1

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R S C 1970, c C-30.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, tests publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c C-30.

GEOLOGY OF ARCHEAN INTERFLOW SEDIMENTARY ROCKS
AND THEIR RELATIONSHIP TO
Ag-Bi-Co-Ni-As VEINS,
COBALT AREA, ONTARIO

by

MARK CORY SMYK, H.B.Sc.

A thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Science

Department of Geology

Carleton University

Ottawa, Ontario

June, 1987

© copyright

1987, Mark C. Smyk

Permission has been granted to the National Library of Canada to microfilm this thesis and to lend or sell copies of the film.

The author (copyright owner) has reserved other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without his/her written permission.

L'autorisation a été accordée à la Bibliothèque nationale du Canada de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur (titulaire du droit d'auteur) se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation écrite.

ISBN 0-315-39376-9

The undersigned recommend to the Faculty of Graduate Studies
and Research acceptance of the thesis

GEOLOGY OF ARCHEAN INTERFLOW SEDIMENTARY ROCKS AND THEIR
RELATIONSHIP TO ~~Ag~~-Bi-Co-Ni-As VEINS, COBALT AREA, ONTARIO

submitted by Mark Cory Smyk, H.B.Sc.

in partial fulfilment of the requirements for

the degree of Master of Science

Thesis Supervisor

Chairman, Department of Geology

Carleton University

Underground at the Buffalo Mine, c. 1908

Here, the ghosts walk upright
never to stare down at the ground that buries them
always looking skyward to stare at the heavens,
sunlit like dreams in our midst,
to see beyond the hungry forest
which grows anew from the dust.

They live inside crumbling walls
with foundations anchored firmly in the earth
where men have fallen like the years
tumbling to empty, timeless graves
carved in rock, the toil
has come to rest in ruin,
lives spent on the capricious winds
that forever smite summer with fall
and our fleeting passage with remembrance.

In sepia mirrors, their quiet smiles
resound with silent triumph
while wistful eyes shall never fail
to give the unspoken warning of their plight
the cost of winning riches from sleeping treasure
and of all the unbestowed honours of their struggle
that compel us to go on.

M.C.S.

Cobalt, 1985

ABSTRACT

Archean interflow sedimentary rocks (ISR) in the Cobalt area are intercalated with massive to pillowed tholeiitic andesite, and autoclastic, hyaloclastic and resedimented pyroclastic units. Most of the ISR are immature turbidites, with minor pelagic and exhalative sedimentary rocks. Stratiform sulphides in the sedimentary succession are predominantly syngenetic base metal sulphides and minor diagenetic Fe-sulphides. Sulphide mobilization is supported by the development of secretion-injection structures, mineralogic zonation and other epigenetic features. Epigenetic sulphides occur as veinlets and as replacements with associated silicification, chloritization and minor carbonatization. Ag-Bi-Co-Ni-As veins are commonly in close spatial association with ISR. There is no clear evidence that they provided metals for the veins but folds, faults and deformation zones in ISR have influenced vein development.

ACKNOWLEDGEMENTS

The author would like to thank Dr. D.H. Watkinson for his supervision, and Drs. J.A. Donaldson and K. Bell for their guidance throughout the preparation of this thesis. Funding was supplied primarily from Ontario Geoscience Research Grant #173. Peter Whittaker put in a good word for me from the onset. Paul MacRobbie provided enthusiastic field assistance in 1985. Peter Jones conducted the electron microprobe analyses. I would like to acknowledge the assistance of the following people in Cobalt: Doug Robinson and Brian Thorniley, Agnico-Eagle Mines Ltd.; Leo Owsicki and Staff, Resident Geologist's Office; Art Beecham, Sulpetro Minerals Ltd.; Lawrence Othmer, Canadaka Mines Ltd.; "K.V." at the Haileybury School of Mines; and Bell-White Laboratories, Haileybury. A special thanks is extended to all those who helped out in the "Town That Silver Built", especially Bob Montgomery and family, Albert Chitaroni and family, Paul Gillett and family, Mike Gabbani and family and all the other "Cobaltites". I appreciate all the help I received from the temporary "CoAsS's", Elaine Dodd, Pete Mustard, Rob Rainbird, Brad Wilson, and from wayward sedimentologists, Geof Burbidge and Larry Aspler. George Patterson and Bernie Schnieders, Ministry of Northern Development and Mines; Phil Fralick and Steve Kissin, Lakehead University; Peter Hinz, Perry Sarvas and David Laderoute made the trips back home to Thunder Bay enlightening. Ian Jonasson, Geological Survey of Canada, went through great lengths (and hammer handles) to retrieve and polish samples for me. Louise Kraschewski, Graphic Services, made sure my Letratone greys came out. Much gratitude

is deserving of all those who suggested, prodded, proofread, acted as sounding boards and joined me in a beer or two, including Dave Kingston, "Cobalt Kate" Grapes, Gary Yeo, Suzanne Paradis, Jean Richardson, Henry Dillon-Leitch, all the "495'ers", past and present, Karen Pelletier and Jennifer Wahlroth, Barb and Roy Reed, Dave Melling, Richard Taylor, Jack Hogg, and the rest of the Carleton crew. Finally, I'd like to extend a special thanks to Miriam and my family for all their patience and encouragement.

TABLE OF CONTENTS

	PAGE
NOTICE OF ACCEPTANCE.....	ii
ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
LIST OF PHOTOGRAPHIC PLATES.....	x
CHAPTER 1: INTRODUCTION.....	1
Background.	1
Purpose of Thesis.	1
Method.	2
CHAPTER 2: REGIONAL AND LOCAL GEOLOGY.....	3
Regional Geology.	3
Geology of the Main Cobalt Mining Camp.	5
Distribution of the Silver Veins.	8
CHAPTER 3: ARCHEAN STRATIGRAPHY AND THE DISTRIBUTION OF INTERFLOW SEDIMENTARY ROCKS.....	9
Volcanic Stratigraphy.	9
Distribution of the Interflow Sedimentary Rocks.	11
CHAPTER 4: SEDIMENTOLOGY AND PETROLOGY OF THE INTERFLOW SEDIMENTARY ROCKS.....	15
Stratigraphic Nomenclature.	15
Facies Interpretations.	15
Metamorphism.	21
Geochemistry of Interflow Shale.	21
CHAPTER 5: SULPHIDE MINERALIZATION IN INTERFLOW SEDIMENTARY ROCKS.....	26
Stratiform Sulphides in Interflow Sedimentary Rocks.	26
Syngenetic Base Metal Sulphides.	26
Fe-sulphides in Shale.	27
Metamorphic Sulphide Textures.	31
Sulphur Isotope Data.	41
CHAPTER 6: DISCUSSION - THE ROLE OF INTERFLOW SEDIMENTARY ROCKS IN SILVER ORE VEIN DEVELOPMENT.....	47
Structural Relationships.	47
Folds and Faults.	47
Relationship to the Archean - Proterozoic Unconformity.	48
Stratigraphic Considerations.	50
Significance of Dykes.	53
Application of General Relationships.	53
Mineralogic Relationships.	55
Significance of Sulphide Mobilization.	55
Morphology of Mobilized Sulphides.	55
Mineralogy of Mobilized Sulphides.	57

Genetic Mechanisms of Mobilization.	59
Importance of a Fluid Phase.	60
Nature of Fluid and Fluid Interaction.	60
Significance of Lead-isotopic Data.	61
CHAPTER 7: CONCLUSIONS.....	63
REFERENCES.....	67
APPENDIX A: MINERAL ABBREVIATIONS.....	76
APPENDIX B: GEOCHEMICAL ANALYTICAL TECHNIQUE.....	77
APPENDIX C: ELECTRON MICROPROBE DATA OF CHLORITE AND SPHALERITE.....	80
APPENDIX D: GROUND MAGNETOMETER SURVEY RESULTS.....	87

LIST OF TABLES

TABLE	DESCRIPTION	PAGE
1	Stratigraphic Column, Cobalt Area	7
2	Archean Interflow Sedimentary Lithofacies Descriptions	back pocket
3	Geochemistry of Interflow Shale	22
4	Sulphur Isotopic Ratio Data	42
5	Summary of Archean and Proterozoic Geologic Events, Cobalt Area	44
6	Veins and Faults Spatially Associated with Archean Interflow Sedimentary Rocks	51
7	Composition of Coexisting Sphalerite and Chlorite	81
8	Ground Magnetometer Survey Data	87

LIST OF FIGURES

FIGURE	TITLE	PAGE
1	Location of the Cobalt Mining Camp	4
2	Regional Geology of the Cobalt Embayment	6
3	Local Geology of the Main Cobalt Camp	back pocket
4	Reconstruction of Archean Stratigraphy and Fold Structures	back pocket
5a	Schematic Section of Volcano-Sedimentary Stratigraphy	13
5b	Detailed Schematic Section of Contact Relationships	14
6a	Stratigraphic Sections, Northern Interflow Sedimentary Unit, Nipissing RL 404 Property	back pocket
6b	Stratigraphic Sections, Southern Interflow Sedimentary Unit, Nipissing RL 404 Property	back pocket
6c	Location of Stratigraphic Sections, Nipissing RL 404 Property	back pocket
7	Geology of Nipissing RL 404 Property	back pocket
8	Sketch showing Black Chert Breccia	17
9	Sketch showing Contact Relationships	18
10	Sketch showing Synsedimentary Deformation Features	19
11	Sketch showing Synsedimentary and Tectonic Deformation Features	20
12	Sketch of Pyrrhotite Morphology in Shale and Chert	28
13	Sketch of Fe-sulphide Morphology in Shale	29
14a	Plot of Sulphur versus Carbon, Interflow Shale	32
14b	Plot of $\text{Fe}_2\text{O}_3\text{T}$ versus Sulphur, Interflow Shale	33
15	Sketch showing Syngenetic and Epigenetic Sulphides and Sulpharsenides in Shale and Chert	36
16	Sketch of Epigenetic Pyrrhotite in Deformed Shale	37

17	Sketch of Epigenetic and Syngenetic Sulphides in Deformed Shale	38
18	Composite Sketch of Spatial Relationships between Sulphides and Sulpharsenides	39
19	Geology of Drift Section, Beaver - Temiskaming Mine	40
20	Geology of "19-28" Shear Zone, Nipissing RL 404 Property back pocket	
21	Sketches showing Small-scale Features, "19-28" Shear Zone	49
22	Sketch Showing Spatial Relationships between Veins and Faults, Nipissing RL 404 Property	56
23	Block Diagram of Vein 60 Open Cut, Nipissing RL 401 Property	65
24	Chlorite Composition, Archean Interflow Sedimentary and Volcanic Rocks	84

LIST OF PHOTOGRAPHIC PLATES

PLATE	TITLE	
1	Photographs and photomicrographs of sedimentologic and tectonic features in interflow sedimentary rocks	25
2	Photographs and photomicrographs of sulphide mineralization features in interflow sedimentary rocks	46

CHAPTER 1: INTRODUCTION

Background

Since its discovery in 1903, the Cobalt camp has produced approximately 500 million ounces of silver. Many workers, including Miller (1913), Knight (1924) and Thomson (1957; 1960 a,b,c; 1961a,b,c,d), have described the local geology and the ore veins. More recent studies have investigated the relationships between the veins and their host rocks in an attempt to develop a genetic model for veins and mineralization (e.g. Berry, 1971; McDonald, 1986).

These studies have provided much new information, but the origin of the veins is still enigmatic. Although a spatial association between Archean interflow sedimentary rocks (ISR) and the silver veins has long been noted, these rocks and their relationship to the veins have not been documented.

Purpose of Thesis

This thesis serves:

- (1) to describe and classify the Archean interflow sedimentary rocks with emphasis on sulphide-bearing units.
- (2) to attempt to use the ISR as marker horizons in describing the volcano-sedimentary stratigraphy and subsequent tectonic deformation.
- (3) to describe the nature of sulphide mineralization and alteration in ISR with respect to syn- or post-depositional processes.
- (4) to attempt to correlate observed structural, mineralogic and alteration features which may suggest possible genetic (source) relationships between ISR and the Ag-Bi-Co-Ni-As veins.

Method

Field work was initiated during the summer of 1985 and completed in 1986. Reconnaissance mapping of Archean rocks at a scale of 1:4800 was conducted near Sasaginaga and Clear Lakes and near the town of Cobalt. Air photos and pace-and-compass traverses were employed. This mapping augmented field data compiled by Knight (1924) and Thomson (1964a,b,c). Mining records and files at the Resident Geologist's Office, Ontario Ministry of Northern Development and Mines, Cobalt, were also studied. Detailed maps (e.g. 1:40, 1:400 scale) were prepared to describe key outcrops and areas, using chained control lines. Underground mapping at the Beaver - Temiskaming Mine involved detailed description of key drift sections mapped by D. Robinson (Mine Geologist, Agnico - Eagle Mines Ltd.) at a scale of 1:240, as well as study of diamond drill core from underground drilling.

Representative samples for petrographic and petrologic study were collected to complement map information. In areas where outcrop exposure was minimal or absent, mine dumps and diamond drill core were sampled. Polished thin sections were prepared at Carleton University in addition to cut and polished, slabbed samples. Lithogeochemical analyses were obtained on shale samples by the Analytical Chemistry Section, Economic Geology and Mineralogy Division of the Geological Survey of Canada, Ottawa.

CHAPTER 2: REGIONAL AND LOCAL GEOLOGY

Regional Geology

The Cobalt area is underlain predominantly by Precambrian rocks of the Superior and Southern Structural Provinces of the Canadian Shield. A small outlier of Paleozoic strata is exposed at the northern end of Lake Timiskaming (Figure 1).

Archean volcanic, sedimentary and intrusive rocks comprise the southernmost part of the Abitibi greenstone belt (MERQ-OGS, 1983). However, correlation of these rocks in the Cobalt and Temagami areas with their counterparts in the main Abitibi Belt is impeded by an intervening cover of unconformably overlying Proterozoic sedimentary rocks of the Huronian Supergroup.

Huronian strata are exposed in the northeastern part of the Southern Province termed the Cobalt Embayment. In this basin, the upper part of the Supergroup is represented by rocks of the Cobalt Group, including the Gowganda, Lorrain and Gordon Lake Formations (Sims et al., 1981).

Nipissing diabase, a suite of gabbroic intrusive rocks and differentiates, extends from Cobalt to near Sault Ste. Marie and occurs as dykes, sills and cone sheets (Card and Pattison, 1973). It intrudes Archean and Huronian rocks and has most recently been dated at 2219 ± 3.6 – 3.5 Ma (Andrews et al., 1986b) in the Gowganda area.

Late diabase dykes intrude all aforementioned rocks and are probably related to fault systems active in the Late to Middle Proterozoic.

Figure 1: Location of the Cobalt Mining Camp

Strongly metamorphosed and deformed rocks of the Grenville Province are juxtaposed along the southern margin of the Southern Province at the Grenville Front Tectonic Zone, approximately 50 kilometres south of Cobalt.

Regional fault systems are dominated by a prominent northwest-striking fault set which parallels the Timiskaming Rift Valley System (Lovell and Caine, 1970), the northern extension of the Ottawa - Bonnechere Graben.

Silver mining camps have developed in an arcuate zone along the northern margin of the Cobalt Embayment. These include the Cobalt, South Lorrain, Casey Township, Elk Lake and Gowganda areas (Figure 2).

Geology of the Main Cobalt Mining Camp

The general geology of the Cobalt camp has been summarized by Jambor (1971a), Donaldson and Munro (1982), Owsiacki (1984) and Andrews et al. (1986a). The local stratigraphy is outlined in Table 1. The local geology is depicted in Figure 3.

Archean rocks occur as isolated inliers; they are usually overlain by Gowganda Formation sedimentary rocks and intruded by Nipissing diabase. The petrology and stratigraphy of the Archean basement is addressed in Chapter 3.

The Gowganda Formation has been subdivided into the lower, Coleman Member and the upper, Firstbrook Member which have been ascribed to glaciomarine (Mustard, 1985) and prodeltaic (Rainbird, 1985) deposition, respectively. The thickness of the Coleman Member is highly variable and reflects irregularities in

PROTEROZOIC

Nipissing diabase

Huronian sedimentary rocks

ARCHEAN

Granitic rocks

Volcanic and sedimentary rocks

Mining Camp

Figure 2: Regional Geology and Location of the Main Silver Mining Camps, Cobalt Embayment

TABLE 1

STRATIGRAPHIC COLUMN, COBALT AREA

P R E S E N T O R D O V I C	Recent		Fluvial and lacustrine deposits	
	Pleistocene		Glacial sand, gravel and varved clay	
	unconformity			
	Silurian	Thornloe Formation	Dolomite, limestone,	
		Wabi Formation	Limestone, shale	
	disconformity			
	Ordovician	Dawson Point Formation	Shale	
		Farr Formation	Limestone	
		Bucke Formation	Shale	
		Guigues Formation	Sandstone	
unconformity				
P R O T O L I T H I C	Olivine and quartz diabase			
	intrusive contact			
	Nipissing diabase			
	intrusive contact			
	Huronian Supergroup	Cobalt Group		
		Lorrain Formation	Quartz arenite, arkose	
		Gowganda Formation		
		Firstbrook Member	Laminated siltstone	
		Coleman Member	Conglomerate, sandstone, laminated siltstone	
	unconformity			
A R C H E A N	Diabase, minor lamprophyre			
	intrusive contact			
	Algoman	Granite, granodiorite, syenite		
		intrusive contact		
	Dykes and sills of mafic and ultramafic rocks; lamprophyre			
	intrusive contact			
	Timiskaming	Lithic and feldspathic arenites and wackes; conglomerate		
		unconformity		
	Keewatin-type Volcanic Rocks	Mafic to intermediate flows and tuffs; minor felsic tuff, quartz-feldspar porphyry; Interflow Sedimentary Rocks		

Modified after Donaldson and Munro (1982)

the Archean basement paleotopography. It attains a maximum thickness of approximately 180 metres (Jambor, 1971a).

Nipissing diabase locally occurs as an undulating sheet or sill, 300 to 335 metres thick (Jambor, 1971b; Lightfoot et al., 1986). The diabase sill developed as basins and arches and intruded both Archean and Huronian rocks.

Distribution of the Silver Veins

The distribution and general characteristics of the Ag-Bi-Co-Ni-As deposits are summarized by Petruk (1971a,b) and Andrews et al. (1986a). The deposits occur as veins in zones of intense fracturing in all aforementioned rocks. Ore bodies occur proximally to the diabase contacts and are localized by faults, contacts and the Archean - Proterozoic unconformity. The veins are typically narrow and pinch and swell. Productive ore shoots are erratic but carry exceptionally high silver grades. Ore minerals are native elements (Ag, Bi), Co-Ni-Fe-arsenides, sulpharsenides and sulphides. The gangue mineralogy consists of calcite, dolomite, quartz and chlorite.

CHAPTER 3: ARCHEAN STRATIGRAPHY AND THE DISTRIBUTION OF INTERFLOW SEDIMENTARY ROCKS

Archean rocks are exposed within approximately 25% of the Cobalt area and consist largely of volcanic rocks, with lesser amounts of related sedimentary and younger intrusive rocks, including the Lorrain granite and lamprophyre dykes (Figure 3).

Volcanic Stratigraphy

Archean volcanic rocks in the Cobalt area have most recently been studied by Patterson (1979), Dillon-Leitch (1980), Patterson and Andrews (1981) and MacRobbie (1986). These rocks bear marked similarities to volcanic rocks described in the Temagami area by Bennett (1978) and Smyk and Owsicki (1986).

The volcanic succession consists primarily of tholeiitic, massive to pillowed andesitic flows with associated autoclastic and hyaloclastic units. Calc-alkaline rhyodacitic tuffs, related pyroclastic rocks and quartz-feldspar porphyry comprise a minor part of the succession. Conformable volcanogenic and epiclastic interflow sedimentary rocks (ISR) commonly delineate flow units.

The volcano-sedimentary succession was deformed and altered by regional greenschist facies metamorphism during the Kenoran Orogeny (ca. 2500 Ma). This metamorphism was accompanied by the intrusion of mafic to felsic rocks. Steeply plunging, tight, isoclinal folds are marked by northwest-trending fold axes (Thomson, 1961b; Patterson and Andrews, 1981). Recognition of the major fold structures is hindered by widespread Proterozoic cover despite excellent bedrock exposure in the main volcanic inliers. Extrapolation of volcanic and ISR units beneath

Proterozoic cover based on information derived from surface and underground mapping is possible to some extent. This has been attempted in the area between Sasaginaga and Peterson Lakes (Figure 4). This reconstruction reveals major folds and minor, asymmetric folds with northwest-trending fold axes. The development of northwest-trending, steeply dipping faults, including the "Z", 64, Shaft 6, Galena and "X" faults, was presumably controlled by these fold structures.

The structural complexity of the volcano-sedimentary succession makes stratigraphic interpretation difficult. The interpretation of volcanic cycles locally has been made by Lovell (1978), Patterson (1979), Dillon-Leitch (1980) and Patterson and Andrews (1981). They are considered to be large-scale cycles which range from komatiitic rocks, near Temagami, through mafic and intermediate volcanics, which culminate in a series of felsic volcanic centres located between Cross and Sasaginaga Lakes. Few felsic volcanic rocks were found by the author during mapping. Field observations suggest that local silicification of mafic to intermediate rocks may be responsible for their apparent felsic nature. Silicification has also been noted by Patterson (1979) and Dillon-Leitch (1980).

Studies of flow morphology and the spatial association of units on a smaller scale aid in the recognition of relationships between volcanic and ISR, sulphide mineralization, deformation and alteration. Such studies were undertaken at the Beaver - Temiskaming Mine (Figure 19), on the Nipissing RL 401 Property (Vein 60 area; Figure 23) and on the Nipissing RL 404 Property (Nipissing Hill south area; Figure 7).

Distribution of Interflow Sedimentary Rocks

ISR usually occur as thin (<40 m) units intercalated with volcanic flows. Idealized stratigraphic sections are shown in **Figures 5a,b**. Despite their relative paucity in many areas, they commonly exhibit lateral continuity over several hundred metres. Sections up to 400 m thick occur near the northern end of Sasaginaga Lake, around Clear Lake and at the southwest end of Cross Lake. These may be thickened by tectonic deformation, however. Contacts with the enclosing volcanics are usually distinct except, for example, where underlying tuffaceous units have been resedimented within the ISR.

KEY**SULPHIDE MINERALIZATION****(A) VOLCANOGENIC SULPHIDES:****(1) Exhalative, syngenetic sulphides**

(1a) disseminated, or as stratiform
bands in chert^b

(1b) as massive sulphide lenses^a

(2) Hydrothermal sulphides

(2a) in pillow selvages or
in interpillow spaces^b

(2b) in flow/ pillow breccia^b

(2c) in phreatic breccia^b

(2d) in stockwork zones^a

SEDIMENTARY/ VOLCANOGENIC SULPHIDES:**(3) Diagenetic Fe-sulphides**

in black, carbonaceous shale^b

^adepicted in Figure 5a

^bdepicted in Figure 5b

massive to pillowed andesitic flows

Figure 5a: Schematic Section of Volcano-Sedimentary Succession showing Lithologic Relationships and Associated Sulphide Mineralization

Figure 5b: Detailed Schematic Section of Contact Relationships between Interflow Sedimentary and Volcanic Rocks

CHAPTER 4: SEDIMENTOLOGY AND PETROLOGY OF THE INTERFLOW SEDIMENTARY ROCKS

Stratigraphic Nomenclature

The volcanics and ISR, originally correlated with Keewatin-type volcanic units, unconformably underlie an extensive sequence of clastic sedimentary rocks to the north correlated with the Temiskaming Group. Local Temiskaming rocks are conglomerate, greywacke and sandstone (Boutcher et al., 1966; Hyde, 1980). These sediments have been assigned to a Nonmarine (Hyde and Walker, 1977) or Continental (Turner and Walker, 1973) Association. Timiskaming and "Keewatin-type" (interflow) sedimentary rocks may locally be distinguished by their respective sedimentological characteristics and by the marked absence of silver veins in Timiskaming rocks.

Recent studies of Archean sedimentary rocks have employed facies models based on features such as grain size, bedding and sedimentary structures (e.g. Turner and Walker, 1973; Hyde and Walker, 1977). Although these studies have documented relatively thick epiclastic sequences which represent major hiatuses in volcanism, rather than thinner sequences intercalated with volcanic units (e.g. Barley et al., 1979), facies can still be employed in subdividing the ISR. Constituent lithofacies are described in Table 2.

Facies Interpretations

Facies interpretations based on sedimentological and field relationships indicate that the majority of the ISR are turbidites. These rocks are characteristic of what Turner and Walker (1973) termed a Resedimented Association. Although pelagic

or exhalative sediments were not resedimented in the strict sense, they are included in this association because of their intimate stratigraphic association with the turbidites (cf. Hyde and Walker, 1977) (Figures 6a,b,c). Resedimentation took place in relatively shallow water, to deeper water below wave base where sedimentary structures were preserved. Deposition occurred on a seafloor consisting mainly of submarine pillowed to massive andesitic flows, whose non-vesicular nature may be partly ascribed to extrusion in very deep water (Dillon-Leitch, 1980).

Local stratigraphy apparently reflects successive, cyclical submarine extrusive and sedimentation events (Figure 7). Original stratigraphic relationships and lateral continuity were altered by turbidite scouring of unconsolidated volcanic fragmental, exhalative and/or pelagic deposits and the resultant juxtaposition of turbidites upon these units (Figures 8 and 9). Syndepositional deformation structures were caused by slumping of unstable sediment accumulations, perhaps induced by synvolcanic tectonism (Figures 10 and 11). The close spatial association between ISR and the volcanics, the predominance of volcanic detritus and the presence of interbedded pyroclastic units suggest that sedimentation and volcanism were in part contemporaneous. A lack of paleocurrent data and the degree of subsequent tectonic deformation prevents reconstruction of basin paleogeography and determination of the sediment provenance. The presence of minor detrital muscovite, biotite and zircon in the epiclastic sediments suggests a contribution from an early granitic or metamorphic terrane.

Figure 8: Sketch Map showing Black Chert Breccia and Sedimentary Features, Nipissing RL 404 Property Detail Map Area (see Figure 7 for location)

Figure 9: Sketch Map showing Contact Relationships between Interflow Sedimentary and Volcanic Rocks, Nipissing RL 404 Property Detail Map Area (see Figure 7 for location)

Figure 10: Sketch Map showing Synsedimentary Deformation Features, in Interflow Sedimentary Rocks, Hudson Bay Property, eastern arm of Sasaginata Lake

Figure 11: Sketch Map showing Synsedimentary and Tectonic Deformation Features, "Turnoff Outcrop", Junction of Highway 11B and West Coleman Road

Metamorphism

Metamorphic features are more clearly developed in ISR as compared to the volcanic rocks. Strongly foliated to schistose rocks contain lepidoblastic sericite, chlorite and muscovite. Foliation is apparently co-planar with bedding and was deflected by larger framework clasts.

Strain shadows infilled with drusy quartz develop on pyrite nodules which are flattened parallel to foliation (Figure 12d, Photograph 2-2). Small "veinlets" of carbonaceous material oriented obliquely to foliation have buckled during flattening (Photograph 1-8). These veinlets may be the result of mobilization of carbonaceous material during deformation (Wilson and Rucklidge, 1986). The effects of simple shear are less obvious, but in rare cases, sigmoidal-shaped fragments have been noted.

Rocks proximal to the Lorrain granite and the Nipissing diabase show the effects of contact metamorphism. Chloritic spotting is ubiquitous in all rocks within approximately 100 m of the diabase sill contacts (Jambor, 1971b) and is attributed to metasomatism (Appleyard, 1981). Near the Lorrain granite, garnet and amphibole occur in banded magnetite - siltstone ironstone on the Fisher - Eplett property. Garnet has also been noted in the volcanics of the nearby Beaver - Temiskaming Mine (Dr. Robinson, personal communication, 1986).

Geochemistry of Interflow Shale

Major and trace element geochemical analyses were conducted on nine samples of black interflow shales. These analyses are listed in Table 3. Samples contained approximately 2 to 40% sulphides.

TABLE 31
GEOCHEMISTRY OF INTERFLOW SHALE

Sample No.	75215	75216	75217	75218	75219	75220	75221	75222	75223	Composite ^a
SiO ₂	41.5	60.9	61.5	68.4	64.5	68.3	75.7	52.4	68.9	58.0
TiO ₂	0.15	0.30	0.30	0.39	0.39	0.45	0.35	0.56	0.46	0.73
Al ₂ O ₃	6.40	11.7	8.19	14.9	16.6	15.7	12.3	14.0	14.4	16.9
Fe ₂ O ₃ T	39.0	13.0	14.0	3.33	4.94	3.25	1.99	17.2	2.98	7.60
MnO	0.02	0.02	0.02	0.03	0.07	0.03	0.02	0.01	0.03	0.09
MgO	1.42	1.23	0.65	1.86	1.97	1.76	0.79	0.72	1.49	3.33
CaO	0.31	0.63	0.33	0.79	0.66	0.55	0.67	0.37	0.59	2.07
Na ₂ O	0.95	2.47	0.56	2.56	5.41	3.94	1.74	3.46	2.16	2.50
K ₂ O	3.16	4.67	3.84	3.14	2.22	3.49	3.86	7.12	4.14	2.73
H ₂ O ^T					2.1	2.0	1.9			3.40
C	0.4	0.4	6.5	1.1	0.3	0.2	0.6	0.7	0.8	0.70
Cu ₂ S	0.1	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.0	1.1
P ₂ O ₅	0.05	0.08	0.09	0.17	0.15	0.16	0.08	0.09	0.13	0.16
S	17.3	5.69	6.44	1.67	0.52	0.32	0.56	7.85	1.15	0.66
Ba	700	1100	800	680	520	480	670	880	710	550
Ag	15	31	1	0	7	22	2	3	69	0.4
Be	0.2	1.4	0.6	1.2	1.6	1.7	0.6	0.4	1.3	3.0
Co	190	75	64	13	28	22	15	55	20	35
Cr	0	16	25	29	28	34	32	52	85	133
Cu	780	2000	110	61	560	2600	30	630	7800	66
La	8	26	11	14	13	7	7	11	26	24
Ni	200	49	180	36	68	27	26	99	41	127
Pb	120	5800	67	90	290	1000	15	1100	350	26
V	14	30	52	43	44	57	50	83	75	130
Yb	0.0	1.4	0.8	0.9	0.6	0.8	0.7	0.6	1.5	
Zn	400	12000	7700	110	6500	430	14	190	140	323
Au	12.9	3.8	6.1	<1.	<1.	<1.	<1.	4.9	1.2	
B	17.4	41.0	40.3	42.5	46.1	23.3	38.6	2.2	55.7	33
Mo	24.4	3.0	7.4	2.4	2.9	1.8	2.2	2.8	3.8	2.2
W	1.7	1.7	<1.	<1.	2.0	<1.	<1.	<1.	<1.	
As	19.7	37.1	229.8	46.5	311.4	374.5	32.1	12.3	376.9	46
Sb	6.0	13.5	5.1	2.6	7.4	7.3	1.0	0.9	51.1	1.2
TOTAL (Σ)	111.0 [*]	103.2	103.4	98.6	100.8	100.6	100.8	104.8	98.2	99.98

^a Archean Shale Composite (Cameron and Garrels, 1980)

(n.b. all trace element data in ppm, except for Au in ppb)

Marked variations in major element percentages exist in the samples. Significant amounts of sulphides and quartz veinlets in some samples may account for some of this variation. Local major element compositions are similar to an Archean shale composite determined by Cameron and Garrels (1980). They believed that this composition reflected weathering of a dominantly volcanic source and rapid deposition.

Trace elements (Ag, Co, Ni) and base metals are strongly correlative with sulphur, indicating their association with sulphide and sulpharsenide mineralization. Correlation of elements with carbon content is not evident. All samples, however, contain amounts of carbon similar to or greater than the Archean composite. Relatively high carbon contents in local shales may be indicative of originally high primary carbon production in the sediments, low degrees of reoxidation, and/or minimal postdepositional biologic, diagenetic and metamorphic degradation (Strauss, 1986).

PLATE 1: SEDIMENTARY FEATURES

- PHOTO 1-1:** Very thinly bedded A(D)E turbidites, Nipissing RL 404 Property. Load casts, graded sandstone beds and flame structures (arrow) indicate top direction. (see **Figure 7** for photograph location)
- PHOTO 1-2:** Sandstone load casts and flame structures in thinly laminated mudstone, "Turnoff Outcrop". Note foundered sand lens (S) causing disruptions in mudstone laminations, and late chloritic breccia dyke (C). (see **Figure 11** for photograph location).
- PHOTO 1-3:** Syndimentary mud infilling "pull-apart structure" in slumped, overturned, very thinly bedded turbidites; Nipissing RL 404 Property (see **Figure 7** for photograph location).
- PHOTO 1-4:** Photomicrograph of poorly sorted lithic wacke, Nipissing RL 404 Property. Note clast of wacke (W), angular plagioclase and sub-rounded quartz grains. Matrix is partially altered to sericite and chlorite. Field of view is 3.1 mm. (transmitted light, crossed nicols) See **Figure 7** for sample location.
- PHOTO 1-5:** Photomicrograph of siltstone with disseminated magnetite grains (opaque), Fisher - Eplett Property. Small quartz veins may represent syndimentary de-watering cracks. Field of view is 3.1 mm. (transmitted, plane polarized light)
- PHOTO 1-6:** Photomicrograph of siltstone with locally graded, magnetite-rich laminations, Fisher - Eplett Property. Magnetite (opaque) is concentrated in the upper part of the siltstone bed, which is approximately 2 mm thick. (transmitted, plane polarized light)
- PHOTO 1-7:** Isoclinal fold in interbedded wacke and siltstone (grey), and pyritiferous black shale, near station 1463-5, 1450' level, Beaver - Temiskaming Mine. Pyrite nodule (Py) is flattened parallel to axial trace (approximately parallel to pencil). See **Figure 19** for photo location.
- PHOTO 1-8:** Photomicrograph of buckled "veinlet" of carbonaceous material (black) in thinly laminated, carbonaceous shale, Windsor - Cobalt Property. Foliation is co-planar with bedding. Field of view is 3.1 mm. (transmitted, plane polarized light)

CHAPTER 5: SULPHIDE MINERALIZATION IN INTERFLOW SEDIMENTARY ROCKS

Perhaps the most striking and noteworthy feature of the ISR is the ubiquity of associated sulphides. While base metal sulphides are interesting from an economic viewpoint, they also provide information about the possible metallogenetic relationships between basement sulphides and silver vein deposits.

Stratiform Sulphides in ISR

Stratiform sulphides in the volcano-sedimentary succession result from synvolcanic, synsedimentary and later epigenetic processes. Different events of sulphide precipitation may be distinguished on the basis of their mineralogy, textures, morphology and geochemistry.

Synsedimentary sulphides in ISR are either syngenetic or diagenetic. Ohmoto (1987) defines syngenetic sulphides as those formed within the water column which subsequently settle to the seafloor with other chemical and clastic sedimentary components. Diagenetic sulphides form within the sediments themselves.

Syngenetic Base Metal Sulphides

Base metal sulphides in local volcanic and ISR have been described by Thomson (1960a,b,c; 1961a,b,c,d), Patterson (1979), Dillon-Leitch (1980), Patterson and Andrews (1981), MacQueen (1985) and MacRobbie (1986). Sphalerite, chalcopyrite, pyrite, pyrrhotite and galena occur typically in ISR as disseminated grains to massive, stratiform bodies intercalated with chert and black shale.

Chlorite, predominantly prochlorite and pycnochlorite (cf. Saggerson and Turner, 1982), is invariably intergrown with sulphides (Photograph 2-3). Electron microprobe analyses of coexisting chlorite and sphalerite in volcanic and ISR disclose that chlorites display significant variation in their $\text{Fe}/(\text{Fe} + \text{Mg})$ ratios while the amount of Fe in intergrown sphalerite is relatively constant (Appendix C). In isolated occurrences, chlorite occurs either immediately above or below sulphide bands (Figure 12). This mineralogic asymmetry suggests that the precipitation of chlorite (or its precursor) accompanied that of the sulphides.

Fe-sulphides in Shale

Pyrite, pyrrhotite and marcasite occur in carbonaceous shale. Fe-sulphide - rich shales are interbedded with turbidites and throughout the entire camp and are often spatially associated with silver veins (Thomson 1961a,b,c,d). Fe-sulphides ($\pm$ quartz) assume a variety of shapes, including: banded to colloform, lenticular to reniform, and nodular to botryoidal (Figure 13, Photographs 2-1, 2-2). These subdivisions do not imply drastically different genetic histories but merely reflect developmental changes effected by their respective growth environments. Carbonaceous and fine-grained detrital material is commonly intercalated with the sulphides. Although Elliott (1984) considered the ratio of pyrite to carbonaceous material in nodules in Archean shales in the Timmins area to be a function of the developmental maturity of the nodules, compositional variation may only be indicative of depositional and genetic processes.

Similar Fe-sulphide deposits in Archean sediments have been

Figure 12: Sketch of polished slab of Chert and Shale with Syngenetic, Diagenetic and Epigenetic Pyrrhotite showing Asymmetry of Chloritic Bands, "19-28" Shear Zone outcrop, Nipissing RL 404 Property Detail Map Area

(a) banded to colloform

(b) lenticular to reniform

(c) nodular to botryoidal

(d) flattened, with strain shadows

0 5cm

Figure 13: Morphology of Diagenetic and Syngenetic Fe-Sulphides in Shale

documented in the Abitibi greenstone belt (Goodwin and Ridler, 1970), such as at the Owl Creek Mine, Ontario (Kingston, 1987) and in the Jackfish area, Ontario (B. Schnieders, personal communication, 1987).

Sedimentary pyrite may form during diagenesis from the reaction of H_2S with detrital Fe-minerals (Berner, 1984). H_2S results from the bacterial reduction of dissolved seawater sulphate under anoxic conditions (Berner, 1984), or from volcanogenic exhalation (Strauss, 1986). The former reaction is accompanied by the oxidation of organic matter in the sediments. Pyrite formation in marine shales is therefore controlled by:

- (1) deposition and diagenesis of organic matter
- (2) sulphate and H_2S concentration in seawater, and
- (3) availability and reactivity of detrital Fe-minerals

(cf. Berner and Raiswell, 1984).

The abundance of dissolved sulphate in Archean seawater and the role of sulphate-reducing bacteria are contentious issues. Evidence is based largely on the interpretation of S- and C-isotopic data. Due to anoxic conditions, sulphate has been considered to be a minor component in Archean seawater ($< 0.001 \text{ mol}^{-1}$) (Cameron, 1982). Abiogenic sulphate reduction by organic matter may occur at the site of mineral deposition where sulphides are precipitated from H_2S -poor ore fluids and a sulphur species of lower valence exists to initiate the reaction (Ohmoto, 1987). Furthermore, Strauss (1986) and Cameron and Garrels (1980) have stated that no evidence exists that supports widespread bacterial sulphate reduction in the Archean. This contradicts the

ideas of Holland (1984), and the findings of Berner (1970, 1984) and Berner and Raiswell (1984) in younger sediments.

A hydrothermal origin for sulphides in shales proximal to volcanic vents has been proposed by Strauss (1986) and Cameron and Garrels (1980). Base metals are derived from the vents; sulphur originates either from a juvenile magmatic source or from high-temperature reduction of seawater sulphate. This hypothesis is supported in Cobalt shales by field evidence showing transitions from disseminated to massive sulphides, and from Fe-sulphides to base metal sulphides. The relative paucity of carbon (usually <1%) relative to sulphur (Figure 14a), suggests that sulphide accumulation was not due to simple biogenic sulphate reduction during diagenesis (Ohmoto, 1987). The positive correlation of Fe and S (Figure 14b) and the lack of correlation between Fe and C further implies a syngenetic, rather than a diagenetic origin (Raiswell and Berner, 1985; Ohmoto, 1987).

Local stratiform sulphides are therefore considered to be:

- (1) predominantly syngenetic base metal sulphides associated with volcanogenic exhalative and hydrothermal processes in chert and black shale, and/or
- (2) diagenetic Fe-sulphides resulting from abiogenic sulphate reduction in carbonaceous shales.

Metamorphic Sulphide Textures

Distinct textures and fabrics have developed as the result of metamorphic recrystallization, deformation and the replacement and mobilization of pre-existing sulphides. Similar features have been described by Vokes (1969; 1971) and Maiden (1984).

Metamorphic recrystallization is shown by changes in

Figure 14a: Plot of weight percent Sulphur versus weight percent Carbon in Interflow Shale.
 Shaded Area represents Field of Sedimentary-Hosted Base Metal Deposits (after Ohmoto, 1987).

Figure 14b: Plot of weight percent Fe₂O₃ versus weight percent sulphur in interflow shale.

Calculated Fe/S = 0.91, and is probably correlative with pyrrhotite.

mineral morphology and grain size. Porphyroblastic arsenopyrite, pyrite and magnetite occur in foliated ISR and in shear zones and commonly develop caries and sieve textures with inclusions. The predominant recrystallization feature is the pervasive annealing of basement sulphides. Granoblastic polygonal or allotriomorphic mosaics are ubiquitous and may be used to distinguish basement from vein sulphides (e.g. Goodz et al., 1986b).

Deformational fabrics, although often obscured by recrystallization, are varied and widespread in ISR. Brittle fracturing, brecciation and cataclasis are displayed by pyrite. Strain shadows, boudins and elongated sulphide schlieren are present in intensely deformed rocks. Chalcopyrite may exhibit deformation twinning and undulose extinction. Small-scale faults and shear bands are locally delineated by idiomorphic arsenopyrite.

Although these metamorphic textures illustrate the alteration experienced by the sulphides and their host rocks, features indicative of mobilization are perhaps more interesting and significant in documenting sulphide mobility during vein-forming events.

Mobilized sulphides typically occur in secretion (Vokes, 1971) or injection structures (Maiden, 1984) in which they remain spatially linked to the parent sulphide body. Secretion-injection structures (SIS) display a varied geometry which is largely dependent upon the nature and deformational condition of the host rock to the sulphides. In relatively undeformed rocks, SIS extend sub-radially from their source,

while in sheared or foliated rocks they occur in sub-parallel arrays. These arrays may define tensional, shear-related fractures, faults or shear zones, or foliation (Figures 15, 16, 17, Photograph 2-6).

Pyrrhotite is the dominant mobilized sulphide and may occur in discordant lenses that contain abundant fractured and brecciated fragments of wall rock (Photograph 2-7). SIS are often zoned on a small scale (Figure 18). Pyrrhotite SIS may contain chalcopyrite and galena veinlets in wallrock xenoliths.

Interflow sulphide mobilization related to the intrusion of lamprophyre dykes was studied by the author and Irwin (1987) in a drift section on the 1450' level of the Beaver - Temiskaming Mine (Figure 19). A thin (≤ 2 cm) band of sphalerite, quartz and calcite was locally developed along the contact between a lamprophyre dyke and pyrite-rich, carbonaceous shale. Narrow, elongate sulphide bodies may reflect minor shearing parallel to the contact, oblique to the foliation in the shale. Later fractures have developed and pyrrhotite - quartz veinlets occupy a reticulate fracture set that straddles the contact.

Other textures are the result of pervasive hydrothermal alteration and the introduction of sulphides as replacement phases and veins, perhaps related to mobilization processes. These features are best observed in clastic ISR where they appear as extensive sulphide replacements of both framework and matrix constituents (Photograph 2-4). Coarser-grained beds may be preferential sites for sulphide replacement (Photograph 2-5). Monominerallic replacement is also prevalent; chalcopyrite may completely replace nodular pyrite, for example.

Figure 15: Sketch of polished slab of Shale and Chert showing Relationship between Syngenetic and Epigenetic Sulphides and Sulpharsenides, "19-28" Shear Zone outcrop, Nipissing RL 404 Property Detail Map Area

Figure 16: Sketch of Massive to Anastomosing Po SIS in intensely foliated shale, near station 1463-5, 1450' level, Beaver - Temiskaming Mine (see Figure 19 for location)
Note shale fragments and hairline Po ± Sp, Gn, Ccp veinlets subparallel to foliation.

Figure 17: Sketch of Po SIS defining axial planar cleavage in folded shale with stratiform sulphide bands, near station 1463-4, 1450' level, Beaver - Temiskaming Mine (see Figure 19 for location)

In more intensely foliated zones, subparallel hairline fractures are infilled by Po and Sp. Large, elongate sulphide bodies predominate.

Figure 18: Composite sketch showing spatial relationships between stratiform and deformed syngenetic sulphides and mobilized, epigenetic sulphides and sulpharsenides. Bedding in the sediments is parallel to the top of the sketch.

Figure 19: Geological map of drift section, 1450' level, Beaver - Temiskaming Mine
 Note disposition of interflow sedimentary and volcanic rocks, faults and syngenetic and epigenetic sulphides.
 (geology modified after D. Robinson, mine geologist, personal communication, 1986)

In areas of pyrite desulphurization (e.g. Goodz, 1985), it appears that pyrrhotite mobilization followed the alteration of pyrite to pyrrhotite. Pyrrhotite SIS crosscut partially altered pyrite.

Sulphur Isotope Data

Samples of stratiform and epigenetic sulphides were collected by the author; $\delta^{34}\text{S}$ values for these samples were determined by Wilson (1986) (Table 4).

Stratiform sulphides have relatively high $\delta^{34}\text{S}$ values (average $\delta^{34}\text{S} = 3.71\%$) and a narrow $\delta^{34}\text{S}$ fractionation range (3.0 to 5.0%) which suggest a hydrothermal rather than a biogenic source for the sulphur (Strauss, 1986; Faure, 1986; respectively). Limited data and the possibility of subsequent adjustment of the S-isotopic signature preclude a definitive statement on the source of the sulphur, however. Epigenetic sulphides have similarly high $\delta^{34}\text{S}$ values.

Sample SMK-1 consists of nodular to banded pyrite (Py) and pyrrhotite (Po) with $\delta^{34}\text{S}$ values of +5.0 and +3.6%, respectively. These values are similar to those obtained on Py-Po sulphide pairs in Archean basement sulphides by Goodz *et al.* (1986a), which yielded $\delta^{34}\text{S}_{\text{Py-Po}}$ values ranging from 0.1 to 1.4% (averaging 0.6%). The desulphurization of pyrite during interaction with a fluid results in the formation of pyrrhotite and an increasingly ^{34}S - and metal-enriched fluid.

Presuming that the SMK-1 Py-Po sulphide pair is in equilibrium, the temperature of equilibration can be determined. Using the equation of Kajiwara and Krouse (1971),

TABLE 4:

LIST OF SULPHUR ISOTOPIC RATIOS
FOR SULPHIDES IN ARCHEAN INTERFLOW SEDIMENTARY ROCKS

SAMPLE NUMBER	DESCRIPTION/ LOCATION	CONTENTS	TYPE	$\delta^{34}\text{S}$ VALUE (‰)
SMK - 1	Nodular Po, Py, Windsor - Cobalt trench	Po (100%) Py (100%)	Po Py	3.6 5.0
SMK - 2	Interbedded shale and chert with stratiform Po and base metal SIS, Nipissing RL 404 property	Ccp (75%) + Po (15%) + Sp (5%) + Gn (5%) Po (100%)	Σ S Po	3.6 3.0
MCK - 017	Paraconglomerate with inter- stitial and veinlet sulphides,	Ccp (100%) vein Ccp (100%)	Ccp Ccp	3.4 3.2
SMK - 022	Massive sulphide vein in siltstone, Nipissing RL 404 Property	Sp (60%) + Gn (40%)	Sp + Gn	4.5

(data from Wilson, 1986)

(abbreviations after Kretz, 1983)

(n.b. : Σ S = total sulphides, SIS = secretion-injection structures)

$$\Delta^{34}\text{S}_{\text{Py-Po}} = 3 \times 10^5 / T (^{\circ}\text{K})^2 ,$$

a temperature of equilibration of 190°C is obtained.

Calculated equilibration temperatures for Archean basement sulphide pairs obtained by Goodz (1985) and Goodz et al. (1986a) range from 304° to 727°C and are considered to represent isotopic disequilibrium. Data from silver veins and wall rock breccias yielded temperatures between 130° and 254°C. Approximately 65% of sulphide pairs analyzed by Wilson (1986) in Proterozoic sedimentary rocks yielded temperatures ranging from 394° to 593°C. Thus, the temperature of equilibration of 190°C does not correspond to data obtained from either basement or Proterozoic sedimentary rocks. There is no evidence for proximal silver vein mineralization to account for this low temperature; it remains enigmatic in this regard.

A summary of lithogenic, alteration, mineralization and structural events is given in **Table 5**.

TABLE 5
SUMMARY OF ARCHEAN AND PROTEROZOIC GEOLOGIC EVENTS, COBALI AREA

LITHOGENIC EVENT	ALTERATION EVENT	MINERALIZATION EVENT	STRUCTURAL EVENT
Archean			
Intrusion of subvolcanic, mafic to intermediate volcanics and subsequent erosion	Synvolcanic epilitization, hydrothermal silicification, chloritization, carbonatization	Syngenetic disseminated to stratiform sulphides in volcanics and interflow sedimentary rocks	Synvolcanic faulting
Deposition of interflow sedimentary rocks		Diagenetic Fe-sulphides in black shales	Synsedimentary deformation
	Kenoran Orogeny: Regional greenschist facies metamorphism		Kenoran Orogeny: local to regional scale fold, fault and shear zone development
Intrusion of Lorrain Granite	Contact metamorphism (hornblende hornfels facies)	Sulphides in quartz veins	Deformation related to intrusion
Intrusion of lamprophyre dykes	Local contact metamorphism	Disseminated magnetic sulphides, mobilization of pre-existing sulphides along dyke contacts	faulting and fracturing continue
*Intrusion of chloritic breccia dykes and mafic dykes	Local chloritization		
*Intrusion of felsic breccia dykes	Local silicification	Minor sulphides in quartz veins	
Proterozoic			
Deposition of Huronian sediments	Local diagenetic effects	Deposition of detrital sulphides	
Intrusion of Nipissing diabase	Contact metamorphism, development of hydrothermal system, metamorphic chlorite spotting	Sulphides and sulphoselenides associated with chlorite spots	Local folding (horizontal compressional stress regime), development of conjugate fault sets and joints
	Pervasive hydrothermal silicification, chloritization and carbonatization	Mobilization of pre-existing sulphides, development of veering-injection structures	Development of subparallel local fracture sets, minor shearing, fault movement
		Sulphides and sulphoselenides associated with hydrothermal fluid in permeable Archean and Proterozoic rocks (replacement, vein and blebby mineralization)	
	Local vein rock alteration (feldspathization and chloritization)	Silver Vein Development (Ag - Bi - Co - Ni - As mineralization)	Dilatancy and shearing associated with new and preexisting joints and faults
		Barren, sulphide-poor (exhalite) veins	Shallow-dipping faults and shear zones

* denotes previously undocumented event

PLATE 2: SULPHIDE MINERALIZATION

- PHOTO 2-1: Lenticular to reniform and nodular pyrite in massive black shale, near station 1463-5, 1450' level, Beaver - Temiskaming Mine. Pyrite bodies may coalesce to form massive pyrite lenses. (see Figure 19 for photograph location).
- PHOTO 2-2: Lenticular to reniform and nodular pyrite, partially altered to pyrrhotite, in black shale, Windsor - Cobalt Property. Note shale core of nodule (N) with quartz-filled strain shadow.
- PHOTO 2-3: Lathlike chlorite crystals (light grey) intergrown with sphalerite (opaque) in thinly laminated, silty shale, Hudson Bay Property. Field of view is 5 mm. (transmitted, plane polarized light)
- PHOTO 2-4: Epigenetic chalcopyrite and galena in graded paraconglomerate, Nipissing RL 404 Property. Sulphides are interstitial to clasts and replace both matrix and clasts, or occur as veinlets. Note angularity of sedimentary (dark grey to black) and altered volcanic clasts (light grey). (see Figure 7 for sample location)
- PHOTO 2-5: Epigenetic chalcopyrite, sphalerite and pyrrhotite (opaque) in lithic wacke interbed in siltstone, Cross Lake - O'Brien (Deerhorn) Mine. Sulphides are interstitial to framework grains and restricted to coarse-grained beds. Field of view is 3.1 mm. (transmitted light, crossed nicols)
- PHOTO 2-6: Sulphide secretion-injection structures branching from stratiform pyrrhotite bands and lenses in interbedded chert and shale, "19-28" Shear Zone outcrop, Nipissing RL 404 Property. Note pyrrhotite schlieren (S) and late-stage microfaults (M) with arsenopyrite. (see Figure 20 for sample location).
- PHOTO 2-7: Large, discordant pyrrhotite secretion-injection structure in faulted and foliated black shale, near station 1463-4, 1450' level, Beaver - Temiskaming Mine. Note shale fragments and relict fold structure (arrow). (see Figure 19 for photograph location).
- PHOTO 2-8: Banded to colloform, lenticular and nodular pyrite in black shale, Hudson Bay Property.

CHAPTER 6: THE ROLE OF INTERFLOW SEDIMENTARY ROCKS IN SILVER VEIN DEVELOPMENT

Three genetic hypotheses were presented for the generation of silver ore veins by Jambor (1971c). They are:

- (1) a deep-seated, parental magma source of vein elements
- (2) direct derivation of vein elements from differentiated Nipissing diabase
- (3) distillation of metals from Archean rocks as a result of diabase intrusion.

Boyle (1968) and Boyle and Dass (1971) were early proponents of the distillation or lateral secretion theory, based largely on the high metal contents of ISR. The present study investigates some aspects of the relationship between ISR and silver veins. Current observations will be discussed in conjunction with those presented by previous workers.

The role of ISR in the development of ore veins may be considered in terms of structural, mineralogic and geochemical parameters.

Structural Relationships

The strong spatial association between ISR and ore veins has long been acknowledged and was initially attributed to structural factors (Miller, 1913; Knight, 1924). Reassessment of the local structural geology and detailed mapping has confirmed this association in some areas.

Folds and Faults

The development of isoclinal folds with northwest-trending

fold axes and parallel, steeply dipping faults has apparently influenced vein distribution in the area near Cobalt Lake. Knight (1924) has described the occurrence of veins within these faults in ISR, and within ISR parallel and proximal to them. Thomson (1961a) considered the position of the ISR bands to be the most important factor in determining the location of the vein sets.

The structural incompetence of the ISR as compared to that of the enclosing volcanic succession during folding may have facilitated fault development. Shearing likely accompanied folding and faulting, especially along contacts between the ISR and volcanics, perhaps due to flexural slip. Narrow, intensely foliated zones, may be small-scale, para-autochthonous contacts. Synsedimentary slump planes, faults and lithologic heterogeneity in ISR would facilitate such deformation. The absence of pervasive deformational features and fabrics in the volcanics and in much of the ISR suggests that shearing along faulted contacts was the predominant method of stress release. The presence of ductile shear zones in the volcanics (e.g. "19-28" Shear Zone, **Figures 20 and 21**) indicates that this type of deformation occurred during peak metamorphic conditions accompanying late Archean tectonism (cf. Hugon and Schwerdtner, 1985).

Relationship to the Archean - Proterozoic Unconformity

Commonly, vein structures crossing the unconformity pinch out upon entering the basement rocks. Ore zones are accordingly restricted to the vicinity of the unconformity and usually extend upward into the Huronian sediments. Although the size and tenor of a vein may decrease in the basement rocks, the basement

Figure 21: Sketches showing small-scale features associated with the "19-28" Shear Zone, Nipissing RL 404 Property

- (a) passive rotation of early quartz vein in dextral simple shear
- (b) truncation and transposition of feldspar porphyroblasts (stippled) along subparallel, secondary shear bands (C); note locally developed sulphides (black).

Schistosity (S) is locally subparallel to the shear direction in these sections.

(Terminology after Hugon and Schwerdtner, 1985)

structure, and in particular the presence of ISR, may still control the location of veins in the Huronian rocks. Nichols (1985) has noted that 42% of all silver was produced from veins parallel to Archean strata. An abridged list of veins and faults spatially associated with ISR units is given in Table 6.

Petruk (1971a) noted that many of the ore veins occur in pre-Huronian paleovalleys. In many cases, these depressions in the Archean paleotopography coincide with ISR units, indicating the relative susceptibility of ISR to erosion. Erosion was perhaps facilitated by faulting and shearing. Fracturing and faulting of Huronian rocks in paleovalleys is intense and this suggests that Archean faults were still active or were reactivated during the Proterozoic. Drag-folded and sheared veins also attest to coeval deformation.

Andrews et al. (1986a) have stated that there is abundant evidence of tectonism before, during and after Nipissing diabase intrusion which generated regional scale faults. Faults and shear zones were reactivated during vein formation. Veins are juxtaposed with ISR sulphides laterally, or along strike (e.g. Figure 19). Vein structures postdate Archean shearing; steeply dipping veins occur in the hanging wall of Archean faults and shear zones (Knight, 1924; Thomson, 1960a).

Stratigraphic Considerations

The area of productive ore deposits is roughly bounded by the Columbus, 64, O'Brien and Contact faults and the Lorrain granite (Petruk, 1971a). Although the volcano-sedimentary stratigraphy is not easily decipherable because of deformation,

TABLE 6:

**VEINS AND FAULTS SPATIALLY ASSOCIATED
WITH ARCHEAN INTERFLOW SEDIMENTARY ROCKS**

<u>PROPERTY</u>	<u>VEIN</u>	<u>FAULT</u>
Cochrane	No. 1, No. 2 Shaft	
Brady Lake	C - 4 group	
Consolidated Silver Banner	No. 1	
Christopher	No.'s 5, 7	
Violet	No. 5	
Colonial	Menago No. 1, No.'s 2, 3, (6)	
O'Brien RL 403	No. 2 (and proximal)	
Chambers - Ferland + Right-of-Way North	No.'s 1, 1-SE, (1 C-F)	
Larose	No.'s 1, 3, 5, 6, 10, Powder House, McDonald	
Nipissing RL 401	No.'s (10), 60, 65, (127)	
Nipissing RL 400	No.'s 64, 80, 100, Meyer (No. 73)	No. 64
Hudson Bay	No.'s 1, 2, 3, 4, 6, 7	No. 64, "Z"
Trethewey	Main	
Coniagas	No.'s (4, 7), 9	
City of Cobalt	No.'s 24, 32	Galena
Buffalo	No.'s 3, 6, 10, 34	Galena, No. 6
"Gamey Lot"	No. 2 Shaft	No. 6 (?)
Paymaster	No.'s 4, 5	
Kerr Lake	No. 7, McDonald, Shaft No. 13	
Lawson	No.'s 2, 8, 9, 10-S, 11	

<u>PROPERTY</u>	<u>VEIN</u>	<u>FAULT</u>
Penn - Cobalt (Foster)	No.'s 1, 5	
University	unnamed vein	
Mensilvo (Silver Bar)	No.'s 2, 3, 6	
Waldman	No. 1 Shaft	
Nu - Silco	W - 1	
Cross Lake O'Brien (Deerhorn)	No.'s 2, 6	
King Edward	No. 5	
Nova Scotia	No. 1	
Peterson Lake	Shaft 3 Group	
Townsite	"X", No. 8, L-west	Vein 8, "X"
McKinley - Darragh	(in northwest corner)	
Nipissing RL 406	No.'s 105, 141	
Silver Queen	No. 1	
Little Nipissing	"Adit"	
Coballoy	unnamed vein	
Argentite Group	North Shaft, Middle Shaft	
Harrison - Hibbert	No. 1	Main Shear
Cobalt Contact	(No. 1)	
Hunter Cobalt	No. 2 Shaft	
Green - Meehan	No. 6	
Beaver - Temiskaming	No.'s 3, 5, (6), 7	

(Sources of Information: Knight (1924), Thomson (1961 a,b,c,d,e;
1964 a,b,c), unpublished files, Resident Geologist's Office, Cobalt)

the productive area may correspond to a favourable stratigraphic unit or units characterized by abundant ISR. The O'Brien - 64 fault separates a productive area in the south from a relatively barren one to the north. Rocks north of the fault are dominantly more felsic lavas and tuffs and Timiskaming-type sediments (Thomson, 1961a). Changes in the character of the volcano-sedimentary succession apparently imparted controls on ore vein distribution, perhaps governed by their response to imposed structural elements. Faults may have developed due to competency contrasts between intercalated sedimentary and volcanic rocks.

Significance of Dykes

Fault, shear and contact zones in ISR are commonly occupied by late Archean dykes. Miller (1913) stated that some veins in Archean rocks follow lamprophyre dykes, while Jambor (1971a) noted that many dykes are loci for fracturing and subsequent silver mineralization. Mafic dykes in the Beaver - Temiskaming Mine were emplaced in shear zones which have had a role in the localization of silver ore (Goodz, 1985). Native silver has been mobilized and introduced along these zones and into associated veins and fractured wallrocks. Thomson (1961b) suggested that lamprophyre dykes exert an influence on the structure and metallic content of veins transecting them. In ISR, dykes can mobilize preexisting sulphides in addition to delineating faults and fracture zones.

Application of General Relationships

In the detailed map area, Nipissing RL 404 (Figure 7), structural and lithologic relationships are somewhat consistent

with observations on a camp scale.

Steeply dipping lamprophyre dykes and smaller mafic dykes intrude ISR sub-parallel to stratigraphy. Faults between ISR and the volcanics have attenuated ISR units and contain dykes. They are characterized by shearing, folding, fracturing and local hydrothermal alteration. Fault 28 and Vein 28, as described by Knight (1924), show the coincidence of Archean faults, dykes and Proterozoic ore veins. Systematic joint measurement by Wilson (1986) in this area identified a strong joint set trending 100° to 125° , sub-parallel to Fault 28.

Steeply dipping, conjugate faults are oriented approximately north-northwest and northeast, at high angles to Archean strata. Smaller faults with similar orientations are evident and locally cut Archean shear zones (Figure 20). Sub-parallel sulphide veinlets and secretion-injection structures are also sub-parallel to this conjugate fault set. Faults themselves commonly contain semi-massive sulphides and sulpharsenides with quartz and chlorite.

If these conjugate faults are presumably steeply dipping, then observed displacements would be attributable to strike-slip motion resulting from a horizontal maximum compressive stress, oriented probably north-south. Wilson (1986) has attributed the development of joints and thrust faults in the Coleman Member to a horizontal maximum compressive stress within a changing stress regime.

Field observations in the detailed study area indicate the presence of two broad groups of faults and related joints in ISR:

- 1) a steeply dipping set sub-parallel to Archean strata, possibly related to late Archean folding, serving as loci for late Archean dykes, and

- 2) a possibly steeply dipping, conjugate set obliquely oriented to Archean strata, with sub-parallel SIS, probably related to horizontal maximum compressive stress(es) prior to vein development.

The Cobalt Vein and Veins 128, 81, 19 and 49 are local examples of silver veins subparallel to these faults (Figure 22).

The association of SIS with vein-related faults and joints implies that sulphide mobilization in ISR accompanied or predated the development of the hydrothermal system for the silver veins.

Mineralogic Relationships

Significance of Sulphide Mobilization

Although the mobilization of elements in Archean sulphide deposits at Cobalt has been discussed (Goodz, 1985; Goodz et al., 1986a; Watkinson, 1986), the mobilization of sulphides has not been fully addressed. The ubiquity of sulphide mobility in ISR is significant in any appraisal of a hypothesis based on lateral secretion and mobilization involving metamorphism, deformation and hydrothermal alteration. Even if not directly related to ore vein genesis, sulphide mobilization serves to document these processes preceding vein development. Morphologic and mineralogic characteristics of mobilized sulphides are the main comparative criteria.

Morphology of Mobilized Sulphides

The most striking and convincing evidence of sulphide mobilization is the development of secretion-injection structures (SIS) in which parent and mobilized sulphides are spatially

Figure 22: Sketch map of part of the Nipissing RL 404 Property showing spatial relationship between veins and faults

linked. Their size, geometry and shape result from the disposition of their host rock or sulphide, which is in turn governed by deformational and metamorphic processes. Examples of the migration of sulphides into zones of low pressure and/or low strain, such as brittle fractures and fold hinges, have been documented by Vokes (1969, 1971) and Maiden (1984). The parallelism of many SIS suggests development along pre-existing structures such as foliation planes and tension fractures.

Sulphides and sulphide textures not directly attributable to local mobilization may involve pervasive hydrothermal alteration and sulphide replacement. Abundant disseminated sulphides and sulphide veins and replacement are largely associated with coarser interflow units, indicating the importance of permeability. Permeability may be enhanced by shearing or faulting and apparently results in a concomitant increase in mobilized sulphides in such zones.

Mineralogy of Mobilized Sulphides

Mineralogic variation and zonation are common in mobilized sulphides within individual bodies or aggregates and on larger scales. However, it appears as though these sulphide distribution patterns are only applicable on a local scale. The most obvious governing factors on the distribution of certain sulphides is either their initial (pre-mobilization) concentration or their relative abundance in a mobilized sulphide aggregate. The predominance of pyrrhotite, for example, as a mobilized sulphide, is probably related to its initial abundance in ISR. The amount of pyrrhotite is apparently augmented by secondary pyrrhotite

created during pyrite desulphurization.

Despite local disparities in some base metal sulphides, distinct spatial and temporal zonation patterns have developed. Veinlet SIS extending from stratiform pyrrhotite bands display a symmetrical sulphide zonation on both sides of the parent body (Figure 18). Pyrite invariably occupies the innermost part of the SIS, followed outward by chalcopyrite, pyrrhotite, sphalerite and galena in variable amounts and in different relative positions. Zonation patterns imply relative sulphide mobility. Vokes (1969, 1971), for example, has suggested that relative mobility increases in the order: pyrite - sphalerite - pyrrhotite - chalcopyrite - galena. This succession is a generalization, however, based on comparative field observations of different deposits. It seems unlikely that such a scheme may be adopted universally.

Lateral ore mineral zonation proximal to veins as noted by Goodz (1985) and Goodz et al. (1986b) comprises galena - sulpharsenide assemblages near the vein and Fe-sulphides farther away. Galena proximal to the vein, considered to be co-depositional with the vein minerals, commonly occurs as monomineralic veinlets in rocks and other sulphides. It is also found marginally and parallel to veins, juxtaposed with deformed basement sulphides. This apparent dichotomy of galena and the other sulphides may be the result of the different reactions of sulphides to mobilization mechanisms.

Genetic Mechanisms of Mobilization

Sulphide mobilization has been ascribed to:

- (1) plastic (solid state) flow of ductile sulphides, and/or
- (2) generation of a fluid phase during metamorphism

(Maiden, 1984; Vokes, 1969, 1971).

Plastic flow in sulphides is related to deformation mechanisms such as translation gliding, polysynthetic twinning and kinking, which cause progressive weakening of the sulphide with increasing temperature and pressure. Flowage requires an adequate tectonic or lithostatic stress, sufficient time for flow and a pore pressure in available open spaces less than the maximum stress operating on the sulphide (Salmon *et al.*, 1974). The activation of ductile flow in galena requires, in geological terms, very small stress differences. Galena is always weaker and more ductile than chalcopyrite, sphalerite and pyrrhotite over a wide temperature range (Kelly and Clark, 1975). Perhaps the distinction between galena and the other sulphides is due to its susceptibility to ductile flow at low temperatures and pressures at which other sulphides are either immobile or have already lost their mobility.

It has been noted that the relative strengths of sulphides, and thus their mobility, change with temperature (Kelly and Clark, 1975). The relative strengths of pyrrhotite and sphalerite, for example, reverse at approximately 250°C and 1 kb confining pressure (Clark and Kelly, 1973). Inconsistencies in generalized mobility successions may be in part due to temperature-dependent changes and conditions associated with deformation. The development of narrow, high strain zones along

faults and shear planes, differences in fluid composition in different areas, and erratic thermal gradients due to lithologic heterogeneity within Archean strata preclude broad generalizations of relative sulphide mobility in ISR.

Importance of a Fluid Phase

Kelly and Clark (1975) have stated that lower sulphide strengths and increased ductility may be enhanced in natural geological systems because of slower strain rates and the presence of solvents. The generation of a fluid phase during metamorphism has been considered to be important in metal mobilization (Vokes, 1969, 1971; Boyle, 1979; Maiden, 1984). Mobilized sulphides in ISR are almost invariably associated with quartz, calcite and chlorite, either as gangue constituents in veinlets, or in hydrothermal wallrock alteration assemblages. Maiden (1984) proposed that a fluid phase could be generated by the release of water trapped in open spaces in hydrated and carbonated minerals during deformation.

A source for the fluid, however, is not considered to be problematic in the case of Cobalt. There is widespread acceptance of the development of a diabase-heated, hydrothermal fluid derived from pre-existing intraformational pore fluid and meteoric water in Huronian sediments. This is based largely on evidence gathered from fluid inclusion and oxygen isotope data (Kerrick et al., 1986).

Nature of Fluid and Fluid Interaction

Kerrick et al. (1986) determined that the ore-forming fluids for the silver veins were hypersaline Na-, Ca-chloride brines

with hydrocarbon compounds; the nature of the transporting ligands of Ag, Co, Ni and As is unknown. Metal and sulphide solubility would have been great as a result.

The desulphurization of pyrite through interaction with this brine is believed to have produced a metal- and ^{34}S -enriched fluid (Goodz, 1985; Goodz *et al.*, 1986a). Moreover, unaltered pyrite contains up to one percent each of Co, Ni and As; altered pyrite or pyrrhotite pseudomorphs are significantly depleted in these elements (MacQuaen, 1985; Goodz *et al.*, 1986a; Watkinson, 1986). Similar sulphide trace element geochemistry suggests that syngenetic and mobilized sulphides were equilibrated with this fluid.

Significance of Lead-Isotope Data

Lead-isotope analyses on galena within and proximal to silver veins define a very homogeneous composition for common leads (Thorpe *et al.*, 1986). Most samples yielded model ages corresponding to the age of the Nipissing diabase (ca. 2220 Ma), while one-third of the analyses indicated mobilization or a subsequent mineralization event ca. 1650-1945 Ma.. Galena lead in sulphide-rich ISR was found to be much less radiogenic than the other Proterozoic leads. This has prompted Thorpe *et al.* (1986) to discount the interflow sulphides as the source of the Pb and perhaps, certain other vein metals.

Mineralogic, textural and S-isotopic similarities exist between sulphides in ISR and those in Proterozoic sedimentary rocks (Wilson, 1986). These similarities support the hypothesis

that vein-related fluids permeated Proterozoic sedimentary rocks and sections of the ISR with originally high or enhanced permeability and deposited isotopically similar sulphides. This was accompanied by the mobilization of pre-existing basement sulphides which perhaps augmented the dissolved metal and sulphur content of the mineralizing fluids.

CHAPTER 7: CONCLUSIONS

The following conclusions are drawn regarding the four main purposes of this study:

- (1) The majority of Archean interflow sedimentary rocks in the Cobalt mining camp are immature turbidites. Constituent lithofacies include interbedded sandstone - siltstone - mudstone, paraconglomerate and arenaceous oxide facies ironstone. Carbonaceous shale and jaspilitic banded oxide facies ironstone represent basinal or pelagic sedimentation and constitute a minor part of the sedimentary succession. Chert and volcanogenic massive sulphide units are exhalative.

Stratiform sulphides within the ISR are considered to be:

- (1) predominantly syngenetic base metal sulphides associated with volcanogenic exhalative and hydrothermal processes in all lithofacies, and/or
- (2) minor diagenetic Fe-sulphides resulting from abiogenic sulphate reduction in carbonaceous shale.

- (2) Interflow sedimentary rocks are usually thin (<40 m) units intercalated with massive to pillowed tholeiitic andesite, and autoclastic, hyaloclastic and resedimented pyroclastic rocks. Despite lateral continuity of interflow units over several hundred metres, distinct marker horizons do not exist because of complex turbiditic interbedding and syndepositional and tectonic deformation.

Stratigraphic reconstruction reveals major folds and minor, asymmetric folds with northwest-trending fold axes in the area around the town of Cobalt. The development of northwest-trending, steeply dipping faults was apparently controlled by these fold structures. Contacts between the volcanic and ISR are typically faulted and intensely foliated and sheared, and are commonly loci for the intrusion of mafic dykes (Figure 23).

- (3) Stratiform sulphides in the volcano-sedimentary succession result from synvolcanic, synsedimentary and later epigenetic processes. Epigenetic sulphides result from the mobilization of pre-existing sulphides and/or the introduction of mineralizing fluids into permeable interflow rocks. Mineralization is accompanied by pervasive silicification, chloritization and minor carbonatization. Sulphide mobilization, supported by the development of secretion - injection structures and mineralogic zonation, is related to deformation and alteration preceding and/or accompanying silver vein development.

- (4) Faults and zones of deformation have preferentially developed within ISR and along contacts with enclosing volcanic rocks. The development of these faults and zones has influenced silver vein distribution in many areas. Veins occur within these faults, and parallel and proximal to them

Block Diagram of Vein 60 Open Cut

Nipissing RL401 Property

(section looking northwest)

Figure 23: Block diagram of Vein 60 Open Cut, Nipissing RL 401 Property.

Note disposition of interflow sedimentary, volcanic and intrusive rocks, the unconformity surface and the silver vein.

in volcanic and ISR and in overlying Proterozoic rocks. Proterozoic, vein-related faults are recognized in ISR and may be delineated by epigenetic sulphides and minor sulpharsenides. This implies that sulphide mobilization and the introduction of sulphide-mineralizing fluids predated and/or accompanied the development of the silver vein hydrothermal system.

Mineralogic, textural and sulphur-isotopic similarities existing between sulphides in ISR and in Proterozoic sedimentary rocks support the hypothesis that vein-related fluids permeated these rocks and deposited isotopically similar sulphides and minor sulpharsenides.

Interflow shale analyzed in this study reveal that these rocks are not markedly enriched in Ag, Co, Ni or As. This contradicts the findings of Boyle and Dass (1971) and leaves the question of the source of the vein metals unresolved.

REFERENCES

- Andrews, A.J., Owsicki, L., Kerrich, R., and Strong, D.F.
 1986a: The silver deposits at Cobalt and Gowganda, Ontario. I: Geology, petrography, and whole-rock geochemistry; Can. Jour. Earth Sci., v. 23, no. 10, p.1480-1506.
- Andrews, A.J., Masliwec, A., Morris, W.A., Owsicki, L., and York, D.
 1986b: The silver deposits at Cobalt and Gowganda, Ontario. II: An experiment in age determinations employing radiometric and paleomagnetic measurements; Can. Jour. Earth Sci., v. 23, no. 10, p.1507-1518.
- Appleyard, E.C.
 1981: Host-rock alteration at the Silverfields Mine, Cobalt, Ontario, Grant 70; Ontario Geological Survey, Final Report, 83p.
- Barley, M.E., Dunlop, J.S.R., Glover, J.E., and Groves, D.I.
 1979: Sedimentary Evidence for an Archean Shallow-Water Volcanic-Sedimentary Facies, Eastern Pilbara Block, Western Australia; Earth Plan. Sci. Let., v. 43, p.74-84.
- Barrett, T.J. and Fralick, P.W.
 1985: Sediment Redeposition in Archean Iron Formation: Examples from the Beardmore - Geraldton Greenstone Belt, Ontario; Jour. Sed. Pet., v. 55, no.2, p.205-212.
- Barton, P.B., Jr. and Toulmin, P., III
 1966: Phase relations involving sphalerite in the Fe-Zn-S system; Econ. Geol., v. 61, p.815-849.
- Bennett, G.
 1978: Geology of the Northeastern Temagami Area, District of Nipissing; Ontario Geological Survey, Report 163, 128p. Accompanied by Maps 2323 and 2324, scale 1 inch to 1/2 mile (1:31,680), and 1 chart.
- Berner, R.A.
 1970: Sedimentary Pyrite Formation; Am. Jour. Sci., v. 268, p. 1-23.
-
- 1984: Sedimentary Pyrite Formation: an update; Geochim. Cosmochim. Acta, v. 48, p.605-615.
- Berner, R.A. and Raiswell, R.
 1984: C/S method for distinguishing freshwater from marine sedimentary rocks; Geology, v. 12, p.365-368.
- Berry, L.G., editor
 1971: The Silver - Arsenide Deposits of the Cobalt - Gowganda Region, Ontario; Can. Miner., v. 11, pt. 1, 429 p.

- Boutcher, S.M.A., Edhorn, A.S., and Moorhouse, W.W.
 1966: Archean conglomerates and lithic sandstones of Lake Timiskaming, Ontario; Geological Association of Canada, Proceedings, v. 17, p.21-42.
- Boyle, R.W.
 1968: Fahlbands, sulfide schists, and ore deposition; Econ. Geol., v. 63, p.835-838.
-
- 1979: The Geochemistry of Gold and Its Deposits; Geological Survey of Canada, Bulletin 280. 584p.
- Boyle, R.W. and Dass, A.S.
 1971: The Origin of the Native Silver Veins at Cobalt, Ontario; in Can. Miner., v. 11, Berry, L.G., ed., p.414-417.
- Cameron, E.M.
 1982: Sulphate and sulphate reduction in early Precambrian oceans; Nature, v. 296, p.145-148.
- Cameron, E.M. and Garrels, R.M.
 1980: Geochemical compositions of some Precambrian shales from the Canadian Shield; Chem. Geol., v. 28, p.181-197.
- Card, K.D. and Pattison, E.F.
 1973: Nipissing Diabase of the Southern Province, Ontario; Geological Association of Canada, Special Paper 12, p.7-30.
- Clark, B.R. and Kelly, W.C.
 1973: Sulfide deformation studies: I. Experimental deformation of pyrrhotite and sphalerite to 2000 bars and 500°C; Econ. Geol., v. 68, p.332-352.
- Dillon-Leitch, H.
 1980: Alteration and Mineralization in Archean Volcanic Rocks of the Cobalt Area; in Summary of Field Work, 1980, by the Ontario Geological Survey, edited by V.G. Milne, O.L. White, R.B. Barlow, J.A. Robertson, and A.C. Colvine, Ontario Geological Survey, Miscellaneous Paper 96, p.191-194.
- Donaldson, J.A. and Munro, I.
 1982: Field Excursion Guide Book, Excursion 16B: Precambrian Geology of the Cobalt Area, Northern Ontario; Eleventh International Congress on Sedimentology, McMaster University, Hamilton, Ontario, Canada, 72p.
- Elliott, S.R.
 1984: Geochemical, Mineralogical and Stable Isotope Studies at Owl Creek Mine, Timmins, Ontario; unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 109p.

- Faure, G.
1986: Principles of Isotope Geology; John Wiley and Sons, New York, 589p.
- Gebert, J.S.
1985: Base Metal Mineralization along the Archean - Proterozoic Unconformity at Drummond Cairn, Cobalt, Ontario; unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 54p.
- Goodwin, A.M. and Ridler, R.H.
1970: The Abitibi Orogenic Belt; in Precambrian Basins and Geosynclines of the Canadian Shield, edited by A.J. Baer, Geological Survey of Canada, Paper 70-40, p.1-24.
- Goodz, M.D.
1985: Geology and Isotope Geochemistry of the Beaver - Temiskaming Silver Mine, Cobalt, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, 246p.
- Goodz, M.D., Watkinson, D.H., Smeykal, V., and Pertold, Z.
1986a: Sulphur-isotope geochemistry of silver-sulpharsenide vein mineralization, Cobalt, Ontario; Can. Jour. Earth Sci., v. 23 no. 10, p.1551-1567.
- Goodz, M.D., Jonasson, I.R., and Watkinson, D.H.
1986b: Geology and Geochemistry of Silver-Sulpharsenide Vein Deposits, Cobalt, Canada: Implications for Ore Genesis and Mineral Exploration; Geocongress '86, Geological Society of South Africa, Extended Abstracts, p.1029-1034.
- Holland, H.D.
1984: The Chemical Evolution of the Atmosphere and Oceans; Princeton University Press, 582p.
- Hugon, H. and Schwerdtner, W.M.
1985: Structural Signature of Deformed Gold-bearing Rocks in Northwestern Ontario, Grant 149; in Geoscience Research Grant Program, Summary of Research, 1984-1985, edited by V.G. Milne, Ontario Geological Survey, Miscellaneous Paper 127, p.62-72.
- Hyde, R.S.
1980: Sedimentary Facies in the Archean Timiskaming Group and Their Tectonic Implications, Abitibi Greenstone Belt, Northeastern Ontario, Canada; Precambrian Research, v. 12, p.161-195.
- Hyde, R.S. and Walker, R.G.
1977: Sedimentary Environments and the Evolution of the Archean Greenstone Belt in the Kirkland Lake area, Ontario; in Report of Activities, Part A, Geological Survey of Canada, Paper 77-1A, p.185-190.

Ingram, R.L.

- 1954: Terminology for the Thickness of Stratification and Parting Units in Sedimentary Rocks; Geol. Soc. Amer. Bull., v. 65, p.937-938.

Irwin, D.A.

- 1987: Geology and Petrology of Sulphide Mineralization and Chloritic Alteration of Archean Lamprophyres Near Cobalt, Ontario; unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 68p.

Jambor, J.L.

- 1971a: General Geology; in Can Miner., v. 11, Berry, L.G., ed., p.12-31.

- 1971b: The Nipissing Diabase; in Can. Miner., v. 11, Berry, L.G., ed., p. 34-75.

- 1971c: Origin of the Silver Veins of the Cobalt - Gowganda Region; in Can. Miner., v. 11, Berry, L.G., ed., p. 402-412.

Kajiwarra, Y. and Krouse, H.R.

- 1971: Sulfur Isotope Partitioning in Metallic Sulfide Systems; Can. Jour. Earth Sci., v. 8, p.1397-1408.

Kalogeropoulos, S.I. and Scott, S.D.

- 1983: Mineralogy and Geochemistry of Tuffaceous Exhalites (Tetsusekiei) of the Fukazawa Mine, Hokuroku District, Japan; Econ. Geol., Monograph 5, p. 412-432.

Kelly, W.C. and Clark, B.R.

- 1975: Sulfide deformation studies: III. Experimental deformation of chalcopyrite to 2000 bars and 500°C; Econ. Geol., v. 70, p.431-453.

Kerrick, R., Strong, D.F., Andrews, A.J., and Owsicki, L.

- 1986: The silver deposits at Cobalt and Gowganda, Ontario. III: Hydrothermal regimes and source reservoirs -- evidence from H, O, C and Sr isotopes and fluid inclusions; Can. Jour. Earth Sci., v. 23, no. 10, p.1519-1550.

Kim, W.S.

- 1979: Sulphide Mineralization in the Coleman Member in the Cobalt Area, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, 112p.

Kingston, D.M.

- 1987: Geology and Geochemistry of the Owl Creek Gold Mine, Timmins, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, (in progress).

Knight, C.W.

- 1924: Geology of the Mine Workings of Cobalt and South Lorrain Silver Areas; Ontario Department of Mines, Annual Report, 1922, v. 31, pt. 2, 356p.

Kretz, R.

- 1983: Symbols for rock-forming minerals; Am. Miner., v. 68, p.277-279,

Lightfoot, P.C., Conrod, D., Naldrett, A.J., and Evensen, N.M.

- 1986: Petrologic, Chemical, Isotopic, and Economic Potential of the Nipissing Diabase, Grant 230; in Geoscience Research Grant Program, Summary of Research, 1985-1986, edited by V.G. Milne, Ontario Geological Survey, Miscellaneous Paper 130, p. 87-103.

Lovell, H.L.

- 1978: Possibilities for Large Tonnage, Low Grade Silver Production; unpublished report, Resident Geologist's Office, Ministry of Natural Resources, Kirkland Lake, Ontario, 65p.

Lovell, H.L. and Caine, T.W.

- 1970: Lake Timiskaming Rift Valley; Ontario Department of Mines, Miscellaneous Paper 39, 16p.

MacQueen, J.K.

- 1985: Sulphide Mineralogy and Chemistry in Archean Rocks near Silver Veins, Cobalt, Ontario; unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 57p.

MacRobbie, P.A.

- 1986: Archean Volcanic Rocks and Associated Base Metal Sulphides, Nipissing Hill (South) Area, Cobalt, Ontario; unpublished B.Sc. thesis, Carleton University, Ottawa, Ontario, 52p.

Maiden, K.J.

- 1984: Metamorphic Features of Stratiform Gold Ores in the Barberton Greenstone Belt, Eastern Transvaal; in Gold '82: The Geology, Geochemistry and Genesis of Gold Deposits, edited by R.P. Foster, Geological Society of Zimbabwe, Special Publication No. 1, p.325-338.

McDonald, J.A., editor

- 1986: Silver Vein Deposits; Proceedings of a Symposium of the Geological Association of Canada and the Mineralogical Association of Canada, Can. Jour. Earth. Sci., v. 23, no. 10.

MERQ-OGS

- 1983: Lithostratigraphic map of the Abitibi Subprovince; Ontario Geological Survey, Ministère de l'Energie et des Ressources, Quebec; 1:500 000; catalogued as "Map 2484" in Ontario and "DV 83-16" in Quebec.

Miller, W.G.

- 1913: The cobalt-nickel arsenides and silver deposits of Temiskaming; Ontario Bureau of Mines, Annual Report, v. 19, pt. 2.

Mustard, P.S.

- 1985: Sedimentology of the Lower Gowganda Formation Coleman Member (Early Proterozoic) at Cobalt, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, 143p.

Nichols, R.S.

- 1985: Recent Observations on Keewatin Stratigraphy and Geological Controls of Silver Mineralization at Cobalt, Ontario; submission to Canadian Institute of Mining and Metallurgy Bulletin.

Ohmoto, H.

- 1987: Systematics of Sulphur Isotopes in Recent Marine Sediments and Ancient Sediment-Hosted Basemetal Deposits; Geological Society of Australia, Special Publication, International Conference on Stable Isotopes and Fluid Processes in Mineralization (in press).

Owsiacki, L.

- 1984: Geology and Silver Deposits of the Cobalt Area; Geological Association of Canada -- Mineralogical Association of Canada Joint Meeting, Fieldtrip Guidebook 4, p.1-16.

Patterson, G.C.

- 1979: Metallogenetic Relationships of Base-Metal Occurrences in the Cobalt Area; in Summary of Field Work, 1979, by the Ontario geological Survey, edited by V.G. Milne, O.L. White, R.B. Barlow, and C.R. Kustra, Ontario Geological Survey, Miscellaneous Paper 90, p.222-229.

Patterson, G.C. and Andrews, A.J.

- 1981: Preliminary Report on the Relationship Between Base Metal Mineralization and Silver - Cobalt Vein Deposits in the Cobalt Area, Ontario; unpublished report, Ontario Geological Survey.

Petruk, W.

- 1971a: General Characteristics of the Deposits; in Can. Miner., v. 11, Berry, L.G., ed., p.76-107.

- 1971b: Mineralogical Characteristics of the Deposits and Textures of the Ore Minerals; in Can. Miner., v. 11, Berry, L.G., ed., p.108-139.

Pettijohn, F.J., Potter, P.E., and Siever, R.

- 1973: Sand and sandstone. Springer - Verlag. Berlin.

Rainbird, R.H.

1985: Sedimentology and Geochemistry of the Firstbrook Member of the Gowganda Formation in the Eastern Cobalt Basin, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, 157p.

Raiswell, R. and Berner, R.A.

1985: Pyrite Formation in Euxinic and Semi-Euxinic Sediments; Am. Jour. Sci., v. 285, p.710-724.

Saggerson, E.P. and Turner, L.M.

1982: General Comments on the Identification of Chlorites in Thin Section; Miner. Mag., v. 46, p.469-473.

Salmon, B.C., Clark, B.R., and Kelly, W.C.

1974: Sulfide deformation studies: II. Experimental deformation of galena to 2000 bars and 400°C; Econ. Geol., v. 69, p.1-16.

Sims, P.K., Card, K.D., and Lumbers, S.B.

1981: Evolution of Early Proterozoic Basins of the Great Lakes Region; in Proterozoic Basins of Canada, F.H.A. Campbell, ed., Geological Survey of Canada, Paper 81-10, p.379-397.

Smyk, M.C. and Owsicki, L.

1986: Geology of Banting Township and the Western Part of Best Township, District of Nipissing; in Summary of Field Work and Other Activities, 1986, by the Ontario Geological Survey, edited by P.C. Thurston, Owen L. White, R.B. Barlow, M.E. Cherry, and A.C. Colvine, Ontario Geological Survey, Miscellaneous Paper 132, p.292-296.

Strauss, H.

1986: Carbon and sulfur isotopes in Precambrian sediments from the Canadian Shield; Geochim. Cosmochim. Acta, v. 50, p.2653-2662.

Thomson, R.T.

1957: Cobalt Camp; in Structural geology of Canadian ore deposits: v. 2, Sixth Commonwealth Mining and Metallurgy Congress, 1957, Canadian Institute of Mining and Metallurgy, p.377-388.

1960a: Geology of the north part of Lorrain Township (Con. VII to XII), District of Timiskaming; Ontario Department of Mines, Preliminary Report 1960-1.

1960b: Bucke Township, District of Timiskaming, with description of mining properties; Ontario Department of Mines, Preliminary Report 1960-2.

Thomson, R.T.

1960c: Report on parts of Coleman Township and Gillies Limit to the south and southwest of Cobalt, District of Timiskaming; Ontario Department of Mines, Preliminary Report 1960-3.

1961a: Part of Coleman Township, Concession VI, Lots 1 to 6, District of Timiskaming; Ontario Department of Mines, Preliminary Report 1961-3.

1961b: Part of Coleman Township, Concession V, Lots 1 to 6, District of Timiskaming; Ontario Department of Mines, Preliminary Report 1961-4.

1961c: Parts of Coleman Township, Concession IV, Lots 1 to 5, and Gillies Limit, the Eastern "A" claims, District of Timiskaming; Ontario Department of Mines, Preliminary Report 1961-6.

1961d: Parts of Coleman Township, Concession III, Lots 1 to 3, and Gillies Limit, Blocks 1 and 2, claims A48 to 58 and A88 to 100, District of Timiskaming; Ontario Department of Mines, Preliminary Report 1961-7.

1961e: Part of Coleman Township, Concessions V and VI, Lots 1 to 6, District of Timiskaming, Ontario; Ontario Department of Mines, Preliminary Map P-97, scale one inch to 400 feet.

1964a: Cobalt Silver Area, Northern Sheet, Timiskaming District; Ontario Department of Mines, Map 2050, scale 1:12,000 or 1 inch to 1000 feet.

1964b: Cobalt Silver Area, Southwestern Sheet, Timiskaming District; Ontario Department of Mines, Map 2051, scale 1:12,000 or 1 inch to 1000 feet.

1964c: Cobalt Silver Area, Southeastern Sheet, Timiskaming District; Ontario Department of Mines, Map 2052, scale 1:12,000 or 1 inch to 1000 feet.

Thorpe, R.I., Goodz, M.D., Jonasson, I.R., and Blenkinsop, J.

1986: Lead-isotope study of mineralization in the Cobalt district, Ontario; Can. Jour. Earth Sci., v. 23, no. 10, p.1568-1575.

Turner, C.C. and Walker, R.G.

- 1973: Sedimentology, stratigraphy and crustal evolution of the Archean greenstone belt near Sioux Lookout, Ontario; Can. Jour. Earth Sci., v. 10, p.817-845.

Vokes, F.M.

- 1969: A Review of the Metamorphism of Sulphide Deposits; Earth Sci. Rev., v. 5, p.99-143.

- 1971: Some Aspects of the Regional Metamorphic Mobilization of Preexisting Sulphide Deposits; Miner. Deposita, v. 6, p.122-129.

Walker, R.G.

- 1984: Turbidites and Associated Coarse Clastic Deposits; in Facies Models, R.G. Walker, ed., Geological Association of Canada/ Geoscience Canada Reprint Series 1, p.171-188.

Watkinson, D.H.

- 1986: Mobilization of Archean Elements Into Proterozoic Veins: An Example From Cobalt, Canada; International Conference on the Metallogeny of the Precambrian, Proceedings, Geological Survey of Czechoslovakia, p.133-138.

Wilson, B.S.

- 1986: A Sulphur Isotope and Structural Study of the Silver Vein Host Rocks at Cobalt, Ontario; unpublished M.Sc. thesis, Carleton University, Ottawa, Ontario, 156p.

Wilson, G.C. and Rucklidge, J.C.

- 1986: Lithological Features and Economic Significance of Reduced Carbonaceous Rocks in Gold Deposits, Grant 262; in Geoscience Research Grant Program, Summary of Research, 1985-1986, edited by V.G. Milne, Ontario Geological Survey, Miscellaneous Paper 130, p.177-189.

APPENDIX A: MINERAL ABBREVIATIONS

Mineral abbreviations used in Tables and Figures in this manuscript are taken from Kretz (1983). For purposes of convenience and easy reference, they are listed here.

Apy arsenopyrite

Gr graphite

Cal calcite

Pl plagioclase

Chl chlorite

Po pyrrhotite

Ccp chalcopyrite

Py pyrite

Ep epidote

Qtz quartz

Gn galena

Sp sphalerite

APPENDIX B: GEOCHEMICAL ANALYTICAL TECHNIQUE

Nine samples of black interflow shale were collected from surface exposures and from underground diamond drill core for geochemical analysis. Sampling technique was not systematic; samples were collected from various locations within the Cobalt area. Samples contained 2-40% base metal sulphides. Sample descriptions are presented below. Geochemical analysis served mainly to determine whether these rocks were markedly enriched in Ag, Co, Ni, As and C, in order to identify any possible correlation between the distribution of major and trace elements and to consider these rocks as a source for vein-related hydrothermal minerals.

Technique

Major element analyses reported as the oxides SiO_2 , TiO_2 , Al_2O_3 , Fe_2O_3 , MnO , MgO , CaO , Na_2O , K_2O , and P_2O_5 were obtained by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP/AES) performed by the Analytical Chemistry Section of the Geological Survey of Canada, Ottawa. H_2O , CO_2 , C and S analyses were obtained by chemical methods involving decomposition in a Leco furnace and detection by infrared spectroscopy. ICP/AES data were obtained on 0.5g of sample fused with lithium metaborate, dissolved in 5% HNO_3 and diluted to 250ml. The following trace elements were analyzed in 1.0g of sample dissolved in 10% $\text{HCl}_{(\text{aq})}$ and diluted to 100ml: Ba, Be, Co, Cr, Cu, La, Ni, Pb, V, Yb, Zn, B, Mo, W, As, Sb, Ag and Au. Analyses were then conducted using ICP/AES.

Estimate of Validity of Results

ELEMENT	+/-	(ABSOLUTE	+	RELATIVE)
SiO ₂	+/-	0.4 %	+	2% of CONCENTRATION
TiO ₂		0.02	+	" "
Al ₂ O ₃		0.2	+	" "
Fe ₂ O ₃ T		0.1	+	" "
MnO		0.01	+	" "
MgO		0.1	+	" "
CaO		0.1	+	" "
Na ₂ O		0.1	+	" "
K ₂ O		0.1	+	" "
FeO		0.2	+	5% of CONCENTRATION
H ₂ O(t)		0.1	+	" "
CO ₂		0.1	+	3% of CONCENTRATION
C				
P ₂ O ₅		0.02	+	1% of CONCENTRATION
S(t)		0.04	+	5% of CONCENTRATION
LOI				
Ba	+/-	20 ppm	+	5% of CONCENTRATION
Be		0.5	+	" "
Co		5	+	" "
Cr		10	+	" "
Cu		10	+	" "
La		10	+	" "
Ni		10	+	" "
Pb		20	+	10% of CONCENTRATION
V		5	+	5% of CONCENTRATION
Yb		0.5	+	" "
Zn		5	+	" "
Au		1 ppb	+	10% of CONCENTRATION

Sample Descriptions

Sample Number	Sulphide Mineralogy/ Location
75215, 75216	Irregular to nodular Po with Po veinlets, core from diamond drill hole 16-386, 1600' level, Beaver - Temiskaming Mine
75217, 75218	Lenticular to nodular Py, partially altered to Po, Windsor - Cobalt trench
75219, 75223	Minor banded and nodular Ccp, Hudson Bay property
75220	Shale with silty interbeds, disseminated Sp, Hudson Bay property
75221	Minor Py veinlets, "Turnoff Outcrop", junction of West Coleman Road and Highway 11B
75222	Nodular Py, partially altered to Po, Pan Silver - Silver Miller property

APPENDIX C: COMPOSITION OF COEXISTING SPHALERITE AND CHLORITE

Electron microprobe analyses were conducted on coexisting sphalerite and chlorite in Archean volcanic and interflow sedimentary rocks by P. Jones, Department of Geology, Carleton University. Eight sections, collected by the author, and seven sections collected and described by Goodz (1985) were studied, providing 99 sphalerite and 112 chlorite compositional analyses. Average values for atomic concentration of Fe in sphalerite and the Fe/(Fe + Mg) ratio of chlorite are presented in Table 7.

Sphalerite

Atomic concentrations of Fe in sphalerite lie within a range from 0.437 to 0.588 (5.09 to 6.85 weight percent Fe), averaging 0.5167 (6.02 weight percent). There is little variation in Fe content between samples or within individual grains. These compositional data are similar to those obtained by Kim (1985), Gebert (1985), MacQueen (1985) and Dillon-Leitch (unpublished data, 1982) in both Proterozoic and Archean rocks near Cobalt.

Barton and Toulmin (1966) found that the Fe content of sphalerite is a function only of a_{FeS} , except for very Fe-rich compositions. Local data suggest that mineralizing fluids had similar a_{FeS} , or that the compositions of preexisting sphalerites were homogenized during equilibration with a common hydrothermal fluid, perhaps related to silver vein mineralization.

TABLE 7
COMPOSITION OF COEXISTING SPHALERITE AND CHLORITE

SECTION	CIRCLE	ANALYSES		HOST LITHOLOGY	ASSOCIATED MINERALS	ATOMIC CONC. Fe IN SPHALERITE	Fe / (Fe + Mg) IN CHLORITE	MINERALIZATION TYPE
		SP	CHL					
MCS-005	1	3	2	Carbonaceous Shale	Qtz, Py, Pl	0.0327	0.3887	S _D
MCS-006	1	10	5	Carbonaceous Shale	Qtz, Ccp	0.0319	0.4093	S _D
MCS-011	1	8	6	Chert near Massive Sulphide	Gn, Ccp, Po, Py, marc.	0.0366	0.4023	S _P
MCS-016	1	10	5	Black Chert Fragment in Wacke	Qtz, Pl	0.0372	0.3772	S _{P,D}
MCS-022	1	8	6	Sp - Gc Vein in Siltstone	Qtz, Gn	0.0437	0.3699	S _{SIS}
MCS-036	1	7	7	Interbedded Chert and Black Shale	Qtz, Ccp, Po-Gn-Sp SIS	0.0388	0.3776	S _{SIS}
MCS-044	1A	3	3	Altered Andesite	Qtz, Ccp, Po, Gn, Pl, Cal, S-Ae	0.0320	0.4749	E _V
	1B	4	3			0.0303	0.4100	
MCS-045	1	6	6	Altered Andesite	Qtz, Ccp, Po, Gn, Pl, Cal, S-Ae	0.0356	0.4072	E _V
BTG140 (6912)	1	2	4	Lithic Wacke	Qtz, Ccp, Po, Ae, S-Ae, S-Sh	0.0335	0.3283	E _V
	2	4	3			0.0332	0.3374	
	3	2	4			0.0350	0.3348	
COB053 (6913)	1	3	5	Massive Sulphide near Ag Vein	Qtz, Ccp, Po, Gn, Cal, Ae	0.0469	0.3293	S _P , E _V
	2	2	4			0.0442	0.3517	
BTG127 (6914)	1	2	3	near S-Ae Vein in Lithic Wacke	Qtz, Ccp, Po, Gn, S-Ae	0.0317	0.3330	E _V , S _D
	2	2	4			0.0329	0.3371	
	3	2	3			0.0322	0.3283	
BTG135a (6915)	1	2	4	Silicified Andesite	Qtz, Po, Ccp, Gn, Ae	0.0309	0.5434	E _V , S _P
	2	2	4			0.0324	0.5196	
	3	2	4			0.0483	0.5369	
BTG135b (6916)	1	2	3	Silicified Andesite	Qtz, Po, Ccp, Gn, Ae	0.0446	0.5178	S _P , E _V
	2	2	7			0.0487	0.5198	
BTG136c (6917)	1	2	3	Silicified Andesite	Qtz, Po, Ccp, Gn, Ae	0.0339	0.5366	S _P , E _V
BTC080 (6927)	1	2	4	Lithic Wacke	Qtz, Po, Gn, Py, Gr	0.0331	0.2410	S _P
	2	3	6			0.0317	0.3002	
	3	3	4			0.0311	0.4276	

Abbreviations after Kretz (1983)

Additional abbreviations: Ae = arsenides
marc. = marcasite
S-Ae = sulpharsenides
S-Sh = sulphantimonides

SIS = seafloor-injection structures

n.b. see text for MINERALIZATION TYPE description

Chlorite

By comparison, there is a marked variation in the Fe content of chlorite. Average Fe/(Fe + Mg) ratios range from 0.3772 to 0.6095. Most samples are prochlorites and pynochlorites (Figure 24). Kalogeropoulos and Scott (1983) have suggested that compositional variation in chlorite coexisting with sulphides may in part be due to sulphidization reactions such as,

Such a reaction would result in the relative Fe depletion of chlorites associated with Fe- and base metal sulphides. Similar trends are inferred in local samples as described below.

Significance of Compositional Data

The relative homogeneity of sphalerite compositions as compared to those of coexisting chlorite precludes strong positive correlation of the respective Fe contents of sphalerite and chlorite. However, the variation in chlorite composition may be correlative with distinct mineralization events and/or characterize the environment of precipitation.

The data have been subdivided into four broad mineralization types based on mineralogic and lithologic associations:

- (1) syngenetic sphalerite and chlorite, occurring distal to, or largely without any sulphides other than sphalerite (S_D)
- (2) syngenetic sphalerite and chlorite, occurring proximal to, or in association with other sulphides (S_P)
- (3) epigenetic sphalerite and chlorite, occurring proximal to, or in association with Ag-Bi-Co-Ni-As minerals (E_V), and
- (4) epigenetic sphalerite and chlorite, occurring in secretion-injection structures proximal to syngenetic sulphides (E_{SIS}).

KEY

▲ Hudson Bay and Nipissing RL 404 Properties

● Beaver - Temiskaming Mine

other plotted samples:

☑ Conisil Mine 8105 (D.H. Watkinson, Carleton University, unpublished data, 1981)

☑ Conisil Mine (H. Dillon-Leitch, Carleton University, unpublished data, 1982)

⊙ Nipissing RL 404 Property (H. Dillon-Leitch, Carleton University, unpublished data, 1982)

☐ Cross Lake - O'Brien (Deerhorn) Mine, H. Dillon-Leitch, Carleton University, unpublished data, 1982)

Figure 24: Classification plot of Total Fe/(Fe + Mg) versus Si, for chlorites in Archean rocks, Cobalt area (after Saggerson and Turner, 1982)

2

Total Fe in octahedral sites

Although considerable overlap and juxtaposition of mineralization types is inevitable, these data indicate a trend of decreasing $\text{Fe}/(\text{Fe} + \text{Mg})$ in chlorite in the succession:

Despite the generality of this succession, it may be stated at least that mineralization and alteration events can be distinguished on a local scale using chlorite chemistry.

APPENDIX D: GROUND MAGNETOMETER SURVEY RESULTS

A ground magnetometer survey was conducted by students of the Haileybury School of Mines under the supervision of V. Kunduri. Traverses were made over part of the Nipissing RL 404 Property (Figure 7) selected by the author. Measurements were made at 50 foot intervals on a line spacing of 50 feet.

The data were contoured and responses were compared to local geological features. Special attention was made in the distinction of lithologic units and sulphide-mineralized zones within them. Typical magnetic responses are listed in **Table 8**.

Magnetic responses are correlative with sulphide content in all cases, largely due to the ubiquity of pyrrhotite in the sulphide zones. These data suggest that magnetic and other geophysical methods may help in delineating Archean strata in areas of poor exposure or Proterozoic cover. More study is required in assessing their applicability, however.

TABLE 8: GROUND MAGNETOMETER SURVEY
NIPISSING RL 404 PROPERTY

<u>ROCK/ MINERALIZATION TYPE</u>	<u>MAGNETIC RESPONSE (γ)</u>
andesitic flows (TSC = <1 to 5%)	1000 to 3000
interflow sedimentary rocks (TSC = <1 to 15%)	1000 to <2000
stockwork sulphide zone (TSC = 5 to 25%)	<4000
massive sulphide unit (TSC = 35 to 90%)	<5000
stratiform Po + Po SIS zone (Po ≤40%)	≤5000

n.b. TSC = Total Sulphide Content

(source: personal communication, V. Kunduri,
Haileybury School of Mines, 1987)

ARCHEAN INTERFLOW SEDIMENT

LITHOFACIES	LITHOTYPES ¹	GRAIN SIZE AND SHAPE	COMPOSITION	BEDDING ²
(A) Interbedded Sandstone- Siltstone- Mudstone	arkose arenite lithic arenite quartz wacke feldspathic wacke siltstone mudstone	poorly to moderately sorted, fine to coarse sand, sub- rounded to angular very fine to medium sand rounded to subangular	some framework clasts altered to sericite and chlorite lithic fragments are sedimentary, mafic to inter- mediate volcanic rocks. accessory detrital minerals: muscovite, biotite zircon	thinly to thick bedded (0.0' to 1.0' avg. 0.05 to 0.
	intraformational oligomictic paraconglomerate	medium sand to pebbles, cobbles; very angular to sub-rounded, tabular	monolithic clasts (e.g. mudstone) in sandstone matrix	usually indistin- guishable massive
(B) Conglomerate	polymictic paraconglomerate	subangular to sub- rounded pebbles in mudstone to very fine sandstone	quartz, feldspar and lithic clasts local chloritic alteration of lithic clasts	disorganized to medium bedded
(C) Oxide Facies Ironstone	banded magnetite - siltstone siltstone/arenite with disseminated magnetite jaspilitic chert with disseminated magnetite	well sorted silt to medium sand with 0.05 to 0.1 mm magnetite cryptocrystalline quartz, 0.005 to 0.05 mm magnetite grains	quartz comprises all framework grains metamorphic chlorite, amphibole, garnet jaspilitic chert, hematite dust	magnetite thin laminated to very thinly interbedded with clastic beds massive, ≤ 45% disseminated magnetite thinly to thick laminated chert

TABLE 2:

STRATIGRAPHIC LITHOFACIES DESCRIPTIONS

	SEDIMENTARY STRUCTURES		INTERPRETED DEPOSITIONAL FACIES AND ASSOCIATED LITHOTYPES
	PRIMARY	PENECONTEMPORANEOUS	
o ded 0.15m)	graded bedding, planar X-bedding, scour marks ripple marks	slump structures microfolds, microfaults, load casts, ball-and-pillow structures, flame structures, pseudonodules, sand dykes, convolute bedding, fluid escape structures, starved ripple marks	source-proximal turbidites (mid-fan, channel and supracut lobe deposits)
			source-distal turbidites (lower fan deposits)
			fine-grained, upper portion (E horizon) of AE Bona sequence
inct,	clast imbrication, flow alignment		turbidite scour (proximal channel deposits)
to ed	graded bedding clast imbrication		turbidite-associated subaqueous debris flow (upper fan, channel marginal deposits)
lnly very added beds	graded magnetite beds parallel lamination	authigenic magnetite	
ited		de-watering cracks	thin mass flows/ fluidized sedimentary flows (sharply bounded sandstone and siltstone beds without mud)
ckly ert	microbanding	syneresis cracks	clasts are commonly scoured, re-sedimented (proximal channel migration re-sedimentation)

(D) Black shale	carbonaceous shale with silty to sandy, interbeds and/or disseminated to stratiform sulphides	poorly to moderately sorted mud rare subangular, sand- sized lithic clasts predominantly Fe- sulphides (Po > Py > marc)	clay minerals metamorphic chlorite and sericite amorphous carbon	massive to fissile very thinly inter- bedded with siltstone, sulphides, carbon
(E) Chert	banded to massive chert black chert breccia	cryptocrystalline quartz subrounded to angular chert cobbles in sandstone	chert with minor sulphides black chert in sandstone	massive; very thinly to thickly bedded massive
(F) Massive Sulphides		anhedral to euhedral coalescing aggregates, typically annealed	Po, Py, Ccp, Sp, Gal, (+ Qtz, Chl, Ct)	massive, to thickly interbedded with clastic lithofacies

Note:

- 1 - Clastic lithotypes after Pettijohn et al. (1973)
- 2 - after Ingram (1954)
- 3 - Turbidite facies after Walker (1984)
- 4 - Ironstone facies after Barrett and Fralick (1985)

le
r-
one,
1

microbanding
graded arenaceous
interbeds

slump structures

pelagic, restricted basinal deposition
with minor interbedded turbidites

predominantly syngenetic base metal sulphides
with minor diagenetic Fe-sulphides

ily
d.

exhalative, commonly interbedded with
clastic sediments

slumped or scoured, turbidite-influenced deposit

ly
is

nodules,
colloform banding,
microbanding

vent-proximal, volcanogenic exhalative deposits

thinner, stratiform bands
of syngenetic sulphides interbedded
with black shale and chert

A₁

A₂

0 1m

B₂

B₃

0 1m

Figure 6b: Stratigraphic
Sedimentary
Map 1950

Figure 6c: Location of Stratigraphic Sections, Nipissing RL 404
Property Detail Map Area
(see Figure 7 for detailed geology)

Figure 3: Local Geology
(after Thomson, 1964a,b,c)

FIGURE 10

Figure 6a: Stratigraphic Sections across Northern Interfluvial
Sedimentary Unit, Nipissing Rd 404 Property
Map Area

low
Detail

Figure 6b: Stratigraphic
Sedimentary
Map Area

c Sections across Southern Interflow
y Unit, Nipissing RE 404 Property Detail

LITHOFACIES

A		bed contacts sharp, planar
	sharp, irregular
B		slumping
	large scale
C		small scale
	normal graded bedding
D		planar crossbedding
	load casts, flames
E		pseudonodules
	bedding
F		lenticular
	convolute
	sulphide nodules, lenses

PROTEROZOIC

LATE PROTEROZOIC

Olivine diabase and
quartz diabase dykes

EARLY PROTEROZOIC

Nipissing diabase

Huronian Supergroup
Gowganda Formation
Coleman Member

ARCHEAN

Lamprophy
mafic int

Lorrain gr

Mafic to i
volcanics
sediment

Fault

unconformity

0

re and
rusive rocks
anite

ntermediate
interflow
ary rocks

500 m

FIGURE 4

ARCHEAN

Lamprophyre and mafic intrusive rocks

Lorrain granite

Mafic to intermediate volcanics, interflow sedimentary rocks

Fault

Giroux

Lake

Lak

Figure 4: Stratigraphic Reconstruction

(after Knight, 1924; Thomson, 1961e)

interflow sedimentary rocks

within Archean volcanic succession

interflow sedimentary rocks

Sketch showing interpreted
fold structure

Sasaginaga
Lake

ault 64

Valley Fault

O'Brien - Violet Fault

Lake Fault

within Archean volcanic succession

extrapolated under Proterozoic cover

synformal axis

antiformal axis

minor fold axis

fault

inclined

vertical

normal

reverse

Ragged Chute Road

LEGEND

LEGEND

Geology of the Nipissing Hill RL404 (South) Area, C

12° W dec.

Low Grade Mill Site

fault

inclined

vertical

normal

reverse

bedding

inclined

vertical

overturned

top of bed

pillow top direction

foliation, vertical

unconformity

Lake

metres

EARLY PROTEROZOIC

HURONIAN SUPERGROUP COBALT GROUP GOWGANDA FORMATION COLEMAN MEMBER

- 6a basal breccia
6b basal diamictite

~~~~~ unconformity ~~~~~

ARCHEAN

Late Intrusive Rocks

- 5 felsic breccia dyke
4a chloritic breccia dyke
4b mafic dyke
3 lamprophyre

- 2 interflow sedimentary rocks
▲ black chert breccia

Intermediate Volcanics

- 1a massive andesite
1b pillowed andesite
1ec exhalative chert
1f flow/pillow breccia
1h hyaloclastite
1mi subvolcanic mafic intrusion
1ms massive sulphide
1sf sulphide-rich breccia
1st sulphide stockwork zone

- outcrop
—— geological contact
..... subunit contact
~~~~~ unconformity
—— bedding
—— inclined
—— dip unknown
—— vertically dipping
—— overturned
—— fault
~~~~~ assumed
~~~~~ observed, vertical
—— joint(s)
—— inclined, vertical
—— foliation
—— minor fold axis
—— glacial striae
—— bedding top direction
○ pillow top direction

map

vein network

FIGURE 20

metres.

3

of/de

3

NEC

"19-28" Shear Zone Nipissing RL 404 Property

partially pillowed andesite,
pillow breccia

very thinly interbedded
chert and shale

black chert

strongly foliated, altered andesite

foliated, gossany zone

black sulphide stain

subparallel sulphide veinlets/
secretion-injection structures

assumed contact between
sedimentary and volcanic rocks

assumed boundary of shear zone

ET

ear bands.

1 2 3 4 5

metres

subparallel sulphide veinlets/
secretion-injection structures

assumed contact between
sedimentary and volcanic rocks.

assumed boundary of shear zone

secondary shear bands

orientation of aligned porphyroblasts

fault, dip unknown

subvertical bedding

outcrop boundary

trench

END

29-06-88

FIN

8