (Nye, 1923).

Elsewhere, the silver-lead-zinc mineralization occurs in the Cambrian sediments and in the basic and ultrabasic igneous rocks. These latter comprise dyke-like bodies of gabbro or diabase, up to 5 miles long, and up to 1500 ft. wide, with local marginal bands of pyroxenite or serpentinite, and of irregular intrusive bodies of pyroxenite and peridotite, in places altered to serpentinite. Weak nickel sulphide mineralization is associated with these rocks immediately to the south-west of the lead-zinc region (Williams, 1958).

A large intrusive mass of syenite (of uncertain age) is associated with the basic and ultrabasic rocks in the western part of the area (Nye, 1923), with lead-zinc mineralization in the ultrabasic rocks and Silurian sediments adjacent to its southern end; and a small dyke of syenite porphyry occurs in mineralized ultrabasic rocks just south-west of Heazlewood Hill, at the western end of the lead-zinc belt.

The Cambrian sediments comprise two formations; an upper (younger) Bischoff Group comprising thinly laminated black slates and fine-grained flaggy micaceous sandstones; and a lower (older) Dundas Group, consisting of slates (reddish at the surface), cherts, blue-grey felspathic "breccias" (greywackes) cemented by carbonates and hematite, and dark-grey micaceous "breccias", consisting of fragments of quartz, felspars and micas, in a fine matrix of felspars and plentiful iron oxide. Both "breccia" formations are thought to be derived from igneous rocks (Nye, 1923).

Upper Mesozoic dolerite intrusions outcrop along the Magnet- Magnet Siding tramway, about a mile north of the Magnet mine, and along the Magnet water race, near Seven Mile Creek.

An extensive sheet of Tertiary olivine basalts, underlain by fossiliferous freshwater sediments, locally stanniferous, extends southwards from Waratah over the granite, and residuals of these basalts and sediments cap hills in the north-eastern part of the area, including the Magnet Range, north of the Magnet mine.

The Magnet Orebody

Geological Setting

The Magnet orebody occurs at the junction of branching shears within a composite basic dyke (Nye, 1923; Cottle, 1953). The dyke is about 5 miles long, and follows the course of a strong fault that strikes north-east, and throws down to the north-west.

The dyke, which dips at about 50°NW is 1300 ft. wide at the mine, but thins to 250 ft. along its strike.

At the mine it consists of a central zone of diabase porphyrite, about 500 ft. wide, with a zone of pyroxenite (websterite porphyrite, partly serpentinized) on its south-eastern side, and a further zone of pyroxenite (locally orbicular) on its north-western side. The pyroxenite zone on the south-eastern side is 360 ft. wide at the surface (No.4 level adit), but thins out to north-east and south-west, and down the dip, to about 30 ft. at the No. 10 level, below which it maintains this narrow width (Fig. 3) and is largely serpentinized. The pyroxenite zone on the north-western side is longer and about 400 ft. wide.

A small body of Bischoff slates, enclosed in the south-eastern pyroxenite zone, was intersected in the No.4 level adit, and a second was encountered between the pyroxenite and the diabase porphyrite to the south of the open cut. A body of Dundas "breccias" is reported enclosed by the pyroxenite from above the No. 11-level to midway between the No.9- and No.8-levels. The footwall rocks of the dyke are Dundas Group sediments, while the hanging wall rocks are Bischoff Group sediments, and the bodies of Bischoff slates within the dyke are regarded as remnants of down-faulted Bischoff Group sediments caught up by the dyke as it rose up the fault plane or planes. The dyke is interpreted as a composite intrusion, with later diabase porphyrite injected into, or between earlier intruded pyroxenite (Nye, 1923).

Structure

The shears on which the Magnet orebody developed, consist of the Main or Hangingwall Shear, which strikes NE. along the contact of the diabase porphyrite core with the south-eastern pyroxenite zone, and two branch shears, which developed below the No.4-level and which trend N-S. through the pyroxenite, more or less parallel to its contact with the Dundas sediments (Fig. 4).

At the surface mineralization was confined to the Hangingwall Shear, as a narrow lode 10 to 15 ft. wide, along the contact of the diabase (hangingwall) and pyroxenite (footwall). For a short distance south of the open cut a "xenolith" of Bischoff Slates formed the hangingwall.

Below the No.4-level, mineralization developed along the two branch shears, which junctioned with the narrow lode about midway along its length. The mineralization extended along each of the branch shears, dwindling away southwards to narrow, uneconomic seams, at distances of 150 ft. to 200 ft. from their intersections with the Hangingwall Shear, although the shears carry veins of carbonate gangue for much greater distances (up to 1400 ft. along the Footwall Shear).

Two other changes accompanied this change. The length of the mineralized section of the Hangingwall Shear was reduced both north and south of its junction with the Footwall Shear: and the ground in the angle between the shears, for about 85 ft. to 120 ft. south from the junction became mineralized.

Below this level the economic orebody was confined to a section about 120 ft. long, southwards from the junction of the shears; and in the section between the junction of the shears and the cross-cut from the main shaft filled the full width between the Hangingwall Shear and the Footwall Shear, so that at the cross-cut the orebody was 50 ft. wide (Fig.4). It has been mined down to the No.16-level (about 1200 ft. vertical) and continues underfoot, so that the main orebody has the form of a triangular pipe, about 50 ft. across the base and 75 ft. long, with three arms projecting southwards, the most easterly arm being the strongest, and a short arm projecting north-eastwards from its apex. The pipe dips (pitches) to the north-east at about 55°.

The hangingwall of the lode consists of body of massive white ferriferous dolomite, separated from the ore by a band of soft pug. About 2 ft. beyond the pug seam, the dolomite becomes more coarsely crystalline, and contains an increasing number of dark residuals of partly replaced diabase porphyrite. The total thickness of "hangingwall dolomite" is 10 to 11 ft., beyond which occurred a second narrow lode, The Back Lode, 3 to 10 ft. wide, but mostly 3 to 5 ft., filling a shear parallel to the Hangingwall Shear. Just above the No.16-level the Back Lode increased in width and near the junction of the Hangingwall Shear and the Footwall Shear became contiguous with the Main Lode.

Nature of Orebody

The Main lode consisted of narrow veins and bunches of coarse grained ore minerals, chiefly galena with lesser sphalerite, and abundant manganosiderite, dispersed through residuals of brecciated and serpentinized pyroxenite, in all stages of replacement by white dolomite, with a concentration of the ore minerals into a continuous body along the footwall side (Footwall Lode). It was of good to fair overall grade from the junction of the shears to the main cross-cut, with higher grade ore along the footwall side, as shown by assays of stope samples (Table 1).

Table 1

Assays of Stope Samples

(from Nye, 1923)

	No. 11 Stope	Footwall Ore No.13 Stope
Ag	12.75 oz./ton	45.73 oz./ton
Pb	10.10 per cent	29.70 per cent
Zn	4.46 per cent	12.88 per cent

Over much of the Main Lode the galena was coarse-grained and was not intimately associated with the sphalerite, but occurred in bunches and veins, so that it could be concentrated by handpicking, into "firsts" and "seconds". In 1923 the "firsts" averaged 32 per cent lead and 53 oz. silver per ton. The "seconds" were subjected to gravity concentration, and yielded a concentrate assaying about 59 per cent lead and 91 oz. silver per ton. Zinc minerals were dumped with the tailings.

The ore from No.11 Stope, whose assay is cited in Table 1, is described as good grade "seconds", much above the average grade of the mine, which was about 4 per cent lead and 6 oz. silver per ton, with some of the poor grade "seconds" as low as 2 per cent lead and 3 oz. silver per ton.

The ore on the footwall side of the orebody (the Footwall Lode) differed in showing a pronounced banding, in the form of a repeating crustification. Photographs (Nye, 1923) show that the banded zone, which was 7 to 8 ft. wide in places, enclosed a central zone 2 to 3 ft. wide, showing prominent cockade textures.

The Back Lode comprised impersistent veins and patches of high grade set in a 3 to 5 ft. width of dolomite and dolomitized diabase. In the No.13-level stope coarse-grained galena and manganosiderite were present, showing banding, and resembling the ore in the Main Lode. Elsewhere, however, the galena was fine-grained. The massive fine-grained galena assayed up to 200 oz. silver per ton.

Mineral Composition

The mineralogy of the ores is relatively simple, and is similar in both the Main lode, including the Footwall lode, and in the Back lode, except that the Back lode ore tends to be distinctly richer in silver minerals (up to 200 oz. silver per ton). They consist essentially of sphalerite and galena, with lesser amounts of arsenopyrite, pyrite, boulangerite, pyrargyrite, tetrahedrite, and traces of chalcopyrite, together with an abundance of manganosiderite, contemporaneous with the sulphides, and an even greater abundance of ferrian dolomite (ankerite), deposited in the closing stages of mineralization. In addition, in places, there are many unreplaced fragments of country rock.

The sphalerite is jet-black in hand specimen, and contains about 8.95 per cent of iron (Table 2). Much of it appears homogenous, but a distinct proportion of it is closely studded with oriented micron size blades of chalcopyrite (Fig.19). These tend to be concentrated in the marginal parts of the sphalerite crystals, leaving the cores free of such inclusions, and some show partial segregation of the chalcopyrite into narrow discontinuous seams in the grain boundaries of the sphalerite crystals. The portions of the sphalerite studded with exsolution bodies show a weak, patchy anisotropism, resembling, but not as strong as, the anisotropism of similar sphalerite-chalcopyrite intergrowths in the Aberfoyle and Moina ores of Tasmania (Edwards and Lyon, 1957; Williams, 1958).

Much of the sphalerite is finely ramified with veinlets of carbonate, so much so that it is impossible to make a carbonate-free sphalerite concentrate. This is apparent from the analyses of Table 2, in which the total (Zn + Fe + Mn) falls considerably short of 67 per cent. In view of the fact that some of the iron reported in the analyses could be derived from the intergrown carbonate, the iron content of the sphalerite remains a little uncertain. The lowest value reported, 14.1 per cent FeS, seems the most reliable, the more so that in Analysis No.2 (14.3 per cent FeS), the sulphides total 97.9 per cent of the sample. This amount is equivalent to 12.8 mol. per cent FeS.

Table 2.

Composition of Magnet Sphalerite

	1.	2.	3.
Zn	51.64	55.58	50.84
Fe	8.89	8.92	8.40
Mn	0.25	0.66	-
Cu			-
Pb	0.16	-	-
S			30.34
Insol.	0.25	-	-
Calculated			
ZnS	84.2	84.6	85.9
FeS	15.3	14.3	14.1
MnS	0.5	1.1	

1. ~~x~~ Stope, No.15 level. Analyst.- A.W. Hounslow.
2. Footwall of South Stope, No.15 level. Analyst.- A.W. Hounslow.
3. Unstated locality, on or above No.14 level, (Nye, 1923, p.66).

The pyrargyrite and tetrahedrite accompany the galena, occurring chiefly as minute drop-like inclusions in it, presumably precipitated from solution solution in the galena. In some specimens the pyrargyrite and tetrahedrite occur side by side in the same galena crystals; in others only one of these two minerals is present.

In the tetrahedrite-rich galena there are, in addition to the numerous small drop-like inclusions (0.005 mm. to 0.010 mm. across), occasional much larger irregular areas of tetrahedrite, up to 0.75 mm. across. These contain a ramifying network of thin, more or less discontinuous, seams of galena, up to 0.002 mm. thick, and are possibly segregations of the "droplets". In some of these tetrahedrite bodies the galena seams are short and sicontinuous, and resemble sub-graphic intergrowths (Fig.20). In such specimens, also, areas (residuals) of sphalerite or pyrite, isolated in the galena, are commonly fringed with a concentration of tetrahedrite droplets (Fig.19); and a very small amount of tetrahedrite may be intergrown with the marginal sphalerite. No tetrahedrite has been observed, however, in the more massive sphalerite.

The pyrargyrite, also, occurs largely as minute inclusions, but the individual grains are commonly more anglular than those of tetrahedrite. They vary equally in size. In the more silver-rich specimens (200 oz. Ag per ton), a small but significiant amount of pyrargyrite occurs either independently of the galena, as veinlets in the manganosiderite and the sphalerite, or in composite galena-pyrargyrite-carbonate veinlets through the sphalerite. The pyrargyrite veinlets in the carbonate may be 2 to 3 mm. long and 0.02 mm. wide. Some appear as "ghost veins" - continuously aligned, but discontinuous vein fragments crossing several coarse crystals of later dolomite, with no obvious vein channel between the pyrargyrite sections (Fig.21). Such a "ghost vein", on encountering sphalerite becomes a definite vein of pyrargyrite and manganosiderite through the sphalerite (Fig.22). Its discontinuous form in the dolomite results from a replacement of the former "wall" minerals, and any manganosiderite in the vein, by dolomite. A little galena accompanies the pyraggyrite in some "ghost veins" (Fig.21).

In the better grade ore the chief gangue mineral is a buff-coloured manganosiderite. An analysis of cleaned material from the No.15 level, Main lode, is given in Table 3, No.1, together with an earlier analysis of manganosiderite from a higher level in the mine.

Table 3.

Manganosiderite from the Magnet Mine.

	1.	2.
$FeCO_3$	56.10	54.84
$MnCO_3$	33.15	29.32
$MgCO_3$	8.53	12.10
$CaCO_3$	1.27	3.70
Insol.	0.21	-
	99.26	99.98
Mn	15.8	13.2

1. Manganosiderite, intergrown with sphalerite, No.15 level, Main lode. Analyst.- A.W. Hounslow.
2. Manganosiderite from Main lode (Nye, 1923,p.68)

In the banded section of the ore the manganosiderite is about as abundant as the total sulphides, or more so, so that apart from a little manganese in the sphalerite, manganese as carbonate constitutes up to 10 per cent of these sections of the orebody. This abundance of manganese associated with an undoubtedly hydro- ...

thermal lead-zinc ore, and introduced at an early stage of mineralization, is of considerable interest, in view of the controversial ideas expressed elsewhere, concerning the origin of the manganiferous minerals in the Broken Hill lode.

Manganiferous carbonates occur also in several of the smaller silver-lead-zinc ores in the Magnet area, and in fact, are a feature of most of the lead-zinc ores in western Tasmania:- the manganiferous siderite of the silver-lead-zinc ores of Zeehan, Mount Farrell, and Round Hill; the less abundant rhodochrosite at Rosebery and Hercules. Late stage "pistomesite" occurs in the cassiterite-sulphide ores of Renison Bell and Mount Bischoff. Charlewood (1935) notes that siderite and manganosiderite are the carbonates characteristically associated with silver-lead-zinc veins.

In the closing stages of mineralization a white carbonate mineral was introduced, following upon localized shearing and brecciation of the previously deposited minerals. The white carbonate mineral filled the resulting fractures, replacing the earlier ore minerals (Figs. 5, 7, 8, 12) and the country rocks, both pyroxenite and diabase, in the walls and where they occurred as residuals in the ore (Figs. 9, 10).

On the hangingwall side of the Main lode this white carbonate formed a massive layer, several feet thick, separated from the orebody proper by a seam of soft "pug", up to 24 inches thick, with slickensiding on the face of this carbonate "wall". Further into the hangingwall the carbonate was more coarsely crystalline, with increasingly numerous rounded to sub-angular dark patches of partly replaced diabase porphyrite, until at about 10 ft. or more it gave place to the diabase or to the Back lode. The Back lode, itself, was invaded extensively by this late-stage carbonate.

The white carbonate, which stands out in contrast to the buff to biscuit-coloured manganosiderite, may be described variously as ferriferous dolomite, or as ankerite. An analysis of a cleaned sample from the hangingwall of the Main lode, on the No.15 level, gave the analysis shown in Table 4, No.1, where it may be compared with earlier analyses of this carbonate from higher levels.

Table 4

Composition of White Ferriferous Dolomite of Magnet Lode.

	1.	2.	3.
$CaCO_3$	54.90	56.64	54.60
$MgCO_3$	39.73	32.74	39.63
$FeCO_3$	4.86	8.26	6.74
$MnCO_3$	0.90	3.76	-
Insol.	0.49	-	-
	100.85	101.42	100.97

1. Ferriferous dolomite from the hangingwall, No.15 level, Main lode. Analyst.- A.W. Hounslow.

2, 3. Ferriferous dolomite from Main lode (Nye, 1923, p.69)

In places the dolomite was a bright green, the green colouration being due to a small amount of chromium derived from the replaced pyroxenite (Nye, 1923).

Quartz is a very minor gangue constituent, occuring as veinlets, some of them sheared, in the grain boundaries of the manganosiderite. Some of these veinlets carry a little galena.

Crustification Textures

Various Australian lead-zinc ores show banding, e.g. Rosebery, Tas. (Stillwell, 1934); Captain's Flat, N.S.W. (Edwards, 1943); and Mount Isa, Qld. (Grondijs and Schouten, 1937; O'Malley and McGhie, 1939), but crustification is rare. The Magnet ore, by contrast, displays beautiful crustification textures (Figs.5-11) in which all of the sulphide minerals, and particularly the galena, sphalerite and arsenopyrite, occur interlayered with manganosiderite. This crustification gave rise to prominently banded ore on the footwall side of the Main lode (the Footwall lode), where the ore was of highest grade, and in parts of the Back lode (Figs. 5-8). In parts of the Main lode it gave rise to equally striking cockade textures (Figs. 9-10).

These textures provide clear evidence of overlapping crystallization of the ore minerals and the manganosiderite. The sequence of deposition revealed in the specimen illustrated in Fig. 5 is:-

(1) sphalerite, (2) manganosiderite, (3) sphalerite, (4) galena, (5) manganosiderite, (6) galena, (7) manganosiderite, (8) galena, (9) sphalerite, (10) galena, (11) manganosiderite, (12) galena, (13) manganosiderite, (14) sphalerite, (15) manganosiderite, (16) galena, (17) manganosiderite, '18) galena, (19) manganosiderite, (20) galena, (21) manganosiderite, (22) galena; followed by fracturing and veining by white ferroferous dolomite.

These twenty two bands occur in a width of 6 inches, and represent an overlapping sequence of deposition of manganosiderite, sphalerite and galena, with the sphalerite beginning before the galena, and ceasing before it.

The specimen illustrated in Fig. 6 shows a sequence of deposition:-

(1) manganosiderite, (2) galena, (3) manganosiderite, (4) sphalerite, (5) manganosiderite, (6) sphalerite and galena, (7) manganosiderite, (8) sphalerite and galena, (9) manganosiderite, (10) sphalerite, (11) manganosiderite with isolated crystals of pyrite, (12) galena, (13) manganosiderite, (14) sphalerite, (15) galena with isolated crystal of pyrite.

Figure 7 shows some finely banded ore, in which sphalerite alternates with manganosiderite. The earliest sphalerite band contains a band about 1 mm. wide of fine-grained arsenopyrite crystals. Fractures cutting through the specimen have been filled with white dolomite.

Figure 8 shows a band of manganosiderite speckled in its lower part with galena and arsenopyrite crystals, between sphalerite bands above and below. Two fractures cutting the bands are filled with white dolomite, which appears to have displaced the fracture walls by a process of "vein growth".

In the specimen of cockade texture illustrated in Figs. 9 and 10, the sequence is simpler. The rock was originally a breccia of serpentinized pyroxenite, with fragments up to 10 cm. long and 1 to 5 cm. across, with open spaces between. These open spaces were invaded by the mineralizing solutions, and incompletely filled with coatings of manganosiderite, arsenopyrite and sphalerite. There seems also have been some replacement (solution) and rounding of the rock fragments.

The sequence of deposition involved an initial deposition of arsenopyrite and manganosiderite, apparent as a sequence of five bands of manganosiderite and four pencil-line thick bands of minute arsenopyrite crystals around the rock fragments on the right hand side of Figs. 9 and 10, followed by deposition of a composite narrow band of arsenopyrite encrusted by sphalerite, a broader band of manganosiderite, and an equally broad band of sphalerite (with isolated pyrite crystals), which filled some of the interstitial spaces between the rock fragments, but left unfilled cavities in others. Then followed a period of fracturing, which gave entry to white dolomite. The white dolomite filled the fractures and filled or partly filled the still interstices (Fig. 9). It also vigorously attacked and replaced the residual serpentinized pyroxenite fragments, particularly the long thin fragment in the centre of the specimen (Figs. 9 and 10).

The boulangerite also occurred in this crustiform association, as evidenced by a specimen from the No.6 level, consisting of a band about 2 cm. wide of galena and boulangerite enclosed by bands of manganosiderite above and below. The inner 5 mm. of the band is massive galena: then follows a 5 mm. band of interleaved galena and bladed crystals of boulangerite, grading upwards with decreasing proportions of galena into a band 5 to 10 mm. wide of coarse bladed prisms of boulangerite in a matrix of finergrained, almost fibrous boulangerite. The boulangerite (confirmed by x-ray powder pattern) tends to form acicular to radial growths inwards from the curved outer surface of the band, suggesting crystallization from an original gel condition.

The general picture of deposition revealed by such specimens is a relatively normal paragenesis - arsenopyrite, sphalerite, pyrite, galena and silver minerals, with considerable overlap, and continuous deposition of manganosiderite and a very little quartz.

As may be seen from Figs 5 to 10, the bands in the crustified ore have a finely "scalloped" form, all facing ~~outwards,~~ inwards away from the wall, that causes them to resemble colloform banding. Examination reveals that the manganosiderite bands are crystalline, the grain size of the individual crystals being relatively uniform within a given band, but varying from band to band. The crystals tend to be in parallel or radial groups with their long axes normal to the surfaces of the bands. Where the bands are narrow, the individual crystals extend from inner to outer surface of the band.

The narrower sulphide bands show a generally similar texture, and in places grade out into isolated crystals or groups of crystals marking the contact between two adjacent (successive) bands of manganosiderite. Isolated sphalerite crystals encrusting a pencil-thin band of arsenopyrite can be seen in the central parts of Figs. 9 and 10. A sulphide band is moulded on the outer crystal faces of the inner manganosiderite band, and vice versa; but the galena shows a tendency to send off minute "stringers" into fractures in individual sphalerite or manganosiderite crystals, and into their grain boundaries.

Shearing Textures

The ~~late-stage~~ shearing and brecciation that preceded the introduction of the white dolomite affected the galena and sphalerite very differently. The galena flowed in response to the shearing, forming elongated, and commonly, bent crystals (Fig. 11). Ultimately much of it recrystallized as fine-grained granular mosaics ("steel galena") in which, however, the pattern of the former parallel stretched crystals is preserved, and is apparent in the hand specimen. The grain size of some of the mosaics seems to have been determined by the grain size of former exsolution precipitates of pyrargyrite and tetrahedrite.

The sphalerite(and included fine-grained arsenopyrite) responded as a brittle substance, and was fractured and brecciated (Fig.12). Where the shearing was intense, and particularly where bands of sphalerite and galena were interleaved, the sphalerite became finely granulated. The galena invaded the fractures, and the granulated sphalerite was drawn out into lenses and strings of granules in the galena (Figs. 13, 14). Where the sphalerite occurred in more massive bands, the galena flowed into the fractures in the sphalerite, forming a texture that gives the impression that the galena was distinctly younger than the sphalerite.

In some bands of sphalerite, closely spaced parallel fracture cleavage developed. The manganosiderite tended to flow into, and fill, such fractures, but any left unfilled were filled by later white dolomite.

The invasion of the sphalerite by dolomite was preceded or accompanied by slight corrosion and replacement of the sphalerite with an accompanying deposition of a minor amount of pyrite as minute micron-size cubes, which formed fringes and seams around the individual fragments of sphalerite (Figs.15, 16). As the replacement of the sphalerite by dolomite progressed these pyrite fringes and seams became isolated in the widening seams of dolomite (Figs.15,16).

In the sheared galena the pyrargyrite exsolution bodies tend to a sub-parallel orientation as regards their lengths, aggregating into sub-parallel "strings" (Fig.17); and whereas in the unsheared ore the pyrargyrite is practically restricted to the galena bands, in the sheared ore it has got caught up to some extent in the lenses and "strings" of granulated sphalerite (Fig.18).

Late Stage Crustification

A proportion of the late-formed dolomite developed crustification textures comparable with those formed during the deposition of the sulphide minerals and the manganosiderite. Mostly they consist of successive scalloped bands or crusts of white dolomite, when they are most readily seen in weathered blocks on the dumps. Locally they take the form of cockade textures, composed of successive encrustations of dolomite about fragments, up to several inches across, of sheared and recrystallized galena bands, shattered sphalerite bands, and pieces of rock. Small vughs mark incompletely infilled interstices between some of the individual cockades.

In some of the cockade textures the ore and rock fragments are isolated in the dolomite and do not touch at any point. Either they were partly replaced by the encrusting dolomite, or more probably they became separated by the forces exerted by the growing dolomite crystals, as happened also with some of the brecciated ore, in the same way as brecciated slate fragments became separated by quartz in the Bendigo quartz veins (Stillwell, 1918). The author has observed a similar displacement of fragments of coal by the growth of calcite veins in coal seams.

Conditions of Deposition

The mode of occurrence of the Magnet ore leaves no doubt that it is epigenetic and of hydrothermal origin; and its crustification textures, particularly the cockade textures, leave no doubt that it was, in part at least, deposited in open spaces. Its deposition was accompanied by variable, and in places significant, replacement of the pyroxenite and diabase during the deposition of the sulphide minerals and the manganosiderite, with rather more intense replacement of these rocks, and also of the ore minerals and manganosiderite, during the stage of dolomite deposition.

On the basis of Kullerud's (1953) observations, the iron content of the sphalerite (Table 2) sets a minimum temperature of about 400°C for the deposition of the sulphide minerals and the manganosiderite, when allowance is made for a confining pressure during deposition of about 400 atm. The preservation of chalcopyrite precipitated from solid solution and showing slight aegregation in the sphalerite points to deposition at about 400°C. Evidence provided by heat treatment experiments in progress on galena-pyrargyrite and galena-tetrahedrite exsolution intergrowths from the Mount Farrell lead-silver ores of western Tasmania, indicates that unmixing of these minerals from solid solution in galena occurs at above 400°C (probably about 425°C).

The depth at which deposition occurred cannot be determined with precision, but the aggregation of topazized quartz porphyry dykes at Mount Bischoff, only 4 miles distant, and the occurrence of small unroofed granite intrusions 3 to 4 miles both to the east and west of the zone of lead-zinc mineralization, suggests that the lead-zinc ores lie in a trough in the roof of a partially unroofed granite batholith. This suggests that deposition occurred at a depth of about 5000 ft. (1500 metres).

The relation of the lead-zinc ore to the granite is not proved, but both/are post-Silurian; and the tin lodes at Mount Bischoff and Cleveland include sulphide-rich veins containing some galena and sphalerite.

It seems probable, therefore, that the ore-forming solutions were in the fluid state, at least during the period of sulphide deposition. The alternating deposition of manganosiderite, sphalerite and galena presumably arose from the repeated, but independent, development of supersaturation of the mineralizing fluids with these three substances in particular, each development of supersaturation leading to renewed precipitation of the substance concerned (Shaub, 1934). The scalloped form of the banding suggests that the minerals may have deposited as gels, and subsequently crystallized.

The metamorphic textures in the ore must be attributed to renewed local movements along the fault or shear planes that gave entry to the ore solutions; and not to any general metamorphic effects, because the Silurian sediments which have suffered mineralization are in an unmetamorphosed state, as are the granites. The fact that so much of the ore has been affected by these shearing movements suggests that in the absence of the unusual crustification textures a wrong impression could be obtained of the manner of origin of the deposit.

Acknowledgements

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279

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List of Illustrations

Fig. 9. Cockade texture in crustified ore from Magnet, developed about fragments of brecciated (and serpentinized) pyroxenite with some rounding by replacement of the rock fragments. The crustification results from alternating deposition of manganosiderite, arsenopyrite, and sphalerite, and is described in detail in the text.

Later fracturing let in white dolomite, which filled residual open spaces in the interstices of the breccia, and selectively replaced the rock fragments in the cores of the cockades. X 1.

Fig. 10. Cockade structure, similar to Fig.9.

Fig. 11. Crustified ore that has been sheared, with brecciation and granulation of the sphalerite bands (dark), and stretching and flowage of the galena bands (white). The galena eventually recrystallized as "steel galena". X 1.

Fig. 12. Sphalerite (black) brecciated, and veined by white dolomite. X 1.

Fig. 13. Finely granulated sphalerite (grey) drawn out into lens and strings by the flowage of the enclosing galena (white) which was stretched, and then recrystallized as a mosaic of fine equi-granular crystals. X 30.

Fig. 14. Finely granulated sphalerite (grey) drawn out into strings parallel to the flow direction of the stretched and finely recrystallized galena (white). The black areas are gangue or pits. X 30.

Fig. 15. Brecciated sphalerite (medium grey) invaded by dolomite carbonate (dark grey). Rims of fine-grained pyrite (white) have formed on the surfaces, and along fractures in the sphalerite, or form central bands in the carbonate - possibly as residuals left when the adjacent sphalerite was dissolved by the carbonate.

Lower left is a cluster of arsenopyrite crystals, originally enclosed in sphalerite, now partly enclosed by carbonate. X 30.

Fig. 16. Area of brecciated sphalerite (dark grey), with strings of fine-grained pyrite crystals (white) fringing the sphalerite or isolated in later carbonate (black) which has replaced the sphalerite.

In the top left corner is a cluster of arsenopyrite crystals (white) enclosed by sphalerite (dark grey) and by galena (light grey). The galena has to some extent replaced sphalerite. X 30.

Fig. 17. Sub-parallel "strings" of pyrargyrite grains (medium grey) in stretched and recrystallized galena (light grey). The black areas are pits and gangue.

X 100.

Fig. 18. Finely granulated sphalerite (dark grey) and gangue (black), drawn out into strings, and enwrapping a grain of pyrargyrite (light grey; in central) a matrix of stretched and recrystallized galena (white). X 100.

Fig. 19. Area of sphalerite (black), studded with minute blades of chalcopyrite, which have partially segregated into grain boundaries in the sphalerite, as small bodies associated with small bodies of galena. Larger bodies of tetrahedrite (medium grey) are moulded on the sphalerite, and are enclosed by massive, recrystallized galena.

Oil immersion, X 750.

Fig. 20. Segregated ex-solution tetrahedrite (grey) in galena (white), with entrapped galena in the grain boundaries of individual tetrahedrite grains. The black patches are gangue. Oil immersion X 750.

Fig. 21. "Ghost vein" of pyrargyrite (white), in coarsely crystalline dolomite (grey), which shows no vein structure. The "vein" can be traced for about 1 cm. across the polished section by the linear distribution of pyrargyrite particles, into a fracture in sphalerite, which is filled by a vein of pyrargyrite associated with manganosiderite (Fig.). A little galena accompanies the pyrargyrite, along its margin.

X 30.

Fig. 22. Composite veinlet of pyrargyrite (light grey) and manganosiderite (dark grey) through fractured sphalerite (medium grey).

X 30.

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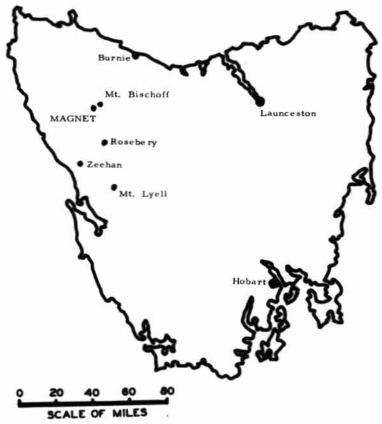
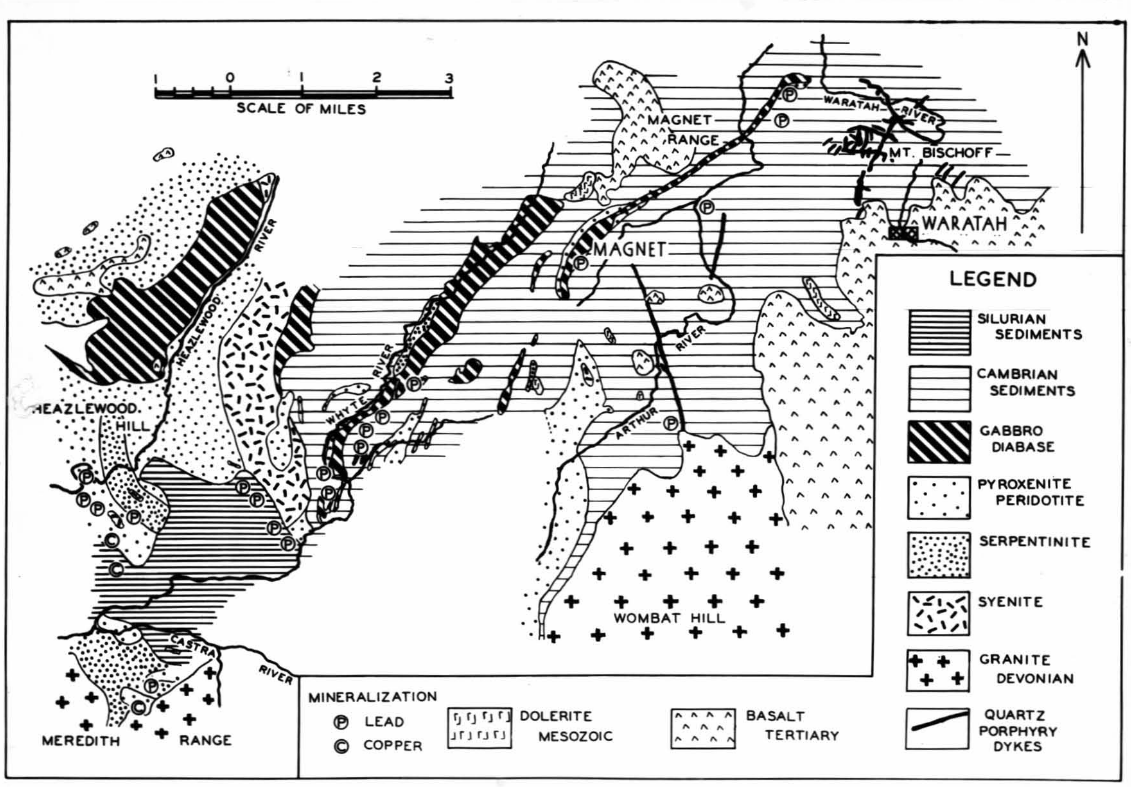


FIG.1

5 cm

FIG.2



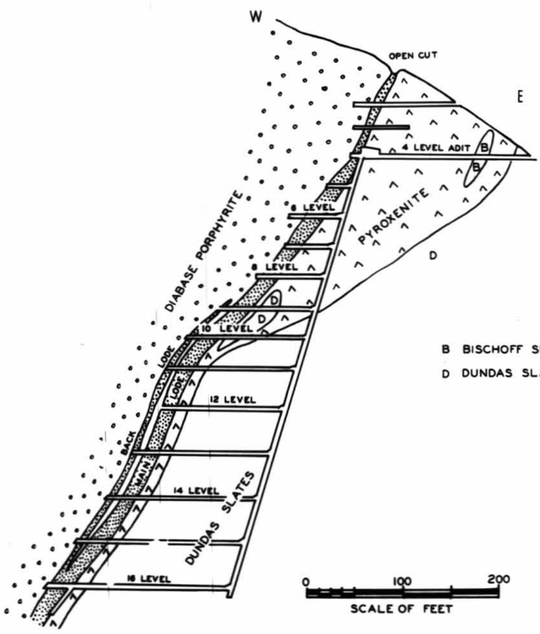


FIG. 3

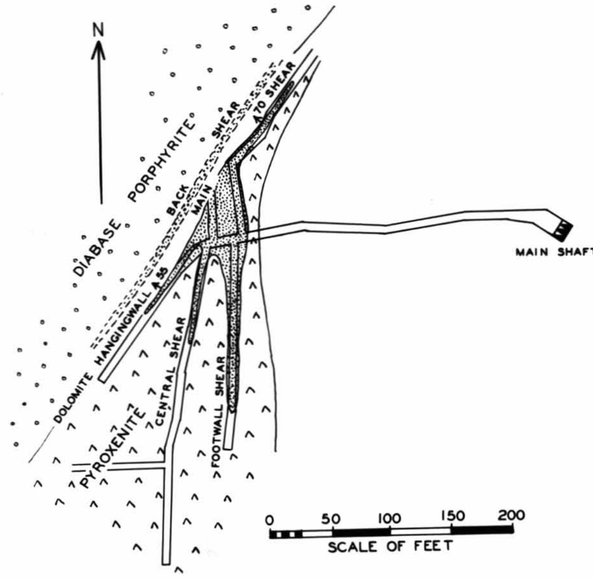


FIG. 4

5 cm

FIG. 5

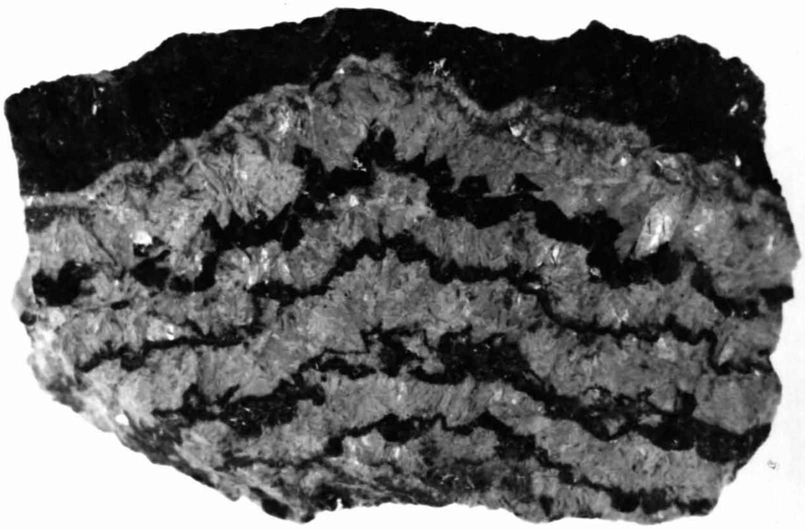


FIG. 6.

FIG. 7.

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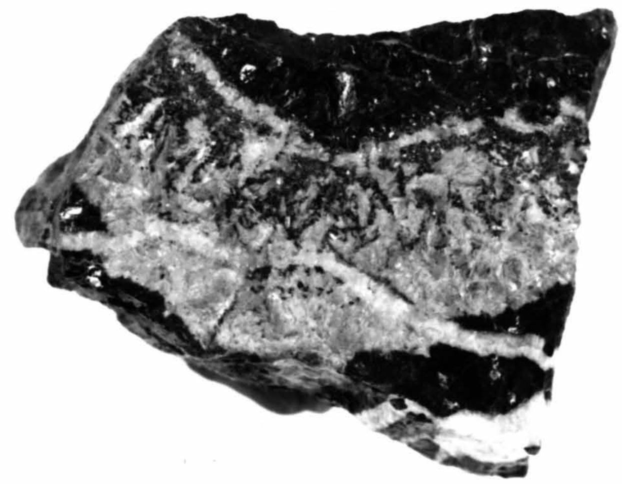

FIG. 8

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FIG. 9

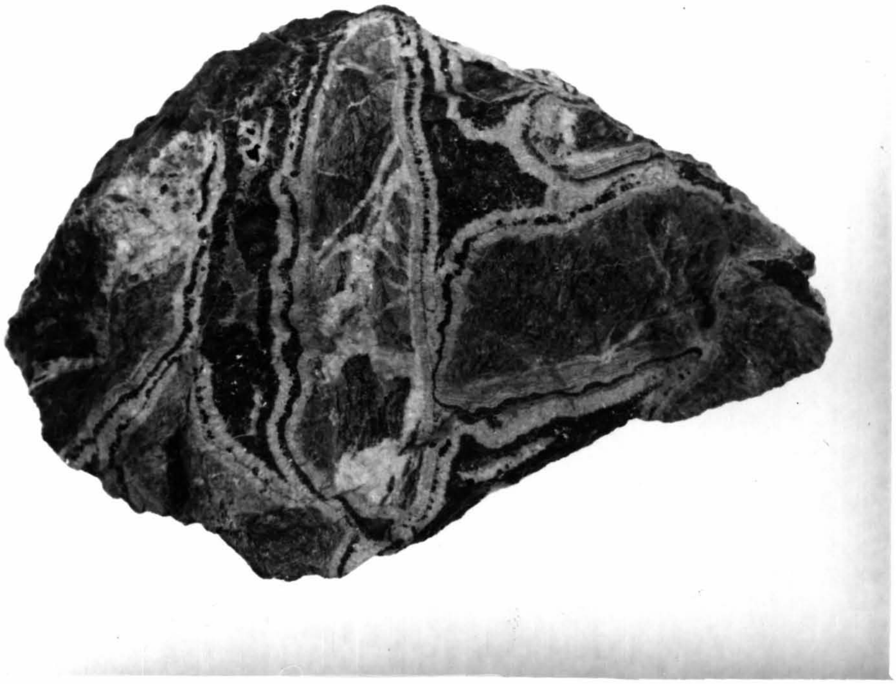


FIG. 10

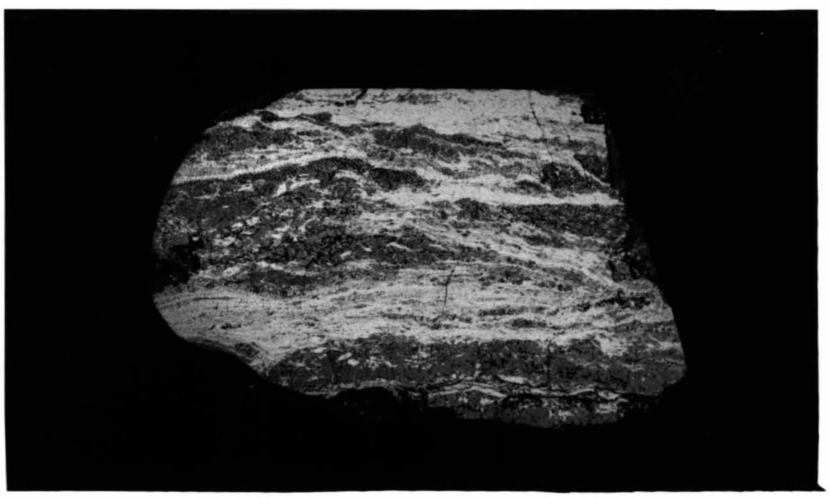


FIG. 11

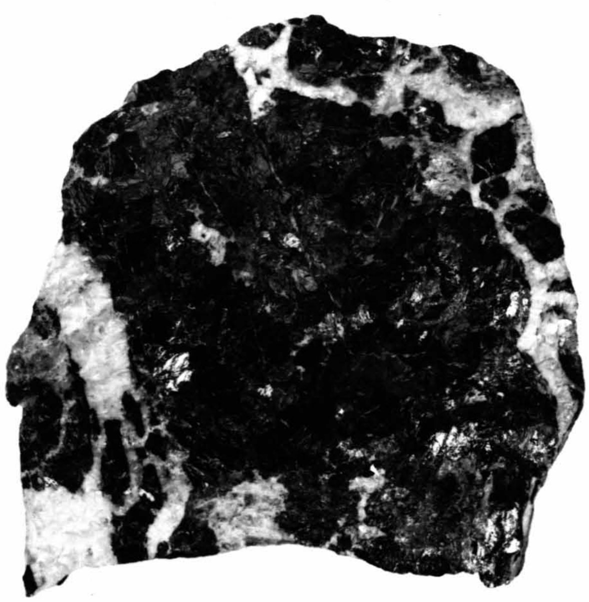


FIG. 12

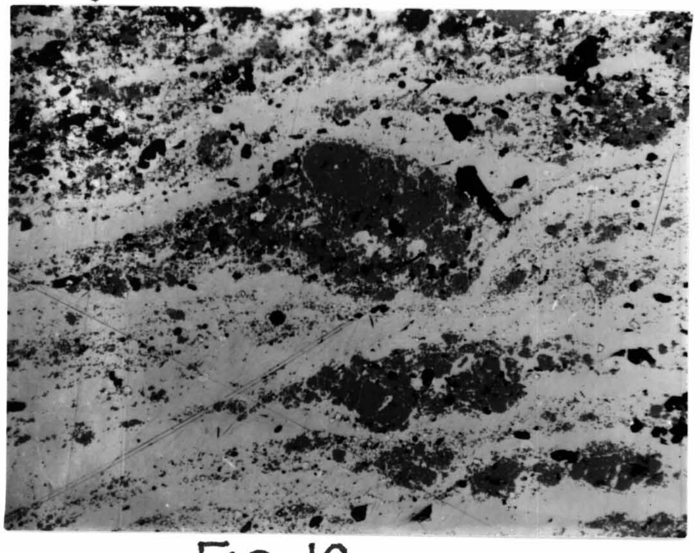


FIG. 13

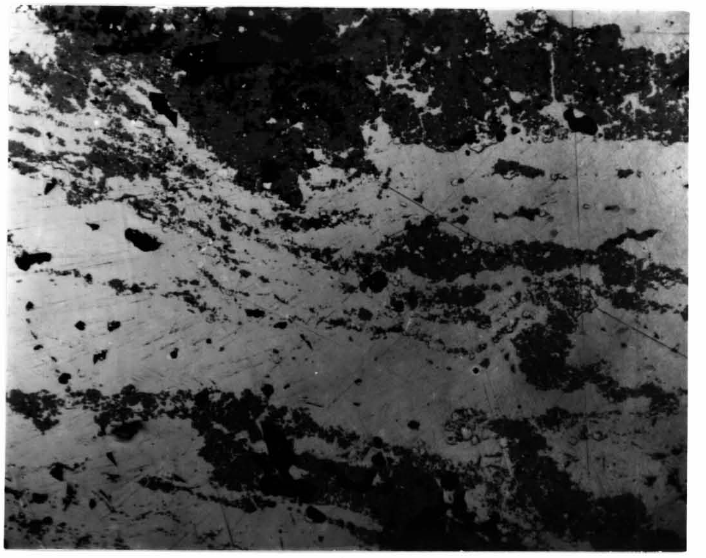


FIG. 14

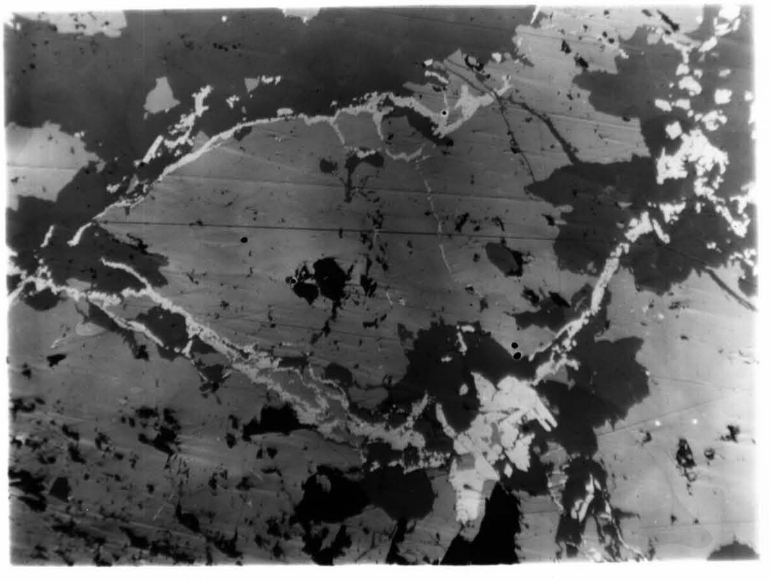
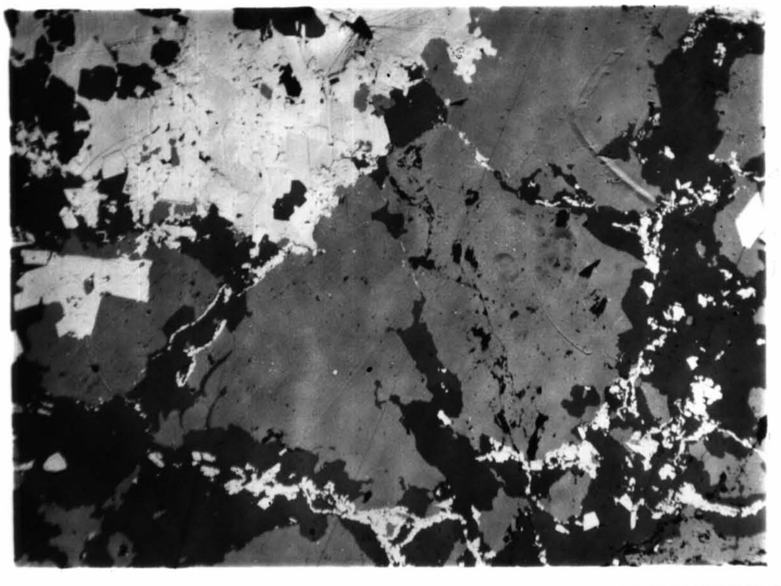


FIG. 15

FIG. 16



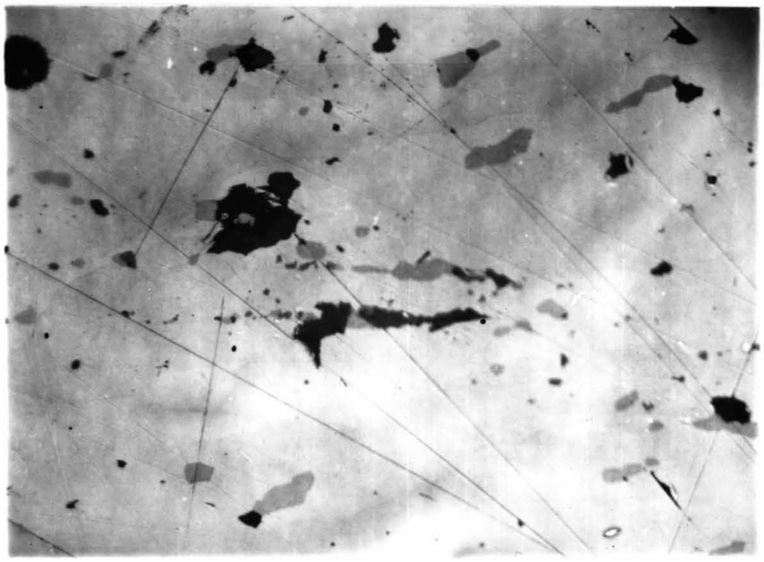


FIG. 17

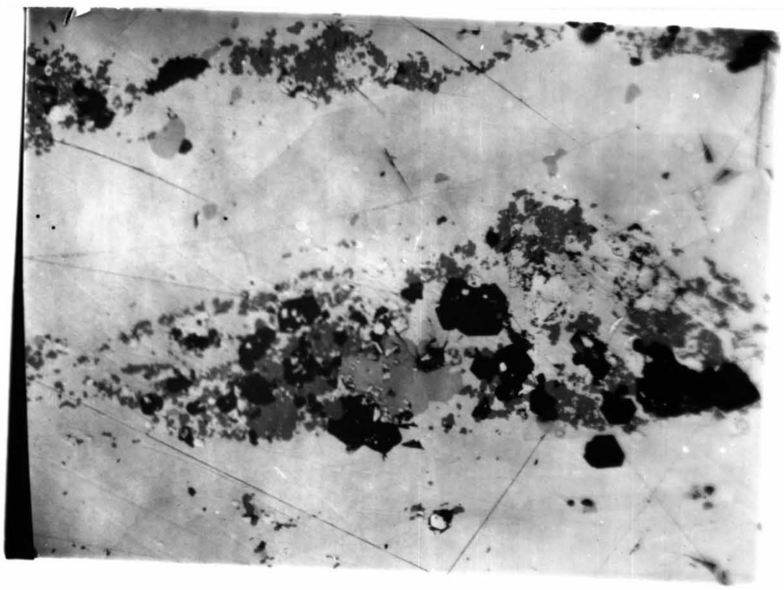
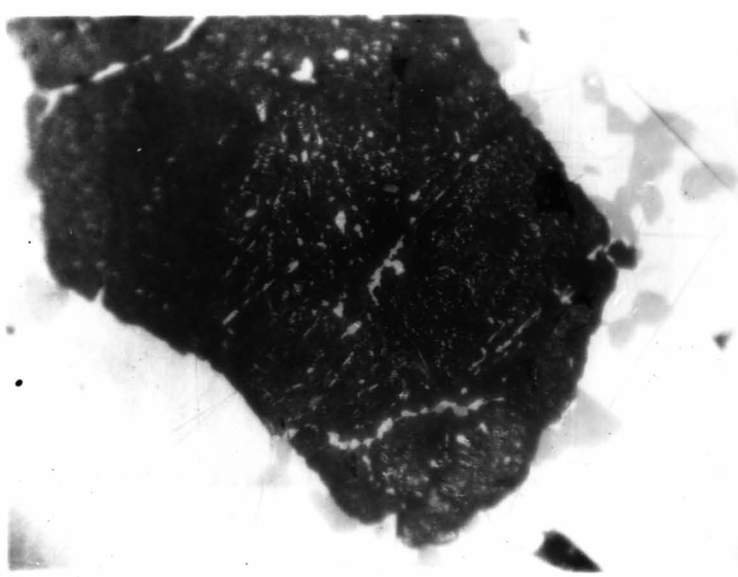


FIG. 18



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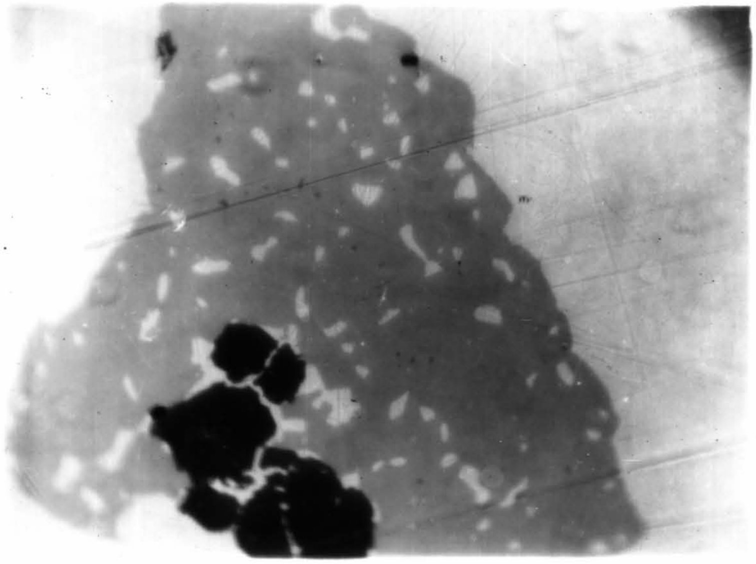

FIG. 20

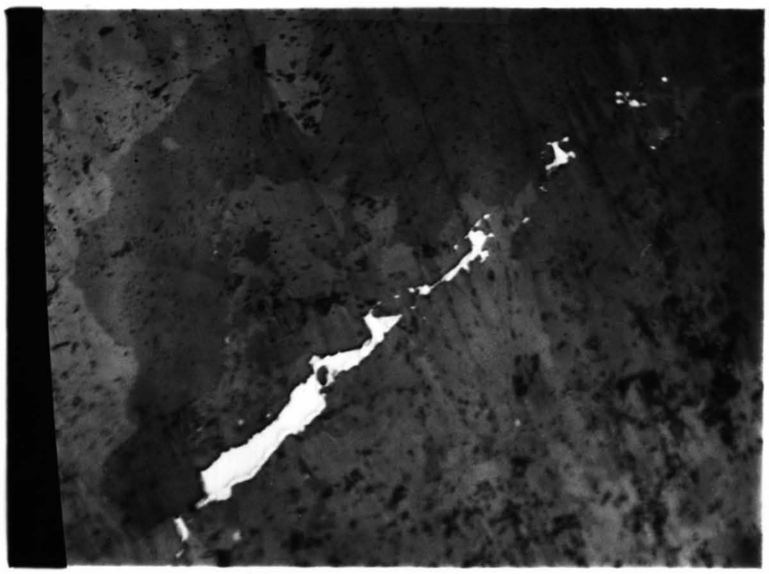

FIG. 21

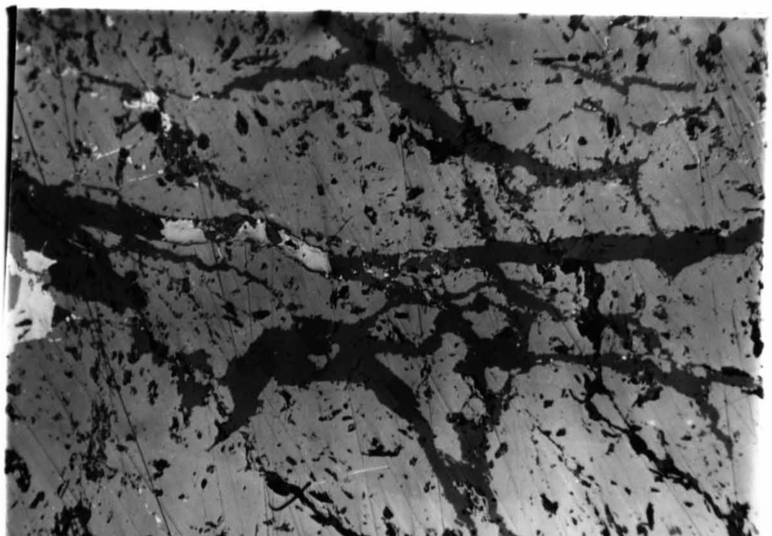

FIG. 22