

A MINERALOGICAL INVESTIGATION OF THE  
LETABA COPPER-ZINC ORES AND THE  
MONARCH CINNABAR DEPOSITS LOCATED IN THE  
MURCHISON RANGE OF THE EASTERN TRANSVAAL

By

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## PART I: THE COPPER-ZINC DEPOSITS

### 1. INTRODUCTION

In the year 1869 Dutton and Sutherland prospected the Transvaal low country near the Olifants River, and reported that they had crossed a range of hills composed of metamorphic rocks striking W.S.W. to E.N.E. In the stream draining the area they found traces of alluvial gold. Further to the south they encountered natives working copper in hills of porphyritic granite but were not allowed to visit the actual workings.

In June, 1870, travelling from Lydenburg, they returned to the low country and after crossing the "Selate River" (Selati) reached their destination. Being of the opinion that the range held great promise, they named it the Murchison Range in honour of Sir. R.I. Murchison, a British Geologist who had shortly before predicted that the Limpopo country would prove to be auriferous. (Shinas 1877)

This account is probably the earliest recorded visit of any European to this area.

### 2. ACTIVITIES OF THE ANCIENT MINING TRIBES

From the writings of Stanley (1910), Trevor (1912), Schwellnus (1937) and the investigations of Wagner (Wagner file kept in the office of the Archaeological Survey, University of the Witwatersrand) it is certain that an ancient tribe was very much concerned with the mining of copper in the Northern Transvaal and in Northern Rhodesia.

Further evidence is the large extent of the ancient workings at both Messina and Phalaborwa. Small ancient workings were also found on the copper-zinc deposits of the Murchison Range, being only some fifteen miles north of Phalaborwa. Wagner's map (unpublished map kept in the museum of the Archaeological Survey, University of the Witwatersrand) showing the location of ancient copper workings in Southern Africa notes the occurrence at Solomon's Mine which falls within the schist belt of the Murchison Range.

The art of metallurgy was not new to these people, for in the Rooiberg area they mined tin which was smelted with copper to make bronze. It is possible that they used the zinc to produce a type of brass.

Who these ancient miners were and where they came from has not been established with any certainty. Their activities are assumed to date back to a period prior to the Bantu we know today.

From the extent of the old copper workings at Messina and Phalaborwa it is inferred that several thousand tons of copper were produced. Of this amount extremely little was found by early Europeans to be in possession of the Bantu. From this it must be concluded that the old miners took their copper back to their homeland or to other countries.

### 3. EARLY LITERATURE ON THE MURCHISON RANGE

The first available mineral and geological publication about the Murchison Range was written by A.R. Sawyer in 1892. It was based on some two years work in the area as manager of a gold mining company.

His view was that the Range is composed of various crystalline and metamorphosed rocks of great age which had been folded and, in places, tilted up from 60° to 90°. He mentions the presence of copper in some reefs but does not report on either the zinc or the cinnabar deposits.

Ever since the discovery of gold in 1870 the Range attracted the attention of more people associated with mining.

In 1895 Wilson-More read a paper on the "Importance of the Murchison Range" before a meeting of the Geological Society.

To him can be credited the discovery of the cinnabar deposit, about which he wrote as follows :-

"The mercuriferous ore so far found is cinnabar. It occurs in two places neither of which have been submitted to development operations of any magnitude. The one is far east on the 'Langweberg' in quartzite sandstone abutting on porphyrite and the other is to the north of Witkopjes". Unfortunately, there is no map with this paper so the exact location of the occurrences are difficult to establish with any certainty. Sawyer has not recorded the position of the "Langweberg" on his map, so the writer assumes that the name refers to a range of hills near Monarch Kop, (See Map No. 2) where the deposit investigated in this thesis occurs. The "Witkopjes" are shown on Sawyer's map to be situated out to the far east of the Range, but this occurrence has as yet not been substantiated.

Subsequent to the work of these early pioneers the geology of the Murchison Range has been described by Hall (1912), and van Eden (et al, 1939) mapped the area and described the mineral deposits found in the Range.

#### 4. REGIONAL GEOLOGY AND STRUCTURE

The Murchison Range is situated in the North Eastern Transvaal lowveld where it stretches from the Drakensberg escarpment in the west to the Kruger National Park in the east, a distance of some fifty miles.

##### a) General Stratigraphy

van Eden (et al, 1939) have mapped the area and subdivided the rock types encountered in the Murchison Range as listed below:-

		Sand and Alluvium
		Banded ironstone
		Carbonate-rich rocks
		Serpentines
Swaziland System	No.1 Division	Rocks above No. 2 division: Slates and various unclassified rocks some of which are lavas. Carbonates are very prominent in these rocks.
	No.2 Division	Quartzites grits and schists, bands of green carbonate rocks are prominent along the quartzite horizons. Bands of crushed conglomerate with perhaps sheared conglomerate.
	No.3 Division	Rocks below No. 2 division and rocks of unknown stratigraphical position. Schists of varying composition massive hornblende rocks etc. Sheared quartz porphyries micaceous schists of volcanic origin and hornblende rocks.
		Karoo Dolerite
		Diabase of pre-Karoo age
		Old Granite intrusive into the Swaziland system and Rooiwater igneous complex.
Rooiwater Igneous Complex intrusive into Swaziland rocks		Hornblende granite Rooiwater basic rocks Magnetite bands.

The accuracy of the sub-division of the rocks of the Swaziland system as they occur in the Murchison Range depends largely on the correct interpretation of their structure. van Eden (1939) believes his interpretation to be correct as far as the essentials are concerned, but he states, "Naturally generalizations had to be resorted to in separating the middle group from the lower and upper groups - especially so in the eastern portion of the schist belt".

The rocks of the Murchison Range are considered to be old sediments and quartz porphyries which were intruded by hornblende granites and basic rocks belonging to the Rooiwater igneous complex. This assemblage was then intruded by the older granite of the Nelspruit type (Hall, 1912, van Eden, et al, 1939).

According to van Eden, (et al, 1939), the intrusive relationship between the Nelspruit granite and the rocks of the Murchison Range was established beyond doubt. Contemporaneous with the development of this granite, metamorphism, contact and dynamic affected the rocks of the Murchison Range area. This has resulted in the formation of quartzites and a variety of rocks of a highly schistose character.

The result of a more recent investigation of the older granites in the Barberton area is that the Nelspruit granite is no longer considered to have consolidated from a normal primary granitic magma. Visser (et al, 1956) considers this granite to represent a product or a series of products of a process or a series of processes generally known as granitization. The intrusive features of the Nelspruit granite observed by earlier workers are considered to have resulted from the local mobilization subsequent to its formation by processes of granitization.

Although the origin of many granite bodies is still somewhat controversial, and this may also apply to the "Old Granite" of the Murchison Range area, nevertheless it is regarded as the source of the hydrothermal solutions which were responsible for the mineralization in that area.

Basic igneous intrusions are common in the schists and have a general strike of N. 40° E. (refer Map No. 2.) Those associated with the ore bodies at the Letaba mine are very altered and are probably older than the Karroo dolerites encountered in the granite surrounding the Murchison Range schist belt. The basic dikes encountered at the Mashava occurrence are probably of Karroo age.

#### b) Structure

The average strike of the rocks is N. 65° E and the general dip is from 60° - 90° to the north, although in some areas the dip is to the south due to the overturning of isoclinal folds. The schist belt attains a maximum width of about six miles near Gravelotte and then decreases gradually towards the east.

The foliation or flow cleavage of the schists developed during the metamorphism is generally parallel to the strike of the beds. Mendelsohn (1938, p 257) states, "Since the direction of flow cleavage



may be regarded as parallel to the direction of maximum strain (east of north-east), the flow cleavage was developed during the action of either a non-rotational stress acting approximately from north to south, or to a rotational stress acting as a couple from some other direction." As a result of the stressed zones of shearing were developed which acted as channel ways for the hydrothermal solutions responsible for the mineralization. The dominant direction of these zones of shearing was parallel to the strike of the schists.

### 5. THE COPPER - ZINC DEPOSITS

In the Marolison Range there are known to exist three occurrences of copper-zinc mineralization. These are indicated on Map No. 1 on the farms (a) Solomon Mine; (b) Platveld and Vlaklaagte; and (c) Mashava.

As it was not possible to obtain fresh samples from (a) only the ore from (b) and (c) was investigated.

By far the major occurrence is that at (b) which is known as the Lotaba Copper and Zinc Mine. It is located 1.8 miles north of the Malati Post Office, just north of the Castle Koppies range of hills.

The Lotaba Copper and Zinc Mine is at present under water, so it was not possible to carry out any systematic underground mapping of the deposit or collection of samples.

In 1955 the owners of the property de-watered the Mine and mined several tons of ore from the 450 foot level. This ore was placed in sealed metal drums to prevent oxidation. It is from some of these drums that fresh samples of ore were obtained. Samples of unoxidized ore were also selected from the dumps of No. 1 and No. 2 shafts, and are assumed to have been mined from the South and North Reefs respectively.

On the occurrence at Mashava there is a small inclined shaft on reef down to a vertical depth of 200 feet. At this point fresh samples of ore and wall rock were obtained. Samples of ore and wall rock were also obtained from the core recovered during a recent drilling program carried out to investigate this property.

## 6. RESULTS OF MINE GEOLOGY

### (I) The Letaba Copper and Zinc Mine

This deposit occurs in highly sheared quartz-mica and quartz-chlorite schists belonging to the No. 3 division of the Murchison Range succession as mapped by van Eden, (et al, 1939).

The ore deposit consists of two parallel lodes about 450 ft. apart and are known as the North Reef and South Reef, with a proved strike length of 2200 ft. and 3500 ft. respectively. The average strike of the rocks in the mine is fairly constant and is N.70° E. The dip varies from vertical to 80° N. The average width of the ore lodes is 33 inches, but may vary from 8 inches to 127 inches. Dip and strike of the lode conforms to that of the enclosing country rocks.

Associated with the ore samples there was sufficient wall rock in the specimens obtained to enable the determination of the grade of metamorphism of the associated rock and the type of gangue associated with the ore.

Macroscopically the wall rock associated with the ore is a fine-grained green rock with a well pronounced schistosity. Occasionally 'eyes' of quartz up to half inch long are present; their direction of elongation is parallel to the schistosity.

Other rock types encountered from samples collected on the dump are, a fine-grained white quartz-muscovite schist, and a dark coloured quartz schist containing porphyroblasts of sodic plagioclase feldspar, and a chloritoid-quartz schist.

### (A) Petrological features of the rocks associated with the ore.

From a study of several thin sections it was found that the common wall rock is a quartz-rich schist containing variable amounts of chlorite, minute sericite needles, chloritoid or muscovite. The quartz grains have invariably been recrystallized due to dynamic stress, as the grains are elongated parallel to the schistosity. In some instances the quartz grains have been bent so as to align themselves with minor folds and crenulations in the schists. Refer photograph No. 1. Wavy extinction of the minerals due to stress is a common feature.

#### (a) The Quartz-Mica Schist

This rock is composed of fine to medium grained quartz, generally recrystallized, which makes up the major portion of the slide. Medium grained flakes of muscovite are the second major constituent. Plagioclase feldspar, if present, is a minor constituent and its composition varies

between that of albite and oligoclase. Numerous apatite needles are present as an accessory mineral. In some instances chloritoid was present in small amounts.

(b) The Quartz-Chlorite Schist

In this rock the quartz is again the major constituent, and occurs as described above. The dark mineral is chlorite. This is a strongly pleochroic variety; from pale green to dark green, with maximum absorption when the  $\gamma$  direction is parallel to the vibration direction of the polarizer. The birefringence as determined with a Berek Compensator was  $(\delta - \alpha) = 0.0091$ . This is Pennine with composition  $Mg(Al, Fe)(OH)_8(Al, Si)_4O_{10}$ .

Apatite is a common accessory while nodic plagioclase feldspar is occasionally present as anhedral grains, with sericite needles as an alteration product.

Generally both the above rock types were found to contain varying amounts of chloritoid, although it was not always present.

A chloritoid-quartz schist containing many rutile needles is also present. This is not a common rock type in the mine suite.

In addition to the features described above for the main rock types, most of the rock types contain additional minerals as described below.

Small flakes of biotite were sometimes present. It was not possible to establish with certainty whether the biotite had been formed from the chlorite, as a product of metamorphism, or whether the small flakes were relics of the hydrothermal alteration of biotite to green chlorite. The latter explanation is favoured by the writer. The chlorite which had the composition of pennine was found as complete pseudomorphs of chlorite after biotite. This chlorite had a very low ultra blue interference colour, and Schwartz (1936) regards this type of chlorite as having formed as the result of hydrothermal alteration of biotite.

In two sections of quartz-chlorite schist were found short prismatic crystals — pale brown to olive green in colour — and strongly pleochroic. This was identified as the iron-rich tourmaline known as schorlito.

In a few sections there are small concentrations as well as small veinlets of calcite. In these sections it was not uncommon to find minor concentrations of epidote as well.

The quartz schist mentioned above is a rock composed essentially of irregular quartz grains with an average size of 0.04 m.m. and contains porphyroblasts of both quartz and feldspar. In between the quartz grains there are present small amounts of sericite needles, small green chlorite laths, and a few calcite grains with an average size of 0.11 m.m.

The quartz porphyroblasts vary in size from 1.70 m.m. to 0.20 m.m. and have an average size of 0.90 m.m. The feldspar porphyroblasts vary in size from 0.45 m.m. to 1.29 m.m. and have an average size of 0.83 m.m.

The feldspar present is a plagioclase, usually an albite containing from 5 to 7% anorthite. It has a  $2V_x$  of  $80 - 82^\circ$  and is twinned according to the albite law.

A basic dike is known to cut through the eastern section of the underground workings. This dike has an ophitic texture and is composed essentially of calcic plagioclase laths and hornblende. The plagioclase is labradorite which has been partially altered to sericite. The hornblende has been almost completely altered to chlorite.

This dike is considered to be a diabase of pre-Karoo age. This agrees with the findings of van Eken (et al, 1939) who states that there were basic intrusions into the rocks of the Murchison Range of both diabase and Karoo dolerites.

#### (B) The Metamorphism

The mineral composition of the schists indicates that they were formed under conditions of low grade metamorphism. The complete lack of amphiboles and the minor distribution of epidote indicates a grade of regional metamorphism equivalent to the low temperature portion of the green schist facies as introduced by Eskola (1921). These rocks could then have recrystallized at a comparatively low temperature, accompanied by a relatively high shearing stress, which was responsible for the elongation of the quartz grains and the development of pressure effects resulting in undulating extinction.

In the small area examined, no evidence of contact metamorphism was noticed. It would appear that the mine is situated outside the aureole of contact metamorphism produced by the development of the Nelspruit granite.

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(II) THE DEPOSIT ON THE FARM MASAWA

This occurrence is situated approximately 1.4 miles north of the main Gravelotte-Game Reserve road, on the farm Masawa 470.

The ore occurs in quartz-chlorite schists dipping at  $60^{\circ}$  to  $65^{\circ}$  to the S.E. and striking N.  $27^{\circ}$  E, which is a large deviation from the general strike of the rocks of the Range. These rocks have been classified as belonging to the No. 2 division of the Murchison Range. (van Eien, et al, 1939)

The ore deposit proved is smaller than the Letaba deposit. The only development consists of an incline to the 200 ft. level and a short winze on reef.

Five inclined boreholes were drilled in a line parallel to the strike of the lode, but failed to intersect any ore body.

Both in the hand specimens collected from underground and microscopic sections prepared from them, there appears to be very little difference between the wall rock and gangue on this property and that of the Letaba Mine. However, the composition of the rocks intersected in the deep boreholes is somewhat different.

(A) Petrological features of the rocks associated with the ore.

The wall rock is a quartz-chlorite schist but has a higher calcite content than the wall rock from the Letaba Mine. Epidote is a common accessory mineral. With an increase in depth the epidote content increases so that at a vertical depth of 500 ft. the epidote constitutes approximately 60% of the rock. The epidote is present as long needles aligned parallel to the schistosity. The average length and breadth of the needles is 0.18 m.m. by 0.03 m.m. respectively. A small proportion of the grains of epidote are equidimensional in habit, and vary in grain size from 0.20 m.m. to 0.30 m.m. The epidote is colourless to light grey in colour and shows no pleochroism. It has a high relief, a strong birefringence namely  $(\gamma - \alpha) = 0.04$  and is biaxial negative with a  $2V_{\alpha} = 79^{\circ}$ . According to data provided by Winchell (1933) this is an epidote which contains 25 molecular percent of  $H Ca_2 Fe_2 Si_3 E_{13}$ .

Quartz is the other main constituent of this rock. It makes up about 10% by volume and occurs as small grains with an average size of 0.03 m.m. These grains tend to be elongated parallel to the schistosity. Accessory minerals are green chlorite and sericite.

The rock is considered to be an epidote - quartz schist and is illustrated in photograph No. 2.

In this particular area there have been intrusions of acid igneous dikes. These dikes appear to have exercised a structural control on the ore body. Thus it is considered that the intrusion of these acid dikes occurred prior to the period of copper-zinc emplacement.

The acid igneous rocks are composed essentially of quartz and feldspar. Minor amounts of chlorite and garnet are also present. The quartz grains vary in size from 0.20 m.m. to 0.78 m.m. and have an average size of 0.44 m.m. Generally the feldspar present is an albite containing 5% anorthite. It is biaxial positive with  $2Vx = 79^{\circ}$ . The grain size varies from 0.24 m.m. to 0.74 m.m. and the average size is 0.50 m.m.

This rock has an allotriomorphic texture and is considered to be an aplite.

In a thin section cut from a specimen of wall rock at a vertical depth of 350 feet close to a major aplite dike, the predominating dark mineral was hornblende, and chlorite was present in minor amounts. Epidote was still abundant and garnet was also present. Possibly the aplite dike was responsible for the increase in grade of metamorphism in the immediate vicinity to the amphibolite facies. In another borehole a similar rock type without garnet was encountered at a depth of 290 feet. These rocks would belong to the epidote-amphibolite facies.

Numerous basic dikes have intruded this area and are probably of Karroo age.

#### (b) The Metamorphism

The rocks of this area also show evidence of having been subjected to dynamic metamorphism. The ubiquitous content of epidote is regarded as being indicative of a higher grade of metamorphism, which increases with depth. The temperature is regarded as being towards the upper half of the green schist facies, but not in the epidote-amphibolite facies.

The localized increase in metamorphic grade, noted in two boreholes about 570 feet apart on surface, may be attributed to the intrusion of the acid igneous rocks in that area.

The quartz shows recrystallization and a wavy extinction due to the effects of pressure to which it was subjected.

#### (c) Structure

The strike of the ore body is  $N.27^{\circ} E.$  which represents a swing of some  $38^{\circ}$  to the north from the general strike prevailing on the Range.

From the geology of the Murchison Range shown on Map No. 2 it can be seen that the schists of the No. 2 division have been drawn out to the north and the hornblende schists of the Kooiwater Igneous Complex have been drawn out to the north-west at a point north of the deposit. Further, the presence of many quartz veins in the area seem to point to a disturbed zone.

The writer is also of the opinion that the wall rock of this occurrence is closely related by reason of the similar mineralogy to that of the Lataba Mine, in which case it may be correlated with the older rocks of the No. 3 division.

The similarity in the mineral composition of the rocks in this area with those of the Lataba occurrence suggests that both the occurrences are in the same general sub-division of the stratigraphy. Possibly, therefore, the rocks in this area belong to the No. 3 sub-division. This might have resulted from some local complex structural condition whereby an area of rocks of the No. 3 sub-division have been brought into line with the general trend of the No. 2 division rocks.

## 7. DESCRIPTION OF THE ORE

### (A) Method of Polished Section Preparation

Fresh samples of ore were cut, mounted in bakelite and then ground down on a glass plate using the following grades of abrasive carborundum powders - 60, 400 and 600, the latter being the 'Aloxite' type. The next stage was to smooth the specimen on a felt-covered lap, using magnesium oxide as the polishing agent. The final polish was obtained by employing diamond dust in a paste as follows:-

A metal lap was covered with nylon suede, and revolved at approximately 600 r.p.m. On the lap were evenly spread small concentrations of the paste containing 4 to 6 micron grade of diamond dust. Lubrication is effected by adding a few drops of paraffin when required during the polishing operation. The amount of paraffin added should be such that when the specimen is taken off the lap it has a thin oily film over the polished surface. The specimen must be held firmly and should be moved about on the lap to avoid it being held in one fixed position. The downward pressure must not be excessive, but the correct amount is soon found by the operator. The time of polishing varies from 5 to 8 minutes. One impregnation with diamond dust was found to be sufficient to polish about twenty to twenty five specimens. On completion of this stage the specimen is washed in acetone to remove all traces of diamond dust adhering to its surface.

For the next stage the lap wheel is covered with nylon suede, which is in turn covered with nylon bolting and prepared with a 1 to 5 micron diamond dust paste. The procedure is identical to that of the previous stage.

For the final stage the lap is covered as described in the second stage, but is prepared with a 0 to 2 micron grade of diamond dust paste. If a very highly polished surface is desired the period of polishing can be increased, and a lesser pressure exerted on the lap.

The above procedure is very suitable for ores with no large hardness differences between the individual minerals. In the case of the copper-zinc ore it was most successful and did not produce a high relief even between the pyrite and the chalcopyrite.

The main disadvantage is that, if the ore minerals are very soft or contain minor inclusions of a soft mineral, there is a tendency for the specimen to become pitted due to a picking action, and in the case of minor soft constituents these are generally removed almost entirely.

### (B) Description of the Lataba Copper and Zinc Ore

The following is a list of the ore minerals recognized under the reflecting microscope:

Early Euhedral Pyrite, Marcasite, Later Pyrite, Chalcopyrite, Cubanite, Sphalerite, Pyrrhotite, Digonite, Covellite and Selena

The proportions of the different minerals in the ore was determined by measurements made on an integrating stage, and the value given is an average of a number of determinations.

#### (a) Early Pyrite

This mineral often occurs as euhedral crystals showing perfectly developed cubes although a few pyritohedra were seen. Occasionally an octahedron face is developed on some of these cubes. Due to partial replacement by later sulphides the corners of the cubes are occasionally rounded. The distribution of pyrite is not regular. It is a major constituent and makes up 15% by volume of the ore. In some samples of ore the euhedral crystals are arranged in bands and are composed of small and larger cubes of pyrite, the larger crystals having usually been fractured and later sulphides have filled-in the cracks. These pyrite-rich bands are oriented parallel to the schistosity of the surrounding rock.



Between the pyrite-rich bands the pyrite content gradually decreases as is illustrated on photograph No. 3. The pyrite grain size varies from 4.0 m.m. to 0.07 m.m. with an average size of 0.35 m.m.

Under the microscope the pyrite has a pale cream-yellow colour and is devoid of inclusions. If minor pits are seen, they are probably cavities originally present in the crystals opened up by polishing.

In several specimens the pyrite was weakly anisotropic. This anomalous anisotropism was also noted in the chalcopyrite, but the writer is of the opinion that this anisotropism is related to the polish, as found by Stanton (from unpublished paper entitled "Anisotropism in Pyrite", read at the 59th Annual General Meeting of The Canadian Institute of Mining and Metallurgy, April 1957). It was found on several occasions that samples showed anisotropism after polishing for the first time and not after a second polishing or vice versa. There is perhaps an intermediate stage, between a high and a low polish at which the pyrite and chalcopyrite are anisotropic. This anisotropism is not related to the temperature of formation of the pyrite as stated by Smith (1942)

#### (b) Marcasite

Marcasite is present in the ore in minor quantities only. It occurs surrounded by sphalerite or in the later pyrite. The marcasite, generally only occurs in the sphalerite in the form of narrow discontinuous elongated grains with an average width of 0.14 m.m. and varying in length from 0.10 m.m. to 0.88 m.m. The marcasite has been partially replaced by the sphalerite which has formed deep cusps into the marcasite. These grains are aligned parallel to the schistosity of the surrounding rocks. Typical marcasite grains are illustrated in photograph No. 4.

Small marcasite grains are also present as inclusions in the later generation of pyrite. This type of intergrowth is a common feature of the Lataba copper-zinc ore. The marcasite inclusions have no apparent preferred orientation and are distributed at random in the pyrite of a later age. These grains of marcasite are small and irregular in shape with a variation in grain size from 0.01 m.m. to 0.0 m.m. A marcasite grain in later pyrite is shown in photograph No. 5.

The marcasite is distinguished from the pyrite by its strong anisotropism which is from steel blue to a reddish-brown colour. Generally the marcasite is paler in colour than the surrounding pyrite and shows a weak reflection pleochroism from white to pale blue.

Some grains of marcasite were only weakly anisotropic and were then not readily distinguished from the surrounding pyrite. Possibly this is due to the optic orientation of the marcasite which in such a section may have been cut at right angles to the optic axis.

In the few instances where marcasite was seen to occur in contact with chalcopyrite the latter appears to be later and surrounds the marcasite, although in a few instances the marcasite enclosed a few grains of chalcopyrite.

#### (c) The Later Pyrite

Pyrite of a later age is present in the ore as irregular masses enclosing the earlier formed sulphides such as euhedral pyrite, marcasite and chalcopyrite. The fact that this pyrite is not present as euhedral crystals but as irregular intergrowths distinguishes it from the early formed variety. This pyrite, like the marcasite shown in photograph No. 4, is also present as discontinuous grains in the sphalerite, aligned parallel to the schistosity of the enclosing rocks. The sphalerite has partially replaced the pyrite.

The late pyrite does not often occur in contact with the chalcopyrite but generally the chalcopyrite encloses the pyrite, although the reverse was also noted. An example of chalcopyrite partially replacing the later pyrite is shown in photograph No. 6.

A marked feature of this later generation of pyrite is its close association with the marcasite. In the association of the pyrite and the marcasite the pyrite is present in much larger amounts than the marcasite. The intergrowth of these two sulphides is also present in the form of a discontinuous grain. This could possibly be an original marcasite grain which has been partially replaced by the later pyrite.

#### (d) Chalcopyrite

Chalcopyrite is the main copper mineral found in the ore. It is present as irregular masses which have been deposited around the earlier formed ore minerals or gangue. It constitutes 14% by volume of the ore.

It is readily identified because of its brass yellow colour and it scratches easily with a steel needle. It is isotropic, although a few sections showed weak anisotropism, possibly a polishing effect.

In the chalcopyrite narrow oriented laths of a mineral somewhat paler in colour and strongly anisotropic, were seen to be present.

This the writer assumes to be cubanite formed by ex-solution. Unfortunately, the laths were too small (maximum diameter less than 10 microns) to allow for any positive identification either by means of etch tests, X-rays or microchemical tests.

The chalcopyrite frequently occurs as an intimate intergrowth with sphalerite as shown in photograph No. 7. This intergrowth showing mutual boundaries texture is considered to be a result of simultaneous deposition of these two ore minerals.

Rarely the chalcopyrite occurs as minute oriented grains in sphalerite. This is illustrated in photograph No. 8.

This type of texture is considered by several authorities (Randohr, 1950, Edwards, 1954) to be indicative of chalcopyrite formed by ex-solution from the sphalerite along its (100) and (111) directions.

#### (\*) Sphalerite

This mineral is the major constituent of the ore suite and comprises 30% by volume of the ore. It occurs as large irregular masses surrounding the earlier formed minerals, either replacing them partially at the edges or almost completely.

The sphalerite is pale grey in colour and isotropic. The dark ruby red internal reflection is very distinctive and indicates a fairly high iron content. This colour stays relatively constant from one section to another so it is not possible to detect any change in iron content.

In thin sections of the ore the sphalerite can be distinctly seen to replace the wall rock along the schistosity or along minor cracks and fractures. Its colour in thin sections is dark red to brown. No darker rims could be seen in the sphalerite surrounding grains of pyrite which would have indicated that the blende had absorbed any iron from the pyrite.

The sphalerite was etched with a solution of  $\text{KMnO}_4$  in  $\text{H}_2\text{SO}_4$ . This produced the pattern of cleavage as well as marked polysynthetic twin lamellae. No deformation textures were revealed by this etching. An example of etched sphalerite is shown on photograph No. 9.

Photograph No. 10 illustrates stars of sphalerite in chalcopyrite. These stars of sphalerite have been formed by ex-solution from the chalcopyrite. This zinc was possibly included in the chalcopyrite lattice and as a result of cooling it ex-solved. According to Randohr (1950) the star-like pattern is typical of sphalerite formed by ex-solution from chalcopyrite. This type of sphalerite does not occur frequently.

(f) Pyrrhotite

Pyrrhotite occurs only as small grains usually in the sphalerite or in contact with chalcopyrite. It was also seen in a few instances included in the chalcopyrite.

It has a pale pink to cream colour with a very marked anisotropism from grey to greenish brown. It does not exhibit reflection pleochroism. The grains are very small and are sparingly distributed through the ore.

(g) Galena

In a few polished sections of the ore there were found to be present several minute grains of an isotropic silvery white mineral with a Mohs hardness of approximately 3. The grains vary in size from 0.02 m.m. to 0.10 m.m. and the average size is 0.03 m.m. Occasionally the white mineral is present in the early pyrite and is connected to the surrounding sphalerite by means of a minute crack. The white grains in the sphalerite were generally located near to, or in small cracks although isolated small grains with no evidence of cracks leading to them were also observed.

By systematically employing the etch reagents as described by Short (1940) the mineral was identified as galena, but due to its small size no confirmatory test by means of X-rays could be made. An example of this mineral is illustrated in photograph No. 12.

(h) Digenite

Digenite occurs as small veins in cracks in chalcopyrite, or at the contacts of chalcopyrite with sphalerite. Small amounts occasionally occur in sphalerite where the digenite has completely replaced grains of chalcopyrite or left only small remnants of that mineral.

It is pale royal blue in colour and isotropic. It is only a minor copper constituent of the ore, but nevertheless has a fairly even distribution. An example is shown in photograph No. 11.

(i) Covellite

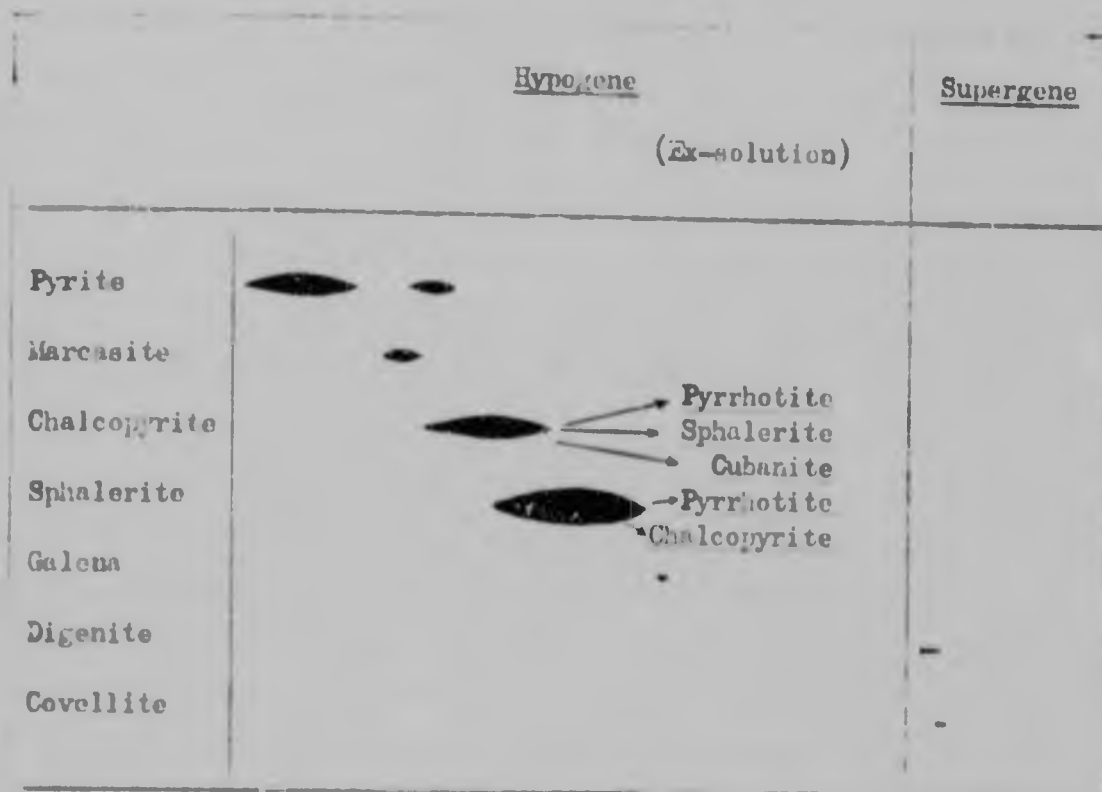
This mineral is generally present in minor amounts associated with digenite which it replaces. In ordinary light it has a darker blue colour than the digenite. Its anisotropism is distinctive, from a pale pink to an orange red. It shows a weak reflection pleochroism from pale blue to dark blue.

## 8. PARAGENESIS

From a study of the polished sections, the succession of ore mineral formation from the earliest to the latest is as follows: euhedral pyrite, marcasite, late pyrite, chalcopyrite, sphalerite, pyrrhotite, cubanite, galena, digenite and covellite.

Thin sections of the mineralized zones show that the ore minerals crystallized later than the gangue silicates and often replaced them. To aid the study of ore and gangue relations, polished thin sections about 0.5 m.m. thick were made. These were viewed under a binocular microscope. This gives a very good third dimensional view of how transparent ore minerals like sphalerite entered along a crack or grain boundary of gangue, and then by a process of replacement formed a small concentration of the ore mineral. It clearly shows how the ore replaces the gangue minerals parallel to the schistosity.

The paragenesis is illustrated by means of the diagram on page 18. The thickness of the lines is proportional to the quantity of ore mineral present and the length represents the period of mineral formation. A column showing the minerals formed by ex-solution is also included.

PARAGENETIC CHART

The minerals underlined in red were formed by ex-solution, and are shown connected to their hosts by arrows.

From the above paragenetic chart it is seen that the euhedral pyrite is the first sulphide to have been formed, and has no overlap in age of formation with the later sulphides.

The later sulphides are present surrounding the euhedral pyrite and have partially replaced this pyrite. This has resulted in the rounding off of the corners of the pyrite crystals. In some cases the pyrite has been replaced along certain crystallographic directions. In photograph No. 13 is illustrated how both chalcopyrite and to a lesser extent sphalerite, have replaced pyrite along the cube face.

As the euhedral pyrite was never seen enclosing any of the other sulphides it is concluded that there was no overlap in the period of formation between the euhedral pyrite and the later sulphides.

The marcasite surrounds the early pyrite and is replaced by the later pyrite, chalcopyrite and sphalerite. The amount of marcasite present in the ore is very small, and probably is in the order of 1 or 2 percent by volume. For this reason it was not possible to determine the relation between the marcasite and the chalcopyrite with certainty. Generally however, the chalcopyrite surrounds and partially replaces the marcasite as is illustrated in photograph No. 14.

A few instances were observed where the marcasite surrounds minor concentrations of chalcopyrite. From this observation it is concluded that there is probably a small overlap in the period of marcasite and chalcopyrite formation. However the majority of the marcasite is regarded to have been formed before the chalcopyrite.

In several of the polished sections examined the only marcasite present occurs as minute inclusions in the later pyrite. This is illustrated in photograph No. 5. These small inclusions of marcasite occur only in the later generation of pyrite.

The pyrite of a later age surrounds the earlier formed sulphides. Due to the lack of contacts between the later pyrite and the chalcopyrite the age relationship between these two minerals could not be determined with absolute certainty. From a study of the polished sections it appears that the chalcopyrite was formed later than the pyrite and has replaced it in part. A few instances were observed where the later pyrite partially replaced the chalcopyrite. From the above it is considered that the majority of the late pyrite formed before the period of chalcopyrite formation but some of the pyrite formed after the chalcopyrite resulting in a slight overlap in the periods of deposition.

Sherrill (1934) considers a mineral to have a colloform texture if it occurs in a series of curved and scalloped layers convex towards the younger or free surface. According to Boydell (1925) these curved surfaces are considered to be: "manifestations of surface tension effects in viscous material, and are therefore indicative, though by no means exclusively, of colloidal origin". Supergene pyrite may show a highly developed colloform texture, especially the variety termed 'melnikovite-pyrite' by Schneiderhahn and Randoehr (1931). In the later pyrite no colloform textures were observed, hence it is concluded that this pyrite was not transported by the mineralizing solutions as colloidal  $FeS_2$ .

The period of chalcopyrite formation is considered to have commenced before the close of the late pyrite stage of mineralization hence the slight overlap in the period of deposition of these two minerals. The chalcopyrite has replaced the euhedral pyrite, the marcasite and the pyrite of a later age.

In the chalcopyrite stage of ore formation there were recognized two distinct textural patterns, namely:

1) Early chalcopyrite following the late pyrite. This chalcopyrite shows evidence of replacement by the sphalerite

and also a period of simultaneous deposition with the sphalerite.

2) With a lowering of the temperature of the ore forming fluids ex-solution of chalcopyrite from the sphalerite took place. This has resulted in the formation of minute grains of chalcopyrite oriented along certain crystallographic directions in the sphalerite. These grains are distributed in the (111) or (100) directions and are illustrated in photograph No. 8. This crystallographic control is not always apparent and small chalcopyrite grains are occasionally more or less evenly distributed through the sphalerite. This ex-solution of chalcopyrite from sphalerite has been observed by many investigators, and references to it are numerous in the literature. (Edwards, 1954, Randohr, 1950, Coleman, 1957)

The deposition of the sphalerite is likely to have occurred over a considerable length of time, as this sulphide is the major component of the ore suite and comprises 30% by volume of the ore. The sphalerite was very reactive and was partially replaced all the earlier formed sulphides, especially the chalcopyrite. In photograph No. 11 is illustrated how the later sphalerite has veined the chalcopyrite as well as replaced it along its grain boundaries.

Photograph No. 7 illustrates a mutual boundary texture between sphalerite and chalcopyrite which is the result of simultaneous deposition of these two minerals.

Photograph No. 12 illustrates how sphalerite has entered pyrite along a thin crack connected to the surrounding sphalerite and replaced the pyrite. The grain of chalcopyrite also included in the pyrite was probably formed at the same time as the sphalerite.

A minor amount of sphalerite occurs as minute inclusions in the chalcopyrite. Some of these inclusions are star-shaped and are considered by Randohr (1950) to be typical of sphalerite formed by ex-solution from the chalcopyrite. An example is shown in photograph No. 10.

From the paragenetic chart it is seen that the pyrrhotite is considered as having been formed by ex-solution from both the chalcopyrite and the sphalerite. According to Edwards (1954) it has been established experimentally that pyrrhotite can form by ex-solution from either sphalerite or chalcopyrite. In each of the above cases the pyrrhotite occurs as minute grains varying from 0.01 m.m. to 0.40 m.m. in size and are surrounded by either sphalerite or chalcopyrite.



In some polished sections the pyrrhotite was seen to occur in the sphalerite in contact with a grain of chalcopyrite. It is possible that both these minerals ex-solved from the sphalerite at the same time and would thus have the same temperature of formation. An example of a large pyrrhotite grain in contact with chalcopyrite is shown in photograph No. 16, and in photograph No. 17 is seen a more typical ex-solution grain of pyrrhotite in sphalerite.

In a few grains of chalcopyrite thin little laths and minor concentrations of cubanite were seen to occur. The laths were generally orientated parallel to each other in an échelon fashion. Both the laths and the small grains are regarded to be products of ex-solution from the chalcopyrite.

As stated earlier a few grains of galena were found in the sphalerite, in the euhedral pyrite and one grain was observed in a grain of chalcopyrite. In all the above cases the galena was associated with cracks in the mineral in which it had formed. Furthermore no galena grains were seen which had the shape or distribution of typical ex-solution lamellae. From the above it is considered likely that the galena formed as a late hypogene sulphide and not by ex-solution from the sphalerite. An example is shown in photograph No. 12.

The digenite occurs essentially along the contacts of the chalcopyrite with other sulphides where it was deposited as a supergene sulphide. The contact between the chalcopyrite and adjoining sulphide was used as a channel way by the supergene solutions. It also occurs in cracks through the chalcopyrite, the crack acting as a channel in a similar manner, for the alteration of the chalcopyrite.

A common feature of the ore is the presence of the digenite developed at the contact of the chalcopyrite and sphalerite, especially where the latter has formed a vein in the chalcopyrite. An example is illustrated in photograph No. 11.

Some of the digenite has been subsequently replaced by covellite to form minor concentrations of this mineral with a maximum grain size of approximately 0.02 m.m.

In the ore sample obtained from the Mashava occurrence there is more covellite present than in the Letaba ore. This increase in covellite content is attributed to a stronger supergene action as the ore was obtained from a depth of only  $\pm$  200 feet, which is probably close to the level of the water table in the area.

Apart from greater development of covellite mentioned above there do not appear to be any marked differences between the ore found at the Letaba copper-zinc mine and that obtained from the deposit on the farm Mashawa 470.

#### 9. ORIGIN OF THE ORE DEPOSIT

The Letaba copper and zinc deposit is considered to be a hydrothermal deposit, that is it was formed by heated ascending solutions. These ore forming fluids were probably associated with the development of the Archean granite (Old granite) which covers a large part of the Murchison Range area. This granite is considered to be similar to the Nelspruit granite which is regarded by Visser (et al, 1956) to have been formed as a product of granitization.

During the folding of the rocks of the Murchison Range shear zones were developed and these zones then acted as channel ways for the hydrothermal solutions.

The deposit was formed essentially by the replacement of the country rock by the ore minerals. The microscopic evidence indicates that certain minerals present in the ore suite have preferentially replaced a specific constituent of the country rock. In some hand specimens of the ore it was seen that there were pyrite-rich bands oriented parallel to the schistosity of the surrounding rock. Between the pyrite-rich bands the pyrite content gradually decreases as is illustrated in photograph No. 3. These bands have probably been formed as a result of the pyrite having preferentially replaced some constituent of the country rock which was present originally as bands. This mineral which the pyrite replaces appears to be mainly quartz although it is not limited to quartz only as it was seen replacing chlorite as well. It would appear that this quartz was originally present in the country rock and was not formed by the hydrothermal solutions.

The marcasite occurs as discontinuous elongated grains but unfortunately no gangue mineral occurs in contact with the marcasite and thus it is not possible to determine whether the marcasite formed by replacement of earlier pyrite or partly by replacement of gangue minerals.

The formation of the pyrite of the later age was responsible for the replacement of most of the marcasite. The relationship between these two

which revealed the age relationship with certainty. However as illustrated in photograph No. 5 the small inclusions of marcasite have irregular margins with a textural pattern suggesting replacement by the later pyrite. None of the marcasite grains show any signs of having optical continuity.

Buergor (1934) points out that marcasite and pyrite do not form a dimorphous pair but are chemically distinct compounds. From the foregoing it is concluded that the small marcasite inclusions in the pyrite could not have formed by ex-solution. Although marcasite and pyrite have the same chemical formula, namely  $FeS_2$ , the amount of iron present in the marcasite is slightly higher and the sulphur content somewhat lower than in the pyrite. From this fact Buergor (1934) deduced that the marcasite forms at a low temperature in an acid environment.

If the above views are applicable here it would mean that after the period of pyrite deposition the marcasite was formed during a phase of falling temperature in the ore solutions and changing chemical condition, from alkaline to acid. For the introduction of the later pyrite the environment became once again alkaline in character. Though these changes may have only been very slight the nature of the conditions producing such changes is rather complex. Further in this ore body a gradual decrease in temperature was responsible for the order of deposition of the individual ore minerals of the ore suite.

On the other hand in Dana's Textbook of Mineralogy (1937) it is stated that marcasite is a far less stable compound than pyrite, and that marcasite can be formed under comparatively limited conditions at a temperature below  $450^{\circ}C$ . The higher the temperature of deposition the more acid the solution must be, but at ordinary temperatures, marcasite may be deposited from nearly neutral solutions.

From the above data it is possible that the marcasite, being a fairly unstable mineral later inverted mainly to pyrite, but in some portions of the ore lode this process of inversion was not complete and remnants of marcasite remained in the pyrite. A study of these marcasite remnants showed that the pyrite often appears to be replacing the marcasite as is illustrated in photograph No.5. The writer does not consider this to be a true replacement texture but prefers to term it a pseudo-replacement texture resulting from the incomplete inversion of marcasite to pyrite.

Assuming that the marcasite was deposited in a neutral environment it is considered possible that only slight variations in the pH value of the mineralizing solutions rendered the marcasite unstable and resulted in its inversion to pyrite. As there are certain portions of the ore where marcasite is present with no later pyrite it appears that the changes in pH value occurred only in small localized sections of the ore lode. This would explain the presence of discontinuous <sup>elongated</sup> grains of later pyrite with minor marcasite inclusions in certain sections of the ore lode and similar grains composed entirely of marcasite in other sections. The latter type of grain is not encountered in the ore as frequently as the former. It is concluded that the formation of marcasite and its subsequent inversion to pyrite was probably controlled locally in the ore lode by slight variations in the pH value of the mineralizing fluids.

Marcasite is known to form quite commonly by the supergene alteration of pyrrhotite but the marcasite present in this ore suite is not considered to be of supergene origin, as it does not occur in veinlets.

None of the polished sections examined showed any evidence suggesting that the marcasite formed as a replacement of pyrrhotite. Marcasite and pyrrhotite were not observed in contact with each other and there is no evidence suggesting the existence of any relationship between these two minerals in this ore.

Before the close of the period of later pyrite formation there was an introduction of copper into the mineralizing solution. This resulted in the formation of chalcopyrite.

The development of chalcopyrite was fairly widespread for it partially replaced the early pyrite, the marcasite and the later pyrite. In addition there is evidence of the chalcopyrite replacing the silicate minerals of the country rock, and possessing at the same time the foliated texture of the rock.

Towards the later stages of the copper mineralization period the stage of sphalerite formation commenced. The sphalerite appears to be the most widespread mineral introduced in the ore body. From a study of the thin sections it is seen that the zincblende replaced mainly the softer constituents of the wall rock like chlorite and sericite. It has also partially replaced the earlier formed sulphides as illustrated in photographs Nos. 4 and 11. The chalcopyrite is the sulphide which has been replaced to a larger extent by the sphalerite than any of the other sulphides. The chalcopyrite masses are transected by sphalerite veins and have had deep cusps and indentations made into

them by this mineral. This is illustrated in photograph No. 11.

An examination of the thin sections of the ore showed that the colour of the sphalerite does not vary appreciably from a dark orange-red in the different sections of the ore body. Even where the sphalerite surrounds iron-rich minerals like pyrite and marcasite there is no rim of a darker coloured sphalerite around these iron-rich sulphides to show that the sphalerite had absorbed more iron. From this it is inferred that generally the iron content of the sphalerite does not vary appreciably.

As the pyrrhotite grains do not exhibit any typical replacement textures with the sphalerite or the chalcopyrite it must have formed before these two minerals. Further no pyrrhotite occurs as veins transecting the earlier sulphides or in cracks through the sulphides. From the shape of the grains, and in view of the foregoing it is concluded that the pyrrhotite formed by ex-solution from either the chalcopyrite or the sphalerite. A typical ex-solution lamella is illustrated in photograph No. 17. Edwards (1954) records the formation of pyrrhotite by ex-solution from either chalcopyrite or sphalerite.

The small oriented lamellae of cubanite are regarded as ex-solution products from the chalcopyrite.

In the chalcopyrite there occur occasionally minute star-shaped inclusions of sphalerite as illustrated in photograph No. 10. These are considered to be ex-solution products of sphalerite from chalcopyrite by Radochr (1950).

The small oriented grains of chalcopyrite occurring in the sphalerite as shown in photograph No. 8, were formed by ex-solution of chalcopyrite from sphalerite.

Small grains of galena occur in the sphalerite. These did not generally exhibit any textural relations with the sphalerite indicative of ex-solution products. Generally the grains are angular and occur in or adjacent to cracks through the sphalerite which acted as channel ways for the later lead-bearing solutions. In one polished section two small grains of galena were seen in a euhedral pyrite crystal, one in the centre of the pyrite and the other in the marginal part close to the surrounding sphalerite. A grain of galena was also found in a grain of chalcopyrite. From these facts it is inferred that the galena did not form by ex-solution from the sphalerite since it does not occur exclusively in that mineral. It was probably introduced by

hydrothermal solutions towards the latter stages of the ore formation period.

The mine assay plans show that the ore from the Letaba copper-zinc mine contains an average of 0.58 dwts. of silver per ton. No silver minerals were identified in the polished sections. There is a possibility that if the silver mineral was present as small grains, less than 0.01 m.m. in size, they were plucked out during the polishing process. However this is only considered to be a remote possibility in view of the fact that some galena was found in the ore.

Edwards (1954) states that galena is capable of some degree of solid solution with a variety of silver minerals at high temperatures, but at normal temperatures it can accommodate not more than 0.10% of silver in its structure. Argentiferous galena containing less than 0.10% of silver tends to be homogeneous but galena with silver in excess of this amount invariably contains included silver minerals.

Owing to the small size of the galena grains it was not possible to determine either by staining tests, chemical analysis or X-ray diffraction whether the galena contains any silver minerals or not. It is considered very likely however, that the galena present in the ore is in fact argentiferous and as such, is considered to be the source of the silver recovered from the ore.

A spectrographic analysis of the sphalerite indicates the presence of silver as a trace element only, hence the silver present in the ore does not appear to be derived from this mineral.

As stated previously the digenite and the covellite were formed entirely by supergene action. The intergrowth of digenite with covellite does not appear to have been formed by unmixing. According to McKinstry (1946) these minerals probably crystallized below 30°C. and are thus not of hypogene origin.

#### 10. TEMPERATURE OF FORMATION

The nature of the ore minerals present suggests that mineralization occurred under conditions of intermediate to high temperature, that is the deposit is not a distinctly high temperature or a low temperature type. An attempt has been made to determine more definitely the temperature existing at the time of mineralization from the evidence of ex-solution features which have been observed in some of the ore minerals.

From Edwards (1954) a list of host minerals and ex-solution products and temperatures below which ex-solution occurs have been listed below, host minerals being listed first. In the case of sphalerite ex-solving chalcopyrite and sphalerite ex-solving pyrrhotite the two temperatures listed in each case denote the range of temperature between which ex-solution can take place.

Host

Chalcopyrite	→	Cubanite	-	450°C.
Sphalerite	→	Chalcopyrite	-	350° - 400°C.
Chalcopyrite	→	Sphalerite	-	550°C.
Sphalerite	→	Pyrrhotite	-	138° - 894°C.
Chalcopyrite	→	Pyrrhotite	-	600°C.

Assuming that the above data is applicable to the copper-zinc ores investigated in this thesis, the pyrrhotite present in the chalcopyrite ex-solved from it at a temperature below the maximum of 600 C. The pyrrhotite formed by ex-solution from the sphalerite may have formed at a higher or lower temperature. It was seen in several sections that the pyrrhotite and the chalcopyrite occurred near to or in contact with each other in the sphalerite. If this chalcopyrite formed as an ex-solution product it is inferred that the pyrrhotite in contact with the chalcopyrite probably ex-solved from the sphalerite at a similar temperature as the chalcopyrite. From the table listed above it is seen that the chalcopyrite can only unmix from the sphalerite at a temperature ranging between 350° and 400°C. Hence this is probably the temperature at which the pyrrhotite ex-solved from the sphalerite.

The small sphalerite stars ex-solved from the chalcopyrite can form at any temperature below 550°C. In view of the general mineralogy this is not considered to be a high temperature deposit. Further from the discussion in the previous paragraph it is possible that this sphalerite formed at a temperature well below 550°C.

The cubanite laths in the chalcopyrite cannot be employed as a temperature indicator. It can only be definitely stated that they formed below a temperature of 450°C.

The work of Kullerud (1953) and Coleman (1957) has shown conclusively that the iron content of sphalerite is related to its temperature of formation and further that the size of the unit cell is a function of the iron content. This latter relation is shown on the graph in fig. No. 2. These relations are only applicable if the

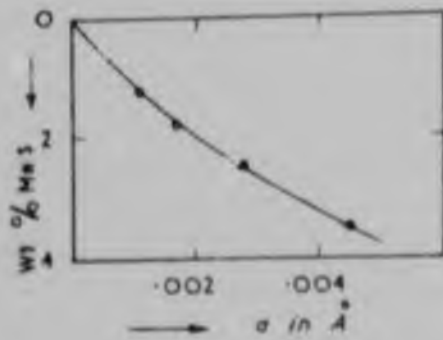


Fig 1 Effect of MnS Solid Solution  
on Cell Length of Sphalerite  
(after L C Coleman, 1957)

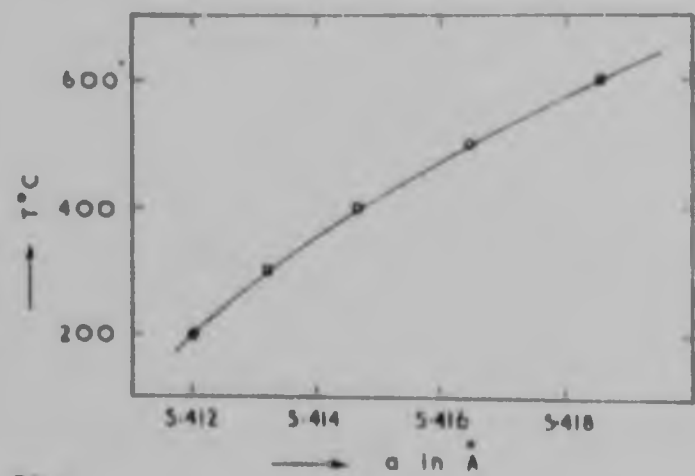


Fig 2 Length vs Temperature of Formation of  
Fe-bearing Sphalerite (after L C Coleman, 1957)

...elements found in an  
is stated previously that  
near concentrations of  
that there is an excess  
period of deposition and

The sphalerite was  
determined using x-ray  
method however affects  
near the true length of  
which appear to be  
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of formation for the sphalerite.

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zincblende formed in an environment where an excess of FeS prevailed. As stated previously there are present in the Murchison copper-zinc area minor concentrations of pyrrhotite in the sphalerite which indicates that there was an excess of FeS present in the sphalerite during its period of deposition and hence the above relations are applicable.

The sphalerite unit cell was measured by means of an X-ray diffractometer using cobalt radiation. The presence of MnS in the mineral however affects the measurements, necessitating corrections to obtain the true length of the unit cell. In the sphalerite from the Letaba copper-zinc mine, there is present  $\pm 1\%$  MnS. By employing the graph in fig. 1 the results were adjusted accordingly and it was found that the length of the unit cell is from 5.416 - 5.417 Å. From the graph illustrated in fig. 2 compiled by Coleman (1957) a temperature of formation for the sphalerite ranging from 460° to 520°C. is indicated.

The presence of trace elements in sphalerites has also been used for indicating the temperature of formation of the sphalerites. Some workers mention that the nature of the trace elements present varies with the temperature. El Shalzy (et al, 1957) found that in sphalerites formed at a relatively high temperature In, Mn, and Sn were the most common trace elements, whilst Ga, Ge, and Sb were associated with sphalerites formed at a medium to low temperature.

Bartham and Salama (1949) state that as a general rule hydrothermal sphalerites formed at high temperatures contain cobalt as well as much iron and manganese; gallium and indium favour sphalerites formed at intermediate temperatures.

Other investigators however have mentioned that there is no direct relation between the temperature of formation of the sphalerite and the nature of the trace element present. Fryklund and Fletcher (1956) found that the trace element distribution in sphalerites from the Coeur d'Alone district was random and that the presence of Cd, Ga, Ge, Mg, In and Co were in no way related to the temperature of formation of the sphalerite.

A spectrographic analysis of the sphalerite from the Murchison area indicated the presence as trace elements of Mn, Mg, Pb, Ag, Co and In. This would indicate a medium to high temperature of formation.

From the temperatures of formation of the different ore minerals present, as given by various workers and described above, it would appear that there are certain contradictions between the temperatures of formation and the age relations of the minerals as determined under the microscope.

As shown on the paragenetic chart sphalerite has formed later than the marcasite-pyrite intergrowth. Yet the temperature of formation of the sphalerite as determined by a measurement of its unit cell is approximately  $470^{\circ}\text{C}$ . Marcasite is considered to be unstable at this temperature and is thought to have been deposited at a lower temperature under more or less neutral conditions. With an increase in alkalinity the marcasite may have inverted to pyrite at a temperature between  $300^{\circ}$  and  $400^{\circ}\text{C}$ .

The general features of the ore deposit indicate that it is a hydrothermal copper-zinc deposit. Due to the lack of typical high temperature minerals in the ore suite the deposit could not have formed at a high temperature.

Generally this type of deposit has been classified by Lindgren (1913) as a mesothermal deposit for which he quotes a temperature range of  $175^{\circ}$  to  $300^{\circ}\text{C}$ .

As the euhedral pyrite is earlier in age than the sphalerite it must be presumed that it was introduced at the same temperature as the sphalerite, or at a higher temperature. This would imply that the earliest part of the sulphide mineralization took place at a temperature appreciably above the mesothermal range which is considered to be unlikely.

From the foregoing it appears that the temperature of formation of the sphalerite as determined by means of the unit cell measurement is too high. From the graph in fig. 2, it is evident that a small variation in the third decimal place of the unit cell dimension results in an appreciable difference in the temperature of formation. It is possible that the experiments carried out on the sphalerite suffered from the lack of ideal equipment for measuring the unit cell with the desired accuracy required for this purpose.

In view of the above it is concluded by reason of the general mineralogy of the ore and the known temperatures of certain ex-solution phenomena, that the temperature of formation was probably in the range of  $350^{\circ}$  to  $400^{\circ}\text{C}$ . This temperature is somewhat higher than the upper limit given by Lindgren (1913) for his mesothermal type of deposit. However the writer feels that it is not possible to classify a type of deposit by virtue of its temperature of formation only. From the general considerations of the mineralogy of the ore minerals this deposit is classified as a mesothermal type.

## 11. DEFORMATION AFTER DEPOSITION

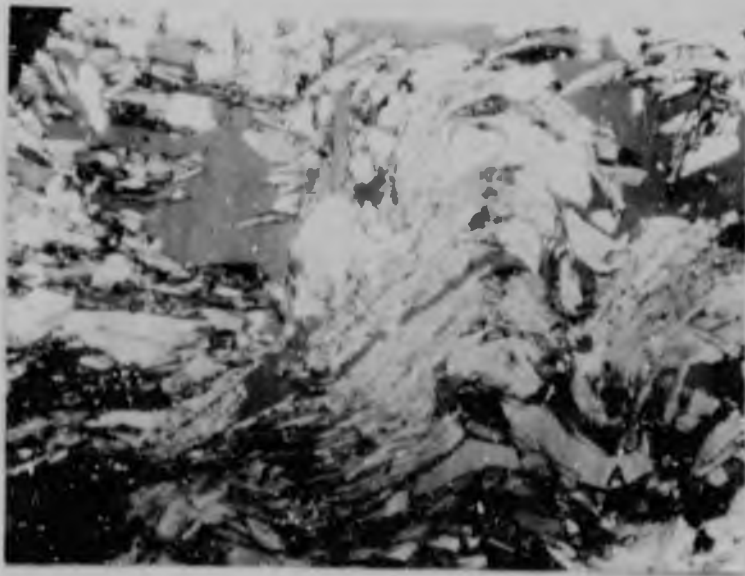
In the ore minerals present in the suite, certain minerals by reason of their physical or optical properties would show if there had been any appreciable amount of deformation of the ore deposit subsequent to its formation.

The cubical pyrite is almost entirely unfractured, and is brecciated to only a minor degree in one or two instances. This would suggest very local minor movement along small post-ore faults.

The sphalerite after etching with  $KMnO_4 + H_2SO_4$  shows twin lamellae and grain boundaries as illustrated in photograph No. 9, but the twin lamellae show no bending or deformation due to stress as illustrated by Rindohr (1950).

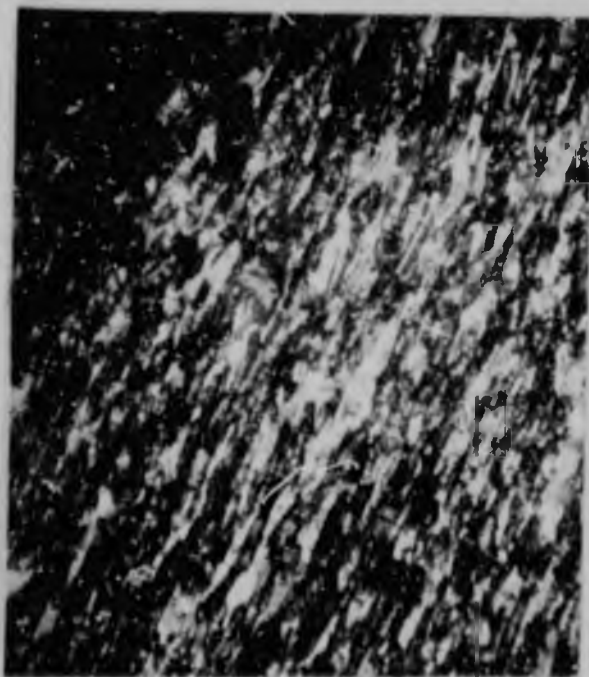
Pyrrhotite, although a very brittle mineral, shows no marked fracturing.

From the features mentioned above it is evident that there was no post depositional deformation in the copper-zinc deposits of the Murchison Range. Thus it is concluded that the major folding of the Murchison Range rocks occurred before the period of mineral deposition and not after.



Photograph No. 1 (thin section)

Fold in quartz-chlorite schist.  
 Note how quartz grain (A) has  
 been bent. X nicols x 30.



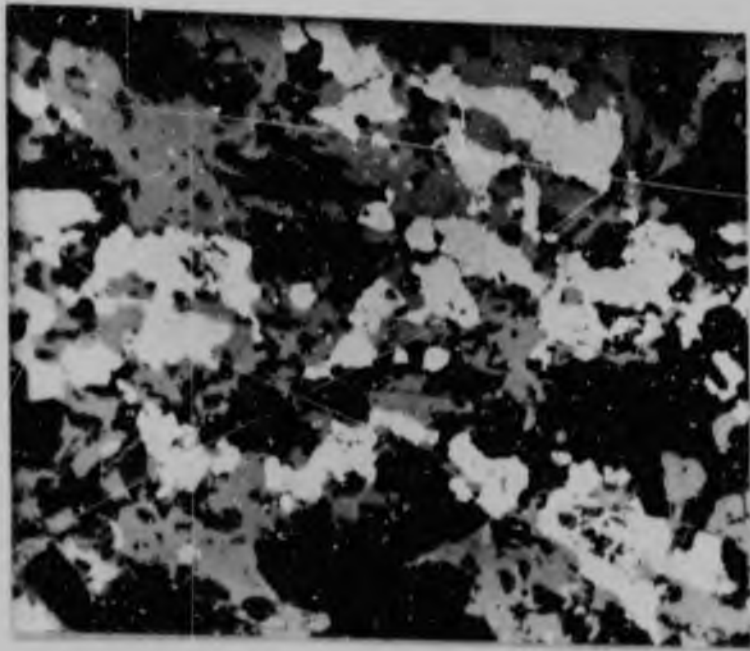
Photograph No. 2 (thin section)

Epidote needles (dark)  
 in epidote-quartz schist.  
 X nicols x 30.

Photograph No. 3 (polarized section)

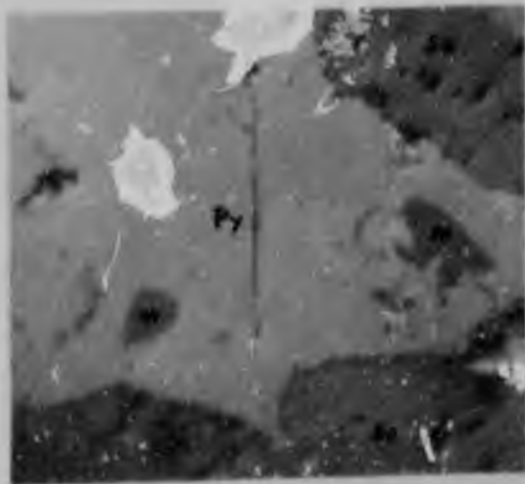
Concentration of pyrite in  
 bands parallel to the schistosity  
 due to selective replacement.  
 x 12.





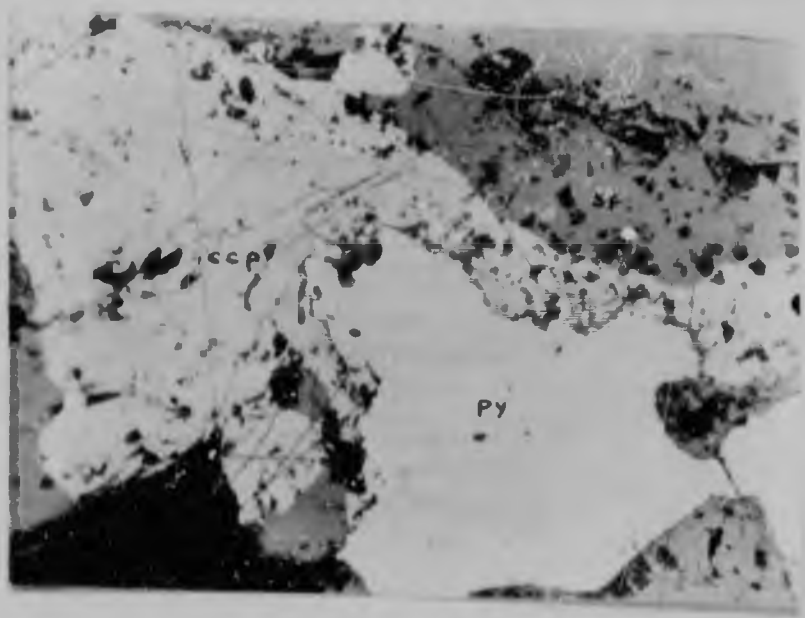
Photomicrograph No. 4 (polished section)

Remnants of marcasite grains (white)  
replaced by sphalerite (grey)  
x 142



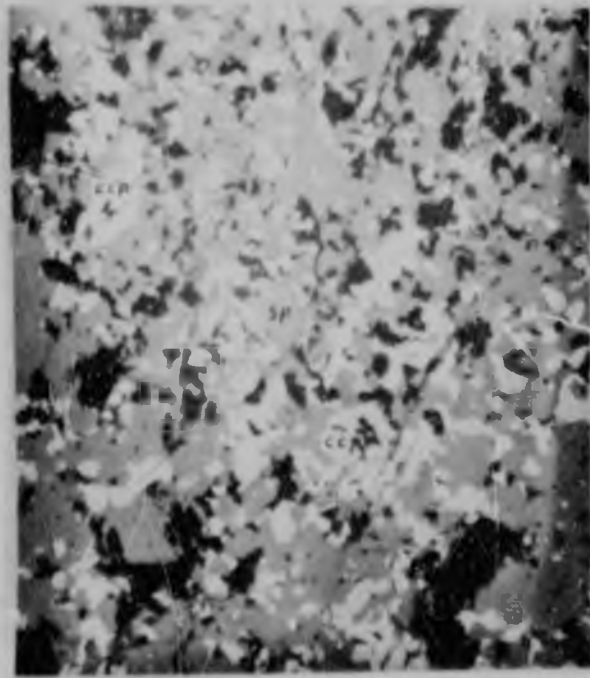
Photomicrograph No. 5 (etched section)

Remnants of marcasite (m) in pyrite (py)  
exhibiting "pseudo-replacement" texture.  
X nicols x 460



Photomicrograph No. 6 (polished section)

Calcopryite (ccp) replacing later pyrite (py)  
and sphalerite replacing the earlier sulphides.  
x 142



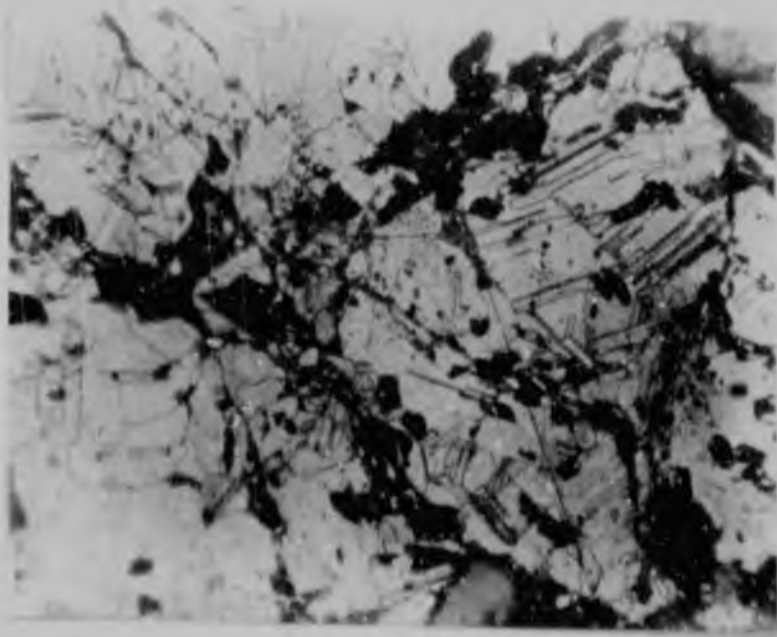
Photomicrograph No. 7 (polished section)

Calcopryite (ccp) and  
sphalerite (sp) deposited  
simultaneously showing  
mutual boundaries texture.  
x 142

Photomicrograph No. 8 (polished section)

Oriented re-solution grain of  
calcopryite (ccp) in  
sphalerite (sp)  
x 216.





Photomicrograph No. 9 (polished section)

Twin lamellae and grain boundaries in sphalerite produced by etching with  $K_2MnO_4 + H_2SO_4$

x 160



Photomicrograph No. 10 (polished section)

Dissolution stars of sphalerite (dark grey) in chalcocite (light grey)

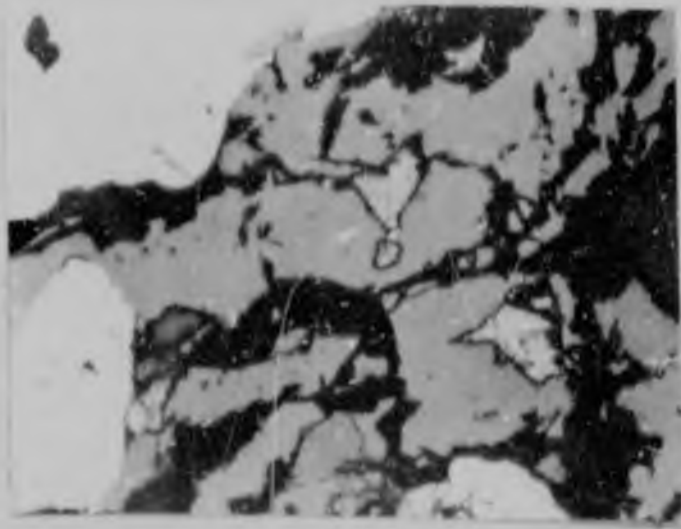
x 240



Photomicrograph No. 11 (polished section)

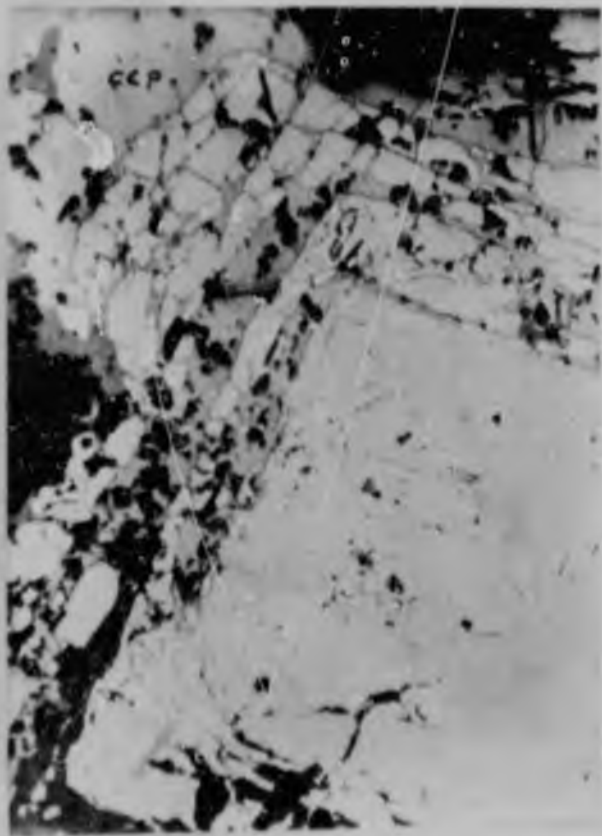
Chalcocite (cc) transected by sphalerite (sp) veins and digenite at the contacts of these veins as shown by arrow. The surrounding sphalerite (sp) has partially replaced the chalcocite.

x 215



Photomicrograph No. 12 (polished section)

Grains of galena (light grey) present in and near  
 cracks in the surrounding schalchrite (dark grey)  
 x 300



Photomicrograph No 13 (polished section)

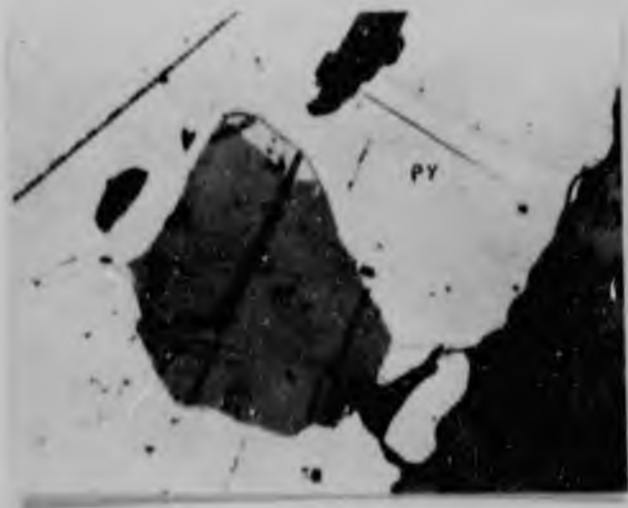
Pyrite (white) replaced by  
 malachite (grey)  
 and schalchrite (dark grey)  
 along the cube face.  
 x 142

Photomicrograph No. 14 (polished section)

Malachite (ccp) replacing the  
 arsenite pyrite intergrowth (py),  
 and schalchrite replacing these  
 earlier formed sulphides.  
 x 160







Photomicrograph No. 15 (polarized section)

Sphalerite (sp) in pyrite (py) connected to the surrounding sphalerite by means of a small grain. Note the presence of a chalcopyrite grain in the sphalerite.

x 215



Photomicrograph No. 17 (polarized section)

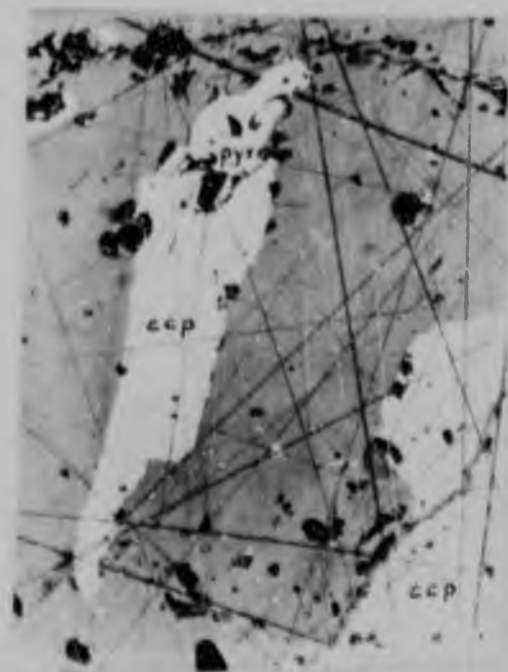
Pyrrhotite (pyrr) in sphalerite (sp) in contact with pyrite (py).

x 130

Photomicrograph No. 16 (polarized section)

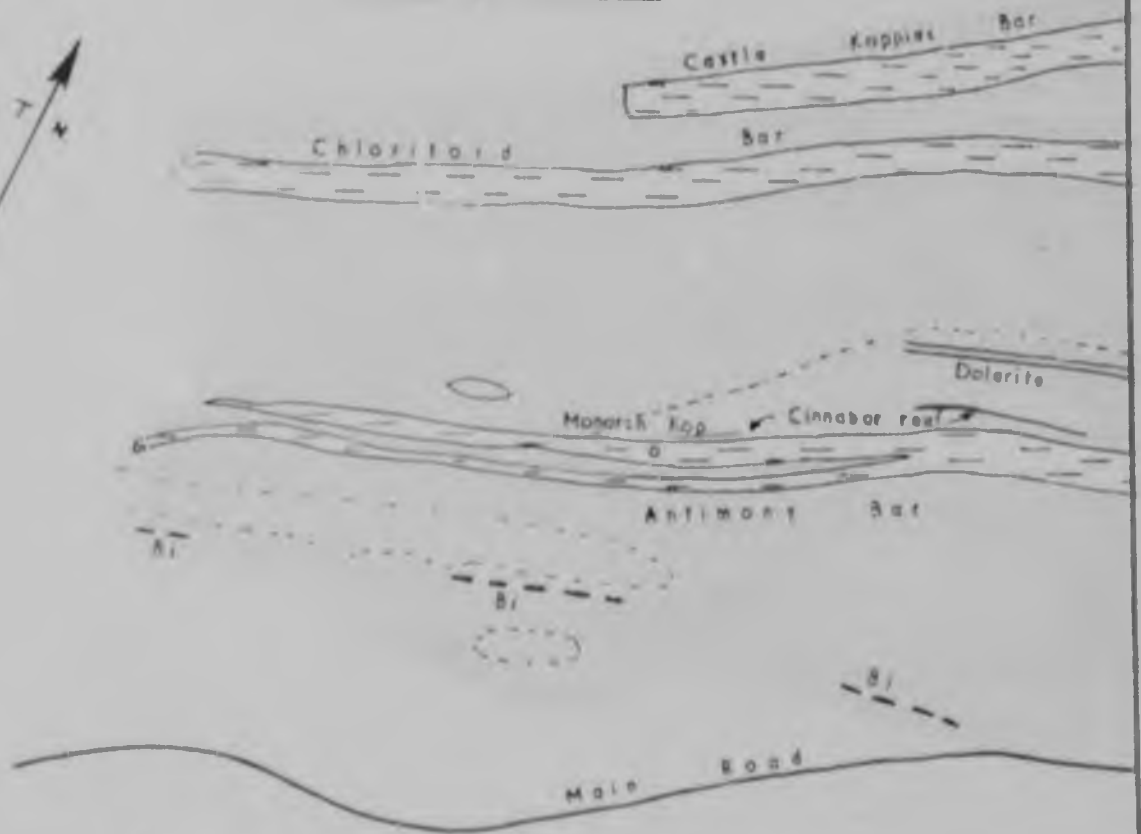
Pyrrhotite (pyrr) grain in sphalerite (sp) in contact with chalcopyrite (ccp).

x 122








GEOLOGICAL MAP OF THE CINNABAR  
REEF AREA, MURCHISON RANGE  
after van Eden, 1939.

Scale 1:10,000



Legend

-  Banded ironstone
-  Prominent quartzite & quartz schist horizons
-  Carbonate-rich rocks
-  Chlorite, mica carbonate schist
-  Granite

## PART II: THE MONARCH CINNABAR DEPOSIT

1. INTRODUCTION

The Monarch Cinnabar Mine is situated in the Murchison Range, some 8.4 miles east of Gravelotte and approximately 0.3 miles north of the Gravelotte-Guze Reserve national road. Its position is shown on Map No. 2. The deposit was discovered by Mr. H.A. Harington in 1936, although Wilson-Moore (1896) mentioned the presence of mercury in the Murchison Range in a paper read to the Geological Society in 1896. As a result of a shortage of mercury during the second world war the Mine was worked for a limited period. The deposit could only be mined economically for this period due to the high price of mercury prevailing at that time. At present the World's main producers are Italy, Spain and Mexico.

2. RESUMÉ OF THE MINE GEOLOGY

At the Monarch Cinnabar Mine two ore lodes were mined; the one to the west, outcrops on the north flank of Monarch Kop; the one to the east, outcrops on the south flank of Harington Kop. The lower adit at Monarch Kop has an elevation of 1808 ft. above mean sea level, and the adit at Harington Kop has an elevation of 1804 ft. a.m.s.l., that is, it is four feet lower. The two hills are separated by a saddle and form part of the ridge known as the Free State Kopjes.

The cinnabar-rich lodes occur in carbonate-rich rocks north of the Antimony Bar and south of the Chloritoid Bar (van Eden, et al, 1939) and are illustrated on Map No. 3. Quartz-stibnite veins with no cinnabar associated with them are present a few hundred feet to the south of the Antimony Bar, at a point opposite the cinnabar ore lodes. Similar veins are also present north of the ore lode situated on the eastern slope of Harington Kop (Wilson, 1945).

The ore body at Harington Kop has a strike length on surface of 550 ft., an average width of 8.75 ft. and contains approximately 0.16% of mercury. The strike of the ore body is  $N.70^{\circ} E.$  and the dip is to the north at angles varying between  $80^{\circ}$  and the vertical.

According to Wilson (1945) the presence of an anticlinal dragfold in the Antimony Bar at Harington Kop, with an axis dipping north at  $80$  to  $85^{\circ}$  and pitching east at about  $80^{\circ}$ , has undoubtedly controlled the deposition of the mercury ores in the Harington Kop ore body.

The Monarch Kop mineralization at the outcrop, consists of a zone of lenses with an average width of nine feet and a mercury content of 0.30%. In general the carbonate-rich schist present at Monarch Kop is more compact and more silicified than the rock at Harington Kop. Wilson (1945) states that there is little drag-folding about a vertical axis, and considers it possible that dragfolds about near-horizontal axes may account for the presence of the ore body.

(A) Petrological features of the rock associated with the ore

The wall rock associated with the cinnabar ore is a rock with a high carbonate content. It is composed essentially of carbonate and quartz in the approximate ratio of three to one, and minor amounts of chlorite.

The carbonate has a refractive index  $n = 1.712 (\pm 0.002)$ . It is considered to be an ankerite with a composition intermediate between magnesiodolomite and ferrodolomite. This ankerite is present as large irregular masses which appear to have replaced some of the quartz.

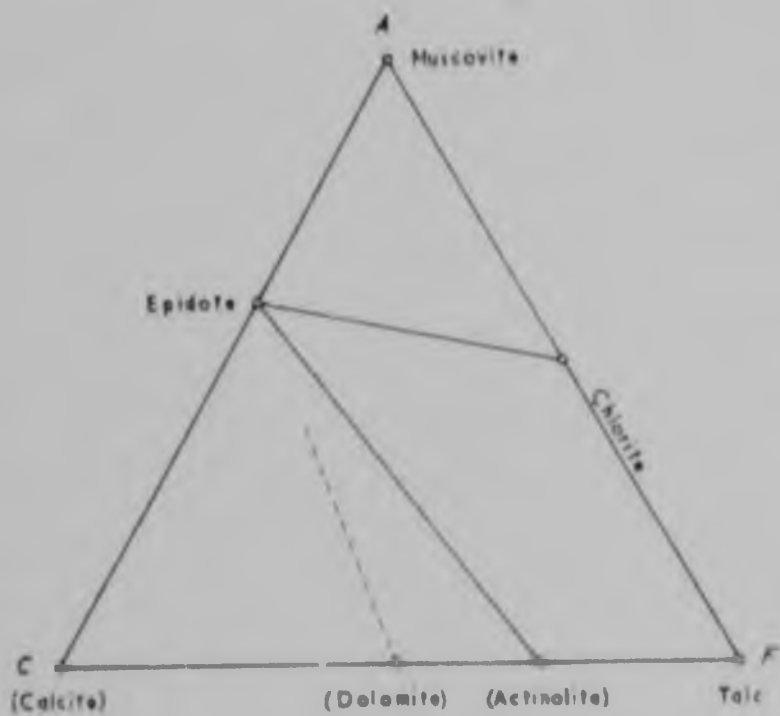
In some thin sections it was seen that the ankerite had a tendency to be elongated parallel to the schistosity of the rock, but this is not a well-marked feature.

The quartz occurs in the rock as irregular grains, which vary in size from 0.01 m.m. to 0.25 m.m. The distribution is fairly regular but the size of the grains varies considerably between the above mentioned two limits. Generally, the grains have been recrystallized during the process of metamorphism. No quartz veins of a later period appear to be present in these rocks.

The chlorite is the colourless variety which is not pleochroic and has a low birefringence. It occurs generally as lamellae intercalated between the other constituents. These lamellae vary in width from 0.05 m.m. to 0.20 m.m. and are oriented parallel to the schistosity of the rock.

The rocks of this area have probably been subjected to considerable stress, as both the quartz and the chlorite exhibit a marked wavy or undulating extinction.

In one polished section examined there were found grains of hematite which were positively identified by means of X-ray diffraction. These grains vary in size from 0.04 m.m. to 1.8 m.m. and have an average size of 0.12 m.m. This hematite is considered to have formed prior to the period of hydrothermal mineralization in the Murchison Range. It is likely to have formed during the regional metamorphism of the rocks



**Fig 3 ACF Diagram of the Mineral Associations  
in the Greenschist Facies (after Barth, 1952)**

of the Madison Range, as in the  
rocks which could have been the  
for the formation of the hornite.  
necessary and is illustrated in pho  
Barth and Origin of the

Do high carbonate content  
the silicates or amphibole in the  
likely formed under conditions of  
of substitution is considered to be  
data as described by Barth (1952)

A general feature of this pro  
which tend to lose both water and  
minerals find it easy to agree to  
to be rich, as they are retained  
the pressure will increase during

According to Barth (1952), the  
forming rocks. During cooling  
the type of rock. This nearly always  
silica or dolomite in lime-rich rocks  
in Fig. 3, it is seen that no lime-  
[part of the diagram. Hence, in  
a sample either calcite or dolomite  
is substituted.

Barth (1952) states: "The  
of the silicates as 'supersaturated'  
formed by the carbonate content

In the foregoing discussion  
carbonate-rich rocks were not originally  
so less calcitized, but were produced  
by the presence of metamorphism  
and of lime was present. This is  
original contact, or was produced by

In Fig. 3 it is seen that  
in the Madison Range, and according  
for very few rocks in this area which  
had but the carbonate-rich rocks  
in calcite. Van Mar (1939) con  
sented; rocks represent altered bas  
a distinctly of sedimentary origin.

of the Murchison Range, as in the area there are present many banded ironstones which could have been the source of the iron required for the formation of the hematite. It is only present as an accessory and is illustrated in photograph No. 1.

### (B) Metamorphism and Origin of the Carbonate

The high carbonate content and the absence of any epidote, lime silicates or amphiboles in this schist, indicates that it was probably formed under conditions of low grade metamorphism. This grade of metamorphism is considered to be the equivalent of the green schist facies, as described by Eskola (1921).

A general feature of this grade of metamorphism is that the sediments tend to lose both water and carbon dioxide. Either these constituents find an easy egress to the atmosphere and are thus lost from the rock, or they are retained in the rock where their partial vapour pressure will increase during the metamorphism.

According to Bath (1952), field observations indicate that circulating carbonate-bearing solutions are almost always present in this type of rock. This nearly always results in the formation of calcite or dolomite in lime-rich rocks. From the equilibrium diagram, see fig. 3, it is seen that no lime-rich silicates are stable in the C corner of the diagram. Hence, in this facies a lime-rich rock has to develop either calcite or dolomite or else the rock has to change its composition.

Bath (1952) states :- "The carbonates, therefore, grow together with the silicates as 'supernumerary' phases, the amount of which is determined by the carbonate content of the rock-making solutions".

From the foregoing discussion it is thus considered that these carbonate-rich rocks were not originally quartz-chlorite schists which had been carbonatized, but were probably rocks formed at a low temperature by the process of metamorphism in an environment in which a large amount of lime was present. This lime could have been present in the original sediment, or was produced during the process of metamorphism.

From Map No. 2 it is seen that carbonate rocks occur frequently in the Murchison Range, and according to van Eken (1939), there are in fact very few rocks in this area which are free from carbonate. He found that the carbonate-rich rocks often grade into rocks with little or no carbonate. Van Eken (1939) considers that the bulk of the carbonate rocks represent altered basic lavas, although a certain portion is undoubtedly of sedimentary origin.

He divided the carbonate rocks into two classes as follows:-

- (1) the carbonate of magmatic origin, associated with nearly all the reefs of the schist belt, and,
- (2) carbonate rocks derived from basic intrusives and effusive rocks, and from sediments.

With regard to formation of the carbonate schists associated with the cinnabar deposits, the writer agrees with the views expressed by Bartl (1952), that is, these schists were formed under low grade metamorphic conditions by the metamorphism of a sediment consisting of quartz, magnesium carbonate and argillaceous material. This resulted in the recrystallization of both the carbonate and the quartz and the formation of chlorite from the aluminous constituents.

### 3. METHOD OF POLISHED SECTION PREPARATION

As cinnabar sublimes at approximately 580°C. it can only be mounted in a material which has a low melting point. The method employed was as follows:- The ore specimen was placed in a metal mould, whose outside dimensions are equal to a normal bakelite polished section lapquette. A metal possessing a low melting point was poured into the mould and this then secured the specimen in the desired position.

It was found that the cinnabar ore does not polish readily. Employing the diamond dust powder in the same manner as described on page 11, was found to be very unsatisfactory, as the specimen retained a large number of scratches on its polished surface.

A reasonable polish was eventually obtained by employing a Graton Vanderwilt polishing machine, manufactured by the Micro Instrument Company. This machine employs a slowly revolving lead lap which does not have a strong plucking action on the softer constituents. This plucking action is more marked when using a cloth-covered lap revolving at a high speed.

### 4. DESCRIPTION OF THE MINERALS PRESENT IN THE ORE SUITE

The following ore minerals were recognized under the reflecting microscope:-

Pyrite, corymbite, tetrahedrite, chalcopyrite, mineral X, stibnite, cinnabar, digenite, and covellite.

(a) Pyrite

The pyrite was the first sulphide to have formed. It is present in minor amounts evenly distributed throughout the ore. The grains vary in size from minute specks to 3.00 m.m., and are generally cubic in outline. The grains have straight crystal boundaries which have not been replaced by the later sulphides, and the corners have not been rounded. It has a pale yellow colour and is isotropic. The pyrite is almost devoid of inclusions, except where cinnabar has entered a grain along a crack and then partially replaced some of the pyrite to form a cinnabar concentration. Some minute specks of pyrite occur as minute concentrations in the hematite which the pyrite is partially replacing.

(b) Corymbite

Corymbite was not found associated with any of the other sulphides, and its occurrence is limited to the presence of isolated grains in contact with the gangue minerals. The grains which are equidimensional are more or less rounded in shape and have an average size of 0.04 m.m. It only occurs in very minor amounts with a colour paler than pyrite, a high reflectivity and isotropic in character.

(c) Tetrahedrite

The tetrahedrite is present as fairly large irregular masses, as well as smaller irregular grains, with an average size of 0.03 m.m. The smaller grains usually occur as isolated individuals in the gangue, whereas larger masses are generally associated with the cinnabar and enclose some of the earlier formed sulphides. The tetrahedrite has a pale-green-to-white colour; a Mohs hardness of approximately C to D and is isotropic. The colour of this tetrahedrite is paler than normal and may perhaps be attributed to the presence of a minor amount of mercury.

(d) Chalcopyrite

The chalcopyrite occurs only in association with the mineral X. It appears to be replaced by both the mineral X and the cinnabar, whilst the chalcopyrite also replaces the mineral X in part. The textural relationship between these three minerals is illustrated in photographs Nos. 3 and 3a. The chalcopyrite appears to be isotropic, has a pale brass colour, and was stained by 5% silver nitrate solution, which distinguished it from gold.

(e) Mineral X

In the cinnabar there occasionally occurs a fine graphic intergrowth with the cinnabar of a dark grey soft, isotropic mineral.



This mineral occurs only in the cinnabar and only as a graphic intergrowth. The mineral is not evenly distributed, but minor concentrations are found locally in the cinnabar. The mineral appears to be negative to all the reagents listed by Short (1940) and the grains are too small to allow for positive identification by either X-rays or chemical analysis. Wilson (1945) assumed this mineral to be a metacinnabar known as gundalenczarite which contains up to 4% of zinc. Because of the close association with cinnabar and this mineral this assumption may be correct.

The microscopic evidence indicates that the cinnabar has replaced the mineral X to form the relics as shown in photograph No. 3 or else formed a eutectic intergrowth with it.

(f) Stibnite

Stibnite occurs very locally in the ore body as a minor constituent. It is found as small grains varying in size from 0.02 m.m. to 0.07 m.m. and are more or less circular in shape. The grains occur mainly in the cinnabar and are illustrated in photograph No. 2.

The stibnite is white in colour and exhibits a higher relief and a more marked reflectivity than the cinnabar. It is strongly anisotropic from white to dark brown, but shows no reflection pleochroism. In one instance, two grains of stibnite were found in a grain of hematite. It had partially replaced the hematite along a thin crack to form a small sulphide concentration.

(g) Cinnabar

Cinnabar is the most prolific of the ore minerals in this deposit. According to Wilson (1945) the assays vary from 1 to 8% of mercury, according to the amount of unreplaced carbonate present. It is present either as irregular masses of a varying size, or as very minute disseminations in the carbonate gangue.

The cinnabar is strongly anisotropic from grey to a dark fiery red. The large individuals of cinnabar are not single crystals but consist of an aggregate of grains of varying crystallographic orientation as shown by the different extinction positions of the grains observed under crossed nicols. The anisotropism and red internal reflection of the cinnabar are so strong that only a few minute specks present in the calcite imparts a strong reddish colour to the carbonate.

Certain grains of cinnabar present in the larger masses exhibit a weak reflection pleochroism from white to grey, the latter being the

normal colour of the surrounding cinnabar. These particular grains showing the reflection pleochroism are also remarkably free from scratches, as compared with the normal cinnabar. From the above it is concluded that these particular grains are harder in certain crystallographic directions than others, and they also exhibit a weak reflection pleochroism in this particular crystallographic orientation.

(h) Digenite and Covellite

On the contacts of the tetrahedrite and the cinnabar, or on the contacts of the gangue and the tetrahedrite, there occur locally in the ore small concentrations of digenite and covellite. The digenite is pale blue and isotropic, while the covellite exhibits a reflection pleochroism from pale to dark blue, and is strongly anisotropic from pale pink to orange. These minerals were found occurring in two polished sections only.

5. PARAGENESIS OF THE ORE

The following paragenetic chart indicates the order of deposition of the ore minerals present in the cinnabar ores. The length of the lines indicates the period of deposition, and the thickness of the lines indicates the relative quantities of the particular mineral present.

PARAGENETIC CHART

	HYPOGENE	SUPERGENE
Pyrite	●	
Corynite	●	
Tetrahedrite	●	
Chalcopyrite	●	
Mineral X	●	
Stibnite	●	
Cinnabar	●	
Digenite		●
Covellite		●

From the paragenetic chart above it is seen that the pyrite is the first sulphide to have formed, and the microscopic evidence is the fact that the later sulphides surround the pyrite grains. The textural relationships indicate that there is no overlap in age

of the pyrite with any of the other sulphides.

As there are no contacts to show the textural relationship between the corynite and the other sulphides, it could not be placed in the paragenetic chart with certainty. Its position in the paragenetic chart is based mainly on the fact that it is harder than the tetrahedrite..

From the microscopic evidence it is clear that the cinnabar has partially replaced the tetrahedrite, as is illustrated in photograph No.4 . This shows that the tetrahedrite formed before the cinnabar.

The age relationship between the tetrahedrite and the stibnite is not clear, as there are no contacts between these two minerals. As the stibnite does not occur in the tetrahedrite, and since Edwards (1954) gives a lower temperature of formation for the stibnite than for tetrahedrite, it is considered to have formed after the period of tetrahedrite deposition. Grains of stibnite in the cinnabar are shown in photograph No. 2. As there are no contacts between the mineral X and the stibnite the age relationship between these two minerals could not be determined.

Because of the close association between the mineral X and the cinnabar, the tetrahedrite is considered to have formed before the mineral X, although there are no textural relationships between the mineral X and the tetrahedrite to prove this.

The textural relationships between the mineral X and the chalcopyrite as illustrated in photograph No. 3a indicate that these two minerals were probably deposited simultaneously.

As the cinnabar is not replaced by any other sulphides and replaces the earlier sulphides it is considered to be the last hypogene sulphide to have formed.

The digenite and later the covellite, were formed as a result of supergene action, after the period of hypogene sulphide deposition.

#### 6. ORIGIN OF THE ORE BODY

The ore deposit is considered to be a hydrothermal type of deposit, formed under conditions of a fairly low temperature. The period of cinnabar mineralization is considered by Mendelsohn (1938) to be the last stage of hydrothermal mineralization which occurred in the Murchison Range.

The pyrite grains only constitute a minor component of the ore suite, and appear to have mainly replaced some of the carbonate gangue. The pyrite crystals have been replaced by the later sulphides to a very small degree, for the contact between the crystal faces of the pyrite and the surrounding sulphides are straight with virtually no indentations into them. The corners of the grains have not been rounded off to any marked degree.

The tetrahedrite was positively identified by means of X-ray diffraction patterns. It is a fairly common constituent in these cinnabar ores and in the antimony ores of the Marchison Range. In these ores it is virtually devoid of inclusions, and is only associated with the cinnabar as the latter has partially replaced the tetrahedrite, as is illustrated in photograph No. 4. The tetrahedrite was probably deposited under intermediate temperature conditions. Edwards (1954) gives the temperature range for the formation of tetrahedrite as being between 250°C to 500°C. The minor concentrations appear to have mainly replaced the carbonate gangue, probably because it is more reactive than the other gangue minerals.

The eutectic intergrowth of the mineral X with the cinnabar resembles a graphic intergrowth. Lindgren (1930) and Anderson (1934) consider this type of texture to be indicative of hypogene replacement. This particular replacement intergrowth does not appear to be related to any specific crystallographic direction, but has advanced more or less evenly through the host, similar to a normal type of mineral veinlet. Some of the grains show definite small indentations which are curved concave towards the cinnabar, which is further evidence that the mineral X has been replaced by the cinnabar. On account of the intimate association of these two minerals it is considered possible that this mineral X is a metacinnabar as suggested by Wilson (1945).

Usually there is found in the ore a concentration of several relic crystals of the mineral X showing the graphic intergrowth with the cinnabar. It is considered that this concentration of relic crystals may well have been larger grains up to 0.20 m.m. in size of cinnabar. This introduction of the cinnabar resulted in the replacement of the major portion of the mineral X leaving only the relic crystals as shown in photograph No. 3c.

The chalcopyrite must have formed prior to the cinnabar as the latter is considered by Edwards (1954) to be a very low temperature sulphide and must have been the last sulphide to form.

The mineralizing solutions probably contained minor amounts of zinc and copper after the formation of the tetrahedrite. The zinc was possibly taken up by the mineral X to form the gudalcazarite and at the same time the little copper in the solution formed chalcopyrite locally in the ore. This has resulted in the texture illustrated in photograph No. 3a which is considered to be representative of simultaneous deposition of chalcopyrite and the mineral X, and cinnabar replacing these earlier sulphides.

With a further decrease in temperature and after a depletion of the Zn and Cu the mercury remaining <sup>in</sup> the ore forming fluids was deposited as cinnabar.

The microscopic evidence indicates that the stibnite formed prior to the cinnabar, as the latter has replaced the stibnite. This replacement has resulted in the rounding off of the stibnite grains, and in small indentations of cinnabar into the stibnite. These features are illustrated in photograph No. 2. Edwards (1954) considers stibnite to be formed in hydrothermal deposits below 250°C., so that there must have been a general drop in temperature after the formation of the tetrahedrite in order that the stibnite could form.

The stibnite grains are not considered to be a product of ex-solution, and Edwards (1954) does not record the formation of stibnite in cinnabar by ex-solution. In addition, there are no cracks near the stibnite to indicate that it may have been introduced into the cinnabar at a later period.

Cinnabar is considered by Edwards to be a low temperature sulphide, which is deposited by hydrothermal solutions below 250°C. From photograph No. 5 it can be seen that the cinnabar mainly replaced the gangue around the edges of the ankerite grains.

Narrow veinlets of cinnabar about 0.01 m.m. wide, were found in some of the chlorite bands. These veins are oriented parallel to the schistosity of the rock and have replaced the chlorite in this preferred orientation. In the hand specimen it is seen that the cinnabar is occasionally concentrated in bands 5.0 m.m. wide, and these bands are also oriented parallel to the schistosity of the enclosing rock. This banding is probably due to a preferential replacement of the carbonate-rich layers in the carbonate-quartz schist.

A gold assay of the cinnabar showed that the ore contains only 0.56 dwts. of gold per ton. This also suggests that the yellow mineral associated with the mineral X is chalcopyrite and not gold, since the

amount of this mineral present is considerably in excess of the quantity which would give rise to such an assay result.

The few minor concentrations of digenite and covellite are considered to have formed by supergene action on some of the copper-bearing minerals. As these minerals occur only on the contact of the tetrahedrite with the other sulphides they are not thought to have been formed by hypogene action.

From the foregoing discussion it is considered that the ore body was formed by replacement of the wall rock by hydrothermal solutions. During the later stages of ore formation when the cinnabar ore was deposited, the temperature of formation was probably initially about 250°C. and probably the majority of the cinnabar was deposited below 250°C., as this is the temperature of formation of cinnabar as stated by Edwards (1954). According to Lindgren (1913) deposits falling within this temperature range are classified as epithermal, but the mercury mineralization can only be considered as the final stage of a long period of mineralization in the Murchison Range, in which temperatures varied from high temperature at the commencement, to the low temperatures indicated above. It was during the period of intermediate temperature that the copper-zinc deposits were formed.

#### 7. ACKNOWLEDGEMENTS

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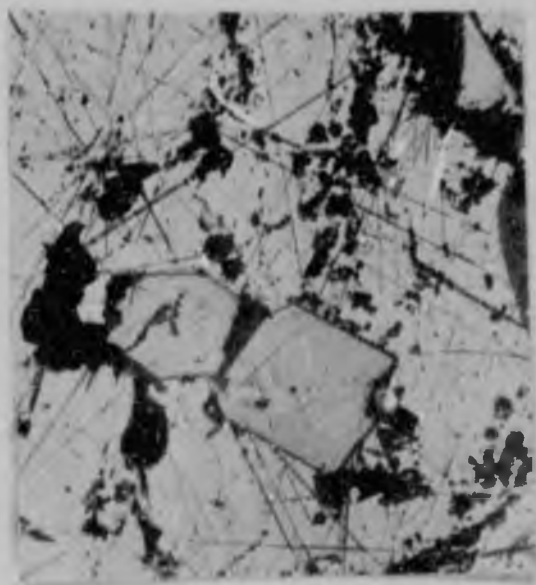
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Photograph No. 1 (polished section)

Grains of hematite (dark gray)  
surrounded by cinnabar (gray)  
x 140



Photograph No. 2 (polished section)

Grains of stibnite (white)  
being replaced by cinnabar (gray)  
x 210



Photograph No. 3 (polished section)

Antitaxial intergrowth of cinnabar  
(gray) with mineral X (dark gray)  
x 350

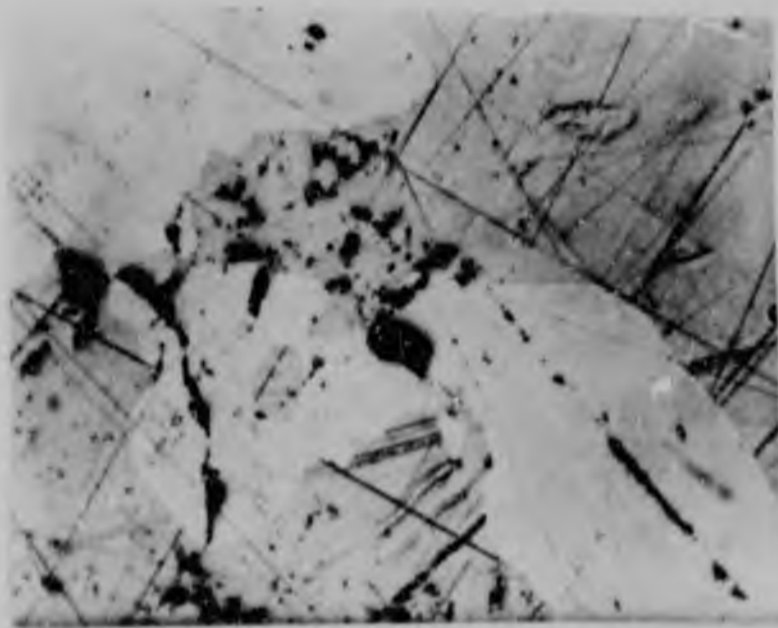


Photograph No. 3a (polished section)

Simultaneous deposition of chalcopyrite  
(white) and mineral X (dark gray)  
Note how the cinnabar replaces both  
the mineral X and the chalcopyrite.  
x 330

mineral X

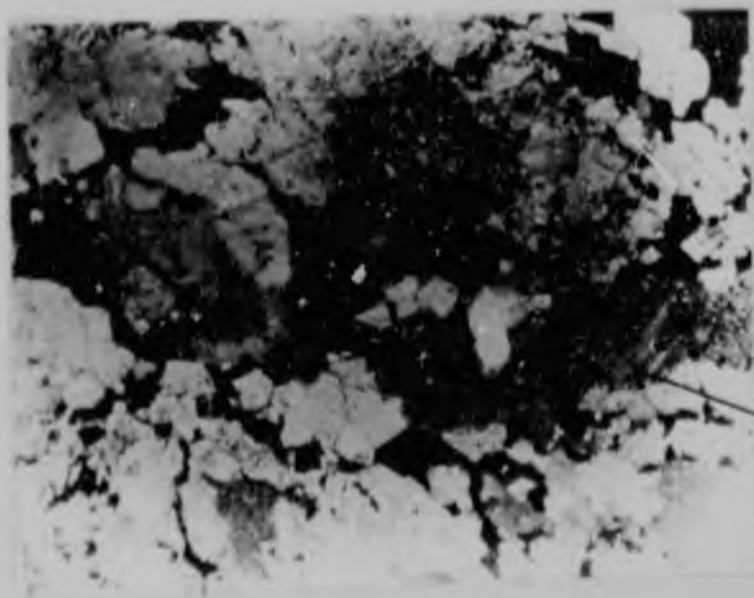




Photomicrograph No. 4 (polished section)

Cinnabar (light grey) replacing the tetrahedrite  
(Tet).

x 200



Photomicrograph No. 5 (thin section)

Cinnabar (black) replacing arsenite along crystal  
boundaries. The dark grains in the centre of the  
fields are arsenite grains in extinction position.  
The grain indicated shows narrow twin lamellae.

X nicola x 90

DECLARATION:

I hereby declare that the dissertation entitled:  
"A Mineralogical Investigation of the Letaba Copper-Zinc Ores and  
the Monarch Cinnabar Deposits, located in the Marchison Range of  
the Eastern Transvaal", has not been submitted for a Master's degree  
at any University.

  
S.G. MAUSMANN

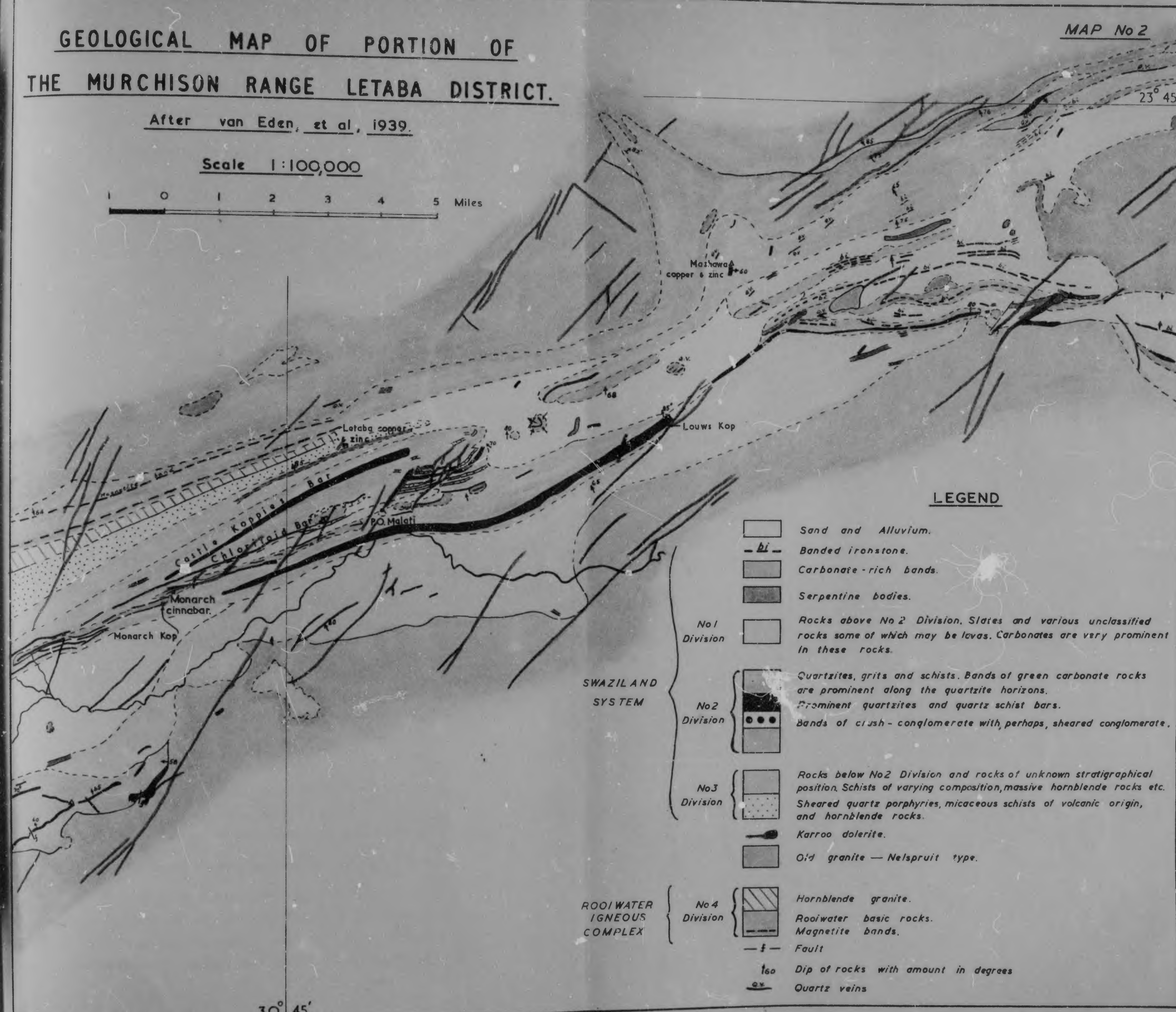
15th January, 1959.

# GEOLOGICAL MAP OF PORTION OF THE MURCHISON RANGE LETABA DISTRICT.

MAP No 2

After van Eden, et al, 1939.

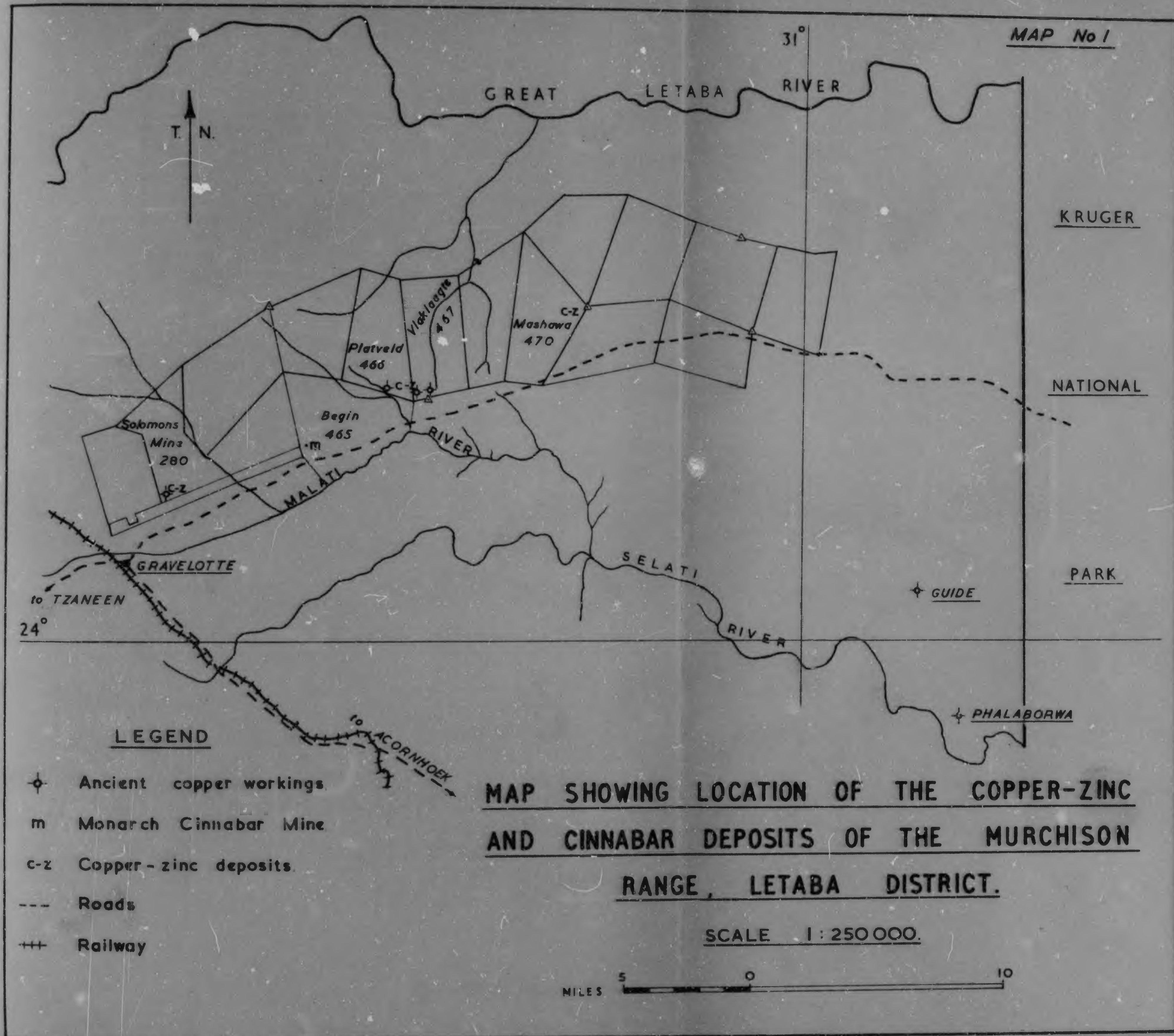
Scale 1:100,000



## LEGEND

- Sand and Alluvium.
- Banded ironstone.
- Carbonate-rich bands.
- Serpentine bodies.
- No 1 Division Rocks above No 2 Division. Slates and various unclassified rocks some of which may be lavas. Carbonates are very prominent in these rocks.
- No 2 Division Quartzites, grits and schists. Bands of green carbonate rocks are prominent along the quartzite horizons. Prominent quartzites and quartz schist bars.
- No 2 Division Bands of crush-conglomerate with perhaps, sheared conglomerate.
- No 3 Division Rocks below No 2 Division and rocks of unknown stratigraphical position. Schists of varying composition, massive hornblende rocks etc.
- No 3 Division Sheared quartz porphyries, micaceous schists of volcanic origin, and hornblende rocks.
- Karroo dolerite.
- Old granite — Nelspruit type.
- No 4 Division Hornblende granite.
- No 4 Division Rooiwater basic rocks.
- No 4 Division Magnetite bands.
- Fault
- Dip of rocks with amount in degrees
- Quartz veins

30° 45'



**Author** Hausman S G

**Name of thesis** A Mineralogical investigation of the Letaba Copper-Zinc ores and the Monarch Cinnabar deposits located in the Murichson range of the Eastern Transvaal 1959

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