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A

MINERALOGICAL

STUDY ON SOME ORE

FROM THE FRENCH MINES

AT HEDLEY, B.C.

22/3/62.

Did not lay down format
in black + white.
RM

8th March, 62.

A. M. Coode.

Geology 409, suite 4.

Introduction.

The suite of ores came from the French Mines (originally the Oregon Property) near Hedley, B.C. The camp is not far from the Nickel plate intrusions and the ores lie in the same limestone formation.

MEGASCOPIC DESCRIPTION.

The most casual inspection of the hand specimens shows that the rock which hosts the ore minerals is a skarn. In places there are large anhedral crystals of calcite, having a vein-like structure, but these are rare and the rock is predominantly a ~~skarn~~ garnet-diopside skarn.

The skarn itself varies from a coarse grained rock, showing good euhedral crystals of garnet and radiating and fibrous crystals of Wollastonite and diopside, to a fine grained rock showing the same components. The latter texture is the most commonly met.

At places through out the skarn, it was noticed that quartz was present as anhedral 'blebs', though this was not a common occurrence.

The metallic minerals were distributed evenly throughout the garnet^{diopside} and calcite, but ~~did~~ never seem to ~~be~~ lie, in any quantity, in the Wollastonite. If we assume that the original limestone was the host rock, then these facts seem to indicate that either the metallic minerals developed faster than the garnets^{diopside} and calcite but not as fast as the

Wollastonite, or that they (the metallic minerals) were deposited after the Wollastonite and before the diopside, garnets and calcite.

It is a well known fact that Wollastonite, in a closed system, can be formed from the reaction of calcite and silica together. It may be argued that the limestone on the Oregon property was not a closed system; however if we initially only introduce silica ^{and heat} (plus or minus water - ~~and~~ pressure) then it can be considered to be a closed system. Thus it is proposed that

$$\text{CaCO}_3 + \text{SiO}_2 + \text{H}_2\text{O}(\text{hot}) \rightleftharpoons \text{CaSiO}_3 + \text{H}_2\text{CO}_3(\text{liquid})$$
where the carbon dioxide is taken out of the system ~~and is removed~~, leaving behind the silica, unaltered limestone and Wollastonite.

This theoretical approach is substantiated ^{by evidence} from the property (see previous paragraph Re: Wollastonite crystallization being first completed).

The rocks of the suite are usually compact but in one specimen vugs are present. These vugs are lined by limonite and molybdenite. These vugs were probably solution cavities in the limestone and were not filled in, completely, during the period of contact metamorphism.

The following minerals were found and tentatively identified in the hand specimen:-

- 1) Molybdenite. Previously described (Suite #3).
- 2) Arsenopyrite. Previously described (Suite #3).
- 3) Chalcopyrite. Previously described (Suite #2).
- 4) Bismuth Tellurides. These minerals (two types were seen in the hand specimen) are soft (H=2)

have a bright reflecting surface and are platey.
In the hand specimen the tellurides are subhedral to anhedral and have a maximum size of 20 mm in diameter. In one specimen the two tellurides lay side by side in an 'atoll' texture. It was possible, by comparing one with another, to differentiate them ~~as to texture~~. In another specimen the telluride had been untouched ~~and~~ for some time and had a dirty brown-yellow ^{tarnish} ~~color~~ on it.
5) Niccolite. Previously described (Suite #1).

MICROSCOPIC EXAMINATION.

THIN SECTION.

Mode:-

10% Calcite

50% ~~Diopside~~ Diopside.

30% Garnet (Andradite and/or Grossularite).

10% Bismuth Tellurides (?) - Opaque minerals.

Texture:-

The slide is composed of anhedral crystals of ~~Diopside~~ ~~Diopside~~, Calcite, Garnet and an opaque mineral. The calcite only appears as remnants in the rock & ~~is~~ is in contact with the ^{diopside} ~~Diopside~~ indicating that equilibrium had been reached with the rejection of the carbon dioxide. The garnet and opaque mineral(s) are alligned to a certain extent, and appear to lie in a "fracture" system.

The Garnet is isotropic.

MICROSCOPIC EXAMINATION

THIN SECTION

Modal

10% Calcite

20% ~~Diopside~~ Diopside

30% Garnet (Androsite and/or Grossularite)

10% Biotite (Tremolite?) - Opaque minerals

If the fluid pressure (in bars) in the skarn falls within the limits $0 < P < 1000$, then the temperature of formation of diopside, which is less than the temperature of formation of wollastonite, from calcite and silica falls between 400 to 600°C. This indicates that ~~the~~ the garnets were not subjected to stress and the temperature of formation of the skarn is $500 \pm 100^\circ\text{C}$, depending on the ~~the~~ fluid pressure. Taking later information into account (see Fig XI), i.e. the exsolution of chalcopyrite from bornite at 475°C, it appears ^{that} the deposit was formed between 500-600°C. Turner and Verhoozen (1960)

History & Origin.

The rock was once a limestone (purity unknown) which has been altered by the presence of a hot batholith (at depth) and dikes. The ferromagnesium and alumina content may be partially derived from the impurities that were originally in the limestone (such as argillaceous and siliceous material) and partially from the influx of minerals from the batholith that were deposited during the period of metasomatism. The opaque mineral(s) and garnets were concentrated along a "fracture" system whereas the ~~Diopside~~ ^{Diopside} was evenly distributed throughout the rock. This indicates (~~Diopside~~) that the ~~Diopside~~ ^{Diopside} was one of the first minerals formed and that only later ~~Diopside~~ ^{did} the garnets and metallic minerals crystallized.

The Garnet is isotropic. This indicates that either there was no stress present and the garnet formed and crystallized at "whatever temperature it pleased" or else stress may or may not have been present but the temperature was ~~in excess of~~ ^{greater than} ~~800°C~~ 800°C (it has been suggested that garnets in skarn stressed below 800°C are not isotropic). As the limestone has most probably been stressed by the intrusion of the batholith it would mean that the skarn zone was formed at a temperature in excess of 800°C . However both points of view should be considered in the light of other evidence.

The "fracture" system, along which the later minerals were intruded, were probably the remnants

of the cracks in the limestone, along which water flowed, rather than tension cracks,

STUDY OF THE POLISHED SECTION.

1) Molybdenite.

2) Arsenopyrite.

3) Chalcopyrite.

4) Niccolite.

5) Gold. Previously described (Suite # 2).

6) Bismuth Tellurides (Josite & Hedleyite) have a bright white colour, ~~with~~ a good polish, a hardness of A to B and good anisotropism.

Optical data.

Bismuth Tellurides have a good polish, a bright white colour. They are not pleochroic but have a reasonably strong anisotropism going from light pink to yellow to light blue. When the two tellurides lie side by side one appears a darker-grey colour than the other.

Etch tests.

Mineral "A". $HgCl_2$, KOH , KCN , HCl all negative, but there is a slight reaction with $FeCl_3$ and effervescence with HNO_3 .

Mineral "B" $HgCl_2$, KOH , HCl , $FeCl_3$ positive with brown staining and etching. KCN , negative. HNO_3 positive with brown stain, etch and effervescence.

Mineral "A" appeared to surround Mineral "B".

7) Bornite has a characteristic pink colour, a hardness of 5, it is not sectile and will not react with $HgCl_2$ (Cu reacts quickly).

Optical data.

Bornite has a good polish, a pink colour, is non pleochroic and non-anisotropic.

Etch data.

HNO_3 effervesced and stained the surface brown. KCN and $FeCl_3$ stained the surface brown and orange respectively and HCl , KOH and $HgCl_2$ were all negative.

8) Sphalerite. Previously described (Suite #2).

9) Cobaltite. Previously described (Suite #3).

10) Skutterudite has a dirty white (yellowish) colour, is very hard ($H=F$) and is isotropic.

Optical data.

Skutterudite has a 'creamy colour', a good polish, is non-pleochroic and non-anisotropic.

Etch data.

The specimen effervesced slowly with HNO_3 and etched. FeCl_3 turned brown ~~stain~~ but all other tests (HCl , KCN , KOH , HgCl_2) were negative.

- 11) Saffrolite has a greyish white colour is strongly anisotropic, resembling arsenopyrite, but HgCl_2 stains differentially light brown.

Optical properties.

Saffrolite is a greyish white colour, has a good polish, is non-pleochroic but strongly anisotropic.

Etch data:

HCl , KCN , KOH all negative. FeCl_3 and HgCl_2 ^{both} ~~are~~ stained brown. HNO_3 slowly effervesced and etched.

- 12) Chalcoite has a bluish-grey colour, is soft ($\text{H}=\text{B}$) and has a very weak anisotropism.

Optical data:

Chalcoite has a good polish, a bluish-grey colour, is non-pleochroic and slightly anisotropic.

Etch data:

HCl , KOH and HgCl_2 all negative. FeCl_3 stains blue, KCN stains black and etches. HNO_3 effervesces strongly and stains mineral blue.

TEXTURES AND EVIDENCE FOR A PARAGENETIC SEQUENCE

The minerals present can be split up into three groups. The first group is composed of the cobalt-nickel minerals. The second is composed of the copper-iron minerals. The last group is composed of the remaining minerals.

The minerals of the first group are: cobaltite, skutterudite, niccolite and saffrolite. Euhedral to subhedral crystals of cobaltite lie in an anhedral mosaic of skutterudite, indicating that the skutterudite crystallized later than the cobaltite. Euhedral to subhedral crystals of niccolite lie in the saffrolite (Fig III), which has crystallized as a crystal mosaic. Once again the niccolite must have started to crystallize before the saffrolite. The skutterudite surrounds the saffrolite (see Figs III & IV), both ~~crystals~~ ^{crystallized} minerals are anhedral and composed in crystal mosaics. The author believes that the saffrolite was crystallized in vugs and channels in the skutterudite (as well as being a reaction product, by the introduction of nickel ions into the saffrolite) as the ionic concentrations of the nickel (~~increased~~) in the gas or vapour increased. (~~the gas or vapour~~) The skutterudite has crystallized as euhedral to subhedral crystals in both chalcopyrite and bornite indicating that the copper-iron minerals came in ~~off~~ later than the cobalt-nickel group (see of Figs IV & V).

The minerals of the second group are: sphalerite, bornite, chalcopyrite and chalcocite.

There are no euhedral or subhedral crystal interrelationships; ~~and~~ but all crystal boundaries in this group are anhedral, so that, when several crystals of a certain mineral have crystallized the resulting texture is a allotriomorphic-granular, crystal mosaic. The relevant crystal ~~inter~~ interrelationships in this group are between the bornite and chalcopyrite and chalcocite and bornite. In some samples the chalcopyrite only appears as small inclusions in the bornite, which are aligned along the crystallographic directions of the bornite ^(see Fig. VI). In other samples the concentrations of the chalcopyrite are equal to that of bornite so that the ex-solution of the chalcopyrite is less common and only seems to occur ^{near the} borders of the bornite, chalcopyrite contact ^(see Fig. VII). These are three possible processes which could have occurred :-

- ① replacement of bornite by chalcopyrite
- ② replacement of chalcopyrite by bornite
- ③ crystallization of both bornite and chalcopyrite at the same time.

Although all three have probably occurred the author prefers the last to describe the general picture, i.e. the bornite and chalcopyrite crystallized contemporaneously and, where there were higher pockets of iron ions in the bornite, chalcopyrite was formed by exsolution.

The chalcocite seems to be formed as a replacement product of bornite rather than the result of exsolution from bornite.

The sphalerite appears only in contact with chalcopyrite. The sphalerite lies between the chalcopyrite and gangue indicating it crystallized before the chalcopyrite.

The chalcopyrite and bornite "anhedrally" surround subhedral cubes of ~~skutterudite~~ skutterudite (see Fig II & V), hence the copper-iron minerals ~~crystallized~~ crystallized later than the cobalt-nickel minerals.

The last group of minerals is composed of both the bismuth-tellurides, Tossite and Hedleyite, molybdenite, gold and arsenopyrite.

Wherever molybdenite occurs in contact with other minerals, the second mineral surrounds the molybdenite or lies interstitially between curving plates. Chalcopyrite and saffrolite both ~~appear~~ lie interstitially between plates of molybdenite (see Fig II). Arsenopyrite has crystallized around molybdenite plates as has both bismuth tellurides, (see Fig II and IX). The molybdenite must have crystallized out before all these minerals and groups, hence it must have crystallized first. The gold is anhedral ~~and~~ (Fig IX) and probably started to crystallize before the arsenopyrite but continued crystallizing after the arsenopyrite ^{had} stopped.

Good euhedral crystals of arsenopyrite were seen partially replaced by a bismuth telluride and completely surrounded by bornite. This fact as well as the relationship between the arsenopyrite and gold indicate that the

arsenopyrite crystallized out before (or may have crystallized at the same time as) the cobalt-nickel group. Also the bismuth tellurides must have crystallized after the arsenopyrite and before the copper-iron group. However ~~about~~ the bismuth tellurides' relationship with the cobalt-nickel minerals could not be found. There are two different bismuth tellurides, A and B (one is Joseite and the other is Hedleyite). A crystallized first, ~~and~~ ~~was~~ while B crystallized in the vugs of A (see Fig I).

MINERAL MODE.

1)	MOLYBDENITE	10%
2)	GOLD	3%
3)	ARSENOPYRITE	10%
4)	COBALTITE	5%
5)	SKUTTERUDITE	15%
6)	NICCOLITE	3%
7)	SAFFROLITE	10%
8)	SPHALERITE	2%
9)	BORNITE	11%
10)	CHALCOPYRITE	10%
11)	CHALCOHITE	3%
12)	BISMUTH TELLURIDE 'A'	15%
13)	" " 'B'	8%

The following ~~is~~ diagrammatic paragenetic sequence is based on the evidence from the polished sections. The gold and arsenopyrite could have crystallized out at any

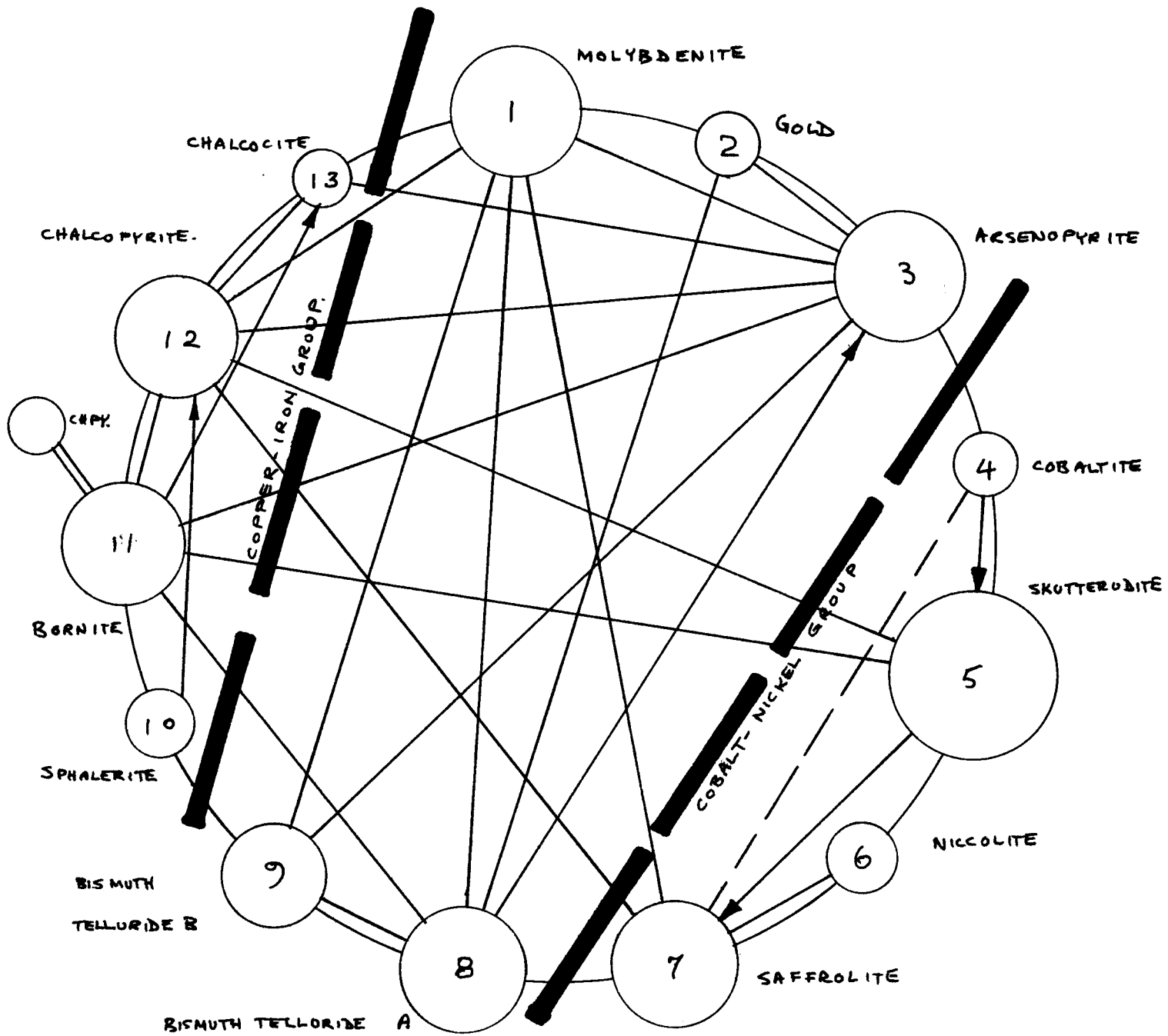
temporal position on this paragenetic sequence between 2 and 7; similarly the bis muth Tellurides could have crystallized out at any position between 4 and 9.

The deposit is a contact-metasomatic, or pyrometasomatic, deposit with temperatures ^{above} ~~at~~ ^{start of} 475°C (temp. of exsolution of chalcopyrite from bornite), Schwartz (1931) and "high" pressures (according to Bateman (1950)).

Bibliography.

- Schwartz, G.M., Econ. Geol., 26, pp 186-201 (1931).
Bateman, A.M., Economic Mineral Deposits, p 358 (1950).
Turner, F.J. and Verhooogen J., Igneous and metamorphic Petrology, 2nd Edition. pp (518-520) (1960).

PARAGENETIC SEQUENCE.



A and B Bismuth Tellurides

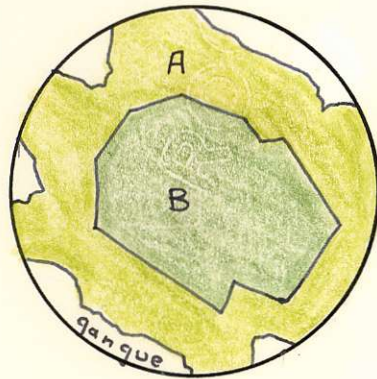
Arseno = Arsenopyrite

Mo = molybdenite

Chpy = Chalcopyrite

Sk = Skutterudite

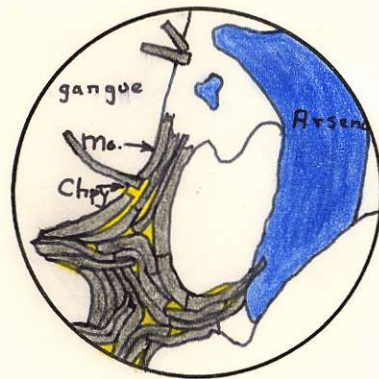
Sa = Saffrolite



LOW POWER.

FIG I.

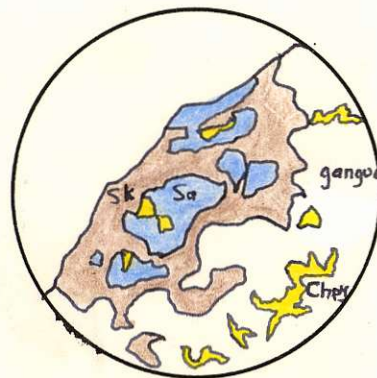
BISMUTH TELLURIDE 'A'
SURROUNDING BISMUTH
TELLURIDE 'B'.



MEDIUM POWER.

FIG II

MOLYBDENITE PLATES LATER
INTRUDED BY CHALCOPYRITE.
A PLATE OF MOLYBDENITE
'INTRUDES' ARSENOPYRITE.



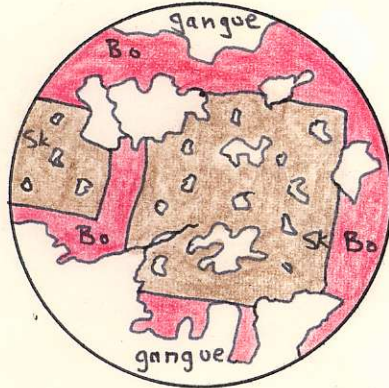
MEDIUM POWER.

FIG III

SAFFROLITE WITH CHALCOPYRITE
INCLUSIONS SURROUNDED BY
SKUTTERUDITE. CHALCOPYRITE
FILLS VUGS IN THE GANGUE.

Bo = Bornite.

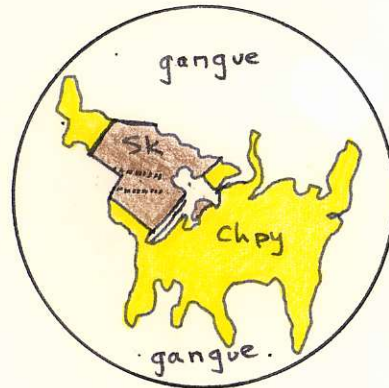
Chcite = Chalcocite.



CRYSTALS OF SKUTTERUDITE
LIEING IN BORNITE WITH A
SIEVE TEXTURE.

MEDIUM POWER

FIG IV



SUBHEDRAL CRYSTAL OF
SKUTTERUDITE LIEING IN
CHALCOPYRITE.

HIGH POWER

FIG V

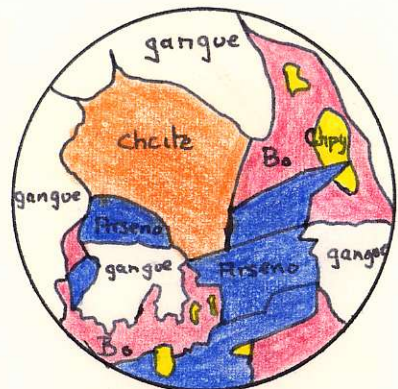


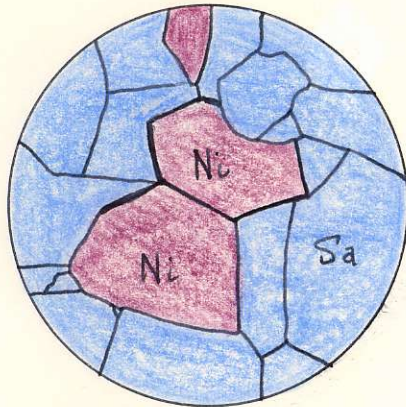
DIAGRAM SHOWING THE
INTER-RELATIONSHIP BETWEEN
BORNITE, CHALCOPYRITE, CHALCO-
CITE AND ARSENOPYRITE.

MEDIUM POWER

FIG VI

Ni = Niccolite

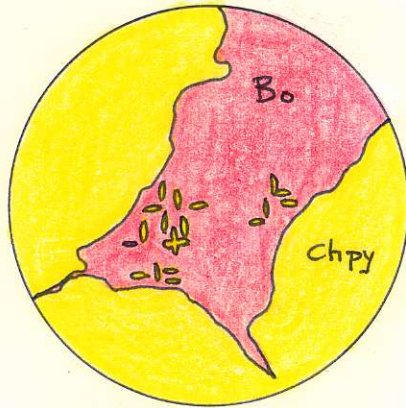
Bo = Bornite



SUBHEDRAL CRYSTALS OF
NICCOLITE SURROUNDED BY
ANHEDRAL SAFFROLITE CRYSTALS.

MEDIUM POWER

FIG VII



EXSOLUTION OF CHALCOPYRITE
FROM BORNITE

HIGH POWER

FIG VIII

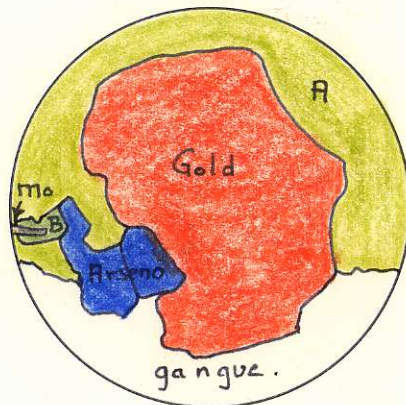


DIAGRAM SHOWING THE
INTER-RELATIONSHIP BETWEEN
GOLD, BISMUTH TELLURIDE A#B,
ARSENOPYRITE AND GANGUE
AND MOLYBDENITE.

MEDIUM POWER

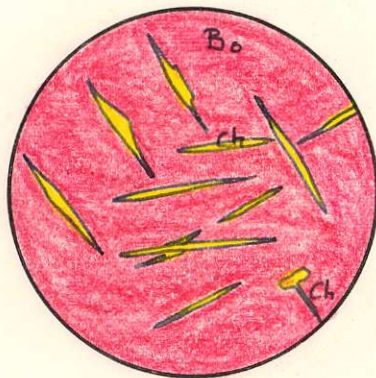
FIG IX



SAFFROLITE SURROUNDED BY
SKUTTERUDITE.

MEDIUM POWER

FIG IX.



EX-SOLUTION OF CHALCOPYRITE
FROM BORNITE. NOTE HOW
THE LATER EXOLUTIONS
DISPLACE EARLIER ONES.

HIGH POWER.

FIG XL.