UNIVERSITE DU QUEBEC A CHICOUTIMI

GEOLOGY OF THE CHIBEX GOLD DEPOSIT, CHIBOUGAMAU, QUEBEC

PAR

© WAYNE R. WAGNER

DEPARTEMENT DES SCIENCES APPLIQUEES

MEMOIRE PRESENTE EN VUE DE L'OBTENTION DE
MAITRE EN SCIENCES APPLIQUEES (M.Sc.A.)
(SCIENCES DE LA TERRE)

NOVEMBRE, 1978

Bibliothèque
Paul-Émile-Boulet

UQAC
Université du Québec
à Chicoutimi

<u>Mise en garde/Advice</u>

Afin de rendre accessible au plus grand nombre le résultat des travaux de recherche menés par ses étudiants gradués et dans l'esprit des règles qui régissent le dépôt et la diffusion des mémoires et thèses produits dans cette Institution, **l'Université du Québec à Chicoutimi (UQAC)** est fière de rendre accessible une version complète et gratuite de cette œuvre.

Motivated by a desire to make the results of its graduate students' research accessible to all, and in accordance with the rules governing the acceptation and diffusion of dissertations and theses in this Institution, the **Université du Québec à Chicoutimi (UQAC)** is proud to make a complete version of this work available at no cost to the reader.

L'auteur conserve néanmoins la propriété du droit d'auteur qui protège ce mémoire ou cette thèse. Ni le mémoire ou la thèse ni des extraits substantiels de ceux-ci ne peuvent être imprimés ou autrement reproduits sans son autorisation.

The author retains ownership of the copyright of this dissertation or thesis. Neither the dissertation or thesis, nor substantial extracts from it, may be printed or otherwise reproduced without the author's permission.

ABSTRACT

A gold copper deposit in Archean mafic volcanic rocks, near the eastern limit of the Abitibi Greenstone belt about 2 km north of the Grenville Front, and 65 km southwest of Chibougamau, Quebec, is described with reference to major mineralogy, textures and alteration. Host rocks consist of an intrusive subvolcanic gabbro sill and mafic and felsic volcanic rocks formed in a volcano-sedimentary environment. This sequence was intruded by felsic and diabase dykes. Mineralization consists of native gold and chalcopyrite in brecciated quartz veins, formed as fracture-fillings, located in three subparallel shear zones cutting the gabbro, mafic and felsic volcanic rocks. Chalcopyrite, pyrite, pyrrhotite and minor sphalerite are found in breccia interstices and in disseminations near the veins but are not spatially related to the gold mineralization. The gold is contained in quartz and albite. Textures show it was the last mineral to be deposited in the veins.

A mineral identified as anhydrite is found in the 'main' shear and the mafic volcanic rock unit of the mine sequence. As anhydrite has not been found elsewhere in the region it may be possible to use its presence as a stratigraphic indicator.

A hydrothermal lateral secretion origin is postulated for the deposit. Basic, reducing, carbonate and H_2S-bearing fluids have the capability to transport the mineralization of the deposit and to produce the alteration noted in the host rocks. The deposition of the gold mineralization took place during late stages of, or after, regional metamorphism.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

I. INTRODUCTION

I.A. LOCATION

The Chibex deposit is located approximately 400 km north of Montreal and 65 km southwest of Chibougamau in the eastern Abitibi district of Quebec. The shaft is located in the northwest corner of Rohault Township near the north boundary and the mine workings extend north into La Dauversiere Township. (Figure 1,2)

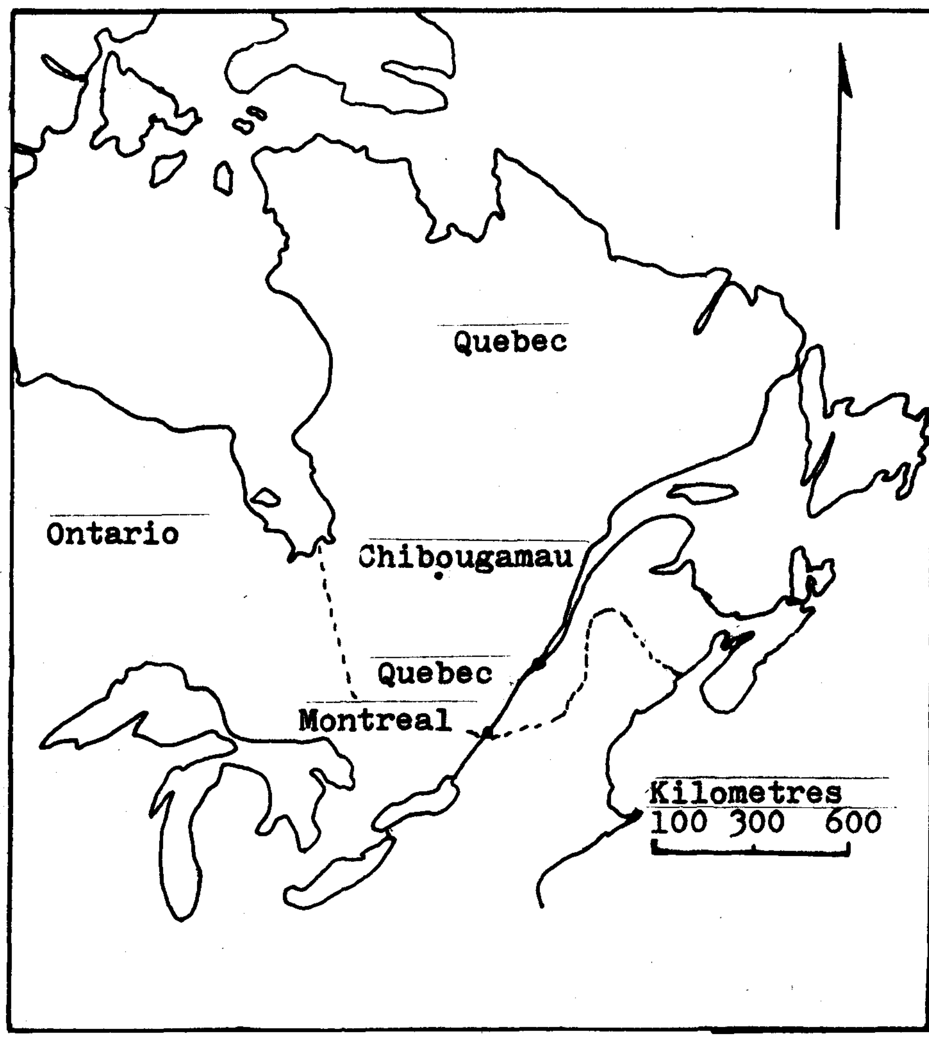


Figure 1: General location Map.

I.B. HISTORY

The history of the property is complex and difficult to describe in detail. Initial development work was done by Chibougamau Explorers Ltd, with the major work after this done by Anacon Mines Limited, Chibex Limited, and Valley Mining Corporation. Presently the property is controlled by NBU Mines and Falconbridge.

Mineralization was discovered in 1950 during surface prospecting on the property on which the Chibex mine is now located. The main ore-bearing zone was discovered and outlined by drilling carried out in 1951-1952. Underground development and production from this zone and others found subsequently were carried out from a 585 metre three-compartment shaft until 1960 when the mine was shut down for refinancing, shaft deepening and further underground development. In 1961 when the surface plant was destroyed by fire the operation was closed.

Surface exploration in the mine area was started again in 1970 in anticipation of higher gold prices. The mine was dewatered and rehabilitated in late 1973 and was in production by late 1974. Financial and metallurgical problems, with lower gold prices, forced the operation to close again in late 1975.

Exploration during the 1950s indicated mineralized areas throughout the region especially to the north and west of the mine. However, nothing of economic significance has been found. Underground development by inclined ramp has been carried out on two of these mineralized areas, one located 1½ km west of the shaft on the continuation of the main zone and another approximately 5 km to the southwest.

The deposit has previously been described by Malouf and Thorpe (1957) who concluded that the mineralized veins are localized by "acid trap dykes" in fault and shear zones. They postulated a hydrothermal origin for the deposit. Mamen (1955) has briefly described the geology of the deposit and the initial operation.

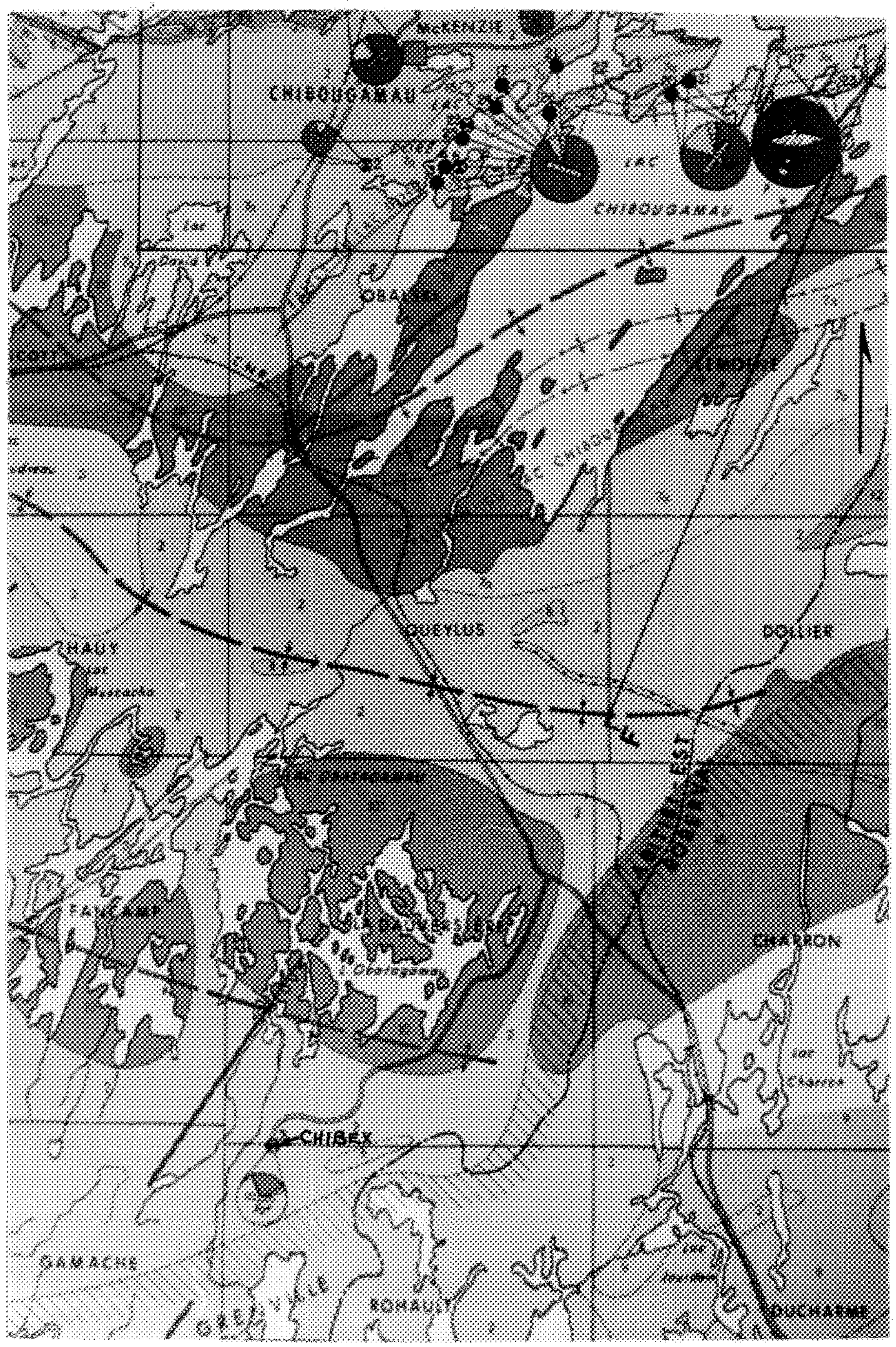
Production from the mine between 1956 and 1960 was 622,215 tonnes grading 0.24 oz,Au/tonne, 0.17 oz.Ag/tonne and 0.50% Cu. Production figures for 1974-1975 are not available.

I.C. REGIONAL GEOLOGICAL CONTEXT

The geology of the La Dauversiere and Rohault Townships was mapped and described on a scale of 1 mile to 1 inch by Imbault (1959) and Gilbert (1959). Hebert (1974, 1976, 1977) has remapped and described parts of this area on a scale of 1:12,000. Generalized geology is shown in Figure 2.

The deposit is located near the eastern limit of the Superior Province in a belt of Archean mafic lavas and pyroclastic rocks extending west to Desmaraisville, (Duquette 1970) which has been called the South Chibougamau Greenstone Belt. At this time not enough detailed mapping has been done to correlate these units with those found near Chibougamau which are described by Allard (1976) and Duquette (1970). Age dating done in the immediate vicinity shows a range of dates related to: rock type, method used, and distance from the Grenville Front (Wanless and Loveridge 1972, Wanless et al 1970, Allard 1976). In general, dates become younger towards the south ranging from 3825 my in the La Dauversiere stock to 950 my south of the Grenville Front. Problems exist in the interpretation and application of this age data to mineral deposits of the area. (Allard 1976, p.307 to 311)

The deposit is approximately 5 km south of the La Dauversière granodiorite stock (13 km diameter), 1½ to 3 km northwest of the garnet isograd associated with the Grenville Front, and is situated on the south limb of a postulated east plunging anticline shown by Duquette (1970). Figure 2. The host rocks dip steeply and strike nearly east-west with all tops facing south. Recrystallization under medium to upper greenshist facies grade regional metamorphism has taken place. Metamorphic grade of the



0 5 10 km.

1. Felsic pyroclastics and mafic lavas
2. Mafic lavas, minor felsic pyroclastics
3. Felsic pyroclastics, mafic lavas
4. Pyroxenite
7. Anorthosite
8. Gabbro-diorite
9. Undetermined
10. Tonalite-diorite
12. Sedimentary rocks
13. Diabase dyke

Figure 2 Regional geology and location map
Source: Duquette 1970.

host rocks increases to amphibolite grade toward the Grenville Front to the south and to amphibolite hornfels facies towards the La Dauversière stock (Hebert 1979).

The stratigraphy in the region of the mine is described by Hebert (1979). The sequence, between the La Dauversière stock and the biotite gneisses of the Grenville Province consists predominantly of mafic pillowed and tuffaceous volcanic rocks which have metagabbro sills and feldspar porphyry dykes associated with them. A minor zone of undifferentiated meta-tuffs (200 m thick) is found immediately south of the La Dauversière granodiorite. This is followed by approximately 2800 m of porphyritic mafic volcanic rocks with increased alteration, carbonate-rich zones and porphyry dykes. The mine is located approximately 1600 m above the porphyritic-nonporphyritic contact in a part of the sequence which includes some felsic volcanic rocks and which is intruded by gabbro and numerous feldspar porphyry dykes. A graphite horizon lies immediately above the nonporphyritic mafic volcanic rocks followed by agglomerate and metasedimentary rocks which grade into biotite gneiss.

A large, northeast striking, diabase dyke, one of the many such dykes found in the region, is found 6 km west of the mine (Figure 2). Numerous smaller, finer grained diabase dykes are found parallel to this dyke in the mine area.

Major regional foliation is generally parallel to the rock unit contacts in the mine area. Regional fault systems striking approximately east-west, northeast and northnorthwest are described by Hebert (1979), Allard (1976), Duquette (1970), Graham (1957) and others. Discussion of the relative ages of these systems by Graham (1957) suggests that the east-west system is older than the one oriented north to northeast. Graham does not discuss the northwest system. Duquette (1970 pp 23-13) does not discuss the relative ages of these systems but leads one to believe that the east-west system is older than the northeast one. He feels that the north system is related to the Grenville Front and younger than the rest.

Personal observation and discussions with C. Hebert lead to the conclusion that all systems, at least in the Rohault-La Dauversière area, have undergone repeated movements. Relative ages and movements along faults and joints associated with these fault systems, as shown by evidence in the mine vicinity, are not always consistant. The relationship between these fault systems will only be partially known until a thorough structural analysis of the mine area is completed.

I.D. GENERAL MINE SEQUENCE

The mine units are described as found in a typical cross section through the mine from north to south or from the bottom to top of the sequence (Appendix 1-Figure 3). Metagabbro is found at the bottom of the sequence followed by metabasalts and finally by meta-rhyolite-rhyodacite. Felsic dykes, ore veins and various alterations are found throughout the section. Diabase dykes cut the entire section.

Mineralization (as seen in the developed area) is contained in multiple (brecciated) quartz veins located within, but not restricted to, three parallel sheared, altered zones about 100 m apart. The attitude of these ore zones is subparallel to the mine stratigraphy. The sequence of the zone is as follows:

1. The 'north' zone is about 120 m below the gabbro-metabasalt contact.
2. The 'main' zone (in the area of the shaft) is 10 to 60 m below the gabbro-metabasalt contact. Further west in the mine (700 m west of the shaft) the zone is closer to the contact. To the east and at depth it moves into the gabbro.
3. The 'south' zone is found 50 m above the mafic-felsic volcanic contact in the felsic volcanic rocks.

Along the eastern extensions of the 'north' and 'main' zones narrow veins occur in mafic volcanic blocks which are contained in the gabbro. It should be noted that the name 'main' zone has no general size or grade significance.

I.E. PURPOSE AND LIMITS OF STUDY

The mineralization in this deposit consists of native gold and chalcopyrite in brecciated quartz veins located in fractures and sheared altered zones in metagabbro, mafic and felsic volcanic rocks. Unmineralized shears, quartz veins and apparently similar altered zones are abundant in the region. In addition, however, areas within the mine have features such as pyrite and/or pyrrhotite rich bands (Plate 1) which suggest a volcanogenic type environment. Therefore a study of the mine was undertaken to describe the deposit with reference to the geological context, major mineralogy, textures, major alteration types and the general evidence for structural controls on the deposit. This study describes the major ore controls aiding in the development of a theoretical model for the deposit. When combined with Hebert's (1979) work which has been carried out concurrently the complete work will be an asset in definition of exploration targets in the La Dauversière-Rohault region.

Microscopic study and description of major mineralogy and textures of the host rocks has been concentrated on the 1350 level crosscut which shows the geological sequence containing the known mineralization. Although some parts of most veins and areas in the mine have their own megascopic peculiarities of alteration and other physical features such as shearing which vary in intensity and change abruptly, geological cross-sections through the deposit are similar and most of the alteration types are found throughout the mine. Specimens from other mine workings and drill core have been studied in addition to the 1350 level samples to confirm and assure completeness of the general microscopic study.

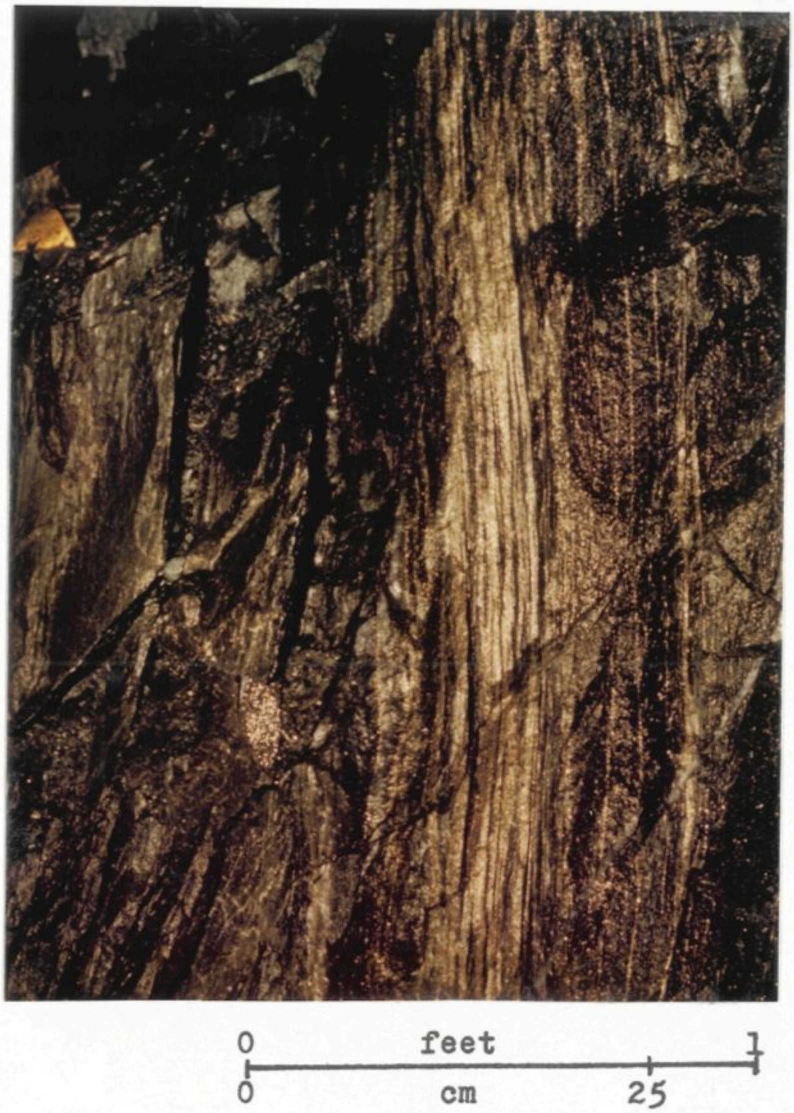


Plate 1 Sheared metagabbro showing pyrite-pyrrhotite rich bands (yellowish-white) and quartz stringers (white) in the main shear on the 900 level.

Textures and mineralogy of the major opaque phases in samples from the veins and host rocks throughout the mine and from drill core have been studied with the aid of polished sections and polished thin sections, X-ray diffraction and electron probe. No chemical analysis of rock types has been done because of the high degree of alteration and the general high volatile component of the host rocks.

The background for this study was obtained during employment in the Chibougamau area from 1971 to 1975, initially as field geologist and later as mine geologist in the Chibex mine.

II. PETROLOGY

A. GENERAL MINE UNIT DESCRIPTION

1. Metagabbro

(a) Megascopic Description

Metagabbro is found on the north (bottom) side of the mine sequence. Diamond drilling results indicate its thickness is greater than 500 m on the 1050 level near the shaft. Available information is consistent with a sill shaped body. Some areas of the mine, especially in the upper levels near the 'north' zone, have large blocks of volcanic rocks (75x75x25 m) which are surrounded by gabbro. The contact relationships of these blocks of volcanic rocks with the gabbro are not well exposed. In some instances they appear to be fault contacts while in others the volcanic rocks appear to be inclusions in the gabbro as found elsewhere in the Chibougamau area and described by Horscroft (1957).

This massive unit is fine to coarse grained, dark to medium green (colour index 70-90%) with hornblende and actinolite (to 1.5 cm). Generally, plagioclase is not obvious in hand specimen because of the extensive epidote alteration. Scattered zones have rounded blue quartz grains in 'eyes' (to 5 mm). Biotite, magnetite and pyrite occur as accessory minerals.

(b) Contacts

No evidence of contact metamorphism on the host rocks by the gabbro is apparent. Contacts are variable and range from sharp to a gradational or erratic zone up to 25 m as described below.

Core obtained from extensive drilling in the west end of the mine between the 450 and 750 levels of the mine has allowed detailed study of the gabbro-volcanic contact for a strike length of about 500 m. This contact appears conformable with the volcanic rocks and shows in detail the many features of the zone type of contact. In this area this zone consists of patchy, typically coarse gabbro interspersed with fine grained gabbro and lesser amounts of banded volcanic rocks. The contacts between the different textures and rock types as well as relative proportions of volcanic to intrusive rocks are generally gradational. The direction of the layering in the banded volcanic inclusions conforms to the direction of the gabbro-volcanic contact (and banding in the host volcanic rocks).

A vertical cross-section through the shaft (Appendix 1-Figure 3) shows the gabbro-mafic volcanic contact becomes closer to the mafic-felsic volcanic contact with depth. On the 1650 level, drilling indicates no mafic volcanic rock between the felsic volcanics and the gabbro whereas in the 1350 level crosscut there are 20 m of mafic volcanic rocks. This suggests a crosscutting relationship of the upper gabbro contact with the enclosing mafic volcanic rocks, as mafic volcanic layering is parallel to the mafic-felsic contact.

The north contact is only slightly known. The gabbro cuts across banded volcanics at an angle of 15° in the decline $1\frac{1}{2}$ km west of the shaft. Drilling indicates that the contact is predominantly sharp with a fine grained border zone 1-2 m thick.

(c) Microscopic Description

The metagabbro has been almost totally recrystallized to greenschist assemblages by regional metamorphism and all the original pyroxene and olivine have been replaced (Plate 2a). Blue-green hornblende pseudomorphs of pyroxene and poikiloblasts (to 1.5 cm) are the major constituents

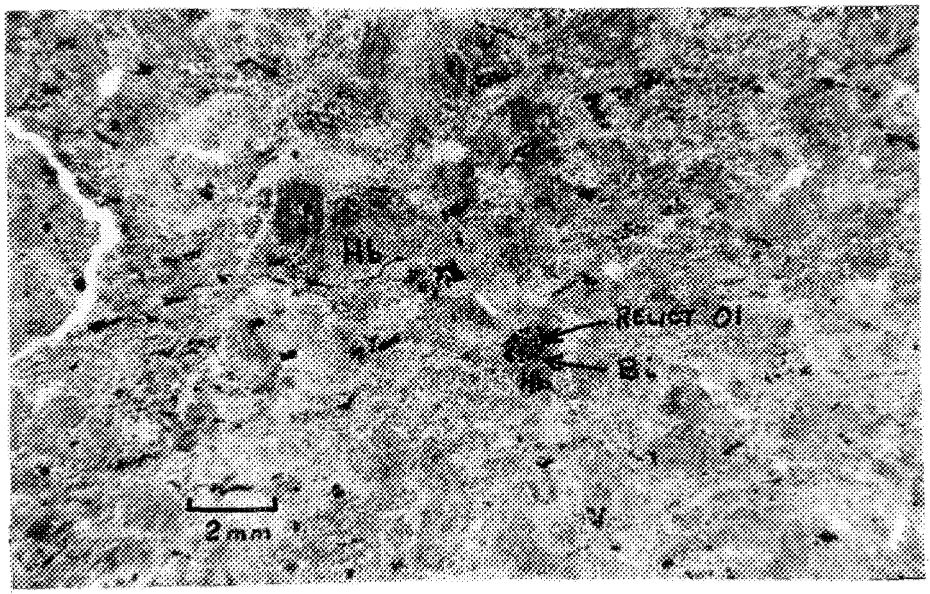


Plate 2a CBX 105 Typical fine grained metagabbro showing gabbroic texture. Cluster of anhedral to euhedral magnetite (outlined, relict Ol) showing relict olivine texture, hornblende (Hb) and biotite (Bi). See discussion p 15, Plate 3a, 3b. Plane polarized light.

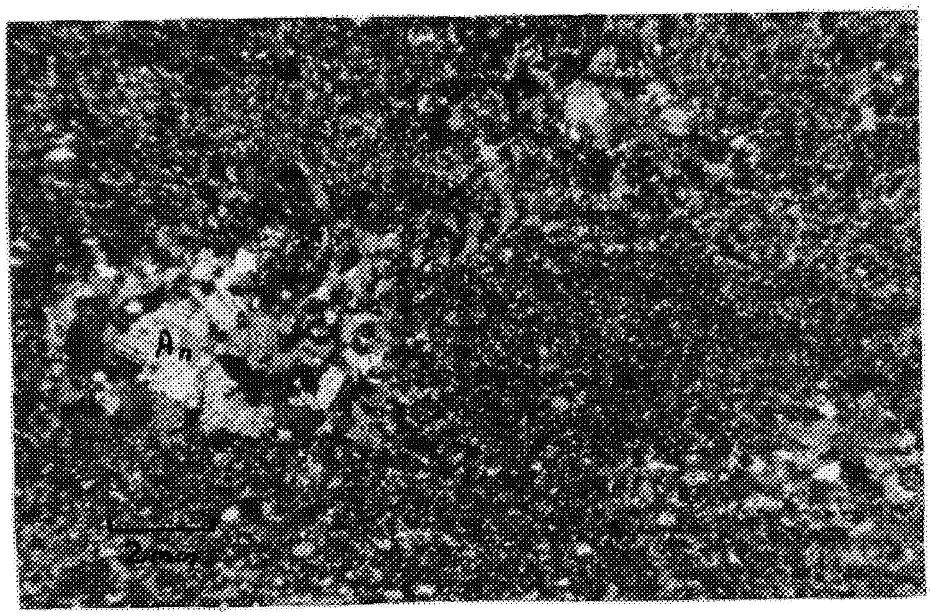


Plate 2b CBX 113 Sheared metagabbro from 'main' zone showing development of anhydrite (An). Crossed nicols.

of the rock. Blue-green actinolite (to 1 cm) occurs inter-stitial to and as overgrowths on the hornblende. Untwinned saussuritized plagioclase in polygonal grains (0.2 mm) is interstitial to and contained in the amphiboles. Epidote minerals are disseminated in semirectangular patches (2x1 mm) (relict feldspar texture) in veins throughout the rock and as replacement of hornblende and actinolite. The overall texture is subophitic and gabbroic. Hornblende pseudomorphs of pyroxenes (to 2 mm) are noted in some sections. Rounded patches (2 mm diameter) of subhedral lath-shaped oxides (0.2 mm) appear to show relict textures after olivine (Plate 3a,b) in which the original oxide breakdown products of olivine have been partly remobilized into subhedral grains. These patches are found within and interstitial to the amphiboles. Titanomagnetite is found in euhedral crystals (to 5 mm) in addition to the oxide relicts of olivine noted above. Some crystals have been partly altered to leucoxene which in places has been replaced by pyrite. Minor biotite and chlorite are concentrated near and in patches of opaque minerals. Pyrite (to 4%) is found as disseminated euhedral crystals (to 5 mm). Sericite, phlogopite-annite, tourmaline, carbonates and anhydrite are accessory minerals.

(d) Textural Variations

All thin sections of the metagabbro have approximately the same sized oxide pseudomorphs of olivine (2 mm) and saussurite pseudomorphs of feldspar (2 mm) showing the original grain size was uniform. Hornblende pseudomorphs of pyroxene have not been seen in enough thin sections to define size changes, if any. Grain size changes of the hornblende and actinolite (produced by recrystallization during regional metamorphism) occur within this unit and define megascopically discernable 'layers' generally

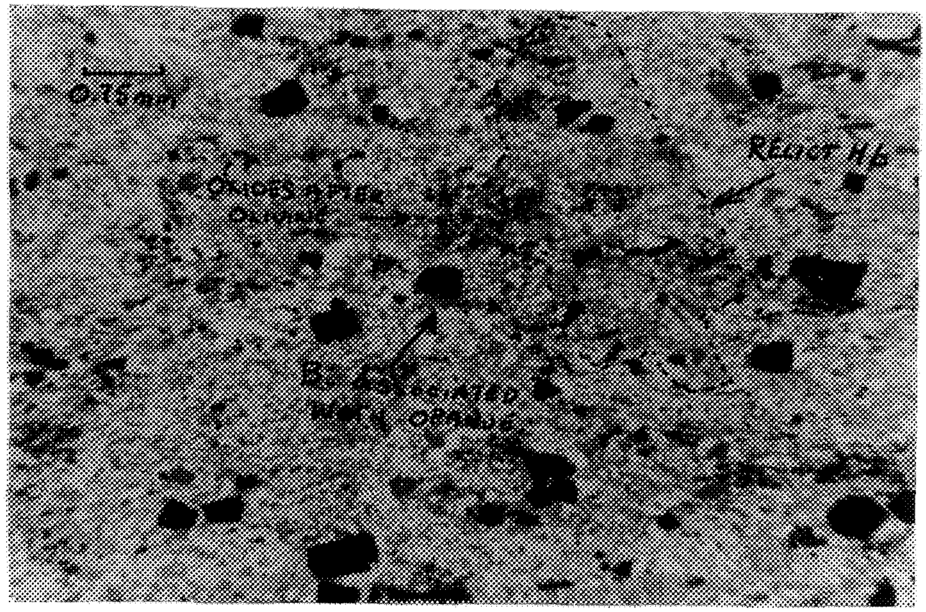


Plate 3a CBX 143 Metagabbro showing euhedral grains and aggregates (relicts after olivine) of oxides (titano magnetite) in a fine matrix of chlorite, biotite and plagioclase. Hornblende pseudomorph of pyroxene shown by increased concentration of chlorite is outlined. Plane polarized light.

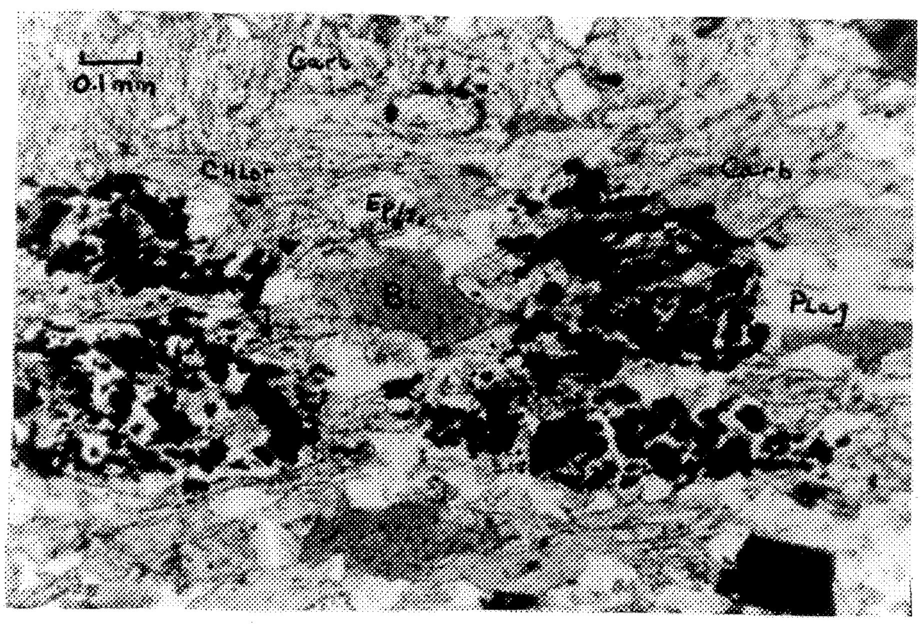


Plate 3b CBX 143 Detail of titanomagnetite aggregates above. Bottom right aggregate is stretched. Ferroan dolomite (Carb), plagioclase (Plag), finely crystalline epidote (Ep), biotite (Bi) and chlorite (Chlor) make up the rest of the rock. Plane polarized light.

parallel to the unit's contacts although no mineralogical layering has been noted. In several locations within this unit more leucocratic lenses (colour index 50-70%) 2-5 m thick and up to 20 m long are found, generally aligned with the contacts.

The grain size changes occur both sharply and gradationally over distances of 0.5-30 m. In some places the size change is from one extreme to the other (ie. from 1 mm to 1.5 cm). In most instances, however, the change is less drastic (ie. from 1 mm to 5 mm or from 5 mm to 1 cm). Zones of similar grain size range from 10-30 plus m thick in which lateral continuation of 100 m is common.

Close to the mafic volcanic-metagabbro contact the grain size of the amphiboles in the metagabbro is medium to coarse as noted on the 450 and 750 levels in the west end of the mine. Often a fine to medium grained section follows this initial coarse grained section and is followed by another coarser grained section. Laterally near the contacts, in some locations, the gabbro grain size changes rather abruptly between drill holes 15 m (50 feet) apart.

Foliation reflected in the orientation of the biotite and chlorite (amphiboles are relatively unoriented) is parallel to the regional foliation with the exception of local areas of cross faulting and within the shear zones where a second foliation is sometimes present. Fluxion textures (such as described by Higgins, 1971) are often shown around amphiboles and less often around the plagioclase in the gabbro.

(e) Regional Metamorphic Effects

The result of dynamic metamorphism is the general gradational sequence from regular massive metagabbro

Plate 4a CBX 1138 17.0 Unsheared metagabbro, chlorite (Chl) and biotite (Bi) after hornblende (outlined). Titanomagnetite (Mg) grains after olivine in anhedral clusters. Carbonate (Carb) in fine disseminations. Groundmass; plagioclase, chlorite, biotite and carbonate. Plane polarized light.

Plate 4b CBX 1138 17.0 Showing less well defined semi-rectangular patches which appear to be more thoroughly altered (top lefthand corner and center). Crossed nicols.

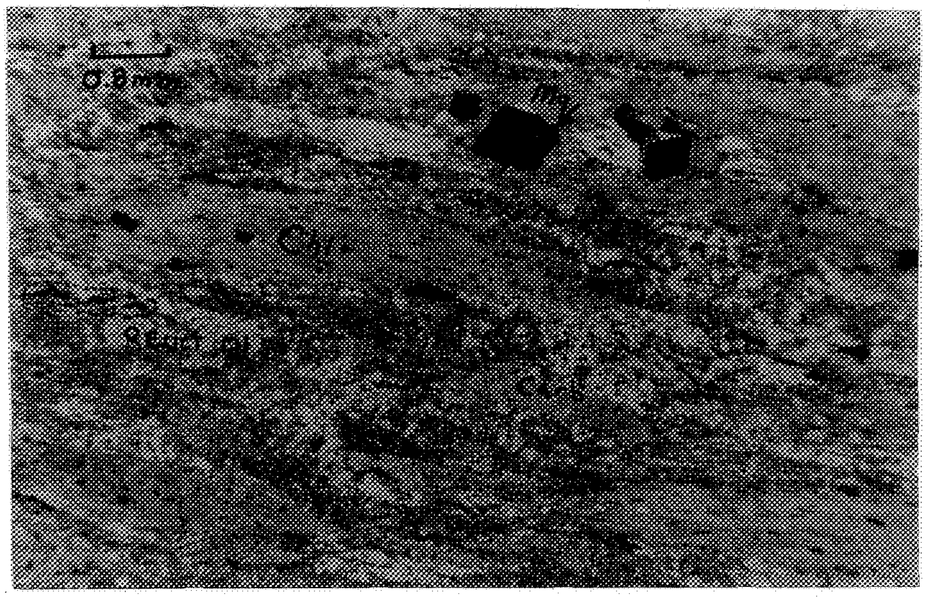


Plate 5a CBX 1138 57.0 Sheared metagabbo. Chlorite (Chl) replacing stretched hornblende and biotite (Bi). Titanomagnetite (Mg) crystals and aggregates (circled left border) after stretched olivine. Carbonate porphyroblasts (Carb) partly developed. Plane polarized light.

Plate 5b Same as 5a Showing sharp outline of the chlorite/biotite pseudomorphs. Crossed nicols.

through fluxion textured (amphiboles after pyroxene) metagabbro, elongate ovals and streaks of chlorite (after amphiboles) with abundant biotite in clumps, magnetite and pyrite, to a massive 'greenstone'. Fluxion texture of the amphiboles grades in size from 1 cm to 2-3 mm. With increased metamorphism the amphiboles, initially near opaques, alter to biotite; to biotite and chlorite (Plate 4a,b) with subsequent chloritization of the biotite (Plate 5a,b). With increased foliation opaques (particularily oxides) tend to become concentrated in and along the foliated part of the rock. Thin sections of the highly sheared metagabbros show stretched relict textures after olivine (Plate 5a). This most sheared and altered gabbro (greenstone) can be mistaken for a volcanic rock in megascopic occurrence unless it is seen to grade into unaltered gabbro.

In some places definite hornblende pseudomorphs of pyroxene remain while in others only the stubby shape of the pseudomorph (as seen in Plates 5a,b) suggest original pyroxene crystals. The original general hornblende replacement of the original pyroxene likely took place during initial regional metamorphism. Broken and rolled crystals of hornblende suggest that the hornblende was pre- or syn-tectonically formed. Retrograde metamorphism succeeding this metamorphism was late syn-tectonic, or more likely, post-tectonic since actinolite is relatively unoriented.

(f) Origin

Two different origins can be postulated for the metagabbro: intrusive as a mafic magma, in a sill-shaped body; or as a thick mafic flow unit which crystallized slowly. Subsequent regional and local metamorphism has resulted in recrystallization and alteration.

Basic considerations in the discussions of the origin of the metagabbro are as follows:

1. Available information suggests that the overall shape of this unit is tabular.
2. The original grain size was 1-2 mm as indicated by relict textures.
3. The basal contact is oblique to banding in the volcanic rocks (as seen in the incline). The upper contact appears conformable on a 2-5 m scale in crosscuts and in drill core. However, on a larger scale in the lower levels of the mine it is oblique to the mafic-felsic volcanic rocks.
4. Banding in volcanic blocks contained in the contact zone is parallel or subparallel to that in the enclosing rocks.
5. Compositional layering is absent.

Although there are arguments in favour of both, an origin as an intrusive in a shallow (sub-volcanic) environment is suggested for the following reasons:

1. Both contacts are crosscutting.
2. Included fragments in a flow top would likely be disordered and contacts and banding would be at various angles to the contacts and banding of the host volcanic rocks. Therefore, the contact zone of included volcanic rock fragments is more consistent with mechanisms such as flow or settling to keep the fragments aligned.
3. Original grain size, as indicated by relict textures, is fairly fine (1-2 mm). Lack of apparent microscopic or megascopic layering suggests cooling was fast enough to inhibit more than minimal differentiation. (Murata and Richter, 1961, report that grain size was 4-5 mm in a small laccolith -30 m thick- in Kilauea Caldera with 45-120 m of cover.)

Subsequent regional metamorphism and recrystallization of the gabbro intrusion produced the coarser grain size of the amphiboles near the gabbro-mafic volcanic contact where metamorphism would have been most intense along the contact of the competent unit. Grain size variation within the metagabbro and along the contact would be due to the variable access of water within the unit via shears during regional metamorphism changing recrystallization conditions through the unit.

2. Mafic Volcanic Rocks

(a) Megascopic Description

The volcanic unit is found south of the gabbro and is cut at a slight angle by the gabbro as discussed above. The south (upper) contact with the rhyolite is sharp. In the shaft area the mafic unit is 30-50 m thick, thickening to 80 m roughly 700 m west of the shaft. At depth this unit becomes thinner (absent on the 1650 level, See Appendix 1-Figure 3). In several locations smaller rhyolite units (1-5 m bands) are found interbedded with these mafic volcanic rocks. In addition to the mafic volcanic unit shown in Figure 3 large blocks of similar rocks are found enclosed in the gabbro in the upper levels of the northeast part of the mine.

These massive, recrystallized, microcrystalline volcanic rocks range in colour from medium green to light grey. They are megascopically foliated in one direction with more pronounced foliation than the gabbro. Megascopically discernable volcanic textures, other than banding consisting of minor compositional and colour changes on a scale of 1 cm to 2 m, are not found in the mine workings although pillows and pillow breccias are found in the rocks drilled west of the shaft (in the incline area). Any fragmental layers may have been misidentified as tectonic breccias due to the abundance of tectonic brecciation and general recrystallization within the mine area.

Disseminated pyrite and magnetite crystals (to 5 mm) are frequently locally abundant. One-half to five percent of the rock is composed of pyrrhotite, chalcopyite, lesser pyrite and sphalerite, found in small lenses (to 1½ cm long by 3 mm thick) parallel to the foliation. Quartz 'eyes' (to 5 mm) are found in some zones. Other accessory minerals are biotite, tourmaline and anhydrite.

(b) Microscopic Description

Microscopically this unit is almost totally recrystallized and consists of a very fine subpolygonal to polygonal granoblastic matrix of plagioclase and quartz with an average grain size of 0.02-0.04 mm. Blue-green actinolite (to 1 mm) and minor hornblende constitute to 15% of the rock. Biotite (to 10%), epidote after hornblende, saussurite on plagioclase, phlogopite, chlorite (after micas), carbonates, leucoxene, tourmaline, anhydrite, magnetite and pyrite are accessory minerals. Primary compositional layering is reflected in the variation of the amount of quartz, feldspar and ferromagnesian mineral content.

These rocks are medium to well foliated which is shown microscopically by the alignment of actinolite, micas and chlorite (after micas) with the major foliation direction. Some development of fluxion or augen texture (Higgins, 1971) is noted of the carbonates and plagioclase.

(c) Origin

The presence of pillows and pillow breccias in drill core from this unit approximately 1000 m west of the shaft, the pillows found in surface outcrop near the mine, the presence of compositional banding, and the general fine-grained nature of this unit as seen in thin sections from the 1350 level crosscut, point to an origin in a volcano-sedimentary environment.

3. Felsic Volcanic Rocks (Rhyolite-Rhyodacite)

(a) Megascopic Description

This massive, dense, fine grained unit is found on the south end (top) of the mine section. It is one of the least known units in the mine as it has been drilled and worked only in the three lowest working levels. In these levels it is approximately 60 m thick; whereas on surface in an outcrop 150 m west of the shaft it is approximately 80 m thick. In some surface outcrops the felsic volcanic rocks are overlain by mafic volcanic and intrusive rocks.

The rhyolite is light buff and grey to pinkish-tan and contains disseminated magnetite and biotite. Pyrrhotite, pyrite and chalcopyrite are generally locally present in small lenses in the foliation of the rock, as in the other volcanic rocks, in amounts to 20% over 1-1½ m. Ferroan dolomite (grains to 1 mm) and ferroan calcite in very fine disseminations and smears are found in the matrix and foliation of the rock. Chlorite is locally abundant in some shear zones.

Megascopically discernable volcanic textures, other than banding (plate 11b), are not found within the mine. Erosional surfaces (tops south) with slump and erosional channel features are found in weathered surface outcrops within this unit.

(b) Microscopic Description

This rock unit consists of granoblastic subpolygonal quartz and feldspar grains averaging 0.02-0.04 mm. Minor (1%) semi-rectangular plagioclase patches (recrystallized crystals) to 1 mm and rounded quartz 'eyes' to 3 mm are noted within this matrix. Zoned blue to dark greenish-blue tourmaline (to 5 mm), sericite and phlogopite are present in minor amounts in all samples. Chlorite after micas, actinolite and chloritoid are present in minor amounts in most sections. Chloritoid (to 0.4 mm) occurs stratigraphically near the ore zone in lenses (1-2 mm) parallel to regional foliation and in crosscutting fractures. Ferroan calcite is found as grains (0.02 mm) in the matrix, ferroan dolomite in poikiloblastic crystals (to 0.4 mm) and ferroan calcite and calcite in veinlets cutting the rock. Epidote occurs in small amounts in euhedral crystals and poikiloblastic grains (to 0.02 mm). Often the crystals are zoned with darker cores. An association and intergrowth of epidote with tourmaline is noted in some sections. There are rounded quartz 'eyes' (to 0.7 mm) in some samples. Magnetite and pyrite are found in subhedral to euhedral grains (to 3 mm). Other accessory minerals are biotite, leucoxene and apatite.

Stratigraphically above the ore zone the matrix becomes slightly coarser and contains fragments of feldspar crystals (to 1 mm) and quartz (to 0.2mm). Rock textures suggest an origin of this part of the sequence as a crystal tuff.

(c) Origin

The presence of erosional surfaces, with slump features in outcrops suggests a sedimentary origin for part of this unit. The presence of fragments of feldspar phenocrysts in some horizon suggests a possible tuffaceous origin for these horizons. Therefore, a volcano-sedimentary origin is proposed for these felsic volcanics although no shards, flow structures or rock fragments have been recognized in the mine (criteria for recognition of altered tuffs, Moorhouse, 1959, p229).

4. Felsic Dykes

Forty or more felsic dykes, from 1 cm to 35 m thick, intrude all rock units of the mine sequence. They are generally parallel to the regional foliation and the host rock contacts. It is possible to trace most dykes, some as thin as ½ m, for more than 1 km using drill information. They run in the same stratigraphic position with any minor discrepancies easily explained by cross faults which are seen in associated mine workings. Crosscutting relationships of these dykes with the host rocks are seen in a few places and in several locations these dykes are seen to intrude northeast (east dip) fault zones associated with diabase dykes.

Two general types of the dykes are found in the mine. One is porphyritic felsophyric with medium to coarse phenocrysts of plagioclase in a fine matrix, and the other is dense and equigranular (megascopically non-porphyritic). These will be referred to as the porphyritic and equigranular dykes. The equigranular variety is fairly rare (ie. about 5 or 6) found mainly in the 'main shear' and the larger ones are cut by dykes of the porphyritic variety which are therefore, younger. Both types have generally sharp contacts and are similar in shape. Gradational contacts of both types (with all host rock types) are seen in the more sheared and altered areas.

(a) Porphyritic Variety

i) Megascopic Description

Porphyritic dykes range from massive unfoliated to well foliated approaching mylonite in some cases. Dykes with foliation parallel to the contacts are found throughout the section and are not confined to obvious shear zones. Foliation is often stronger along the contacts of dykes found in the shear zones, appearing most intense just within the host rocks. Minor (tectonic) necking of some dykes is found in scattered locations. Both fine-grained chill margins (from 5-25 cm) and reverse chill margins (coarser borders) are seen.

These dykes have fine to coarse plagioclase phenocrysts in a fine matrix of feldspar and quartz and are pink to grey in colour. The colour of individual dykes may be patchy on a scale of 1-2 m. Average feldspar phenocrysts are about 1 cm and sometimes are slightly zoned with a patch of chlorite at the core. Some dykes contain quartz phenocrysts (to 0.5 mm) in the matrix of the dyke. Some of these appear to grade in and out of regular feldspar porphyry over short distances (5 m). Biotite content is variable to 10% generally oriented parallel to the dyke's contacts (and regional foliation). Phlogopite, muscovite and carbonate are locally abundant. Disseminated pyrite (euhedral crystals to 5 mm) is found in quantities of 2-3%. Minor (<1%) small lenses (to 5 mm by 1 mm) of chlorite are found in these dykes.

ii) Microscopic Description

A typical porphyritic dyke is composed of 15-45% of twinned, euhedral, generally elongate, plagioclase phenocrysts (to 1 cm) found in 50-70% matrix of granoblastic amoeboidal to subpolygonal quartz and untwinned plagioclase (to 0.05 mm). Phenocrysts of quartz (<2%, to 5 mm) are found in some thin sections. Clinozoisite and epidote (2-4%) occur as crystals (to 0.2 mm) in the dyke matrix. Saussurite is developed in some plagioclase phenocrysts with traces of sericite. Traces of biotite and chlorite are found in the matrix oriented parallel to the regional foliation and as random aggregates in the centers of plagioclase phenocrysts in some dykes. Leucoxene is present in most dykes as subhedral or euhedral pseudomorphs of opaque crystals (to 2%).

Plagioclase phenocrysts are not strongly zoned. Anorthite content (carlsbad-albite twin method) of phenocrysts in individual dykes varies by approximately 2-5% while the anorthite content of phenocrysts in the suite of dykes ranges from An_{29} to An_{41} based on the average of the anorthite content of 10-15 phenocrysts in each dyke.

Foliation and deformational textures (ie. bent or broken phenocrysts and both bent and straight pressure twins in the carbonates in these dykes) are noted in some thin sections of the dykes. Plagioclase phenocrysts in thin sections of unfoliated and undeformed dykes vary between An_{29} and An_{33}. Phenocrysts in foliated and deformed dykes range from An_{35} to An_{41}. With increased deformational textures and foliation there is a general increase of anorthite content of the plagioclase in the thin section. Two mechanisms may be used to explain variation in anorthite content of feldspar:

1. Anorthite content increases with grade of metamorphism (Winkler 1971).
2. Anorthite content may change as a result of differentiation processes (Bowen 1928).

As the metamorphic grade is of the greenschist facies grade (presence of tremolite in the enclosing rocks, Winkler 1967) any change in the plagioclase would be to lower anorthite contents. Just the opposite is seen. Therefore, the anorthite variation is due to the second mechanism.

As the foliated dykes are found among the unfoliated dykes, it is likely that the dykes have been injected into the host rocks during a time span in which the parent magma of these dykes has changed. During the same time period regional deformation was taking place while the phenocrysts in the magma were between An_{35} and An_{41} and regional deformation had stopped when the phenocrysts in the magma were around An_{31}.

(b) Equigranular Variety

i) Megascopic Description

The massive equigranular (nonporphyritic) dykes are pink to tan, foliated to unfoliated and have a quartz stringer content up to 50% of a 15 m dyke. Omitting the quartz stringers the overall texture of these dykes is dense and uniform. Disseminated magnetite and small lenses of chlorite (1 by 2-3 mm) are found in the dykes (to 1%). Tourmaline is widespread in amounts to 2% concentrated in crosscutting quartz veins. The largest example of this type of dyke is found in the central part of the mine workings just south of the 'main' vein (Appendix 1-Figure 3).

ii) Microscopic Description

Stumpy equidimensional plagioclase crystals (to 4 mm) form 60-90% of this rock. Ferroan dolomite, phlogopite, (paragonite ?), plagioclase and quartz form an equigranular matrix. Opaques (to 2%) are altered to leucoxene. Tourmaline, chlorite after chloritoid, biotite and saussurite are found in trace amounts. Quartz and albite in micropegmatitic overgrowths on the plagioclase phenocrysts are well developed. Staining with sodium cobaltinitrite indicated no potassium feldspar.

Microscopic textures range from panidiomorphic granular to glomeroporphyritic in sections with lower plagioclase phenocryst contents.

iii) Discussion

The unfoliated porphyry dykes cut the equigranular variety and, therefore, are younger. Anorthite content of feldspar phenocrysts of individual equigranular dykes varies between An_{33} and An_{40}. This variation in anorthite content is likely due to primary magmatic differentiation as proposed for the regular porphyritic dyke variety.

Two magma sources are indicated for these two dyke species because of the basic differences in textures and petrology of these dykes.

(c) Regional Metamorphic Effects

As a suite the felsic dykes show a textural variation from sharp, well crystallized plagioclase phenocrysts through ghost (recrystallized) phenocrysts to a fairly uniformly recrystallized nonporphyritic rock which has a generally weak to medium foliation (opposed to the relatively unfoliated equigranular type). This recrystallization is partially shear-related and likely shows this gradation as a function of the age of the dyke and the degree of regional metamorphism it has undergone. This is noted in thin section as granulation of the borders of phenocrysts which works inward and eventually destroys the porphyritic textures.

Host rocks adjacent to these dykes show effects of metamorphism in increased chloritization of the hornblende and actinolite, silicification and development of tourmaline. Increased foliation is the only texture seen in the host rock beside some of the dykes.

(d) Origin

These dykes are of igneous intrusive origin because:

i. They have crosscutting relationships with the host rocks.

ii. They cut the gabbro which has in turn cut the volcanic sequence.

iii. The change in anorthite content of feldspars is not related to stratigraphic height in the sequence.

5. Diabase Dykes

(a) Megascopic Description

Seven to ten subparallel diabase dykes (5 cm to 10 m, averaging 2-3 m) which cut through all rock units and veins are found throughout the mine workings. These dykes strike roughly NNE, dipping 65°-85°E, and have been injected into, or are associated with faults in the same direction. These are parallel to and similar to the large diabase dyke (about 10 km by 500 m) cutting the region described by Hebert (1979). Brecciation associated with post emplacement movement along the fault system is noted in several locations and fractures and interstices contain sulphides (mainly pyrite) or carbonate. Occasional fragments of host rock (to 10 cm) are found in these dykes. Several generations are likely since crosscutting relationships of some subsidiary dykes 5 cm thick are seen in surface outcrop as well as relationships such as those shown in Figure 6b.

In hand specimen the diabase is fine grained and black with a diabasic texture. Plagioclase phenocrysts (lath-shaped to 5 mm) are found in a fine matrix. Pyroxene (to 1.5 cm) is noted in some of the larger dykes. Grain size within individual dykes becomes finer towards the contacts from the dyke's center. Fine grained chilled margins range from almost nil in smaller dykes to ½-1 m in the larger dykes. Grain size in individual dykes increases with increased size of the dyke.

No contact metamorphism is noted in the host rocks. Contacts are generally sharp with slightly finer grained chilled margins. Occasional randomly oriented hairsize to 2 cm apophyses and epiphyses are noted close or adjacent to the dykes in the host. Several brecciation zones parallel to these dykes, in areas away from known dykes, have similar features which are likely lateral extensions of similar dykes.

(b) Microscopic Description

Twinned plagioclase phenocrysts (to 6 mm) are found in a matrix of smaller plagioclase crystals (to 1 mm), orthopyroxene (to 5 mm), minor olivine in subhedral crystals (to 0.5 mm) and altered devitrified brown glass. The plagioclase phenocrysts are slightly zoned and range from An_{55} at the core to An_{35} at the rim and contain some devitrified glass inclusions.

Minor carbonate is contained in small stringers which are associated with quartz-rich patches. Minor chlorite and clinozoisite alteration is noted in the feldspar and devitrified glass. Abundant magnetite is found interstitial to the other minerals in anhedral grains and skeletal crystals. Overall texture is diabasic and in places, subophitic. No foliation is present.

(c) Deuteric Alteration

Fine, pale green deuteric hornblende alteration is noted on the edges of feldspars and devitrified glass in contact with the pyroxenes. In several locations diabase dykes have undergone complete deuteric alteration to clinochlore matrix with epidote (crystals to 4 cm), magnetite (crystals to 1 cm) and minor calcite.

(d) Summary and Origin

The diabase dykes are associated with NE faults and as they cut all the rock units in the mine area they are definitely the youngest rock unit. Several locations show that the introduction of these dykes was spread out in time and that (tectonic) adjustment has taken place along the east-west shear after injection of some of these dykes. Figure 7b (Appendix 1) is a sketch of such an occurrence. It is seen that one dyke has been displaced with an apparent horizontal movement, while a similar dyke in the immediate vicinity cuts straight across the east-west shear. Similar displacement (and east-west brecciation) of other dykes is noted elsewhere. These diabase dykes found in the mine are part of the regional diabase dyke swarm as they have similar mineralogy and are subparallel.

II. B. METAMORPHISM OF THE HOST ROCKS

Recrystallization of the host rocks has occurred during both regional and local metamorphism and matasomatism. In most cases patterns and locations of alteration are broad and difficult to relate to any one cause. Mineralogical products of metamorphism are megascopically related to mineralized zones in only a few areas and are not restricted to the ore zones or to the veins within the zones. When metamorphic products are related to mineralization they are the same products as found in the host rock far from mineralization, differing only in the amount present. There is no general typical alteration envelope or halo around the ore veins (such as seen in other mines, Boyle 1961, Jambor 1971).

1. Regional Metamorphic Effects

Regional metamorphism has altered the original host rocks to their metamorphic equivalents described in the preceding pages. General effects of regional metamorphism have minor variations which reflect the original rock composition and tectonic metamorphism and which are: a general recrystallization; development of amphiboles (in mafic units); chlorite and biotite (in all rock units with increased concentrations in the more mafic units); epidote (in proportion to the original felsic content of the rock); and possibly, a general carbonatization and silicification.

Dynamic regional metamorphism has given most rocks a ~~primary foliation and has brecciated and crushed rocks~~ and minerals aiding in general recrystallization on a local scale within shear zones and near joints and fractures.

Cataclastic textures similar to those described and defined by Higgins (1971) are seen in most altered rocks. In general, cataclasis has localized effect and intensities of metasomatism. The result is that the degree of total recrystallization and production of secondary minerals such as chlorite and epidote is related to the degree of cataclasis with the exception of development of the carbonate and tourmaline.

2. Metasomatism

Metasomatism has intensified the general metamorphic recrystallization in cataclastic zones producing biotite, chlorite, anhydrite, locally high concentrations of carbonate, epidote, tourmaline, quartz and leucoxene. As this suite of minerals is basically the same as those found elsewhere, it is difficult to isolate metasomatic products from regional metamorphic products. It is likely that metasomatism has been carried out at temperatures and pressures close to those present during late stages of regional metamorphism. Therefore, if these alteration products are in part a result of the mineralizing processes, the mineralization has been carried out during late stages of the last regional metamorphism to affect the area.

General mineralogical recrystallization products (alteration products) are described in order of importance of association with ore producing areas. Local alteration types are described briefly as they appear to be relatively unimportant in relation to the mineralization.

(a) Biotite

Biotites of the annite-phlogopite solid solution series make up 1-10% of all rocks in the sequence. They have developed parallel to the regional metamorphism. Optically the colour of these biotites varies erratically in the stratigraphic section from very dark (nearly black- annite) to pale greenish-browns to colourless (phlogopite). The composition, as shown optically by its colour, does not show any trends around the ore-bearing shear zones and does not change with rock type although there may be a microscopic correlation with opaque minerals.

Mineralized shear zones have developed annite near some and in most of the ore veins in amounts from 5-25% (Plate 6a). The annite found in the mineralized quartz veins is predominantly reddish- a characteristic not seen in the unmineralized rocks. Several samples of this reddish-brown annite gave off noticeable quantities of H_2S during XRD sample preparation.

Darker coloured biotite is noted microscopically in and near the contact with opaque minerals (both oxides and sulphides), Medium greenish-brown to medium brown biotite replaces hornblende, actinolite and epidote. Phlogopite is noted to have developed particularily in and around the felsic dykes (Figure 4, p49). The darker varieties are often associated with the mafic rocks and ore veins while the lighter coloured varieties are more often found with the felsic rocks.

Most micas in the host rocks are parallel to the foliation. However, in sections of ore and some highly altered samples, unoriented, undeformed, poikiloblastic and non-poikiloblastic micas are common. Therefore, biotite developed both syntectonically and post tectonically.

(b) Chlorite

Pale green, slightly pleochoic chlorite is found in all altered rock types. It is generally found near opaque minerals and is an alteration product of the hornblende and actinolite in the mafic units, of annite-phlogopite in

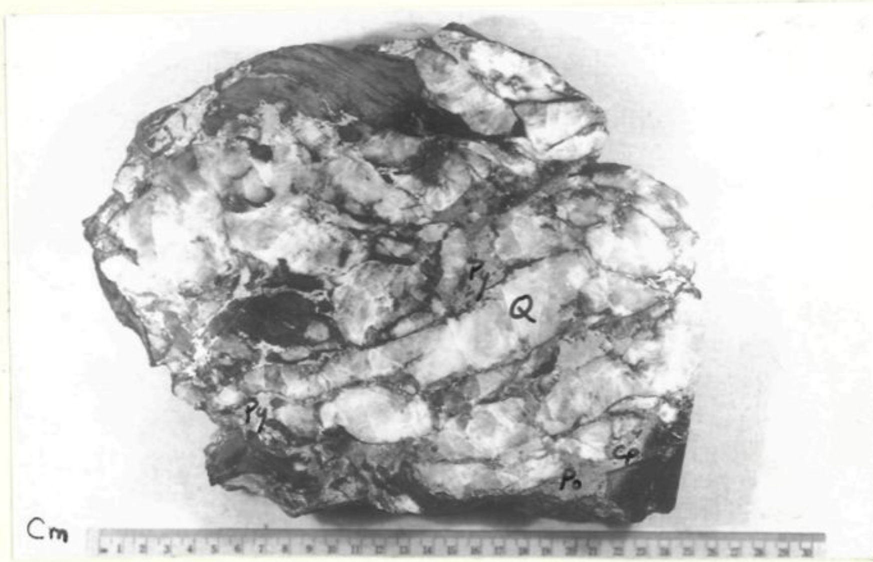


Plate 6a Brecciated quartz vein (Q) containing biotitized (annite) metagabbro fragments (black); chalcopyrite (Cp), pyrite (Py) and pyrrhotite (Po) in the interstices. From the 'main' zone 900 level.

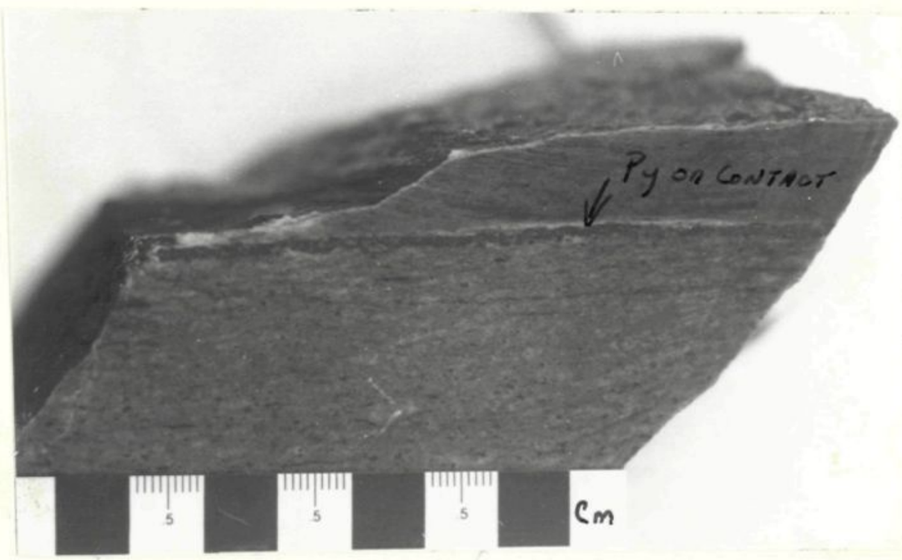


Plate 6b CBX 174 Contact of a feldspar porphyry dyke (bottom) with the rhyolite. Concentration of pyrite (Py) is noted along the contact.

all rock types, and minor alteration of the plagioclase in the felsic porphyry dykes. Optical signs (from optical determinations and interference colours, Albee 1962) vary from positive to negative throughout the mine section. The relationship of optically negative chlorite and ore zones, noted in Chibougamau mines of the Dore Lake complex (Jeffery 1959, Miller 1961, Allard 1976 pp 322-330), is not noted in the Chibex mine section. Polished thin sections of ore show both optically positive and negative chlorite with a definite predominance of positive chlorite in the ore sections (ie. 11 of 13 polished thin sections).

The following variations of the chlorite are noted in the host rocks of the Chibex stratigraphic section:

1. Optically positive chlorite is found in the mafic rocks (gabbro and basalt) with the exception of four thin sections- two in sheared gabbro and two in sheared volcanic rock.

2. Optically negative chlorite (blue interference colours) is found in the felsic volcanic rock with the exception of three thin sections of sheared rhyolite.

3. The majority of chlorite found in felsic dykes is optically negative although both types are found.

4. Optically positive (tan to brown interference colours) chlorite is found in ore veins.

These variations seem to be a reflection of the host rock composition. For example, the chlorite found in the mafic (and opaque rich) rocks is generally positive (Fe poor) while that in the felsic rocks (opaque poor) is generally negative (Fe rich), (Albee 1962). Therefore, chlorite production in the host rocks may be a retrograde regional metamorphic feature in general and not related to the mineralizing event.

(c) Anhydrite

Optical data for a clear, colourless mineral found only in thin section is given in Appendix 4. Optical data is close to, but not identical to published data on anhydrite. Electron probe work confirms the presence of only Ca and S. Therefore, the mineral is likely anhydrite.

Anhydrite is found in amoeboidal to subrectangular equant (generally twinned) colourless crystals (to 3 mm diameter) in amounts to 10%. It is developed predominantly in association with carbonates (ferroan dolomite) and in lesser associations with epidotes, amphiboles, chlorite, and biotite and is concentrated in stringers and pods in the more foliated and sheared mafic rocks (Plate 2b) as well as disseminated throughout the rock. The crystals are partly (50%) aligned with the major foliation and are therefore, late syntectonic or post-tectonic.

Anhydrite is found predominantly in the 'main' shear zone and just above the gabbro-mafic volcanic contact. Hebert (personal communication) has not found it elsewhere in the region and it may be possible to use its presence as an indicator of the Chibex 'main' shear zone and for the host mafic volcanic rocks found in the mine sequence.

(d) Carbonate

Carbonatization in less altered and sheared rocks occurs as fracture-fillings (calcite and ferroan calcite) and as minor development of ferroan dolomite interstitial to the essential minerals of the rock. (Carbonates have been identified by staining methods, Chilingar 1967; and by XRD.) In general, the disseminated carbonate is ferroan dolomite and as veining and foliation increases, ferroan calcite and calcite dominate. This may be due to metamorphic reactions changing the carbonate composition (Winkler 1967,

1974) or to two generations of carbonate- one Mg rich and the other (later) Ca rich.

In some areas of the mine carbonate occurs in greater quantities, from 5 to 50% of the rock. In general these areas are from 1 to 20 m thick by 10 to 75 m long and 10 to 75 m high and are found in all rock types of the mine although they are best developed in the mafic rock units. Although field relationships of these zones are difficult to determine because of the irregular and erratic nature of the carbonate content on a scale of 1 to 2 m, making it difficult to correlate drill core data, information is consistent with a subparallel orientation to the stratigraphy and shearing. In some instances these zones are found to one side or the other of a shear zone although they are not always related to the presence of sheared rocks. In most instances these areas are not spatially directly related to mineralization. These zones do not appear to be recrystalized flowtops as they are discontinous, patchy and irregular in outline and are often found in the gabbro.

A notable porphyroblastic texture is often developed in rocks from the carbonate rich zones (Plate 7). Isolated rhombic to rounded porphyroblasts of ferroan dolomite (to 1 cm) occur in amounts to 50% of the rock. The porphyroblasts contain minor inclusions of feldspar, quartz and opaques. Increased concentrations of biotite (and chlorite) are found around porphyroblast borders (Plate 8a,b). The porphyroblasts in the least sheared rocks consists of one optically continuous crystal and in deformed rocks, the porphyroblasts occasionally have slightly bent pressure twins. Augen or fluxion texture of these porphyroblasts is present in foliated areas. Therefore, this carbonate is very late syntectonic or post-tectonic. The gradation from unaltered rock to the typical poikiloblastic carbonate

Plate 7 CBX 119
Porphyroblasts of ferroan dolomite in metagabbro from 1350 level near the 'main' vein. White fracture is filled with ferroan calcite.

texture is well shown in some of the porphyritic dykes. Ferroan dolomite is contained in small microscopic fractures and interstitial to the fine grains in the matrix. With increased carbonate content the carbonate becomes part of the granoblastic matrix and then poikiloblastic. It may partly replace the feldspar phenocrysts. Later cross-cutting macroscopic fractures are filled with calcite and ferroan calcite.

(e) Epidote

Epidote minerals are well developed in most of the rocks of the mine sequence. Epidotes occur in subhedral masses (to 2 mm) as replacement of hornblende and actinolite, saussuritization of feldspar, well developed crystals (to 4 cm, averaging 1 cm) and as veins. Often crystals are zoned with darker cores. Epidote, zoisite and clinozoisite are all present. Variations in these alterations appear to be erratic and possibly related to the mineralogy of the host rather than the mineralized zones. More than half of the thin sections of ore contain epidote minerals (10 of 16).

Increased epidote alteration is noted in pods of 'leuco' gabbro which are often located near felsic intrusions. Subhedral to euhedral epidotes are found in most rock types in the mine. Nearly colourless epidote alteration and replacement of hornblende and actinolite are seen in localized areas which are shear-related. This feature suggests the possibility of two periods of epidote production: the initial regional metamorphism producing crystalline epidote in most areas, and a second, restricted metamorphism producing epidote from amphiboles.

(f) Tourmaline

Tourmaline occurs in all the rock units of the mine

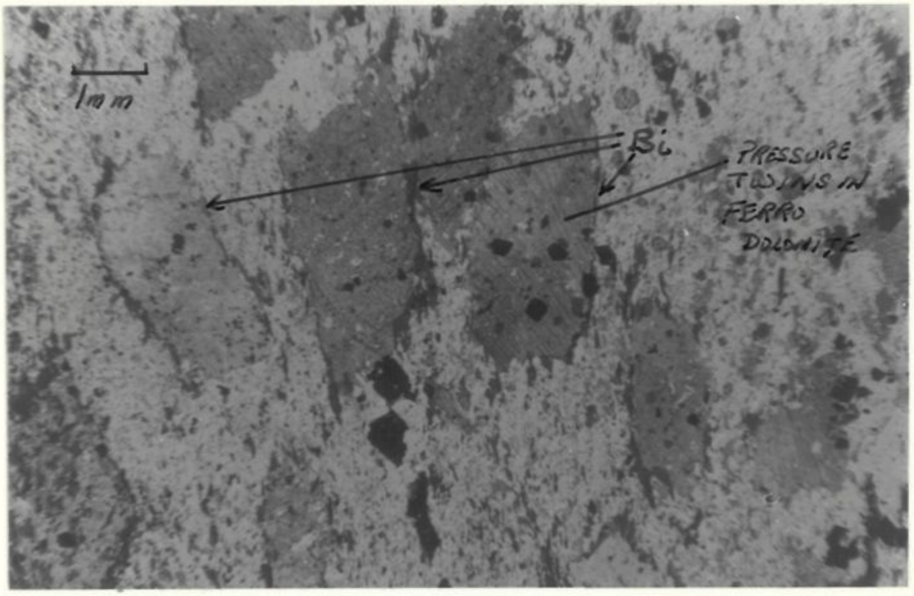


Plate 8a CBX 119 Porphyroblasts of ferroan dolomite showing pressure twins, in sheared metagabbro. Biotite (Bi) concentrated on borders of porphyroblasts. Plane polarized light.

Plate 8b Same as 8a Some porphyroblasts partly polygonized with undulose extinction while others are single crystals. Crossed nicols.

except the diabase, principally in foliated areas in quantities of 1-2%. It is found throughout the 'main' shear zone in the gabbro, near both contacts of the mafic volcanics, in the felsic volcanic rocks, and in the felsic dykes in both the matrix and in crosscutting quartz stringers. Half the thin sections of ore samples show disseminated tourmaline in amounts of 1-2% in euhedral to subhedral crystals (to 1 mm) associated with pyrite and other sulphides, particularily chalcopyrite (Plate 9b). The tourmaline is late syntectonic or more likely, post (regional) tectonic as elongate grains have developed oblique to the foliation, and grains similar to the one shown in Plate 9a have developed after the regional foliation.

(g) Quartz

Silicification, noted within all the mine units, is shown by an increase in quartz in the groundmass of the rock, as blueish opalescent round quartz 'eyes' or porphyroblasts (to 5 mm), as crosscutting stringers of quartz, and in the mineralized quartz veins. Quartz 'eyes' are sometimes associated with pyrite. Silicification of the host rocks is noted to occur as irregular 'patches' stratigraphically below the main shear in the gabbro, as a general silicification near felsic intrusions; and in numerous quartz stringers associated with the ore zones. Although the quartz 'eyes' in the gabbro are located near the upper contact of the gabbro this silicification is likely a metamorphic or hydrothermal feature rather than a result of igneous differentiation since the silicification has occurred in all rock types and in most cases appears to be shear related, particularily in ore zones. No microscopic internal structures other than polygonalization are present in the anhedral quartz 'eyes'.

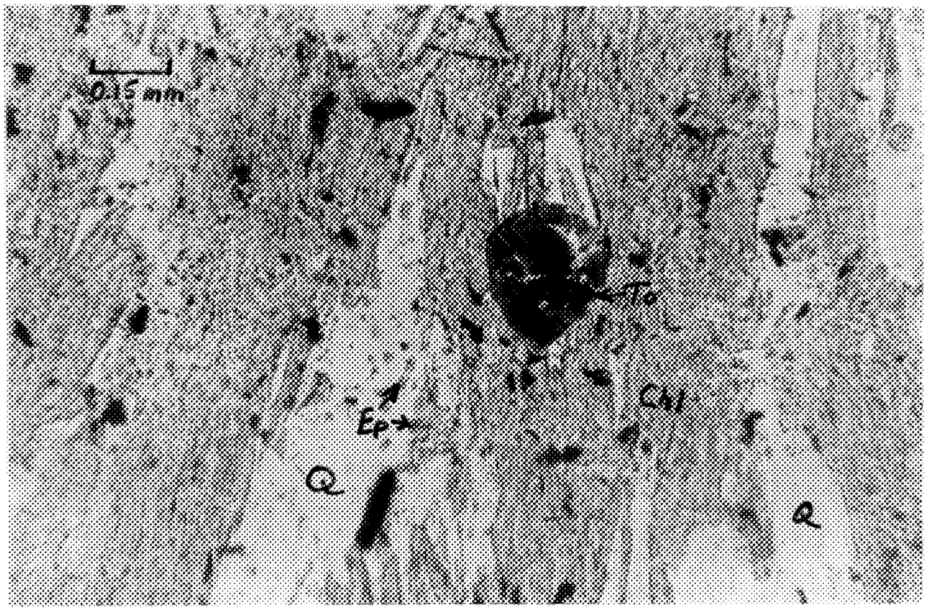


Plate 9a CBX 114 Sheared metagabbro with late or post-tectonic tourmaline (To), deformed chlorite (Chl) after mica, epidote (Ep) and quartz (Q). 'Main' zone, 1350 level. Plane polarized light.

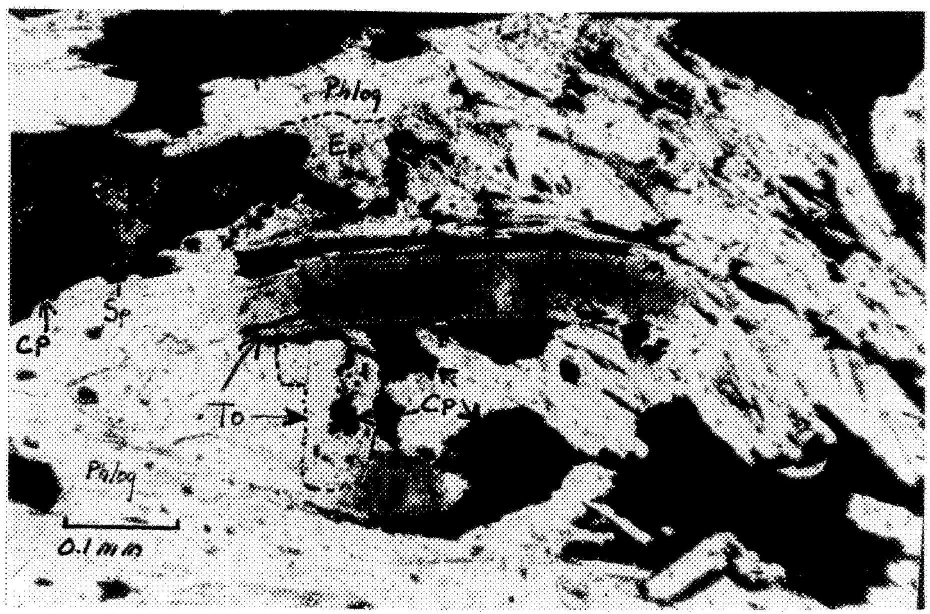


Plate 9b CBX 207 Broken U-shaped tourmaline (To) with chalcopyrite (Cp) inclusions, epidote (Ep) and chloritized phlogopite (resulting from felsic dyke in contact with vein at same location). Opaques are mainly chalcopyrite with sphalerite (sp), pyrite and magnetite inclusions. Plane polarized light.

(h) Leucoxene

Patchy and total leucoxene alteration of the oxides is noted in most of the altered rock of the mine sequence. This alteration is found in both the small (0.2 mm) oxide grains after olivine and the larger euhedral magnetite as shown in Plate 10a,b.

The following alteration products have been noted to be restricted to specific locations in the mine and to particular rock units.

(i) Chloritoid

Chloritoid is found in the felsic volcanic rocks stratigraphically below the south ore zone, in fractures cutting the foliation of the rock and in small pods in the foliation.

Possible chlorite pseudomorphs of chloritoid are found in association with felsic intrusives in the gabbro in the south part of the 'main' shear.

(j) Phlogopite

Phlogopite is developed in and adjacent to the felsic intrusives. This is demonstrated in Figure 4 which shows the development of phlogopite adjacent to the dykes in the mine shear zone.

(k) Green Mica

A few samples from the dumps contain green mica. Samples containing this mica were not found in the current underground workings. Mariposite, (fuchsite) or roscoeite are suggested as the identification on a hand specimen basis.

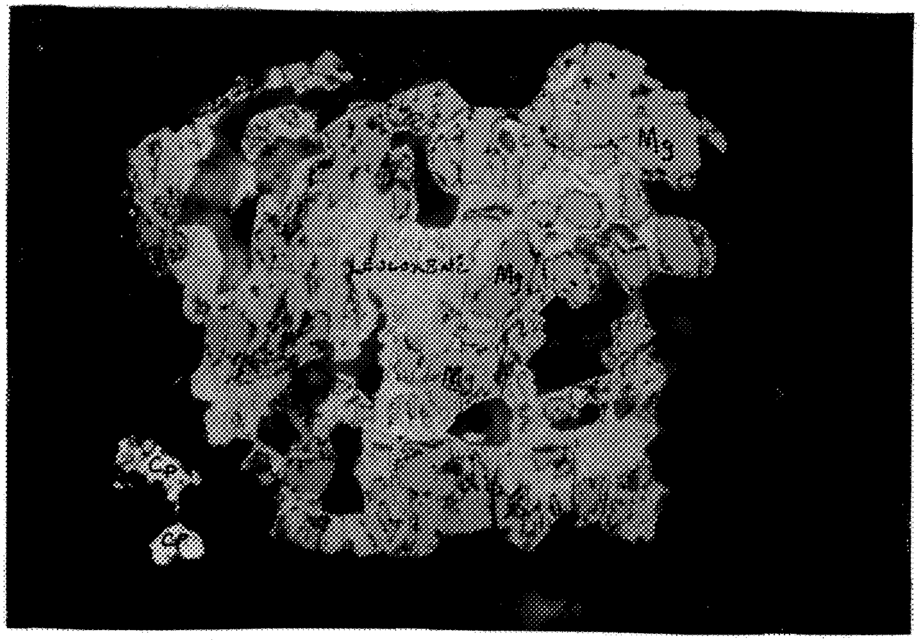


Plate 10a CBX 181a Titanomagnetite (Mg) crystal altered to leucoxene in sheared gabbro adjacent to mineralized vein. Chalcopyrite (Cp) in bottom left corner. Reflected light.

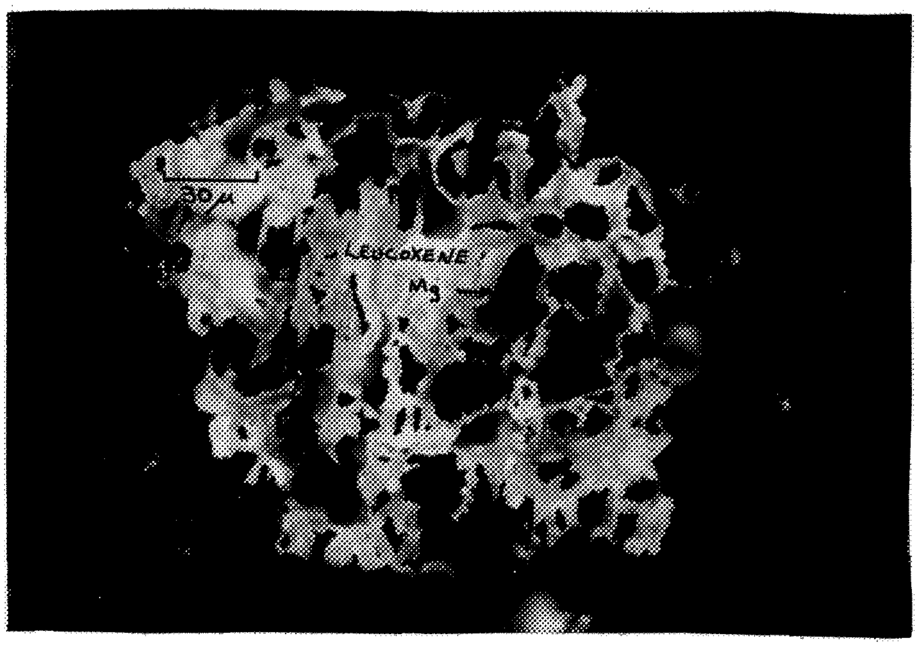


Plate 10b Same as 10a Crossed nicols.

3. Mineralogical Changes Across the 'Main' Shear

Figure 4 shows the major mineralogical changes within the 'main' shear. Mineralized veins occur near CBX 114 (most mineralized) and CBX 122. Points to note are:

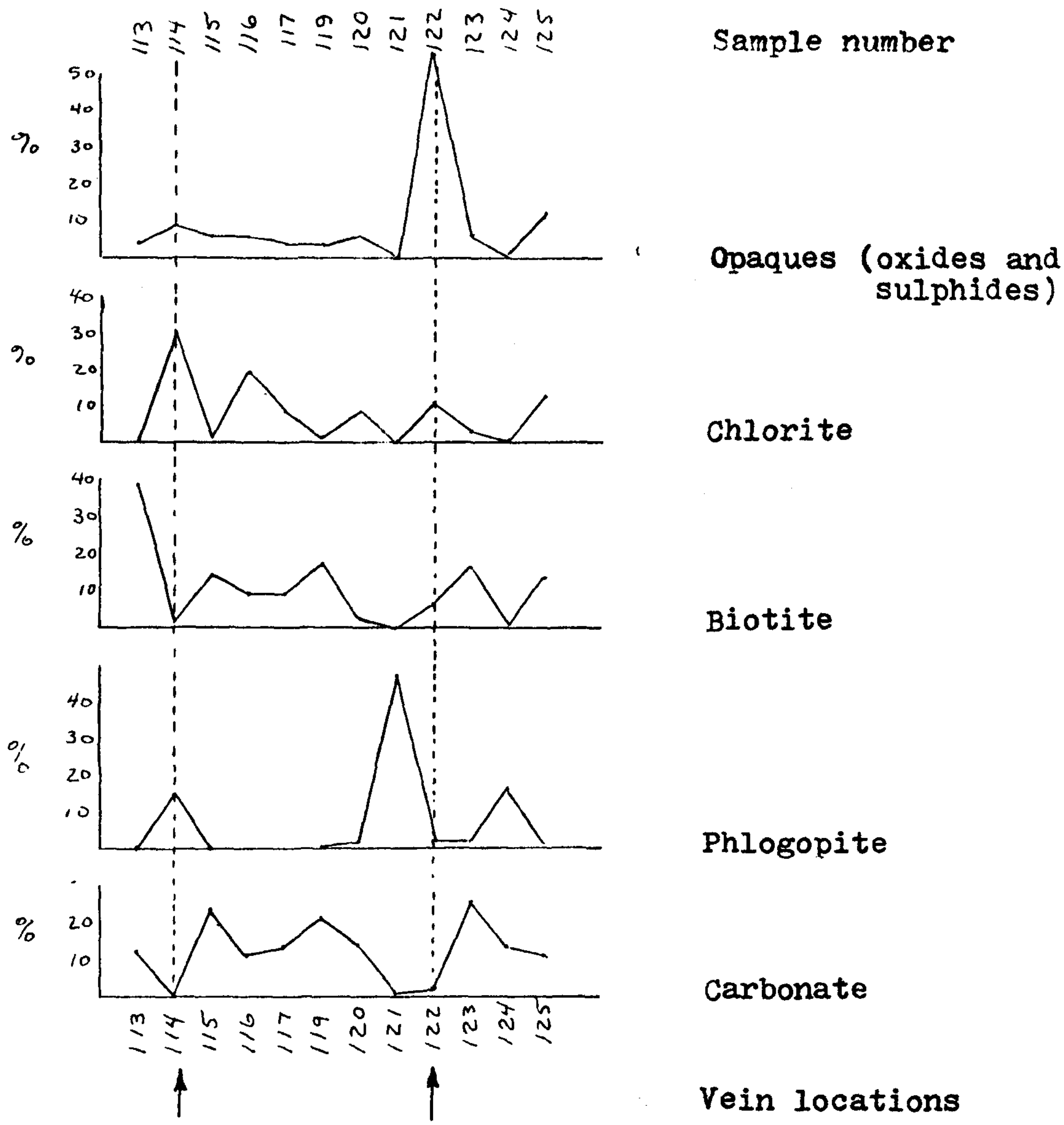
- Phlogopite has developed within and adjacent to feldspathic intrusives (CBX 121, CBX 124) and near the best mineralized vein (CBX 114), possibly due to small felsic intrusives;
- Opaque (oxide and sulphide) content is relatively uniform across the section with increased opaque content in the veins. Feldspathic intrusives have only small amounts of opaque minerals;
- Epidote, biotite, and leucoxene content are microscopically relatively erratic although a definite megascopic correlation of biotite is noted with ore intersections;
- Chlorite content is higher in association with the veins;
- Carbonate content of rocks decreases near mineralized veins; and
- Hornblende is nearly totally destroyed in the shear zone.

4. Summary

In general, alteration appears to be concentrated in and in proportion to the degree of shearing, foliation and brecciation. This may be due to:

1. Increased input of strain energy allowing increased nucleation of metamorphic products in these areas; and/or
2. Subsequent input of thermal energy from hydrothermal solutions percolating along the shear zones; and/or
3. Circulating water in shear zones has increased nucleation and alteration within these zones.

It appears that retrograde metamorphism has occurred after the original regional metamorphism. This may have



Samples 121 and 124 are felsic dykes.
Sample 122 is a sulphide rich vein.

Percentages are calculated from point counts of 1000-1100 grains.

Figure 4: Mineralogical variations in samples of the 'main' shear zone.

been a continuation of the initial metamorphism or a second later event. Continuing metamorphism and metasomatism occurred restricted to local areas during later or after regional metamorphism as noted from the alteration of actinolite and hornblende within the mineralized shear zone. Therefore, alteration associated with these shear zones was produced during the final stages or after regional metamorphism, or the alteration pattern would have been overprinted by the regional metamorphism.

II.C. ORE VEINS

1. General Description

Most of the ore extracted to date is from white massive to glassy quartz veins (from 5 cm to 3 m) crosscutting the stratigraphy (Plate 11b) which contain native gold and chalcopyrite with minor pyrite, pyrrhotite, tellurides, sphalerite, magnetite, (bornite, covellite) and occasionally, arsenopyrite. Galena has been reported by Malouf and Thorpe (1957).

The veins are fracture fillings which occur in schistose and nonschistose rocks. Often there are up to six or seven parallel quartz veins, each ranging in size from 2 cm to 2 m, in any one of the shear zones (Figure 6a). Some of the veins are continuous for 100-150 m with only minor necking and gradual changes in size both laterally and vertically, while others in the same zone are not continuous. As it is to be expected vein widths are larger in the more competent gabbro versus the volcanic rocks. Boudinage is common in all rock types. Openings (to 30 cm) similar in outline to the quartz veins are found in the shear zones for lengths up to 30 m.

Internal structures within the veins, other than brecciation, are uncommon. Zoning, cockade or crustification structures are not present. Occasionally sulphides occur concentrated within a band or zone within a quartz vein but for the most part sulphides are disseminated throughout the vein.

In general, there are three types of single and multiple veins which have been mined and which may be associated with porphyry dykes. These veins have been found in the gabbro, the mafic volcanic rocks, and the felsic volcanic rocks and are concentrated in three shear zones contained in the mine stratigraphic sequence as discussed previously. These vein types are:

1. Quartz veins with low sulphide content, in relatively unfoliated, unaltered and unmineralized host rocks; ie. quartz veins with native gold with 1-2% chalcopyrite and equal or lesser amounts of pyrite and only traces of mineralization in the host rocks.
2. Quartz veins in relatively unfoliated and unaltered rocks with a high sulphide content in the veins; ie. quartz veins with native gold, 4-10% chalcopyrite, 10-20% pyrite and pyrrhotite and traces of mineralization in the host rocks.
3. Quartz veins in highly sheared and foliated and brecciated rocks with chlorite and biotite alteration in the host rocks and a high sulphide content in the veins and host rocks, 1-2% chalcopyrite, 10-20% pyrite and/or pyrrhotite. Sulphide mineralization is contained in zones 10-30 m wide and 100 m long and high, generally concentrated in the host rocks in preference to the quartz veins.

Relationships between these vein types are not consistent. In general, type 2 is found on the lateral extension of some type 3 veins, though not always. All vein types may be found within any particular shear zone.

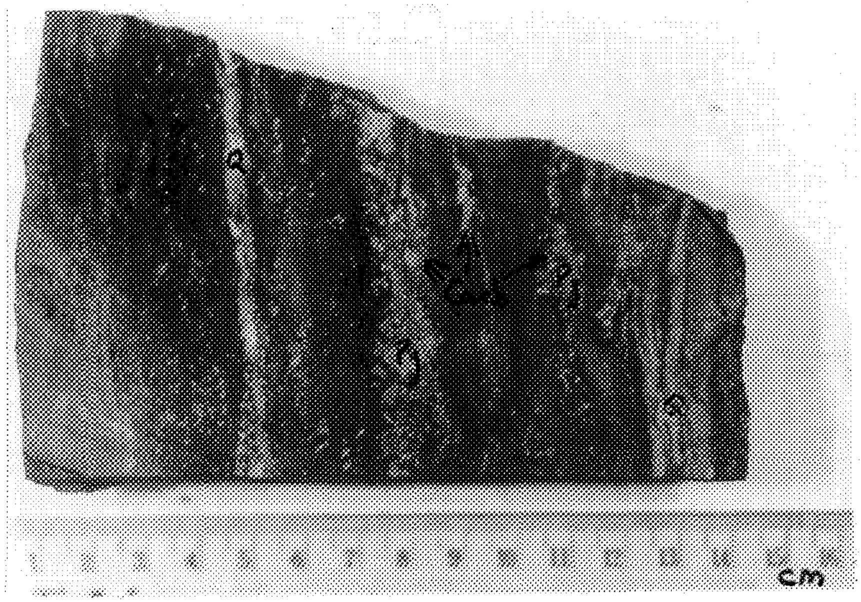


Plate 11a CBX 113 Sheared barren metagabbro from 'main' zone 1350 level, showing development of quartz stringers (Q), pyrite (Py) and ferrocalcite (Carb).

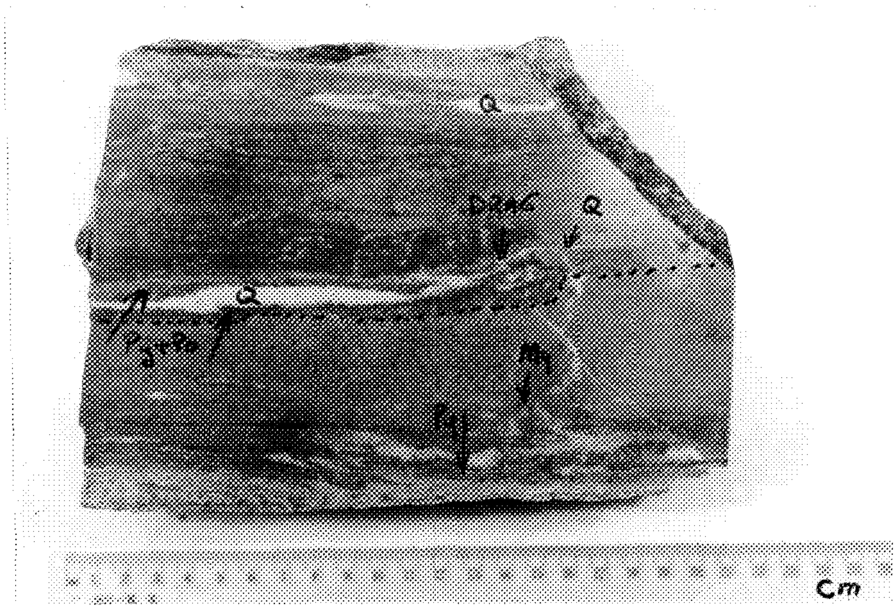


Plate 11b CBX 162 Banded meta-rhyolite showing subparallel nature of quartz vein (Q) with pyrite (Py) and pyrrhotite (Po); drag folds; boudinage and disseminated magnetite (Mg- black spots).

Gold content of the veins is generally erratic on a scale of 1-2 m as in most typical vein gold deposits. In vein types 1 and 2 gold contents are generally higher than in vein type 3, and contents up to 30-100 oz Au/tonne are known over widths up to 20 cm. In vein type 3 gold contents are somewhat lower, in the range of 0.05-0.20 oz Au/tonne over widths up to 10 m (within that width concentrated in quartz). Chalcopyrite content in most areas remains uniform throughout the mine at a steady 1-2% (0.5% copper) although individual areas contain higher concentrations of copper (to 10%).

Vein types 1 and 2 have been found in all host rock types: gabbro, basic and felsic volcanic rocks, while vein type 3 has been found only in the gabbro.

Massive sulphide pods and stringers of pyrite, pyrrhotite and other locally abundant sulphides are found in vein types 2 and 3 in zones of widths to 2 m by 10 m high and 15 m long. Near the periphery of these pods the sulphides occur in bands and stringers in a ribbon texture with the proportion of sulphides to quartz increasing towards the pods.

Zones rich in pyrite and pyrrhotite with lesser amounts of chalcopyrite are associated with vein type 3 (Plate 11a, 1). These zones can be 25 m thick with an extent of 100 m by 100 m. Gold is present only in minor amounts disseminated through the zone in very small quartz stringers and pods in the foliation. Gold content is fairly uniform within the zone and is related to the amount of quartz present in the lenses and stringers. Gold is not always associated with these zones although quartz veins extending laterally from such zones contain gold and copper mineralization. Pyrite generally occurs in anhedral to euhedral crystals (up to 1 cm) concentrated in bands, whereas pyrrhotite occurs in lense-shaped pods and stringers up to 0.5 m thick.

In general, most mineralized quartz veins have sharp linear contacts with the host rocks. The interiors of these quartz veins are brecciated and some contain fragments of sheared host rocks (Plate 6a). The sulphides are concentrated as interstitial breccia-fillings. Native gold, when found in the veins, is concentrated in fractures (similar to those seen in Plate 6a) crosscutting quartz fragments. Native gold is only rarely associated with the sulphide portion of the vein. Recrystallization, shown by partial or complete destruction of macroscopic cataclastic textures, has occurred in most veins. The sulphides-mainly chalcopyrite and lesser pyrrhotite- have remained in cusp shapes from 1-2 cm. Distribution of the more recrystallized veins is scattered and a well recrystallized vein may be spatially close (1-3 m) to a nonrecrystallized vein (with good cataclastic texture) with both located in the same shear zone. Mineralization of the recrystallized and the nonrecrystallized veins is similar.

Gold is associated with quartz in veins with or without megascopic amounts of chalcopyrite and does not follow sulphide concentrations. Other silicate minerals associated with the gold mineralization are albite and annite. Two types of native gold (electrum) are found. One has a pale yellow colour and is found predominantly in leaves and as fracture-fillings. The second type has a deeper orange colour and is found predominantly in specks smaller than 1 mm. These specks occur in peripheral fractures of quartz fragments and are often associated with fractures in albite and in the quartz around albite crystals. The occurrence of orange gold specks is common and they can be found in samples grading approximately 0.10 oz Au/tonne. Both types of gold occur separately or together in all parts of the mine.

2. Relationships with Host Rocks

(a) Gabbro

Veins located in the gabbro are parallel to the regional foliation. They are located at a small angle to the gabbro-mafic volcanic contact.

(b) Mafic-Felsic Volcanic Rocks

Veins located in the volcanic rocks appear to be close to parallel to the banding of the rock (and regional foliation) (Plate 11b).

(c) Felsic Dykes

No felsic dykes are known to contain more than trace amounts of copper or gold. However, as these dykes (principally foliated ones) are often located in or beside ore zones they may contain late fractures (up to 3 cm in width) which are filled with remobilized sulphides or gold in minor amounts leading from the veins into the dykes. Dyke contacts with the veins are knife-sharp. When dykes are found with veins, ore may be found on both dyke contacts but more often it is along one side with traces and/or subeconomic mineralization on the other similar to that shown in Plate 6b. In that case, the ore vein often alternates from one side of the dyke to the other on an individual stope basis (see Figure 6a) and more often on a larger scale between stopes or levels in the mine as a whole.

No dyke fragments are found in the brecciated veins or ore stringers. Therefore, these dykes have been intruded after most of the brecciation and foliation and, therefore, after initial vein formation. This hypothesis is further supported by the greater degree of foliation and shearing in the host rock versus the dyke; the alteration of the vein from one side to the other as if the vein has been cut in one plane of weakness by the dyke intrusion (see Figure 6a); and the sharp contacts with the veins.

(d) Diabase Dykes

Relationships of these dykes with the ore are not totally consistent. All diabase dykes cut the ore zones and most are not affected by other fault systems. However, in several places they have been brecciated by later movement along east-west (ore) shears (in surface outcrop and in the 10-3-6 and 12-A-2 stopes) and fragments of the dykes are strung out in veins over 1-2 m. The north blocks have a horizontal eastward movement (Figure 5b, Note the age difference in the diabase dykes). The contacts between the veins and the diabase dykes are sharp where the dykes are not affected by the east-west shear movement. In some instances the gold content of the veins appears to be higher in the vicinity of the dykes (ie. Figure 5a, north-dragged vein). Thus, the formation of the east-west veins was followed by northeast faulting as most of the diabase dykes and all the observed northeast faults are not offset across the east-west shears. In turn this was followed by diabase injection across the existing veins, followed by minor east-west adjustment as fragments of the diabase dyke found in the 10-3-6 stope are found in the east-west ore vein.

3. Gangue Mineralogical Associations

(a) Quartz

Quartz of the mineralized veins is predominantly white massive to glassy and is the major mineral in these veins.

A few grey sugar quartz veins are seen as in other gold mines, but as a rule, they are not gold bearing. Clear glassy (sometimes smokey) ladder quartz is found in some veins with higher concentrations of pyrrhotite. No internal structures other than brecciation, such as crustification or zoning, are found within the veins. The veins themselves are generally of uniform texture in cross-section.

(b) Albite

Pale green crystals of albite (to 5 cm; Plate 12a) and veinlets of albite (Plate 12b) are common in the ore veins. Albite is the most common silicate associated with the gold (other than quartz) and is found throughout the mine in ore-bearing veins. Gold occurs as a fine orange 'dust' within and around these crystals and as fine leaves and fracture-fillings enclosing the crystals and concentrated in the cleavage of the albite crystals. Microscopically, a network of gold (and minor chalcopyrite, fluid and telluride) inclusions has developed in quartz and albite (Plate 13a,b). Chlorite alteration of the albite crystals is responsible for the green colouration.

(c) Annite

Annite is found in the mineralized veins near concentrations of sulphides (particularily chalcopyrite) in books (to 3 cm) and aggregates in pods (to 1 m by 5 cm). Thin sections of ore samples reveal that annite in ore is reddish-brown in colour in comparison with the regular chocolate brown gradations in the thin sections from the rest of the mine (both are black in hand specimen). Annite (and ferrous phlogopite) found in thin sections of ore are often chloritized.

(d) Carbonates

Only minor amounts of calcite and ferroan calcite (0-2%) occur in mineralized quartz veins. Most of this carbonate

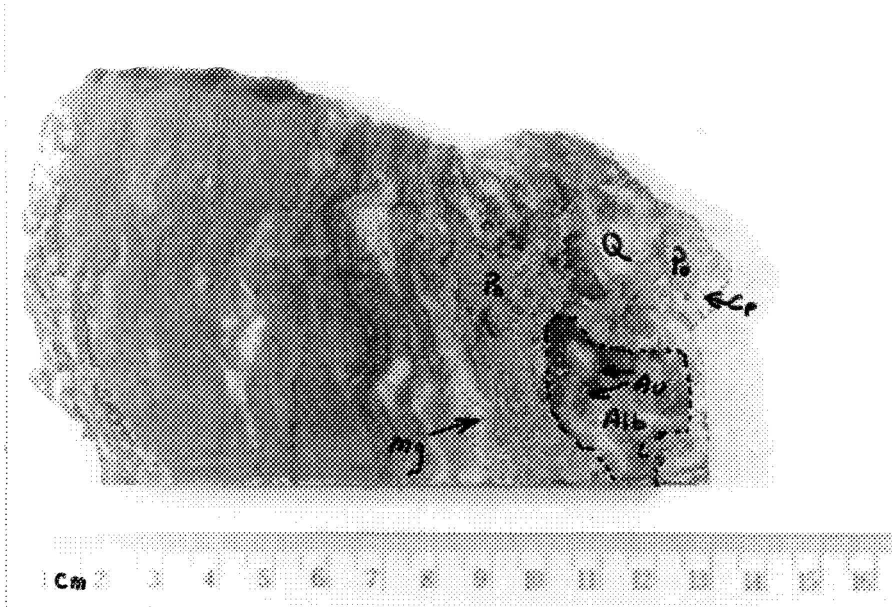


Plate 12a CBX 190 Part of ore vein and contact with sheared felsic dyke. Two foliation directions are present in the dyke; magnetite (Mg) is concentrated near the contact; albite (Alb) crystal with native gold (Au); pyrrhotite (Po) and chalcopyrite (Cp).

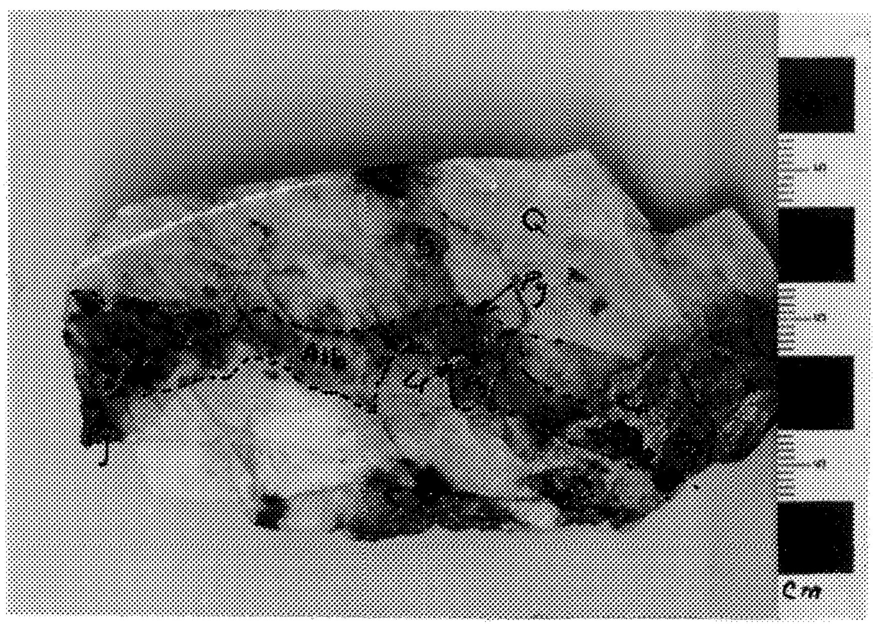


Plate 12b CBX 188 Quartz ore vein. Albite is developed along a fracture associated with sulphides (fuzzy grey, outlined). Pyrite (Py) brecciated with chalcopyrite (Cp) interstitial, on bottom right.

occurs as crosscutting veinlets and in breccia interstices (Plate 13a). An association with pyrite, especially the corroded pyrite shown in Plate 17 is seen in some thin sections.

(e) Tourmaline

Crystals of pink to pale and dark greenish-blue tourmaline (to 1 mm) are noted in approximately one-half of the thin sections of ore. Amounts contained in most of the ore thin sections are small (1-2%). Tourmaline found in ore veins is generally oriented with the foliation. Some crystals are fractured and broken and contain inclusions of chalcopyrite (Plate 9b). Other crystals are intergrown with chalcopyrite and appear to have been deposited with the mineralization.

(f) Sulphides

The major sulphide associated with the gold in the veins is chalcopyrite. Pyrite and pyrrhotite occur in these veins but are more often concentrated in the host rock. Pyrite and pyrrhotite are found throughout the vein system in roughly equal proportions, but on a local basis one may predominate to the total exclusion of the other. No zoning of the sulphide content has been noted within the mine as a whole.

Sphalerite is found in small amounts in association with the sulphide-rich areas in the mine. It is also disseminated in the foliation of the basic volcanic rocks. Arsenopyrite is found in scattered locations in generally small amounts and is located in sulphide-rich areas but is nearly absent in the veins.

(g) Magnetite

Magnetite is found in the veins in smeared-out plates

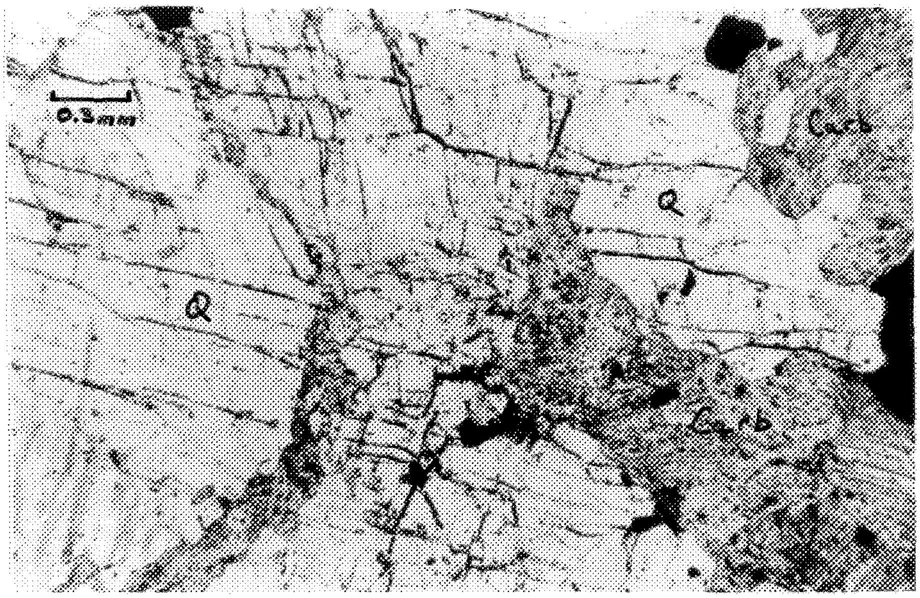


Plate 13a CBX 181 Ore vein. Fractures in quartz (Q) filled by opaque minerals with interstices between quartz fragments filled by carbonate (Carb). Recrystallization shown by the development of triple points between carbonate and quartz along right side of photo. Plane polarized light.

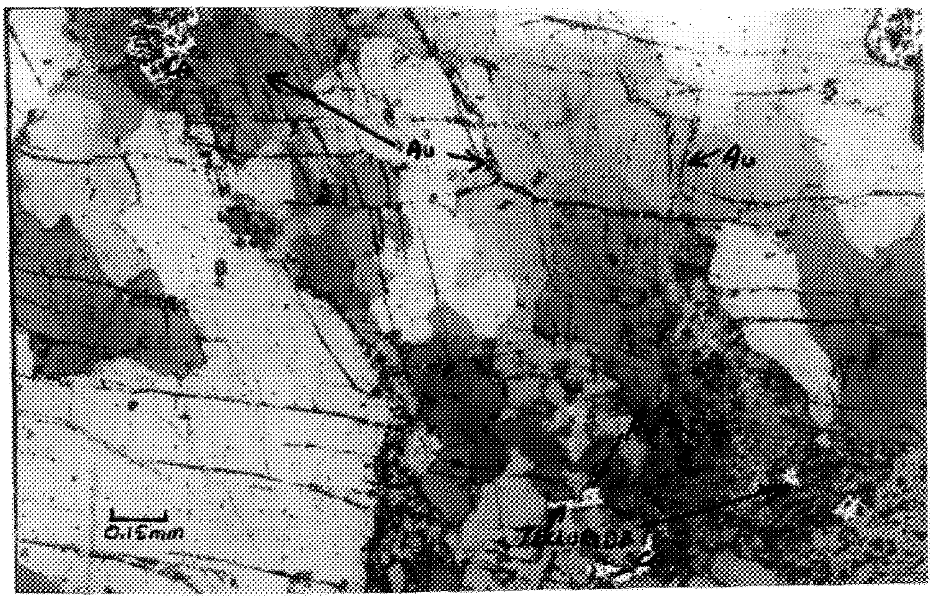


Plate 13b As 13a Shows the nature of gold (Au) in fractures. Minor chalcopyrite (Cp) and telluride. Dark shadows are gold grains in fractures below polished surface. Reflected light.

(to 1 cm by 1 cm) between breccia fragments. It is seen as inclusions in the major opaque minerals found in the ore.

(h) Minor Minerals

Minor amounts of bornite, chalcopyrite, galena (Malouf and Thorpe 1957) and tellurbismuthite (Cimon, personal communication) are seen in the mine. Other minerals are found in microscopic quantities. Tentative identification of these minerals made from optical data is: chalcopyrite family minerals such as talnakhite (XRD), cobalt pentlandite (electron microprobe); tetrahedrite and tellurides such as tellurium, hedleyite, calaverite and tetradymite.

4. Microscopic Textures and Relationships of Opaque Phases

(a) Gold

Eales (1967, 1968), Stumpfl (1969) and Squair (1965) report that variation of reflectivity and colour of gold (electrum) is related to the silver content. The same two colour ranges with corresponding ranges in reflectivity are seen both microscopically and in hand specimen. The orange, fine grained gold is gold rich, and the larger fracture-filling pale yellow to white (electrum) is silver rich. Both types are found in most polished sections of ore and are collectively referred to as 'gold'.

Gold grains, often associated with small amounts of tellurides, are found predominantly within the quartz, albite and, occasionally, carbonate (Plate 13b). The fine gold is often totally enclosed by silicate grains while the sheet gold occurs between the silicate fragments. The only exceptions are: two small gold grains found within a euhedral to subhedral pyrite crystal in sample CBX U-1313-23 (etching with $KMnO_4$ revealed a fine gold-filled fracture leading towards the pyrite grain boundary); several small gold grains found in sphalerite in sample CBX 207 (Plate 14a); (part of a gold veinlet cutting a sphalerite grain); a gold fracture-filling cutting magnetite in sample CBX 198B (plate 14b); and three other grains of gold found in magnetite and sphalerite showing crosscutting relationships similar to those in Plates 14a and b and described above. In summary, most of the gold occurs within silicates. Only a few occurrences of gold within opaque phases have been found and most of these show crosscutting relationships.

In several polished sections the fracture-filling gold is seen tapering down within the silicates leading away from the sulphides- particularly chalcopyrite and pyrrhotite. This texture suggests that gold was initially deposited in the quartz (albite) and the sulphides later filled the breccia interstices or that the gold was somehow removed from the sulphides in an original gold sulphide protore. Smaller aligned gold grains found in the silicates often show a network texture (Plate 13a, b, and Plate 15a, b). Very small trains of fluid inclusions contained in the quartz are often associated with this type of gold occurrence. One, two and three phase fluid inclusions are noted. The small aligned gold grains are noted to cut both porphyroclasts and granulated matrix in a mylonite gneiss (Plate 15a,b).

No changes in ratios of fine to coarse gold contents or of gold/silver- as shown by the colour of the gold- are found along strike or dip projections in or among the different zones, contrary to the observations in other Abitibi deposits by Fitzgerald et al (1967) and Griffis (1962) and as Prochnau (1971) noted in the Chibougamau deposits. Change in the fineness of the gold appears to

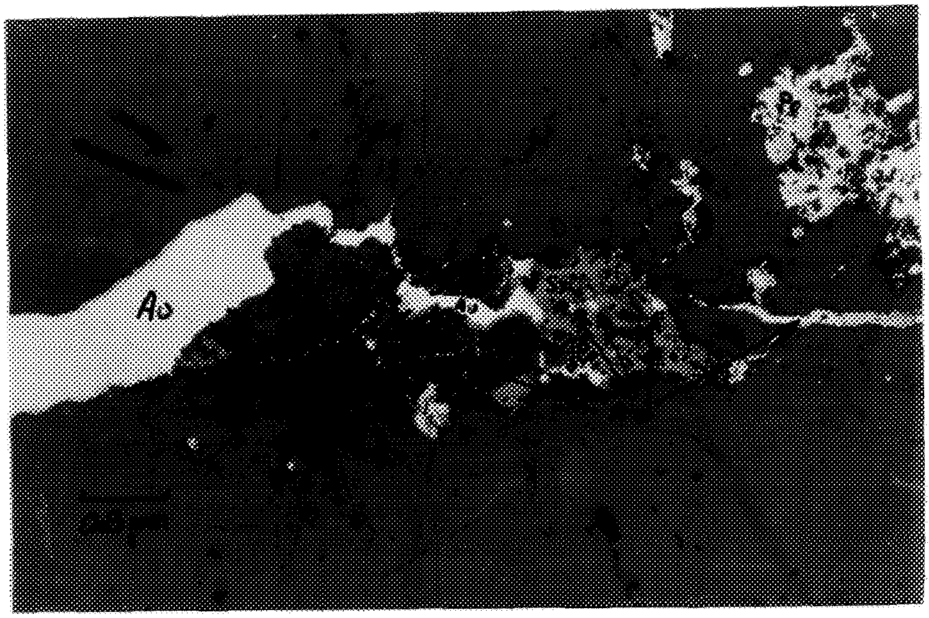


Plate 14a CBX 207 Ore vein (quartz). Gold (Au) veinlet cutting sphalerite (Sp). Pyrrhotite (Po) in top corner and in sphalerite. Reflected light.

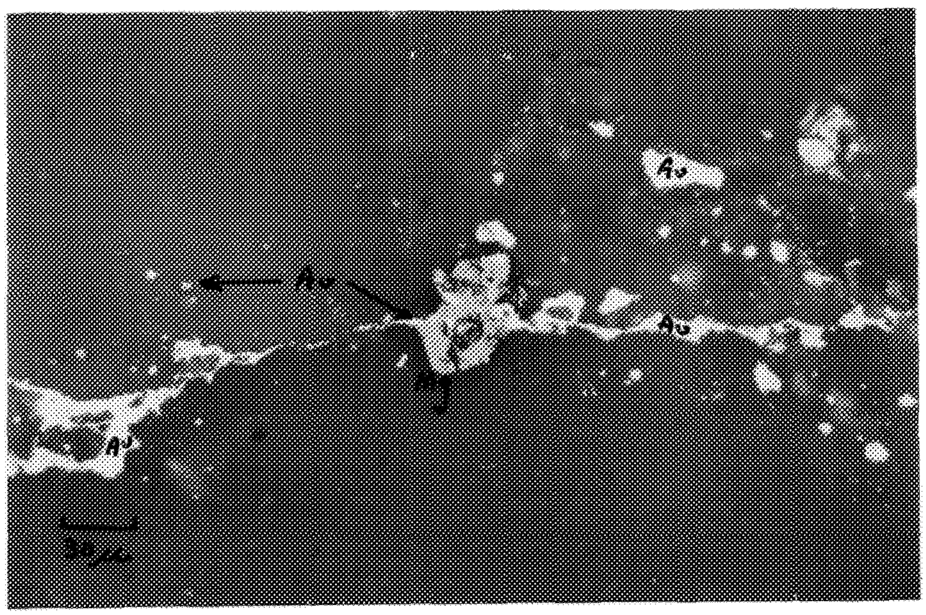


Plate 14b CBX 198b Ore vein (quartz). Gold (Au) veinlet cutting magnetite (Mg). Reflected light.

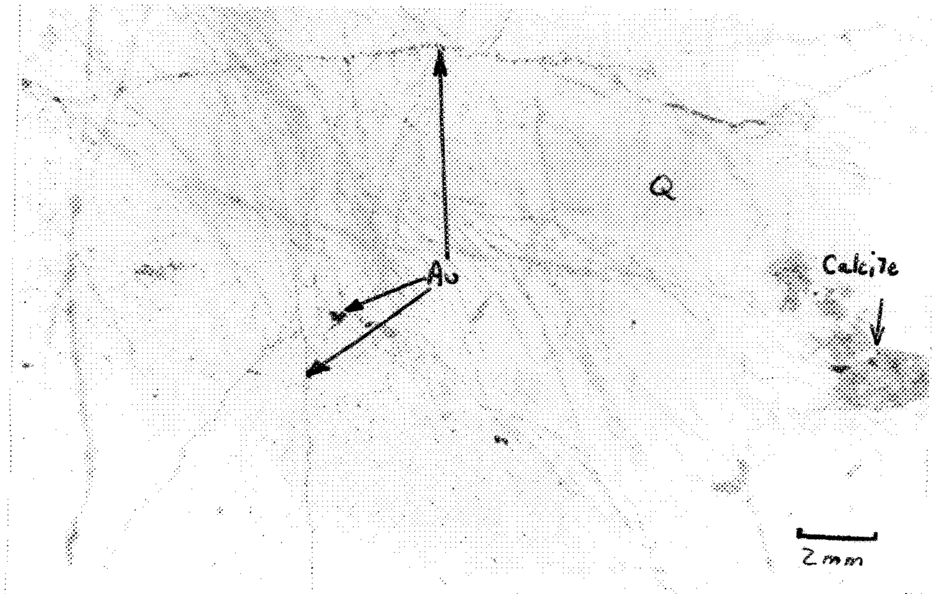


Plate 15a CBX 207 Main vein 600 level. Typical multiple gold (Au) grain 'trains' in quartz (Q) with calcite. Plane polarized light.

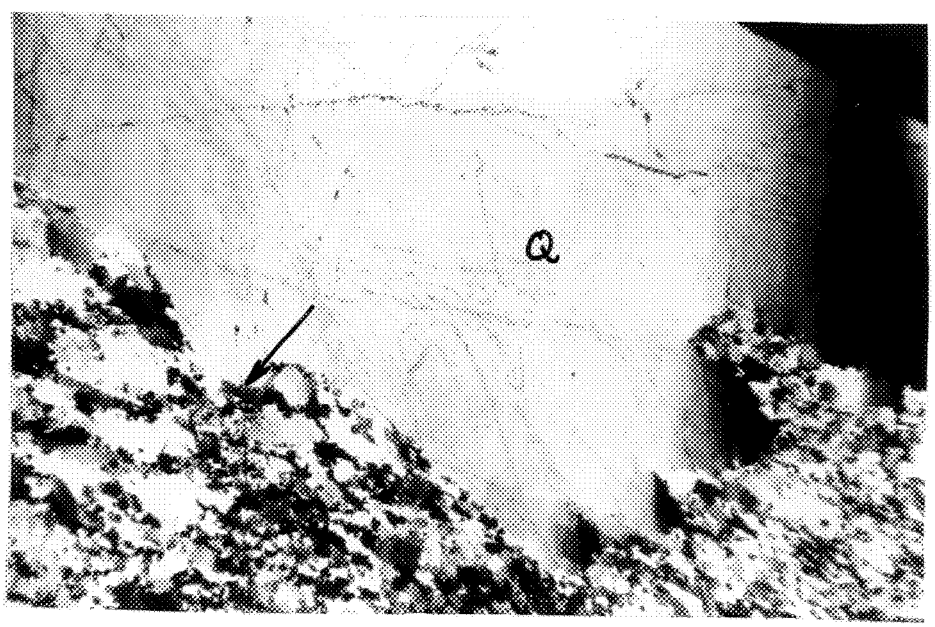


Plate 15b As above Note gold grain 'trains' cross fragments of quartz and breccia matrix with no dislocation of 'train' on the fragment boundary (at arrow). Crossed nicols.

be related to the general grain size and type of occurrence. Coarse sheet gold has a lower fineness and the small gold grains are of higher fineness. This is contrary to observations by Mackay (1944) who noted that in the deposits he studied the coarser gold has a lower silver content than the fine gold and supposedly, that secondary gold has a higher fineness than primary gold.

In the Chibex deposit the sheet gold- often found interstitial to silicate grains- is either remobilized primary gold or gold of a second mineralization, as the fine gold grains are found inside silicate grains and are, therefore, older.

The presence of triple points in and between chalcopyrite, pyrrhotite and pyrite, and the brecciated textures of the ore veins, with the sulphides generally interstitial to the silicates, suggests that the sulphides have been dynamically and/or thermally metamorphosed. The presence of gold crosscutting both matrix and porphroclasts (Plate 15a,b) suggests that the gold was introduced after brecciation as there is no displacement of the gold 'train' at the porphyroclast boundary. All the data is consistent with the theory that most of the gold was introduced to its present location very late during or after the dynamic metamorphism.

(b) Chalcopyrite

Chalcopyrite is found in small amounts in most polished sections. It is found as: patches (to 1 cm); discrete grains in the silicates; within fractures and cleavage in other minerals (quartz, micas, chlorite, pyrite and pyrrhotite); as rounded grains in pyrrhotite masses; as 'rims' around other opaque minerals; and as inclusions in pyrrhotite, magnetite, sphalerite or poikiloblastic pyrite.

Most sections containing chalcopyrite (pyrite, pyrrhotite and sphalerite) show development of triple points indicating that the mineralization had undergone recrystallization.

X-ray diffraction done on samples of chalcopyrite from different areas of the mine indicates they are mixtures of α-chalcopyrite, β-chalcopyrite, and tetragonal chalcopyrite.

Chalcopyrite (and pyrrhotite) in gold-bearing polished sections frequently shows small inclusions and intergrowths of minor amounts of a mineral tentatively identified as talnakite, with possibly other chalcopyrite family minerals.

(c) Pyrrhotite

Pyrrhotite is found in most sections as: fracture-fillings in other minerals; discrete grains in the silicates; and inclusions in chalcopyrite, pyrite and magnetite. In sections containing gold, pyrrhotite (as chalcopyrite) commonly contains minor amounts of other less abundant minerals.

Samples of pyrrhotite from scattered locations in the mine are mixtures of monoclinic, hexagonal and troilite types of pyrrhotite (X-ray diffraction).

(d) Pyrite

Pyrite (and marcasite) are found in euhedral to subhedral grains (to 5 mm) when they are found in quantities to 5%. In quantities greater than 5% pyrite has subhedral to anhedral grains and porphyroblasts (to 5 mm) with some development of triple points between grains (Plate 16a). The larger crystals and porphyroblasts are often fractured and contain chalcopyrite or pyrrhotite. Marcasite occurs in radiating aggregates in some interstices (Plate 16b). Chalcopyrite, pyrrhotite, magnetite and sphalerite are

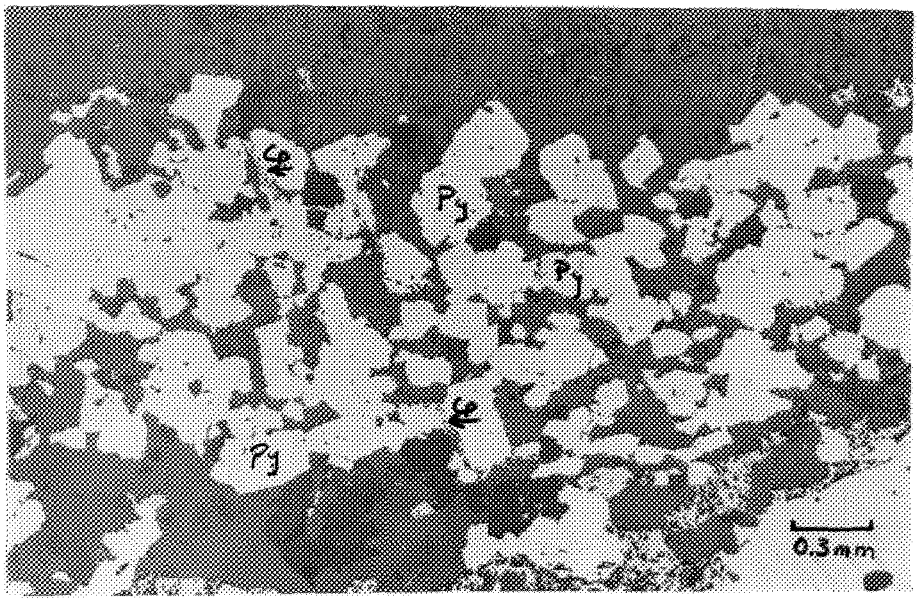


Plate 16a CBX 190 Main vein 750 level. Porphyroblastic pyrite (Py) with development of triple points, minor veinlets of chalcopyrite (Cp) all in quartz. Reflected light.

Plate 16b CBX 201 Radiating marcasite (Marc) with pyrite (Py) in brecciated diabase dyke breccia interstice. Partly crossed nicols, reflected light.

found interstitial to pyrite grains and as rounded to subhedral inclusions contained in the pyrite.

A 'spongey-textured' (corroded?) pyrite is found in polished sections from scattered locations. This 'spongey' pyrite occurs as subhedral 'crystals' and as layers bordering regular pyrite (Plate 17). Chalcopyrite and magnetite are often intergrown with this 'corroded' pyrite. Layers of 'corroded' pyrite, chalcopyrite and pyrrhotite are present in sample CBX 174 (Plate 18a).

(e) Magnetite (and Ilmenite)

Magnetite is the most widespread opaque mineral in polished section and occurs in euhedral to subhedral grains (from 0.02 mm to 5 mm) and as rounded to subhedral inclusions in pyrite, pyrrhotite and chalcopyrite. Magnetite is noted to replace or form surface layers on pyrite (Plate 18b). Exsolution of ilmenite and alteration to maghemite are noted in a few sections. Leucoxene alteration of the oxides is noted in most polished sections (Plate 7a,b). Magnetite in both larger euhedral crystals and the fine crystals from olivine relicts are affected.

(f) Sphalerite

Sphalerite occurs in grains (to 3 mm) associated with concentrations of pyrite and as rounded inclusions (to 0.05 mm) in pyrite, pyrrhotite and chalcopyrite (Plate 6b). Minor exsolution of chalcopyrite is noted. Only minor amounts occur in the mineralized quartz veins.

II.D. STRUCTURAL RELATIONSIPS

1. General

Three main shear zones located about 100 m apart, striking east-west (slightly north of west in some locations)

Plate 17 CBX 1313-23 Sulphide concentration associated with ore vein. Pyrite (Py) with 'corroded' pyrite borders, magnetite (Mg) and chalcopyrite (Cp). 'Corroded' pyrite is filled with carbonates. Reflected light.

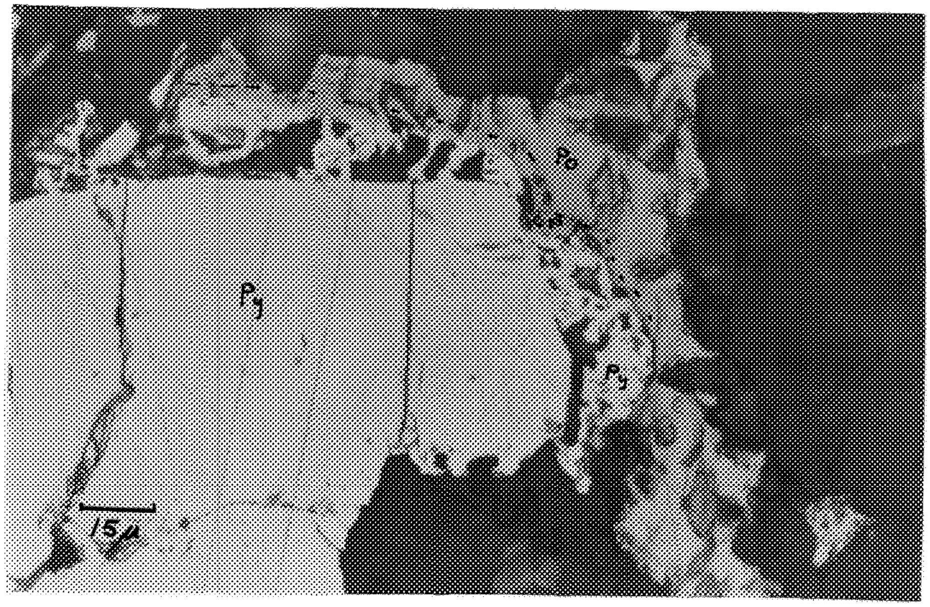


Plate 18a CBX 174 Layers of pyrrhotite (Po), chalcopyrite (Cp) and 'corroded' pyrite (Py) on a pyrite crystal. Reflected light.

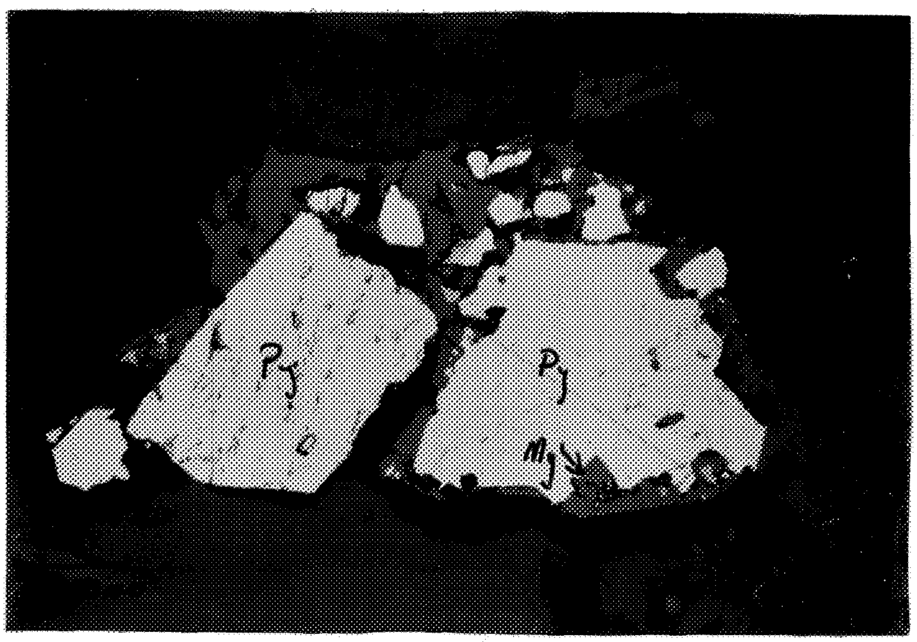


Plate 18b CBX H113-426.5 Magnetite (Mg) surrounding (replacing ?) pyrite (Py). Reflected light.

with a vertical dip, contain most of the ore veins. These shears have a slight roll on a 50-100 m scale but remain essentially vertical and parallel in the explored part of the mine. Two small oblique ore veins are located in a small fault zone which strikes roughly NNW and dips 50-70°E. Mineralization in these latter veins shows the same textural and mineralogical variations as in the east-west system. Nonmineralized faults of a third strike direction (NE) dip both east and west with dips from 10-45°. Stoping and drifting operations on veins have indicated that many of these NE faults appear to have very little horizontal movement component. In most cases it is evident that movement has taken place by a change in the intensity or width of the shear zone, intensity of alteration, dragging of the vein (Figure 5a), or a minor displacement due to variation in the dip of the vein. In all such cases a vertical movement near the dip of the vein structure is indicated for these NE faults. Drilling results suggest the possibility of several faults in this system with suspected movement from 15-50 m. However, drill hole data is only available for an area from 50-125 m on each side of the 'main' zone and in many areas a recognizable stratigraphic indicator is not present in the core or the drift to show horizontal displacement.

No large scale folding is noted in the mine. Minor Z and S folds of veins occur on a scale of 0.1 to 5 m with different plunges and orientations within each and among the different shear zones. Plate 11 shows small scale folds in a mineralized veinlet which are likely due to drag effects of shearing.

Malouf and Thorpe (1957 p 453) suggest a possible fold in the (upper levels of the) mine. No evidence to prove or disprove this theory has been found in the latest underground work. Bichan (1959) suggests that there are three tightly folded synclines in the shaft area. No repetition of stratigraphic units is seen in the mine nor is there other supporting evidence. Hebert (1977 personal communication) did not find evidence on a larger scale of such a series of structures in the vicinity of the mine.

(a) East-west System

The east-west shear system is the major ore control of the mine. It appears to be the oldest fault system as most of the other faults and associated joints cut it and are not displaced by it even though evidence of movement along it is present. Openings (to 30 cm) seen and known to extend 30 m (both in the 'north' and 'main' zones), as well as numerous 'holes' found in drilling are evidence that this area is part of a large dilation zone. Brecciation such as shown in Plate 6a is very common (up to 10 m wide). Interstitial vugs are present in most of these breccia zones.

Plagioclase porphyroclasts in samples from shear zones show a development after initial foliation. Granulation and rotation of porphyroclasts are shown in porphyroclasts with helicitic textures. A third foliation cuts some of these latter porphyroclasts. Microscopic textures found in these shear zones are: bending and crumpling of micas, chlorite, hornblende and tourmaline; brecciation; granulation and recrystallization in porphyritic rocks; and general development of foliation (two directions are present in the strongest shear zones 20-30° apart).

Multiple movements are shown by the following:

1. Felsic porphyry dykes on the 450 level approximately

650 m west of the shaft, contain quartz veins striking N30°E dipping 62°E, which are nearly perpendicular to the dyke contact and within 0.5 to 1 m taper off in a wedge-shape into the dyke. These probable tension gashes indicate that movement took place along this part of the shear zone in a direction perpendicular to these features.

2. Boudinage of dykes and quartz veins is common, particularily in an east-west sense.

3. Small scale Z folds in the 'main' shear in the surface outcrop plunge vertically and show east-west movement.

4. Z folds (drag folds) up to 2 m in ore veins ('main' and 'south' zones) plunge horizontally and show vertical movement (Plate 11).

5. A crosscutting quartz vein on the 1200 level is shear folded by the east-west shear over 2 m but total displacement is less than 0.5 m.

6. Slickensides in part of the main shear on the 1200 level show horizontal movement (north side has moved west).

7. Diabase dykes in surface outcrop and in two stopes show a late horizontal displacement of the shear zone is north side to the east 1-2 m (Figure 5b).

These and other relationships suggest multiple movements in several directions. It is highly likely that this east-west system was a zone of weakness and that recurring movements took place along it in response to changing conditions throughout its history.

(b) Northnorthwest System

Two mineralized shear zones strike from northwest to north dipping from 40° to 80° ast. Very little is known about this system as it is subparallel to all the exploration drilling in the mine. Figure 7 shows part of one of these structures as seen on the 900 level. Relationships with the east-west system suggest that the northnorthwest system is the oldest. Movement suggested by Figure 7 along the east-west system is of the north side west.

Joints in this system seen in outcrop which are cut by the east-west shears appear to be displaced up to 20 m in different directions.

(c) Northeast System

i) Westerly Dipping

Faults with horizontal displacement greater than 50 m, such as those shown by Hebert (1977), have not been encountered in the mine and most of the present workings of the mine are likely located in one fault block (of this northeast system). All mine units have a strike change (over 150-200 m) from east-west to 20°south of east, east of the shaft on the 300 level under Lake Norhart. The associated mine heading was stopped due to high water flows. This evidence supports the presence of a fault in the area with righthand displacement. The fault under the Nemenjiche River was seen in the incline and did not displace the east-west shear zone, on which the drift was driven, horizontally although intensity of the shearing increased on the east side of the fault (dip is 55° west).

Another crossfault of this system is seen on the 600 to the 900 levels. Located near the shaft on the 600 level it dips 30° west (25° on the 700 level, and 40° on the 900 level). This fault does not displace the ore veins it cuts. Joints found in conjunction with the 900 level occurrence strike northeast and dip 83-85° east. Some of these joints appear to have some movement along them (Figure 6b).

This system of faults cuts all the mine units. There are often associated high pressure water zones (higher than natural depth gradients). They are likely the youngest faults in the mine as they are not affected by the other systems.

ii) Easterly Dipping

Northeast striking fault and breccia zones dip 70-85°E and have been intruded by diabase dykes. Horizontal displacement along these fault zones within the mine is generally minimal although offsets up to 10 m are known. Dragging of ore veins such as shown by Figure 5a, suggest that movement took place along the system in a vertical sense with the east block moving upward. Figure 5b shows that faulting in this system was not a single event and adjustment along the east-west system took place between periods of north-east faulting. One of these faults has displaced the ore zone 10 m (east side north, on the 300 level, 100 m east of the shaft). Movement along these faults and subsequent introduction of diabase dykes was spread out in time as shown by relationships such as seen in Figure 5b. The relationships of these faults with the westerly dipping ones has not been observed. However, they may be complementary faults such as described by Moody and Hill (1956). Joints related to a westerly dipping fault on the 900 level (Figure 6b), having the same orientation as the easterly dipping faults, support this view.

(d) Summary

All fault systems show evidence of repeated movements and it is likely that with each succeeding movement along the younger systems the previously formed systems underwent adjustments which affected the east-west system to the greatest degree.

Relationships suggest that the northeast system is the youngest. However, any further speculation on the detailed age relationships of the systems or of reasons for the individual systems is impossible with the available information. For the same reason a comparison of these structures with those around other Chibougamau mines is not possible. On a broad scale they resemble one another in general orientation and shear and fault style. A comparison of the work of Hebert (1978) with that of Allard (1976) and Graham (1957) will further outline the similarities of the tectonic style.

III. DISCUSSION

A. REVIEW OF THEORY

A review of modern literature concerning gold indicates that there has been an interest in this mineral since medieval times with ideas about its formation changing over the years. Most current authors favour aqueous solutions for the geological transport of gold. This appears to be substantiated by theoretical and practical evidence. Other transport mechanisms such as solid state diffusion (Czamanske 1973) or ductile flow due to metamorphic stress may play a minor role on a small scale. The occurrence of gold in naturally occurring ground waters has been reported (Weissberg 1960, White 1967). Boyle's (1975) summary of gold ion species is as follows:

> "The principle soluble species of gold are gold hydroxide, $Au(OH)_3$ or $[AuO_2]^-$, halogen complexes of the type $[Au(Cl_4)]^-$; various thio complexes of the type $[Au(S_2O_3)_2]^{3-}$; cyanide and cyanate complexes of the type $[Au(Cn)_2]^-$ and $[Au(CNS)_4]^-$; and sulphide and polysulphide complexes such as $[AuS]^-$ and $[Au_2(HS)_2S]^{2-}$." pl.

Solutions and conditions for the transport of these species of gold are:

1. Acidic-oxidizing chloride-bearing solutions (Henley 1973, Helgeson and Garrels 1968, Krauskopf 1951, Ogryzlo 1935).
2. Sulphide-rich solutions

   (a) Acidic sulphide-rich reducing solutions (Hattori 1975, Seward 1973), oxidizing solutions (Cloke and Kelly 1964)

   (b) Alkaline sulphide-rich reducing solutions (Seward 1973, Weissberg 1970, Smith 1943).

   (c) Alkaline, sulphide and carbonate-rich reducing solutions (Boyle 1975, Ogryzlo 1936, Weissberg 1969).

Solutions would precipitate gold with a change in pH, Eh or a drop in temperature. Henley's (1973) work suggests pressure drops may also cause precipitation. Electrochemical reactions for the control of the precipitation of the gold similar to those noted in models of sulphide deposits may be important (Govett et al 1976).

Experimental and theoretical determination of gold solubilities by the various authors above are difficult to compare due to the varied conditions and solutions they use for the transport of the gold. There is a general increase of gold solubility with: higher temperatures (quite marked in some instances, ie. chloride species between 400 to 500°C, Henley 1973); concentration of the solution responsible; and with an increase in pressure (Henley 1973). Concentrations of gold vary from almost nil to 1000 ppm of gold chloride species (at 500°C at 2 Kbar, Henley 1973); and to 60 ppm of gold sulphide species in carbonate-bearing sulphur rich (possibly with arsenic or antimony) solution at STP (Boyle 1975). At low temperatures and pressures gold sulphides are more soluble than gold chloride ions. If Boyle's (1975) work had been done at elevated temperatures or pressures, solubilities would likely be higher. Henley's (1973) results at the lowest temperatures and pressure (300°C, 1 Kbar) are much lower than Boyle's (1975) at STP. No matter what type of solution is envisioned, quantities of gold large enough to produce large deposits are transportable in such solutions given an initial metal source.

Due to the complexity of the geological environment it is likely that several types of solutions and/or soluble species are present during the mineralization of one deposit even though one solution or species may be responsible for the bulk of the mineralization. Present data on thermal ground waters (Weissberg 1970, White 1967) suggests that the major ion species responsible in the transport of gold are sulphide ions. Carbonate ions likely play an important role in the process (Boyle 1975). This data is supported by numerous occurrences of gold associated with sulphides and carbonates.

It is difficult to believe that the acidic solutions (pH 2-4) necessary to keep the gold-chloride species in solution would deposit the carbonate associated with many gold deposits (Boyle 1969). If the carbonate was present in the vein before the arrival of the mineralizing solution it would produce a change in pH necessary for the precipitation of the gold. In the deposit under study, however, most of the carbonate is in the host rocks and relationships indicate that the gold is syn- or post-carbonate (Plate 13a,b; 15a,b). Therefore, the precipitation would have taken place in the carbonate in the host rock rather than in the quartz veins if the gold-bearing solutions were acidic chloride solutions. Also carbonate porphyroblasts would be leached out of the host rocks close to the veins by such a solution. Therefore, it seems reasonable to assume that gold-bearing solutions which could possibly form a deposit are mainly alkaline to neutral, containing CO_2 and S (Boyle 1969, 1975).

Boyle (1968, 1970) has discussed the four possible sources of metals and volatiles in hydrothermal solutions: a deep mantle source; a crystallizing magma; the host rocks of the deposit; or an ancient weathered surface. The mechanism he proposes for the transportation of the solutions is diffusion through the host rocks and concentration and flow through dilatant structures. Results of his work led Boyle (1961) to propose that in the case of the Yellowknife deposits the source of the metals is the host volcanic rocks.

Absolute results of analysis and observations on the gold contents of various types of host rocks - such as by Anhaeusser et al (1973), Hollister et al (1975), Keays and Scott (1976), Li et al (1973), Shcherbakov and Perezhogin (1964), Stephenson and Ehman (1971), Tilling et al (1973), Viljoen et al (1969, 1970) - can not be compared due to problems inherent in analysis. Relative results suggest that gold contents of mafic volcanic rocks and intrusive rocks (around 10-20 ppb) are generally higher than in felsic rocks (around 1-5 ppb). All the above authors infer that the sources of the gold for the (gold) deposits they have studied are mafic intrusives and volcanic rocks. They imply mafic rocks are a better source of gold than the felsic rocks.

In the case of the Chibex deposit the large quantities of mafic volcanic rocks and intrusives (greater than 8000 m of the sequence) are a potentially large source of gold. Titanomagnetite, which makes up 5-8% of the host rocks of the deposit, is the probable source of the Fe contained in the pyrite and pyrrhotite, as leucoxene alteration of the titanomagnetite frees Fe. Chalcopyrite, pyrite, and pyrrhotite are present as widespread disseminations in the volcanic rocks of the mine sequence and are a possible source of the copper and sulphur.

Crerar and Barnes (1976) have shown that it is possible to transport Cu in a basic reducing solution at temperatures between 250-350^{o}C, both as cuprous chloride ionic complexes and as cuprous bisulphide with the latter species dominating. Fe is also soluble in small quantities in this solution. Rickard (1974) has also shown that it is possible to transport Cu in a CO_2-bearing solution and that further soluble copper carbonate ions are formed in this type of solution.

Therefore, it is possible that the host volcanic rocks were the source of the Cu and S as well as the Au and the other trace metals. It is also possible to transport the Cu in the same type of solution which has been postulated for the gold transport. These solutions could circulate in fractures and shear zone openings, such as breccia interstices, and by diffusion through the rock. The total system would be dynamic, changing with the precipitation and leaching of the ore minerals on a local scale (Golubev 1975) helping produce the erratic pattern of gold mineralization usual in vein gold deposits.

III.B. TRANSPORT AND PRECIPITATION OF MINERALIZATION

1. Sources and Transport of Solutions

Hansuld (1967) gives electrochemical data for deep mine ground waters which have a pH from 6.5 to 10 and an Eh close to 0 or negative. These conditions fall in the range required for the mineralizing solution described above. Therefore, it is not necessary to have a water source other than natural ground waters. These waters could pick up S and CO_2 in volcanic rocks around the deposit, leaching gold and copper, and transport these elements as long as conditions were stable. Circulation of these waters is a necessity for transport of the metals. Two possibilities exist: 1. a heat source in the vicinity acted as a heat engine circulating the solution;

2. ground water movement due to natural phreatic gradients.

Either mechanism is possible. A heat source in the area would increase ground water temperatures and allow greater metal concentrations in the solutions as well as providing a heat engine for the circulation of solutions, but an intrusion is not necessary because: regional metamorphism would give the same temperatures and create regional ground water phreatic gradients; and appreciable quantities of gold can be carried in solution at these low temperatures.

Data on the composition of the mineralizing solution and the conditions of ore deposition can be inferred from evidence of metamorphism on and mineralogy of the host rock silicate assemblages. Information can also be obtained from the composition of sphalerite and fluid inclusion studies in ore material. Information inferred from the host rock and vein mineralogy is presented below. Further studies of ore materials may provide more detailed information.

The host rock silicate assemblages of quartz, albite, epidote, biotite, chlorite (chloritoid) and actinolite show that the host rocks have undergone medium grade greenschist facies regional metamorphism (Abukuma type quartz-albite-muscovite-biotite-chlorite subfacies, Winkler 1967). This indicates that temperature and pressure conditions of regional metamorphism were about 425°-$450^{\circ}C$ and 3-5 kb P_{H_2O} (Hyndman 1972, p313). The host rocks and fragments in contact with the veins contain the same minerals as the host rocks away from the veins. Therefore, the maximum conditions at the time of the deposition were about the same or slightly lower than those given above.

Vein associations of albite with the gold mineralization and the wider associations of annite, carbonates, tourmaline, chalcopyrite, pyrite and pyrrhotite are not unique to the Chibex deposit and have been noted by other authors: albite by Gallagher (1940), Boyle (1961) and Jambor (1971); albite and biotite by Bateman (1940); and sulphide and quartz are found in most gold deposits. These associations of gangue minerals likely reflect the composition of the mineralizing fluid. This fluid likely contained Na, K, S, CO_2, and Bo in addition to gold, copper bismuth and tellurium which are seen in restricted local mineralogy within the mine. The source of the gold, copper, zinc and other trace metals was likely the volcanic rocks. Transport of Fe for pyrite, pyrrhotite and chalcopyrite is not necessary as the Fe liberated from leucoxene alteration of titanomagnetite is more than adequate (Plate 10a,b). Na and K could be obtained from the essential minerals of the rocks.

Most authors infer that ore solutions are either K-rich or Na-rich with the near exclusion of the other. The association of albite with the quartz veins implies a Na-rich solution while the association of the annite with the ore shears implies a K-rich solution. This means that either two separate solutions were involved or more likely, that the partitioning of precipitates from one solution containing both Na and K somehow occurred with the Na concentrated in the quartz veins and the K in the sheared host rocks. Again, the mechanism for the partitioning of the Na to the veins and the K to the host rocks of the deposit could be regional metamorphic effects on the feldspar. Regional metamorphism in the host rocks would lower An contents in the feldspars (Winkler 1974). This would result in a partitioning of Na into the feldspars. On the other hand, the same process could be reversed at depth and nearer the Grenville Front or some other source of higher metamorphic grade facies. This would mean that solutions in the 'plumbing system' would be richer in Na due to the likely input of solutions from depth (and generally higher metamorphic grade areas), than the solutions coming from and in the host rocks. Fluid inclusion studies and electron probe work on micas may solve this problem although the development of phlogopite beside the felsic dykes implies a possible late nonmineralizing fluid rich in K.

2. Precipitation

The precipitation mechanisms for a mineralizing solution such as described above are: a decrease in temperature or pressure; increase in Eh or pH; or an electrochemical reaction. If the ore solutions originated in the host rock and migrated toward openings in dilation zones within shear zones, temperature gradients would be fairly small and pH conditions would not change from basic unless there was an input of acidic magmatic water. Acidic surface water would not be introduced into the shear system due to the pressure gradient. Pressure gradients would likely be steep in the vicinity of the veins due to the increased flow volumes possible in the shears and may cause gold precipitation. Electrochemical reactions in a sulphide-bearing system have only been partly investigated. Govett et al (1976) have shown that electrochemical reactions occur around a deposit containing sulphides in an acqueous medium. Their data (p 930) shows significant variations in Eh in their system model. These variations, if present in the vein system, would be sufficient to cause local precipitation of the gold and sulphides. Raymahashay and Holland (1969) and Meyer and Hemley (1967) have shown that alteration reactions of host rock silicates may set up local pH and Eh variations. It is likely that any significant variations are local. However, it is not difficult to see the possibility of the precipitation of sulphides or gold from an ore-bearing solution due to these causes.

Therefore, change in pressure and changes in Eh would be expected to be main mechanisms for precipitation of gold from solutions circulating in a vein system. The association of gold with chloritized albite suggests pH played a role as well (Meyer and Hemley 1967). The changes would be brought on by natural flow gradients in the system and by chemical and electrochemical reactions set up in the veins, initially by alteration of the silicate host rocks and later by sulphide concentrations in the system.

Relative solubilities of gold and copper in the type of solution visualized for this process are not known due to a lack of data. Textural relationships between the gold and the sulphides suggest that the gold is the last mineral to precipitate after copper and other sulphides. Therefore, it is likely that initial precipitation of sulphides would be locally triggered by chemical variations in the vein due to silicate alteration reactions. Subsequent local concentrations of sulphides may then set up further chemical variations causing further more extensive precipitation of sulphides and gold. The system would be complex and would change constantly in reaction to the new sulphide depositional areas setting up new Eh variations. This and changes in fluid flow due to plugging of small channels by precipitates would produce a locally erratic deposit. Govett's (1976, p 930) diagrams suggest that oxidizing conditions would occur near initially formed sulphides and reducing conditions further away. This would produce an ore pattern such as the one seen at Chibex, especially in ore type 3 with a high sulphide content in the host rocks. Gold would not be expected to precipitate in the interior of sulphide grains nor in contact with them (also reported in other mines, Goodspeed 1936).

Therefore, it is likely that Eh played the most important part in the localization of the gold precipitation. Pressure effects possibly played a minor role in the process but are hard to evaluate.

The two general fineness ranges of gold in Chibex samples requires two (gold) mineralizing solutions or a mechanism by which two fineness ranges of gold can be produced from the same solution. It is seen that, generally, the finer gold is in smaller grains and is likely of earlier origin than the gold richer in silver. Gold with impurities such as silver, is more soluble than gold without these impurities (Boyle 1975, p 2). Therefore, gold deposited initially from a gold bearing solution would be finer than gold deposited later in the solution history. Also, earlier formed silver-rich gold would tend to be leached from initially deposited grains by the solution. This interpretation is more in line with a dynamic model than the two separate and possibly isolated mineralizing solutions.

III.C, SEQUENCE OF EVENTS

The sequence of events relating to formation of the deposit and its host rocks are:

1. Volcanic activity and introduction of gabbro into the sequence.

2. Regional metamorphism, folding and production of EW (and possibly NNW) shears and fault zones- brecciation and introduction of La Dauversière Stock. Metasomatism and initial formation of quartz veins in dilation zones. Continuing activity along EW shears through to event 7.

3. a) Brecciation of EW (and NNW) quartz veins creating channelways for hydrothermal fluids bringing major sulphide mineralization, further brecciation.

b) Introduction of gold and copper-bearing fluids in late stages of (a). Three possibilities exist that are consistent with observed microscopic evidence. These are:

i. A gold-bearing solution was introduced into brecciated quartz veins already containing minor sulphides, where native gold and minor tellurides and chalcopyrite were precipitated in the fine fractures in the porphyroclasts. Later the sulphides contained in either the same solution or a second solution were precipitated interstitial to the quartz breccia fragments and fragmented early sulphides.

ii. A gold-copper-bearing solution was introduced into the brecciated vein precipitating the gold and copper interstitial to the porphyroclasts. Subsequent metasomatism selectively remobilized gold from the sulphides into fractures of the vein silicates.

iii. A predominantly gold-bearing solution was introduced into previously brecciated sulphide-bearing quartz veins, and deposited gold in fractures concentrated in the silicates.

4. Injection of equigranular felsic dykes and subsequent porphyry dykes with continuation to event 7.

5. NE faulting and brecciation.

6. Injection of diabase in event 5 (east dipping) and felsic dykes.

7. Continued brecciation and remobilization of sulphides and minor gold.

IV. SUMMARY AND CONCLUSIONS

The Chibex deposit is located near the eastern limit of the Abitibi greenstone belt. Mineralization consists of native gold and chalcopyrite contained in fractures and interstices of brecciated quartz veins. The veins occur in three parallel sheared and altered zones which cut mafic intrusive and volcanic rocks and felsic volcanic rocks. Concentrations of pyrite and pyrrhotite occur as lenses and stringers in shear zones in the mafic intrusive rocks and as disseminations in the volcanic rocks.

Major mineralogy, texture and mineral relationships of the host silicate and ore have been studied and described. Macroscopically, gold mineralization is related to the occurrence of quartz, albite, annite and chalcopyrite in the ore veins. Microscopically, only the relationship of gold with quartz and albite is confirmed. The annite contained in the ore shears has a medium reddish-brown colour which is not seen in the host rocks. Anhydrite (to 10%) has been noted to occur in the 'main' shear zone and in the mafic volcanic rocks. As it does not occur in other rocks of the region (Hebert, personal communication) the presence of annite may be an indicator for the 'main' shear and the mafic volcanic rock unit found in the mine.

Textures and relationships of the mineralization with the silicates show that the present ore concentrations are younger than the host rocks and that the native gold was the last mineral to be localized.

A lateral secretion hydrothermal model, such as proposed by Boyle (1961. 1968, 1969; and Golubev (1975), consistent with the features of this deposit, is proposed as the mechanism for the vein formation. The host volcanic rocks may be the source of the metals, as has been proposed by numerous authors for similar gold deposits (Viljoen et al 1970; Boyle 1961, 1970).

A reducing, basic, H_2S- and CO_2-bearing solution such as described by Boyle (1975) appears to be the most likely solution for the transport of both copper and gold. No special solution source is necessary as it is similar to present day deep ground water described by Hansuld (1967). High temperatures are not required for the solution of significant quantities of gold (Boyle 1975) but would aid in the concentration and transport of the mineralization.

Precipitation of the metals from the mineralizing solutions and localization of the gold in the silicates contained in the shears would be caused by: pressure drops; a variation in the Eh and pH of the environment in the vicinity of the veins caused by silicate alteration reactions (Raymahashay and Holland 1969); and by electrochemical reactions around sulphide concentrations (Govett et al 1976).

Albee, A.L., 1962, The relationship between the mineral association, chemical composition and physical properties of the chlorite species: Am. Miner. V. 47, p. 851-870.

Allard, G.O., 1976, Dore Lake complex: Que. Dep. Nat. Resour., Geol. Rep. 368, 446 p.

Anhaeusser, C.R., Fritze, K., Fyfe, W.S., and Gill, R.C.O., 1975, Gold in primitive Archean volcanics: Chem. Geol., V. 16, no. 2, p. 129.

Barton, P.B., and Skinner, B.J., 1967, Sulphide mineral stabilities in Barnes, H.L., ed., Geochemistry of hydrothermal ore deposits: Holt, Rinehart and Winston, New York, p. 236-333.

Bichan, W.J., 1959, Report on property of Anacon Lead Mines (Chibougamau operation): internal report.

Bowen, N.L., 1928, The Evolution of the Igneous Rocks: Dover Publications Inc., New York, 334p.

Boyle, R.W., Alexander, W.M., and Aslin, G.E.M., 1975, Some observations on the solubility of gold: Geol. Surv. Can., Pap. 75-24.

Boyle, R.W., 1970, The source of metals and gangue elements in hydrothermal deposits in Problems of hydrothermal ore deposition, Zpouba, E., and Stemprok, M.,: Int. Union Geol. Ser. A, no. 2, Schweizerbart'sche veblagbuchhandlung Stuttgart, p. 3-6, Miner. Deposita, 1968, V. 3, no. 2, p. 174-177.

---- 1969, Hydrothermal transport and deposition of gold: Econ. Geol., V 64, p. 112.

---- 1968, The source of metal and gangue elements in epigenetic deposits: Miner. Deposita (Berl), V. 3, p. 174-177.

---- 1961, The geology, geochemistry and origin of gold deposits of the Yellowknife district: Geol. Surv. Can., Mem. 310.

Chilingar, G.U., Bissell, H.S., and Fairbridge, R.W., eds., 1967, Developments in sedimentology 9B, Carbonate rocks, physical and chemical aspects: Elsevier Publ. Co., New York, 413 p.

Cloke, P.L., and Kelly, W.C., 1964, Solubility of gold under inorganic supergene conditions: Econ. Geol., V.59, p. 259-270.

Crerar, D.A., and Barnes, H.L., 1976, Ore solution chemistry, solubilities of chalcopyrite and chalcocite assemblages in hydrothermal solution at 200°-350° C: Econ. Geol., V. 71, p. 772-294.

Czamanske, G.K., Desborough, G.A., and Goff, F.E., 1973, Annealing history limits for inhomogenous, native gold grains as determined from Au-Ag diffusion rates: Econ. Geol., V. 69, p. 1275-1288.

Duquette, G., 1970, Archean stratigraphy and ore relationships in the Chibougamau district: Que. Dep. Nat. Resour., Special paper 8, 16 p.

Eales, H.V., 1967, Reflectivity of gold and silver alloys: Econ. Geol., V. 62, p. 412-420.

Fitzgerald, A.C., Graham, R.J., Gross, W.H., and Ruchlidge, J.C., 1967, Application and significance of Au-Ag ratios at Val d'Or, Quebec: Econ. Geol., V. 62, p. 502-516.

Gallagher, D., 1940, Albite and gold: Econ. Geol., V. 35, p. 698-737.

Gilbert, J.E., 1959, Region de Rohault, district electoraux d'Abitibi-est et de Roberval: Ministere des Mines du Quebec, RG 86.

Golubev, V.S., 1975, *A model of hydrothermal* mineralization: Doklady, Earth Sci. Section, V. 221, p. 237-238.

Goodspeed, G.E., 1936, Microstructures and metallization of the gold guartz veins of Cornucopia, Oregon: Econ. Geol., V. 31, p. 398-417.

Govett, G.J.S., Goodfellow, W.D., and Whitehead, R.E.S., 1976, Experimental aqueous dispersion of elements around sulphides: Econ. Geol., V.71, p. 925-940.

Graham, R.B., 1957, Structure of the Chibougamau area, Quebec: Can. Inst. Min. Met., Spec. Vol. Structural Geology of Canadian ore deposits, p. 423-429.

Grenier, P.E., 1959, Region de Gamache, district electoraux d'Abitibi-est et de Roberval: Ministere des mines du Quebec, RG 87.

Griffis, A.T., 1962, A geological study of the McIntyre mine: Can. Inst. Min. Met. Bull., V. 55, p. 76-83.

Hansuld, J.A., 1967, Eh and pH in geochemical prospecting: Geol. Surv. Can., Pap. 66-54, p. 172-187.

Hattori, K., 1975, Geochemistry of ore deposition at the Yatami lead-zinc and gold-silver deposit, Japan: Econ. Geol., V. 70, p. 677-693.

Hebert, C., 1979 , Contexte geologique regional du gisement aurifere de la Mine Chibex, Chibougamau, Quebec. Memoire de maitrise, Universite du Quebec a Chicoutimi.

Hebert, C., 1976, Demie sud du Canton de Fancamp: Ministere des Richesses Naturelles, Geol. Rep. 429, 12 p.

Hebert, C., 1974, Rapport preliminaire, quart sud-ouest du Canton de La Dauversiere, Comte d'Abitibi-est: Ministere des Richesses Naturelles, Quebec, DP 262.

Helgeson, H.C., and Garrells, R.M., 1968, Hydrothermal transport and deposition of gold: Econ. Geol., V. 63, p. 622-635.

Henley, R.W., 1973, Solubility of gold in hydrothermal chloride solutions: Chem. Geol., V. 11, p. 73-87.

Higgins, M.W., 1971, Cataclastic rocks: U.S. Geol. Surv., Prof. Pap. 687.

Hollister, V.F., Anazalone, S.A., and Richter, D.H., 1975, Porphyry copper deposits of southern Alaska and contiguous Yukon Territory: Can. Inst. Min. Met. Bull., V. 68, p. 104-112.

Horscroft, F.D.M., 1957, The petrology of gabbroic sills in the volcanic series of Roy and McKenzie townships, Chibougamau region, Quebec, Unpub. PhD thesis, McGill University, 170 p.

Hyndman, D.W.. 1972, Petrology of igneous and Metamorphic rocks, McGraw-Hill, Inc., Toronto, 533p.

Imbault, P.E., 1959, Region de Queylus, district electoraux d'Abitibi et de Roberval: Ministere des Mines du Quebec, GR 86.

Jambor, J.C., 1971, Wall rock alteration in the silver arsenide deposits of the Colbalt-Gowganda region, Ontario, Berry, L.G. (ed): Can. Mineral. V. 11, (1) p.272-304.

Jeffery, W.G., 1959, The geology of the Campbell Chibougamau mine, Quebec: Unpub. PhD thesis, McGill University,Montreal.

Keays, R.R., and Scott, R.B., 1976, Precious metals in ocean-ridge basalts: Implication for basalts as source rocks of gold mineralization: Econ. Geol., V. 71, p. 705-720.

Krauskopf, K.B., 1951, The solubility of gold: Econ. Geol., V. 46, p. 858-870.

Latulippe, M., 1976, The emplacement of gold in the Malartic-Val d'Or area of northwestern Quebec: Paper presented at the 78th annual meeting, Can. Inst. Min. Met., 23 p.

Li, K.V., and Shokhina, O.I., 1974, Behaviour of gold in progressive regional metamorphism of the Precambrian rocks of the Yenisey Range: Geochem. Int., V. 11, p. 314-322.

Mackay, R.A., 1944, The purity of native gold as a criterion in secondary enrichment: Econ. Geol., V. 39, p. 56-68.

Malouf, S.E., and Thorpe, W., 1957, Chibougamau Explorers mine: Structural geology of Canadian ore deposits, Congress volume, Can. Inst. Min. Met., p 449-454.

Mamen, C., 1955, Chibougamau Explorers-a new gold producer: Can. Min. J., V. 76, p. 56-58.

Meyer, C., and Hemley, J.J., 1967, Wall rock alteration, in, Barnes, H.L., ed., Geochemistry of Hydrothermal Ore Deposits, Holt, Rinehart, Winston Inc., p. 166-235.

Miller, R.J.M., 1961, Wallrock alteration at the Cedar Bay mine: Econ. Geol., V. 56, p. 321-330.

Moorehouse, W.W., 1959, The study of rocks in thin section: Harper and Row, New York, 514 p.

Murata, K.J., and Richter, D.H., 1961, Magmatic differentiation in the Uwekahuna laccolith, Kilauea caldera, Hawaii: J. Petrol., V. 2, part 3, p. 424-437.

Ogryzlo, S.P., 1935, Hydrothermal experiments with gold: Econ. Geol., V. 30, p. 400-424.

Prochnau, J.F., 1971, Distribution and mode of occurrence of gold in the Chibougamau district, Quebec: Unpublished MSc. thesis, McGill University, 134 p.

Pyke, D.R., 1975, On the relationship of gold mineralization and ultramafic volcanic rocks in the Timmins area, Ontario: Ont. Ministry of Nat. Resour., Miscellaneous pap. 62.

Raymahashay, B.C., and Holland, H.D., 1969, Redox reactions accompanying hydrothermal wall rock alteration: Econ. Geol., V.64, p. 291-305.

Rickard, D.T., 1974, Low temperature copper geochemistry-gitological aspects: in, Bartholomé, ed., Centenaire de la Societe Geologique de Belgique, Gisements Stratiformes et Provinces Cupriferes Liege, p. 1-34.

Seward, T.M., 1973, Thio complexes of gold and transport of gold in hydrothermal ore solutions: Geochim. Cosmochim. Acta, V. 37, p. 379-400.

Shcherbakov, Y.G., and Perezhogin, G.A., 1964, Geochemistry of gold: Geochem. Int., V. 3, p. 489-496.

Smith, F.G., 1943, The alkali sulphide theory of gold deposition: Econ. Geol., V. 38, p. 561-590.

Squair, H., 1965, A reflectometric method of determining the silver content of natural gold alloys: Trans. Inst. Min. Met. Lond., V. 74, p. 917-931.

Stephenson, J.F., and Ehman, W.D., 1971, Neutron activation analysis of gold in the Archean igneous and metamorphic rocks of the Rice Lake-Beresford Lake area, southern Manitoba: Econ. Geol., V. 66, p. 933-939.

Stumpfl, E.F., 1969, Determining fineness variation characteristics in gold ores by reflectometry: Econ. Geol., V. 64, p. 341-342.

Tilling, R.I., Gottfried, D., and Rowe, J.J., 1973, Gold abundance in igneous rocks bearing on gold mineralization: Econ. Geol., V. 68, p. 168-186.

Viljoen, R.P., Saager, R., and Viljoen, M.J., 1970, Some thoughts on the origin and processes responsible for the concentration of gold in the early Precambrian of South Africa: Miner. Deposita (Berlin), V. 5, p. 164-180.

----, 1969, Metallogenesis and ore control in the Steynsdorp goldfield, Barberton Mountain Land, South Africa: Econ. Geol., V. 64, p. 778-797.

Weissberg, B.C., 1970, Solubility of gold in hydrothermal alkaline sulphide solutions: Econ. Geol., V. 65, p. 551-556.

Weissberg, B.G., 1969, Gold-silver ore grade precipitates from New Zealand thermal waters: Econ. Geol., V. 64, p. 95-108.

Wanless, R.K., and Loveridge, W.D., 1972, Rubidium-Strontium isochron age studies, Report 1: Geol. Surv. Can., Pap. 72-73, p. 77.

Wanless, R.K., Stevens, R.D., and Loveridge, W.D., 1970, Anomalous parent-daughter isotopic relationships in rocks adjacent to the Grenville Front near Chibougamau, Quebec: Eclogae Geol. Helv., V. 63, p. 345-364.

White, D.E., 1967, Mercury and base-metal deposits with associated thermal and mineral waters, in Barnes, ed., Geochemistry of hydrothermal ore deposits, Holt, Rinehart, and Winston, New York, p. 575-631.

Winkler, H.G.F., 1974, Petrogenesis of metamorphic rocks, third edition, Springer Verlag Inc., New York, 320 p.

----, 1967, Petrogenesis of metamorphic rock, Second edition, Springer Verlag Inc., New York, 237 p.

APPENDIX I

Legend for figures 3-8


Diabase dyke


Felsic dyke

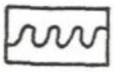

Mineralized quartz vein

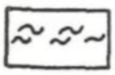

Altered shear zone

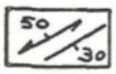

Felsic volcanic rocks


Mafic volcanic rocks


Gabbro


Fault zone, generally with rubble-filled openings and often high water flows.


Presence of foliation, in some cases possible faults.



Dip of foliation, contact or joint

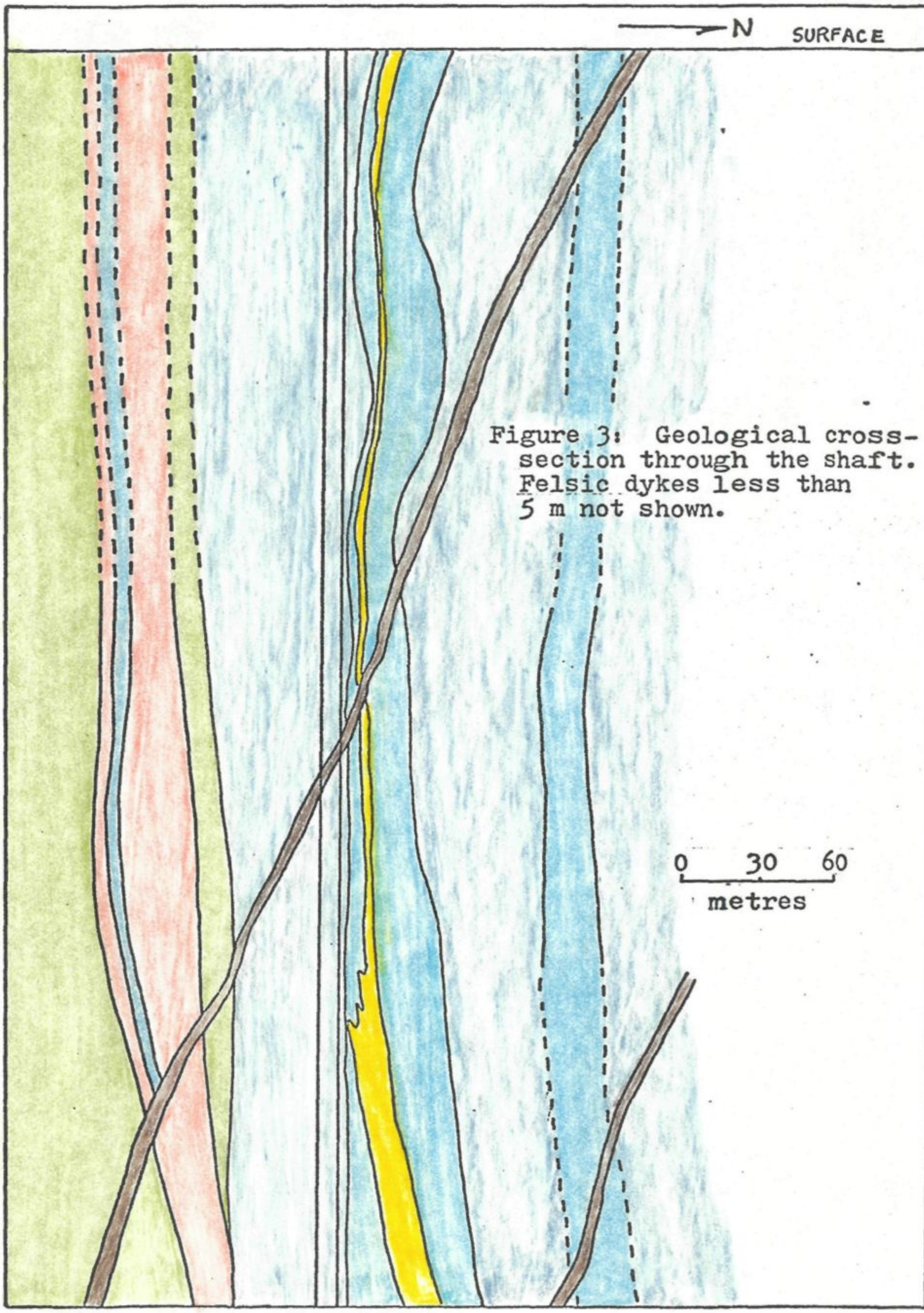


Figure 3: Geological cross-section through the shaft. Felsic dykes less than 5 m not shown.

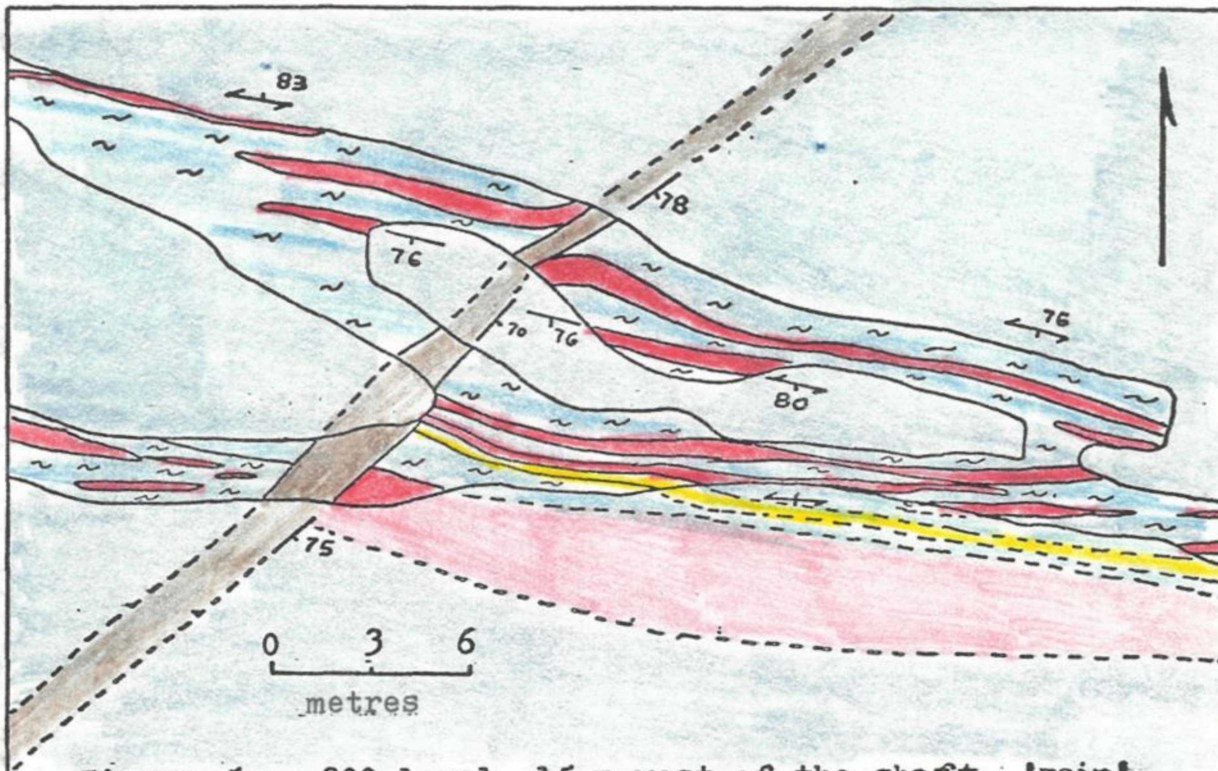


Figure 5a: 300 level, 15 m west of the shaft, 'main' zone, showing relationship of diabase dykes with veins.

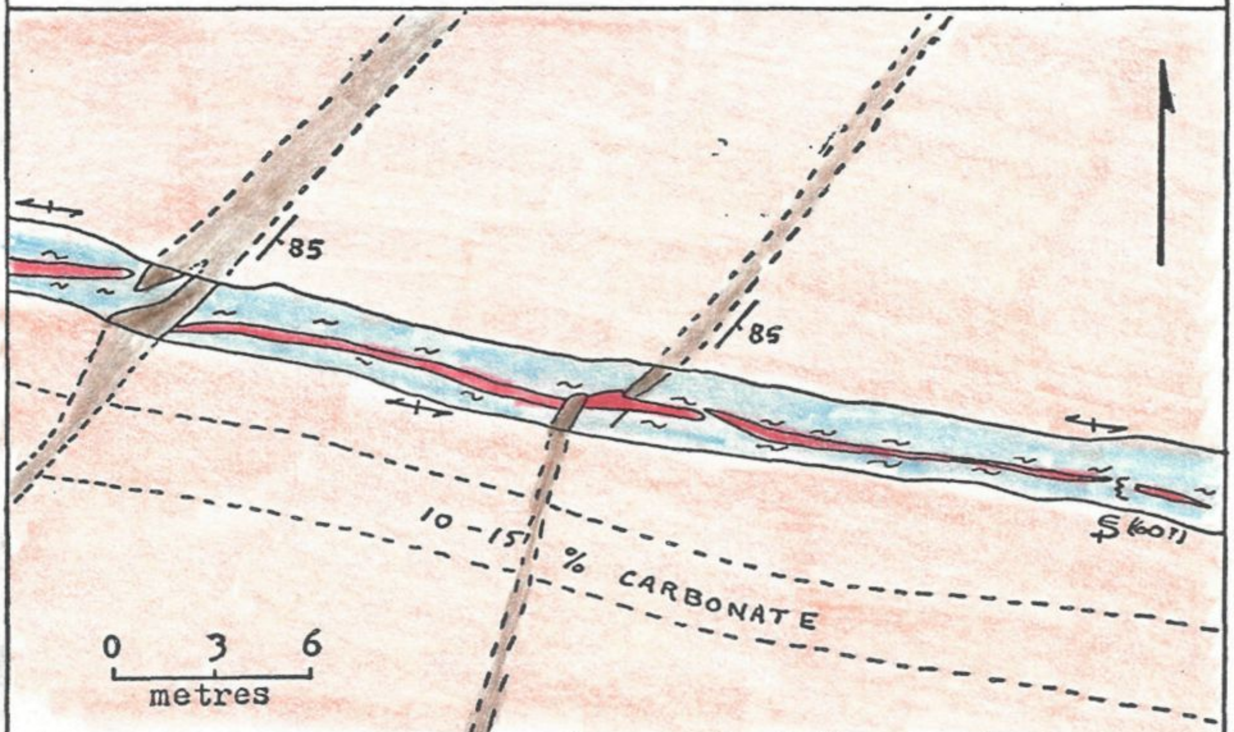


Figure 5b: 1200 level, 60 m west of the shaft, 'south' zone, showing relationships of diabase dykes with ore vein.

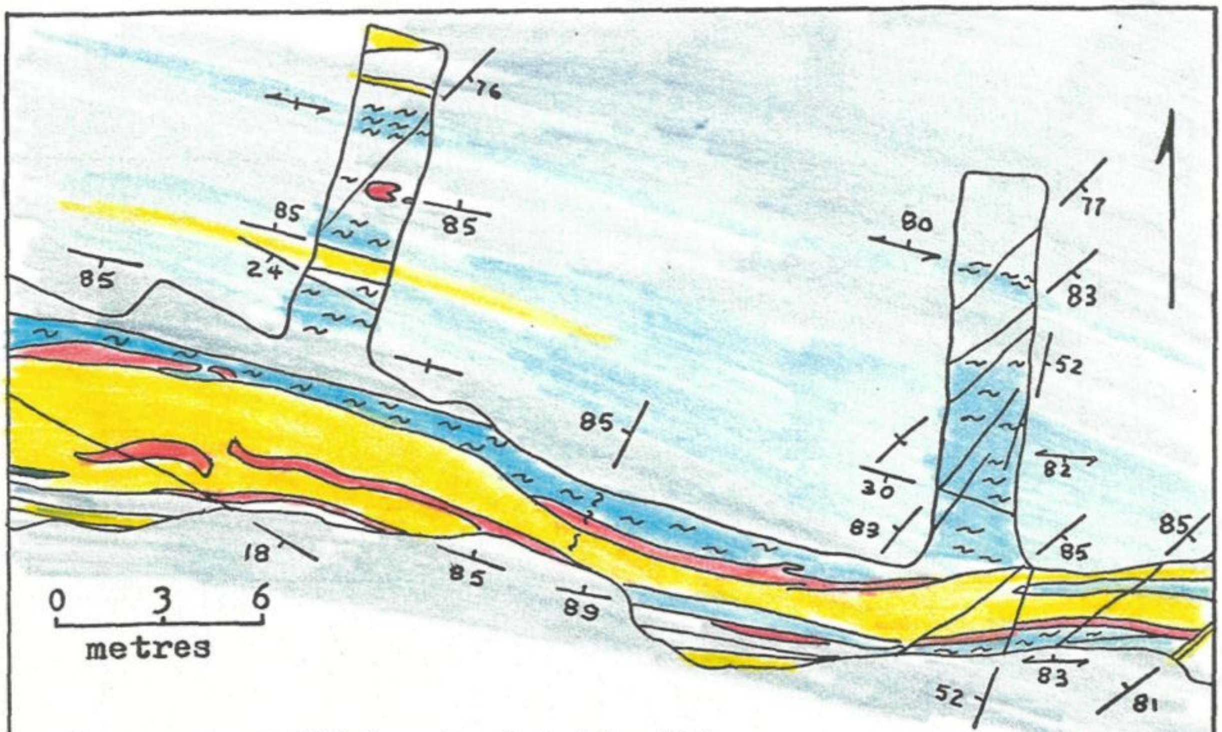


Figure 6a: 750 Level, 7-1-12 sill,
Alternation of vein from side to side of felsic dyke, with fragments of ore vein in dyke.

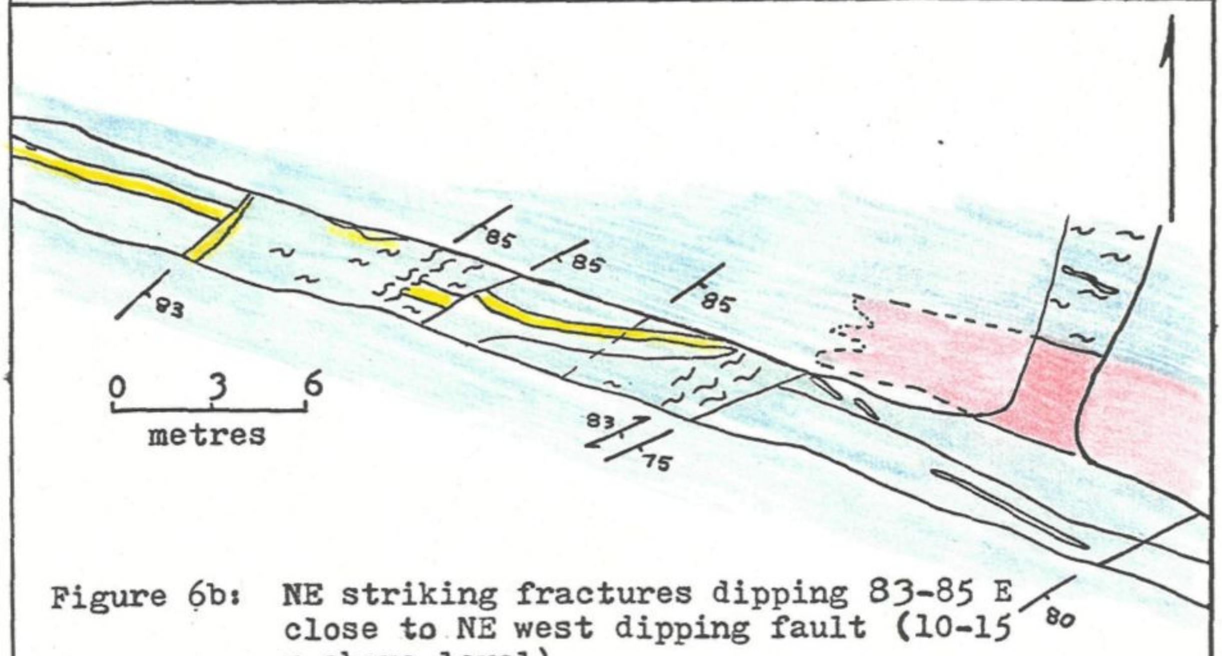


Figure 6b: NE striking fractures dipping 83-85 E close to NE west dipping fault (10-15 m above level)

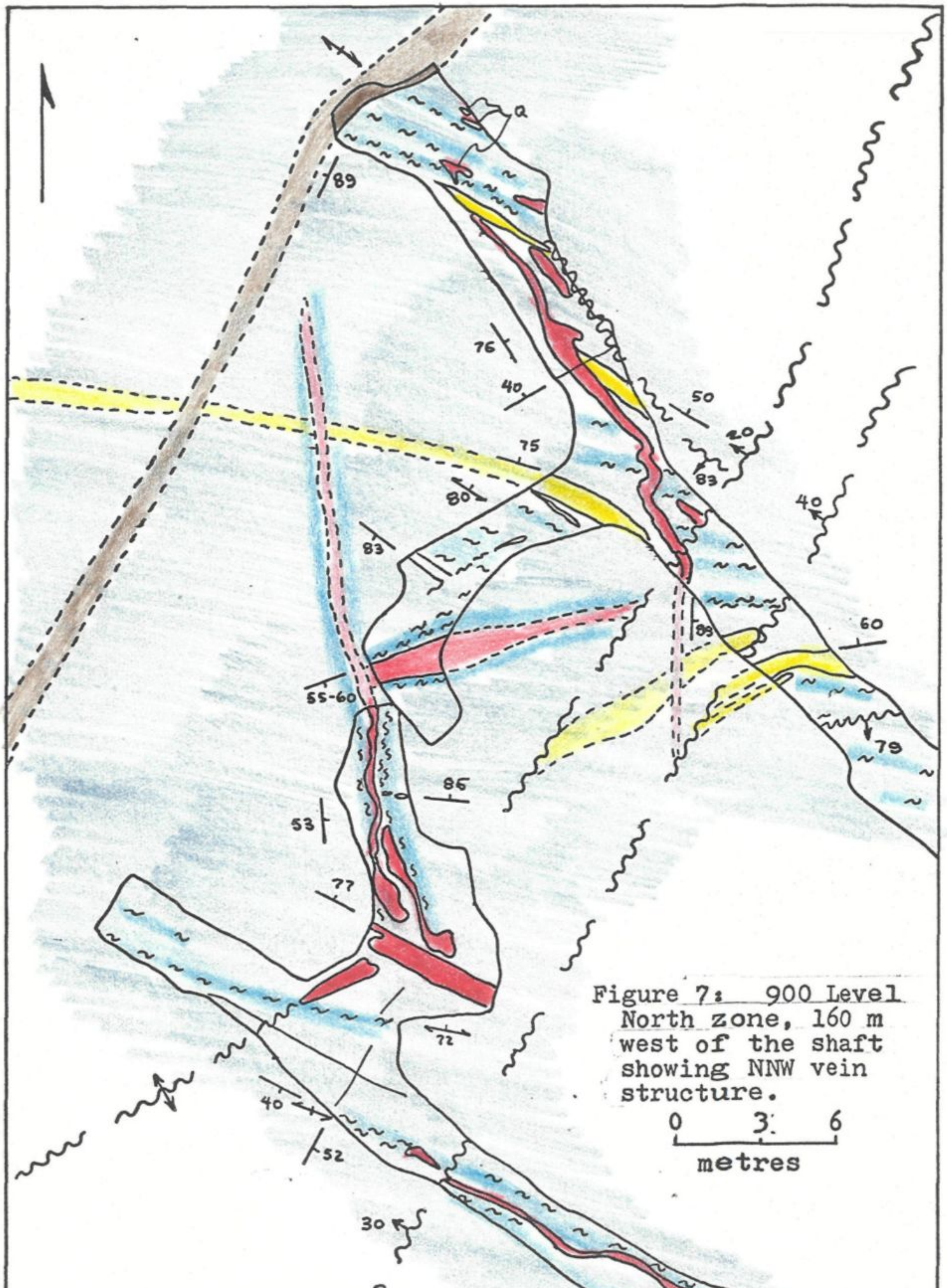


Figure 7: 900 Level North zone, 160 m west of the shaft showing NNW vein structure.

0 3 6
metres

APPENDIX II

RECOMMENDATIONS FOR FURTHER RESEARCH ON THE CHIBEX DEPOSIT

Further work on the following problems is indicated by questions raised by this work:

1. Minor mineralogy of the opaque phase is complex and a detailed study may allow formulation of further conclusions. XRD methods may assist in this work. However, due to the generally small grain size and difficulties in polishing, electron probe techniques will be a necessity.

2. Changes in the optical characteristics of the chlorites have been noted within the stratigraphic sequence and in the ore shears. Changes are also noted in the biotites. Electron probe work on these minerals (on both a mine and regional basis) may reveal trends which would aid in further theoretical and exploration work.

3. Fluid inclusion studies, sulphur and oxygen isotope studies, and possibly, work on the composition of the sphalerite may give further data on the temperature and conditions of formation of parts of the deposit.

4. Structurally, the Chibex area is complex and a detailed study would give insight into many problems seen in the deposit. This would involve extensive surface mapping and at the least, a good review of the underground mine plans. Access to the mine would be helpful but not necessary.

5. A regional study of the gold occurrences in the immediate vicinity and possibly, the occurrence of anhydrite may be useful to judge whether relationships seen in the mine are applicable to the whole region.

6. As the Grenville orogeny affected the mine area (Wanless and Loveridge, 1972, Wanless et al, 1970, Allard, 1976) it is tempting to try to put a date on the deposit as Grenville or younger. Further detailed work on a regional scale may help solve this question.

APPENDIX III

MINERAL IDENTIFICATION METHODS

Transparent Mineralogy

Basic mineralogy for the study was done by optical methods with the use of thin scetions.

Plagioclase anorthite content determination was done by the carlsbad-albite twin method described by Moorhouse (1959). Determinations were done on 10-20 crystals in each thin section and were averaged. A selection of samples of all rock types was stained with sodium cobalt nitrite which confirmed the absence of potash feldspar.

X-ray diffraction, using a vertically mounted Phillips Diffractometer Model PW1050/85 with an Advanced Metals Research monochromator and a chart recorder, was used to extend the optical mineralogy. Monomineral powder mounts were used when possible and various seperations from total rock powders were made when necessary. Cadmium fluoride was added to samples as an internal standard when they did not contain quartz.

Carbonates

Carbonates have been identified by staining methods described by Chilingar (1967). X-ray diffraction confirmed general results. Identification by thermal analysis was tried on one sample. However, due to the numerous problems with this method with multimineral samples, results were ambiguous and impossible to interpret.

Anhydrite

Anhydrite was identified using optical methods including grain mounts; X-ray diffraction; and electron probe work done at Universite de Laval by Jean-Pierre Tremblay and Andre Gauthier (see Appendix IV).

Opaque Minerals

The basis for the opaque mineralogy was optical methods using polished thin sections and polished sections. X-ray diffraction was done on the chalcopyrite and pyrrhotite. The scanning electron probe at the National Research Council at Quebec was tried on several grains with disappointing results. The electron probe at the Universtie de Laval was used on several grains with better results. However, equipment time limitations did not permit the positive identification of any of the minor opaque phases.

APPENDIX IV

CHARACTERISTICS OF ANHYDRITE FOUND IN THIN SECTIONS

A mineral having the following characteristics has been found in amounts to 10% in thin sections of sheared and altered gabbro and volcanic rocks in the mine zone. Methods of identification used were optical methods in thin section,and grain mounts, X-ray diffraction and electron probe. Optical data of this mineral do not exactly conform to published data for any mineral. However because electron probe work done by A. Gauthier and Jean-Pierre Tremblay at Laval University confirm the presence of Ca and S and the optical data as given below appear close to published data on anhydrite, tentative identification has been made as anhydrite. Differences in optical data may be explained by tectonic deformation of the original crystals. Positive identification will be helped by single crystal X-ray diffraction or further electron probe work, and or universal stage methods.

Optical data

Biaxial positive

2 E approximately 30° 2 V approximately 17°

(by Tobi method $2V=10^{\circ}$)

$\alpha=1.571$

$\beta=1.574$

$\gamma=1.610$

2 good cleavages 100, 001

1 medium-poor cleavage 010

2 good twin planes (45° to X)

In thin section colorless, hand specimen white.

Twins are sometimes obvious in plane polarized light with a minor pale greenish pleochroism.

ACKNOWLEDGEMENTS

Dr. E.H.Chown, Dr. J.Guha and Dr. G.Archambault, thesis advisors, for critical reviews of this manuscript and for many helpful suggestions.

Mr. Y.Boudrealt and Mr. J. Villeneuve for help in sample preparation of thin and polished sections and X-ray diffraction work.

The many geologists who have contributed ideas during visits to and during discussions on the Chibex, Chibougamau and Val d'Or deposits.

The various managements of the Chibex property who have been generous in allowing continued access to samples and to the property for this study.