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PETROLOGY AND GEOCHEMISTRY OF THE QUARTZ
PEBBLE CONGLOMERATE OF THE GECO MASSIVE
SULPHIDE DEPOSIT AT MANITOUWADGE, ONTARIO

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By

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SCOPE AND CONTENTS:

The quartz pebble conglomerate is a weakly mineralized unit found above the disseminated copper zone at the Geco base metal deposit.

Petrological evidence shows that the unit is composed of various mineral assemblages which are often in disequilibrium. Bulk compositions and mineral assemblages are similar to those often found with other massive sulphide bodies.

The quartz pebbles are believed to be a sheared and boudinaged siliceous layer associated with volcanic exhalative brines. The matrix is felt to have originally been a separate unit and its bulk composition is similar to that of a shale. This shale may possibly have been derived from the weathering of a basaltic rock.

ACKNOWLEDGEMENTS

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CHAPTER I
INTRODUCTION

i) Location

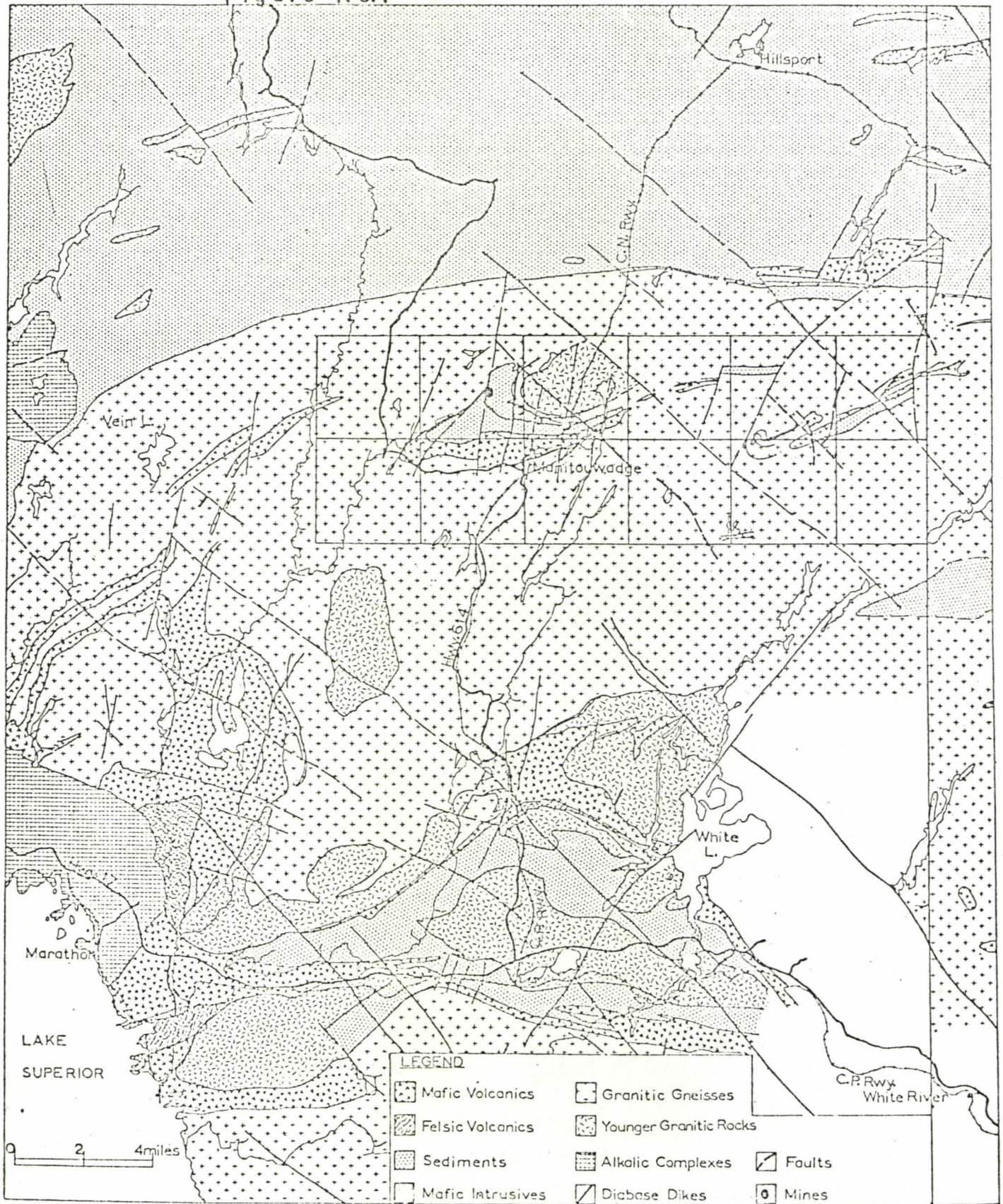
The Geco Mine base metal deposit is part of the Manitouwadge mining camp. The mine is located within the Thunder Bay mining district of Ontario and lies approximately 320 km east of the city of Thunder Bay and can be located on Map P548 of the Ontario Department of Mines (Milne 1969). The general location is given in Fig. I.

The mine is located approximately 1.5 km north of Manitouwadge Lake. It is serviced by a branch line of the CNR running south 40 km from Hillspport as well as a branch line of the CPR extending 65 km north from Struthers. The area is also accessible by Highway 614 extending 56 km north from Highway 17 and by the Caramat industrial road extending approximately 120 km south from Highway 11.

ii) Previous Work

The area was first investigated by Dr. J.E. Thompson in 1931 who noted traces of copper in outcrop. Various prospectors did further work in the area and in 1953 the area was staked by

Figure No.1



After Milne 1969

Barker, Dawidowich and Forester. At this time economic deposits were discovered.

Subsequent to this semi-detailed mapping was undertaken by E.G. Pye between 1954 and 1957. Mine production commenced at Willroy and Geco Mines in 1957. In 1968 the area was remapped by V.G. Milne.

Several detailed studies of the ore body were also carried out. In 1955 a Master's thesis on the Geology of Geco Mine was undertaken by F.F. Langford. D. Watson (1970) further expanded this in a Ph. D. thesis. S. Banerjee (1972) in a Master's thesis investigated the occurrence of tin in the mine.

iii) Accessibility of the Quartz Pebble Conglomerate

The quartz pebble conglomerate as presently mapped is found between 2650 level and 3650 level of the mine which is accessible via No. 4 shaft. It is possible to observe this unit at various points along the ore body and the position of the quartz pebble conglomerate relative to the mine series is given in Figure II.

iv) Statement of the Problem

The quartz pebble conglomerate was first recognized as a distinct and separate unit by mine geologists in 1972. The distinct appearance of the quartz within the rock lead to speculation as to the possible origin and nature of the pebbles and whether the unit could

Figure No.2

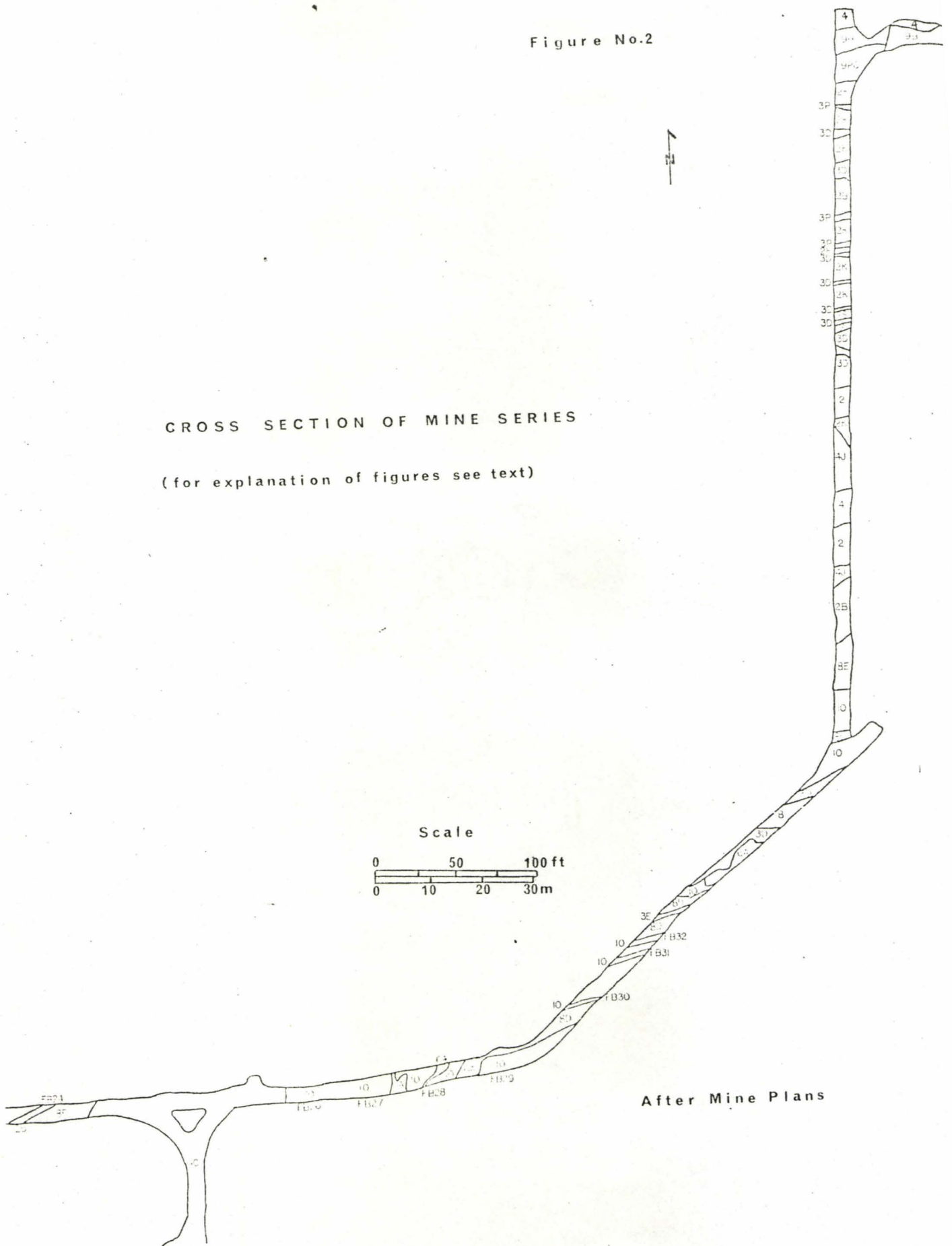
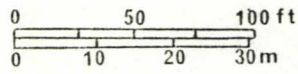
4



CROSS SECTION OF MINE SERIES

(for explanation of figures see text)

Scale



After Mine Plans

be 1) used as an aid in the interpretation of the history of the mine rocks and 2) used as a prospecting tool.

The purpose of this study is to suggest a possible origin for unit and to describe its petrography and geochemistry. The locations of the samples collected are given in the appendix.

CHAPTER II
GENERAL GEOLOGY

i) Regional Geology

Manitouwadge lies just south of the extensive Quetico Belt of metasediments which is also known as the western extension of the Coutchiching rocks. These rocks are felt to be older than the oldest Archean volcanoes (Suffel et al. , 1971). To the south the Precambrian rocks consist of the Abitibi-Wawa metavolcanic belt which is composed predominantly of felsic plutonic rocks which separate small scattered, folded complexes of volcanic, pyroclastic and metasedimentary rock. This is a recognized Greenstone belt but the actual ores are found in schists and gneisses similar to the Coutchiching rocks and attain at least almandine amphibolite grade of metamorphism. The Manitouwadge synform lies on the transitional edge of the two belts. The age relationships between the two belts is quite controversial. A list of the rock types in area is given in Table I.

Along the north shore of Lake Superior, both mafic and felsic volcanism are found to occur in the region near Schrieber and Heron Bay. Conglomerates exist in this area and are present to the Black River area but none have been found to date at Manitouwadge or

TABLE I. Table of Formations

Era	Period	Group	Formation	Lithology	
Ceno- zoic	Recent			Swamp and stream deposits	
	Pleistocene			Gravel, sand and clay	
Unconformity					
Precam- brian	Keween- awan (?)			Quartz diabase dykes.	
	Intrusive Contact				
	Algoman (?)			Biotite granite, pegmatite, mig- matite. Basic intrusives, lamprophyre dykes	
	Intrusive Contact				
	Archean (?)	Feldspar Gneisses	Grey Gneiss		Biotite, oligo- clase gneiss
			Quartzite		Quartz, biotite gneiss
			Biotite Schist		Biotite schist with feldspar
			Iron Formation		Rusty weathering quartz, with magnetite
			Garnet- iferous Amphibole Gneiss		Amphibole gneiss with about 10 per cent garnet
		Amphi- bole Gneisses			Dark green amphibole and lesser plagioc- clase.

After Pye 1959

to the north (Milne 1969) suggesting that a source of clastic material existed to the south.

Within the Black River, Pic River and Manitouwadge regions there are two major fold trends. These are north-northwest and east-northeast. The latter type of which the Manitouwadge synform is one, is the dominant folding trend but both fold trends are felt to have formed contemporaneously (Milne 1969).



















Country rock in the vicinity of the synform has been relatively highly metamorphosed to at least almandine facies and sillimanite facies to the north. There is a gradual gradation from chlorite grade metamorphism on Lake Superior through to sillimanite around the large granitic masses to the north. The synform has attained a relatively high but uniform grade of metamorphism. Cordierite, andalusite, sillimanite and almandine in the Quetico rocks to the north suggest that large parts of the area attained similar grades of regional metamorphism and furthermore that the regional metamorphism attained a maximum thermal level at a time of decreasing stress. The evidence for this lies in the relatively low pressure mineral assemblages attained by many of the rocks.

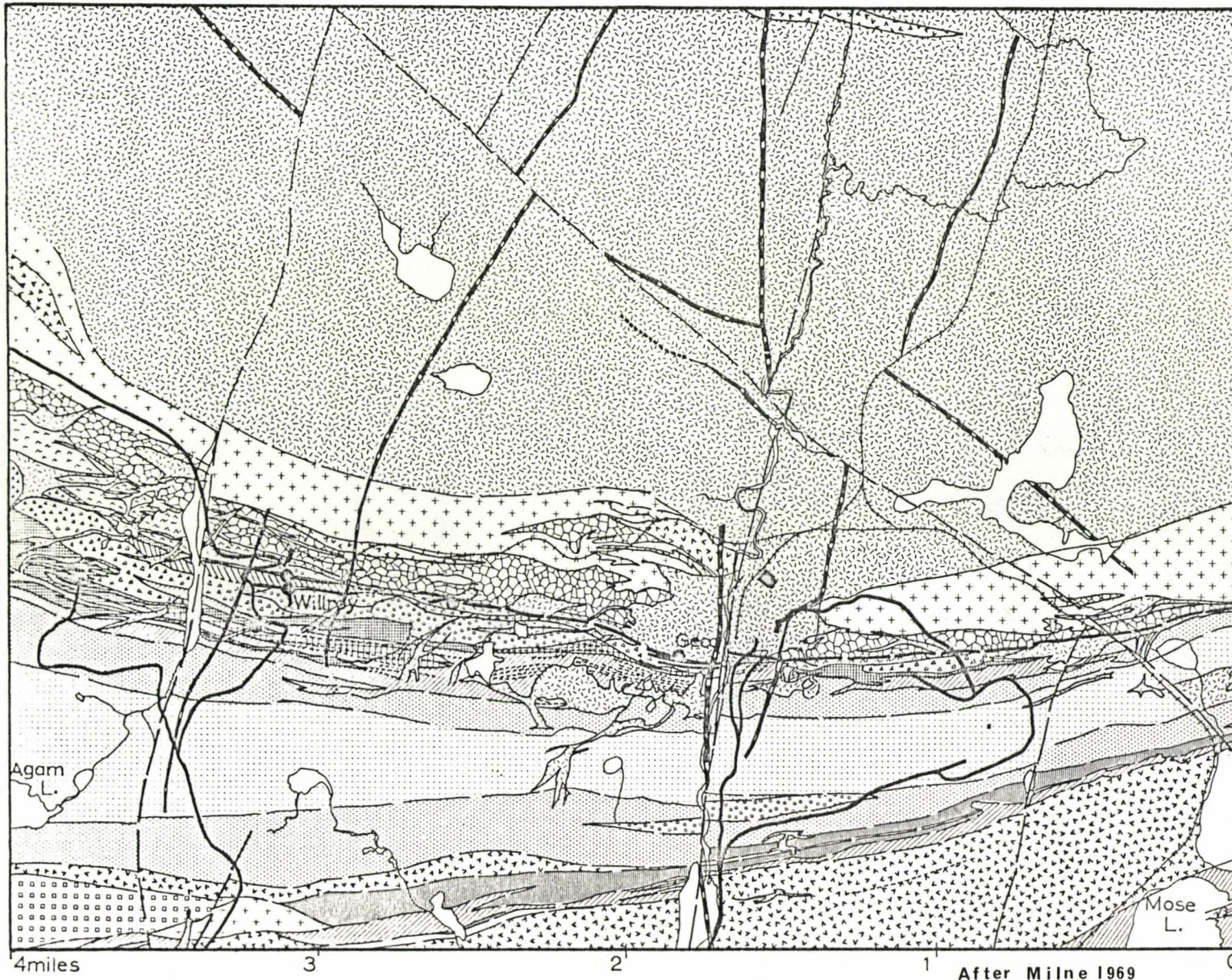
ii) Geology of the Synform

The Geco Mine ore body lies in the southern limb of a synform (Fig. III). Assuming in the absence of conventional facing indicators that the synform is indeed a syncline, then a relatively

FIGURE No.3

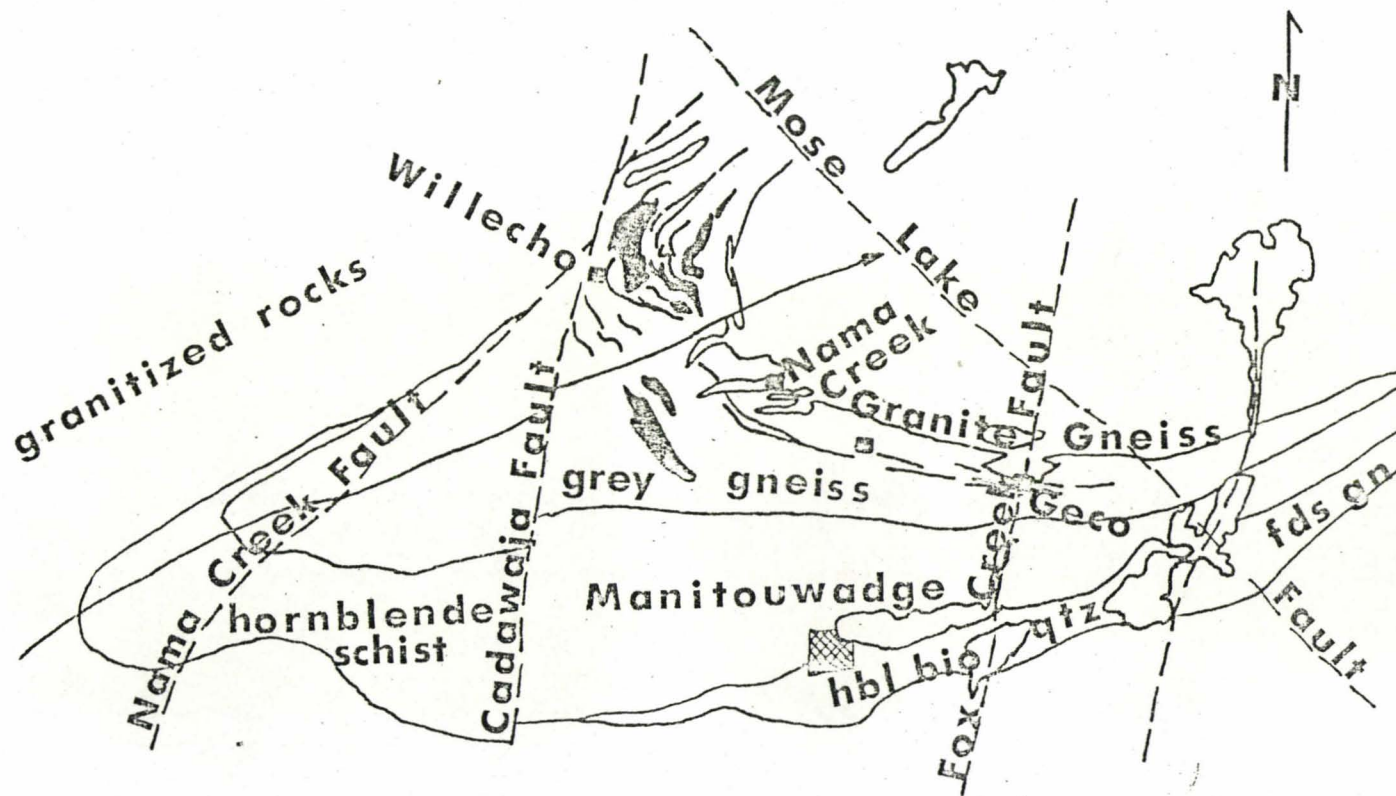
LEGEND

-  Granodior. & Peg.
-  Biot. Trondhj. Gneiss
-  Hbl. Trondhj. Gneiss
-  Garn. Amph. Gneiss
-  Garn. Sillim. Gneiss
-  Sillim. Gneiss
-  Quartz Eye Gneiss
-  Leuco Gneiss
-  Rusty Gneiss
-  Iron Formation
-  Qtz. Feld. Biot. Gneiss
-  Biotite Gneiss
-  Garn. Bia. Hb. Gneiss
-  Felsic Hbl. Gneiss
-  Mafic Hbl. Gneiss
-  Diabase
-  Faults
-  Metagabbro



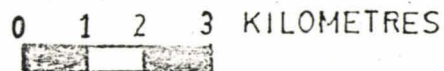
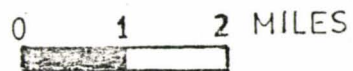
MANITOUWADGE SYNFORM

Figure No.4



After Pye 1957-8

Scale



simple stratigraphic succession can be given.

The mine series within the syncline can be broken into four groups (Fig. IV). These are the hornblende schist group, the grey gneiss group, the sericite schist group (which is too small to be shown on the map) and the granite gneiss group. The terminology of the series has varied considerably (Table II). The terminology used in the remainder of the report is after Watson (1970). There is also a series of regional intrusives. These include metagabbros associated with the hornblende schist group, pegmatites and granitic dikes related to the phases of granitization in the area. The down warping of volcanic and sedimentary rocks in the area is believed to have generated sufficient pressure and temperature in some instances to partially melt and remobilize the rock which was then subsequently intruded into the country rock. A series of Keewanawin diabase dikes which appear to be controlled by the major fault systems were intruded at a later time.

iii) Geology of the Mine Series

The mine series can be further broken down into a distinct assemblage of rock types. A summary of mine terminology for the various units is given in Table III.

The hornblende schist is felt to consist dominantly of pillowed basaltic flows (Milne 1969). The rocks range from tholeiite

TABLE II. Comparative Terminology of the Hornblende and Grey Gneiss Series. Terminology Used After Watson 1970.

PYE (1960)	WATSON (1970)		LANGFORD (1955)	BROWN & BRAY (1960)		
Biotite Quartzite	Biotite Quartzite	GRAY GNEISS SERIES	Quartzite Gneiss	FELDSPAR GNEISSES	Biotitic Quartzite	GRAY GNEISS GROUP
Biotite- Quartz- Feldspar Gneiss	Quartz- Feldspar- Biotite Gneiss		Gray Gneiss		Quartz- Feldspar- Biotite Gneiss	
Biotite Gneiss	Biotite Gneiss		Biotite Schist			
Biotite- Quartz- Feldspar Gneiss	Fine- Grained Quartz- Feldspar- Biotite Gneiss	GRAY GNEISS SERIES	Gray Gneiss	FELDSPAR GNEISSES	Quartz- Feldspar- Biotite Gneiss	
	Biotite Gneiss					
	Quartz- Feldspar- Biotite Gneiss					
Laminated Hornblende Schist	Well- Banded Hornblende Gneiss	HORNBLLENDE GNEISS SERIES	Amphibole Gneisses		Hornblende Gneiss	
Massive Hornblende Schist	Poorly- Banded Hornblende Gneiss					
Laminated Hornblende Schist	Well- Banded Hornblende Gneiss					

TABLE III. Summary of Mine Terminology.

GEOLOGICAL LEGEND		ABBREVIATION	SYMBOL
QUARTZ SILLIMANITE HORNFELS		Qtz.Sill.Hfs.	9k
QUARTZ SERICITE HORNFELS		Qtz.Ser.Hfs.	9z
QUARTZ PEBBLE CONGLOMERATE		QTZ. Peb. Con.	9z
NEAR MASSIVE SULPHIDES		N.Mass.	N.M.
MASSIVE SULPHIDES		Mass.	M
DISSEMINATED SULPHIDES		Diss.	Ds
<u>GREY GNEISS GROUP</u>			
QUARTZ FELDSPAR BIOTITE GNEISS	fine grained	Q.F.B.	8d
QUARTZ FELDSPAR BIOTITE GNEISS	coarse grained	Q.F.B.	8e
QUARTZ EPIDOTE HORNBLENDE GNEISS		Q.E.H.	8f
QUARTZITE THIN BEDDED	well laminated	Q.tb	8g
BIOTITIC QUARTZITE	may be bedded or mottled	B.Q.	8h
MASSIVE QUARTZITE		M.Q.	8m
IRON FORMATION	not including 4j or 8f with which it may be related.	I.F.	10
BIOTITE GNEISS SEDIMENTARY	dark banded and Garnetiferous Sericitic	Bio.Gn.S.	11
GRANITE GNEISS			12
BIOTITE GNEISS	Indeterminate	Bio.Gn.Q.	3x
REMNANTS IN MASSIVE SULPHIDES		R	-r
<u>INTRUSIVES</u>			
DIABASE		Dia.	7
PEGMATITE	course grained; pink (or green)	Peg. 6a	6a
PEGMATITE	medium to fine grain; pink, grey (or green)	Peg. 6b	6b
PEGMATITE	white to grey, Quartz stringers (2 ages of quartz)	Peg. 6c	6c
GRANODIORITE	grey, uniform medium grained	Grd.	5d
GRANITE		Gr.	5
QUARTZ			6z
QUARTZ DIORITE	dark intrusive coarse grained	Q.D.c	3c
QUARTZ DIORITE	dark intrusive fine even grained	Q.D.d	3d
QUARTZ DIORITE	dark intrusive feldspathic	Q.D.f	3f
QUARTZ DIORITE	dark intrusive platy biotite	Q.D.p	3p
QUARTZ HORNBLENDE	dark greenish	Q.D.h	3h
<u>GRANITE GNEISS GROUP</u>			
BIOTITE GARNET GNEISS	dark basic rock with prominent garnets	Bio.Car.Gn.	4j
BIOTITE AMPHIBOLE GNEISS		Bio.Amph.Gn.	4a
BIOTITE SILLIMANITE GNEISS		Bio.Sill.Gn.	4k
BIOTITE AMPHIBOLE GARNET GNEISS		Bio.Amph.Car.Gn.	4aj
BIOTITE GNEISS		Bio.Gn.	4g
<u>SERICITE SCHIST GROUP</u>			
SERICITE SCHIST SILICEOUS		Ser.Sch.	2S
SERICITE SCHIST	predominantly sericitic or siliceous and sericitic	Ser.Sch.	2
SERICITE SCHIST BIOTITIC	like Ser.Sch. but with Biotite replacing Muscovite	Ser.Sch.Bio.	2b
SERICITE SILLIMANITE SCHIST	like Ser. Sch. but streaked with sillimanite	Ser.Sill.Sch.	2k
BIOTITE SCHIST	like Ser.Sch. but with Biotite predominating	Bio.Sch.	2bs
BIOTITE HORNFELS		Bio.Hfs.	9b
QUARTZ BIOTITE HORNFELS		Qtz.Bio.Hfs.	9c
ANTHOPHYLLITE CORDIERITE HORNFELS		Anth.Cord.Hfs.	9a
BIOTITE ANTHOPHYLLITE HORNFELS		Bio.Anth.Hfs.	9ba

to olivine tholeiite and high alumina olivine tholeiite. Amygdules have only been reported in one locality suggesting deep water deposition. The unit has a maximum width of approximately three km. This unit contains minor magnetite chert iron formations. A 100 m layer of heterogenous feldspathic hornblende gneiss overlies the pillowed volcanic formation and mineralogical evidence suggests that this is a mafic tuff zone (Milne 1969). Locally it is garnetiferous. East of the Fox Creek Fault this unit is overlain by a biotitic garnetiferous paragenesis. West of the Fox Creek Fault a westward thickening wedge of mafic volcanic gneiss lies between the tuff and the biotite unit. These units are then in turn overlain by a succession of fine grained rock which have been interpreted as metasediments by Milne (1969) and both metavolcanics (dacites to rhyolites) and metasediments (greywacke) by Watson (1970).

This group of rocks can be divided into three subunits. The upper subunit is 180 m thick, the lower is 275 m thick. These are classified as the biotite gneiss members. The middle subunit which is 370 m thick is a biotite quartz feldspar gneiss. The distinction between the two gneiss types is based largely on biotite content although the two grade into each other.

The upper most unit (assuming a syncline) is overlain by a mixed succession of what Milne (1969) believes is a clastic and chemically precipitated metasedimentary unit composed dominantly

of amphiboles, magnetite and quartz. This has been classified as an iron formation which is interbedded with finely laminated rusty, pyritic, garnetiferous hornblende biotite quartz feldspar gneiss which in some instances actually grades into the iron formation. Watson (1970), however, opposes this interpretation and favours a volcanic origin for the rocks.

The Geco schist group, including the sericite schist conformably overlies the grey gneiss group. The sericite (muscovite) schist (2) which is too narrow to be shown in Fig. IV contains all of the known ore bodies. It is flanked on the north by the granite gneiss (4) group. The 4/2 disseminated copper zone lies along the granite gneiss and sericite schist contact and hence its name. The 8/2 zinc zone lies along the sericite schist - grey gneiss (8) group contact. The 4/2 ore zone is essentially a fine to medium grained disseminated copper zone containing pyrrhotite, pyrite and chalcopyrite as well as "wall rock fragments". In certain areas of the mine a three metre wide band of weakly mineralized rock known as the quartz pebble conglomerate is found between the 4/2 ore and the sericite schist group (Plate I).

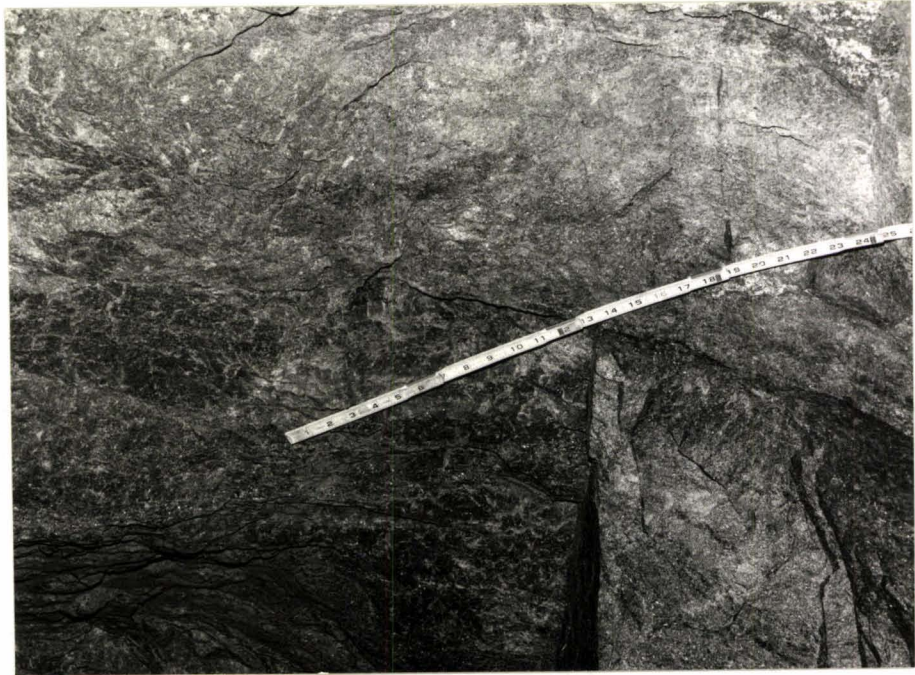
Overlying the ore zones are a diverse group of rocks known as the granite gneiss group. This group contains units of biotite hornblende gneiss, biotite sillimanite gneiss and biotite anthophyllite cordierite gneiss. The granite gneiss itself ranges from mafic to intermediate in composition.

PLATE I

Disseminated copper zone (4/2 ore) in 28-65 east drift north contact. The highly reflective white material consists of the sulphides. The quartz pebble conglomerate is due south.

PLATE II

Banded and folded siliceous iron formation in 28-1E drift.
Compare overall appearance to Plate V and Plate VI.



iv) Structural Geology

The structure of the Geco Mine area is dominated by the Manitouwadge synform. Superimposed on this are sets of folds and lineations which seem to be genetically related to the major fold structures (Watson 1970).

Metamorphic mineral lineations are conformable with the easterly plunging synform. While the plunge of the synform steepens from west to east, no major cross structures were observed (Milne 1969). Small scale folding, although present does not appear to be common. The exception to this is the folding in the Iron formation (Milne 1969). See Plate II.

The area is cut by two main groups of faults. One north-east trending set of faults includes the Wowun Lake Fault, Chip Fault, Fox Creek Fault and the Slim Lake Fault. These have left handed strike separations and there is post ore movement on the Fox Creek Fault. The second fault "group" consists of one fault which trends northwest. This fault is known as the Mose Lake Fault and causes a left handed strike separation of the northeast faults.

The ore zone at Geco has been interpreted as a third fault by some workers (Milne 1969). The schist in these zones is often folded and crenulated. Thin sections were cut from this unit. Much of the folding present in these rocks appears to be due to the bimodal composition of the rock. The quartz grains which may show a bi-axial figure and are often somewhat sheared show a texture

reminiscent of boudinage. It is believed by this author that much of the apparent folding in these beds is due to the different competencies in the quartz-muscovite layers which results in the muscovite adjusting to movement in the quartz rich layers. While some movement has taken place in this rock, Suffel et al. (1971) question calling this unit a fault zone.

Watson (1970) has interpreted this unit to be an alteration zone related to the injection of hydrothermal fluids rich in sulphur which reacted with the original biotite to produce pyrite and muscovite.

While the bedding in the copper zone is considered original by Friesen (1978), quartz diorite dikes cross cut this primary feature. These dikes are intensely folded, however, and are often transposed onto bedding plane foliation. The younger pegmatites seem to intrude along the axial plane of these folds. These pegmatites are in turn cross cut and replaced by the ore (Suffel 1971). This has been used to suggest that the ores are related to the Algoman (Kenoran) orogeny and the granitic intrusion. It is possible, however, that the pegmatites are a product of this orogeny and that the stratiform sulphides were remobilized at this time to cross cut the pegmatites.

It is important to note at this time that axial plane cleavage has not been found at the mine and this has been used as evidence to suggest that the foliation is in fact bedding.

CHAPTER III

PROBLEMS RELATED TO THE GENERAL GEOLOGY

i) Problem of the Synform

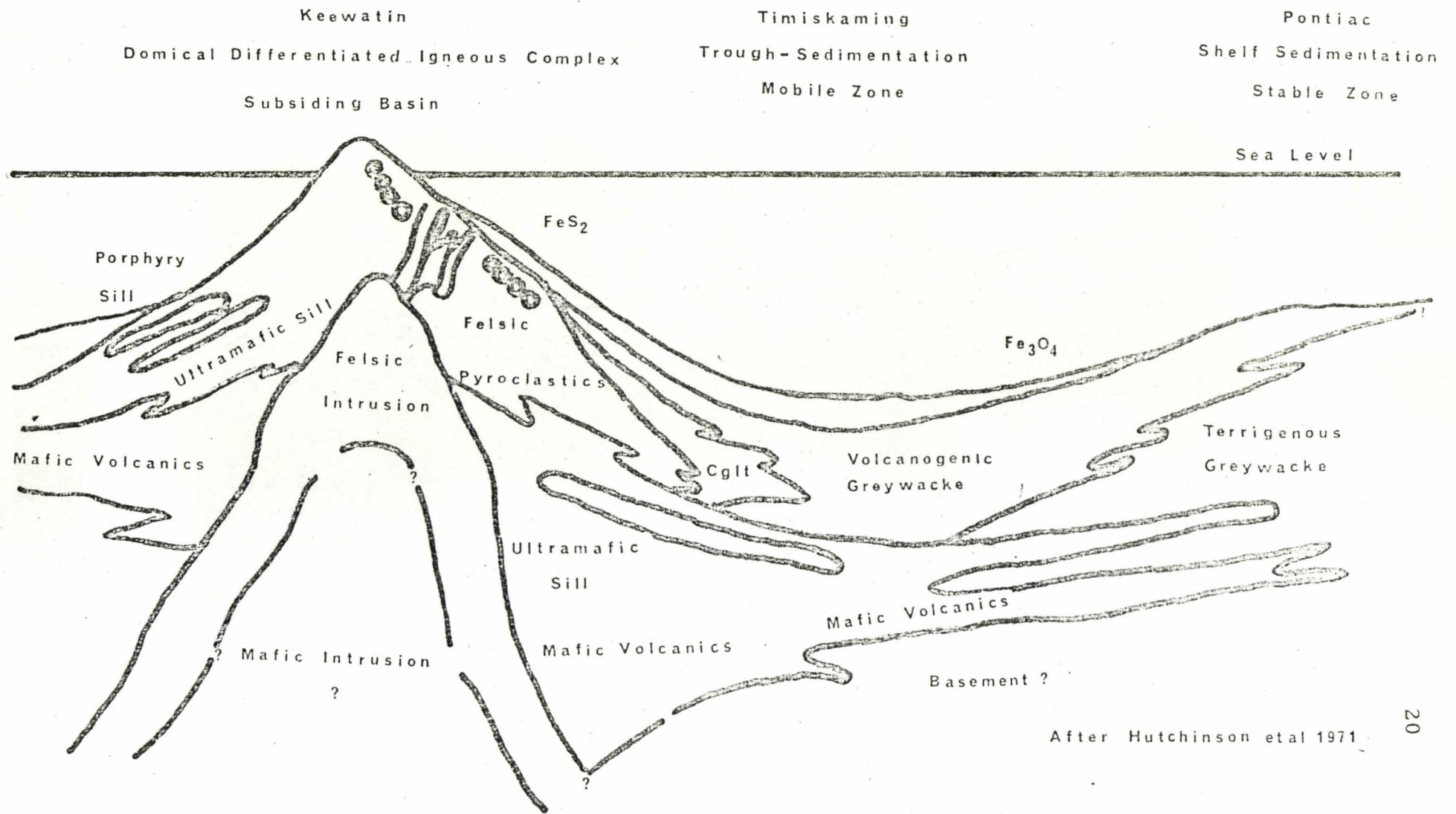
Because of the common association of cordierite anthophyllite rich zones as well as iron formations with massive ore bodies, it is important to know how they are stratigraphically related. The quartz pebble conglomerate which is rich in cordierite and anthophyllite and has also been described as a poorly developed iron formation (Friesen et al. , 1978) is probably related to the formation of the ore body. Therefore it is important to know the stratigraphic relationship of the ore body to quartz pebble conglomerate.

Early workers (Pye 1958, Milne 1969, Watson 1970) have expounded the concept that the Manitouwadge synform is indeed a syncline. More recently, however, workers such as Suffel et al. (1971), Sangster et al. (1977), and Friesen et al. (1978) have presented the idea that the synform is in fact an overturned anticline.

Much of the evidence is based on the comparison of the Geco ore body to other massive sulphide deposits. The iron formation as noted earlier, commonly occurs beneath the ore body. This is the reverse of what is found in most mining camps (Suffel et al. , 1971) and does not agree with the model of volcanogenic ore bodies as

Figure No. 5

VOLCANOGENIC EXHALITIVE MODEL

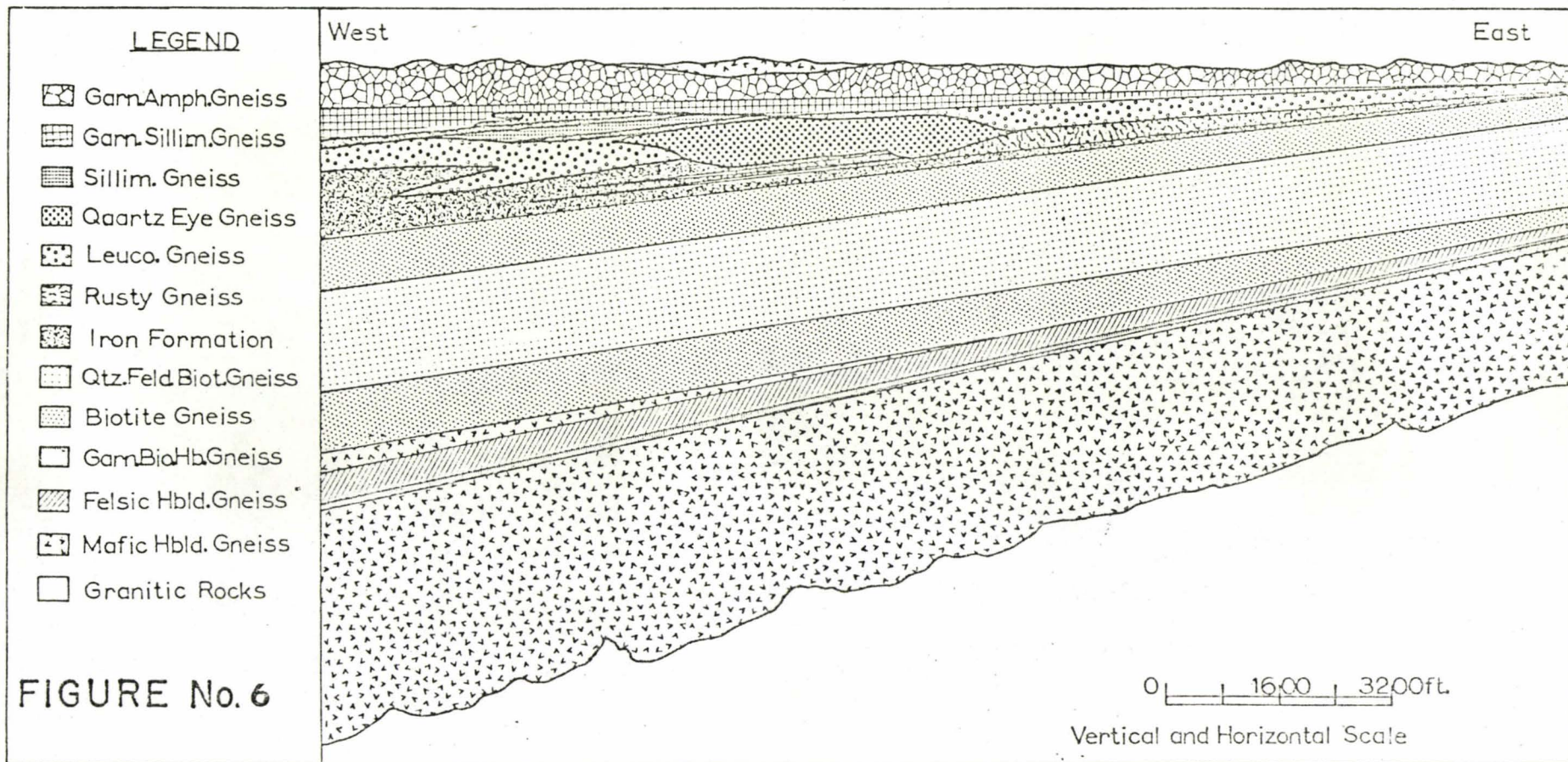


After Hutchinson et al 1971

presented by Hutchinson et al. (1971) (Fig. V).

The zoning in the ore, copper in the hanging wall to zinc in the footwall is again the reverse of most mining camps (Friesen et al., 1978) and the north to south succession of mafic to felsic gneisses are also believed to indicate that the ore body is overturned (Sangster et al., 1977). Comparative changes in the bulk composition have been observed elsewhere in which basalts form the base of the sequence. These rocks are apparently missing at Geco. These are in turn capped by andesite or dacite (granite gneiss group?) which is in turn capped by rhyolite. Again the presence of rhyolites at Geco have never been proven but Watson (1970) believes that part of the grey gneiss group consists of rhyolites. The sequence is then covered in sediments which may be equivalent to the remaining grey gneiss sequence.

In keeping with this line of "evidence" it is felt that the Manitouwadge synform is in all probability an overturned anticline. The stratigraphic section as given by Milne (1969) is, therefore, believed to be overturned (Fig. VI). This is important since it places the quartz pebble conglomerate below the main ore body but directly above the 4/2 disseminated ore zone.



After Milne 1969

ii) The Origin of the Iron Formations

Both sedimentary and igneous origins have been proposed for the iron formations at Geco. Pye (1956) suggested a sedimentary origin for the magnetite rich beds and felt that these were conformable magnetic iron silicates and cherts of a sedimentary origin. Watson (1970) suggests a volcanic origin. The alternating quartz iron oxide layers, the conformability with the quartz feldspar biotite gneisses all point to a sedimentary origin however. The term iron formation has been questioned by some workers (Suffel et al., 1971) due to the relatively low iron content (Table IV) and their high degree of metamorphism.

It is probable that the iron formations at Geco are of a chemical sedimentary origin. Their apparent association with the ore body and their capping of the main ore body suggests that the iron formations are a product of volcanic exhalatives and can be classed as Algoman type iron formations. Iron formations of this type generally cap either dacites or argillaceous sediments and occur toward the end of a period of volcanism. If this origin for the iron formations is accepted then it may be possible to use this as a criteria in the interpretation of the quartz pebble conglomerate.

TABLE IV. Table Comparing Iron Formations

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
SiO ₂	51.18	48.11	50.96	52.18	51.52	70.15	65.10	83.74
Al ₂ O ₃	11.95	3.27	1.09	3.08	0.08	1.30	1.38	0.53
Fe ₂ O ₃	12.15	16.69	30.37	16.68	10.24	9.28	24.13	8.67
FeO	8.09	13.62	5.01	18.30	35.37	10.91	--	--
MgO	2.42	2.91	5.26	4.36	0.20	1.36	2.48	2.03
MnO	2.71	3.27	--	--	--	1.19	1.42	0.43
CaO	1.12	0.80	0.04	2.90	0.02	2.70	4.02	1.98
Na ₂ O	2.12	0.24	--	--	--	0.30	0.11	0.06
K ₂ O	1.86	2.32	--	0.58	--	0.07	0.13	0.01
TiO ₂	0.51	0.52	--	--	--	0.07	0.04	0.02
P ₂ O ₅	0.54	0.44	--	0.28	0.06	0.12	1.19	2.52

1. analysis of Iron Formation, Iron River District, Michigan (James 1954, quoted by Stanton p. 440, 1972)
2. analysis of Iron Formation, Iron River District, Michigan (James 1954, quoted by Stanton p. 440, 1972)
3. Analysis of Iron Formation, Mesabi District, Minnesota (James 1966, quoted by Stanton p. 440, 1972)
4. Analysis of Iron Formation, Verkhsevskovo, Region Russia (Semenenko et al. 1956, quoted by Stanton p. 440, 1972)
5. Analysis of Banded Iron Formation, Mesabi District, Minnesota (Gruner 1946, quoted by Stanton p. 436, 1972)
6. Average analysis of two samples of Iron Formation (Pye p. 25, 1958)
- 7, 8. Analysis of Iron Formation No. 24, No. 66 as per this report.

iii) The Origin of the Geco Massive Sulphide Ore Body

To date the majority of the work on the Manitouwadge sulphides suggests that these are hydrothermal replacement ore bodies (Watson 1970). More recently, however, workers such as Sangster et al. (1977) have proposed an exhalative model for the formation of these cores.

The exhalative concept does not differ remarkably from the classical hydrothermal theory in terms of process. Ore deposition in both cases is from ore fluids emanating from the earth's crust and rising along fractures and other zones of weakness. The passageway is preserved as a metasomatized vent or alteration pipe. The important difference is the timing of the deposition relative to the host rock. This is important because of the close proximity of the quartz pebble conglomerate to the ore body.

The volcanic exhalative theory also advocates that massive sulphides in predominantly volcanic environments are an integral part of the volcanic complex in which the deposits may occur. The geological "evidence" that such was the case at Manitouwadge includes the common occurrence of several ore bodies at or near the same stratigraphic horizon, the consistent relationship between stratigraphy and the zoning of the ores and what is believed to be the widespread association of sialic volcanism, and the capping of the ore zone by iron formation (if the stratigraphy is overturned). Assuming that the ore

body is indeed exhalative then it is possible to apply Hutchinson's model of exhalative ore bodies to the formation of the quartz pebble conglomerate.

CHAPTER IV
FIELD DESCRIPTIONS

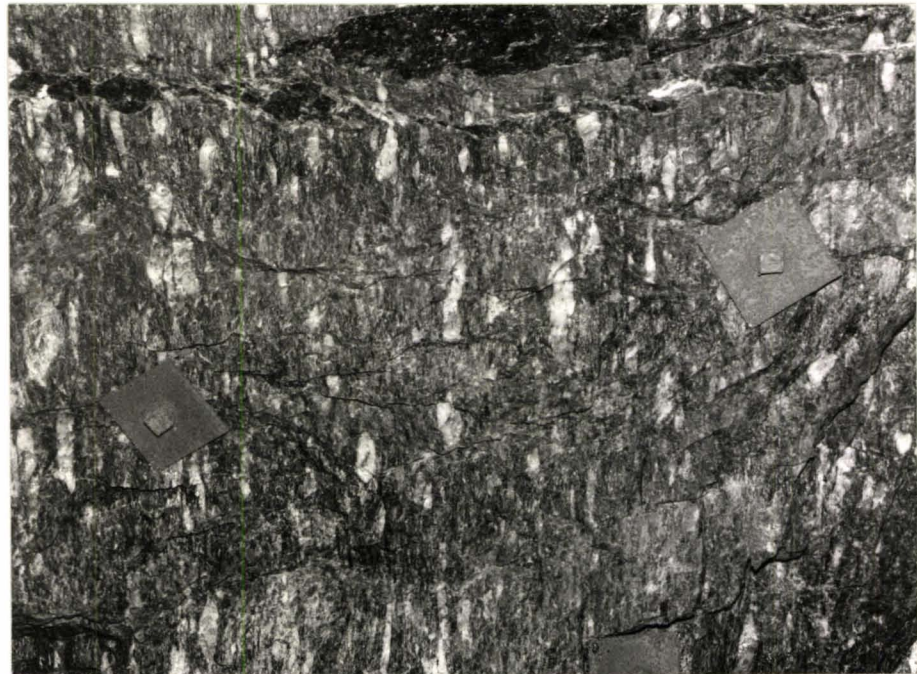
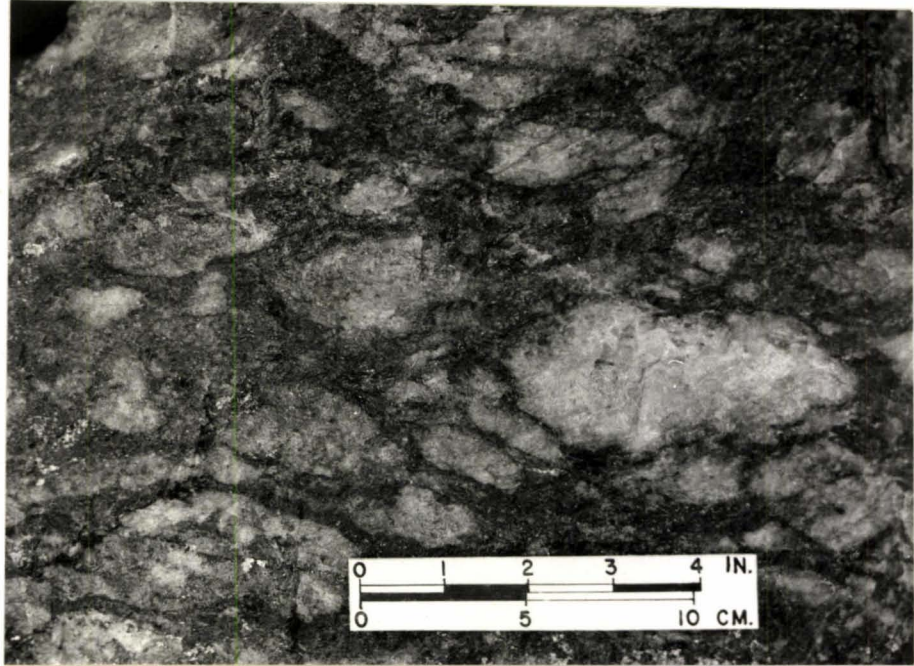
i) The Quartz Pebble Conglomerate

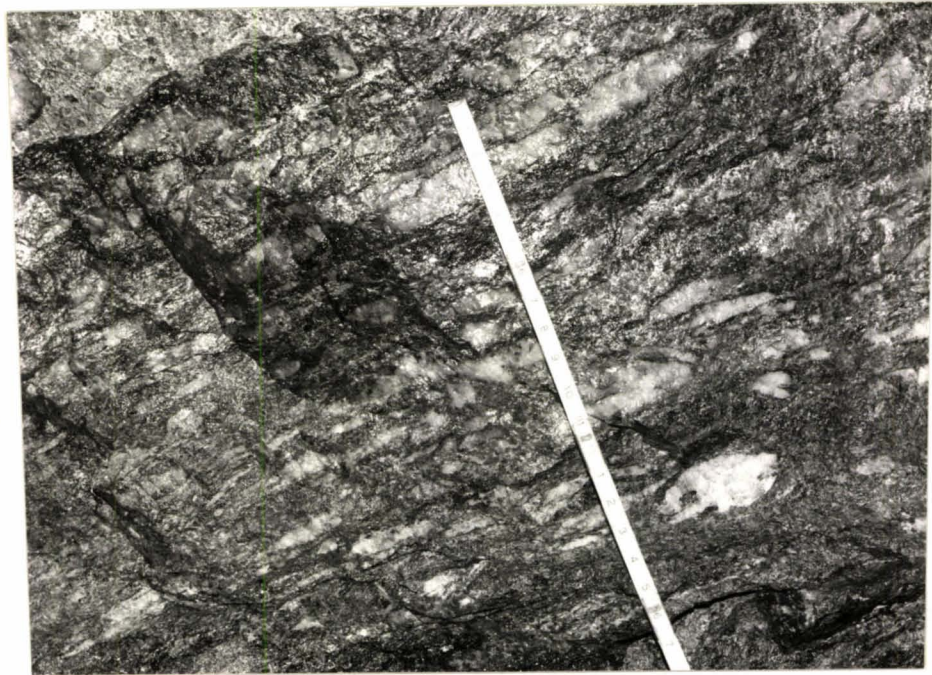
The three meter wide band of weakly mineralized quartz pebble conglomerate which tends to pinch out, forms lenses of what may in fact be a boudinage type structure. The quartz "pebbles" appear to be discus-shaped, are up to 10 cm in diameter and have a roughly subparallel alignment (Plate III, IV). These pebbles often stretch out into what appear to be quartz rich bands or veins (Plate V, VI).

The majority of the matrix in hand specimen appears to be anthophyllite which often has a bluish tinge. The fibres are up to five cm in length. Minor biotite is also present but its existence is masked by the amphibole. Orange red staurolite which resembles garnet and often has been misidentified as such is easily visible in most hand specimens. Sulphides make up approximately 15-20% of the rock in many cases. The dominant sulphides are chalcopyrite, pyrite and minor sphalerite. Magnetite occurs as euhedral grains of up to 5 mm in size.

Then the rock is broken down into hand specimen size, the quartz pebbles are difficult to recognize. Cordierite which is ubiquitous in thin section is rarely visible in hand specimen and when







visible it has a distinct blackish tinge associated with it.

The quartz pebble conglomerate is generally conformable to stratigraphy. In areas it is cross cut by quartz diorite dikes (Plate VII).

ii) The Biotite Hornfels

Three distinct hornfelses were recognized by Watson (1970). These are the biotite hornfels, the quartz biotite hornfels and the anthophyllite cordierite hornfels. Of these only the biotite and the quartz biotite hornfels were recognized and sampled in the thesis area. The two types of hornfels were classified under the common name of biotite hornfels.

These poorly foliated rocks are present as discontinuous bands along the contact between the quartz muscovite schist and the Geco massive sulphide body which is itself included in the schist. Like the quartz pebble conglomerate, these units are often three meters wide and tend to undergo pinch and swell type structures and occur in lenses.

The hornfels are dark coloured rocks which occasionally have "veins" or interbeds of quartz present which in many ways resemble the quartz pebble conglomerate in the neighbouring rock. These veins create a coarse banding in the rock which is often taken up by the biotite and the minor associated anthophyllite. This segregation of the layers may in fact be original bedding.

PLATE VII

One of many quartz diorite dikes running subparallel to the quartz pebble conglomerate. They are often quite rich in feldspar and are relatively unaltered.

PLATE VIII

Sillimanite schist in 28-65 east drift. White knots of sillimanite are set in a matrix of dominantly biotite. Rock bolt for scale.



iii) The Sillimanite Gneiss

The sillimanite gneisses (Plate VIII) are commonly associated with the quartz pebble conglomerate. They are seen to occasionally cross cut the over trend of the rock in the form of a shear (Plate IX). There are both biotite rich and muscovite rich sillimanite gneisses (schists). The overall appearance of the gneisses varies considerably but clusters or knots of sillimanite are characteristic. Toward the main ore body the more siliceous units of a sillimanite sericite schist occur. As they approach the quartz pebble conglomerate however they become enriched in biotite and sillimanite (Friesen et al. , 1978).

iv) The Iron Formation

The iron formation is extremely variable in appearance. It occurs as lenses of very siliceous rock which may be up to 30 m thick (Plate X). It is composed largely of broadly banded medium to coarse grained rock. The dominant mineral is quartz with interbedded amphiboles. Garnet, magnetite and locally pyrrhotite and pyrite make up the remainder of the rock.

PLATE IX

Quartz pebble conglomerate being cut by a sillimanitic shear zone. Note the form displayed by the pebbles and the relatively abrupt contact.

PLATE X

Iron formation in 28-1E drift. Banding is not as evident as in Plate II but contorted quartz rich layers are visible. The dark matrix is largely interbanded amphibole and magnetite with minor sulphides.



CHAPTER V
PETROGRAPHY

Thin sections were cut from the quartz pebble conglomerate, its neighbouring units and from what was believed to be a similar rock type (iron formation).

i) The Quartz Pebble Conglomerate

The quartz pebble conglomerate has been named thus because of its textural features and not as a result of its mineralogy. This has led to a somewhat wide variety of minerals present although the bulk composition tends to remain constant. In hand specimen the amphibole anthophyllite would appear to be almost ubiquitous and the dominant mafic mineral and makes up to 30% of the rock. In some thin sections, however, a pale brown biotite which is often altered to magnesium rich chlorite is found instead. Cordierite occurs to varying degrees in most sections and is usually found to be forming at the expense of some other mineral (often staurolite or gahnite (Plate XI, XII)). Relic plagioclase is fairly common and has been identified as An_{30} . It is found to be altering on its edges to a combination of quartz and cordierite (Plate XIII). Sphalerite may make up to 5% of the thin sections and is invariably accompanied by opaques (Plate XIV). Accessory minerals include epidote, apatite, sillimanite, zircon,

PLATE XI

Remnant porphyroblast of gahnite with a core of cordierite set in a matrix of cordierite. Minor alteration of cordierite to pinite also occurs.

(x'd nicols, 63x)

PLATE XII

Staurolite twin surrounded by cordierite. The staurolite shows a reaction rim with the cordierite. The anthophyllite in the upper right hand corner contains minor inclusions of quartz and cordierite. The cordierite shows some alteration to pinite.

(x'd nicols, 25x)

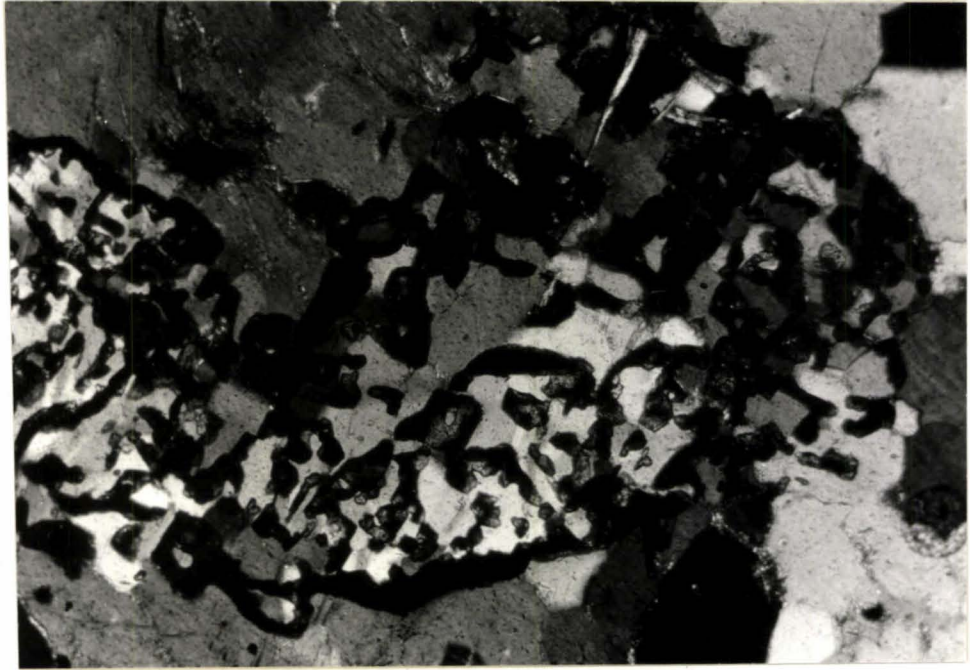


PLATE XIII

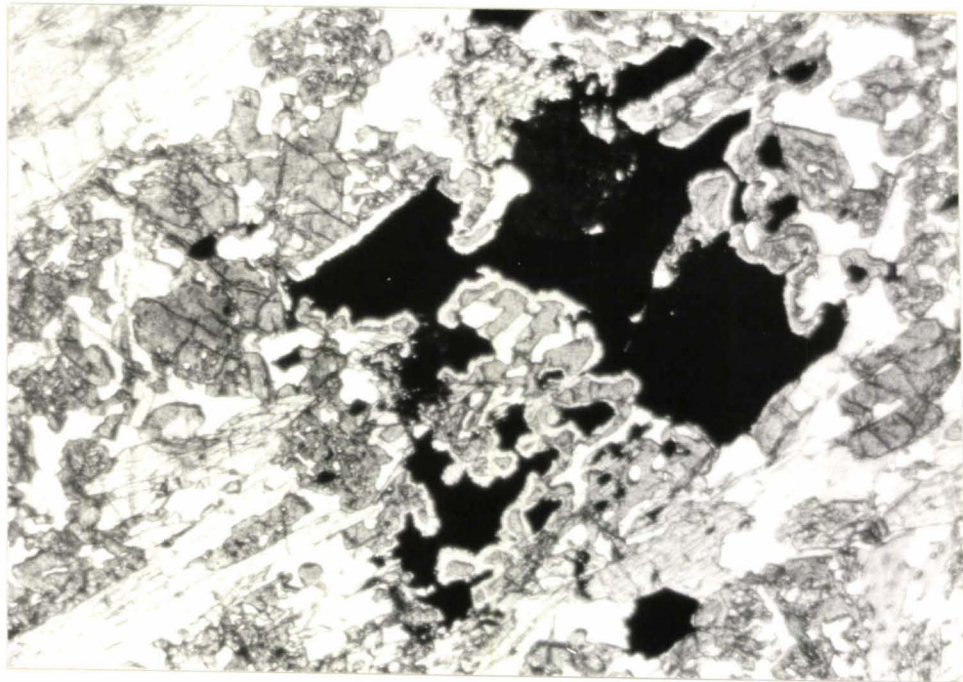
Plagioclase (An_{30}) remnant extensively altered to intergrowth of cordierite and quartz. Chlorite grains cross cut the upper part of the grain. Opaque areas are sulphide grains which may also be included by chlorite.

(x'd nicols, 63x)

PLATE XIV

Opaque (chalcopyrite) showing reaction rim. A sphalerite grain is barely visible in the lower part of the opaque. It shows good crystal form when in contact with the chalcopyrite. The mineral with high relief is the zinc spinel gahnite. It is intergrown with cordierite. Minor anthophyllite is also present.

(plane light, 25x)



white mica and cassiterite.

The orthoamphibole present which has generally been described as anthophyllite was found in fact to consist of both aluminous gedrite and iron rich anthophyllite. The two amphiboles gave opposite signs, but in other aspects are almost impossible to distinguish. The clinoamphibole cummingtonite was also noticed apparently forming a solid solution with the anthophyllite and gedrite. Except for the inclined extinction of cummingtonite it was optically similar to the anthophyllite. By the use of a transmission electron microscope it was possible to differentiate between the amphiboles. While cummingtonite should not be present with anthophyllite because it is a lower temperature form, its presence has been observed elsewhere in similar rock types (Lal et al., 1975) and it is generally attributed to the sluggish nature of the conversion from the low to high temperature form. The cummingtonite is generally included within the orthoamphiboles. The anthophyllite/gedrite occur both as idioblastic massive blade forms up to several cm in length to fine grained fibrous forms. They usually have an overall subparallel schistose texture.

The amphiboles often contain inclusions of cordierite (Plate XV) and quartz. These inclusions are often in the form of tiny blebs and may include both intergrown quartz and cordierite. Cordierite is also found as a discrete alteration product at the ends of amphibole fibres. At times biotite is also included within the amphiboles but

PLATE XV

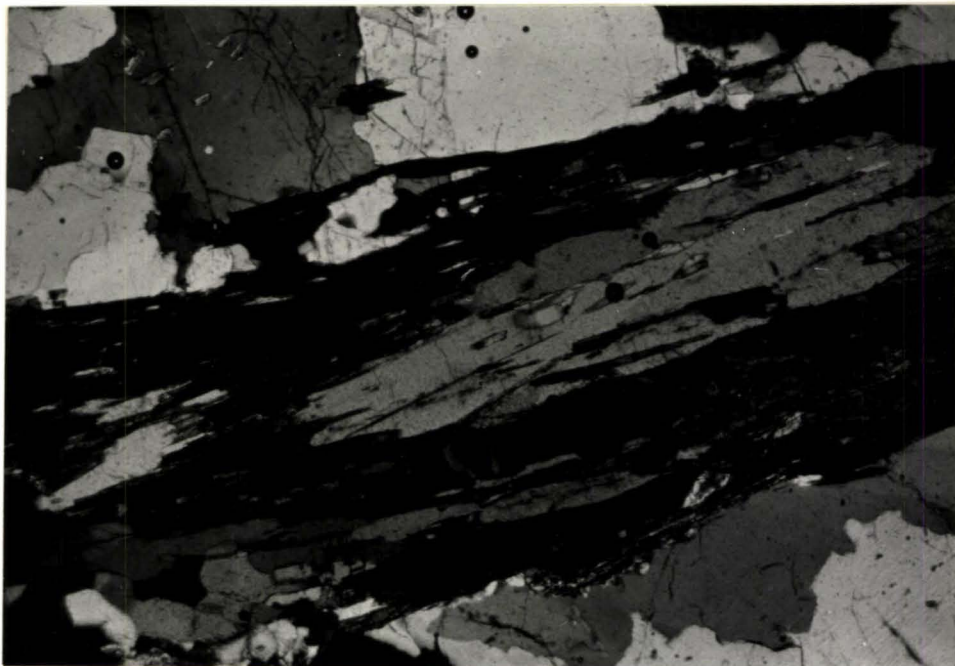
Massive pleochroic grey anthophyllite with a cordierite core. Faint dark areas in cordierite are due to pleochroic halo trains. The cordierite contains small inclusions of quartz. The anthophyllite is surrounded by massive quartz grains and shows a slight reaction with the quartz in the lower portion of the plate.

(x'd nicols, 25x)

PLATE XVI

Plate showing the relationship between the anthophyllite and the biotite. The biotite is the dark mineral and contains an inclusion of anthophyllite. The fibrous mineral is the fibrous form of anthophyllite intergrown with biotite. A grain of gahnite (top) is seen to touch the biotite but is separated by a reaction rim of cordierite from the anthophyllite.

(plane light, 25x)



generally appears to be a relict and is reacting to form anthophyllite. (Plate XVI, XVII). The reverse is also true and biotite may form reaction rims around the anthophyllite. At times the contact between the minerals is sharp and no reaction appears to be taking place. There is, however, an inverse relationship between the biotite and the anthophyllite (i. e., the increase in one causes a decrease in the other). This may be due to the reaction $\text{biotite} + 4 \text{ quartz} = \text{anthophyllite} + \text{cordierite} + \text{K}_2\text{O}$.

Anthophyllite is never found in contact with the staurolite and when staurolite is found included within the amphibole there is usually a very distinct and quite large reaction rim of cordierite separating the two. The same is found to be true for included gahnite (Plate XVIII). The anthophyllite occasionally shows a boudinage type structure showing distinctive pinch and swell. Generally the anthophyllite/gedrite has an overall fresh unaltered appearance but at times its edges are altered to a magnesium rich chlorite, cordierite or biotite (Plate XIX).

Cordierite is found in varying degrees in most of the thin sections. It has a modal abundance from approximately 5% to 20%. It is found to occur in several discrete forms. Its most common occurrence is that of a reaction or alteration rim.

Cordierite also occurs as well formed idiomorphic grains showing a discrete pseudo-hexagonal crystal outline (Plate XX). It has an overall fresh appearance but it is often altered along its edges to pinite. It also shows dusty inclusions and the characteristic pleochroic

PLATE XVII

Same plate as above, but x'd nicols. While the biotite appears to be replacing the anthophyllite, the anthophyllite has a much fresher appearance. Note the zircon in the central anthophyllite grain. The quartz shows good sutured texture.

(x'd nicols, 25x)

PLATE XVIII

Close up of anthophyllite grain being altered to cordierite. The grain is continuous on both sides of the cordierite but is nearly cut in two. The cordierite contains remnants of anthophyllite and contains minor inclusions of quartz.

(x'd nicols, 63x)

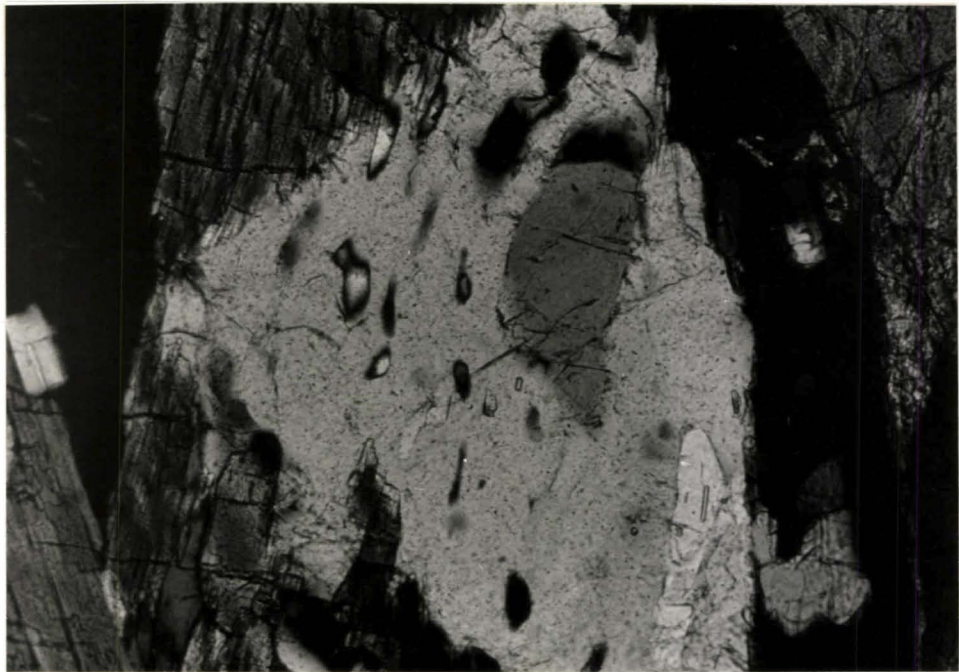


PLATE XIX

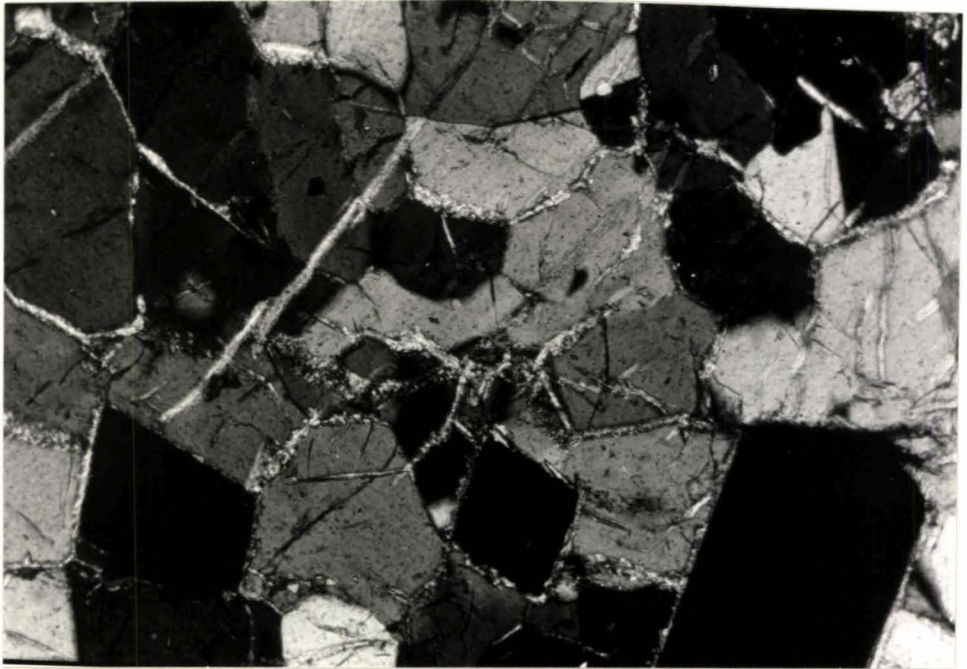
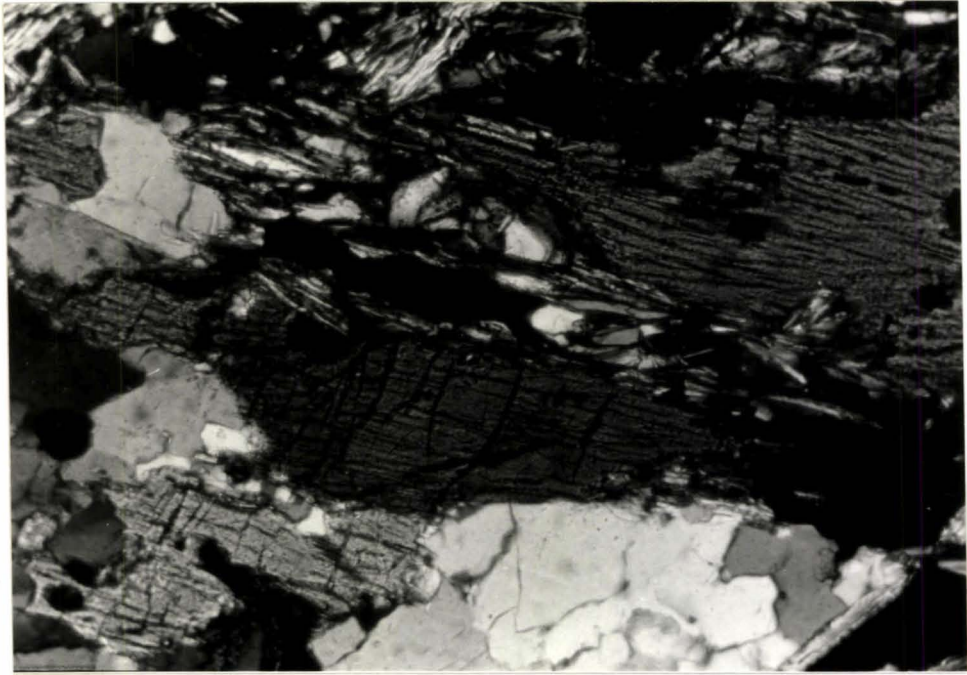
Gedrite/anthophyllite being altered to chlorite. Numerous inclusions of cordierite are also present.

(x'd nicols, 63x)

PLATE XX

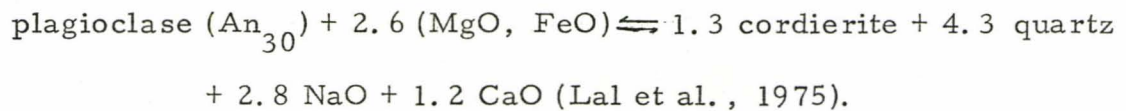
Close up of cordierite and opaques (pyrite?). Reaction rims of pinite surround the individual grains of cordierite as well as the opaques. Pinite also cross cuts the section. Note the overall dusty appearance of the cordierite.

(x'd nicols, 63x)



yellow haloes around zircon inclusions. Twinning in the more massive cordierite is quite common.

The cordierite also often has a remnant core of staurolite or gahnite. This reaction may be due to rising temperature conditions in the rock. Cordierite is also found rimming many of the opaques. The altered plagioclase present forms an intergrowth of cordierite and quartz following the reaction,



Depending on the amount of each present the cordierite may form wormy inclusions with the quartz or vice versa.

The quartz is the most distinctive feature of the rock. It occurs in many forms, the most noticeable of which is the large "pebbles" of almost pure quartz after which this unit is named. These pebbles may comprise up to 50% of the rock and due to their large size most of some thin sections. The transition from these pebbles to interbedded quartz is somewhat difficult to discern particularly in thin section. This results in highly variable modal analysis. While the large pebbles form fairly distinct boundaries with the matrix the same is not true for pebbles less than approximately one cm in size.

The large pebbles are seen to consist of a mosaic of sutured xenoblastic grains of quartz which are often included with biotite. The larger grains in particular show extensive strained

extinction and occasionally give a biaxial figure. On the edges of the pebbles the quartz often shows a mortar texture due to shearing. Opaques are often injected along these shears. Toward the centre of these pebbles, however, the quartz takes on a massive appearance.

Quartz is also found in several other forms. It is found as reaction rims similar to those of cordierite around many of the opaques and in this form is very difficult to distinguish from cordierite unless the two occur together. Cordierite and quartz are found both as discrete interbands and as worm-like intergrowths (Plate XXI, XXII).

The biotite which is generally a pale to dark brown in colour forms large idioblastic subparallel grains. It is often included by relatively large zircons and shows excellent pleochroic haloes (Plate XXIII). Thin bands of opaques are often seen exsolving from the biotite. Some of these opaques may be ilmenite which has been identified in these sections by the use of a transmission electron microscope. When the biotite is included within quartz it is generally unaltered. When it is found within the matrix, however, it is often highly reacted. This is particularly true when it is found within the anthophyllite. The biotite has also been found to react to form chlorite. In some instances the chlorite forms perfect pseudomorphs complete with pleochroic haloes around included zircons (Plate XXIV).

Chlorite is an almost ubiquitous constituent in the thin sections. It is usually found as an alteration product. It is generally

PLATE XXI

Gahnite showing a symplectic intergrowth with cordierite and quartz. The opaques are often embayed by the gahnite.

(plane light, 63x)

PLATE XXII

Distinct alternating bands of cordierite and quartz are visible. The cordierite bands contain numerous inclusions of quartz which gives them a speckled appearance. The quartz bands are composed of relatively massive grains which show undulatory extinction and polycrystalline grains. The biotite present is unaltered.

(x'd nicols, 25x)

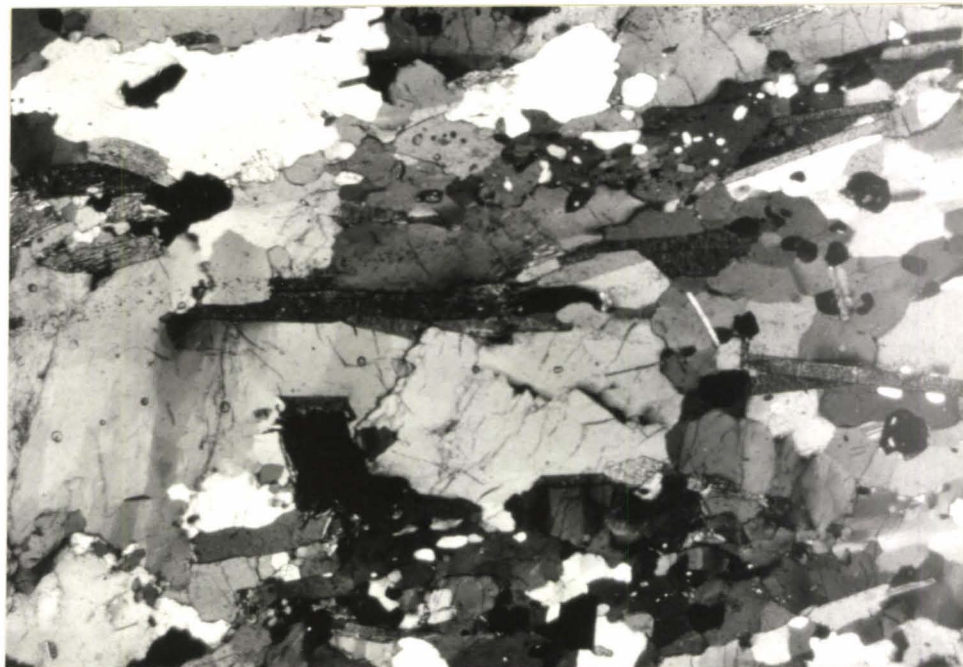
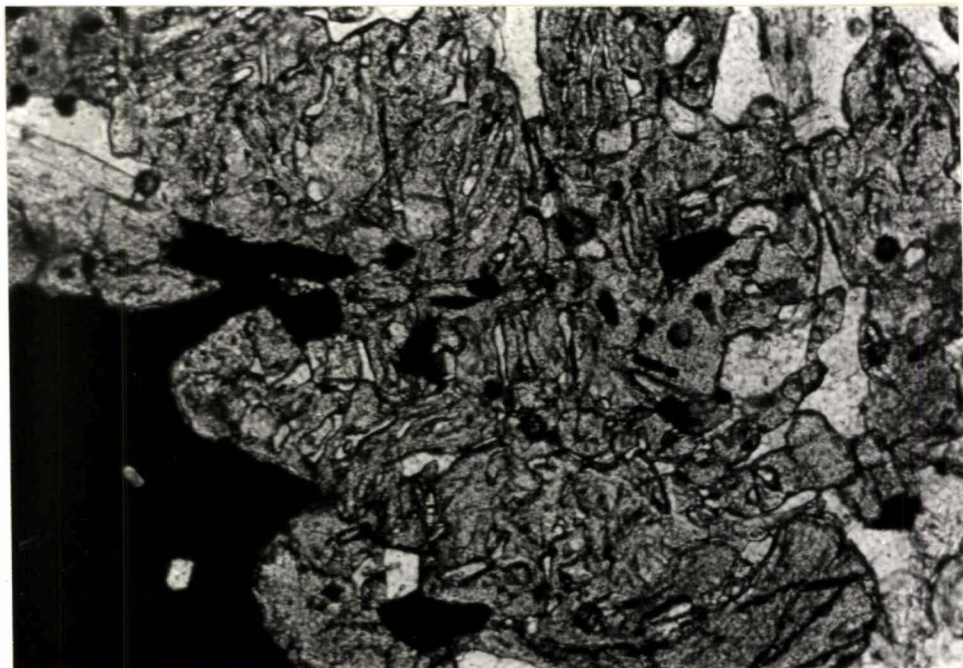


PLATE XXIII

The unaltered magnesium rich biotite shows numerous inclusions of zircons. A relatively large zircon showing the diagnostic pleochroic halo in the biotite is visible in the centre of the plate. The biotite is included in a quartz matrix.

(plane light, 63x)

PLATE XXIV

Massive chlorite showing berlin blue colour under polarized light is seen pseudomorphing biotite. Minor amounts of a retrograde chlorite are seen cross cutting the massive chlorite. Remnants of biotite are visible. The chlorite includes a large intergrowth of cordierite and quartz. Note the strained extinction in the quartz.

(x'd nicols, 63x)



PLATE XXV

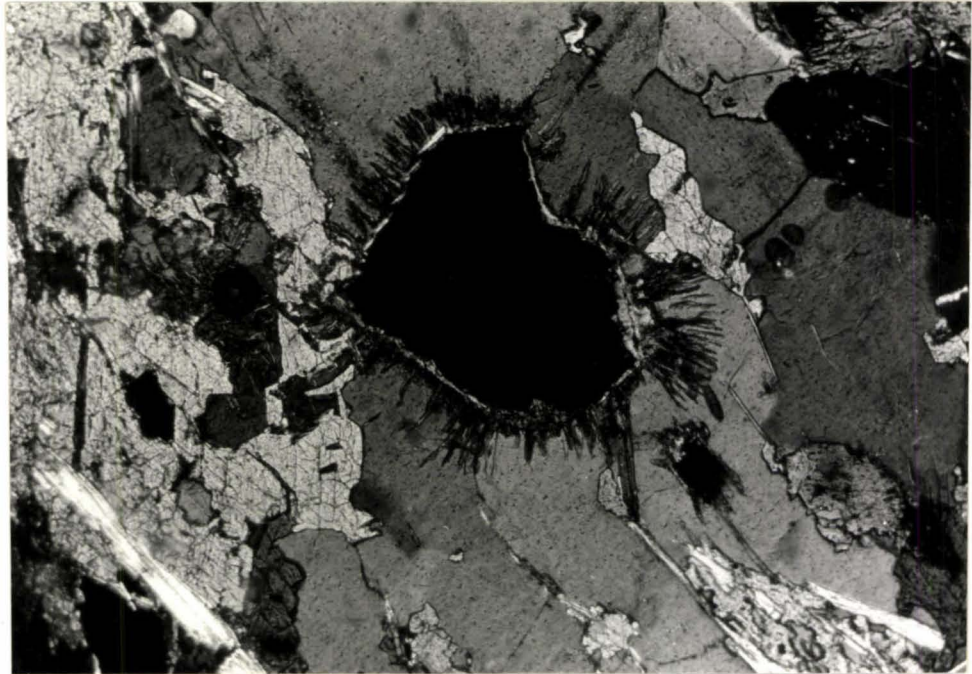
The sulphide grain set in a matrix of cordierite shows a distinctive reaction rim of pale green (Fe rich) chlorite. The anthophyllite present contains minor amounts of chlorite and biotite.

(x'd nicols, 63x)

PLATE XXVI

Well shaped rhombs of chlorite showing berlin blue in polarized light are seen growing in a mixture of pale green chlorite and cordierite. The cordierite contains small blebs of quartz. A reaction rim separates the chlorite rhombs from the matrix.

(x'd nicols, 63x)



associated as a reaction rim around biotite and the opaques. It is also occasionally found rimming the amphiboles. It usually forms fibrous to felted needle like intergrowths and is pale green in plane light (Plate XXV). A second idioblastic chlorite is found to occur in a matrix of felted chlorite. This second chlorite forms well shaped rhombs which display the anomalous berlin blue of magnesium rich chlorite and has tentatively been as penninite (Plate XXVI). It appears to be growing at the expense of the green chlorite which because of its high iron content has been identified as ripidolite. The source of the magnesium in the well shaped chlorite may be from the cordierite which is found included within the felted chlorite.

In several sections the chlorite is also seen to have completely replaced a mineral which due to its crystal outline may have been either almandine or pyroxene.

The spinel in these sections is the zinc spinel known as gahnite. Gahnite forms a solid solution with the magnesium rich variety (Deer et al., 1962). Because of this it is not known how "pure" the gahnite is. In several sections a brown spinel is found mixed with the gahnite. The gahnite has a distinctive blue green colour in plane light and has extreme relief. The gahnite usually occurs as incipient idioblastic porphyroblasts which often form a myremekitic intergrowth with quartz and cordierite. It is often intimately associated with sphalerite, suggesting that it formed by

PLATE XXVII

Incipient porphyroblasts of gahnite are found forming "trains" in a cordierite band which runs through the entire plate and shows a slight contrast with quartz which forms the remainder of the matrix. The quartz contains conclusions of biotite.

(plane light, 25x)

PLATE XXVIII

The mineral with high relief is gahnite. It is surrounded by a mineral or mixture of minerals of unknown composition. Under polarized light this apparently homogeneous mass is seen to be composed of a mosaic of interlocking grains. It is possible that this "mineral" is a mixture of the biotite which surrounds the unknown mineral and zinc from the spinel (i. e. the zinc may be substituting for magnesium in the crystal lattice).

(plane light, 25x)

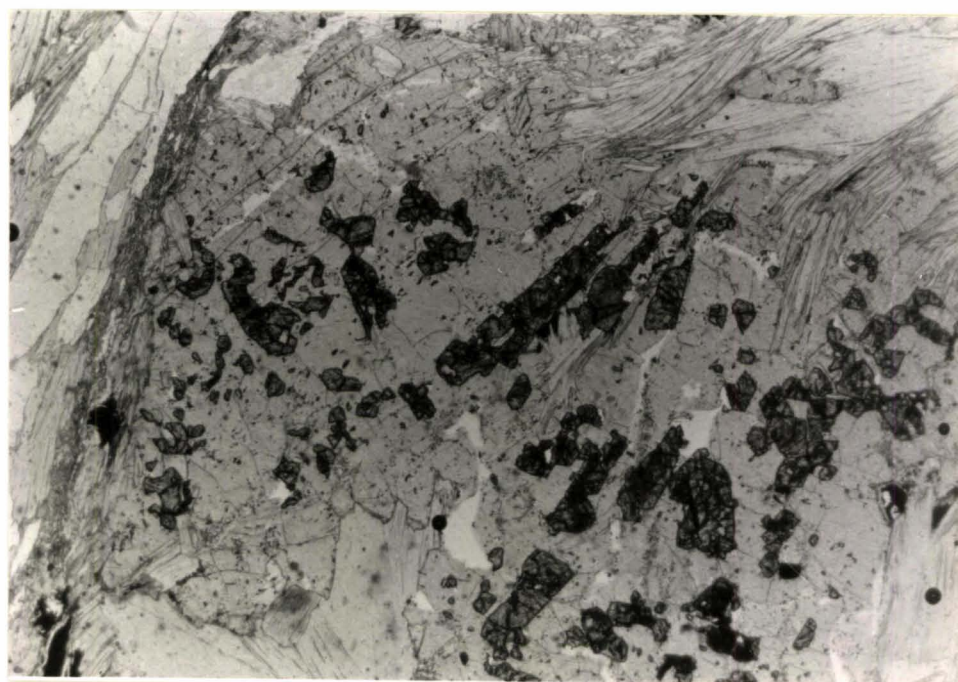
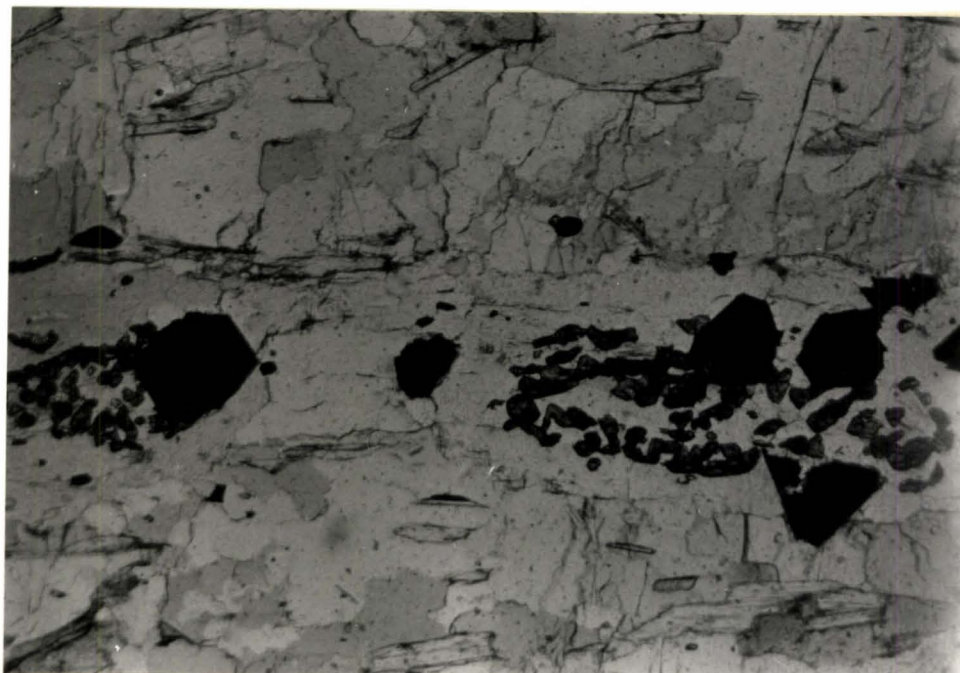


PLATE XXIX

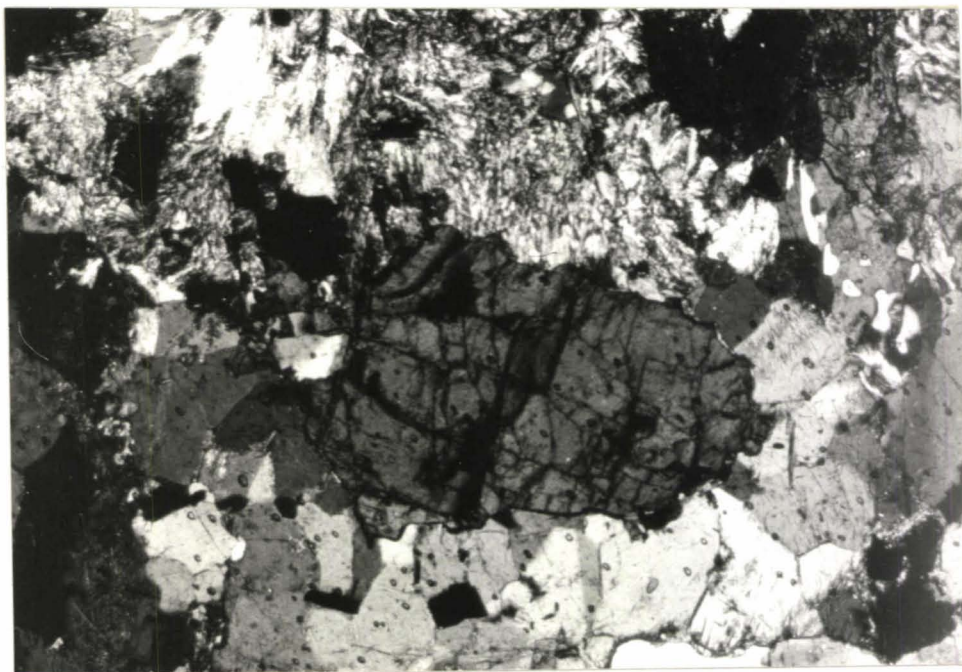
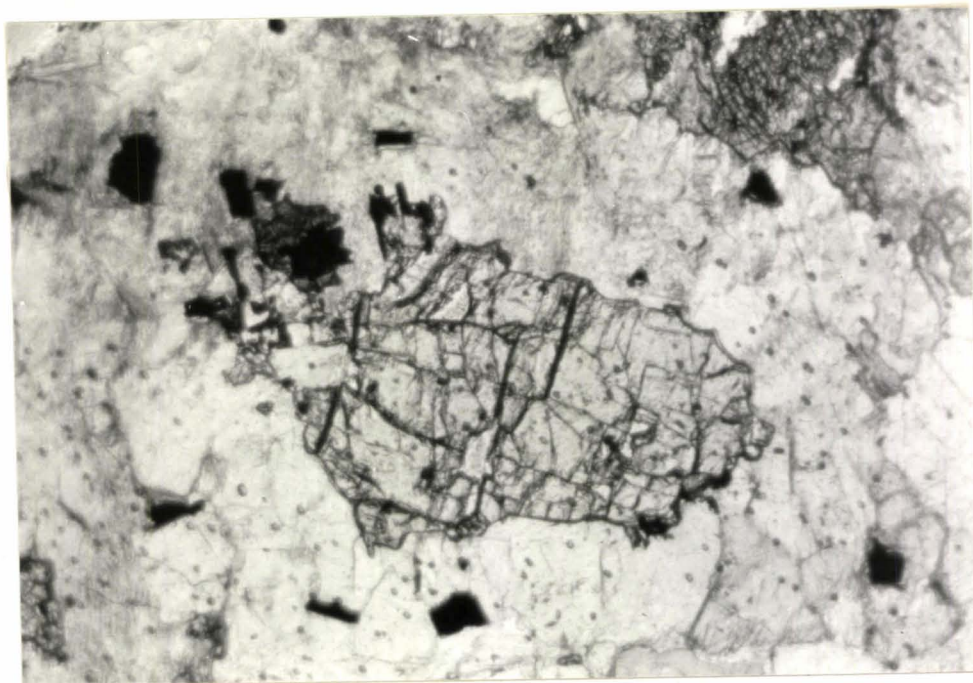
A large grain of staurolite is enclosed in a matrix of cordierite and minor quartz. The mineral showing high relief in upper left hand portion of the plate is gahnite. It surrounds a grain of cassiterite which appears opaque. Minor amphibole is also present.

(plane light, 25x)

PLATE XXX

Same view as above but under polarized light. The upper portion of the section has been altered to chlorite. Some of the cordierite shows alteration to pinite.

(x'd nicols, 25x)



rocks by the use of a transmission electron microscope.

The composition of the plagioclase is that of an andesine. The largest such an aggregate is approximately 1 mm by 2 mm.

Zircons which may often be quite large are found in large numbers in most thin sections. When they occur in cordierite or biotite they display the characteristic pleochroic haloes in the host mineral.

Several grains of reddish brown cassiterite which strongly resembles sphalerite but displays extreme birefringence have been identified. They occur both as tiny droplets and also as small sliver like structures on the edge of the gahnite.

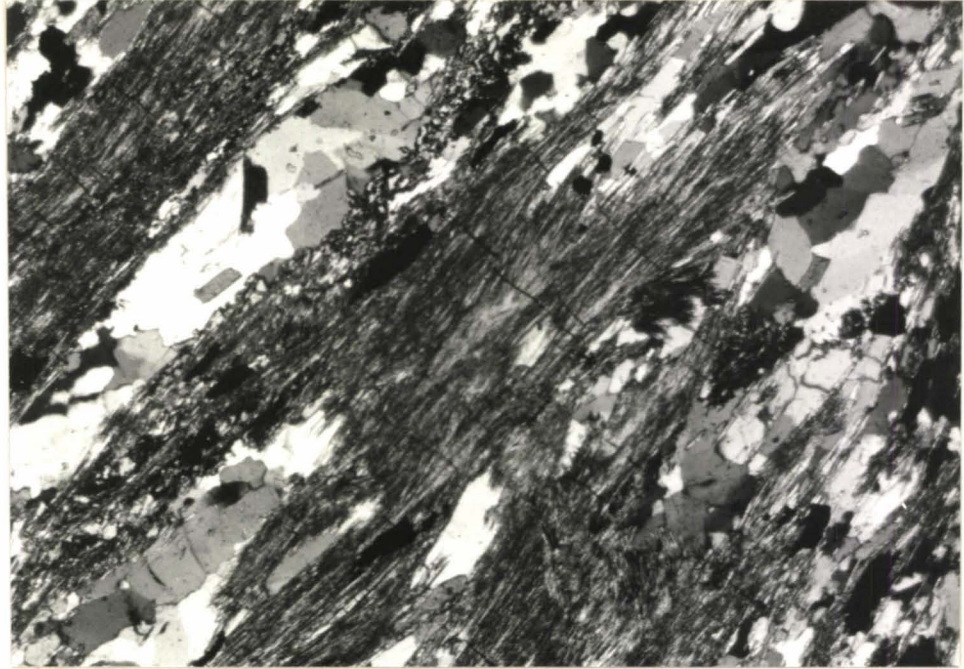
Epidote occurs as an alteration product in association with chlorite and biotite. Idioblastic grains of apatite are occasionally found. These are often included within a quartz matrix but show no signs of reacting. Pinite, a muscovite-chlorite aggregate, is often found surrounding cordierite grains. Sillimanite occurs only in accessory amounts in the thin sections and is often associated with biotite. Even near the contact of the quartz pebble conglomerate and the sillimanite gneiss the amount of sillimanite present is only minor suggesting that the boundary is abrupt.

ii) The Sillimanite Schist and Gneiss

Sillimanite gneisses and schists often occur on both sides of the quartz pebble conglomerate. Quartz is the dominant mineral. The sillimanite is the next most abundant mineral and accounts for approximately 20% of the rock. Felted knots of sillimanite occur as spheroids of up to 1 cm in size. This gives the rock a very distinctive spotted and streaked appearance. The sillimanite also occurs as elongated slender prisms and short stubby prisms. This together with the subparallel alignment of biotite creates a strongly schistone rock (Plate XXXI). The sillimanite often shows a skeletal cross section indicating a core mineral of unknown composition. Cordierite with occasional highly altered plagioclase forms alternating bands with the quartz. The cordierite accounts for approximately 5% of the rock and appears to be related to the occurrence of the plagioclase. The bands are highly variable and pinched out into quartz layers.

The biotite which accounts for up to 15% of the section, occurs as poorly oriented clusters which, due to their more greenish colour, suggest a fairly high iron content. They are seen to prograde longitudinally into sillimanite and chlorite.

The quartz as a rule is xenoblastic and largely equidimensional as opposed to the quartz pebble conglomerate. It forms distinct quartzose layers within the unit.



iii) The Quartz Biotite Hornfels

This unit is often interspersed and appears to grade into the quartz pebble conglomerate. The overall bulk composition of the rock is usually not significantly different from the quartz pebble conglomerate but it displays a higher percentage of sulphides as a rule.

In thin section there appears to be an overall decrease in the anthophyllite present marked by an overall increase in biotite.

Twinned cordierite is often found associated with gahnite, plagioclase remnants and staurolite. Cordierite generally tends to form alteration rims as before and is often altered to pinite on its edges although its overall appearance is fresh.

The major difference between the hornfels and the quartz pebble conglomerate is its appearance in hand specimen. There are no quartz "pebbles" present and the overall appearance is that of a fairly uniform rock. The term hornfels may actually be a misnomer since in thin section in particular, the rock shows a strong preferred orientation. Zircons are a common accessory mineral as before and are particularly noticeable in the biotite which is magnesium rich.

The overall mineral composition and the associated textures suggest that the hornfels may be stratigraphically related to the quartz pebble conglomerate.

iv) Iron Formation

Because the quartz pebble conglomerate was believed by some (Friesen et al. , 1978) to be a poorly formed iron formation several samples of siliceous iron formation which occur approximately 200-300 feet above (south of) the afore mentioned unit were investigated.

Quartz makes up approximately 50% of the thin sections. The quartz grains are generally equidimensional and show sutured edges. Small flakes of green iron rich biotite are present and are often included within the quartz grains.

Hornblende is the only amphibole present. It often forms reaction rims around the clinopyroxene augite. The pyroxene is relatively unaltered, however, and shows good form. The presence of the pyroxene tends to suggest these are not "average" iron formations.

Large porphyroblastic garnets which appear to be almandine are found to be included with quartz. Plagioclase which is usually sericitized is a rare constituent. Most of the opaques are magnetite which show excellent euhedral crystal form. Semitranslucent sphalerite does occur occasionally. Other accessory minerals include zircons and calcite. The calcite occurs both as discrete grains and as veins cross cutting the thin section.

Modal Analysis

Studies by D. M. Shaw (1955) indicate that modal analysis are possible if thin sections are cut either parallel to foliation or cross cutting it. Studies undertaken by Shaw indicate significant error is created by the presence of porphyroblasts (quartz pebbles) whose modal percent he suggests must be estimated beforehand.

In point counting the distance of the points apart must be equal to the grain size (Van der Plas et al. , 1965). When this is applied to many of the thin sections the grain size is much too large to allow the minimum of 500 points recommended (in many cases fewer than 20 points could be counted).

Systematic point counts were repeated for several thin sections. This involved either varying the distance between points, the number of points and the area of thin section. Systematic errors of greater than 25% were encountered.

For this reason modal percents of the minerals were estimated.

CHAPTER VI
GEOCHEMISTRY

i) Discussion of Whole Sample Analysis

The data is summarized in Table V. Various trends are apparent. The overall composition of the quartz pebble conglomerate is remarkably similar. The hornfels and sillimanite gneisses are found as discrete samples but do not differ remarkably from the quartz pebble conglomerate. The iron formations form a distinct unit. They are exceedingly low in Al_2O_3 as compared to the remaining samples and considerably richer in CaO.

The whole sample analysis were then compared to other literature values and data obtained from Geco mines. This is given in Table VI, Table VII and Table VIII. It is apparent that the quartz pebble conglomerate is low in CaO, and Na_2O relative to other units but it is not overly enriched in MgO or Fe_2O_3 as would be suggested if metasomatism occurred.

Comparison to the literature values shows that the quartz pebble conglomerate is roughly equivalent to many other cordierite anthophyllite units. There appear to be no modern equivalents of this unit, however, silica poor shale is similar in many respects. The silica content is too high in the quartz pebble conglomerate for such a

TABLE V. Whole Rock Analyses (Normalized to 100%) in Weight Percent Oxide

Number	Name	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅
FB1	Qtz Biotite Hornfels	46.03	15.16	26.82	6.35	0.43	0.10	2.79	0.32	0.21	1.79
FB2	Qtz Sillimanite Schist	71.47	10.54	9.87	5.17	0.21	0.15	1.92	0.52	0.13	0.01
FB3	Qtz Pebble Conglomerate	56.64	14.29	16.26	5.75	0.37	0.24	3.80	0.37	0.19	2.11
FB4	Qtz Pebble Conglomerate	65.93	9.30	16.08	5.46	0.25	0.45	0.12	0.13	0.18	2.11
FB4A	Qtz Pebble Conglomerate	66.02	9.33	15.97	5.42	0.25	0.43	0.11	0.13	0.18	2.16
FB7	Qtz Pebble Conglomerate	68.74	7.34	13.20	5.49	1.09	0.86	0.90	0.12	0.18	2.09
FB9	Qtz Pebble Conglomerate	64.02	9.12	17.53	5.37	0.73	0.67	0.20	0.14	0.17	2.05
FB13	Qtz Biotite Hornfels	80.96	0.43	16.50	1.14	0.84	0.00	0.06	0.00	0.08	0.00
FB14	Qtz Diorite Dike	74.64	6.40	11.05	4.72	0.36	0.25	0.27	0.14	0.18	1.99
FB14A	Qtz Diorite Dike	74.98	6.34	10.95	4.54	0.34	0.27	0.26	0.14	0.17	2.01
FB20	Qtz Pebble Conglomerate	72.12	7.30	12.15	5.18	0.21	0.32	0.07	0.11	0.16	2.37
FB24	Iron Formation	83.74	0.53	8.67	2.03	1.98	0.06	0.01	0.02	0.43	2.51
FB24A	Iron Formation	83.84	0.62	8.62	2.02	1.95	0.04	0.01	0.03	0.44	2.44
FB25	Iron Formation	71.12	0.82	23.02	1.60	1.30	0.12	0.12	0.04	0.48	1.40
FB33	Qtz Pebble Conglomerate (Garnet)	55.87	13.23	22.08	5.50	0.33	0.59	0.22	0.20	0.18	2.16
FB36	Sillimanite Schist	78.32	9.42	4.25	3.51	0.17	0.23	1.06	0.09	0.08	2.88
FB41	Qtz Pebble Conglomerate	74.55	5.67	11.36	5.15	0.37	0.31	0.11	0.09	0.17	2.22
FB57	Qtz Pebble Conglomerate	73.21	5.34	12.70	5.11	0.50	0.10	0.56	0.10	0.18	2.16
FB66	Iron Formation	65.10	1.38	24.13	2.48	4.02	0.11	0.13	0.04	1.42	1.19
FB70	Iron Formation	78.21	3.28	10.16	1.63	3.89	0.10	1.08	0.14	0.59	0.91

TABLE VI. Comparison of Relatively Unmetamorphosed Sediments to the Quartz Pebble Conglomerate.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO ₂	67.70	69.96	49.85	99.47	64.15	48.67	66.34
Al ₂ O ₃	13.60	10.52	13.88	0.06	15.79	13.30	8.99
FeO	--	--	--	0.17	2.47	0.83	15.28
Fe ₂ O ₃	5.10	3.47	17.85	--	3.51	9.07	--
MgO	1.90	1.41	3.32	--	2.45	6.36	5.38
CaO	3.40	2.17	0.20	0.06	4.02	6.16	0.40
Na ₂ O	2.80	1.51	0.10	0.01	2.84	1.61	0.44
K ₂ O	2.10	2.30	2.74	0.03	2.32	0.96	0.68
TiO ₂	0.80	0.59	1.45	--	0.48	1.99	0.15
MnO	0.10	0.06	0.24	--	0.07	--	0.15
P ₂ O ₅	--	0.18	0.09	--	0.14	0.36	2.16

1. analysis of sandstone (Whetten 1966 quoted by Pettijohn, pg. 199, 1975)
2. analysis of Mississippi Delta shale (Clarke 1924 quoted by Pettijohn pg. 274, 1975)
3. analysis of Dunn Creek Slate (James et al., 1945 quoted by Pettijohn pg. 286, 1975)
4. analysis of Devonian Chert (Start et al., 1945 quoted by Pettijohn pg. 473, 1975)
5. analysis of Archean pelitic sediment (Ronov et al., 1971 quoted by Pettijohn, pg. 590, 1975)
6. analysis of basaltic tuff (Washington 1917 quoted by Pettijohn pg. 305, 1975)
7. analysis of average quartz pebble conglomerate (this paper).

TABLE VII. Comparison of Quartz Pebble Conglomerate
With Other Rocks at Geco Mine.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO ₂	51.25	66.22	69.90	71.23	79.74	62.90	66.34
Al ₂ O ₃	13.08	0.74	8.77	10.56	9.19	15.00	8.99
FeO	26.56	9.88	16.97	6.05	2.82	9.35	15.28
Fe ₂ O ₃	--	16.04	--	--	1.17	1.83	--
MgO	6.83	1.94	4.19	2.79	2.42	5.70	5.38
CaO	1.28	2.21	1.22	0.31	0.16	10.00	0.40
Na ₂ O	0.15	0.30	0.74	0.73	0.18	2.31	0.44
K ₂ O	0.26	0.03	0.20	3.17	1.66	0.30	0.68
TiO ₂	2.92	0.03	0.21	0.13	0.32	1.25	0.15
MnO	0.26	1.65	0.21	0.04	0.02	0.28	0.15
P ₂ O ₅	0.58	0.12	0.07	0.01	0.21	0.09	2.16

1. analysis of hornfels (Geco Mine analysis)
2. analysis of iron formation (Pye 1957)
3. analysis of hornfels (Geco Mine analysis)
4. analysis of sericite schist (sillimanitic) (Geco Mine analysis)
5. analysis of biotite sillimanite gneiss (Pye 1958)
6. analysis of hornblende schist (Geco Mine analysis)
7. average analysis of quartz pebble conglomerate.

TABLE VIII. Comparison of Quartz Pebble Conglomerates to Rocks of Similar Composition.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11
SiO ₂	61.28	40.07	53.02	58.15	65.70	48.87	75.40	60.10	49.38	43.81	66.34
Al ₂ O ₃	12.11	17.01	13.38	12.95	14.24	16.71	12.20	12.60	15.25	15.13	8.99
FeO	10.78	20.26	8.35	10.76	6.37	12.85	2.90	10.50	18.15	22.78	15.28
Fe ₂ O ₃	3.54	5.12	0.52	--	1.51	0.13	1.70	4.90	5.39	3.53	--
MgO	2.36	5.78	8.46	6.44	4.87	9.60	5.90	8.70	7.61	9.21	5.38
CaO	1.52	0.84	5.84	7.05	2.39	5.42	--	.40	0.66	1.06	0.40
Na ₂ O	4.22	1.24	4.28	1.02	1.96	1.61	.40	.90	1.10	1.14	0.44
K ₂ O	0.12	1.25	1.23	0.14	0.27	0.27	.60	.30	0.10	0.14	0.68
TiO ₂	1.64	2.41	1.97	1.85	0.94	2.71	.20	.20	0.74	0.60	0.15
MnO	0.06	0.41	0.12	0.12	0.09	--	--	0.40	0.06	0.38	0.15
P ₂ O ₅	0.41	0.32	0.55	0.49	0.17	0.50	--	--	--	--	2.16

1. analysis of quartz cordierite anthophyllite hornfels derived from amygdaloidal basalt (Vallance 1967)
2. analysis of quartz cordierite anthophyllite hornfels derived from brecciated altered basalt (Vallance 1967)
3. analysis of cummingtonite anthophyllite hornfels (Floyd 1965)
4. analysis of cummingtonite anthophyllite hornfels (Floyd 1965)
5. analysis of anthophyllite cordierite hornfels (Tilley 1937)
6. analysis of cummingtonite anthophyllite cordierite plagioclase hornfels (Tilley 1937)
7. analysis of cordierite gedrite gneiss (Lal & Moorehouse 1969)
8. analysis of garnet cordierite gedrite gneiss (Lal & Moorehouse 1969)
9. analysis of cordierite gedrite cummingtonite rock (Lal & Shukla 1975)
10. analysis of cordierite gedrite cummingtonite rock (Lal & Shukla 1975)
11. average analysis of quartz pebble conglomerate.

a unit but this will be dealt with in Chapter VII.

Various attempts at using the whole rock analysis to arrive at a protolith for the quartz pebble conglomerate were made. This involved the use of various plots as well as equations.

A discrimination function developed by D. M. Shaw (1975), in which it is possible to differentiate between possible protoliths, was used. This function was not applicable to all the rocks analyzed but was applicable for all of the quartz pebble conglomerate and gave a strong sedimentary origin for the rocks involved. This, of course, assumes that quartz pebbles and matrix can be considered a single unit. The method and results are given in the Appendix.

ii) Graphical Representation of Data

It is readily evident that the quartz pebble conglomerate as well as the associated rocks have an unusual bulk composition and generally plot as fairly tight groups in the corners of the various diagrams.

The ACF diagram (Fig. VII) plots the quartz pebble conglomerate on the edge of the greywacke field and slightly below the field for shales and clays as given by Winkler (1975). The overall plot is suggestive of a very iron rich clay or shale. The plot roughly coincides with the cordierite anthophyllite rocks investigated by Vallance (1967) which are thought to have an origin as an altered

Figure No.7

- quartz pebble conglomerate
- iron formation
- sillimanite schist
- biotite hornfels
- ▲ diorite dike

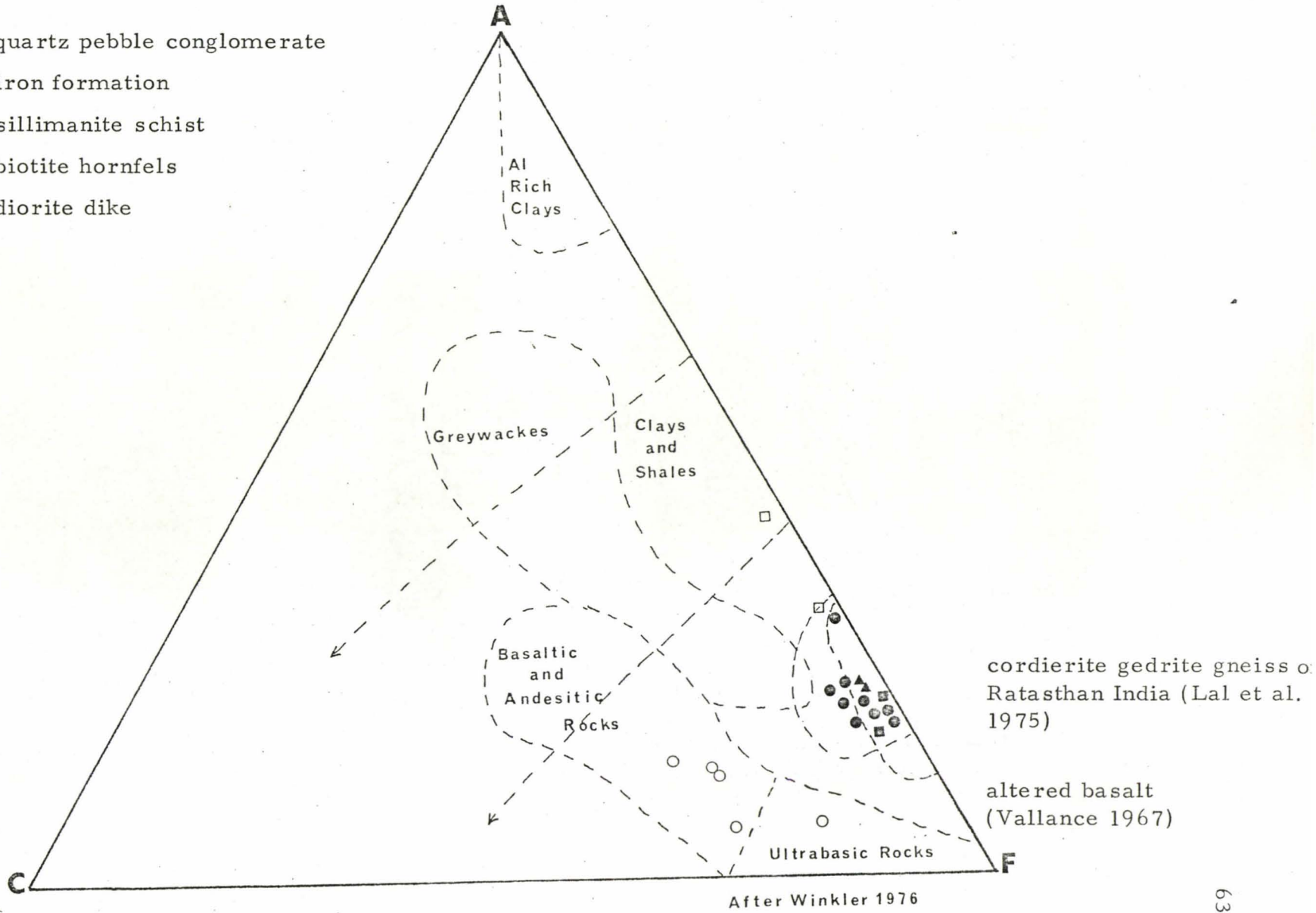
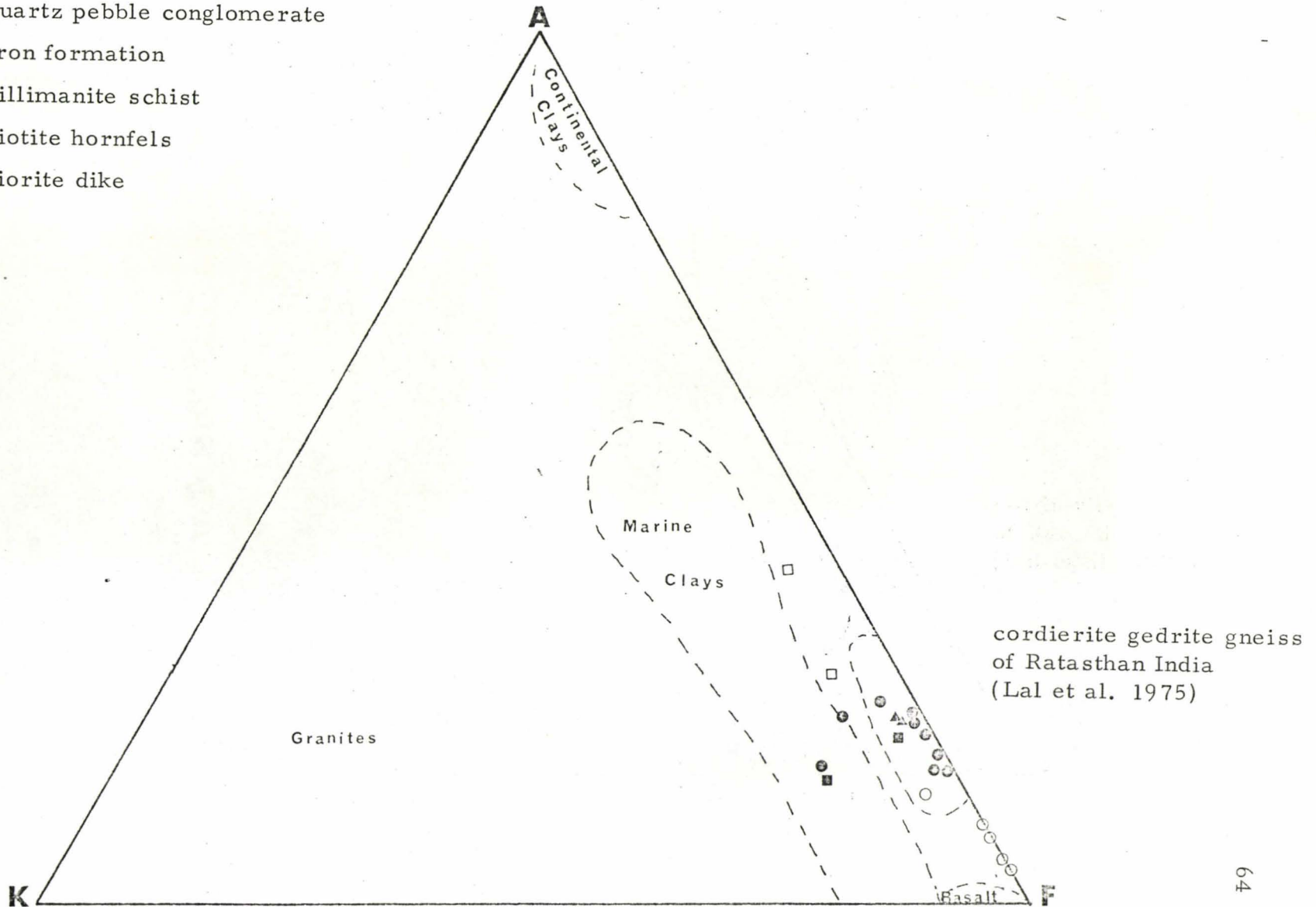


Figure No.8

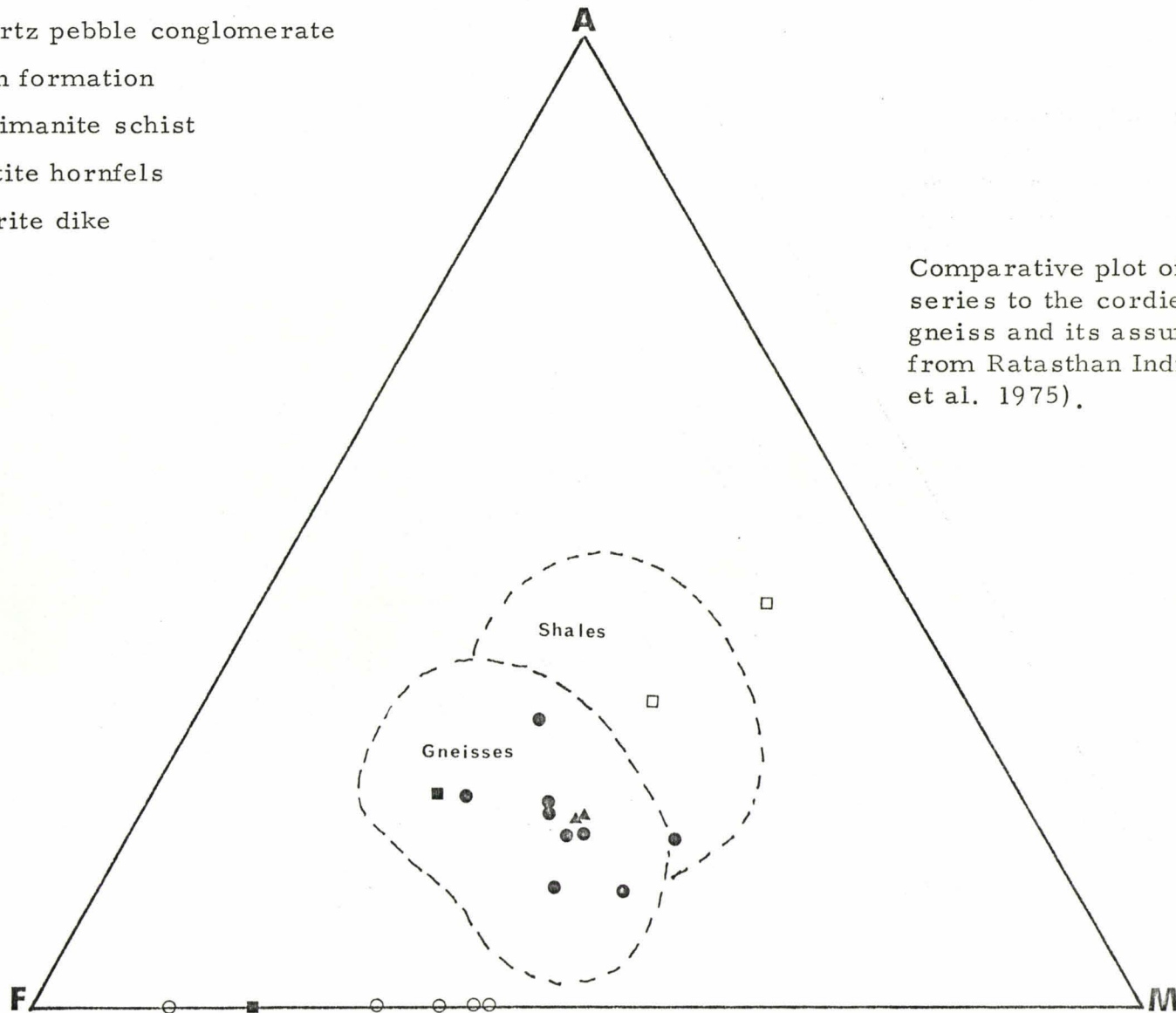
- quartz pebble conglomerate
- iron formation
- sillimanite schist
- biotite hornfels
- ▲ diorite dike



After Winkler 1976

Figure No.9

- quartz pebble conglomerate
- iron formation
- sillimanite schist
- biotite hornfels
- ▲ diorite dike



Comparative plot of the Geco series to the cordierite gedrite gneiss and its assumed parent from Ratasthan India (Lal et al. 1975).

After Lal et al 1975

mafic rock. Excellent correlation is also available with cordierite anthophyllite rocks studied by Lal et al. (1975) which are thought to have originated from a shale.

Similar plots were made on AKF (Fig. VIII) and AFM (Fig. IX) diagrams again with a close correlation to rocks investigated by Lal et al. As a rule the plots are indicative of a rock which although it falls outside normal compositions for rocks, has a composition that is suggestive of an iron rich shale.

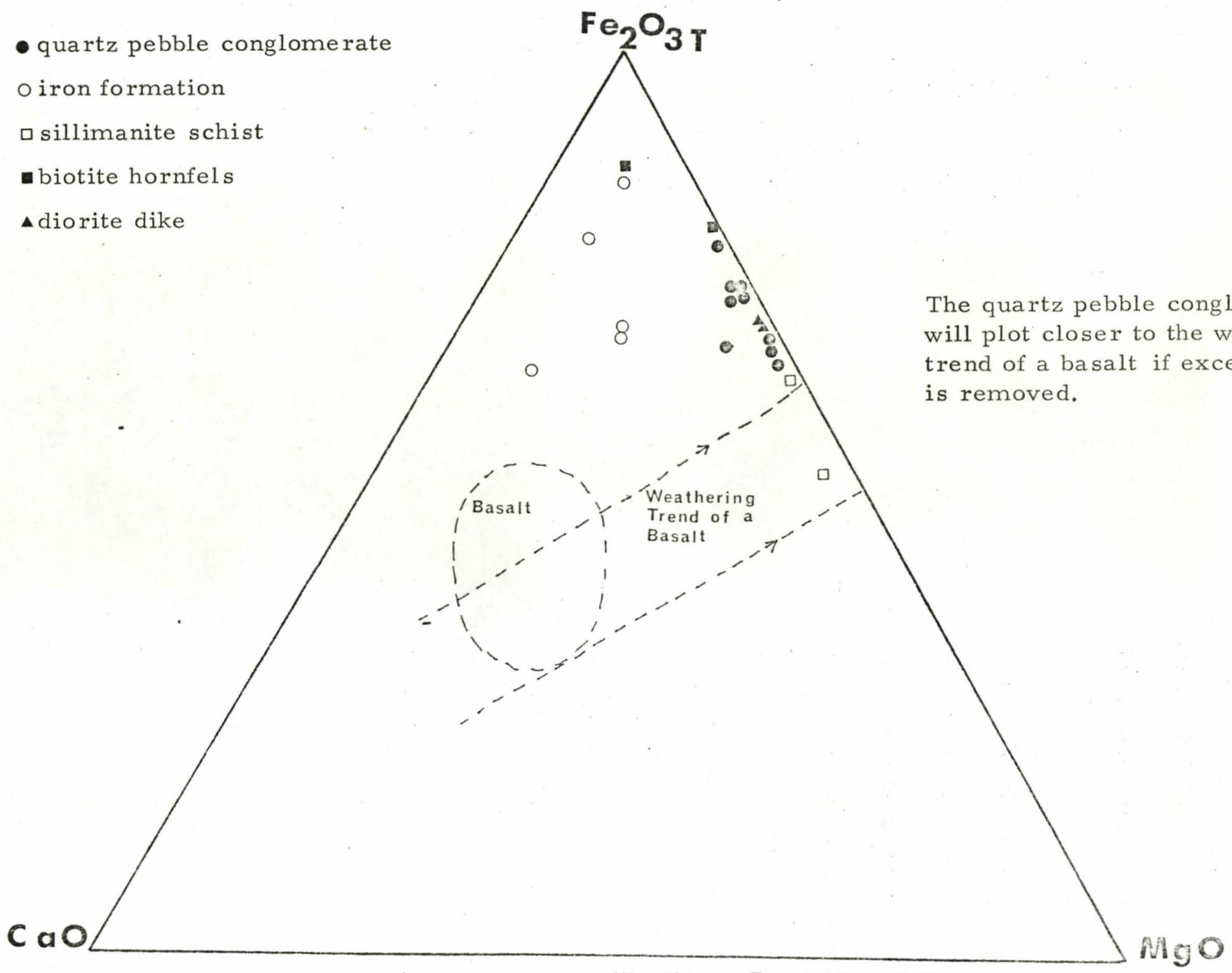
By plotting Fe_2O_3 , CaO, MgO weight percent (Fig. X) a comparison of the quartz pebble conglomerate to the weathering trends of a basalt were made. It is evident that the plot is similar to the position predicted by Vallye (1967) but the composition contains too much iron.

A plot of MgO, K_2O , Na_2O (Fig. XI) in weight percent suggests a protolith of a magnesium clay. An Fe_2O_3 , Al_2O_3 , SiO_2 weight percent plot (Fig. XII) suggests a lithic arenite. The difference in positions plotted may be because of the SiO_2 content. This suggests that at least some of the SiO_2 in the unit had another source.

iii) Trace Element Trends

The results of trace element analysis are summarized in Table IX. All minor elements were present to varying degrees. The exception to this was arsenic which is virtually non-existent. No

Figure No.10



The quartz pebble conglomerate will plot closer to the weathering trend of a basalt if excess iron is removed.

Figure No.11

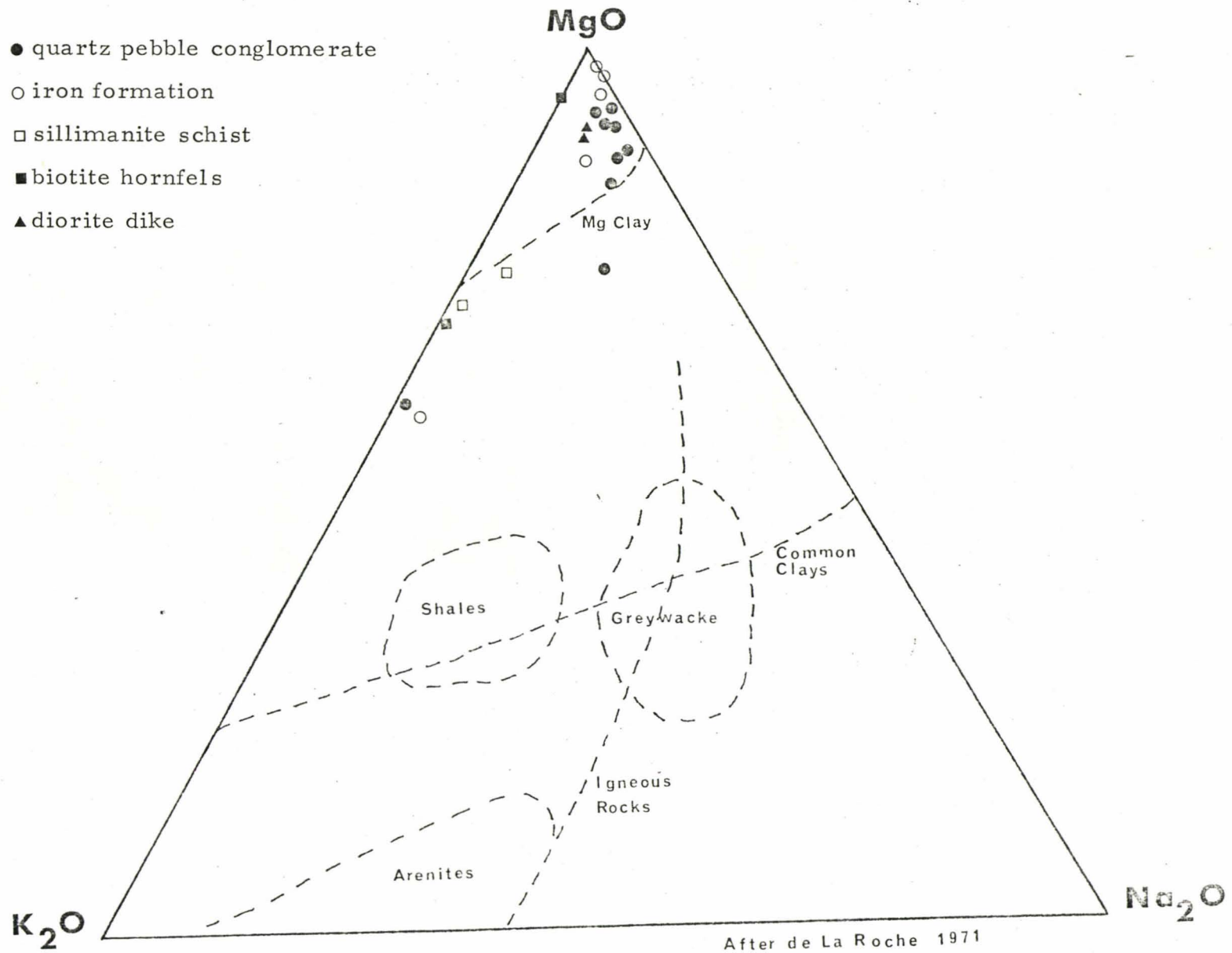
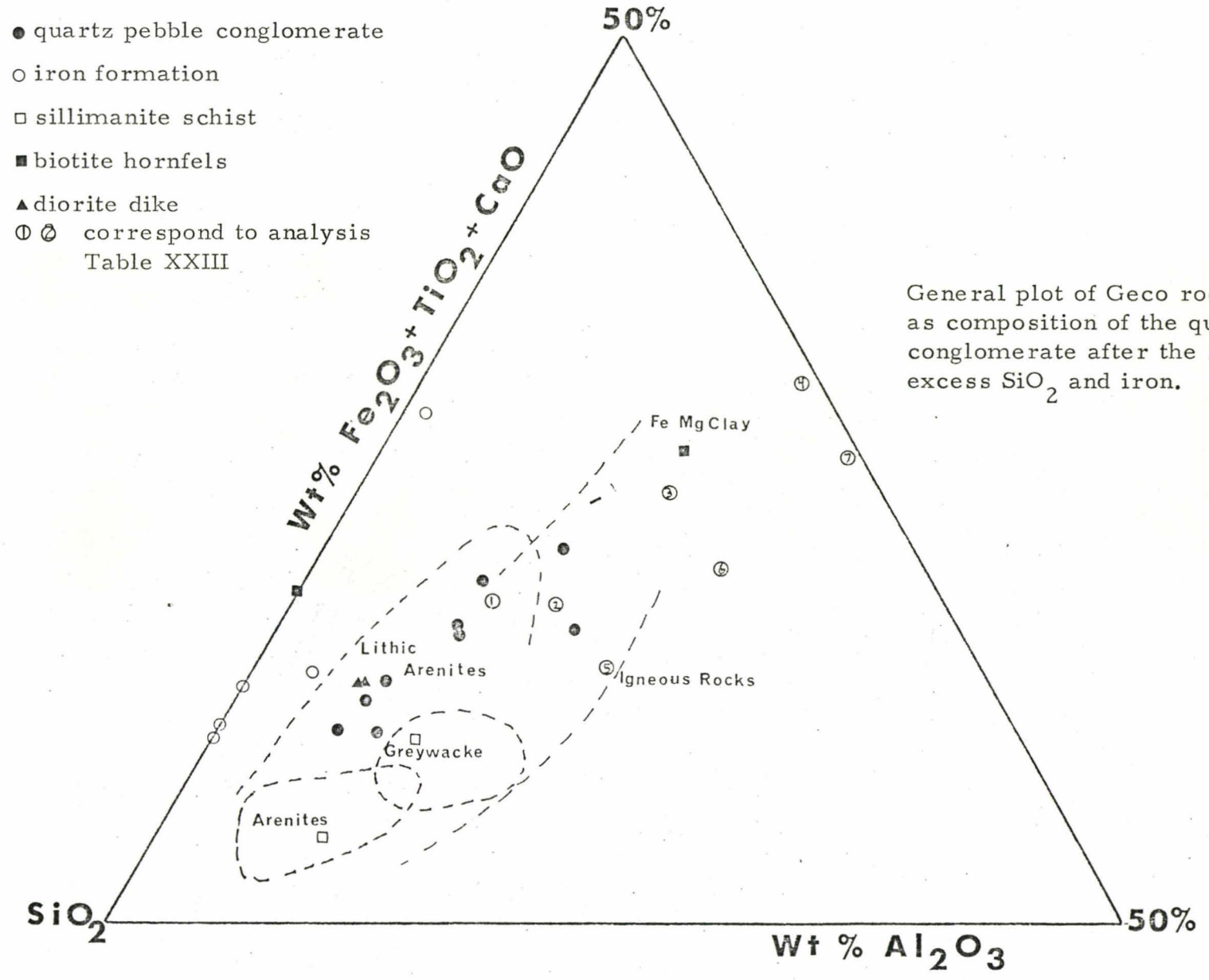


Figure No.12



- quartz pebble conglomerate
- iron formation
- sillimanite schist
- biotite hornfels
- ▲ diorite dike
- ① ② correspond to analysis Table XXIII

General plot of Geco rocks as well as composition of the quartz pebble conglomerate after the removal of excess SiO₂ and iron.

After de La Roche 1971

TABLE IX. Trace Element Analysis in ppm.

Number	Rb	Sr	Y	Zr	Nb	S	Ni	Cr	Co	Pb	Cu	Zn	As
FB1	84.0	53.5	159.2	126.8	21.2	14547	25.0	27	103	96	2067	444	0
FB2	46.0	19.1	107.7	359.4	32.8	1495	15.0	24	44	92	2973	992	0
FB3	76.1	64.0	174.6	172.5	31.1	10591	15.3	17	59	116	1431	8194	0
FB4	0.0	11.4	75.7	113.2	23.6	6884	20.2	16	71	16	1040	1269	0
FB4A	0.0	6.4	67.2	108.5	20.8	6642	19.8	9	71	15	10207	1263	0
FB7	15.7	39.9	68.2	98.2	26.6	12349	17.3	24	67	83	1892	645	0
FB9	0.0	26.6	5.8	17.4	6.4	4085	19.5	14	71	19	474	963	0
FB13	0.0	14.2	1.3	4.2	3.3	58837	56.1	58	387	19	15457	8131	0
FB14	5.4	51.7	75.7	107.8	25.6	9345	11.3	19	41	37	6273	1120	0
FB14A	6.0	53.0	75.1	114.1	22.8	9082	16.5	13	40	33	6241	1143	0
FB20	0.0	8.4	68.6	100.4	26.0	855	14.0	10	61	18	3283	134	0
FB24	0.0	20.4	0.0	19.0	7.3	6822	22.5	18	54	13	18	41	6
FB24A	0.0	11.7	0.0	15.0	4.3	6312	21.2	15	55	11	16	41	1
FB25	2.9	28.3	0.0	2.1	8.0	7197	16.6	22	119	5	22	57	0
FB33	4.0	11.3	47.6	127.5	26.3	341	18.8	23	77	10	19	336	0
FB36	23.9	46.5	64.1	135.3	32.8	727	16.4	26	51	11	32	75	0
FB41	5.2	50.6	24.9	82.2	15.0	12186	11.5	14	54	27	1608	331	0
FB57	7.3	35.3	35.1	74.0	12.7	23411	11.4	21	71	18	13495	2521	0
FB66	0.0	26.6	5.8	17.4	6.4	36476	24.9	22	94	6	59	88	0
FB70	19.2	77.1	28.1	93.7	14.2	5570	14.8	18	50	19	15	127	0

general trends were evident for the various elements present. The trace elements present fluctuated widely for a given rock unit as well as for the various rock types. The trace elements varied for example over a width of approximately two feet from 76.1 ppm Rb to 0.0 ppm Rb for a given unit. The apparent total random distribution of the trace element when compared with the overall homogeneity of the major elements for a given unit tends to suggest a sedimentary origin of the rocks.

iv) Discussion of Mineral Compositions

Samples of several powdered rocks which had been previously analyzed by XRF were investigated using a Phillips 300 Transmission Electron microscope and an Edax Energy Dispersive Microanalyzer. By this method the chemical composition of some of the minerals in the sections was arrived at. The accuracy of the results given in Table X, Table XI and Table XII are not known.

The cordierite analyzed shows an MgO:FeO modal ratio of about 1:1. This coincides closely with the average composition of cordierite as calculated by Deer et al. (1956). The MgO/FeO + MgO ratio of the average quartz pebble conglomerate is greater than .25. This indicates that cordierite is indeed the stable phase and that the chemically similar staurolite should be absent (Winkler 1976). Because staurolite is retrograde in the thin sections, it is likely that the magnesium was previously taken up by another mineral phase

TABLE X. Analysis of Sample FB1 by Use of Electron Microscope.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	S	Cl	Cr ₂ O ₃	Zn
Hornblende	49.90	11.87	16.55	9.05	9.38	.97	.32	--	--	.96	.71	.16	--	--
Gedrite	39.06	14.86	19.62	20.53	--	.22	5.70	--	--	--	--	--	--	--
Gedrite	42.00	15.42	22.67	14.20	--	--	5.70	--	--	--	--	--	--	--
Gedrite	37.17	11.74	35.67	13.81	.70	--	.75	.16	--	--	--	--	--	--
Gedrite	42.47	23.96	18.76	9.03	.00	--	5.08	--	--	--	.70	--	--	--
Chlorite	31.41	17.73	33.47	15.56	.19	.80	.84	--	--	--	--	--	--	--
Chlorite	29.43	15.92	32.25	17.22	--	--	.52	--	--	--	4.52	.09	--	--
Chlorite	35.13	17.24	29.35	15.39	--	.44	.35	--	--	--	--	.11	--	--
Chlorite	35.37	16.67	30.28	15.64	--	--	1.97	--	--	--	--	--	--	--
Pyrite	4.39	1.37	44.79	.93	--	--	.23	.01	--	.19	47.80	.15	.14	--
Sphalerite	10.29	6.40	11.54	4.69	--	--	.91	--	.05	.05	33.58	.26	--	32.23
Sphalerite	9.89	4.18	14.50	1.45	--	--	.15	.13	.05	.05	36.50	--	--	33.10
Sphalerite	7.71	3.36	11.45	.47	.14	--	1.04	--	.09	.07	40.89	.12	.17	34.49

TABLE XI. Analysis of Sample FB2 by Use of Electron Microscope.

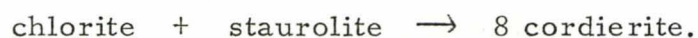
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MsO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	S	Cl	Cr ₂ O ₃
Biotite	39.56	14.44	23.48	13.03	--	.33	8.62	.28	--	--	--	--	.25
Biotite	39.70	14.53	21.75	13.02	.1	--	10.43	.10	.04	--	--	.17	.15
Chlorite	31.09	17.04	38.16	12.17	.09	.15	.03	.16	.45	.15	--	.20	.30
Chlorite	33.45	19.96	27.11	18.77	--	.21	.50	--	--	--	--	--	--
Sillimanite	36.81	57.65	2.81	1.72	--	--	1.01	--	--	--	--	--	--
Sillimanite	35.60	59.81	2.18	1.65	--	--	.36	--	.05	--	--	--	.34
Sillimanite	37.72	57.21	2.47	1.70	--	.12	.42	--	.06	--	.17	.03	.09
Sillimanite	42.58	50.40	3.84	1.72	--	--	1.38	--	--	.08	--	--	--
Sillimanite	36.72	49.02	8.56	2.64	.05	--	2.17	--	--	--	.34	.14	.36
Sillimanite	36.54	51.99	6.47	2.47	--	--	2.11	.11	--	--	.07	--	.25
Ilmenite	7.11	2.38	58.76	1.78	--	--	.73	26.53	2.59	--	--	.10	--
Pyrite	4.88	2.70	60.34	1.69	--	--	.47	.05	.22	.05	29.38	--	.21
Quartz	91.60	2.66	3.04	1.14	.08	--	1.05	.17	.02	.03	--	.13	.08

TABLE XII. Analysis of Sample FB4 by Use of Electron Microscope.

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	MnO	P ₂ O ₅	S	Cl	Cr ₂ O ₃
Cummingtonite	48.69	7.19	30.44	10.96	.38	1.80	--	.05	.03	.03	.25	.00	.16
Anthophyllite	53.56	2.12	24.49	18.24	.15	.23	--	.17	.00	.00	.03	.53	.48
Anthophyllite	55.49	3.04	22.98	18.23	.26	--	--	--	--	--	--	--	--
Anthophyllite	52.26	3.80	28.08	15.85	--	--	--	--	--	--	--	--	--
Gedrite	37.49	11.28	28.45	13.05	.29	.53	.04	--	.09	.03	2.41	.04	.16
Gedrite	40.74	9.95	32.22	14.02	.22	.10	--	--	--	--	2.56	--	.19
Gedrite	42.89	12.36	28.11	22.30	--	.29	--	--	--	--	--	--	.18
Gedrite	37.49	11.28	28.45	22.30	--	.29	--	--	--	--	--	--	.18
Cordierite	51.38	28.50	7.56	11.84	.02	--	--	--	.03	--	.26	--	.42
Cordierite	58.74	27.00	4.82	9.44	--	.95	--	--	--	--	--	--	--
Cordierite	50.90	29.63	8.25	10.27	--	.95	--	--	--	--	--	--	--
Cordierite	53.48	29.06	7.43	8.45	--	--	--	--	--	--	--	.79	.79
Cordierite	53.55	28.03	9.96	7.68	--	--	--	--	--	--	--	--	--
Cordierite	50.76	25.25	12.40	10.89	--	.17	--	.01	.21	--	--	--	.11
Cordierite	52.00	26.58	10.93	10.32	--	--	.07	--	.07	--	.04	--	--
Cordierite	51.37	28.55	9.60	10.47	--	--	--	--	--	--	--	--	--
Pyrophyllite	72.22	24.40	2.17	--	--	1.17	.04	--	--	--	--	--	--
Magnetite	2.36	.23	96.89	.52	--	--	--	--	--	--	--	--	--
Quartz	98.92	.96	.12	--	--	--	--	--	--	--	--	--	--

which subsequently broke down after the initial formation of staurolite.

It is probable that magnesium rich chlorite or biotite which in the absence of muscovite, is stable into the stability field of staurolite, broke down to form the reaction:



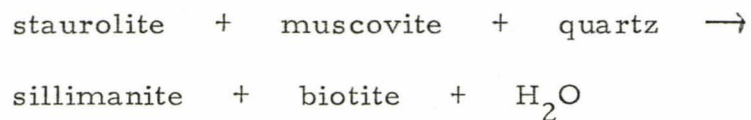
The various amphiboles present were found to have similar MgO:FeO ratios. The gedrite is apparently much more aluminous however and has an approximate MgO:FeO ratio of 3:4. The anthophyllite has a very low Al_2O_3 content and has an MgO:FeO ratio of 4:3. The cummingtonite present is quite rich in MgO and has an MgO:FeO ratio of 2:1.

The biotite has a high MgO content and has an MgO:FeO ratio of 1:1. It is, therefore, approaching phlogopite in composition. Significant amounts of biotite are being altered to chlorite. The chlorite present has an MgO:FeO ratio similar to that of biotite. Since chlorite is often seen polymorphing biotite the reaction occurring is:



Some of this K_2O may be absorbed by the amphiboles. The gedrite, in particular, is quite K_2O rich. The chlorite present most closely resembles pycnochlorite or rodingite.

The sillimanite present in sillimanite gneisses contains minor iron and magnesium. It is commonly associated with biotite. Its formation is believed to be the result of the reaction:



The presence of small quantities of remnant staurolite in the sections suggests that all of the muscovite and most of the staurolite has been used up.

Using the compositions as calculated by the use of the electron microscope, the positions of the various minerals were plotted on an AFM diagram (Fig. XIII).

It becomes readily apparent that it is not possible to draw simple tie lines from the various minerals to explain their origin. What this largely seems to be is a series of mineral assemblages in disequilibrium. What may in fact be happening is that there are two discrete mineral assemblages mixing.

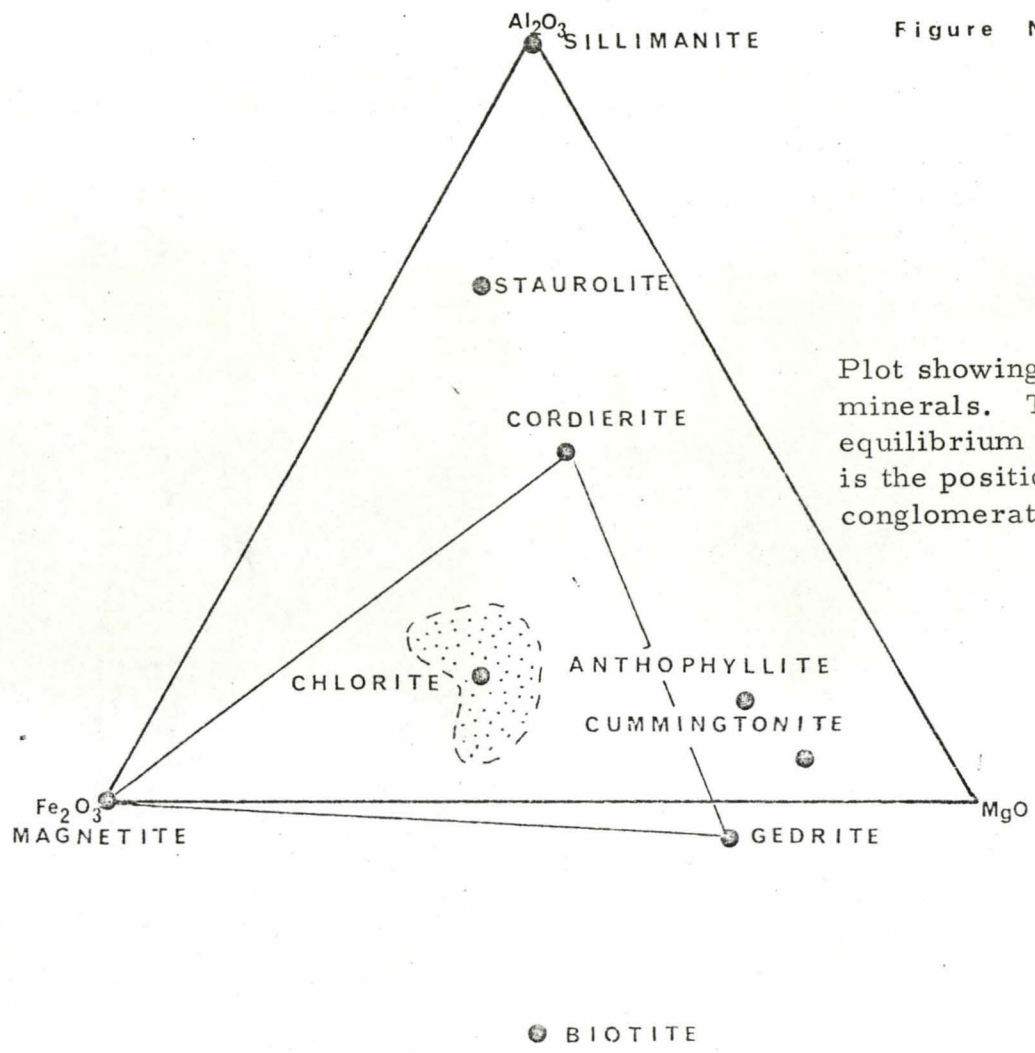


Figure No. 13

Plot showing the positions of various minerals. The lines indicate possible equilibrium assemblage. Stipled area is the position of the quartz pebble conglomerate.

CHAPTER VII

PARAGENESIS OF THE QUARTZ PEBBLE CONGLOMERATE

Two factors must be taken in account in order to arrive at a protolith for the quartz pebble conglomerate. The usual bulk composition must be explained as must a possible origin for the "pebbles".

Cordierite gedrite/anthophyllite rocks have attracted the attention of many geologists for several reasons. Firstly, they are often associated with sulphide ore bodies (Lal et al., 1975). Secondly, the most diagnostic feature of the rock is its unique chemical composition. They are characteristically richer in MgO, FeO and poorer in CaO, K₂O and Na₂O as compared to their assumed parents.

There have been many theories forwarded to explain this apparent chemical change. Classically cordierite anthophyllite assemblages have been identified as the product of metasomatism. The well known anthophyllite cordierite bearing gneisses of the Orijarvi region of Finland were first investigated by Eskola (1914-1915) and were considered to be the products of metasomatic introduction of magnesium and iron from granodiorite magma and acid volcanic rocks.

Other proponents (Grant 1968, Lal and Moorehouse 1969) suggest that the rocks produced are simply the product of a high grade

metamorphism. It is suggested that common sedimentary and igneous rocks undergo partial anatexis and the granitic components are squeezed out leaving the anthophyllite cordierite gneiss as a solid residue. Pegmatites and aplites associated with the gneisses may represent a part of this granitic fluid.

Vallence (1967) has suggested that the weathering of a basalt will produce the desired mineral assemblage since a mixture of aluminous chlorite and silica will produce a cordierite and anthophyllite assemblage. Vallence noted that because cordierite and anthophyllite can form in zones of metamorphism provided the initial composition was correct he reasoned that the leaching and diagenesis of mafic volcanics may produce such an initial composition. During regional metamorphism this would produce lenses and pods of cordierite/anthophyllite rock within a larger unit.

Metamorphic differentiation brought about by shearing and hydrothermal alteration associated with certain types of ore bodies and strong folding have been suggested by Vallence (1967). Altered rock of this type are said to undergo an almost complete loss of lime and alkalies. This gives rise to a quartz-chlorite rock which on metamorphism is changed to a cordierite-anthophyllite assemblage.

Tilly (1937) has shown that remarkably divergent rocks will produce similar assemblages upon metamorphism. While one of the rock units investigated by him was felt to be a metasomatized

basic igneous rock a similar assemblage was produced by regional metamorphism of argillareous sediments.

The concept of metasomatism has been advanced for some of the Manitouwadge rocks. The hornfels group which is very close stratigraphically to the quartz pebble conglomerate is felt by Watson (1970) to be the product of iron and magnesium metasomatism. These rocks have been described in Chapter I.

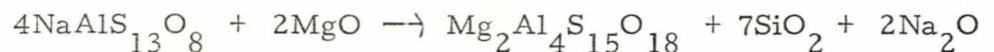
Anthophyllite rich gneisses at Geco on the other hand are felt by Watson (1970) to be the result of isochemical regional metamorphism. Metasomatism is known to occur in the foot wall of massive sulphide deposits but is not generally common along a definite stratigraphic horizon (Hutchinson personal communication) although the Sheridan Mine in Manitoba is known to contain such a horizon. What has been known to happen, however, is that an alteration pipe associated with the massive sulphides originally perpendicular to the stratigraphy has undergone extensive shearing to produce a unit which appears to be conformable (Sangster 1977).

It is, therefore, necessary to look at the various models present for the formation of cordierite anthophyllite rocks and decide which one, if any, is relevant to the quartz pebble conglomerate.

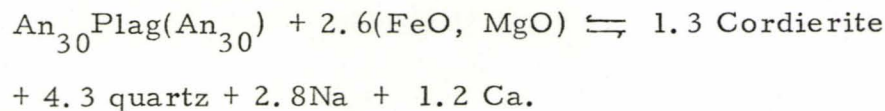
The Geco Mine series has been extensively folded and probably has undergone extensive shearing as well. Many of the thin sections studied exhibit shearing, particularly around the pebbles

along which sulphides have been injected or remobilized. The nature of this shearing, which has created a partial mortar like texture with some sutured intergrowths indicates that this took place at a relatively high temperature and pressure. The 4/2 ore zone is found directly beneath the quartz pebble conglomerate and the unit may actually be a hydrothermally altered zone. The quartz pebble conglomerate and the ore both form a definite stratigraphic unit and recent work suggests that this is a stratiform, stratiband ore body. Therefore, it seems likely that the composition of the unit is not a direct consequence of the 4/2 ore zone (i. e. , the fluids which produced the ore zone did not leach the overlying strata).

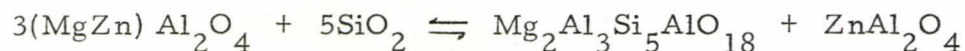
Differential anatexis as suggested by Grant (1968) is a possible and viable mechanism by which the alkalis could be removed. The presence at Geco of large amounts of pegmatite and "granites", which are in fact as a rule compositionally equivalent to granodiorites, and the occasional myrmekitic intergrowths of quartz and cordierite suggest partial melting. The pegmatites were briefly studied by this writer and there appears to be no direct simple correlation between the rock type and the composition of the pegmatites. The myrmekitic intergrowths are in at least part due to the general reaction:



or more precisely for the plagioclase:



While this is suggestive of anatexis this is not necessarily the case and merely implies a very active intergranular fluid phase. The spinel present also displays a quartz cordierite intergrowth. While the reaction has not been studied it is possible that the magnesium and zinc components of the solid solution gahnite are undergoing the reaction:



The presence of the gahnite is important for two other reasons as well. The presence of the zinc rich spinel indicates that primary zinc was probably present from the original depositional environment. The fact that gahnite is forming at the expense of sphalerite is suggestive that this is a primary mineral as well and that sphalerite was already present when elevated temperatures due to high rank metamorphism occurred allowing this reaction to occur (Suffel 1972). The poikiloblastic texture associated with the cordierite gahnite suggests that partial melting may have occurred probably during the Kenoran orogeny (i. e. , prior to the supposed injection of the ore fluids). This necessitates that the ore body was in place prior to

metamorphism. This does not, of course, indicate that the ore solutions were either hydrothermal or exhalative but it does tend to indicate that they are not epigenetic in the sense of the word indicating formation post consolidation.

The overall presence of gahnite is suggestive of a quartz deficient environment since the spinel should break down as per the equation. It is obvious that this has only partially occurred. This tends to suggest that quartz was not an original constituent in the mafic layers. This indicates that the quartz pebbles and matrix at one time were discrete units.

While there is some evidence for the presence of fluids and the partial melting of the quartz pebble conglomerate the overall high silica content suggests that this is not a granitic residue.

A cordierite anthophyllite assemblage brought about by the partial weathering of a basic rock is an unlikely method of formation. If we look at the overall sequences of the rock units at Geco it is evident that the region would classically be defined as deep water and deep water weathering mechanisms are insufficient to produce the rock type desired. The various processes which produced the iron formation are not known either but it is felt to probably have originally been a cherty layer. Noting that special conditions (in particular low oxygen content) are generally believed to be necessary to produce iron formations then the condition present to produce the magnetite

rich quartz pebble conglomerate were probably similar.

In general, the overall abundance of cordierite and anthophyllite throughout the mine sequence and the stratigraphic continuity of many of these units suggests that the composition of most of these rocks is original. There is little reason to suppose otherwise for the quartz pebble conglomerate. This is particularly true if as evidence within this unit suggests the ores were present prior to metamorphism.

If as has been suggested that the matrix and the pebbles are in fact discrete units then an origin for the quartz must be proposed.

It is possible that the pebbles are terrigenous derived pebbles and in fact a true conglomerate. This would be similar to the conglomerate unit proposed in Hutchinson's mode (1971) of massive sulphide genesis. The pebbles are totally quartz, however, and a source rock similar to those of Elliot Lake pebble conglomerate would be necessary. The angularity of the quartz pebble and the mafic nature of the matrix does not allow this to be a viable mechanism. The overall rod-like to disc-like shape of the pebbles suggest that their origin is in fact related to past depositional phenomena.

Due to the high level of metamorphism and the shearing evident in thin section, it is possible that these clasts are of a metamorphic/structural nature. If a cherty layer was compressed and underwent stretching as a result of direction of stress relief then augen or boudinage textures might develop (Hutchinson personal

communication). A fragmented or pyroclastic sediment often found above major ore horizons is another possible source. The large size and the presence of only quartz clasts would suggest that this is improbable. A soft sediment slump prior to consolidation might also produce a similar texture as is seen in hand specimen.

Thin sectional evidence, however, indicates that the unit has undergone high stress. While the center of the clasts are often composed of massive quartz, the boundaries of the pebbles are often extensively fractured and show a mortar texture. The large quartz grains show a high degree of undulatory extinction and are composed of a mosaic of sutured smaller grains. Opaques are often injected/remobilized in and around the sheared quartz pebbles. The anthophyllite and sphalerite in thin section also display a weak pinch and swell type structure. This suggests that the quartz pebbles are in fact a sheared and boudinaged quartz or chert horizon. This appears to be likely.

The main ore body itself is often boudinaged and undergoes extensive pinch and swell (Friesen 1978). Evidence which Sangster et al. (1977) feels "demands" boudinage in the Geco sequence is as follows. The massive ore occurs in a single continuous stratigraphic horizon. The pinch and swell of the ore body occurs both along strike and down dip. The necking of the ore is very abrupt and a 10 meter

wide zone of ore observed by Sangster pinched down to 2 cm over a distance of 20 meters. The pyrite grains often have a cataclastic texture in the "neck" zones and the relatively more mobile chalcopyrite is also concentrated here. The muscovite schist with in which the ore occurs shows a schistosity paralleling that of the ore contact and it also increases in thickness relative to the ore in the pinched zones. The schist in the pinch zones is characterized by small folds which have crenulations in two directions. This is felt by Sangster (1977) to be indicative of flow. The sericite schist was also investigated by this writer and what appears to faintly be suggestive of boudinage is found in the quartz rich layers.

The quartz pebble conglomerate as well does not always show its classic texture. Often the pebbles are exceedingly long with a length to width ratio of greater than ten. While such deformation of an original quartz pebble is possible, field evidence suggests that the quartz pebbles are in fact a boudinaged quartz layer or bed.

The probability that the quartz pebble conglomerate was in fact originally composed of two distinct separate layers must be considered when arriving at a possible protolith. For this reason calculations were made to negate the affect that quartz has on the bulk composition. Furthermore, assuming the quartz rich layers were similar to the iron formation in bulk composition it is possible to negate part of the iron content of the rocks. These results were then

plotted on diagrams directly affected by the loss of quartz and/or iron (Table XIII).

The simple removal of silica from the rock does not change the position of the plot for the majority of the diagrams. Removing silica from the SiO_2 , Al_2O_3 , Fe_2O_3 plot repositioned the rocks so as to have an original protolith of an iron magnesium clay or possibly a basaltic igneous rock. Changing the iron content of the quartz pebble conglomerate would reposition many of the diagrams and in effect move them directly away from the FeO corner. In the case of the ACF diagram this moves the position of the matrix of the quartz pebble conglomerate to that consisting of shales. The removal of the iron also results in the relocation of the position of quartz pebble conglomerate in the weathering field of basalts as proposed by Vallence (1967). The similarities of the matrix to that of ferruginous slates and shales becomes much more distinct as well.

The chlorite which is largely, if not all, retrograde was analyzed. It is interesting to note that this chlorite is remarkably similar in composition to that of the quartz pebble conglomerate and plots in approximately the same position on an AFM diagram. While this chlorite is retrograde it is strongly suggestive that the original mineral present may have been a chlorite as well.

The source of the excess silica must be explained. It is in all probability a cherty horizon. This does not of course say what

TABLE XIII. Composition of Quartz Pebble Conglomerate
After Removal of Quartz and Iron.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
SiO ₂	66.34	51.46	44.63	34.61	57.11	49.59	38.46
Al ₂ O ₃	8.99	13.03	14.98	17.29	14.47	16.64	19.21
Fe ₂ O ₃	15.28	22.14	25.47	29.38	12.14	15.47	19.38
MgO	5.38	7.80	8.97	10.35	8.66	9.97	11.50
CaO	0.40	0.67	0.77	0.88	0.74	0.85	.98
Na ₂ O	0.44	0.64	0.73	0.85	0.71	0.81	.94
K ₂ O	0.68	0.98	1.13	1.31	1.18	1.25	1.46
TiO ₂	0.15	0.22	0.25	0.29	0.24	0.28	0.32
MnO	0.15	0.22	0.25	0.29	0.24	0.28	0.32
P ₂ O ₅	2.16	3.13	3.60	4.15	3.47	4.00	4.61

1. Analysis of average quartz pebble conglomerate
2. Analysis after 35% of modal quartz removed
3. Analysis after 45% of modal quartz removed
4. Analysis after 55% of modal quartz removed
5. Analysis after 35% of modal quartz and 10% Fe₂O₃ removed
6. Analysis after 45% of modal quartz and 10% Fe₂O₃ removed
7. Analysis after 55% of modal quartz and 10% Fe₂O₃ removed.

type of chert or its source.

Ore rich brines as a rule have a high pH and are capable of dissolving large amounts of silica. It is possible that the chert has a volcanic exhalative origin similar to that proposed for the ore itself.

As the silica rich solution moved away from the vent the oxygen fugacity and temperature decreased causing the sea water to become supersaturated with respect to silica and iron. As a result an iron rich chert precipitated. The iron may have been in the form of pyrite or magnetite. It is possible to precipitate pyrite directly because of a high SO_4 content due to a relatively low oxygen fugacity (Large 1977). It is probable that the brine carrying the silica and iron also carried with it the copper and zinc present in the samples.

CHAPTER VIII
MODEL FOR THE FORMATION OF THE
QUARTZ PEBBLE CONGLOMERATE

The exhalation of ore brines and volcanogenic iron formation is believed to occur during a hiatus of volcanism. At this time, therefore, there is relatively little accumulation of volcanic material. Erosion of the volcanic beds would occur and as a result volcanogenic sediments would dominate. In the deeper areas of the basin it is possible that iron and magnesium rich clays and shales of a volcanic origin would accumulate. Occasional pulses of a volcanogenic exhalative would result in the burial of these sediments under an iron rich siliceous chemical precipitation. If these pulses were large enough or became trapped in basins, distinct quartz rich layers would build up which would alternate with the sedimentary shale. These pulses would include the ore fluids.

Subsequent to this, post depositional movement probably after lithification, would result in the shearing and boudinaging of the quartz layers giving them an elongate "pebble" like appearance.

CHAPTER IX
DETERMINING THE METAMORPHIC GRADE

In order to determine metamorphic grade it is important to know the minerals that are producing the reaction as well as the minerals present. Assumptions must also be made. The first of these is the assumption that unless a mineral shows a distinct reaction rim then it is in equilibrium with the other minerals present whether or not it actually touches them. This has been the practice in the past but Winkler (1976) states

"It must now be ascertained which of the minerals in a thin section are in contact. Only minerals in contact may be regarded as an assemblage of co-existing minerals i. e. , a paragenesis".

Several factors to consider are whether the stability of various minerals as predicted by previous workers is applicable to Geco mines. Chlorite for instance in the absence of muscovite will persist into medium grade rocks (Winkler 1976). Similarly, staurolite in the absence of muscovite is stable into high grade pelitic rocks. Staurolite is also affected by the magnesium content of chlorite in the rocks. At present the magnesium content is generally too high to allow staurolite to be stable. Therefore, the breakdown of the staurolite can be interpreted in two ways. The staurolite may be breaking down as a result of its stability in terms of pressure and temperature being

surpassed. It can also be argued that its stability in terms of composition (i. e. , magnesium content) has been surpassed.

Almandine garnet is a common constituent elsewhere but no garnet in these thin section studies showed up except in the iron formation. This suggests that a lower pressure of formation of the cordierite has occurred when compared to its total stability field (Winkler pg. 230 1976). This plots in the vicinity of 5.5 kb pressure and 580°C on the pressure-temperature diagram after Hietenan (1967). The minimum pressure temperature conditions for the formation of sillimanite from Winkler (1976) indicate a considerably higher temperature. From this data the temperature is probably in the neighbourhood of 650°C.

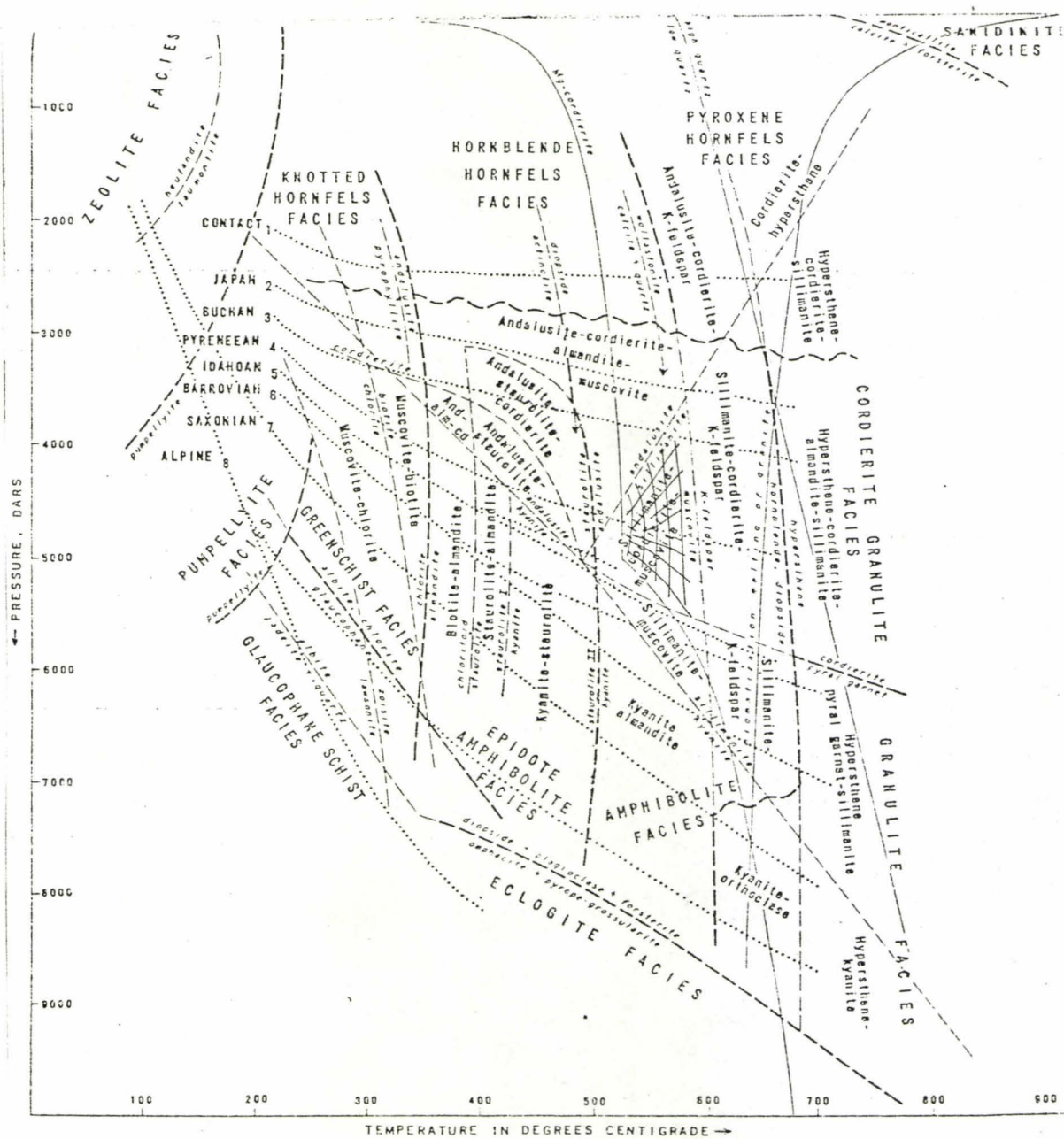
Because of this variation in P-T diagrams an attempt was made to arrive at the pressure conditions using the composition of cordierite and anthophyllite. Both minerals have magnesium and iron end members. The composition of the mineral is dependent on a combination of temperature and pressure. For a given Fe-Mg composition, a pressure temperature curve can be arrived at. The method is outlined in the Appendix. The lack of the data for the iron end members of cordierite and anthophyllite prevented successful calculation of temperature and pressure. These calculations can be done for other (MgFe) minerals as well, including almandine garnet.

While garnet occurs in the iron formation, cordierite is lacking and, therefore, this calculation could not be applied to any of the thesis rocks since garnet was not found in the quartz pebble conglomerate.

The gedrite cordierite gneiss of the Manitouwadge area was investigated by D. Aldrick (1972). This unit was found to contain garnets and microprobe analysis of the cordierite and garnet present were made. The cordierite is somewhat more magnesium rich and has an average $MgO/MgO + FeO$ ratio of .62 as compared to a ratio of .41 for the quartz pebble conglomerate. This is to be expected. The rocks analyzed by Aldrick were stratigraphically below the quartz pebble conglomerate (assuming an anticline). This would suggest a somewhat higher P-T conditions of formation as evidenced by the more magnesium rich cordierite. The garnet present have an average ratio of .109. This can be applied in a similar way to that described in the Appendix for anthophyllite and is described in greater detail by Froese (1976).

The equations have been established in forms of a graph by Hensen et al. (1972). From the graph P-T conditions may be read. Assuming that regional metamorphism is the controlling factor and that it is fairly constant then an approximate pressure and temperature for the area is in the neighbourhood of 5.2 kb and approximately 600°C.

FIGURE 14



After Hietanen (1967)

Estimate of P-T Conditions at Geco Mine.

This agrees closely with the temperature and pressure estimates using data from Winkler (1976) and Hietanen (1967) (Fig. XIV). It is possible that the P-T conditions for the quartz pebble conglomerate may be somewhat lower due to the lower magnesium content in the cordierite.

CHAPTER X

SUMMARY AND CONCLUSIONS

The quartz pebble conglomerate which overlies the 4/2 ore zone at Geco Mines is in fact composed of two discrete rock types which have vastly different protoliths. The pebbles are a sheared and boudinaged quartz rich layer which in all probability contained significant iron. This unit was originally a chemically precipitated ferruginous chert associated with the volcanism which produced the ore bodies. Both the ore and this chert (iron formation) are the product of volcanic exhalatives on the sea floor.

The matrix was probably originally an iron and magnesium rich shale or clay. It is the product of the weathering and erosion of what may be interpreted as basaltic volcanics. The source of these volcanics is not known but may form part of the base of volcanic pile which produced the ore. These sediments were probably produced throughout much of the entire sequence but the rate of deposition of felsic volcanics masked this.

During the hiatus of volcanic activity, however, sufficient accumulations built up to form discrete beds. It is also during the hiatus that ore brines and iron formations are classically formed. This shows that the formation of the ore body was cyclic during which

periods of sedimentation from other sources may have occurred.

Various concepts involving metasomatism have been investigated and while this study does not prove conclusively that metasomatism did not take place, it does show that it is not needed to explain the phenonema observed. While such metasomatic zones have been described as being due to the hydrothermal injection of ore bearing fluids, this apparent lack of metasomatism indicates that we may be looking at a hydrothermal exhalative model.

Furthermore, the deposition of clays and shale which form the matrix of the quartz pebble conglomerate suggests that this is a relatively deep water environment. This suggests that the truly metasomatized vents which produced this ore body have not yet been found and were in fact deposited in a much shallower environment. Because the Geco ore body is overturned these alteration pipes may have been eroded away. It is possible that in the future a reinvestigation of felsic volcanic rocks, in the vicinity of the mine as a possible source of exhalative brines which produced the ore body, is needed.

APPENDIX A

Analytical Methods

Whole rock and trace element analysis of various rock types were obtained using X-ray fluorescence. Seventeen samples were selected as representative phases. The total width of the quartz pebble conglomerate was sampled as were other rock types which were felt might be related stratigraphically or chemically to the unit.

The samples were crushed to -200 mesh using a Spex Industries shatter box with tungsten carbide rings. Using the methods outlined by Mudroch (1978) pellets for major and minor element analysis were made. Generally fused glass discs are used for major element analysis. However, due to what was believed to be high sulphur content (O. Mudroch personal communication) the "glass" tended to stick to the platinum crucibles and shattered on pouring. For this reason powder pellets were used for both major and minor elements. These were analyzed on a Philips Model 1450 AMP automatic sequential spectrometer housed in the Geology Department at McMaster University.

The major elements analyzed for were: Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn and P. They were normalized to 100 weight percent with total Fe expressed as Fe_2O_3 oxide. A Cr X-ray tube was used.

The trace elements Ni, Rb, Sr, Nb, Yb and Zr were also analyzed for using a Cr X-ray tube. The trace elements Cu, Zn, As, Pb, Co, Cr, S were analyzed for using a Hg X-ray tube. All results were expressed in ppm.

For calculations involving FeO, the total Fe content was separated into Fe_2O_3 and FeO components based in Irvine and Barangar's (1971) correction:

$$\text{Wt\% Fe}_2\text{O}_3 = \text{Wt\% TiO}_2 + 1.5.$$

The error involved in using this calculation is not known particularly due to the high sulphur content of the rocks. Corrections for sulphides were made for diagrams involving FeO where ever possible after accounting for copper and zinc.

Three samples FB4, FB14, FB24 were each run twice to check reproducibility of the results. Standards were also run as unknowns to check for accuracy.

Discriminating Function for Origin of Quartz Pebble

Conglomerate (after Shaw 1971)

$$\begin{aligned} \text{Discriminating Function} = & 10.44 - 0.21 \text{SiO}_2 - 0.32 \text{Fe}_2\text{O}_3 \\ & - 0.98 \text{MgO} + .44 \text{CaO} + 1.46 \text{Na}_2\text{O} + 0.54 \text{K}_2\text{O}. \end{aligned}$$

This function is applicable only to rocks which have the following features:

$$\begin{aligned} 50\% < \text{SiO}_2 < 80\% \\ 10\% < \text{Al}_2\text{O}_3 < 19\% \\ \text{MgO} < 6.0\% \\ \text{CaO} < 6.0\% \\ \text{Na}_2\text{O} < 6.5\% \\ \text{K}_2\text{O} < 7.3\% \\ \text{P}_2\text{O}_5 < 2\% \\ \text{CO}_2 < 5\% \\ \text{Larsen index} > 0.0 \end{aligned}$$

This function was applied to the quartz pebble conglomerate analysis:

$$\text{FB3} = -9.687$$

$$\text{FB4} = -13.042$$

FB4 = -13.021

FB7 = -11.254

FB9 = -17.389

FB20 = -13.049

FB33 = -12.415

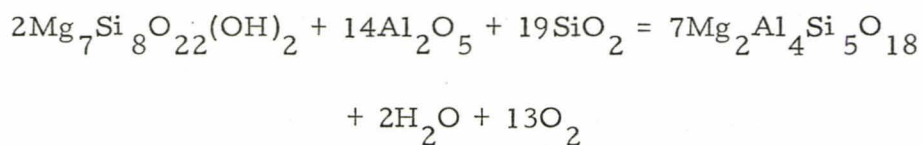
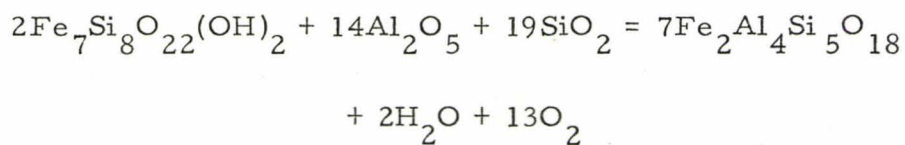
FB41 = -9.259

FB57 = -14.356

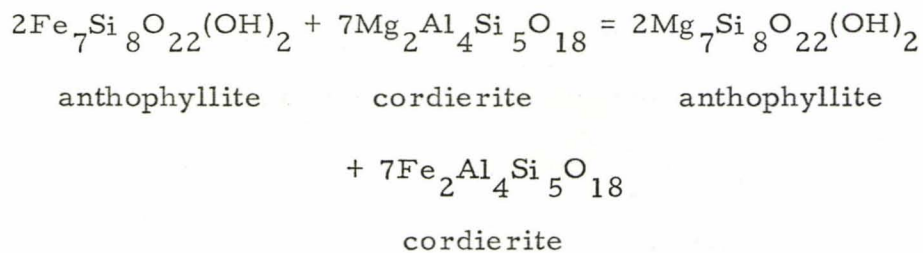
A negative value is indicative of a sedimentary origin. A positive value indicates an igneous origin.

A Possible Method to Estimate P-T Conditions of the
Quartz Pebble Conglomerate

A solid solid reaction occurs for cordierite-anthophyllite in which Mg and Fe are exchanged. This may be represented by the following equations:



subtracting the two equations gives:



An equilibrium constant can be set up:

$$K = \frac{\left[\begin{array}{c} \text{cordierite} \\ A_{\text{Fe}_2\text{Al}_4\text{Si}_5\text{O}_{18}} \end{array} \right]^7 \left[\begin{array}{c} \text{anthophyllite} \\ A_{\text{Mg}_7\text{Si}_8\text{O}_{22}(\text{OH})_2} \end{array} \right]^2}{\left[\begin{array}{c} \text{cordierite} \\ A_{\text{Fe}_2\text{Al}_4\text{Si}_5\text{O}_{18}} \end{array} \right]^7 \left[\begin{array}{c} \text{anthophyllite} \\ A_{\text{Fe}_7\text{Si}_8\text{O}_{22}(\text{OH})_2} \end{array} \right]^2}$$

Assuming ideal ionic solutions:

$$A_{\text{Fe}_7\text{Si}_8\text{O}_{22}(\text{OH})_2}^{\text{anthophyllite}} = \left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]^7 \left[\frac{\text{Si}}{\text{Si} + \text{Al}} \right]^8$$

$$A_{\text{Fe}_2\text{Al}_4\text{Si}_5\text{O}_{18}}^{\text{cordierite}} = \left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]^2$$

Similar reactions can be written for the Mg end members.

Therefore:

$$K = \frac{\left[\left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]^2 \right]^7 \left[\left[\frac{\text{Mg}^7}{\text{Fe} + \text{Mg}} \right]^7 \right]^2 \left[\frac{\text{Si}}{\text{Si} + \text{Al}} \right]^8}{\left[\left[\frac{\text{Mg}}{\text{Fe} + \text{Mg}} \right]^2 \right]^7 \left[\left[\frac{\text{Fe}^7}{\text{Fe} + \text{Mg}} \right]^7 \right]^2 \left[\frac{\text{Si}}{\text{Si} + \text{Al}} \right]^8}$$

$$K = \frac{\left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]_{\text{anth.}}^{14} \left[\frac{\text{Mg}}{\text{Fe} + \text{Mg}} \right]_{\text{cord.}}^{14}}{\left[\frac{\text{Mg}}{\text{Fe} + \text{Mg}} \right]_{\text{anth.}}^{14} \left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]_{\text{cord.}}^{14}}$$

$$KD = K^{1/14} = \frac{\left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]_{\text{anth.}} \left[\frac{\text{Mg}}{\text{Fe} + \text{Mg}} \right]_{\text{cord.}}}{\left[\frac{\text{Mg}}{\text{Fe} + \text{Mg}} \right]_{\text{anth.}} \left[\frac{\text{Fe}}{\text{Fe} + \text{Mg}} \right]_{\text{cord.}}}$$

This value can be calculated from data in Table V-Table VII:

$$KD = \frac{\left[\frac{24.49}{24.49 + 18.24} \right] \left[\frac{11.84}{7.56 + 11.84} \right]}{\left[\frac{18.24}{24.49 + 18.24} \right] \left[\frac{7.56}{7.56 + 11.84} \right]} = 2.102$$

A series of values can be calculated but

$$\Delta G^{\circ} = \Delta H - T\Delta S = -\Delta V(P-1)$$

$$\Delta G^{\circ} = -14RT \ln KD - \Delta V(P-1)$$

At the present time values of G for the Mg end members of cordierite and anthophyllite only are known. However when data for the Fe end members becomes available a value for ΔG^0 can be calculated. ΔV can be readily calculated and therefore a curve of P-T conditions can be arrived at.

APPENDIX B

West wall East wall

Figure No.15

34-73 Crosscut
After Mine
Plans

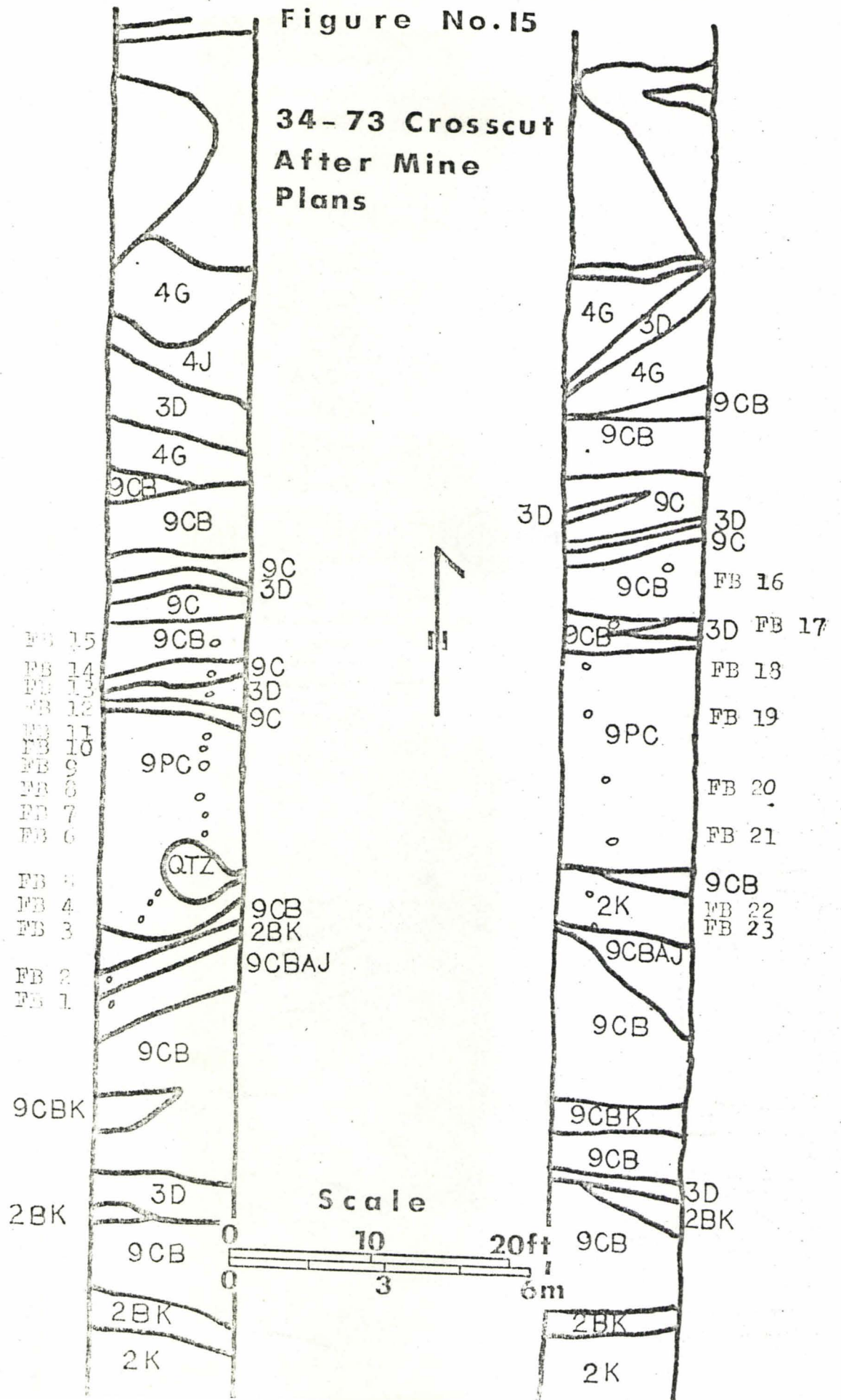
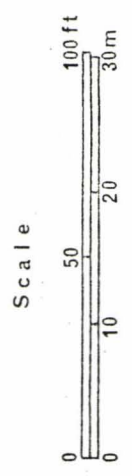
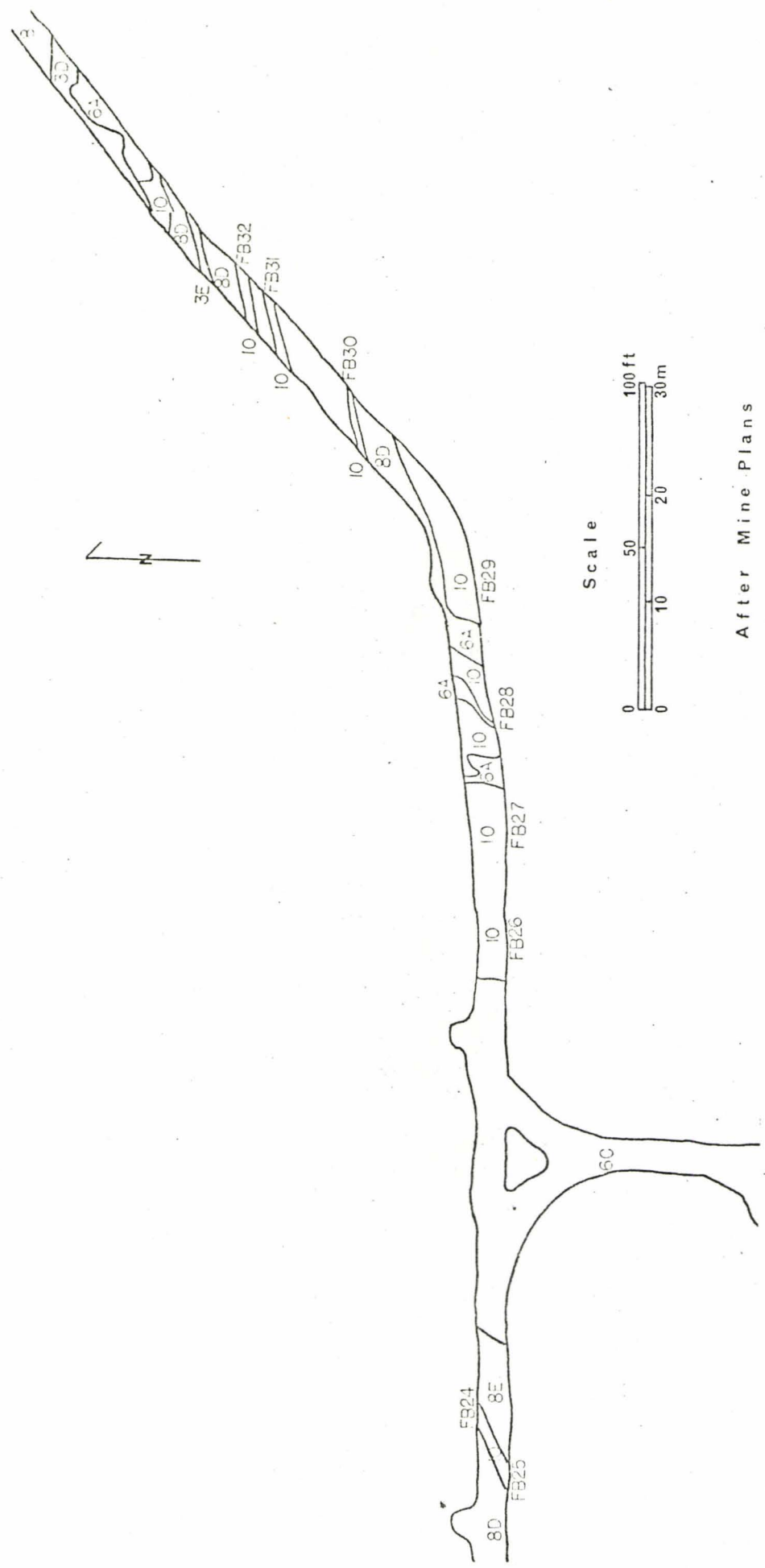


Figure No.16



After Mine Plans

Figure No.17

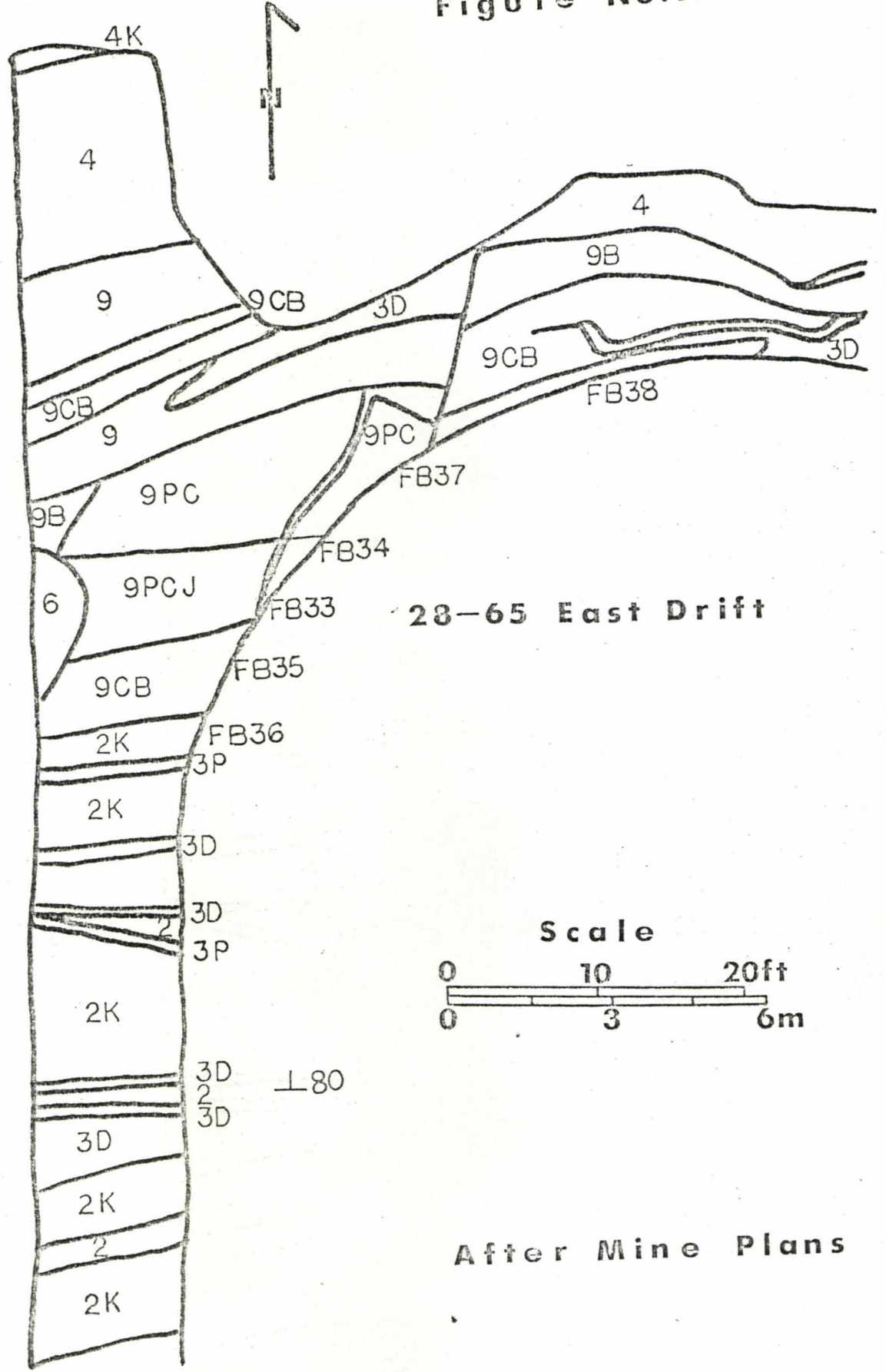
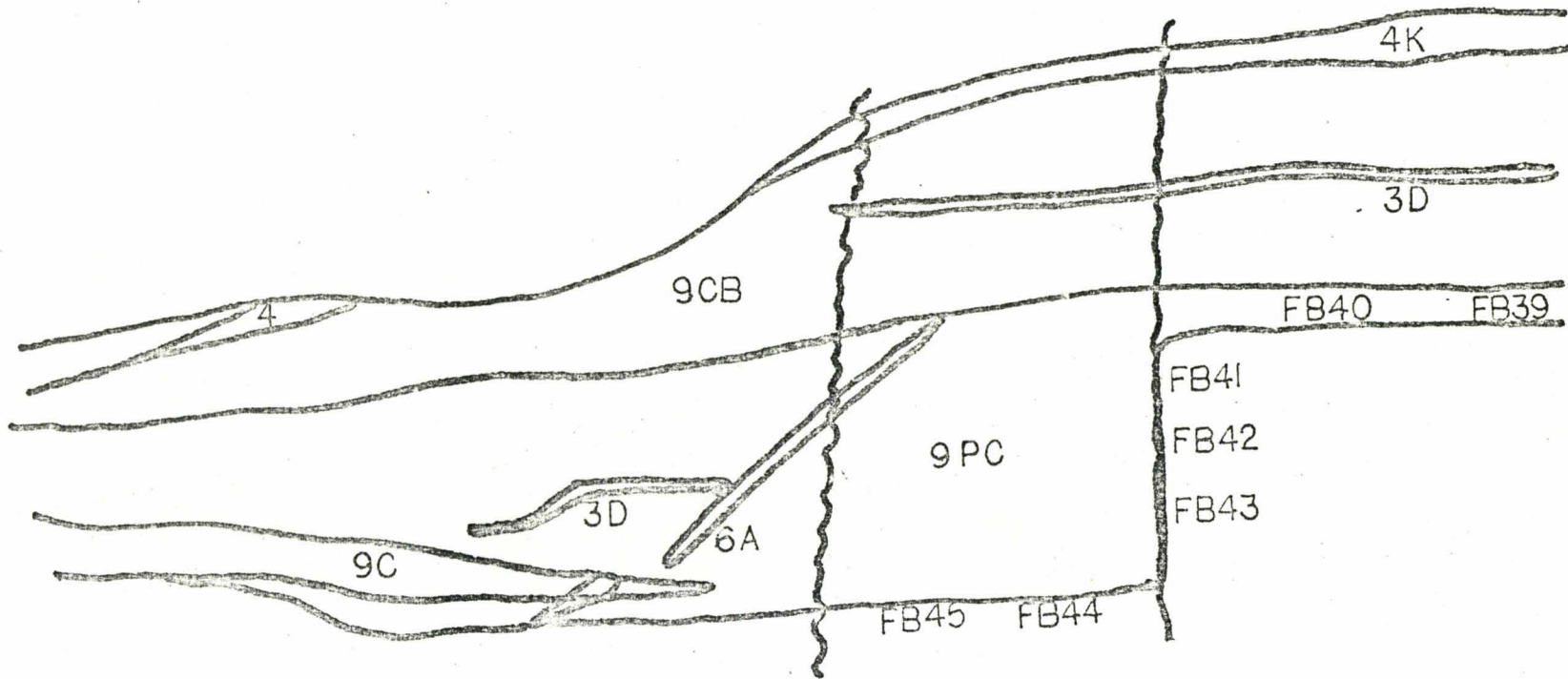
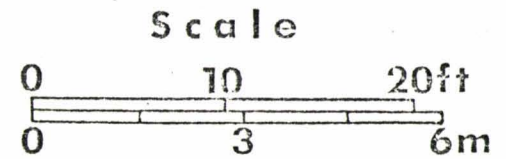


Figure No.18

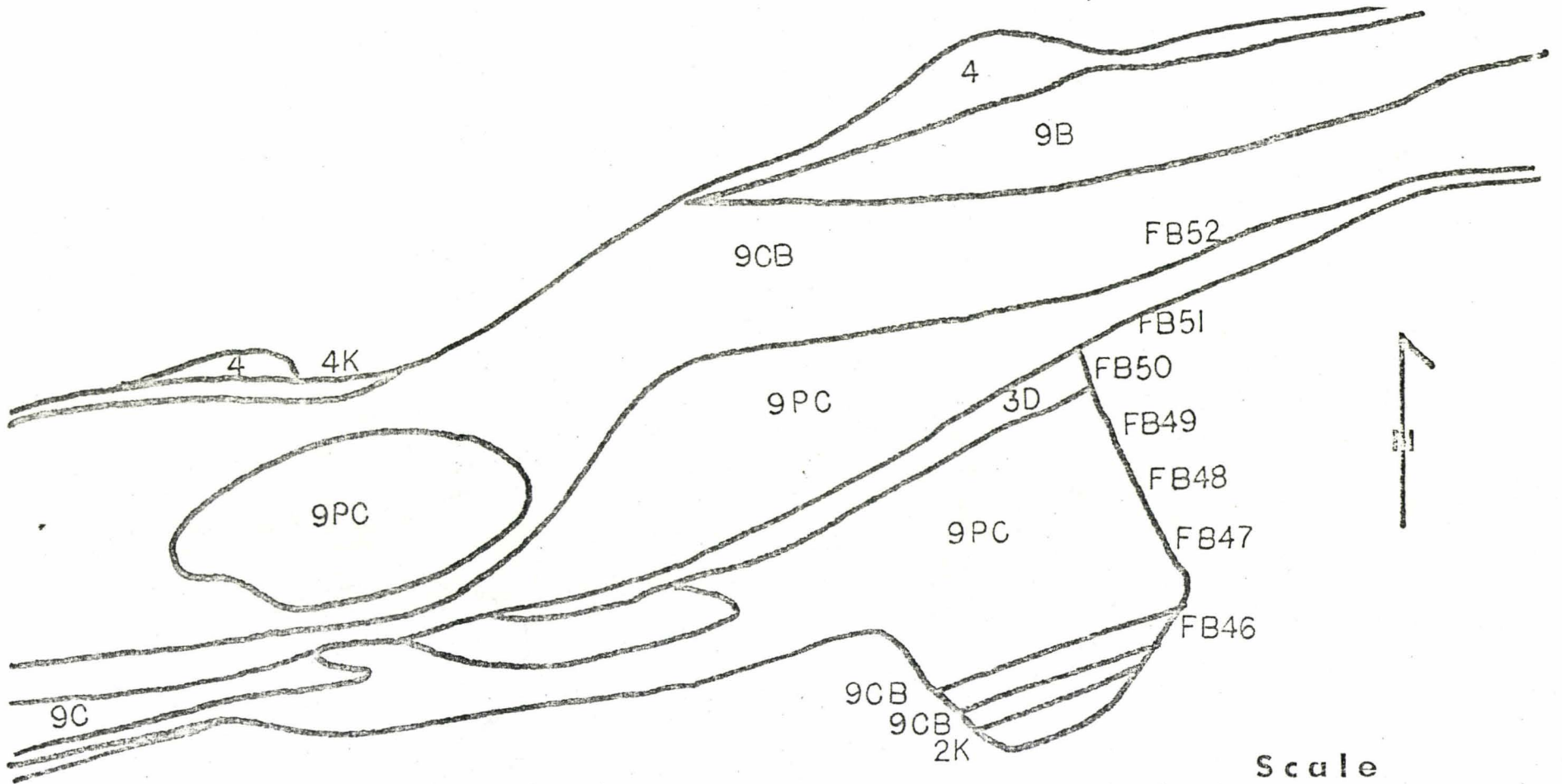


34-65 Stope
No. 3 Sub



After Mine Plans

Figure No.19



34-65 Slope
No. 2 Sub

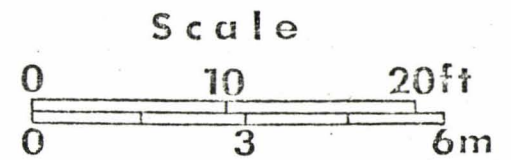
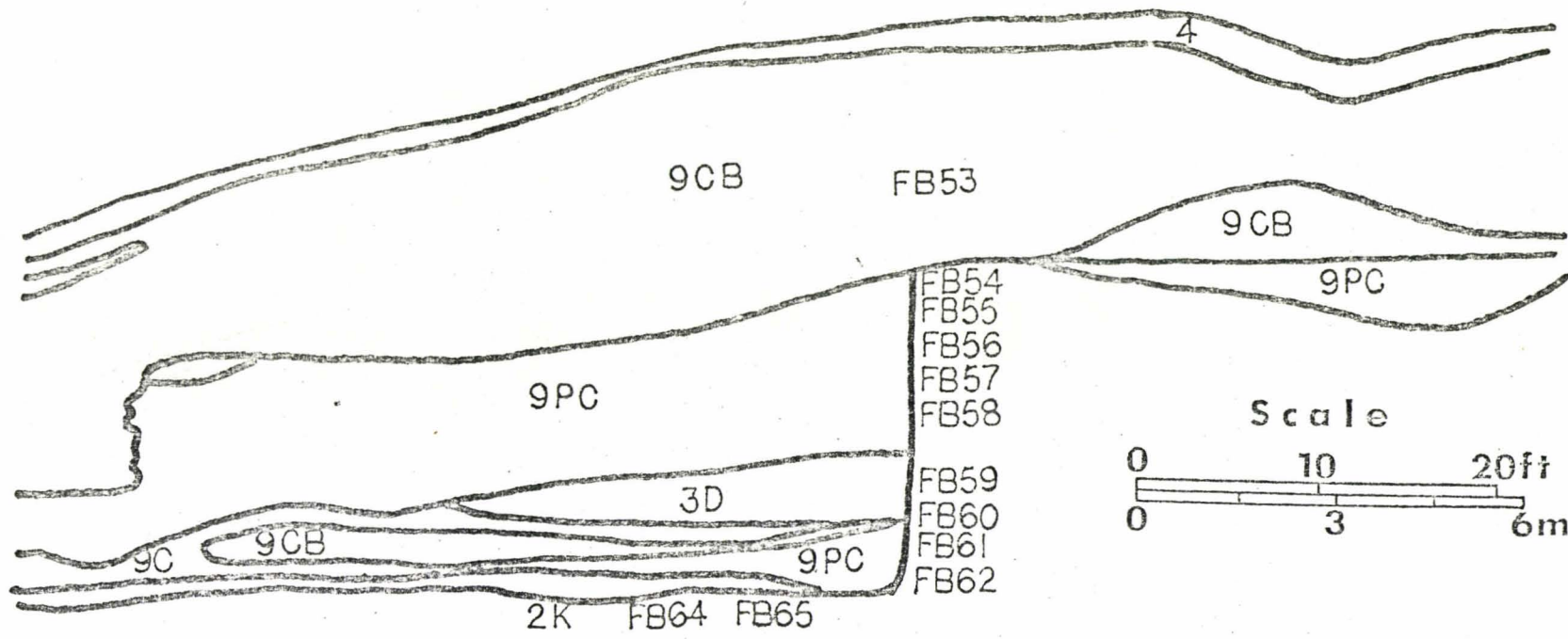


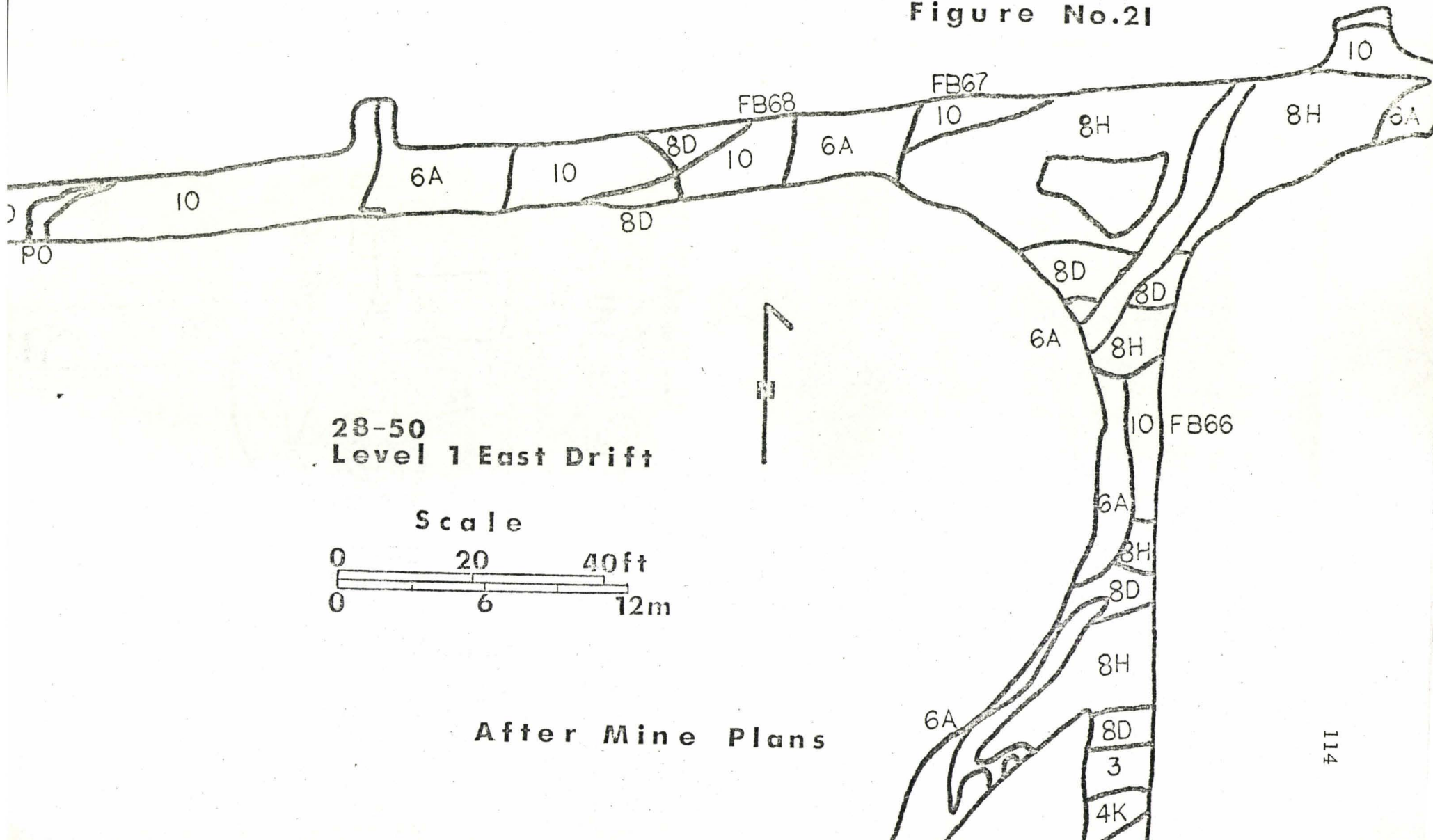
Figure No.20



34-65 Stope
No. 1 Sub

After Mine Plans

Figure No.21



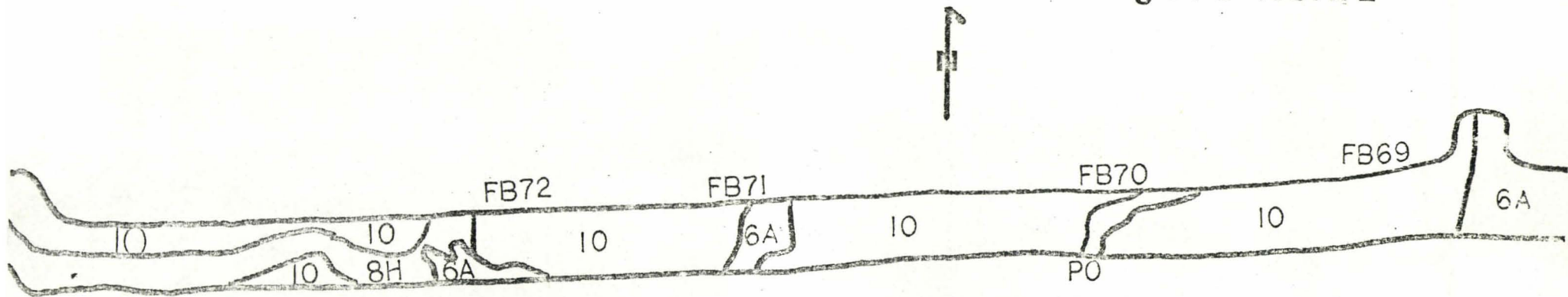
28-50
Level 1 East Drift

Scale

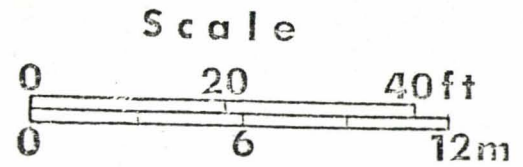


After Mine Plans

Figure No.22



28-50
Level 1 East Drift



After Mine Plans

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