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A STUDY OF THE PICHE GROUP AND VEIN SYSTEMS AT DARIUS MINE, CADILLAC, QUEBEC

Stuart Robert Comline
Western University

A STUDY OF THE PICHÉ GROUP AND
VEIN SYSTEMS AT DARIUS MINE, CADILLAC, QUEBEC

by

Stuart Robert Comline

Department of Geology

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ABSTRACT

The gold mineralisation at Darius Mine, Cadillac Quebec, is associated with quartz veins within the rocks of the Piché group. The Piché group consists of both volcanic and sedimentary rocks, older than 2.68 Ga, which crop out along the southern side of the Cadillac break at the interface between the flyschoid sedimentary rocks of the Pontiac group to the south and the volcano-sedimentary succession of the Abitibi belt to the north. The Cadillac break probably represents an ancestral fault zone along which movement occurred during the deposition of the adjacent Archean rocks. The evolution of the Piché group has been influenced by both Pontiac group sedimentation and Abitibi belt volcanism. It consists of three cycles each of which comprises distinctive volcanic and sedimentary rocks. In the first cycle mafic tholeiitic lavas and tuffs conformably overly the Pontiac group greywackes. Subvolcanic andesite sheets and lenses of greywacke occur within the mafic extrusive rocks which are overlayn by a thin but persistent conglomerate unit. This is interpreted as having been deposited by a mass flow of unconsolidated sediment. The second cycle consists of a unit of calc-alkaline pillowed andesite flows in which auriferous pyritic cherts are developed locally in the pillow interstices and on the upper contact of the unit. Overlying the andesite unit is a thin lens of siliceous greywacke which,

in part, consists of andesitic tuffaceous material. This is overlayn by an epiclastic biotite greywacke at the top of the second cycle. The third cycle is composed of intercalated units of mafic tholeiitic tuffs, lavas and subvolcanic intrusions and volcaniclastic and epiclastic greywackes. Lenses of pyritic chert and carbonaceous argillite are developed on the contacts of the various members of the cycle. In the north the rocks of the third cycle abut against the ankerite talc-chlorite schists of the Cadillac break.

Previously it has been considered that the gold and quartz in the veins was deposited by metasomatic fluids. This study however indicates that two stages of mineralisation have occurred. In the first stage of mineralisation, which is considered to be syngenetic, gold mineralisation is associated with pyritic cherts which are developed as interflow sedimentary rocks and are characterised by a relative enrichment of Cu and Zn and depletion of Cr and As. Here it is suggested that gold was precipitated with chert and sulphides from hydrothermal fluids discharged on to the sea floor during the volcanism of the second and third cycles. The gold quartz veins of the second stage of mineralisation transect the rocks of the Piché group at low angles and are considered to have been emplaced subsequent to the deposition of the Piché group rocks, and are therefore epigenetic. The veins are characterised by a relative enrichment of Cr and As and a depletion of Cu and Zn and are commonly surrounded by a potassic alteration zone. It is suggested that the gold and quartz were deposited in dilatent openings within the rocks of the Piché group from ascending hydrothermal fluids generated at depth by dehydration reactions during prograde regional metamorphism. It is probable that the ore shoots represent the principal channels for the ascent of fluids. Where the veins are developed adjacent to the auriferous pyritic cherts of the first stage of mineralisation it is possible that gold was remobilised and concentrated in the veins.

TABLE OF CONTENTS

Page

* * *

LIST OF PHOTOGRAPHIC PLATES

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

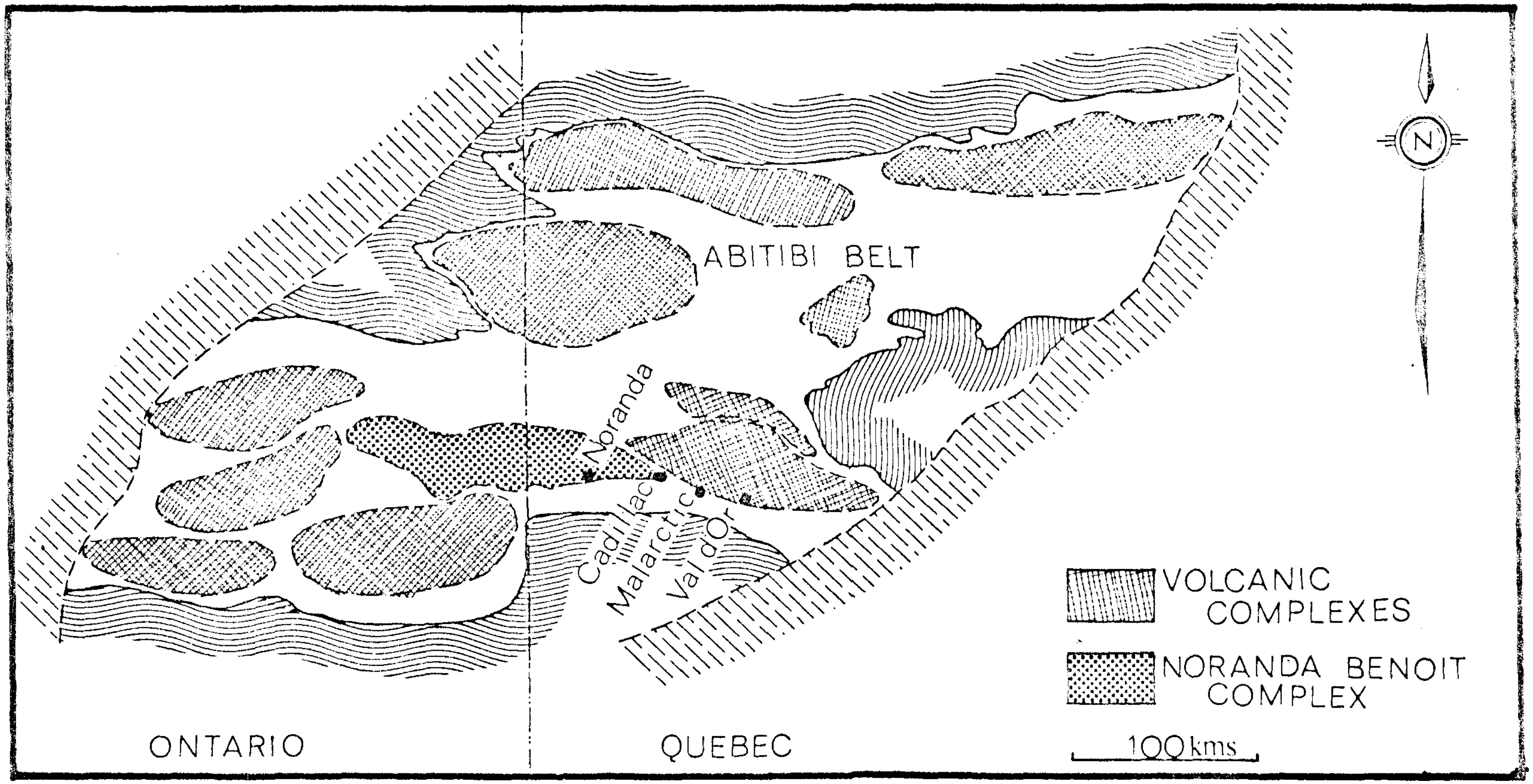
INTRODUCTION

1.1. Location and History

Darius gold mine is situated at the village of Cadillac which is 35 miles east of Noranda-Rouyn, north western Quebec (Figure 1). It is one of 9 mines in the district that have produced gold from along a major lineament that is known as the Cadillac-Bouzan break.

Ten claims, covering 2,300 m of strike were staked in 1924 over surface exposures of auriferous quartz veins that were to become the O'Brien Mine. The mine, under that name produced 612,548 ozs of gold at a grade of 0.467 ozs/ton between the years 1933 and 1956, when the mine was closed. In addition 6,418 tons of As_2O_3 were produced as a by-product between 1941 and 1949. The property was acquired by A. N. Ferris in 1969, renamed Darius Gold Mine and dewatering and underground development commenced in 1973.

During the first period of production, mining was conducted from two surface vertical shafts, Nos. 2 and 3 and an internal vertical shaft, No. 4 to a depth of 1045 m.



LOCALITY MAP OF CADILLAC (DARIUS MINE)

(from Goodwin & Ridler 1970)

FIGURE 1

All the ore has been mined from a narrow zone extending from the Cadillac break for 150 m to the south and for 900 m along strike of the Piché group. To date the workings have been dewatered to the 1500' level and development has been concentrated in the western section of the mine, around No. 3 shaft. Production at the rate of 200 tons per day re-commenced in October 1978.

1.2. Previous Work

The mine and the area immediately surrounding it were extensively studied during the initial period of production. These early studies by Bell and McLean (1930), Gunning (1937), Gunning and Ambrose (1940) and Brown (1948) were restricted to accounts of the regional and general mine geology. Bell and McLean proposed a genetic relationship between minor aplite dykes, believed to be related to granitic intrusions, and the gold mineralisation within the steeply dipping quartz veins in the metavolcanic and metasedimentary succession. Gunning, although subscribing to the concept of an epigenetic deep magmatic source for the gold mineralisation, concluded that the Cadillac break represented a major structural control on the distribution of the mineralisation. He envisaged auriferous fluids ascending through the break, and precipitating quartz and gold within dilatent openings in the adjacent country rock.

Subsequent studies which concentrated on the mineralised quartz veins of the mine included Mills (1950 and 1954), Blais (1955) and Krupka (1976). Mills (1950) demonstrated the association of high grade ore shoots with deflections in the attitude of, and rolls within, the quartz veins. Blais proposed that, in addition to these structural controls, ore shoots are also associated with the intersections of different veins and the intersection of veins with geological contacts and carbonaceous argillite lenses. In a study of the decrepitation temperatures of fluid inclusions within vein quartz, Blais also established a relationship between mineralisation and the presence of quartz containing planes of secondary liquid inclusions, which decrepitate at lower temperatures than primary liquid inclusions.

In 1954, Mills noted that the gold/silver ratio was higher in the upper levels of the mine than at depth, and suggested that the vertical zonation of the ore bodies was due to circulating meteoric waters.

From fluid inclusion studies, Krupka (1976) showed that temperatures decreased from 365° ± 35°C during early stages of vein emplacement to 250° ± 80°C in late stages. He also suggested that mineralisation in the veins occurred at temperatures of 290° ± 40°C. These temperatures are considered to represent minimum temperatures of vein emplacement and mineralisation as corrections were not made for pressure.

Krupka (op. cit.) also noted the presence of an immiscible CO_2 liquid and NaCl crystals in the fluid inclusions of the vein quartz.

It is apparent that past studies have been restricted to determining the nature of the quartz veins, the controls of gold mineralisation, and the conditions prevailing during deposition of the gold. The aspects of the influence of the various rock types on the mineralisation and the development of a genetic model for the gold mineralisation within its tectonic setting has been largely neglected. These aspects are addressed in this study.

1.3. Objectives of the Study

The objectives of the study are:

(a) To describe the rocks of the Piché group which host the mineralisation at Darius Mine and to interpret their depositional history and evolution.

(b) To examine the relationships of the various rock units to the gold mineralisation.

(c) To develop a genetic model for the mineralisation which will assist in the mining and exploration of gold, both within the mine and in other nearby areas along the Cadillac break.

1.4. Research Methods

This study is based on two periods of underground and surface mapping at Darius gold mine in December 1977 and June-July 1978. Petrographic and petrochemical investigations were conducted on samples collected during mapping, between January 1978 and March 1979, at the University of Western Ontario.

Most of the mapping was done underground on a scale of 1":20' and was concentrated in areas exposed by dewatering since the reopening of the mine. Mapping was therefore restricted to a depth of 1500' below surface and mainly in the western section of the mine. Exposures in the eastern section, where the bulk of the ore was extracted during early mining, were either poor or inaccessible.

Laboratory procedures included the microscopic examination of 98 polished thin sections and major element analysis of 27 samples. A total of 50 samples were analysed for selected trace elements and 34 samples were assayed for Au, Ag and As. Electron microprobe analyses were conducted on selected samples in order to determine compositions of carbonates, biotite and gold. A single sample of carbonaceous material was analysed by x-ray powder diffraction.

1.5. Note on Nomenclature

1.5.a. Lithological Nomenclature

For the purpose of this study the lithological nomenclature which is used is defined as follows

(i) Groups are composed of regional rock associations which are mainly of volcanic or sedimentary origins, e.g. Malarctic group, or have a specific regional stratigraphic position and may comprise both volcanic and sedimentary rocks, e.g. Piché group.

(ii) Cycles. The Piché group consists of 3 cycles, each of which is composed of both volcanic and sedimentary rocks, which are spatially closely related and have a distinctive mineralogical and chemical composition.

(iii) Units refer to rocks within a cycle which share a common origin, e.g. mafic volcanic or conglomerate units.

(iv) Members are individual beds or lava flows within a unit which is distinguishable from other members within the unit, e.g. carbonaceous member of an argillite unit.

1.5.b. Rock Nomenclature

Although all rocks within the Piché group have been metamorphosed to greenschist metamorphic facies and by strict definition should be referred to in metamorphic terminology, their original sedimentary and igneous names have been retained.

1.5.c. Vein System Terminology

As many as 15 vein systems are referred to on mine plans and historically those in the east are numbered from 1 to 14, and those in the west are referred to by a letter. For simplicity, where one vein leads into another, the systems have been grouped together. In the case of the mineralised veins the following nomenclature is used.

No. 1 vein refers to all veins within the No. 1 system in both the east and west of the mine.

No. 4 vein refers only to those veins of the 4-14-H vein system which occur within the porphyritic andesite unit in the east of the mine.

"H" vein refers to those veins within the 4-14-H system which occur in the conglomerate unit in the centre and west of the mine.

"F" vein refers to the numerous veins which occur within the rocks of the third cycle of the mine and unless specified includes the "G" vein and No. 9 vein.

1.6. Acknowledgements

I wish to express my appreciation to the management of Goldfields Mining Corporation for financial assistance provided for this study. I would especially like to thank the staff of Goldfields Exploration unit and Darius Mine for their hospitality, assistance and thoughtful discussions. In particular I am indebted to Iky Ferris, Jeff Bever, Dave Wright and Bert Morin. I would also like to thank my supervisor, Professor R. Hutchinson, for his assistance, guidance and advice, and my colleagues and members of the faculty at the University of Western Ontario, in particular Professor R. Hodder and R. Kerrich, Barb McKinnon, Bob Valliant and Bob Barnett for their assistance in various aspects of this study.

CHAPTER TWO

REGIONAL GEOLOGY

2.1. General Statement

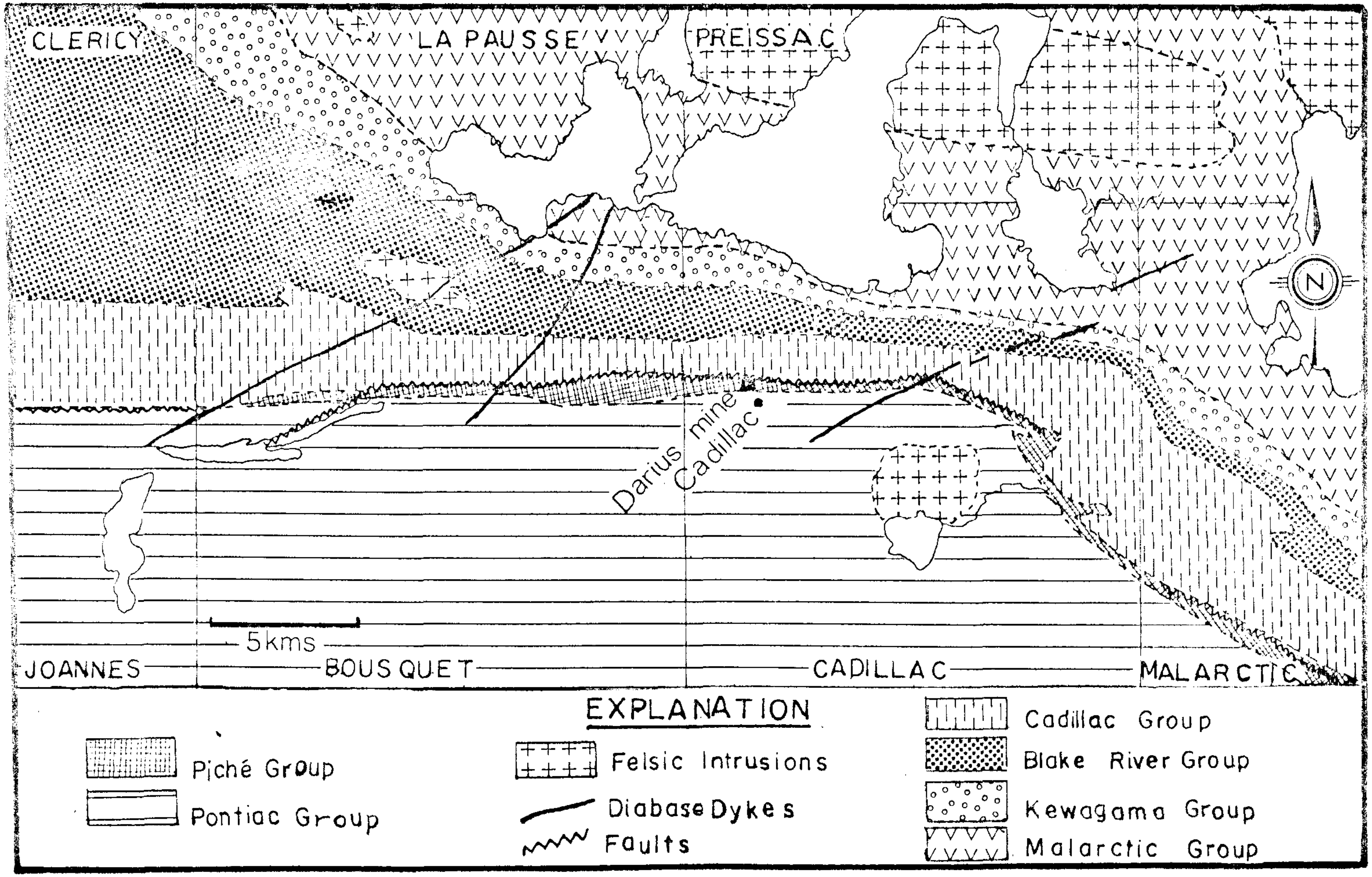
The regional geology of Cadillac township is considered in some detail in order to relate the mineralisation and stratigraphy of the mine to the tectonic evolution of the area. Although no detailed study of the geology of the township has been made since Gunning's work in 1937, a considerable amount of work has been done in the Noranda area to the west (Holubec, 1971; Dimroth et al., 1973, 1974, 1975; Jolly, 1978 and Goulet, 1978). The extent to which interpretations of stratigraphy made in this area can be applied to Cadillac township is questionable, on account of the rapid lateral variations in the Archean volcano-sedimentary succession. However most of the principal stratigraphic groups and tectonic regimes are common to both areas and thus the knowledge of the geology of the Noranda area is used as a basis for synthesising a tectonic model for the Cadillac area.

Cadillac township consists of two principal tectonic regimes (Figure 2), a stable cratonic block to the south, and to the north the linear development of the Abitibi belt volcanics and sediments at the eastern end of the Noranda-Benoit volcanic complex (Goodwin and Ridler, 1970). The two regimes are separated by the Cadillac break.

The strike of the rocks within the area is east-west (Figure 2), except in the east of the township, where it becomes southeast-northwest, and the dominant structural grain parallels this lithologic strike throughout the area. All the rocks have a vertical or near vertical attitude, and in the Abitibi belt they have been infolded about the Malartic syncline during the Kenoran orogeny, which places an upper limit on the age of the rocks in the area of 2.68 Ga. Regional metamorphism associated with the orogeny was of a prehnite-pumpellyite or low greenschist grade in the Abitibi belt and higher pressure amphibolite grade in the south of the southern cratonic block. Low pressure amphibolite grade metamorphism has altered the rocks in the extensive thermal aurioles surrounding granitic intrusions (Jolly, 1978).

2.2. The Southern Cratonic Tectonic Regime

The southern regime is the northernmost part of an extensive terrain lying between the Grenville Front to the south and the Cadillac break in the north. In the mine area it consists of up to 2,400 m of rhythmically

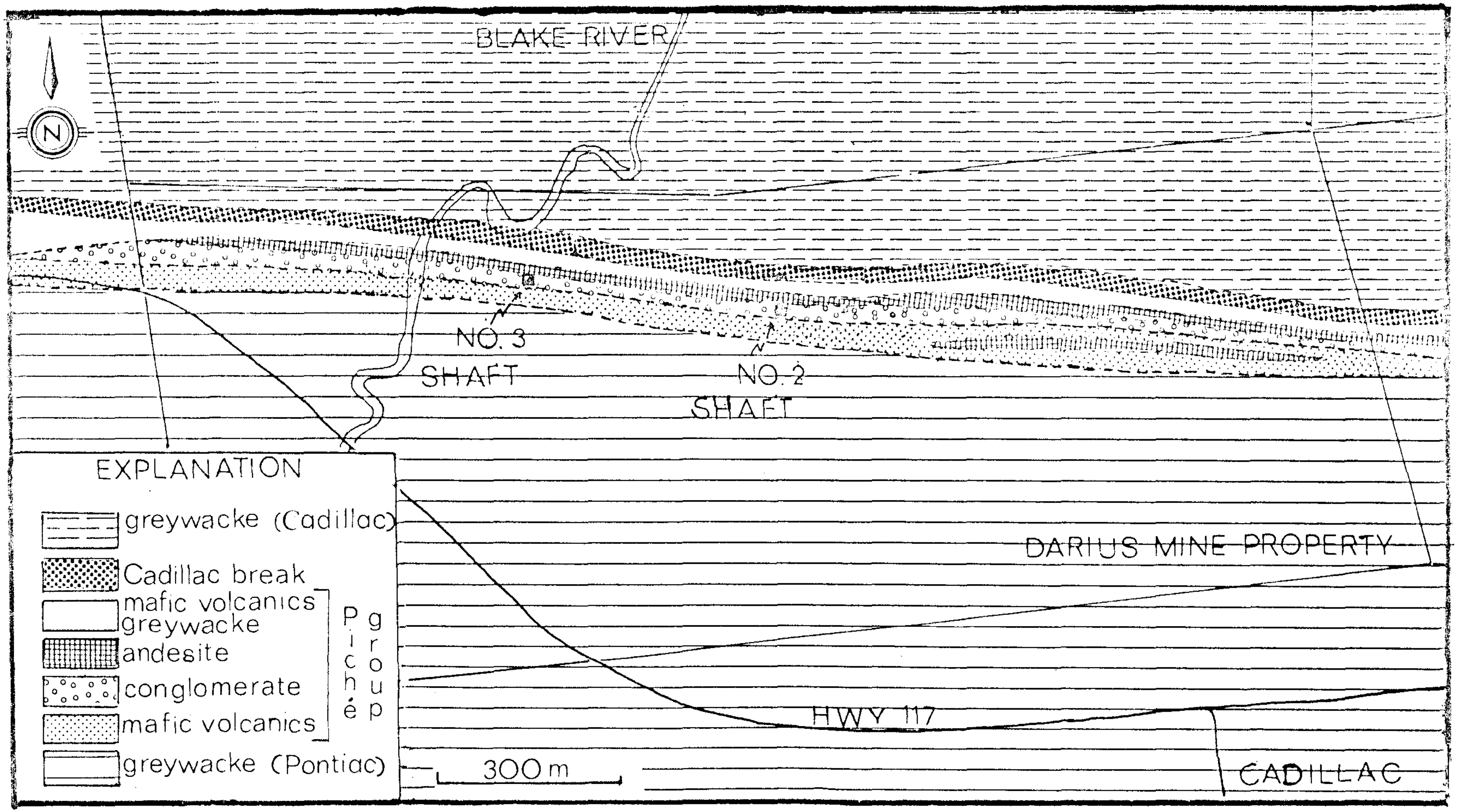


REGIONAL GEOLOGY OF CADILLAC AND SURROUNDING TOWNSHIPS.
(after Blais 1955)

FIGURE 2

bedded clastic sedimentary rocks of the Pontiac group. Further south these rocks are intruded by felsic batholiths. Most of the sedimentary rocks are fine grained polymictic flyschoid facies greywackes and argillites deposited in a stable cratonic environment. The source area from which the sediments are derived is believed to be an ancestral granite terrain to the south (Holubec, 1971). A few sporadic conglomerate lenses, intercalated within the greywackes, indicate local erosional unconformities and were apparently formed as a result of penecontemporaneous uplift, followed by erosion and rapid deposition of sediment by slumping. Their increasing frequency towards the Cadillac break is indicative of periodic uplift along the break during deposition of the Pontiac group sediments (Holubec, op. cit.).

Conformably overlying the Pontiac group in the north is the thin but persistent and economically important Piché Group (Figure 3) which coincides with the Cadillac belt of Gunning (1937) and hosts the gold-quartz veins at Darius Mine and in other mines within Cadillac township, along the south side of the Cadillac break. This group has a maximum thickness of only 300 m and consists of an alternating succession of tholeiitic pillowed and massive lava flows and tuffs, calc-alkaline volcanic rocks and epiclastic and volcaniclastic sedimentary rocks. The geology of this group of rocks will be discussed in more detail in Chapter three.



SURFACE GEOLOGY OF DARIUS MINE PROPERTY.

FIGURE 3

The northern limit of the Piché group is marked by the Cadillac break, which is approximately 50 m wide and consists of ankerite-talc-chlorite schist. The extreme deformation along the break has obliterated virtually all primary textures and therefore also any evidence of the original stratigraphic and lithologic relationship between the Piché group and the Cadillac group to the north.

2.3. The Northern Tectonic Regime (Abitibi Belt)

Rock types north of the Cadillac break belong to the Abitibi greenstone belt, an extensive terrain of metavolcanic and metasedimentary rocks. The distribution of these rocks within Cadillac township is determined by their configuration about the east west striking Malartic syncline. Only the uppermost sedimentary Cadillac group is exposed on the southern limb, between the synclinal axis and the Cadillac break, although the entire succession is exposed on the northern limb.

At the base of the succession is the Malartic group consisting of a basal unit of ultramafic and mafic volcanic rocks of tholeiitic affinity. The upper units are comprised of tholeiitic basalts and interbedded calc alkaline volcanic rocks (Latulippe, 1976). Subsidence, subsequent to the volcanic extrusions, resulted in erosion of parts of the Malartic group rocks and deposition of the chloritic greywacke and interbedded argillites and tuffs of the overlying Kewagama Group (Gunning, 1937).

The Blake River group represents a second period of tholeiiticvolcanism, less mafic than the Malartic group and consists of basalts at the base, overlain by felsic lavas and pyroclastic rocks (Gunning, op. cit.).

During the final stages of Blake River volcanism the northern Abitibi tectonic regime was subsiding while the southern cratonic regime was being uplifted (Holubec, 1971). This resulted in the erosion of the southern craton and deposition of the greywackes of the Cadillac group. Although some of the sediments may have been derived from the volcanic terrain to the north, most of the material originated in the Pontiac sediments and southern granitic batholiths. The southern facies of the Cadillac group in which lenses of conglomerate and iron formation are interbedded with greywacke contrasts with the monotonous succession of greywackes in the northern facies (Gunning, 1937).

As is the case with the conglomerate lenses in the Pontiac group, these coarse pebble deposits are interpreted as representing penecontemporaneous erosion and rapid deposition as a result of movement along the break. The iron formations however reflect a period of stability in which sediment supply to the depositional basin was reduced and conditions favoured chemical precipitation of iron and silica from sea water. The co-existence of these different rock types indicates that conditions prevailing within the depositional basin during deposition of the Cadillac group rocks varied considerably, possibly due to tectonic instability caused by movement along the break.

2.4. The Problem of Correlation Across the Break

Until this point, no attempt has been made to correlate the lithologic groups on the northern and southern sides of the break. North of the break, only the uppermost sedimentary Cadillac group, which outcrops in the axial region, is exposed on both limbs of the Malartic syncline. Correlations of groups lower in the stratigraphic succession across the break are at best speculative.

Many workers, Gunning and Ambrose (1940), Wilson (1948), Holubec (1971) and Goulet (1978), correlate the Kewagama sediments and Blake River volcanic rocks in the north with the Pontiac and Piché groups respectively to the south of the break. However such a correlation does not explain the abundance of sedimentary rocks in the south and the dominance of volcanic rocks in the north. Latulippe (1976) has indicated that there is a closure between the Piché group and the Malartic group between Val d'Or and Malartic. If this correlation is valid the Pontiac group sedimentary rocks in the south represent the first deposited rocks in the area. Considerable uplift of the southern tectonic regime would therefore be required, relative to the Abitibi belt, in order to bring these rocks to their present tectonic level. Evidence for such uplift is perhaps provided by the high pressure Barrovian type metamorphic assemblage within the Pontiac group sedimentary rocks which contrasts with the low pressure facies of the Abitibi belt (Jolly, 1978).

Clearly stratigraphic correlations across the Cadillac break are at present tenuous and therefore, in this account, the stratigraphy of the southern and northern regimes are presented separately (Table 1). It is however considered that the Piché group represents a marginal facies of either the Malartic or Blake River volcanic groups, with interbedded sedimentary rocks of the Pontiac group.

2.5. Intrusive Rocks

Intrusive rocks in the area are of three principal tectonic types. The first includes those intrusions of various ages that penetrate the break. In the Malartic district these include ultramafic and diorite stocks, which are spatially and probably genetically related to the gold mineralisation (Eakins, 1962). Although the schists of the break at Darius have a bulk composition similar to that of an ultramafic rock there is no evidence for an intrusive origin of this rock. In Cadillac township minor aplite plugs occur within the break and are considered to be of little significance although Bell and McLean (1930) related them to the gold mineralisation.

Table 1

Stratigraphic Table

Southern Cratonic Regime	Northern Abitibi Regime
Recent stream, lake and swamp deposits	
Pleistocene sand, gravel, boulders	
Erosion	
Late PreCambrian diabase intrusives	
2.49 b.y. Kenoran orogeny, granitic intrusions, folding and regional metamorphism	
	Cadillac Group - Epiclastic, chemical and volcaniclastic sedimentary rocks
Piché Group - Tholeiitic mafic and calc-alkaline intermediate volcanic rocks, epiclastic volcaniclastic and chemical sedimentary rocks	Blake River Group - Tholeiitic and calc-alkaline mafic, intermediate and acid volcanic rocks
	Kewagama Group - volcaniclastic and epiclastic sedimentary rocks
Pontiac Group - clastic sedimentary rocks	Malartic Group - Tholeiitic, ultramafic and mafic volcanic rocks

The second variety of intrusions is the large felsic batholiths which have intruded both the Abitibi belt and the southern cratonic regime during the Kenoran orogeny and are considered to be, in part, responsible for the downwarping and isoclinal folding of the denser Abitibi belt volcanic rocks. A third type of post orogenic intrusions is a series of northeast-trending diabase dykes which crop out both to the east and west of Darius Mine.

2.6. Structure

A complex history of structural deformation is recognised within the area, commencing with an initial phase of steeply plunging isoclinal folds striking north south (Goulet, 1978). A second set of isoclinal folding is characterised by the east west striking axial surfaces and is responsible for the dominant structural grain in the area. The third and fourth phases of deformation are less prominent and are characterised by northwest and northeast striking foliation planes.

The most significant structural elements in Cadillac township are the Cadillac break and the Malartic syncline, which are both expressions of the second phase of deformation. The complete tectonic significance and history of movement of the Cadillac break is not fully understood. Gunning (1937) demonstrated that movement along the break was in a horizontal direction with the northern side moving east relative to the south. Evidence has been presented here that episodic and perhaps considerable vertical movement has occurred along the break since the deposition of the Pontiac group sedimentary rocks. Dimroth et al. (1975) however suggested that the break was a thrust fault subsequently complicated by strike slip movement. Although it is beyond the scope of this thesis to discuss the break in detail, it is necessary to appreciate that it possibly represents an ancestral fault system active during the deposition of the surrounding rocks and separating the emergent Abitibi belt in the north from a stable cratonic regime to the south. Because this structure influences the geology of Darius Mine it is significant to note that schistosity in the rocks becomes more intense towards the break, as does the frequency of the quartz veins which host the gold mineralisation.

CHAPTER THREE

MINE GEOLOGY

3.1. General Statement

Previous studies of Darius Mine (Mills, 1950 and 1954; Blais, 1955 and Krupka, 1976) have concentrated on the mineralised quartz vein systems and have, to a large extent, neglected the stratigraphy, petrology and geochemistry of the Piché group within the mine. Consequently it is, in part, the aim of this study to describe the stratigraphy and investigate the influence that the various lithologic units have had on the mineralisation.

The Piché group is approximately 150 m thick and consists of approximately equal amounts of volcanic and sedimentary rocks (Figures 4, 5). It is assumed from regional geological relationships that the Piché group faces north, for within the mine no reliable facing directions have been determined. The well developed schistosity close to the break has obliterated many primary features within these rocks although pillow lavas in the mafic unit at the base of the group appear to face north. A similar facing direction is indicated by

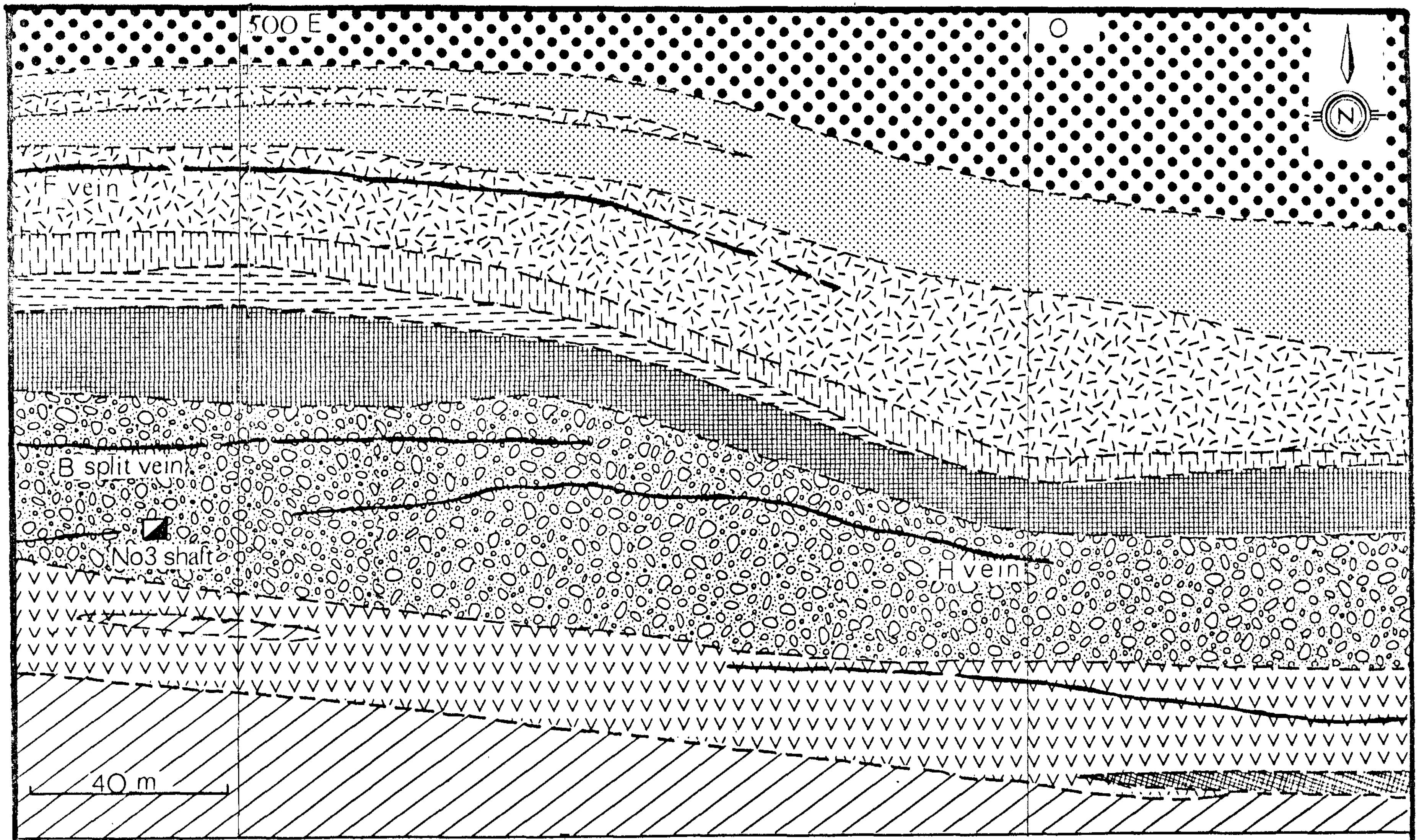
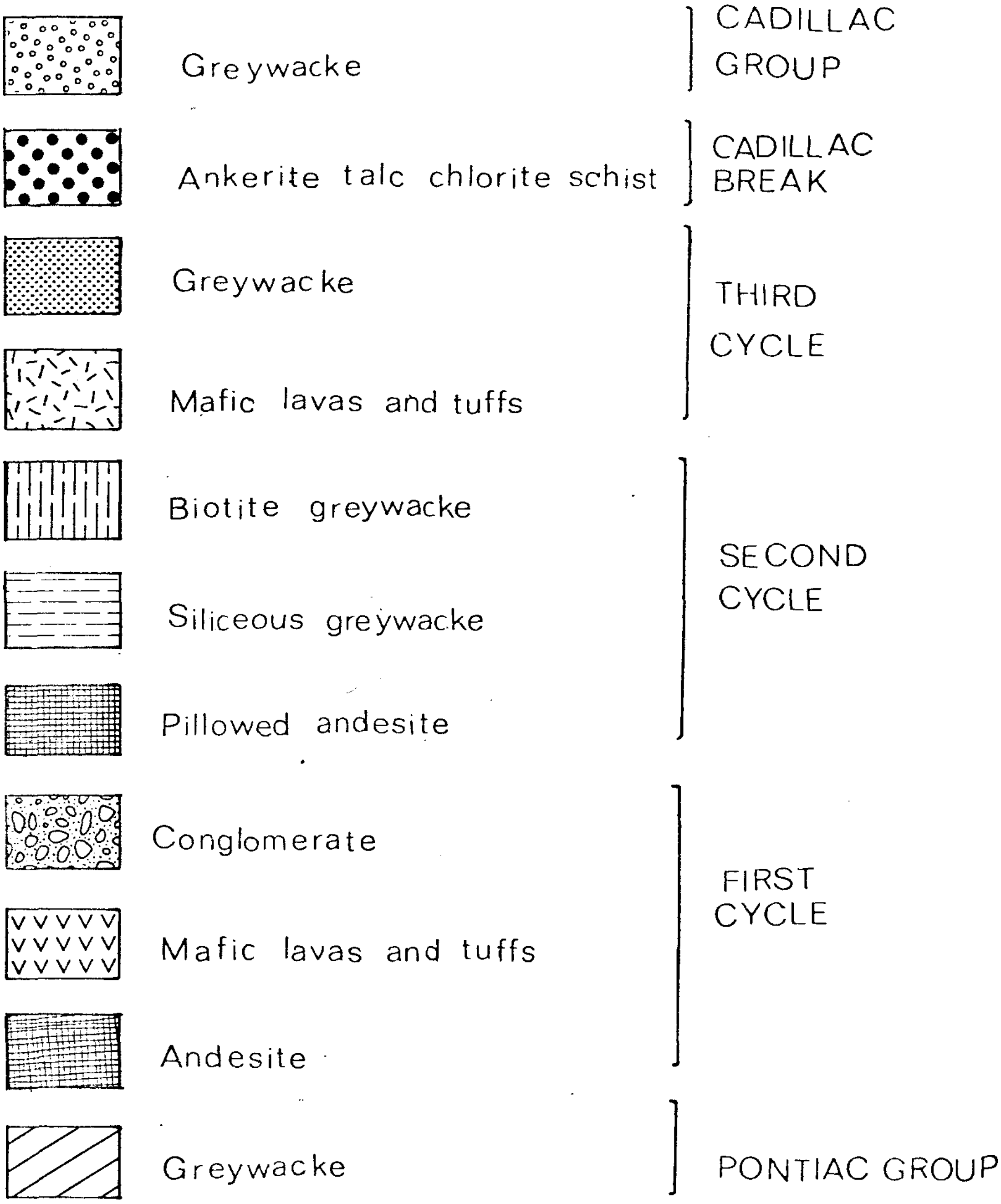


FIGURE 4 500' LEVEL PLAN, WESTERN SECTION OF THE MINE

(explanation see page 24)



EXPLANATION FOR FIGURES 4 AND 5

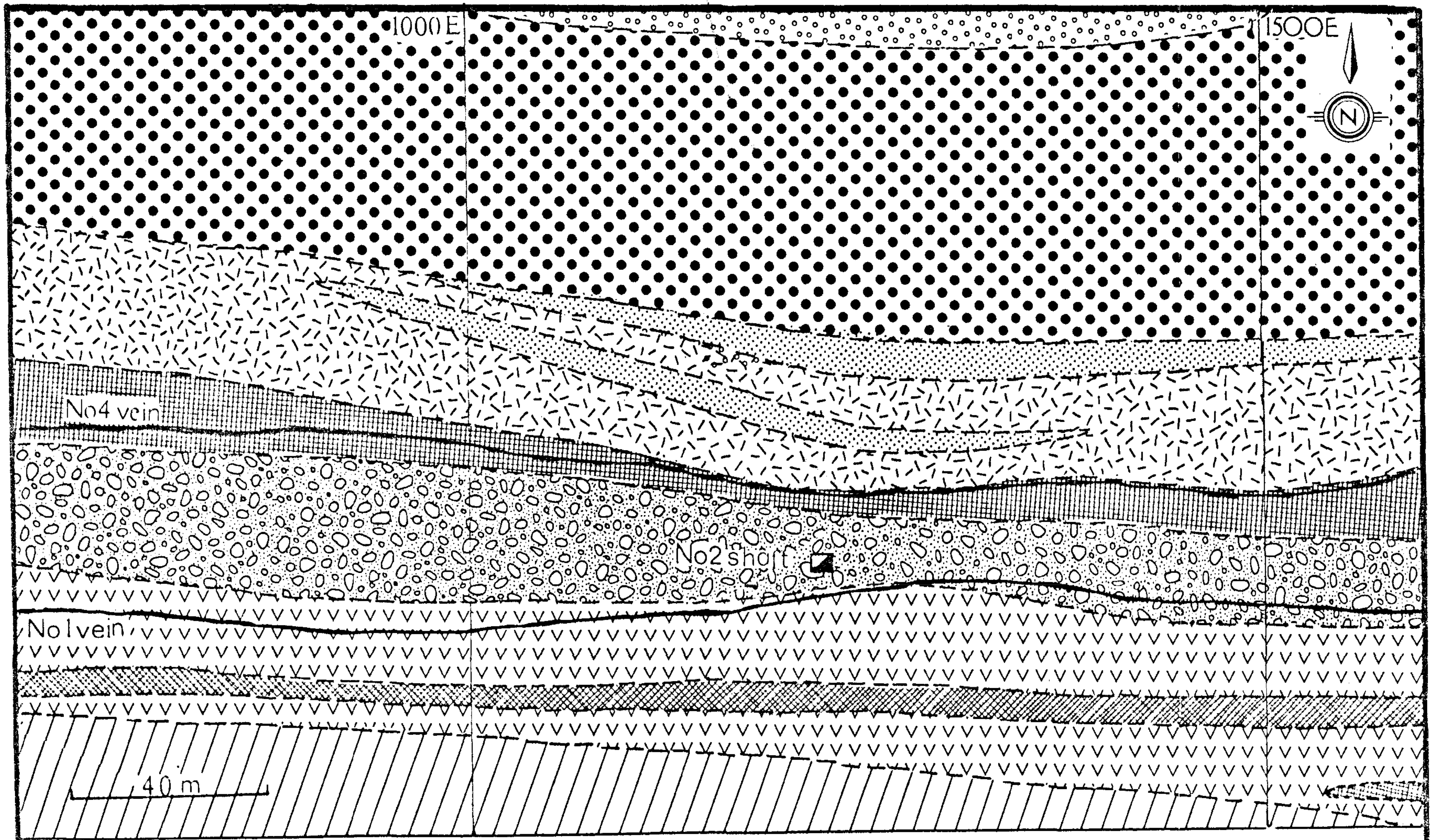


FIGURE 5 500' LEVEL PLAN, EASTERN SECTION OF THE MINE
(explanation see page24)

graded bedding observed under the microscope in oriented samples, however tight isoclinal folding observed in outcrops on surface makes the reliability of these determinations questionable.

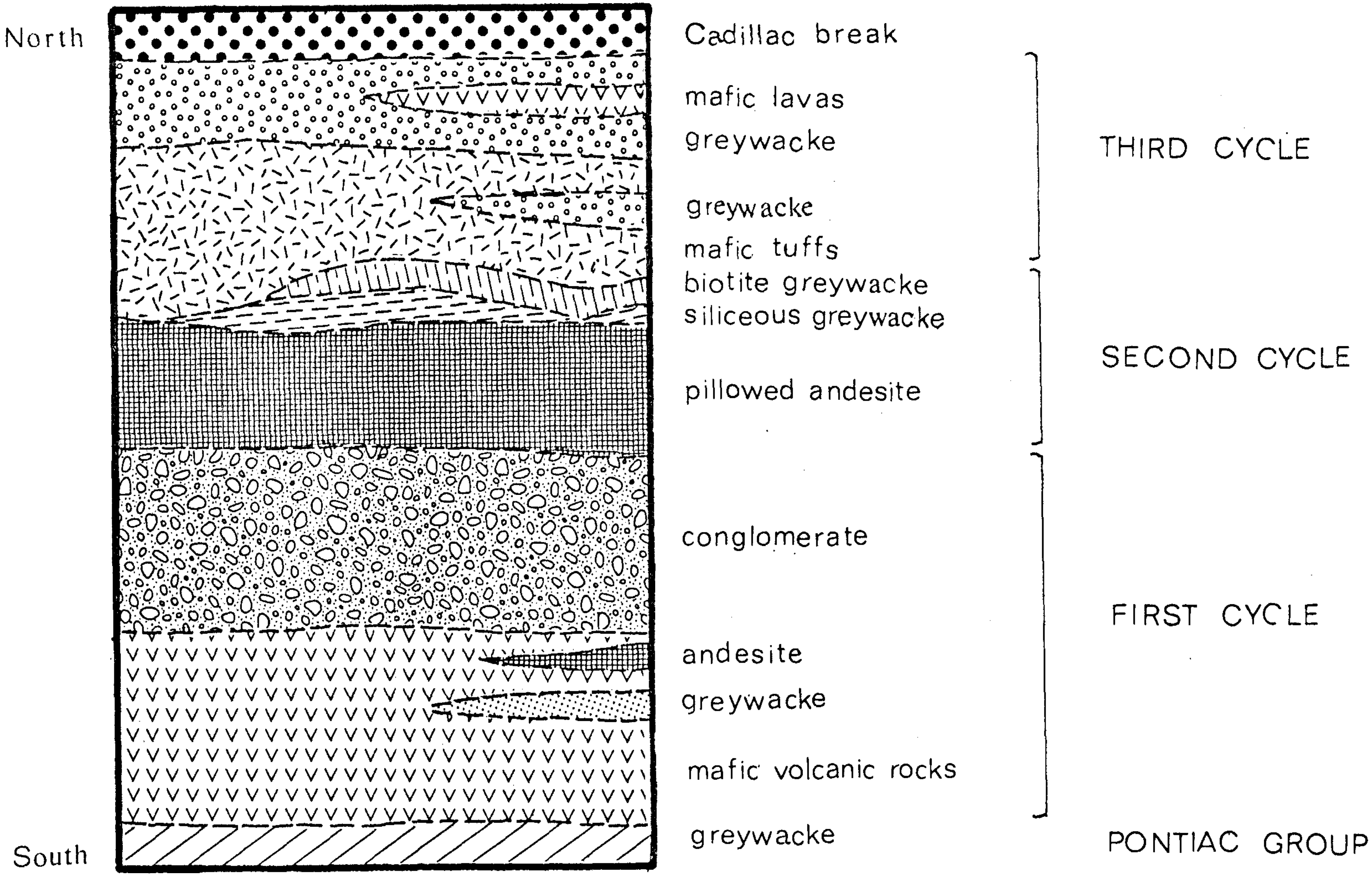
In this account the Piché group is divided into 3 cycles (Figure 6). Each cycle is comprised of volcanic rocks at the base overlain by sedimentary units and these are as follows.

The Third Cycle	Tholeiitic tuffs, lavas and sub-volcanic gabbroic intrusions, overlain by epiclastic, volcaniclastic and chemical sediments.
The Second Cycle	Calc-alkaline porphyritic lavas and volcaniclastic and chemical sediments developed locally.
The First Cycle	Tholeiitic pillowed and massive lava flows, minor calc-alkaline andesites overlain by a pebbly mudstone or conglomerate unit.

Many of the units, particularly in the upper part of the second cycle and in the third cycle are only locally developed in depositional basins of limited extent.

3.2. Pontiac Group Greywackes

The upper greywackes of the Pontiac group are rarely exposed underground and no economic mineralisation has been discovered in them to date. An upper gradational



SCHEMATIC STRATIGRAPHIC SECTION THROUGH THE PICHÉ GROUP

FIGURE 6

contact of these greywackes with the overlying mafic volcanic rocks at the base of the first cycle indicates that sedimentation continued during the extrusion of the volcanic rocks. The greywackes consist of a fine grained matrix of quartz, sericite, biotite, calcite and chlorite and larger (0.1 mm) clasts of quartz and plagioclase. Surface exposures on the mine property exhibit rhythmic bedding as the rocks vary from a quartzitic to an argillaceous variety.

3.3. The First Cycle

3.3.a. Mafic Tholeiitic Volcanic Unit

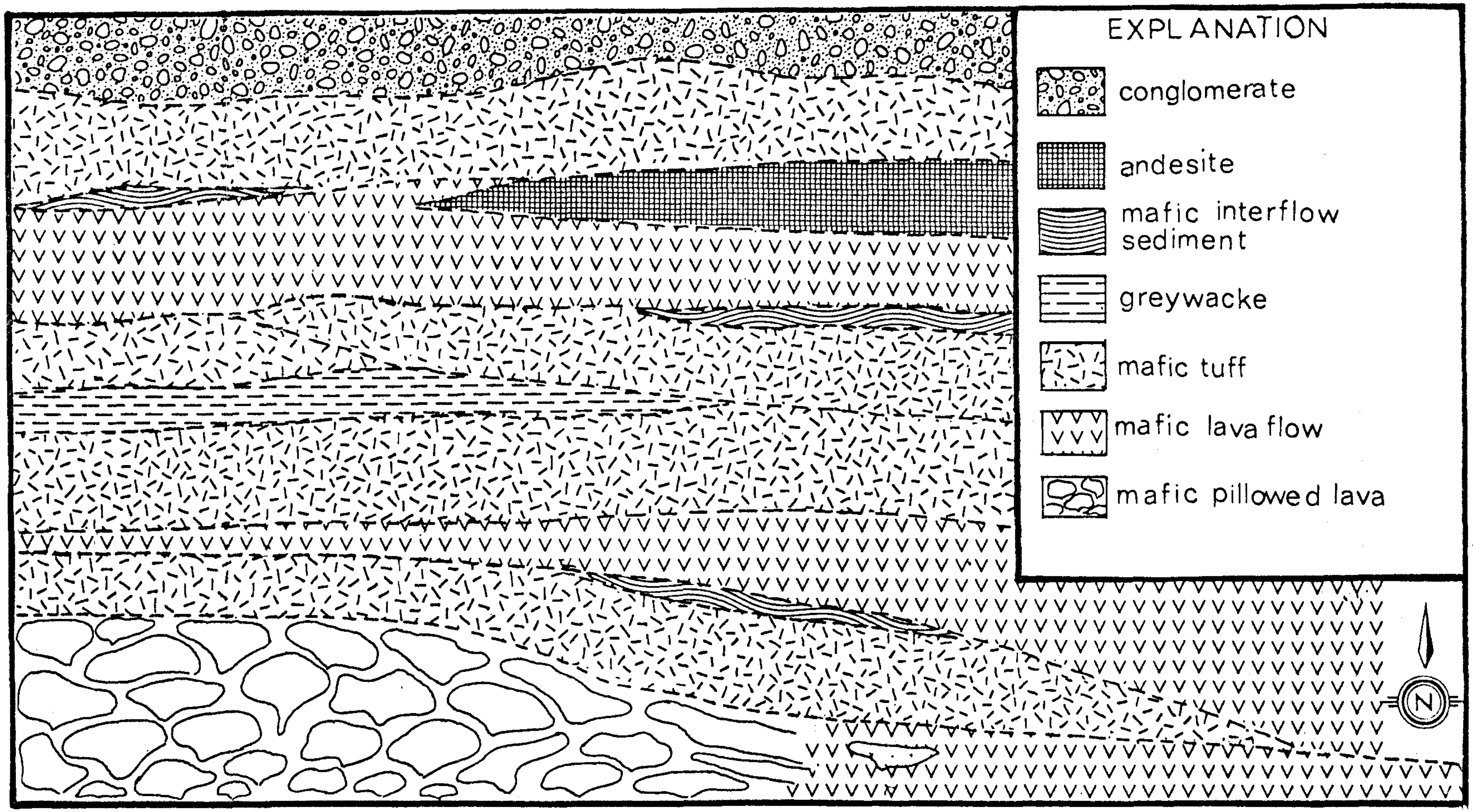
This unit consists of a succession of mafic tholeiitic massive lava flows and tuff beds. Locally pillowed lavas occur at the base of the succession and a sheet of thin calc-alkaline porphyritic andesite is present in places. Thin lenses of volcaniclastic and chemically precipitated sedimentary rocks are common between volcanic members and larger lenses of epiclastic greywacke are sporadically developed. Of economic significance this basal mafic unit hosts the mineralised No. 1 vein system.

Pillow lavas are locally present at the base of the succession, are frequently deformed and are indicative of subaqueous deposition. They consist of a fine grained mass of acicular actinolite crystals intergrown with a groundmass of plagioclase, quartz and chlorite and minor amounts of carbonate, epidote, and magnetite (Plate 1a).

Interstitial to the pillows and overlying the unit is a fine grained chloritic and cherty sedimentary rock. For the most part it is a massive dark green colour, but locally develops laminations with chert bands alternating with chlorite rich bands. Minor disseminated granular pyrite occurs in the cherty bands.

Mapping the pillow lavas along strike indicates that they grade into massive lava flows and interbedded tuff members (Figure 7). Blais (1955) divided the tholeiitic unit into three zones of lavas and tuffs ranging in thickness between 10 m and 30 m. Detailed mapping (Figure 7) of this unit reveals that this division is apparently an oversimplification of the volcanic stratigraphy. Most lava flows and tuff beds are between 50 cm and 5 m thick and the writer found no lava or tuff members that were of the thickness indicated by Blais. The contacts of individual lava flows and tuffs are commonly marked by thin lenses of interflow sediment which vary in composition from chloritic to quartz rich.

The massive lava flows are comprised predominantly of actinolite, plagioclase (An 9-12) quartz, chlorite, and carbonate. Accessory constituents include epidote, sphene, magnetite and disseminated pyrite. Locally biotite partially replaces actinolite grains. In coarser grained varieties the lavas have an ophitic or subophitic



SCHEMATIC SECTION THROUGH THE FIRST CYCLE MAFIC VOLCANIC UNIT

FIGURE 7

texture. In extreme cases the texture is porphyritic with intergrowths of plagioclase and actinolite surrounding large phenocrysts of corroded actinolite crystals.

The mafic tuffs are finer grained than the lavas and the constituent minerals are aligned parallel to schistosity (Plate 1b). Mineralogically and texturally they are more uniform than the lavas and consist predominantly of fine grained chlorite with lesser amounts of microcrystalline quartz, carbonate and sericite. Accessory subhedral pyrite crystals are disseminated throughout the groundmass and secondary carbonate veinlets transect the rock. The lenses of interflow sedimentary rock are up to 50 cm thick and 10 m long. Most are massive, consisting of microcrystalline cherts and fine grained chlorite laths although locally a laminated variety exists in which fine 0.05 mm bands of chert alternate with chlorite rich bands (Plate 1c). These interflow sedimentary rocks are considered to have formed during periods of quiescence between volcanic eruptions in which fine volcanic pyroclastic material settled out of suspension in sea water and silica was precipitated.

Evidence for deposition of epiclastic sediment during the volcanic period is found in the larger beds of greywacke which locally occur within the volcanic pile. These consist of a matrix dominated by chlorite and biotite and lesser amounts of quartz and plagioclase which surrounds large subrounded clasts of plagioclase and quartz. Mineralogically they are similar to both the Pontiac group greywackes and the matrix to the overlying conglomerate unit and thus it is not clear whether they represent a late stage of Pontiac sedimentation or a precurser of the conglomerate deposition. However the absence of large pebbles within these greywackes favours an association with the Pontiac group rocks.

The chemical composition of the mafic lavas and tuffs plot within the basaltic tholeiite field of Myashiro (1973) and the lavas are comparable to the tholeitic basalt composition of Jolly (1975). The similarity in composition between pillowed and massive lava flows confirms their field relationships and suggests a comagmatic origin (Table 2).

By comparison the tuffs which are interbedded with the lavas are significantly depleted in SiO_2 and have variable MgO and CaO contents. Up to 10% of their constituents are volatiles, which, although not determined are probably CO_2 and H_2O. High CO_2, CaO and MgO content substantiates microscopic observations of abundant carbonate minerals within the tuffs. In addition much of the MgO may be accommodated in chlorite which constitutes a large proportion of the tuffs. By comparison the interflow sediments have a higher SiO_2 content than lavas and tuffs which is interpreted as reflecting the presence of precipitated silica, as chert

Table 2

Chemical composition of the first cycle mafic tholeiitic and related rocks.

Rock Type	massive lava		mafic pillow lava	Tholeiitic basalt
Sample	250/14	500/1E/2	500/1	Jolly (1975)
%				
SiO_2	49.67	49.08	48.96	47.6
TiO_2	1.36	.89	1.25	2.14
Al_2O_3	11.91	11.81	16.75	14.1
FeO	15.33	11.54	13.41	14.5
MnO	.22	.21	.23	.25
MgO	5.63	8.45	7.06	5.13
CaO	5.87	8.92	5.84	8.40
K_2O	.90	1.19	.15	.35
P_2O_5	.07	.21	.06	-
Na_2O	3.10	2.43	2.33	2.65
L.O.I.	5.67	5.03	3.25	
Total	99.73	99.76	99.29	
p.p.m.				
Cr	98	45	319	85
Ni	59	101	98	105
Cu	134	270	100	
Pb	10	5	7	
Zn	9	25	142	
Co	70	61	73	
Zr	60	78	64	
Sr	101	370	200	
Rb	27	25	8	

Table 2 (Continued)

Rock Type	mafic tuffs		interflow chloritic and cherty sediments	
Sample	500/1E/1	500/1E/5	500/1E/3	500/4
%				
SiO_2	42.95	43.68	51.46	56.85
TiO_2	.85	.69	.84	.99
Al_2O_3	14.41	11.29	12.44	14.41
FeO	14.83	14.50	11.56	8.81
MnO	.19	.42	.34	N.D.
MgO	10.53	5.70	6.28	5.96
CaO	5.26	12.09	7.30	4.30
K_2O	N.D.	.38	1.25	.29
P_2O_5	N.D.	.12	.09	.15
Na_2O	.84	.13	1.50	2.98
L.O.I.	10.95	11.76	7.16	4.65
Total	100.81	100.76	100.22	99.39
p.p.m.				
Cr	144	227	286	241
Ni	211	106	137	96
Cu	99	86	29	60
Pb	1	8	10	11
Zn	9	N.D.	13	130
Co	87	25	56	60
Zr	38	84	120	63
Sr	81	194	366	279
Rb	2	14	10	28

in these rocks.

3.3.b. Porphyritic Andesite Unit

In the eastern section of the mine particularly at lower levels two sheets of porphyritic andesite occur within the mafic tuff and lava pile (Figure 5). Blais (1955) considered these sheets to be intrusive, but their conformable relationship with the surrounding volcanic rocks suggests that they may be of an extrusive origin. Insufficient exposures in the dewatered portion of the mine prevented detailed mapping of this unit.

Mineralogically and chemically this rock is similar to the extrusive porphyritic andesite unit of the second cycle (Figure 5) however it lacks the pillowed structure of the latter and Blais' interpretation that it is a subvolcanic sill phase of the stratigraphically higher extrusive andesite is adopted here. The rock consists of large (3 mm) phenocrysts of plagioclase (An 8) in an intergrowth of smaller (0.1 mm to 1 mm) plagioclase and actinolite crystals. Biotite replacement of actinolite is extensive and quartz and chloritoid are common. Calcite and quartz have developed in fractures in the large plagioclase phenocrysts. The rock composition plots within the calc-alkaline field and is discussed in more detail in conjunction with the andesite unit of the second cycle.

Plate 1

a. Photomicrograph of mafic pillow lava showing a mass of actinolite crystals in a plagioclase and quartz matrix and carbonate veinlets.

b. Photomicrograph of a fine grained chloritic tuff with minor quartz grains in the lower right of the photograph.

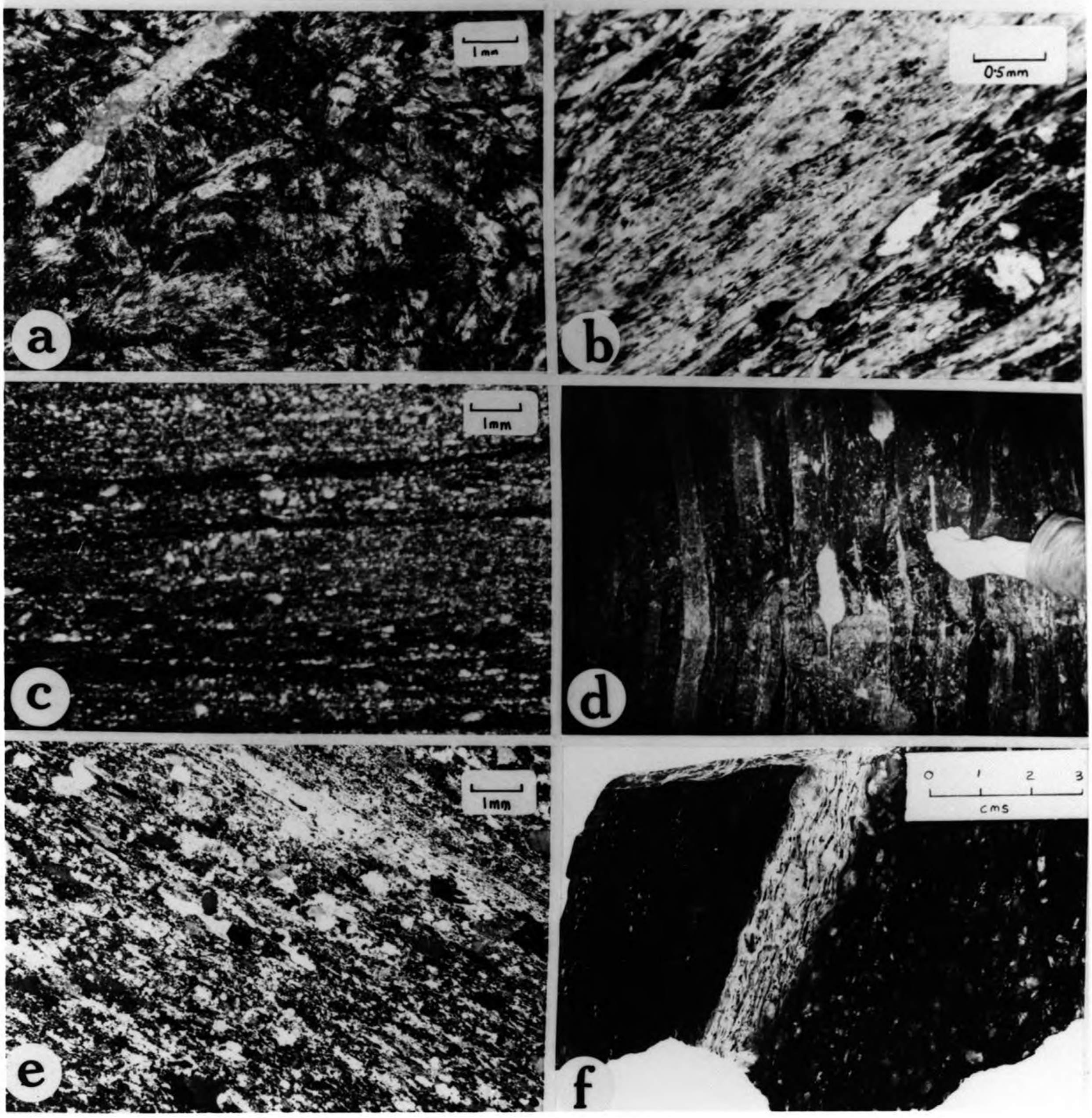
c. Photomicrograph of a fine grained interflow sediment consisting predominantly of a chert and chlorite matrix with dark laminations of chlorite.

d. Underground exposure of the conglomerate unit showing stretched pebbles.

e. Photomicrograph of greywacke matrix of the conglomerate unit consisting of quartz plagioclase and biotite.

f. Photograph through an andesite pillow selvage showing dark porphyritic andesite pillow core (right), bleached and altered pillow selvage (centre), and dark fine grained argillite interstitial to the pillows (left).

PLATE 1

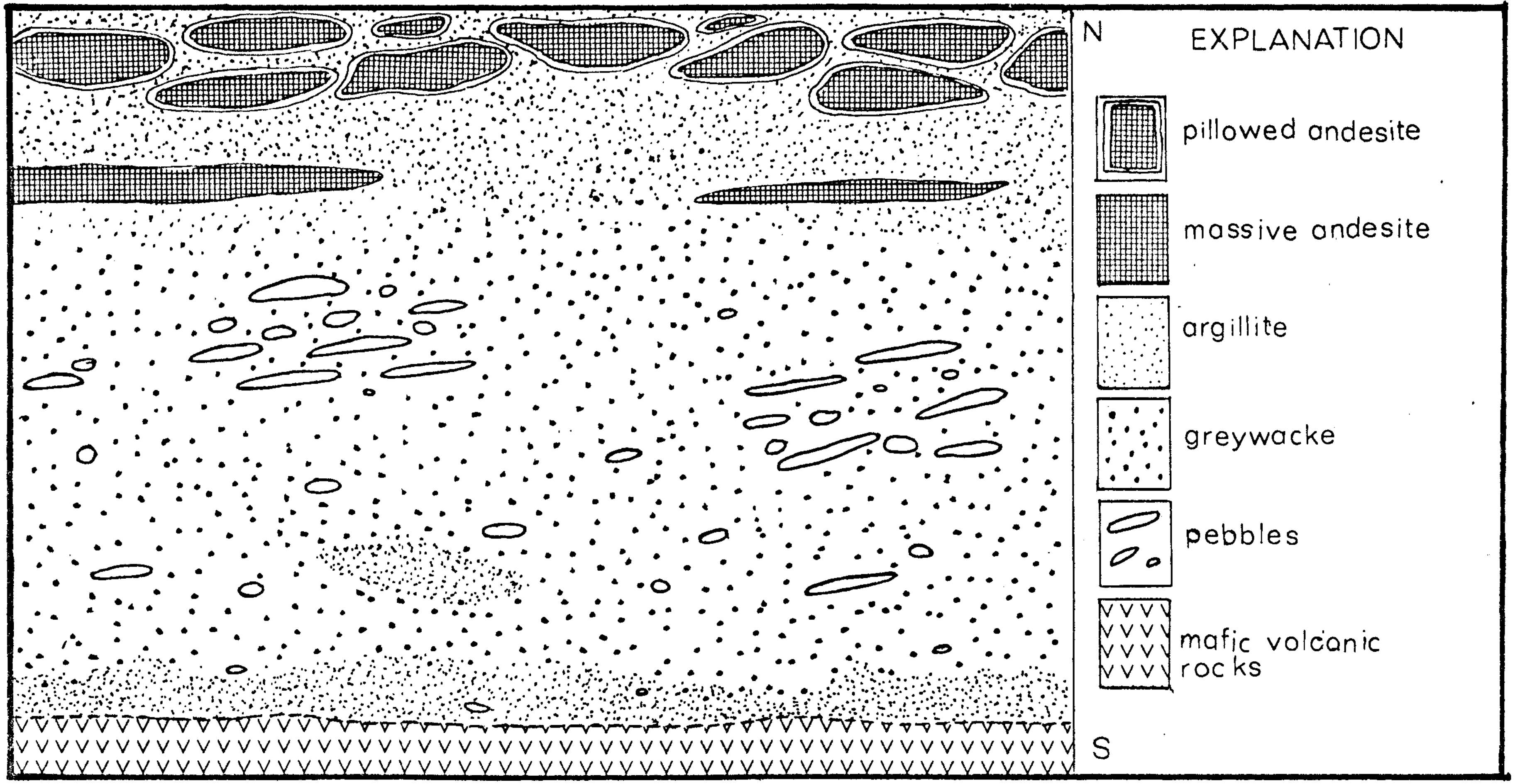


3.3.c. The Conglomerate (Pebbly Mudstone) Unit

Overlying the tholeitic basalt unit is a persistent conglomerate unit which in the mine ranges in thickness between 12 m and 40 m. Regionally it is seldom more than 100 m thick yet extends for over 3 km along strike. Economically it is important for it hosts the No. 1 vein in the eastern section and the H vein in the western section (Figures 4, 5).

It consists of a massive and occasionally thinly bedded argillite and greywacke matrix supporting variable proportions of poorly sorted pebbles ranging in composition from felsic intrusive to mafic volcanic rocks. Features such as graded and cross bedding have not been observed in the matrix and there is no apparent regular gradation of pebble size either vertically or horizontally through the unit. There is a tendency, however, for pebbles to be more abundant in the thinner parts of the unit, whereas in the thicker parts there is an inconsistent trend of pebble distribution from the base to the top of the unit illustrated in Figure 8.

The basal contact of the unit consists of a fine grained chloritic argillite in which pebbles are rare. The chloritic component indicates that sediment was derived, in part, from the underlying volcanic rocks. Above the argillite the matrix is a coarser grained epiclastic greywacke supporting up to 10% (by volume) pebbles. The abundance of pebbles tends to increase up-



SCHEMATIC SECTION THROUGH THE CONGLOMERATE UNIT

FIGURE 8

ward until two thirds the way through the unit where discontinuous lenses containing up to 50% pebbles extend for 20 m along strike. Above these pebble lenses pebbles are rare and 3 m below the upper contact the matrix is predominantly argillaceous. Here minor porphyritic andesite flows, apparently precursers of the second cycle andesite volcanism, intrude the argillite.

The greywacke consists of subrounded to rounded quartz and plagioclase clasts (0.5 mm) set in a fine grained matrix of quartz, plagioclase, biotite, sericite and chlorite (Plate le). The argillite is free of clasts and characteristically contains abundant biotite and sericite. The chemical composition of the greywacke matrix (Table 3) is comparable to the average composition of Archean greywackes (Pettijohn, 1972) except for a slight enrichment in K_2O which reflects the abundance of sericite and biotite in this rock. The comparatively high Zr, Sr, and Rb content of these greywackes is indicative of a predominantly sialic provenance for the sediment, a feature that is supported by the high proportion of felsic intrusive pebbles in the conglomerate.

The longest pebble diameters in the conglomerate vary from as little as 1 cm up to 1.8 cm although they are of the order of 5 to 20 cms in most pebbles. Accurate determination of pebble size is however complicated by subsequent tectonic deformation, for although some

Table 3

Chemical composition of conglomerate unit matrix.

Rock Type	Greywacke		Average Archean Greywacke x
Sample No.	250/1	1280/14	
%			
SiO_2	67.91	66.25	66.75
TiO_2	.58	.56	.63
Al_2O_3	13.30	13.61	13.54
FeO	6.40	6.56	5.14
MnO	.10	.09	.12
MgO	2.80	3.06	2.15
CaO	1.38	2.02	2.54
K_2O	2.82	2.65	1.99
P_2O_5	.12	.10	.16
Na_2O	3.10	2.78	2.93
L.O.I.	1.78	1.97	4.36
Total	100.27	99.65	100.31
p.p.m.			
Cr	200	172	
Ni	86	87	
Cu	70	27	
Pb	10	10	
Zn	N.D.	N.D.	
Co	42	48	
Zr	160	148	
Sr	264	426	
Rb	81	82	

x - Pettijohn (1972).

pebbles show no deformation but have undergone rotation, adjacent pebbles may be greatly flattened and stretched with axial ratios of up to 30:1 (Plate 1d). Underground exposures indicate that most pebbles were either subrounded or rounded on deposition. Four pebble types predominate in the conglomerate and they are, in order of decreasing abundance:

i) felspar porphyry, consisting of plagioclase phenocrysts in a quartz, plagioclase, muscovite, groundmass

ii) vein quartz

iii) biotite and hornblende granite

iv) fine grained chloritic schist and minor chert pebbles derived from the underlying volcanic unit.

It is apparent that the majority of pebbles were derived from a granitic terrain or felsic stocks, distal to the present depositional site. It is noteworthy that Holubec (1971) proposed that sediment of the Pontiac group greywackes was derived from a granitic terrain to the south. Pebbles in the conglomerate from the underlying mafic volcanic rocks are volumetrically insignificant.

3.4. The Second Cycle

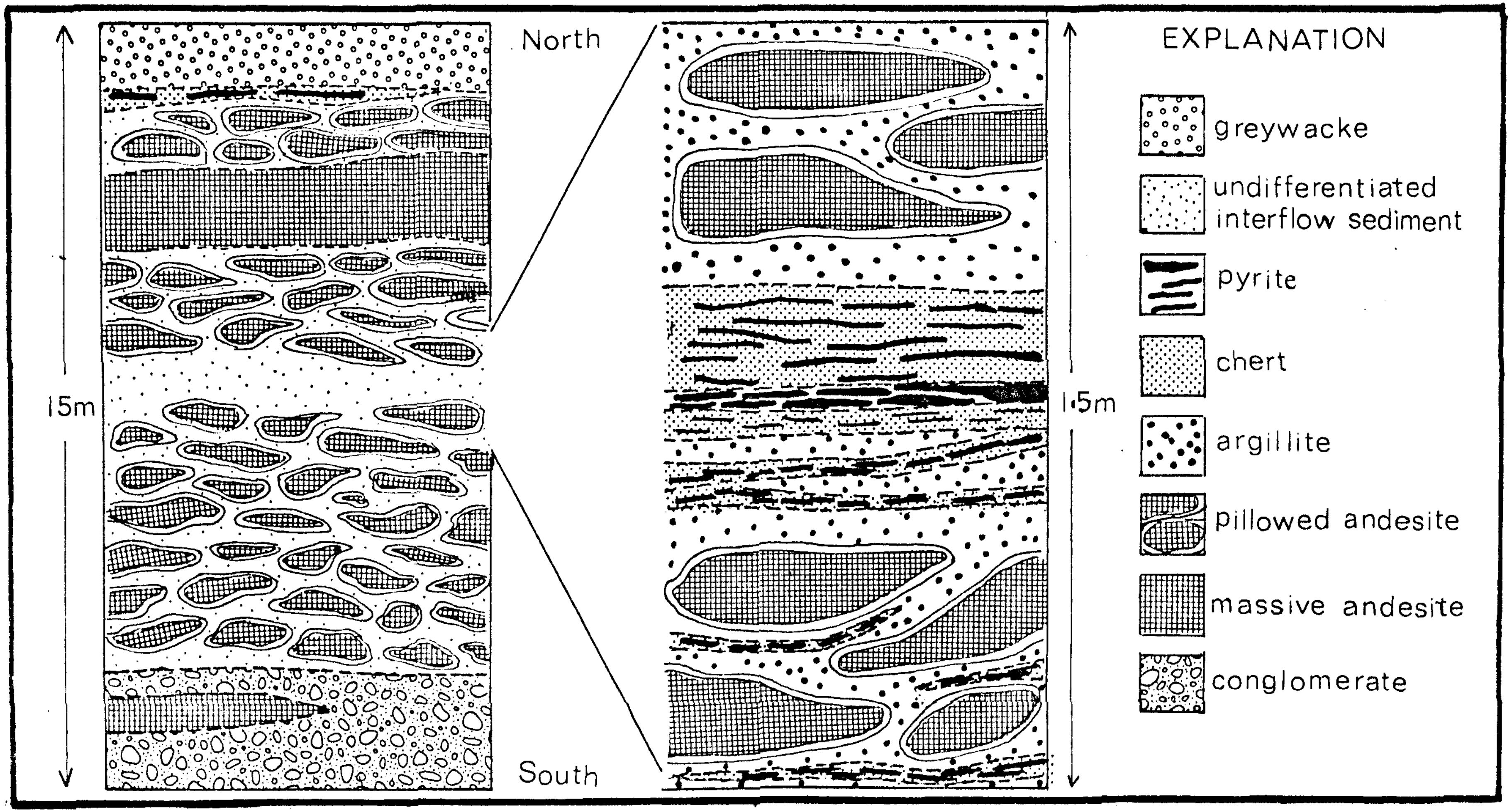
The second cycle consists of a persistent unit of calc-alkaline porphyritic andesite at the base, overlain by impersistent clastic and chemically precipitated sedimentary rocks. It varies between 5 m and 30 m thick depending on whether the sedimentary members are developed.

3.4.a. Porphyritic Andesite Unit

The porphyritic andesite unit is a distinctive and continuous lithologic unit both within the mine and along strike of the Piché group. It ranges in thickness from as little as 3 m, north of No. 2 shaft to in excess of 20 m in the eastern and western extremities of the mine. It has received considerable attention in previous studies on the mine, principally because it is economically important as it hosts the No. 4 vein, from which most of the ore was mined during the initial period of operation.

In its commonest form the andesite occurs as a mass of ellipsoidal pillowed structures, each with a dark grey porphyritic core and a bleached light brown selvage (Plate 1f). Interstitial to the pillows the rock is predominantly a dark biotite rich argillite although locally it is tuffaceous and chert bands are developed (Figure 9). Less commonly, particularly in the upper part, the unit consists of massive dark green porphyritic flows. Deformation of the pillows, subsequent to deposition renders it difficult to determine their original form although larger pillows are up to 2 m long and 1 m in diameter. Smaller lava tubes (0.2 x 0.6 m) extend from the pillows.

In thin section the dark grey pillow cores are seen



SCHEMATIC SECTION THROUGH THE PILLOWED ANDESITE UNIT (data from 750/500E X-cut)

FIGURE 9

to consist of large (< 1 cm) phenocrysts of plagioclase (An 9) in a groundmass of crystals ranging in size from .01 mm to .05 mm and consisting of plagioclase laths, subhedral quartz, biotite, chlorite, chloritoid and muscovite grains (Plate 2a). Apatite, sphene, epidote and rutile occur in varying amounts but are usually accessory. The large euhedral plagioclase phenocrysts are commonly rotated and extensively fractured with calcite, quartz, epidote and sericite developed within the fractures. Chloritoid, chlorite, biotite and quartz have developed in the strain shadows of the large plagioclase phenocrysts. The composition of the andesite is comparable to that of the first cycle (Table 4) and both plot within the calc-alkaline field of Myashiro (1973) and are comparable to the high alkali Archean andesite (Condie, 1976).

The bleached zone surrounding the dark grey porphyritic core is up to 8 cms thick and is interpreted as a chilled pillow selvage. A relict porphyritic texture is evident but the plagioclase phenocrysts are either partially or totally replaced by an assemblage of quartz, calcite and muscovite. The matrix is finer grained than in the pillow core and consists of quartz, sericite, chlorite and chloritoid (Plate 2b).

A chemical analysis (Table 4) of the bleached pillow margin indicates that it is enriched in SiO_2 and CaO and depleted in FeO, MgO and K_2O. When compared to the pillow core it appears that the pillow margins have been more extensively altered than the core. This alteration could have occurred either during deposition of the pillows, as a result of rapid cooling and reaction of the pillow rims with sea water, or during regional metamorphism when the more permeable interstitial argillite adjacent to the margins would have permitted the passage of more metamorphic fluid than the massive pillow cores.

The bleached pillow margins have a sharp contact with the dark interstitial material which consists of variable quantities of argillite chert and volcanic debris. Towards the base of the unit, the rock is predominantly a dark grey argillite, consisting of abundant biotite and sericite (Plate 2c), and is similar to the argillite of the conglomerate unit. An analysis of this rock (Table 4) indicates that it has a high Al_2O_3, MgO, K_2O and FeO content but a low SiO_2 content which reflects the dominance of micas in the rock. In the upper part of the unit, particularly in the centre of the mine the clastic component of the interstitial material diminishes and it becomes more tuffaceous and cherty and is commonly finely laminated. West of No. 2 shaft the chert bands contain stringers of heavily disseminated and massive pyrite (Plate 2d). These pyritic cherts increase in abundance upward through the unit and sporadically developed lenses of massive pyritic chert up to 80 cms thick, locally mark the upper contact of the andesite

Table 4

Chemical composition of calc-alkaline andesites.

Rock	1st cycle Andesite	2nd cycle Porphyritic Andesite		High Alkali Andesite
Sample No.	1500/1	1250/3B	S.P.2	Condie (1976)
%				
SiO_2	56.82	59.41	56.72	58.9
TiO_2	.40	1.22	1.20	.65
Al_2O_3	14.26	15.20	15.30	15.5
FeO	5.49	6.70	6.47	6.0
MnO	.11	.10	.13	-
MgO	4.38	3.44	3.85	4.5
CaO	6.82	4.07	4.42	5.1
K_2O	1.69	1.16	1.81	1.9
P_2O_5	.11	.26	.31	-
Na_2O	3.95	4.44	5.63	4.0
L.O.I.	5.38	3.40	3.54	-
Total	99.41	99.40	99.38	
p.p.m.				
Cr	184	105	93	88
Ni	65	75	72	60
Cu	N.D.	82	70	36
Pb	11	8	10	-
Zn	N.D.	47	57	81
Co	34	35	34	23
Zr	121	254	252	190
Sr	465	324	313	580
Rb	53	44	54	75

Table 4 (Continued)

Rock Type	Bleached Andesite Pillow Selvage	Argillite Interstitial To Pillowed Andesite
Sample No.	S.P.3	S.P.1
%		
SiO_2	67.61	46.94
TiO_2	1.00	1.51
Al_2O_3	12.84	19.01
FeO	1.02	10.83
MnO	.08	.12
MgO	.50	5.51
CaO	7.18	3.84
K_2O	.39	3.46
P_2O_5	.30	.31
Na_2O	4.69	3.24
L.O.I.	3.43	4.79
Total	99.04	99.56
p.p.m.		
Cr	90	121
Ni	49	58
Cu	N.D.	130
Pb	6	18
Zn	N.D.	131
Co	36	35
Zr	244	277
Sr	413	328
Rb	16	97

unit. These pyritic chert bands are considered to be economically important and will be discussed in more detail in a later section, but it will suffice to note here that ore grade within the No. 4 and F veins increases where the veins are developed adjacent to these pyritic chert bands.

The second less common variety of andesite is the dark green massive porphyritic flows. No pillowed structures have been observed in the flows and they differ mineralogically from the pillowed variety in that chlorite is more common than biotite in the quartzo-felspathic groundmass and that plagioclase phenocrysts are more altered to an assemblage of quartz, calcite, epidote and chloritoid.

Considering the economic importance of the andesite unit it is important to understand its origin and to determine its influence on the distribution of mineralisation. The question of whether this unit is extrusive or intrusive has provoked a lively argument amongst previous workers and it is considered necessary here to briefly review this controversy. James and Mawdesly (1927), Gunning (1937) and Blais (1955) all considered this unit to be intrusive into the Piché group. Blais explained the pillowed structures as "compressed, irregularly wave like structures that are most probably due to branching systems of s planes" and added that the dark interstitial material represented a highly sheared variety of andesite.

The writer however agrees with Bell and McLean (1930) who considered the unit to be an extrusive pile of pillow lavas. The conformable attitude of the unit tends to favour an extrusive origin over an intrusive one. Furthermore detailed field relationships and petrographic studies support this view. The numerous minor andesite flows in the upper 3 m of the conglomerate unit is further support for this view. The strongest evidence however is the presence of argillite and pyritic chert in the pillow interstices which are interpreted either as unconsolidated sea floor sediment in which the lavas were deposited or as sediment deposited contemporaneously with the lava flows.

3.4.b. Siliceous Greywacke Unit

Overlying the chert member on the upper contact of the andesite unit are scattered lenses of siliceous greywacke. The lenses are discontinuous and up to 8 m thick and 50 m long. The greywacke is a green, grey colour, mostly fine grained and consists of volcaniclastic, epiclastic and chemically precipitated sedimentary material. Most of the unit consists of subrounded to subangular grains of quartz and lesser plagioclase (0.1 mm) supported by an extremely fine grained matrix (0.005 mm) of quartz, chlorite and carbonate. At the base of the unit the rock has a tuffaceous texture, contains phenocrysts of plagioclase and is considered to represent a pyroclastic phase of the andesite volcanism. Toward the upper contact of the unit however is a 2 m thick massive porphyritic lava flow which is considered to be a late stage of lava extrusion. Most of the unit is massive and shows no evidence of bedding, save for minor lenses of chert, particularly towards the top.

The composition (Table 5) of the greywacke is dissimilar to that of most Archean greywackes (Pettijohn, 1972) and is higher in CaO and Na_2O and lower in K_2O (Table 3). The high CaO and Na_2O content probably reflects the presence of plagioclase although some of the CaO must be due to the extensive carbonate veining. The greywacke is compositionally more like the underlying calc alkaline andesite which suggests that much of this unit was derived from the stratigraphically lower volcanic unit.

The upper contact of the siliceous greywacke is marked by finely laminated carbonaceous chert and argillite which are up to 2 m thick and extend along strike for the length of the greywacke unit. Similar lenses of carbonaceous argillite are common throughout the third cycle and are commonly associated with pyritic chert. Although not extensive, they are economically significant for a number of ore shoots within the quartz veins coincide with local development of carbonaceous argillite and pyritic chert.

In thin section the carbonaceous argillite consists of fine grained (< 0.1 mm) alternating laminae of sericite, chert and carbonaceous material (Plate 2e). Bedded sulphides, predominantly pyrite with minor chalcopyrite, constitute between 2% and 15% of the rock. Crenulation folding of the laminae is common and is considered to be due mainly to regional deformation although soft sediment deformation could be partly responsible.

Chemically these rocks have high SiO_2 and K_2O contents (Table 5) which reflect the presence of abundant chert and sericite respectively. Although the abundance of gold is low (< 15 p.p.b.), copper (200 p.p.m.) and zinc (570 p.p.m.) are higher in this rock than in other rocks of the Piché group. An x-ray diffraction pattern (Figure 10) of the separated carbonaceous material indicates that it is in the form of disordered graphite which corresponds to the upper greenschist facies metamorphism (French, 1964). Myashiro (1975) found that carbon is in the amorphous form under low temperature metamorphic conditions but that the crystallinity of graphite develops under conditions of epidote amphibolite facies.

3.4.c. <u>Biotite Greywacke</u>

The greywacke is similar in distribution to the underlying siliceous greywacke and is present only in two depositional basins in the east and west of the

Plate 2

a. Photomicrograph of porphyritic andesite showing fractured plagioclase phenocrysts in a fine grained quartz, plagioclase and biotite groundmass.

b. Photomicrograph of the bleached and altered selvage to an andesite pillowed flow consisting of a quartz rich matrix and fractured and altered plagioclase phenocrysts.

c. Photomicrograph of fine grained argillite from between the pillows consisting of a quartz biotite plagioclase groundmass and darker bands of biotite.

d. Photograph of banded pyrite in a dark cherty groundmass between the bleached selvages of two pillows (light bands on top and bottom of the sample).

e. Photomicrograph of finely laminated carbonaceous argillite. Carbonaceous material and pyrite (dark), chert (light), and micaceous (medium grey) bands make up the rock.

f. Photomicrograph of chloritic tuffwacke consisting of chlorite, quartz and plagioclase with a large dark chloritic inclusion on the right.

PLATE 2

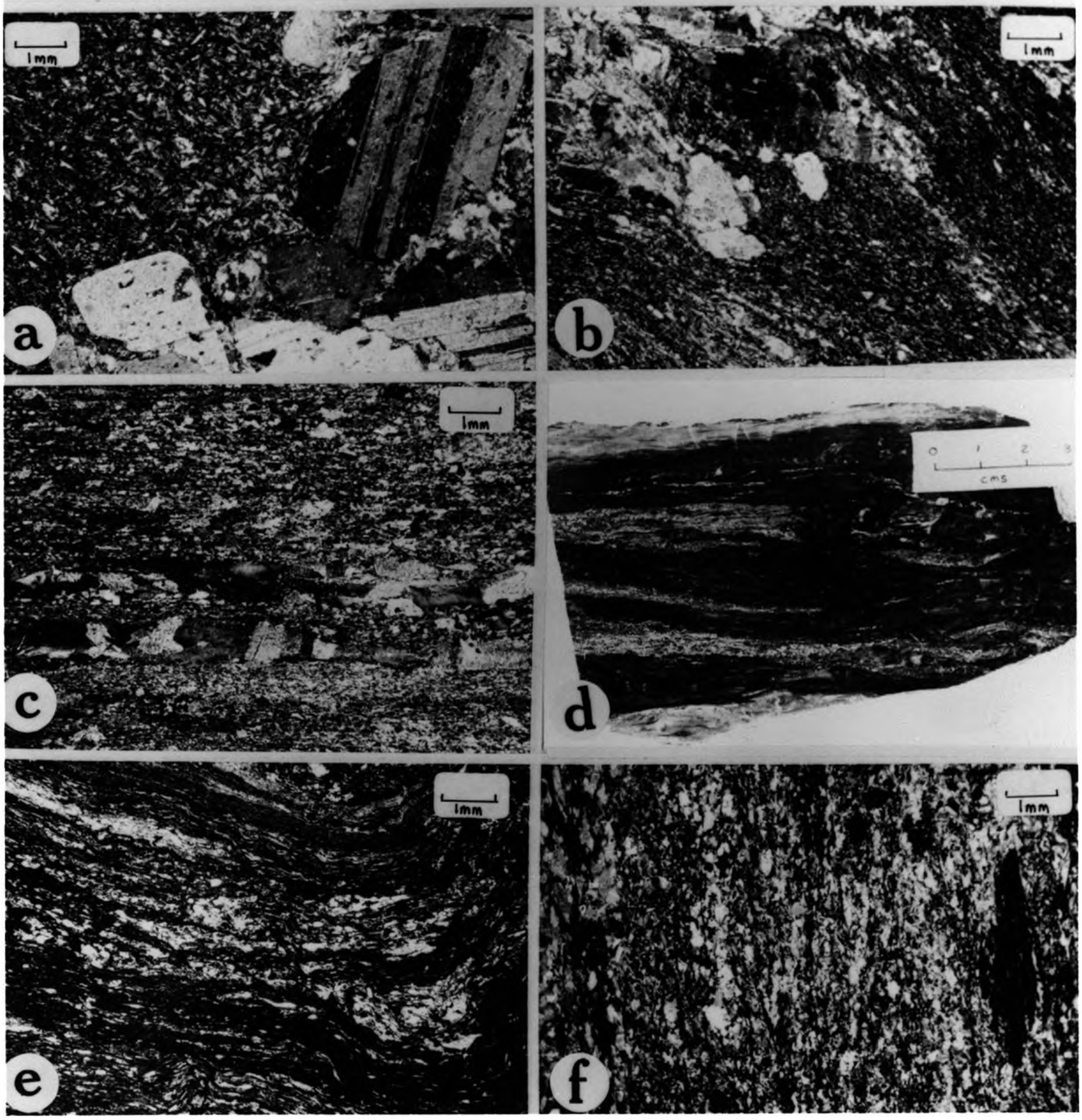
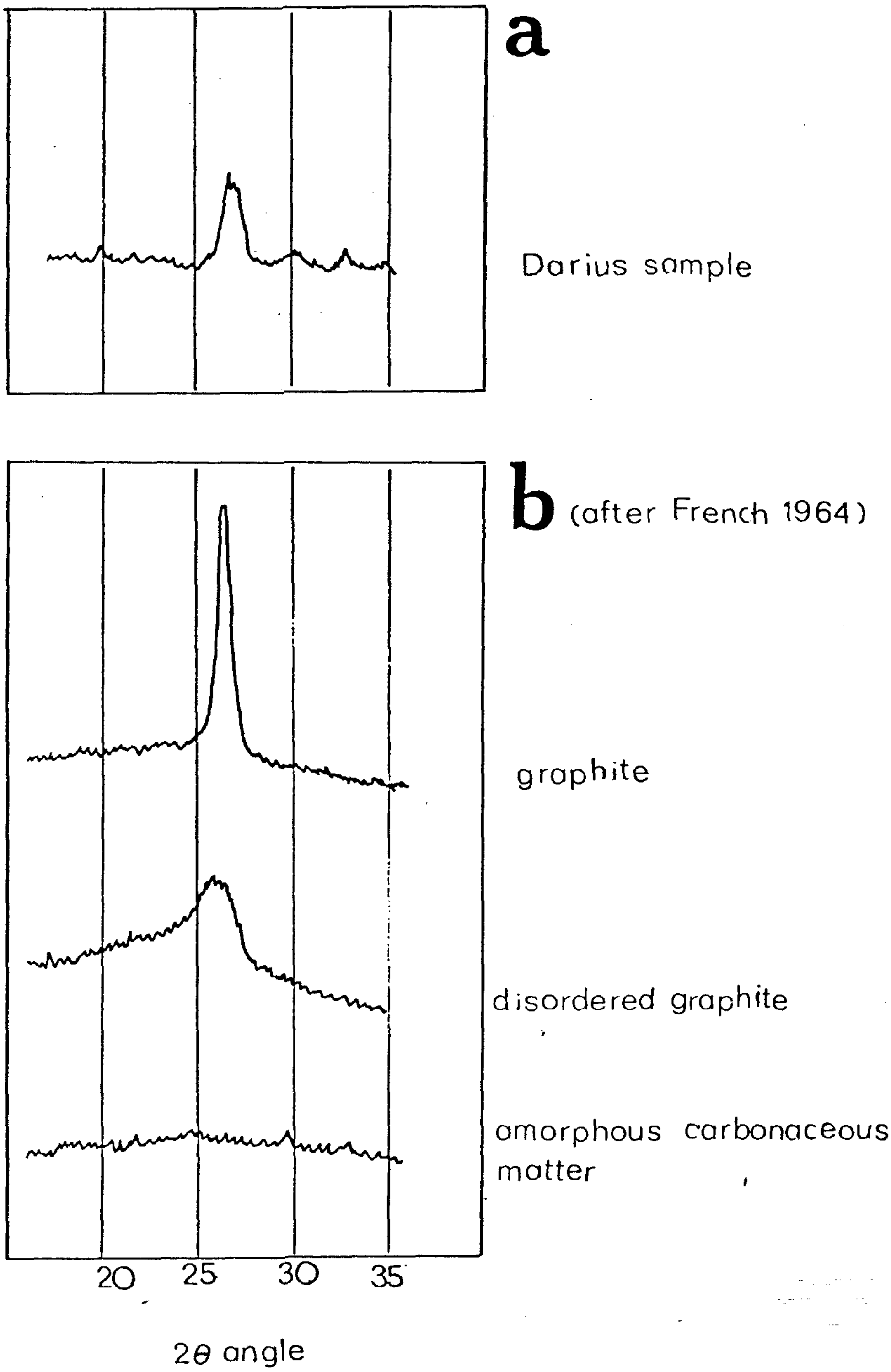


Table 5

Chemical composition of the second cycle sedimentary rocks.

Rock Type	siliceous greywacke		carbonaceous argillite	
Sample	375/2	625/20	375/3	1250/GB
%				
SiO_2	54.20	61.60	66.52	63.12
TiO_2	.77	.58	.52	.56
Al_2O_3	16.71	16.26	12.12	13.52
FeO	6.70	4.68	6.43	6.20
MnO	.17	.12	.04	.07
MgO	3.47	2.04	.97	2.88
CaO	7.01	5.00	2.43	2.92
K_2O	.39	.28	4.13	3.94
P_2O_5	.10	.08	.03	.08
Na_2O	4.20	6.01	N.D.	.50
L.O.I.	5.68	3.24	6.94	5.79
Total	99.40	99.45	100.13	99.58
p.p.m.				
Cr	36	33	30	89
Ni	46	61	65	61
Cu	51	42	200	158
Pb	5	10	9	12
Zn	1	N.D.	570	208
Co	28	33	23	18
Zr	73	77	86	120
Sr	279	388	35	82
Rb	17	13	70	89



X-RAY DIFFRACTION PATTERNS OF CARBONACEOUS MATERIAL

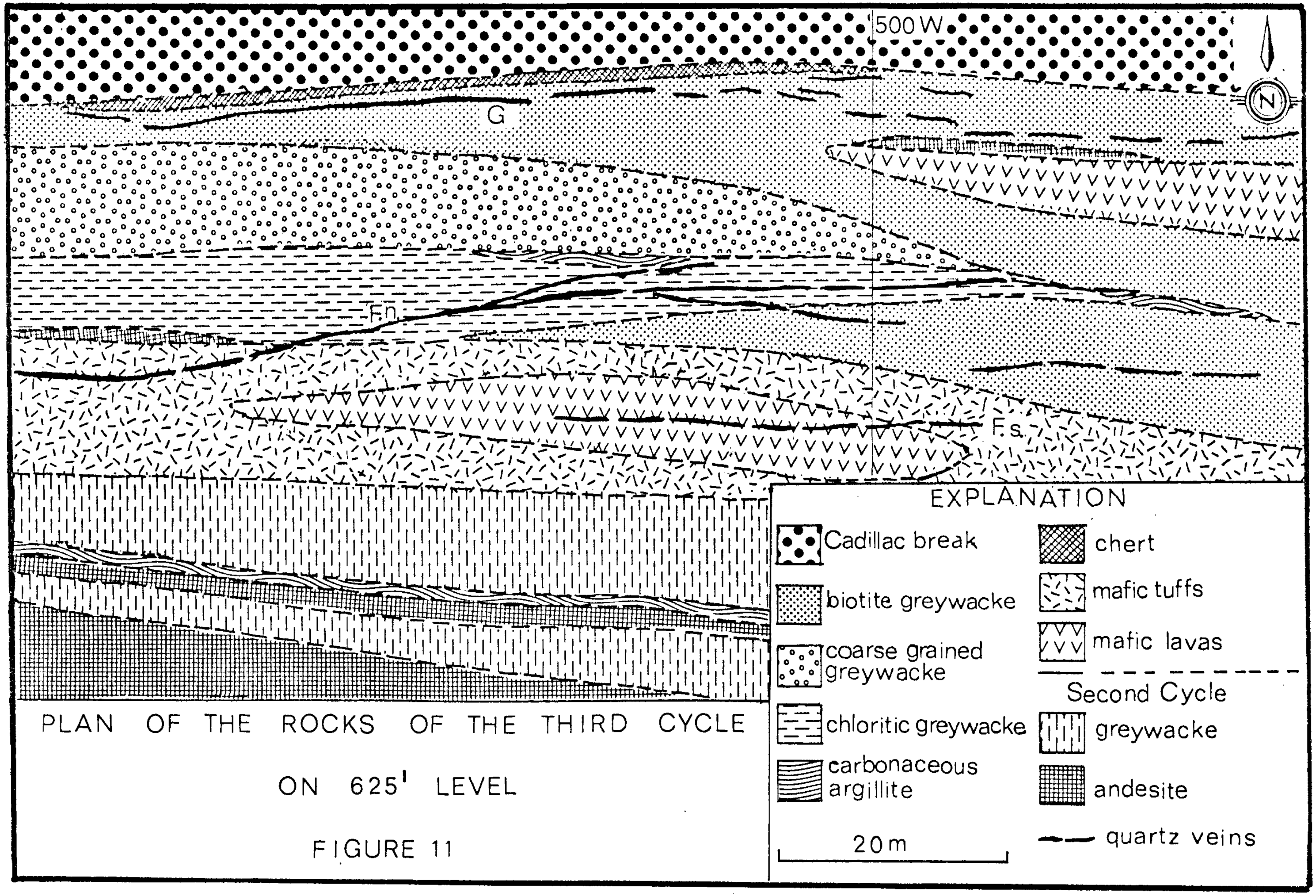
FIGURE 10

mine. It consists of a fine matrix of quartz and biotite with less amounts of calcite and sericite which supports larger (0.5 mm) subrounded to rounded clasts of quartz and plagioclase. In both macroscopic and microscopic appearance it is similar to both the greywacke matrix of the conglomerate unit and the epiclastic greywackes of the overlying third cycle.

North of No. 3 shaft the upper contact of the biotite greywacke is marked by the development of a 2 m wide translucent light brown band of felsic tuff and chert, which extends for 100 m along strike. At the base it is massive and has a tuffaceous texture consisting of anhedral plagioclase grains in a fine grained quartz and sericite matrix, with minor chlorite. In the upper part, microcrystalline chert laminations predominate. The rock is interpreted as representing the contemporaneous deposition of andesite pyroclastic material and chert in isolated depositional basins.

3.5. The Third Cycle

The third cycle (Figure 11) is comprised of mafic tholeiitic lava flows and tuffs, biotite and chlorite rich greywacke, chert and argillite lenses, some of which are carbonaceous. Typically rapid lateral gradations from one of these rock types to another are common within this volcano sedimentary succession. The base of the cycle is defined by the lowest mafic volcanic rocks



PLAN OF THE ROCKS OF THE THIRD CYCLE

ON 625' LEVEL

FIGURE 11

which overlie the calc-alkaline andesites and related sediments of the second cycle, whereas the upper contact of the cycle abuts against the highly schistose rocks of the Cadillac break. The complexity of stratigraphy in this cycle is emphasised by Gunning (1937) who referred to it as a "waste basket division" which consisted of "a complex assemblage including greywacke, tuff, greenstone ... highly carbonated and chloritised and containing micaceous rocks of uncertain origin and probably some basic intrusives."

Economically the rocks of the cycle are important for east of No. 2 shaft the No. 4 vein is conformable with the basal contact of the cycle and in the centre and west of the mine the "F" vein system is developed in these rocks.

3.5.a. Mafic Tholeiitic Volcanic Unit

A mafic volcanic member consistently marks the lower contact of the third cycle and because sedimentary rocks of the second cycle are only locally developed, it is commonly in contact with the porphyritic andesite. In some parts of the mine this is the only mafic volcanic member of the third cycle but elsewhere one or two other mafic volcanic members are intercalated with the higher sedimentary rocks (Figure 12). The pervasive well developed schistosity in the volcanic rocks, close to the break makes it difficult to distinguish between lavas and tuffs in underground exposures although microscopic examination of these rocks indicates that tuffs predominate over lavas.

Mafic flows are highly altered to chlorite schists. Corroded relicts of actinolite and plagioclase (An 8) crystals are surrounded by a ground mass of quartz, chlorite, carbonate and epidote with accessory magnetite and sphene. Associated with the mafic flows are coarser gabbroic rocks, referred to as gabbroic greenstone by Blais (1955). This rock is distinctive underground on account of its blocky outcrop pattern and comparative lack of alteration. Although it is predominantly medium grained it locally becomes coarser grained and porphyritic. Here subhedral phenocrysts of plagioclase are set in a fine grained groundmass of plagioclase, actinolite and lesser amounts of chlorite, quartz and carbonate. An intrusive contact has been observed between this rock and tuff beds but in other exposures the rock is apparently conformable with lava flows. It is also significant that its distribution is restricted to the mafic volcanic members of the third cycle. Although its field relationships with surrounding rocks are not conclusively established it appears that it is a high level subvolcanic intrusion which laterally grades into an extrusive mafic flow.

The mafic tuffs have a pronounced schistosity and are metamorphosed to chlorite schists. Chlorite predominates in a fine grained groundmass which also contains quartz and plagioclase (Plate 2f). Calcite is widespread throughout the rock, occurring within the groundmass and in lenses and veinlets parallel to schistosity. Pyrite and magnetite are accessory minerals. In most places the contact between tuffs and sedimentary rocks is gradational both laterally and vertically and chloritic tuff grades into tuff wacke and eventually into greywacke with a progressive increase in the clastic component in the rock.

The compositions (Table 6) of the mafic lavas and tuffs are comparable to similar rocks in the first cycle and plot within the tholeiitic field of Myashiro (1973) (Figure 13). Of significance the two samples of gabbro analysed are indistinguishable from mafic lavas, suggesting a co magmatic origin and supporting observations made underground and in petrographic studies.

3.5.b. Greywacke Unit

The greywacke unit consists of a number of members of volcaniclastic and epiclastic sedimentary rock intercalated with mafic tuffs and lavas. Individual members extend for up to 300 m along strike and range up to 30 m thick although they are commonly less than 80 m long and 10 m thick. The most widespread development of greywackes is in the eastern and western extremities of the mine. Mineralogically the greywacke ranges from

Table 6

Chemical composition of the third cycle mafic tholeitic rocks.

Rock Type	Mafic tuff	Mafic lava	Gabbro	Gabbro
Sample	1000/1	625/7	750/8	500/9
%				
SiO_2	43.63	47.67	49.01	46.52
TiO_2	1.00	1.00	.98	.94
Al_2O_3	11.79	12.54	14.51	12.91
FeO	13.44	12.24	11.81	13.87
MnO	.23	.19	.26	.23
MgO	8.71	7.80	5.05	9.92
CaO	8.92	5.89	10.99	9.22
K_2O	.09	.72	.43	.32
P_2O_5	N.D.	.02	.01	.01
Na_2O	1.17	2.58	1.87	2.05
L.O.I.	11.46	8.99	4.18	2.95
Total	100.44	99.64	99.09	98.94
p.p.m.				
Cr	100		68	
Ni	119		73	
Cu	107		92	
Pb	1		5	
Zn	N.D.		N.D.	
Co	73		60	
Zr	45		41	
Sr	123		132	
Rb	6		10	

volcaniclastic tuffaceous to epiclastic biotite-rich varieties. Lateral and vertical changes in composition and grain size occur over a few metres. Generally individual beds are apparently massive, for bedding features were not observed, however an upward and lateral fining of grain size was observed in some beds. In underground exposures close to the Cadillac break extreme deformation of the rock rendered it difficult to map individual beds.

Mineralogically the greywacke consists of subangular to subrounded clasts of quartz and plagioclase (0.2 mm - 0.5 mm) set in a fine grained schistose matrix composed of variable amounts of quartz, muscovite, biotite and chlorite. Accessory minerals include epidote, magnetite rutile and pyrite. The commonest varieties include,

i) Chloritic tuffwacke which is a lateral variation of the mafic tuffs and in which chlorite is the dominant groundmass constituent,

ii) Micaceous greywacke in which the matrix is dominated by biotite and to a lesser extent muscovite and contains variable proportions of quartz and plagioclase clasts,

iii) Coarse grained greywacke in which 0.5 mm to 1 mm clasts of quartz and plagioclase constitute the bulk of the rock. A fine grained quartz and micaceous groundmass is interstital to the larger clasts (Plate 3a).

The chloritic tuffwacke is considered to be composed predominantly of volcaniclastic constituents whereas the latter two varieties contain more epiclastic material and are evidence of continued supply of detritus to the depositional environment, during the extrusion of lavas and tuffs. A chemical analysis of the micaceous greywacke is comparable to the average Archean greywacke (Pettijohn, 1972) although it has a higher K_2O content which reflects the abundance of biotite in the rock (Table 7).

3.5.c. Argillite and Chert Units

These two rock types are considered together for despite their petrographic and chemical differences they occur in a similar stratigraphic position, which is economically significant for the veins of the "F" system are commonly mineralised where they are developed adjacent to cherts and argillites, particularly where the latter is carbonaceous. Their common stratigraphic position indicates that tectonically similar conditions prevailed during deposition of both rock types. This supposition is supported by field relationships in which lenses of argillite locally grade into thin lenses of chert along strike.

The argillite is an extremely fine grained rock which is usually massive, although locally it is finely laminated. In thin section it is uniformly fine grained with few grains exceeding 0.01 mm in length. The groundmass is dominated by an aggregate of biotite (Plate 3b)

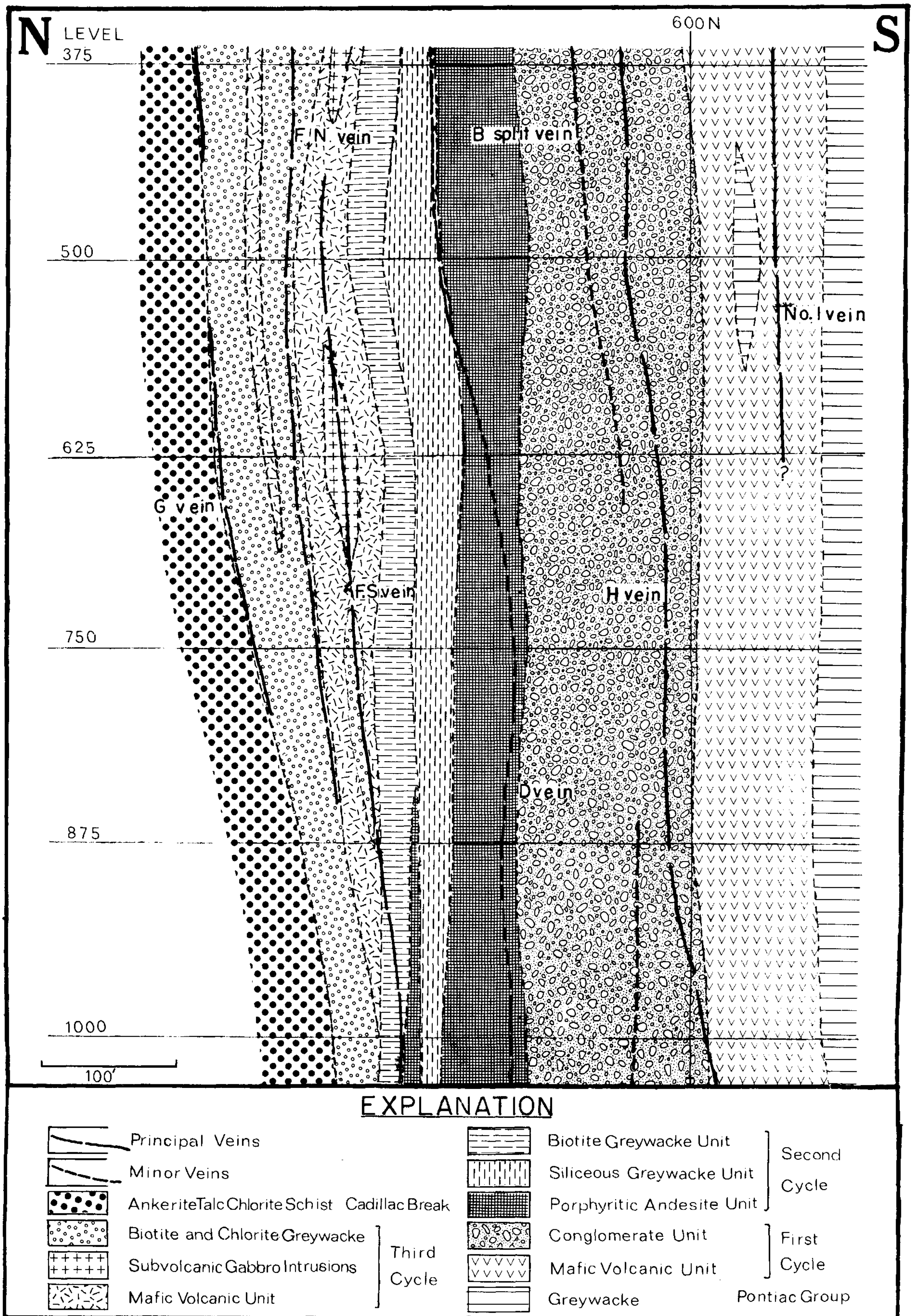
Table 7

Chemical composition of the third cycle sedimentary rocks.

Rock Type	Greywacke	Argillite		Timiskaming Greywacke
Sample	750/5	625/5	625/21	(Pettijohn 1972)
%				
SiO_2	58.51	56.41	53.73	56.95
TiO_2	.57	.79	.78	-
Al_2O_3	16.22	17.63	16.36	16.67
FeO	6.44	8.63	8.57	7.58
MnO	.07	.10	.14	.40
MgO	4.69	3.28	3.32	3.22
CaO	2.02	4.00	5.44	4.15
K_2O	4.52	4.58	3.94	2.43
P_2O_5	.15	.11	.13	-
Na_2O	2.43	2.25	2.87	2.94
L.O.I.	3.70	3.15	4.19	4.0
Total	99.32	100.93	99.47	98.35
p.p.m.				
Cr	38	30	36	
Ni	27	25	40	
Cu	87	142	89	
Pb	N.D.	11	12	
Zn	N.D.	56	N.D.	
Co	26	38	39	
Zr	87	81	77	
Sr	77	163	165	
Rb	89	84	74	

and interstitial microcrystalline quartz with lesser amounts of muscovite and chloritoid. Incipient retrograde metamorphism of biotite to chlorite is observed. The rock has a higher FeO and K_2O content than other sedimentary rocks of the Piché group (Table 7) which reflects its abnormally high biotite content. It is similar in composition to the Timiskaming greywacke at Granada (Pettijohn, 1972) with the exception of a higher K_2O content which reflects the dominance of biotite over detrital quartz. Many of the argillites are carbonaceous as described in section 3.4.b. and are significant for their close association with minor chert lenses. These chert lenses seldom exceed 50 m in length or 1 m in width, and consist of a fine grained matrix of microcrystalline quartz with minor amounts of chlorite and muscovite. Most of the chert is a massive dark grey variety (Plate 5f) but locally it is finely laminated (Plate 5e) and contains bands of massive pyrite.

A distinctive band of laminated chert extending from 375' level to 625' level, marks the contact between greywacke and the schists of the Cadillac break. This chert band coincides with a mineralised portion of the G vein and consists of thick (1 cm) layers of microcrystalline quartz and thin 1 mm laminations of biotite and pyrite. Soft sediment deformation of the fine laminations is evident (Plate 5c). Along strike the sulphide content of this chert band increases until it appears



SECTION 530 W THROUGH THE PICHE GROUP BETWEEN 375 AND 1000 LEVELS.

Figure 12

similar to a sulphide facies iron formation.

3.6. The Cadillac Break

This is the most northerly unit exposed underground and consists of approximately 50 m of highly altered ankerite-talc-chlorite schist. Deformation is so extreme and alteration so pervasive that it is difficult to determine with any certainty the original chemical and mineralogical composition of the rock. In thin section the rock is seen to consist of a well foliated mass of talc, chlorite and Fe and Mg rich carbonates (Table 9). The carbonate occurs both within the groundmass and as lenses and veinlets. Although no significant variations in this mineralogy were observed in five thin sections of samples from various parts of the break, it may perhaps be unrealistic to view the break as a single lithologic unit which is less competent than the surrounding rocks. In a crosscut through the break on 500' level eight chert or argillite lenses were mapped in the ankerite-talc-chlorite schist and appeared to be primary stratigraphic units. They are comparable in appearance, despite deformation, to the interflow sedimentary rocks in the mafic volcanic strata in the first and third cycles.

Blais (1955) believed that, at depth the break progressively cuts across the rocks of the Piché group. The writer could find no evidence of this and believes that any apparent disconformable relationship of the

Table 8

Chemical composition of ankerite talc carbonate schist.

Rock Type	Ankerite-Talc-Chlorite Schist		Ultramafic Basalt
Sample	500/A	500/B	(Jolly 1975)
%			
SiO_2	43.82	32.70	42.30
TiO_2	.33	.84	.51
Al_2O_3	6.19	14.31	6.6
FeO	12.42	16.38	11.8
MnO	.17	.17	.18
MgO	19.50	20.08	24.7
CaO	6.19	4.32	6.93
K_2O	N.D.	.21	.11
P_2O_5	N.D.	.01	-
Na_2O	N.D.	N.D.	.32
L.O.I.	10.54	11.05	
Total	99.16	99.47	
p.p.m.			
Cr	2126	925	
Ni	980	419	
Cu	52	71	
Pb	N.D.	9	
Zn	N.D.	N.D.	
Co	60	100	
Zr	20	47	
Sr	34	67	
Rb	5	9	

Table 9

Composition of carbonates in the schists of the Cadillac break analysed by electron microprobe.

	Average of analysis of 9 grains
MgO	17.18
CaO	29.88
MnO	.59
FeO	7.03
CO_2	45.80
Total	100.48

break to the volcano-sedimentary units of the third cycle can be explained by the rapid thinning of individual units (Figure 12). On a regional scale the rocks of the break are apparently conformable to the Piché group (Figure 2). Support for this conformable attitude is found within the mine in the development of the finely laminated chert of the "G" vein (section 3.5.) on the contact of the break and the underlying greywackes of the third cycle.

Ridler (1970) suggested that the Kirkland-Larder Lake break, a feature similar to and laterally co-extensive with the Cadillac break is an exhalative carbonate rich sedimentary horizon. More recently Stricker (1978) indicated that it may be of carbonatitic origin. Analysis of two samples of rock from the break indicate that at Darius the break is of ultramafic composition and comparable to high magnesium ultramafic volcanic rocks (Jolly, 1975). It is characterised by low SiO_2 content and high FeO, MgO, and variable Al_2O_3 content. In addition it has an exceptionally high Ni and Cr content, features characteristic of ultramafic rocks (Table 8).

3.7. Metamorphism

Two stages of metamorphism are recognised in the Piché group rocks on the mine. Regional metamorphism, associated with the Kenoran orogeny, was low grade and mineral assemblages correspond to the greenschist facies

(Winkler, 1974). In this stage, metamorphism resulted in recrystallisation with both mineralogical and structural transformations in the rocks. Platy minerals such as chlorite,muscovite and biotite have recrystallised in an orientation parallel to the axial plane cleavage of the regional folds. In the mafic volcanic rocks the most common minerals are albite, actinolite, quartz, chlorite, epidote and carbonate, whereas in the sedimentary rocks quartz, albite, biotite, chlorite and muscovite are common. Generally regional metamorphism was prograde, but retrograde metamorphism is widespread, though poorly developed and is most evident as biotite replacement of actinolite and chlorite replacement of biotite.

The presence of altered pillow rims in the porphyritic andesite is inconclusive evidence that regional metamorphism was superimposed on an earlier sea floor metamorphism of volcanic rocks in which extruded lavas and tuffs reacted with sea water.

The second stage of metamorphism is associated with quartz vein emplacement and is restricted to the vein alteration selvages. In this stage, initial temperatures appear to have been higher than during regional metamorphism for biotite is the common mineral in selvages of veins developed in the mafic volcanic rocks.

3.8. Structure

Recognition of the principal structural elements has proved important in locating many ore shoots in the quartz veins. The regional structure of the area has been discussed in Chapter 2 and detailed structural studies in the mine have been made by Gunning (1937), Mills (1950) and Blais (1955). Thus only the main structural elements are summarised here as they effect the stratigraphy and distribution of veins. The dominant schistosity, parallel and subparallel to the steeply dipping lithologic units, is of the axial planar type and corresponds to the second period of folding (Goulet, 1978) about an east-west axis. The schistosity is best developed in the rocks immediately adjacent to the Cadillac break. Quartz veins are emplaced parallel, or at low angles, to schistosity and are best developed in the more competent strata, particularly the conglomerate and porphyritic andesite units. Tight small scale isoclinal folding of strata about steeply plunging axies is common in the Pontiac group south of the mine, but no such folding has been recognised in strata underground.

Six fault sets have been mapped underground and include strike, transcurrent and dip faults (Table 10). The Cadillac break and reverse strike faults predate emplacement of the quartz veins whereas the remainder post date vein formation. However fault displacement seldom exceeds a few metres and faults are not considered

Table 10

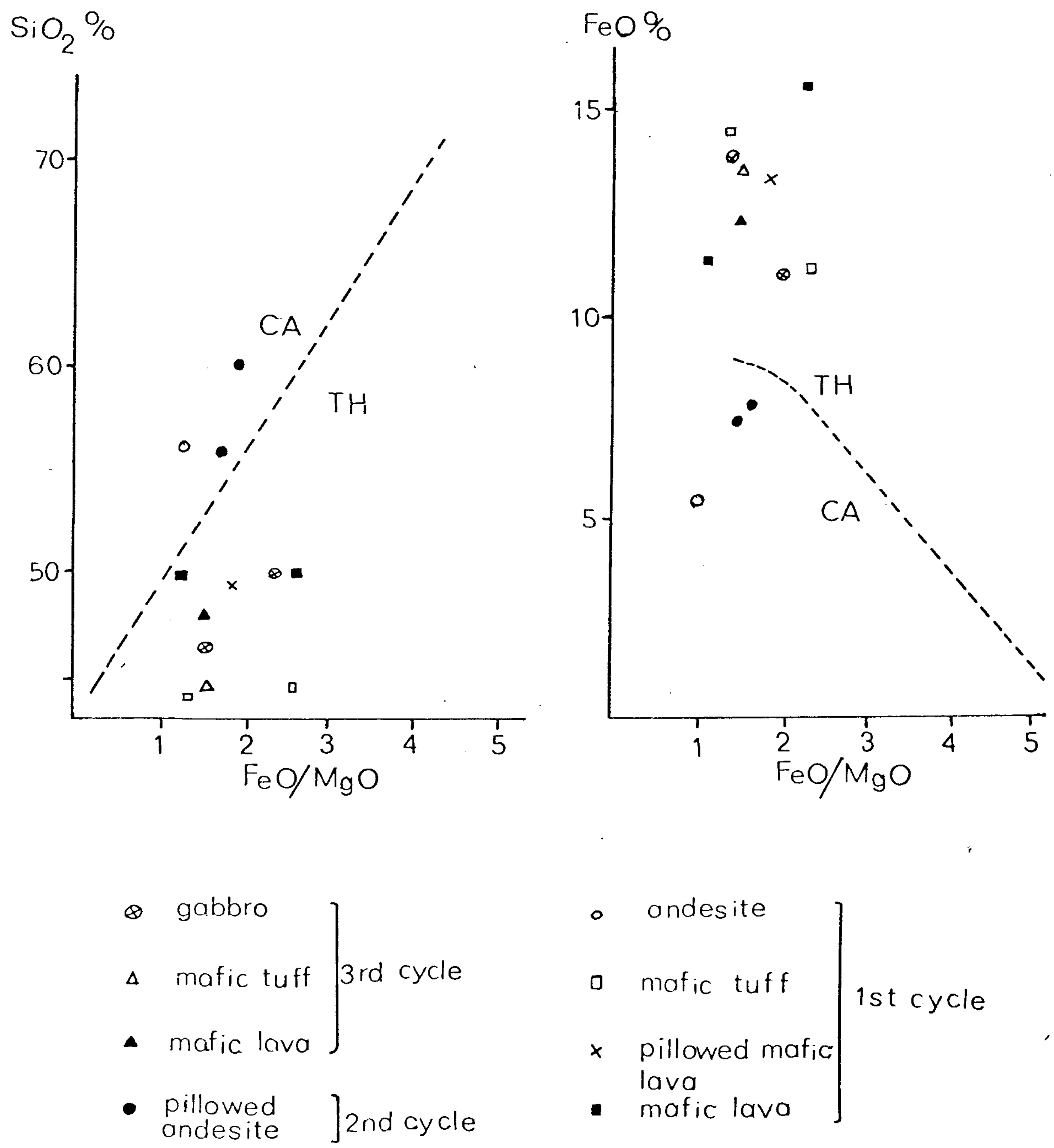
Classification of fault sets - modified from Blais (1955).

Fault Type		Dip	Maximum Displacement
Bedding Faults (Cadillac break)		Steep	?
Strike Faults	Reverse	60-80°N	10 m
	Normal	45-75°N	2 m
Transcurrent Faults	North East striking	Steep	3 m
	North West striking	Steep	4 m
Dip Faults	Reverse dip slip	45°E or W	2 m

a serious problem in mining at Darius.

3.9. Classification of Piché Group Volcanic Rocks

In view of the pervasive alteration of volcanic rocks of the Piché group, which possibly could have affected the Fe^{2+}/Fe^{3+} ratio of the rocks, the normal procedure of rock classification by means of the AFM diagram is of doubtful applicability. Thus the classification of Myashiro (1973), in which the ratio of total FeO to MgO is plotted against total FeO and SiO_2, is adopted here (Figure 13). By this classification the mafic volcanic rocks of both the first and the third cycles and the subvolcanic gabbroic intrusions plot within the tholeitic field. There is however no discernable differentiation trend between the rocks of these two cycles. The andesites in both the first and second cycles, however, plot within the calc alkaline field (Figure 13).



COMPOSITIONAL DIAGRAM OF THE VOLCANIC ROCKS OF THE PICHÉ GROUP

FIGURE 13

CHAPTER 4

QUARTZ VEIN SYSTEMS AND ORE SHOOTS

4.1. General Statement

Darius Mine is noted for the numerous quartz veins which contained most of the ore that has been mined. Two sets of quartz veins have been recognised, the first carries sporadic mineralisation and consists of numerous steeply dipping to vertical veins which strike parallel or at low angles to stratigraphic strike (Figure 12). The second set which post dates the first is horizontally disposed, unmineralised and volumetrically insignificant and shall not be considered further.

The number of first set veins present in the Piché group is related to its thickness. Fifteen vein systems have been mapped including, Nos. 1, 4, 7, 9, 14, A, B, B split, C, D, F (south), F (north), G and H. Although most of these veins have been explored by underground workings, more than 90% of Darius ore has been mined from 4 major vein systems, No. 1, No. 4, H and F. However even in the producing veins gold is erratically distributed in the ore shoots which constitute somewhat less than 10% of the total volume of each vein system.

In this chapter an initial general description of quartz veins is followed by a description of the ore shoots in the four principal vein systems. Sections summarising previous studies, which are pertinent to this study are included where necessary.

4.2. Quartz Vein Systems

4.2.a. Distribution and Configuration of Quartz Veins

Quartz veins occur throughout all rock types of the Piché group (Figure 12). All the veins strike within 10° of east-west, dip within 10° of vertical. Over the length of the mine workings they tend to be slightly discordant to the major rock units, locally however veins may follow bedding or a lithologic contact for a short distance. A few veins, for example No. 1 are continuous for up to 300 m but for the most part veins extend over distances of only 30 to 150 m and within any particular vein system the veins tend to have an en-echelon distribution. They range in thickness from 10 cms to 2 m although most are between 15 and 40 cms. Minor quartz vein stringers are common within 20 cms of the main vein and in places large veins split into a myriad of small anastomising veinlets.

The No. 1 vein system consists of two branching veins, No. 1 S.W. and No. 1 N.W. which diverge from a vein junction south east of No. 2 shaft (Figure 14). At the vein junction located on the contact of the mafic volcanic and conglomerate units of the first cycle, the vein is tightly deformed and is the site of an important ore shoot. The veins are typically single lead and vary in thickness between 10 cms and 1 m. Within this system the southern veins transect individual lava flows and tuff beds of the mafic volcanic unit at a low angle although locally the vein is developed along the contacts of the mafic members. The northern veins of the system are in the massive conglomerate unit.

The H vein system also occurs within the conglomerate unit of the first cycle in the centre and west of the mine, and commonly consists of a principal vein up to 30 cms wide, with 2 or 3 adjacent discontinuous and thinner veins. Locally it splits into 2 major veins. The veins are seldom exceed 150 m in length and underground exposures indicate that this system consists of a number of veins in en-echelon array.

The No. 4 vein system is the most important producer on the mine and is considered in some detail in this study because of its difference to other veins. It commonly consists of a single 30 cm wide vein which in the central section is developed on the contact of the conglomerate and porphyritic andesite units. To the east it transects the andesite unit and eventually follows the upper contact with the mafic volcanic unit of the third cycle. Within the andesite unit the vein is locally conformable to individual flows and is developed within the interflow argillites and pyritic cherts (Figure 15).

The "F" vein system includes a number of veins within the mafic volcanic rocks, greywackes and argillites of the third cycle. The veins are continuous for up to 200 m and their form is variable, ranging from massive single veins (Plate 3d) between 30 and 100 cms thick to a myriad of anastomising veinlets. The veins transect both individual lava flows and beds of tuff and greywacke and are developed along the contacts of these units (Figure 11).

4.2.b. Vein Mineralogy

The veins consist predominantly of mosaic textured quartz with minor amounts of albite, ankeritic dolomite, calcite, tourmaline and sulphides. Altered inclusions of sericitic, biotitic and chloritic wallrock are common.

Most of the veins consist of large (1 mm - 5 mm) anhedral quartz grains although in places the quartz is in the form of fine anhedral grains (Plate 3e). The margins of larger grains are commonly sutured and surrounded by clusters of smaller undeformed quartz grains (Plate 3c) which appears to have formed by recrystallisation. Deformation and fracturing of the larger

Plate 3

a. Photomicrograph of a coarse grained greywacke consisting of large subrounded to subangular clasts of quartz and plagioclase in a quartz plagioclase biotite groundmass.

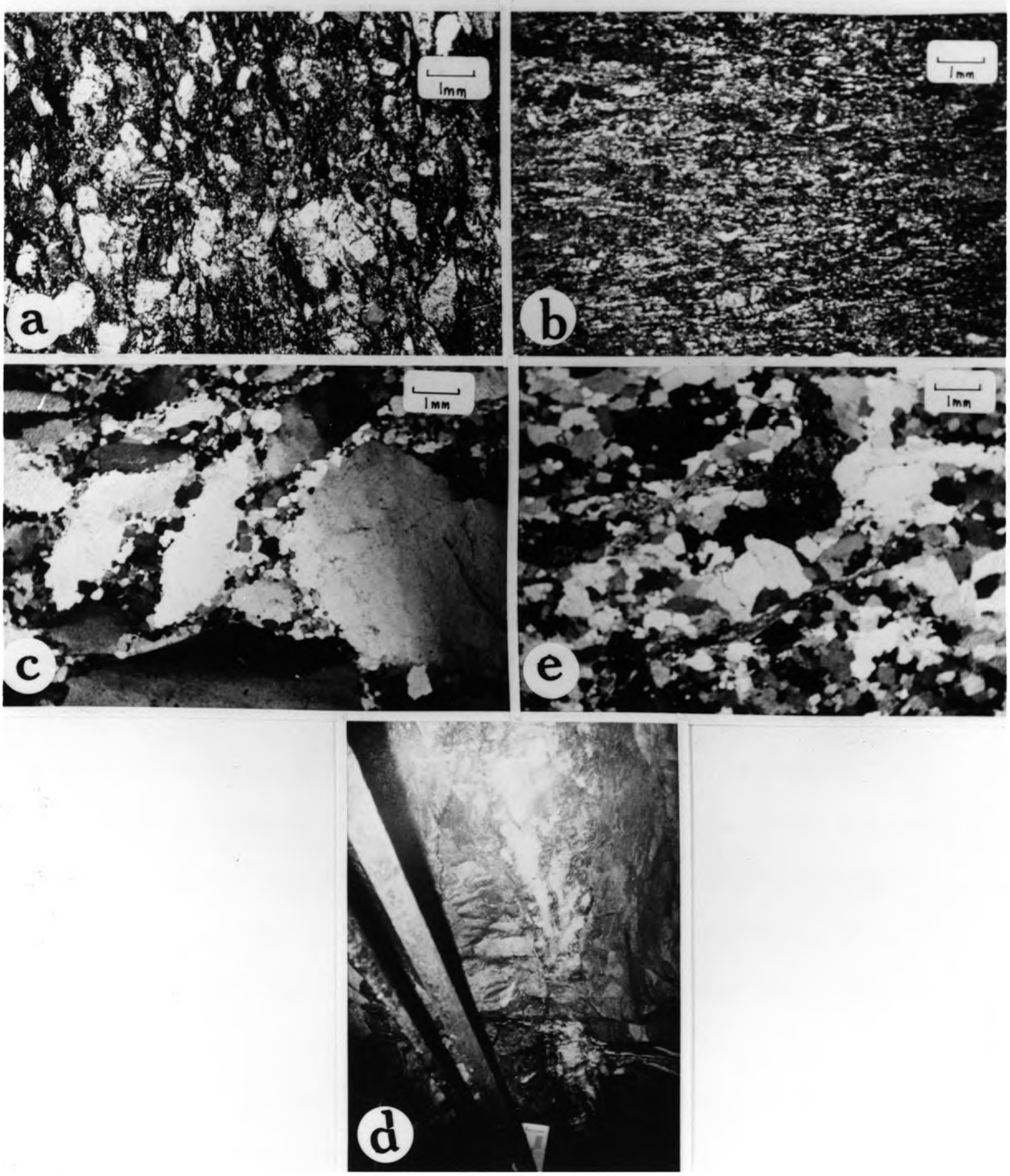
b. Photomicrograph of a massive argillite consisting of biotite (dark), quartz and felspar (light).

c. Photomicrograph of a coarse grained quartz mosaic in a quartz vein.

d. Underground exposure of the "F" vein in greywacke of the third cycle.

e. Photomicrograph of a fine grained quartz mosaic in a quartz vein with a thin veinlet of sericite and carbonate across the lower half of the photograph.

PLATE 3



quartz grains, strain shadows and undulose extinction are widespread features in the vein quartz (Plate 3c). Liquid and solid inclusions in the vein quartz are common.

Carbonate grains are interstitial to the quartz matrix and also comprise later lenses and veinlets which transect the quartz veins (Plate 4a). There is no apparent relationship between the composition of the host rock in which the quartz is developed and the vein carbonate composition. Electron microprobe analyses of carbonates (Table 11) indicate that ankeritic dolomite is commonly interstitial to the quartz whereas the more abundant calcite comprises the later lenses and veinlets.

Albite (An 5-10) locally constitutes up to 10% of the vein and is the most common silicate. Its occurrence as subhedral twinned and unaltered grains within the quartz matrix indicates that it crystallised with the quartz. Tourmaline and sulphides occur as accessory minerals mainly in fractures and veinlets transecting the quartz mosaic particularly close to the vein margins. The most abundant sulphide is arsenopyrite which comprises 2% of the vein. Minor amounts of pyrite, pyrrhotite chalcopyrite, sphalerite and scheelite are occasionally present.

Inclusions in the vein are commonly of the adjacent wall rock. Sericitic inclusions are common in veins transecting conglomerate whereas biotite and chlorite

Table 11

Electron microprobe analyses of carbonate in quartz veins.

Sample	1000 HMA		OBC 7	
Vein system	H		F	
Carbonate habit	Interstitial to quartz mosaic	Veinlets transecting quartz mosaic	Interstitial to quartz mosaic	Veinlets transecting quartz mosaic
Carbonate type	ankerite dolomite	calcite	ankerite dolomite	calcite
No. of grains analysed	8	5	7	3
%				
MgO	15.02	.52	16.02	1.77
CaO	29.38	53.27	29.19	50.81
MnO	.39	.32	.52	.44
FeO	10.33	.86	8.96	1.48
CO_2	45.80	45.80	45.80	45.80
Total	100.92	100.77	100.49	100.30

predominate in inclusions in veins developed in mafic volcanic rocks and argillites. Accessory mariposite occurs in micaceous inclusions in all veins.

4.2.c. The Habit of Gold

The distribution of gold within the veins is highly erratic. It occurs in the native form and is commonly visible as large hackly grains in quartz veins (Plates 4b, 4c) and as a thin film along vein walls. Within the veins it occurs as isolated grains or veinlets occupying late fractures in the quartz or interstitially between grains of the quartz matrix (Plate 4c). The veinlets are usually parallel to the vein contact but are also developed in the alteration zones and here they transect the schistosity at a high angle. Variable amounts of carbonate, sericite, tourmaline and sulphides are present with gold in the veinlets. In some cases the gold occurs on the edge or in fractures transecting arsenopyrite grains (Plate 4d). Less commonly it is associated with chalcopyrite grains.

Electron microprobe analyses of three grains of gold indicate that the proportion of Au:Ag is 915:85 which is comparable to bullion assays in which the Au:Ag ratio is 904:96 (Gunning and Ambrose, 1940).

4.2.d. Vein Alteration Selvages

Wall rock alteration is a consistent and sometimes prominent feature along the margins of all veins. The principal alteration types include the development of carbonate, biotite, sericite and chlorite. Arsenopyrite and tourmaline are also present in vein selvages. The variation in the type of alteration appears to depend on the chemistry of the host rock rather than on any variation in the vein chemistry. Alteration zones range between 2 cms and 1 m in width although there is a tendency for the wider zones to correspond with wider quartz veins, particularly where the latter are mineralised.

Carbonate alteration is most widespread in the form of carbonate veinlets in the wall rock adjacent to the veins. Electron microprobe data (Table 12) indicate that calcite is more abundant than ankeritic dolomite. It is however difficult to assess the extent to which the carbonate content of the alteration zones can be attributed to vein emplacement for all the rocks of the Piché group contain an appreciable carbonate content which could be a primary constituent or a product of greenschist metamorphism.

Biotite alteration is most common in veins in mafic volcanic rocks, chloritic tuffwackes and argillites, for example, the southern veins of No. 1 vein system and "F" vein system. This type of alteration does not appear to be as widespread as reported (Brown, 1948; Blais, 1955) particularly near the F vein where in some cases biotite rich argillite has apparently been confused with biotite alteration. Biotite in the alteration zones occurs as

Plate 4

a. Photomicrograph of carbonate veins diverging from the right edge of the photograph, transecting the quartz vein.

b. Photomicrograph under reflected light of gold (light) in a sericitic and carbonate veinlet (mottled grey) in a quartz vein (medium grey).

c. Photomicrograph under polarised transmitted light of gold grains (dark grey) in the interstices of the quartz vein matrix and surrounding quartz grains (light grey).

d. Photomicrograph under reflected light of a crystal of arsenopyrite (light) with gold occurring in a vertical fracture in the crystal.

e. Underground exposure of a quartz vein folded around pebbles in the conglomerate unit.

PLATE 4

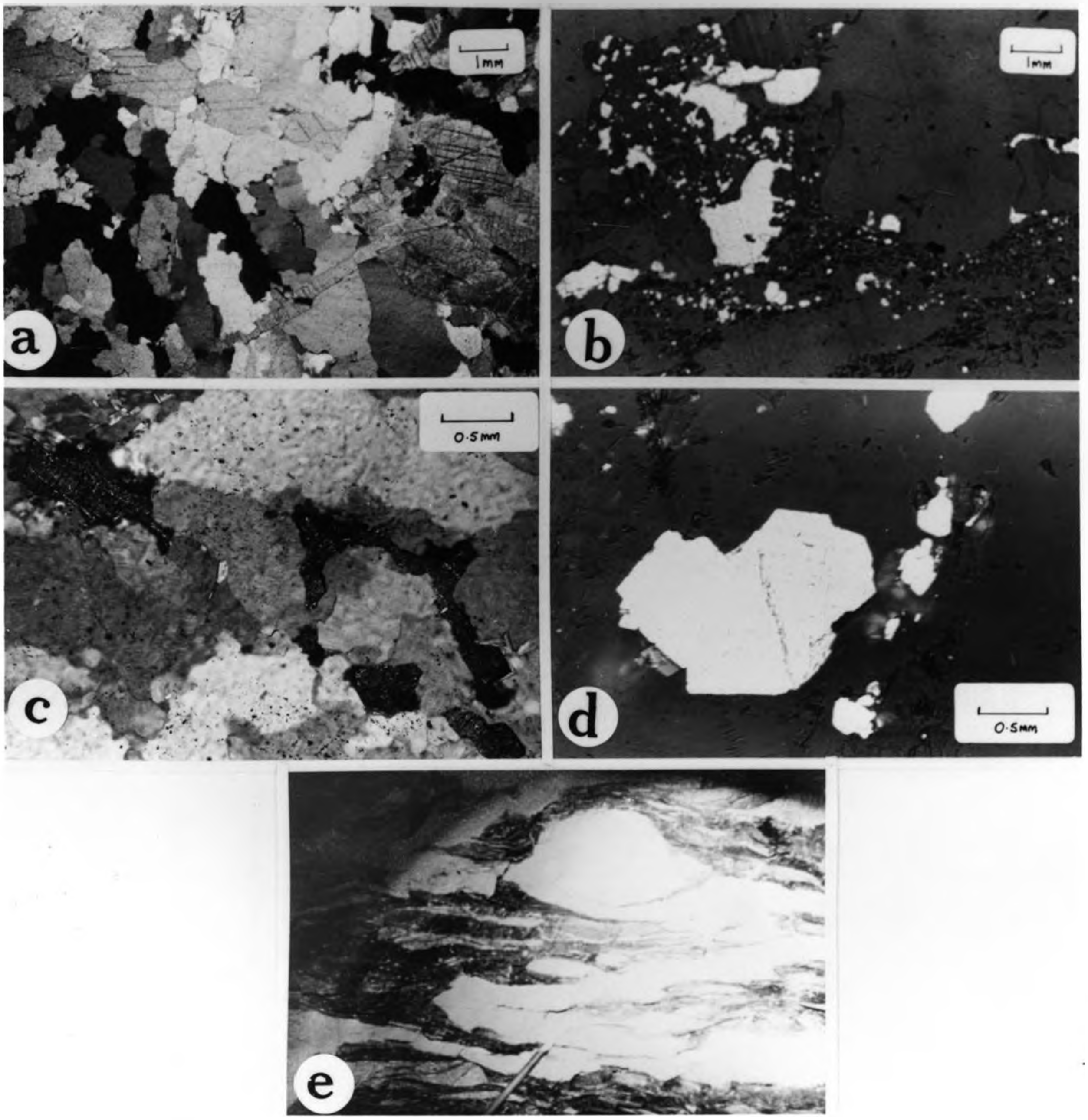


Table 12

Electron microprobe analyses of carbonate in vein alteration selvages.

Sample	1000/IMBA	1000 HMB		750 FMB
Vein system	1	H		F
Carbonate type	calcite	calcite	ankeritic dolomite	calcite
No. of grains analysed	6	6	3	8
%				
MgO	.96	.72	11.45	.71
CaO	50.58	51.56	30.03	52.88
MnO	.71	1.32	.85	.44
FeO	1.08	1.56	13.27	1.04
CO_2	45.80	45.80	45.80	45.88
Total	99.13	100.96	101.40	100.87

clusters of randomly oriented flakes (Plate 5a) whereas in the argillite the biotite is aligned parallel to schistosity. Electron microprobe data (Table 13) of biotite indicates that the two varieties can be distinguished by the FeO/MgO ratio. Biotite from the argillites and greywacke has an FeO/MgO ratio greater than 2.0 whereas biotite in the vein selvages has a ratio of between 0.95 and 1.24.

The development of sericite along vein margins is particularly common in the more felspathic rocks, especially conglomerate and andesite. Sericitic alteration is generally restricted to within 20 cms of the vein margin. Tourmaline usually occurs in small veinlets within 10 cms of the vein margin. Arsenopyrite is the most widespread sulphide in the vein margins and commonly occurs as euhedral crystals disseminated throughout the alteration zone. By comparison it rarely occurs in the country rocks remote from the veins.

4.2.e. Geochemistry of the Veins and Alteration Zones

4.2.e.i. Trace Element Distribution

Eight sampling traverses were conducted across both mineralised and unmineralised quartz veins in order to investigate possible correlations between certain trace elements and the mineralised parts of the veins. The elements selected for assay included those considered to

Table 13

Electron microprobe analyses of biotite.

Rock type containing biotite	1) Conglomerate matrix	2) Conglomerate matrix	3) 3rd cycle argillite	4) F vein biotite alteration	5) F vein biotite alteration
Number of grains analysed	10	13	5	6	7
%					
Na_2O	.07	.11	.07	.05	.08
MgO	9.64	9.01	9.46	14.08	13.29
Al_2O_3	18.28	17.92	18.04	18.22	17.97
SiO_2	35.38	35.25	36.15	38.23	37.07
K_2O	9.60	9.59	9.36	9.93	9.64
CaO	.08	N.D.	.06	.10	.03
TiO_2	1.66	1.91	2.00	1.67	1.69
Cr_2O_3	.04	.03	.02	.44	.06
MnO	.03	.18	.18	.05	.15
FeO	19.62	20.05	19.78	13.39	16.48
Total	94.33	94.05	95.12	96.30	96.49
FeO/MgO	2.04	2.23	2.09	.95	1.24

be abundant in veins and alteration zones and those associated with gold deposits in other areas. At least three samples were collected in each traverse, including a sample of vein quartz, one of the alteration selvage and one of unaltered country rock. In order to overcome the erratic distribution of gold, chip samples were collected over each sample area for 3 m along strike.

Results. The analytical results are presented in Table 14 and are summarised as follows,

As expected, gold in most traverses is concentrated in the quartz veins and to a lesser extent in the alteration zones whereas there are only trace amounts in the nearby country rock. The erratic distribution of gold is emphasised by high gold tenor in samples from veins classified as unmineralised by mine sampling in traverses 4 and 8.

Chromium is present within the quartz veins in concentrations of up to 980 p.p.m. There is however no significant variation in Cr abundance between mineralised and unmineralised parts of the veins. Mariposite has been observed along all vein walls and the biotite in the vein selvages contain up to 0.44% Cr_2O_3 (Table 13). Arsenic increases rapidly from the country rock through the alteration selvage to the vein which supports the observation made during mapping and in petrographic studies that arsenopyrite is concentrated in the veins and vein selvages. However the presence of > 1000 p.p.m.

Table 14

Trace element content of veins, alteration selvages and wall rocks (p.p.m.).

Vein	Traverse	Sample No.	Rock type	Mine * classification	Distance from vein	Au	Ag	As	Cr	Ni	Cu	Pb	Zn	Co
1	1	500/1/D/	Quartz vein	mineralised	-	9.98	1.7	> 1000	259	44	56	45	22	17
		500/1/C	biotite alter^n		0-15 cms	11.98	0.6	> 1000	90	58	107	11	N.D.	54
		500/1/B	carbonate alter^n		15-18 cms	6.73	0.5	> 1000	42	57	113	10	N.D.	49
		500/1/A	Mafic tuff		> 18 cms	< .005	N.D.	118	116	67	120	1	15	62
1	2	500/1U/A	Quartz vein	unmineralised	-	3.08	1.1	> 1000	870	57	14	113	N.D.	4
		500/1U/B	biotite alter^n		0-20 cms	.045	2.9	700	110		80			
		500/1U/C	Mafic tuff		> 20 cms	.017	2.6	65	645		50			
H	3	375/A	Quartz vein	mineralised	-	7.02	1.1	> 1000	700	50	16	14	9	6
		375/B	Sericite alter^n		0-10 cms	6.16	1.4	> 1000	320	52	76	74	12	19
		375/C	Conglomerate		> 10 cms	.075	1.7	168	430	-	73	-	-	-
H	4	1000 HMA	Quartz vein	unmineralised	-	4.84	2.4	> 1000	504	55	43	2	N.D.	280
		1000 HMB	Sericite alter^n		0-22 cms	.043	N.D.	> 1000	129	50	71	16	N.D.	59
		1000 HMC	Conglomerate		> 22 cms	< .005	N.D.	49	180	82	58	12	N.D.	53
4	5	500/4/A	Quartz vein	mineralised	-	.049	1.6	> 1000	786	50	48	46	77	5
		500/4/B	Quartz + pyrite		0-10 cms	1.54	1.2	> 1000	133	42	33	34	N.D.	1
		500/4/C	Graphite		10-100 cms	.096	2.0	> 1000	645	67	164	35	127	14
4	6	500/4/E	Quartz vein	unmineralised	-	N.D.	1.0	> 1000	980	70	6	N.D.	N.D.	4
		500/4/F	Sericite alter^n		0-50 cms	.065	1.8	> 1000	214	21	63	27	27	27
		500/4/G	Andesite		> 50 cms	.037	1.9	80	320	73	75	12	12	38
F	7	500/F/A	Quartz vein	mineralised	-	.014	0.7	860	832	47	12	29	N.D.	4
		500/F/B	Biotite alter^n		0-60 cms	N.D.	1.3	> 1000	278	17	24	22	N.D.	11
		500/F/C	Mafic tuff		> 60 cms	.003	1.9	126	100	70	25	14	N.D.	58
F	8	750/F/A	Quartz vein	unmineralised	-	.90	1.3	> 1000	626	60	31	16	N.D.	59
		750/F/B	Biotite alter^n		0-30 cms	.36	2.2	980	238	62	63	32	5	37
		750/F/C	Mafic tuff		> 30 cms	.06	2.4	129	266	80	53	1	N.D.	55

*Mine classification refers to whether the portion of the vein sampled is considered mineralised or unmineralised as a result of previous mine sampling and assaying.

As in samples with a low gold abundance in traverses 5, 6, and 7 indicates that there is no apparent correlation between As abundance and Au abundance.

Silver, Nickel, Copper, Lead and Zinc are all present in minor quantities in all three sample types but show no consistent sympathetic trend with the Au abundance.

4.2.e.ii. Chemical Data Derived From Previous Studies

Semi-quantitative spectrographic analyses (Blais, 1955) showed that Ca, Mg, Fe, and B were the most abundant trace elements and were present in the veins in quantities ranging in abundance between 0.1% and 1.0%.

Carbon is present within the vein quartz, usually as inclusions in quartz grains, in varying proportions up to .092% by weight ($< 0.5\%$ by volume). Analyses of the carbon content of the veins (Table 15) indicate that the dark colour in certain quartz veins may be attributed to the relatively high carbon content (Blais, 1955).

4.3. Ore Shoots

4.3.a. General Statement

The ore shoots are steeply plunging rich portions of the veins in which the down plunge dimension is up to 10 times the strike length. All the important ore shoots have been located on four major vein systems, No. 1, No.

Table 15

Carbon content in vein quartz (after Blais, 1955).

Sample No.	Vein System	Carbon Content Wt %	Colour of Vein Quartz
22/14/3W	H(14)	.08	Dark grey
21/9/13 2E	F	.092	Dark grey
31/1/22E	No. 1	.07	Dark grey
17/H/11	No. 4	.04	Light grey
30/4/13 1E	No. 4	0	White

4, H and F. Although past production figures are unavailable the relative importance of the various vein systems can be estimated by the amount of stoping and current ore reserves. Combining these two figures, the estimated approximate amount of ore for these producing veins is presented below as a percentage of the entire mine.

No. 1 vein system	32%
H vein system	5%
No. 4 vein system	52%
F vein system	11%

Mills (1950) and Blais (1955) studied the ore shoots in great detail and concluded that most ore shoots commonly coincide with deformed portions of quartz veins. Although it is acknowledged that this control of mineralisation is relevant to most ore shoots, certain important ore shoots in the No. 4 and F veins occur in undeformed portions of veins, which neither Blais nor Mills could satisfactorily explain. Initial mapping of these ore shoots revealed a close association between the mineralised veins and pyritic cherts and carbonaceous argillites. Thus in the following sections a summary of the structurally controlled ore shoots as determined by Blais and Mills will be followed by a description of the stratigraphically controlled ore shoots on No. 4 and F veins systems.

4.3.b. Structurally Controlled Ore Shoots (Mills, 1950; Blais, 1955)

Deformational features in veins associated with ore shoots include vein rolls (folds), vein deflections and vein intersections. In these ore shoots the quartz veins commonly undergo a local thickening, the quartz grains are highly brecciated and the alteration zones increase in width.

Vein "rolls" are parts of a vein which have been isoclinally deformed about a steeply plunging axis resulting in replication of the veins and fracturing of the quartz (Plate 4e). These features were considered by Blais (1955) to have formed by horizontal movement along schistosity planes, resulting in the deformation of the veins. Vein deflections are sudden changes in strike of a vein where for a short distance the vein transects bedding at a higher angle than normal. Vein intersections are simply the junction of converging veins of the same system, for example, the intersection of the two veins of the No. 1 system (Figure 14). Such an intersection results in the thickening of the vein and cataclasis of the quartz veins.

4.3.c. Stratigraphically Controlled Ore Shoots

A number of ore shoots in the No. 4 and F vein systems occur independent of the above mentioned deformational features, but instead are associated with lenses

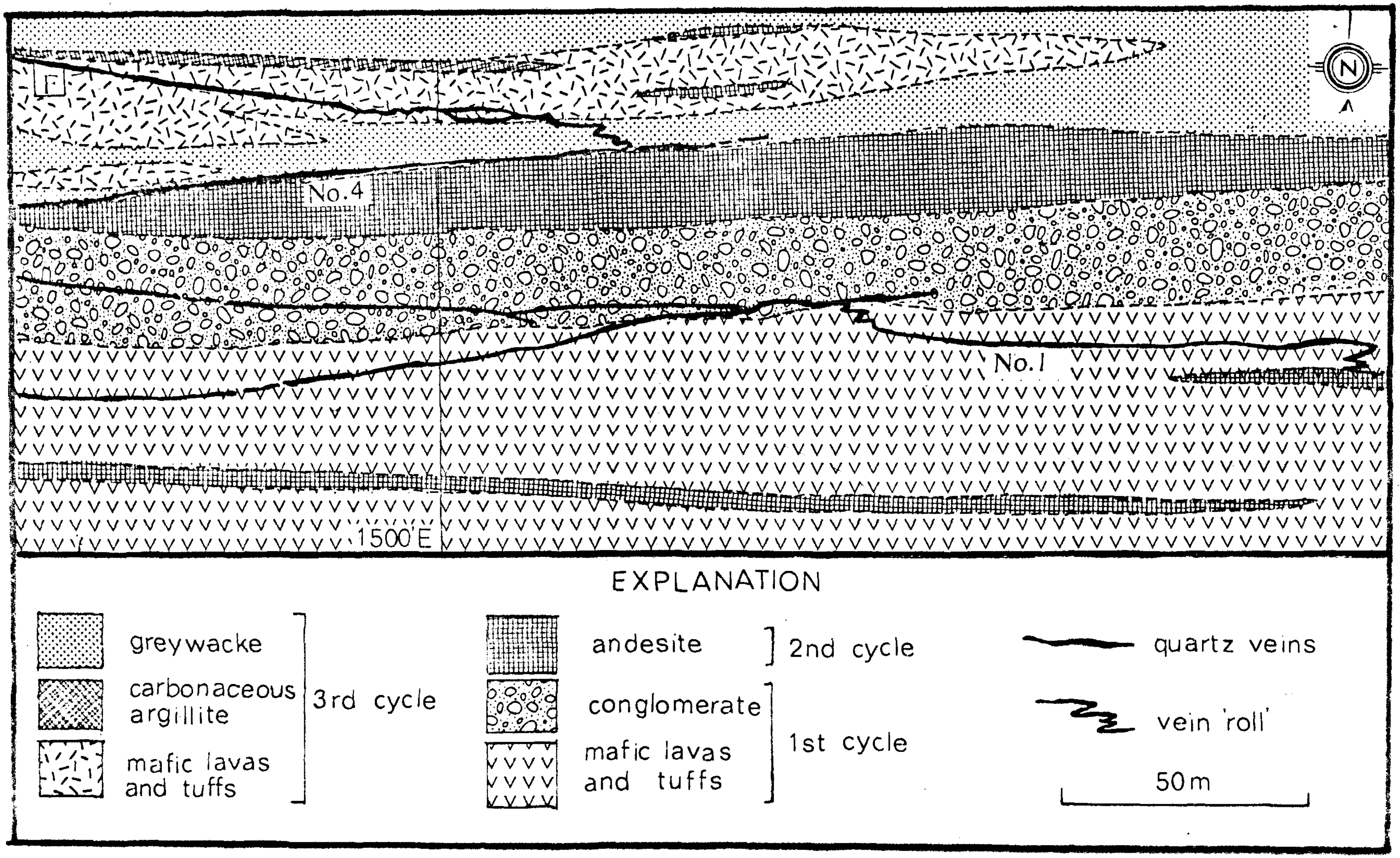


FIGURE 14 PLAN OF NO.1 VEIN ON 2000' LEVEL (from Blais 1955)

of pyritic chert and carbonaceous argillite. These ore shoots are developed in three particular stratigraphic positions, which are as follows:

(i) Where quartz veins are developed in the pyritic cherts interstitial to the pillowed flows of the porphyritic andesite unit between 600'E and 1200'E (Figure 15). These include the most important ore shoots on the mine in the No. 4 vein system.

(ii) Where quartz veins are developed in lenses of carbonaceous argillite and pyritic chert on the upper contact of the porphyritic andesite unit. Examples of ore shoots in this stratigraphic position are those on No. 4 vein between 1350'E and 1800'E (Figure 15) and on the F vein between 900'W and 1100'W.

(iii) Where quartz veins are associated with carbonaceous argillites and cherty interflow sedimentary rocks in the volcano sedimentary succession of the third cycle. An example of mineralisation in this stratigraphic position is the "G" vein on 625' level between 300'W and 400'W.

As most of the old stopes on these ore shoots are either inaccessible or poorly exposed it is relevant to repeat here Gunning's description (1937) of the ore shoots within the porphyritic andesite unit between 600'E and 1200'E.

"Furthermore a few bodies of massive sulphide carrying commercial values across mineable widths have been encountered in No. 4 vein" and "...drifts and cross cuts (on) No. 4 vein have encountered a rather persistent occurrence of lenses and streaks of pyrite and some pyrrhotite and chalcopyrite. The porphyry (porphyritic andesite) alongside them is completely silicified."

The latter description applies to that part of the porphyritic andesite unit described in Figure 15b and the sulphides described are illustrated in Plates 2d and 5d. Significantly pyritic chert is only well developed in the pillow interstices between 500'E and 1100'E which coincides with the zone of ore shoot development.

Routine mine sampling of these lenses indicated a subeconomic gold content and as a result their relationship and significance to mineralisation has not been considered. However it should be emphasised that the pyrite occurs in seams that are commonly less than 5 cms thick (Plate 2d) so that in a normal mine sample the gold content would be diluted in assay by the surrounding lower grade silicates. In order to overcome this problem 3 samples of pyritic chert were collected from localities distant from the veins, in order to minimise any possible enrichment of Au in the pyrite by remobilisation during vein development. These samples were determined to contain between 0.55 p.p.m. and 1.04 p.p.m. Au (Table 16). By comparison a sample of pyritic chert containing quartz veinlets from the edge of a No. 4 quartz vein contains 1.54 p.p.m. Au (sample 500/4/B ,

Plate 5

a. Photomicrograph of biotite grains randomly oriented (on left of photograph) in greywacke in the alteration selvage adjacent to the F vein. A band of carbonate grains and euhedral arsenopyrite crystals cross the photograph vertically. On the right is greywacke.

b. Photomicrograph of sericite (light) in conglomerate in the alteration selvage adjacent to the H vein.

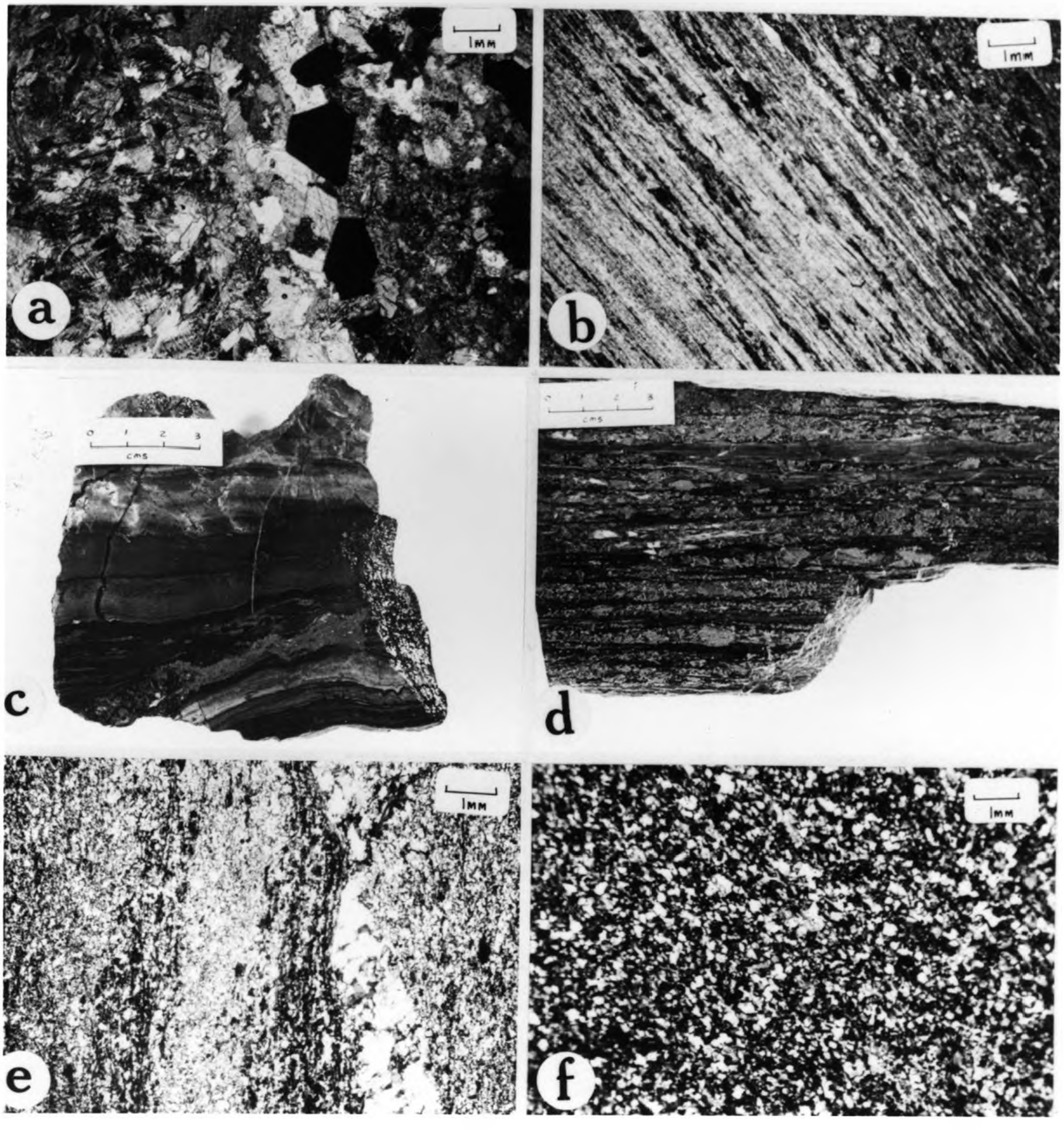
c. Photograph of a finely laminated chert from the "G" vein showing a thin pyrite band above dark laminations which show evidence of soft sediment deformation.

d. Photograph of a sample of banded pyrite and chert from the pillowed andesite interstices.

e. Photomicrograph of finely laminated chert from the third cycle showing a mosaic of microcrystalline chert (light) and layers of biotite (dark) and a coarse grained quartz veinlet (white).

f. Photomicrograph of a mosaic of microcrystalline quartz from a massive chert band.

PLATE 5



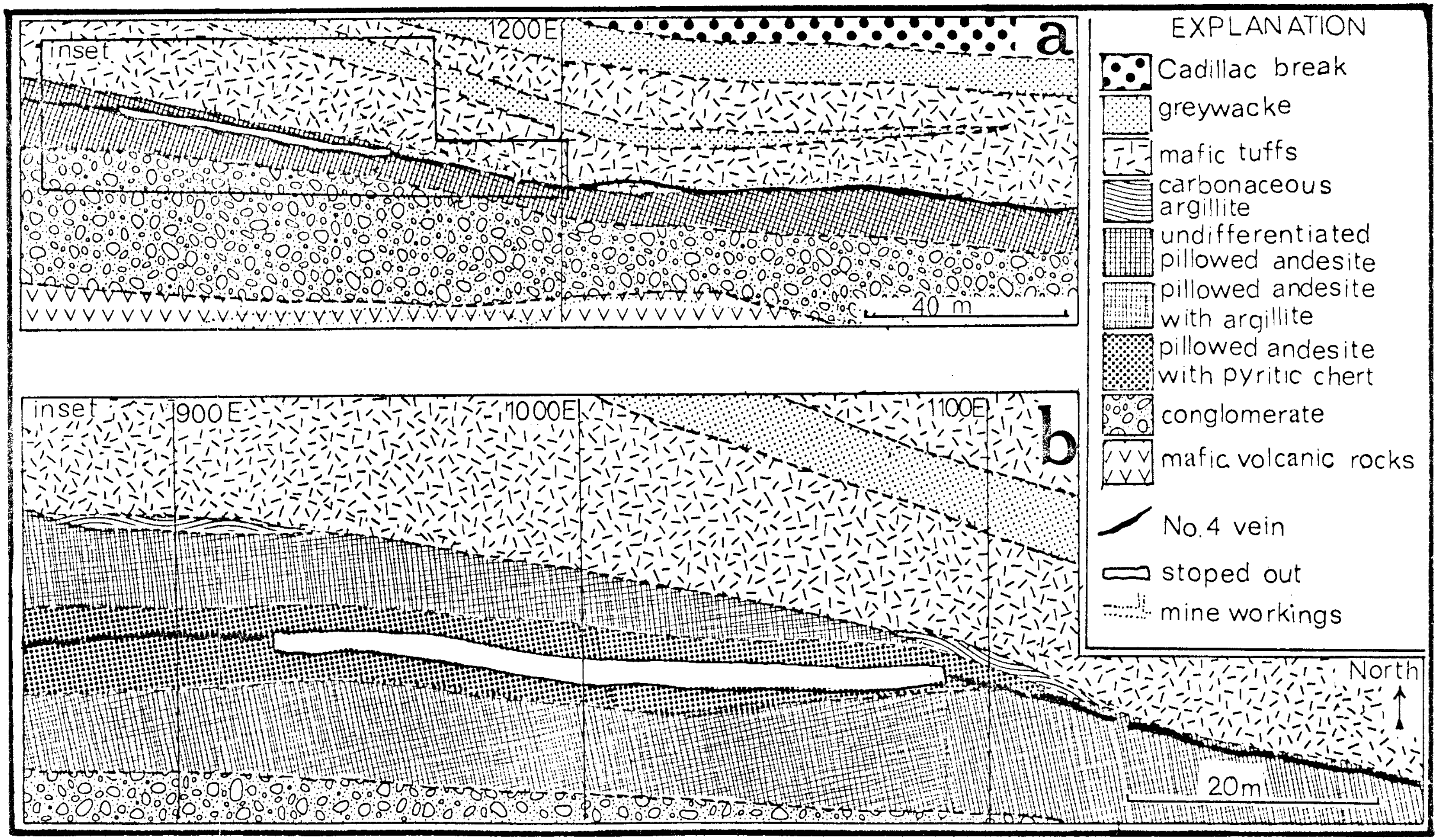


FIGURE 15 PLAN OF NO.4 VEIN ON 500' LEVEL

traverse 5, Table 14). Although gold of this order of abundance does not constitute economic quantities it is higher by many orders of magnitude than the gold abundance in unaltered wall rock samples (Table 14) and other interflow sediments, the conglomerate and the schists of the Cadillac break (Table 16). The abundance of Cu and Zn is also significantly higher in the pyritic cherts and carbonaceous argillites than in other rock types.

Table 16

Gold and trace element abundance in selected rock types.

Rock Type	Carbonaceous argillites			Pyritic cherts		
Sample	500/4/C	1250/GB	375/3	1250/4B	S.P.4	S.P.6
p.p.m.						
Au	.096	.015		1.04	.55	.91
Ag	2.0			1.6	0.4	
As	> 1000	11		648	918	
Cr	130	89	30	48	30	
Ni		61	65	55	67	
Co		18	23	87	153	
Cu	164	158	199	106	152	
Pb		12	9	8	17	
Zn		208	570	302	40	

Rock Type	Argillite interstitial to pillows	Interflow chert sediment in mafic lavas	conglomerate matrix	break
Sample	S.P.3	500/4	250/12	500/B
p.p.m.				
Au	N.D.	.025	.005	< .005
Ag	N.D.	0.1	N.D.	0.2
As	18	25	49	> 1000
Cr	121	241	200	925
Ni	58	96	86	419
Co	35	60	42	100
Cu	130	66	70	71
Pb	18	11	10	9
Zn	131	130	N.D.	N.D.

CHAPTER FIVE

PETROGENESIS

5.1. General Statement

In this chapter the data presented are considered as the basis for an interpretation of the origin of the Piché group and of the petrogenesis of the gold mineralisation. Two stages of mineralisation are considered, the first of which is considered to be syngenetic and is associated with the stratigraphically controlled ore shoots. The second stage, considered to post date the deposition of the Piché group rocks, is therefore epigenetic and resulted in the mineralisation in the structurally controlled ore shoots. Finally the implications of the petrogenetic models on mining and exploration will be considered.

5.2. Evolution of the Piché Group

The widely varying lithologic types of the Piché group reflect its tectonic position at the interface between the predominantly sedimentary regime of the Pontiac group to the south and the volcano sedimentary regime to the north. The thin development of all lithologic types and the rapid stratigraphic transition between sedimentary and volcanic units of differing composition are indicative of the influence of both the Abitibi volcanism to the north and the Pontiac sedimentation to the south during the deposition of the Piché group. The presence of pillowed lavas and chemically precipitated interflow sediments throughout the succession indicates that deposition was predominantly, if not entirely in a submarine environment.

Rapid deposition of the mafic tholeitic lavas and tuffs of the first cycle was in part contemporaneous with the deposition of sediment of the underlying Pontiac group, as illustrated by the gradational contact and intercalated greywacke lenses in the mafic volcanic rocks. Volcanism was followed by deposition of the conglomerate unit. Similar units, marginal to volcanic belts are common throughout the Archean and are described by Pettijohn (1972 and 1975) as pebbly mudstones. Middleton and Hampton (1973) proposed that such conglomerate units form as a result of gravity slumping and mass flow of sediment in which clasts are supported by the matrix and on deposition the unsorted clasts are frozen in the matrix. This conglomerate unit which extends for 5 kms along strike and seldom exceeds a thickness of 100 m has comparable dimensions to a similar unit in the Cap Enrage formation in which Davies and

Walker (1974) determined a sediment flow direction parallel to regional strike along the length of a depositional trough. It is therefore suggested that subsidence following the extrusion of the underlying mafic volcanic rocks initiated slumping of unconsolidated sediment into a mass flow along a linear trough of the Piché group.

A period of calc-alkaline volcanism is manifest both as subvolcanic andesite sheets intruding the lower mafic volcanic rocks and as pillowed andesite lavas overlying the conglomerate unit. The initial flows were deposited in the unconsolidated sediment in the upper part of the conglomerate unit, and with successive flows fine argillaceous sediment was displaced around the pillows, mixed with the tuffaceous pillow fragments and settled as fine grained argillite between pillows. As the pile of pillows built up, the amount of clastic sediment deposited between pillows decreased and silica and sulphides were precipitated from sea water. This resulted in the development of laminated pyritic chert in the pillow interstices of the higher parts of the andesite unit.

With the termination of volcanism, precipitation of silica and sulphides continued in isolated depressions, resulting in the development of pyritic chert lenses up to 50 cms thick on the upper contact of the unit. Commonly thin lenses of carbonaceous argillite are developed in this environment. These rocks are common throughout Archean greenstone belts and are interpreted as synsedimentary deposits of kerogenous compounds accumulated under anaerobic conditions within isolated depositional basins (Schopf, 1977).

The development of thin lenses of siliceous greywacke with a similar composition to the andesite unit suggests that the sediment was derived from the underlying volcanic rocks. However the presence of isolated outcrops of the overlying biotite greywacke is indicative of a renewed, if brief, supply of clastic detritus to the depositional basin. Minor lenses of massive andesite flows and felsic tuffs within these greywacke units are evidence of continued, but minor volcanic eruptions during sedimentation.

A third period of volcanism, again of tholeiitic composition was contemporaneous with the deposition of clastic sediment in isolated basins which resulted in an intercalated assemblage of lavas, tuffs and volcaniclastic and epiclastic sedimentary rocks. The development of chert and argillite which is locally carbonaceous, between the various members of the third cycle is interpreted as representing periods of relative quiescence and chemical sedimentation between stages of volcanism and clastic deposition.

5.3. Petrogenesis of the Gold Mineralisation

Mills (1950) and Blais (1955) concluded that the ore shoots were structurally controlled, although they acknowledged that certain ore shoots on No. 4 and F veins did not coincide with structural features commonly associated with other ore shoots. This study indicates that these ore shoots on No. 4 and F veins are stratigraphically controlled and have developed where veins coincide with auriferous pyritic chert of the first stage of mineralisation.

5.3.a. First Stage of Mineralisation

Analyses of the pyritic chert associated with the porphyritic andesite unit of the second cycle indicate that gold is concentrated in these rocks in concentrations of between 0.55 and 1.54 p.p.m. The association of gold deposits with pyritic cherts has been recognised by Ridler (1970), Hutchinson et al. (1971) and Fripp (1976). Gold is considered to have been leached from the underlying volcano sedimentary pile by circulating sea water driven by a convective system established during volcanism. Submarine extrusion of the second cycle porphyritic andesite and third cycle tholeiitic volcanic rocks was probably accompanied by the hydrothermal discharge of the heated brines on to the sea floor. Experimental studies have shown that gold may be transported as a thiocomplex in near neutral solutions (Weissberg, 1970) or as gold chlorocomplexes (Henley, 1973). Regardless of the transporting agent the discharged hydrothermal fluids would be subjected to changes of Eh-pH and temperature in the sea floor environment as a result of mixing with sea water. Critical changes in any of these factors might result in the precipitation of the gold in association with the pyrite, between periods of volcanism (Fryer and Hutchinson, 1976). The thin and discontinuous lenses of auriferous chert in the second and the third cycles of the Piché group indicate that deposition was in basins of limited extent. Furthermore the preservation of thin lenses of carbonaceous argillite commonly associated with the pyritic chert is evidence of anaerobic conditions prevailing during deposition (Schopf, 1977).

Although economic quantities of gold have been recorded in the pyritic cherts (Gunning, 1937), limited analyses in this study indicate that the gold abundance is of the order of 0.5 - 1.5 p.p.m. Furthermore most of the gold in the stratigraphically controlled ore shoots in No. 4 and F vein system occurs within the quartz veins that are developed in or adjacent to the pyritic cherts. This suggests that here gold has been remobilised and concentrated in the quartz veins. It is also possible that where the veins coincide with chert lenses, some of the quartz in the vein has been derived by recrystallisation of the chert. However the preservation of finely laminated cherts adjacent to the quartz veins indicates that this is not a widespread phenomena.

Petrographic and chemical data support this view, for there is no apparent petrographic difference between the quartz veins adjacent to, and those that are distant from, chert lenses. A comparison of the trace element content of the pyritic cherts and quartz veins indicates that there are significant differences between the two rock types. The pyritic cherts are characterised by relatively high Cu and Zn, low Cr and an As content of less than 1000 p.p.m. (Table 16). By contrast the quartz veins, and the alteration selvages, commonly have high Cr, and low Cu and Zn contents and in excess of 1000 p.p.m. As (Table 14).

5.3.b. The Second Stage of Mineralisation

In the second stage of mineralisation, gold in the quartz veins was concentrated in ore shoots that are apparently structurally rather than stratigraphically controlled. The development of veins transecting the bedding indicates that their emplacement post dates the deposition of the Piché group rocks. Furthermore the apparently erratic distribution of ore shoots, irrespective of host rocks indicates that gold has been remobilised from its original source area and concentrated in the ore shoots. It is necessary that an acceptable genetic model for the auriferous quartz veins should also explain their trace element chemistry and associated alteration affects.

Boyle (1961) suggested that gold quartz veins at Yellowknife had formed by lateral secretion and grain boundary diffusion of silica and gold. However if vein material was derived from the wallrock at Darius there would be a tendency for mobile base metals such as Cu and Zn to concentrate in the veins (Kerrich, pers. comm.). Analyses of the veins (Table 14) indicates that they have a lower abundance of Cu and Zn than most rocks of the Piché group. Furthermore there is no apparent explanation for the concentration of Cr, a relatively immobile element, in the veins by lateral secretion. Kerrich (1978) presented evidence suggesting that grain boundary diffusion extends for only a few metres, and therefore with this constraint it would require that the host rocks adjacent to the ore shoots had an abnormally high primary abundance of gold. These conditions exist where ore shoots of the No. 4 and F veins are adjacent to the auriferous pyritic cherts of the first stage of mineralisation, and thus it is possible that here some of the gold may be concentrated in the ore shoots by lateral secretion. For the No. 1 vein in the mafic volcanic rocks of the first cycle a primary abundance of gold is not apparent for the mafic tuffs contain between .005 and .017 p.p.m. Au (Table 14). The chloritic and cherty interflow sediments contain .025 p.p.m. (Table 16), are thinly developed, volumetrically insignificant and are not spatially related to ore shoots.

Ridler (1970) and Hutchinson et al. (1971) have suggested that auriferous veins in certain Archean conglomerates, for example at McWatters and Pamour Mines may represent remobilised and concentrated palaeoplacer deposits. In the Witwatersrand palaeoplacer deposits the conglomerates are interpreted as being fan deposits at a fluvial lacustrian interface. Successive pulses of sedimentation effectively removed the clastic material and resulted in the concentration of pebbles and interstitial heavy minerals such as gold (Pretorius, 1976).

By comparison the Darius conglomerate is interpreted as being deposited from a single mass flow dominated by greywacke matrix and there is no evidence of any mechanism for concentrating gold. Furthermore the gold content of the conglomerate unit ranges between .005 and .075 p.p.m. which supports the view that there has been no primary concentration of gold in this rock. It is apparent that without a primary enrichment of gold in the mafic volcanic and conglomerate units the possibility of these rocks being the source of the gold in the No. 1 and H vein ore shoots is remote.

It is therefore necessary to consider that the quartz and gold has been introduced from a source that is distant from these ore shoots. Fluid inclusion studies (Krupka, 1976) indicated that the quartz and gold were deposited at temperatures in the range of

365° ± 35°C to 250° ± 80°C, which represent minimum temperatures, uncorrected for pressure. The presence of NaCl crystals and CO_2 in inclusions in the vein quartz (Krupka, op. cit.) and the potassic alteration in the wallrock adjacent to veins (Blais, 1955) suggest that gold and quartz in the veins were deposited by CO_2 charged brines. During prograde regional metamorphism from the greenschist to the amphibolite facies, residual brines may be derived from waterlain mafic volcanic rocks and up to 2% structural water released from the constituent minerals of these hydrated rocks (Fyfe and Henley, 1973). Furthermore CO_2 and SiO_2 are released from minerals by metamorphic reactions under these conditions (Myashiro, 1973b) and would be free to enter solution. Henley (1973) has shown experimentally that gold solubility in chloride solutions increases significantly under amphibolite facies conditions and Fyfe and Henley (1973) consider that sufficient fluid is generated during prograde regional metamorphism to leach a considerable amount of gold from a large volume of rock with a normal crustal abundance of the metal. Although the rocks of the Piché group in the mine are metamorphosed to a greenschist facies grade the rocks of the Abitibi belt to the north and the Pontiac group to the south have been metamorphosed to amphibolite facies grade (Jolly, 1978) and therefore could be considered a possible source for the vein forming fluids and gold. However if auriferous pyritic cherts similar to those exposed in the mine, occur in the Piché group at depth, the amount of gold that would be available to enter solution would be significantly increased.

The most obvious source of Cr in the veins is the ankerite talc chlorite schist of the Cadillac break which contains up to 2126 p.p.m. Cr. If base metals were leached by the vein fluids in proportion to their abundance in the rocks of the break the high Cr and low Cu and Zn content of the quartz veins are explained. However in this case it would be expected that Ni would also be concentrated in the veins and the writer sees no explanations for the apparent deficiency of Ni in the veins.

Accumulation of fluid at depth would eventually result in fluid pressure exceeding lithostatic pressure whereupon fracturing of the overlying rock would occur permitting the focussed ascent of fluid through dilatent openings in the Piché group adjacent to the Cadillac break. In order that dilatent openings developed parallel to schistosity the least principal stress direction was necessarily normal to schistosity and the confining stress across schistosity tensile (Kerrich and Allison, 1978). As the fluids ascended, a decrease in temperature would result in a decrease in gold and silica solubility (Henley, 1973) and cause precipitation of gold and quartz in the veins. As the gold concentration of the fluids is estimated to be less than .15 p.p.m. (see

Henley, op. cit.) it appears that the gold tenor in any part of a vein would be proportional to the volume of fluid which had passed through that part of the vein. It is therefore suggested that the structurally controlled ore shoots represent principal channels for the ascent of fluid. This is supported by field observations where these ore shoots coincide with a thickening of both the vein and alteration selvage.

5.4. Application of Genetic Models to Mining And Exploration

5.4.a. Mining

Previous studies (Mills, 1950 and Blais, 1955) recognised the importance of structural controls of mineralisation, particularly in the case of the No. 1 and H vein systems. This study, however, indicates that auriferous pyritic cherts are an important factor in the distribution of certain ore shoots in the No. 4 and F vein systems. Although the abundance of gold within the pyritic cherts may not always be of economic grade they are important where the quartz veins are developed adjacent to them. An example of this type of ore shoot is on No. 4 vein, west of No. 2 shaft, the richest ore shoot on the mine, where the gold is considered to have been remobilised from the adjacent pyritic chert and concentrated in the vein.

The gold content of the carbonaceous argillites is low and therefore they are not considered to be a source of gold. Nevertheless their close spatial relationship with pyritic cherts overlying the pillowed andesite unit and in the third cycle volcano sedimentary succession explains the importance attached to them by Blais (1955). The significance of the pyritic cherts and carbonaceous argillites and their influence on mineralisation has not been recognised to date. It is therefore recommended that these rocks be mapped and sampled in more detail than has been the case in the past, particularly in the following three stratigraphic zones.

(i) Within the pillowed andesite unit, concentrating on the pyritic cherts developed in the pillow interstices, particularly in the centre of the mine and in the upper part of the unit.

(ii) Along the northern, upper contact of the andesite unit throughout the mine where discontinuous lenses of pyritic chert are developed, commonly in association with carbonaceous argillite.

(iii) Within the volcano sedimentary succession of the third cycle where pyritic cherts and carbonaceous argillites are developed as interflow and interbedded lenses.

5.4.b. Exploration

As no reliable geophysical or geochemical methods of exploring for gold have been developed, the use of genetic models and geological mapping is of great importance in exploration. In the case of Darius Mine two genetic models are considered which have an application in exploration in the Piché group along strike from the mine.

According to the first model gold was syngenetically concentrated within chemically precipitated cherts associated with the pillowed andesite unit and mafic volcanic units of the second and third cycle respectively. Exploration for pyritic cherts occurring as interflow sedimentary rocks in these units of the Piché group along strike from the mine would be warranted.

In the second model it is suggested that gold was concentrated in the veins by metamorphic hydrothermal processes as a result of focussed discharge of auriferous fluids through dilatent openings in the Piché group adjacent to the Cadillac break. Exploration based on this model should be concentrated in the Piché group along the Cadillac break. As there is a long history of gold exploration, and numerous minor gold discoveries have been made, in this area it is suggested that exploration efforts be concentrated on reassessing known gold occurrences. Emphasis should be placed on locating thicker deformed portions of veins where alteration zones are widest following the controls of mineralisation identified by Mills (1950) and Blais (1955). Attention should also be directed towards parts of these veins that are developed adjacent to the pyritic cherts of the first stage of mineralisation.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1. Summary

The rocks of the Piché group are developed adjacent and parallel to the Cadillac break, which probably represents an ancestral fault zone, active during the deposition of the Archean rocks in the area. The Piché group rocks mark the interface between the flyschoid sedimentary rocks of the Pontiac group to the south and the volcano sedimentary succession of the Abitibi belt to the north. The evolution of the Piché group has been influenced by both Pontiac group sedimentation and the Abitibi belt volcanism. It consists of three distinct cycles, each containing volcanic rocks and associated sedimentary rocks. In the first and third cycles volcanism was of a mafic tholeitic composition whereas in the second cycle calc-alkaline pillowed lavas predominate. Sedimentary rocks of the first cycle are generally coarse grained epiclastic deposits comparable to the rocks of the underlying Pontiac group. In the second cycle, chemically precipitated pyritic cherts are associated with the andesite pillowed lavas which are overlain by isolated lenses of volcaniclastic and epiclastic greywacke. In the third cycle mafic volcaniclastic tuffwacke and epiclastic greywacke are interbedded with the volcanic rocks. Minor lenses of chert, argillite and carbonaceous argillite occur as interflow sediments within the volcano sedimentary succession. The rocks of the third cycle abut against the ankerite-talc-chlorite schists of the Cadillac break. The existence of pillowed lavas and chemically precipitated sediments indicates that the Piché group rocks were deposited in a subaqueous environment.

Gold mineralisation occurs in both pyritic cherts and in quartz veins. The veins regionally transect the rocks of the Piché group at low angles but locally are conformable to individual lithologic members. Two stages of mineralisation are recognised, the first of which is considered to be syngenetic. Here the gold occurs in pyritic chert interflow sediments which also have a minor enrichment of copper and zinc and are commonly associated with lenses of carbonaceous argillite. The pyritic cherts are interpreted as being chemically precipitated sediments. The gold was leached from the volcanic succession of the Piché group by circulating brines which were hydrothermally discharged on the sea floor following the deposition of volcanic rocks of the second and third cycles. With the mixing of hydrothermal brines and sea water critical changes in temperature or Eh-pH may have reduced the solubility of the gold, sulphur species and silica which resulted in their precipitation and the formation of lenses of interflow auriferous pyritic chert.

The gold in the quartz veins of the second stage of mineralisation was epigenetically introduced into the rocks of the Piché group, subsequent to their deposition. A potassic alteration zone is commonly developed in the wall rocks alongside the quartz veins which characteristically have a high chromium and low copper and zinc content. Arsenopyrite is the most common sulphide associated with the quartz veins. There is however no apparent difference in the abundance of trace elements between the mineralised and unmineralised portions of the vein. During the second stage of mineralisation it is suggested that fluids were generated by metamorphic dehydration of hydrated rocks undergoing prograde regional metamorphism. Under amphibolite facies conditions gold solubility increases significantly and gold could have been leached from a large volume of rock with a normal crustal abundance of the metal. However the presence of auriferous pyritic cherts in the Piché group at depth would significantly increase the amount of gold that could enter solution. With the accummulation of metamorphic fluids at depth, hydrostatic pressure would eventually exceed lithostatic pressure and result in fracturing of the overlying rocks. This would facilitate the ascent of fluids through dilatent openings in the Piché group. Gold and silica would have precipitated out of solution under lower temperature and pressure conditions resulting in the concentration of native gold in the ore shoots which are considered to represent the principal channels for the ascending fluids. During the second stage of mineralisation gold from the pyritic cherts was possibly remobilised and concentrated in adjacent quartz veins.

The recognition of auriferous pyritic cherts associated with certain ore shoots in the No. 4 and F veins is of significance to underground and surface gold exploration.

6.2. Conclusions

The Piché group is developed adjacent and parallel to the Cadillac break at the interface between the Pontiac group sedimentary rocks to the south and the Abitibi belt volcano sedimentary succession in the north. It consists of three cycles each consisting of both volcanic and sedimentary rocks. In the first and third cycles volcanic rocks are of a tholeitic composition whereas the andesites of the second cycle are of a calc-alkaline composition. In the first cycle, coarse grained epiclastic rocks are most common whereas in the second and third cycle epiclastic, volcaniclastic and chemically precipitated sedimentary rocks are intercalated with the volcanic rocks.

Two stages of gold mineralisation are recognised. In the first stage gold was syngenetically deposited with pyritic cherts in thin discontinuous lenses interbedded with the second and third cycle volcanic rocks. It is considered that the gold, pyrite and chert were precipitated from hydrothermally discharged brines on the sea floor.

The gold in the second stage of mineralisation occurs in quartz veins which transect the Piché group at low angles and locally are conformable to individual lithologic members of the Piché group. The veins are commonly surrounded by a potassic alteration selvage and have an anomalously high chromium content. Arsenopyrite is commonly disseminated throughout the veins and vein selvages. It is suggested that the gold was leached from rocks at depth by fluids released from hydrated waterlain rocks undergoing prograde regional metamorphism. As fluid accumulated at depth, hydrostatic pressure eventually exceeded lithostatic pressure which resulted in fracturing of the overlying rocks and the focussed discharge of the fluids through dilatent openings in the Piché group. Gold and silica were precipitated from the ascending fluid as their solubility decreased with the decrease in temperature and pressure and gold was concentrated in ore shoots which represent principal channels for the ascending fluid. Where quartz veins were developed adjacent to auriferous pyritic cherts of the first stage of mineralisation it is possible that gold was remobilised and concentrated in the quartz veins.

APPENDIX A

MAJOR AND TRACE ELEMENT ANALYSIS

A) Method of Analysis of Major Element and Some Trace Elements by X-ray Fluorescence Method

Analyses of all major elements and the following trace elements: Ni Co Pb Zn Zr Sr Rb, were done by the x-ray fluorescence method. The samples were prepared by crushing the rock in a jaw crusher and Bleular Mill to about 200 mesh. Pressed pellets and fused discs were made from the powder of each sample following the method of Norrish and Chappell (1967) and Norrish and Hutton (1969) respectively. All analyses were conducted in a Phillips PWl 450 AMP automated x-ray fluorescence spectrometer. The analyses are considered accurate to within 1% of the amount present for all major elements.

The total volatile content of the samples were determined by the loss on ignition method in which approximately 1 gram of powder was heated in a porcelain crucible for 12 hours at a temperature of 1000°C. The weight loss was assumed to represent the volatile loss (L.O.I.) for each specimen. In the analyses presented in this study FeO includes FeO and Fe_2O_3.

B) Gold and Trace Element Analyses

Analyses of samples for Au, Ag Cr and Cu were done at the Laboratories of Assayers Limited, Rouyn, Quebec. Arsenic analyses were done by Bondar Clegg Laboratories, Ottawa.

APPENDIX B

X-RAY DIFFRACTION ANALYSIS OF CARBONACEOUS MATERIAL

X-ray diffraction analysis of the carbonaceous material from the argillites was done following the method of French (1964). About 100 g of carbonaceous argillite were ground to -200 mesh in a Bleuler Mill and treated with hot hydrofluoric acid for 48 hours to remove silicate and carbonate minerals. The insoluble residue was then treated with hot hydrochloric acid for 24 hours in order to remove fluorides and fluorsilicates. The carbonaceous residue was then studied by x-ray diffraction with Ni filtered Cu $\kappa\alpha$ radiation.

REFERENCES

Bell, L. V. and Maclean, A. 1930. Report on the geology of Bousquet-Cadillac gold area, Abitibi district, Quebec: Quebec Bureau of Mines, Ann. Rept. 1929, pt. C.

Blais, R. 1955. A petrologic and derepito-metric study of the gold mineralisation at the O'Brien mine, northwestern Quebec. Unpubl. Ph.D. thesis. Univ. Toronto. 292 P.

Boyle, R. W. 1961. The geology, geochemistry, and origin of the gold deposits of the Yellowknife district. Geological Survey of Canada Memoir 310.

Brown, R. A. 1948. O'Brien Mine. In Structural geology of Canadian ore deposits. Canadian Institute of Mining and Metallurgy, Jubilee Volume, pp. 809-816.

Condie, K. C. 1976. Trace element geochemistry of Archean greenstone belts. Earth Science Reviews, Vol. 12, pp. 393-417.

Davies, I. C. and Walker, R. G. 1974. Transport and deposition of resedimented conglomerates: the Cap Enragé Formation, Cambro-Ordovician, Gaspé, Quebec: Jour. Sed. Petrol., v. 44, pp. 1200-1216.

Dimroth, E., Boivin, P., Goulet, N. and Laroche, M. 1973. Preliminary report on tectonic and volcanological studies in Rouyn-Noranda area. Quebec Dept. Natural Resources, open-file report G. M. 28491.

Dimroth, E., Rocheleau, M., Boivin, P., Larouche, M. and Coté, R. 1974. Preliminary report on stratigraphic and tectonic work in the Rouyn-Noranda area. Quebec Dept. Natural Resources, open-file report DP-246.

Dimroth, E., Coté, R., Provost, G., Rocheleau, M., Tassé, N. and Trudel, P. 1975. Third progress report on the stratigraphy volcanology, sedimentology and structure of Rouyn-Noranda area. Quebec Dept. Natural Resources, open-file report DP-300.

Eakins, P. R. 1962. Geological settings of the gold deposits of Malarctic district. Province of Quebec, Department of Natural Resources, Geology Report 99, 133 pp.

French, B.M.1964. Graphitisation of organic material in a progressively metamorphosed PreCambrian Iron Formation. Science, vol. 146, 917 P.

Fripp, R.E.P. 1976. Stratabound gold deposits in Archaean banded iron formation, Rhodesia. Economic Geology, 71, pp. 58-75.

Fryer, B. J. and Hutchinson, R. W. 1976. Generation of metal deposits on the seafloor. Canadian Journal of Earth Science, 13, pp. 121-135.

Fyfe, W. S. and Henley, R. W. 1973. Some thoughts on chemical transport processes, with particular reference to gold. Minerals Science Engineering, 5, pp. 295-303.

Goodwin, A. M. and Ridler, R. N. 1970. The Abitibi orogenic belt. In Baer, A. J., ed., Symposium on basins and geosynclines of the Canadian Shield: Geol. Surv. Canada, Paper 70-40, pp. 1-31.

Goulet, N. 1978. Stratigraphy and structural relationships across the Cadillac-Lardo Lake fault, Rouyn Beauchastel Area, Quebec. Unpubl. Ph.D. thesis. Queen's University.

Gunning, H. C. 1937. Cadillac area, Quebec. Geol. Surv. Can. Mem. 206, Publ. 2434.

Gunning, H. C. and Ambrose, J. W. 1940. Malarctic area, Quebec; Geol. Surv. Can. Mem. 222, Publ. 2454.

Henley, R.W. 1973. Solubility of gold in hydrothermal chloride solutions. Chem. Geology, v. 11, pp. 73-87.

Holubec, J. 1972. Lithostratigraphy, structure and deep crustal relations of Archean rocks of the Canadian Shield. Krystalinikum 9, pp. 63-88.

Hutchinson R. W., Ridler, R. H. and Suffel, G. G. 1971. Metallogenic relationship in the Abitibi Belt, Canada, A Model for Archean Metallogeny: C.I.M. Transactions Vol. LXXIV, pp. 106-115.

James, W. F. and Mawdsley, J. B. 1927. La Motte and Fournière Map-Areas, Abitibi County, Quebec; Geol. Surv. Can., Summ. Rept., 1925, pt. C, pp. 71-73.

Jolly, W. T. 1975. Subdivision of the Archean lavas of the Abitibi Area, Canada, from Fe-Mg-Ni-Cr relations. Earth and Planetary Science Letters, 27, pp. 200-210.

—————————. 1978. Metamorphic history of the Archean Abitibi Belt. In Metamorphism in the Canadian Shield, Geol. Surv. Can. Paper 78-10, pp. 63-78.

Kerrich, R., Fyfe, W. S. and Allison, I. 1977. Iron reduction around gold-quartz veins, Yellowknife district, Northwest Territories, Canada. Economic Geology, 72, pp. 657-663.

Kerrich, R. and Allison, I. 1978. Vein geometry and hydrodynamics during Yellowknife mineralisation. Canadian Journal of Earth Science, 15, pp. 1653-1660.

Krupka, K. M. 1976. Neutron activation analysis of Na/K ratios in fluid inclusions in quartz from gold quartz veins at the O'Brien Mine, Quebec, Canada. Unpublished M.Sc. thesis. Pennsylvania State University.

Latulippe, M. 1976. Guidebook for the geological excursion of the Val D'or-Malarctic region. C.I.M.M.

Mills, J. W. 1950. Structural control of orebodies as illustrated by the use of vein contours at the O'Brien Gold Mine, Cadillac, Quebec; Econ. Geol., Vol. 45, No. 8, pp. 786-807.

—————————. 1954. Vertical zoning at the O'Brien Mine, Kewagama, Quebec. Economic Geology, Vol. 49, pp. 423-430.

Middleton, G. V. and Hampton, M. A. 1973. Sediment gravity flows: mechanics of flow and deposition. In Middleton, G. V. and A. H. Bouma (co-chairmen), Turbidites and deep water sedimentation: Pacific Coast Section, Soc. Econ. Paleontologists and Mineralogists, Los Angeles, pp. 1-38.

Miyashiro, A. 1973. The Troodos ophiolitic complex was probably formed in an island arc: Earth Plant. Sci. Lett., 19, pp. 218-224.

Miyashiro, A. 1973. Metamorphism and Metamorphic Belts. Wiley. 492 P.

Norrish, K. and Chappell, B. W. 1967. X-ray fluorescence spectrography: Zussman, J., Ed., Physical methods in determinative mineralogy, Academic Press, London, pp. 161-214.

———————— and Hutton, J. T. 1969. An accurate x-ray spectrographic method for the analysis of a wide range of geological samples: Geochim. et. Cosmochim. Acta, v. 33, pp. 431-453.

Pettijohn, F. J. 1972. The Archean of the Canadian Shield: a resume. Geol. Soc. Amer. Mem. 135, pp. 131-149.

————————. 1975. Sedimentary Rocks. Third Ed. Harper and Row Publishers.

Pretorius, D. A. 1976. Origin of the gold deposits of the Witwatersrand Triad. In Mineral resources of the Republic of South Africa. C. B. Coetzee, Ed., Geological Survey, South Africa.

Ridler, R. H. 1970. Relationship of mineralisation to volcanic stratigraphy in the Kirkland-Larder Lakes Area, Ontario. Proceedings of the Geological Association of Canada, 21, pp. 32-42.

Schopf, J. W. 1977. Evidences of Archean Life. In Chemical evolution of the early Precambrian. C. Ponnamperuma, Ed., Academic Press.

Stricker, S. J. 1978. The Kirkland-Larder Lake Stratiform Carbonatite Mineralum Deposita, Vol. 13

Weissberg, R. C. 1970. Solubility of gold in hydrothermal alkaline sulphide solutions: Econ. Geol, Vol. 65, pp. 551-556.

Wilson, M. E. 1948. Structural features of the Noranda-Rouyn Area. In Structural Geology of Canadian ore deposits. C.I.M.M. Jubilee volume, pp. 809-816.

Winkler, H.G.F. 1974. Petrogenesis of metamorphic rocks: 3rd ed., Berlin, Springer.