GEOLOGICAL SURVEY OF CANADA

OPEN FILE 2159

Mineral deposits of Noranda, Quebec and Cobalt, Ontario (Field Trip 4)

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edited by

D.H. Watkinson

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GEOLOGICAL SURVEY OF CANADA

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MINERAL DEPOSITS OF NORANDA, QUEBEC AND COBALT, ONTARIO

[FIELD TRIP 4]

BY

DAVID H. WATKINSON[1]

8TH IAGOD SYMPOSIUM

FIELD TRIP GUIDEBOOK

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[1] Department of Earth Sciences, Carleton University, Ottawa, Ontario, K1S 5B6

8th IAGOD SYMPOSIUM

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Tuesday, Aug. 7:	A.M. - Underground Mine Tours at the Ansil (Minnova Inc.) or Mobrun Mines (Les Ressources Audrey Ltee.). P.M. - Mine Gallen (Noranda Mines Ltd.). Semiconformable alteration.
Wednesday Aug. 8:	A.M. - Alteration and metamorphosed alteration pipes: F-Shaft and Upper A Deposit, Amulet Mines area. P.M. - Travel to Cobalt area. Arrival at Hotels, Haileybury, Ontario.

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The field trip leaders and IAGOD wish to thank the companies, government organizations and individuals who have given of their time in the preparation and execution of this field excursion. We particularly thank the companies who have made available their geological staff and who have granted access to their mines and their surface properties. Much of this guidebook has been written using information generated during extensive research in both the Cobalt and Noranda areas by many of my Ph.D., M.Sc. and B.Sc. students at Carleton University, Ottawa-Carleton Geoscience Centre. Foremost of these have been the contributions of Harold L. Gibson during the course of two theses at Carleton. He and the following students have permitted the use of some of their unpublished and published works in this guidebook: Suzanne Paradis, Henry Dillon-Leitch, Peter Whittaker, Justin Ikingura, Paul MacRobbie, Morrie Goodz, Mark Smyk, Brad Wilson, Genevieve Camire, John McEwen, Ray Westendorp, Marcus Buck, Marilyn Atkinson, Terry Smith, Jamie Gebert and Ken MacQueen. Their contribution to this is inestimable. Thanks are also due to the Canadian Institute of Mining and Metallurgy for permission to reproduce material from papers coauthored with Gibson, McEwen, and Ian Jonasson (Geological Survey of Canada) that CIMM is publishing as Special Volume 43 on "The Northwestern Quebec Polymetallic Belt". This guidebook has also benefitted from on-going discussions with my colleagues George Skippen, Ian Jonasson, Dan Marshall and Peter Jones.

INTRODUCTION

This field trip is designed to give the participants the opportunity to examine two major types of ore deposits of the Canadian Shield and, especially, to study some of the essentially unmetamorphosed and undeformed Precambrian rocks that are the hosts to the deposits (Figure 1). Volcanogenic massive sulphide deposits, the most significant in the Noranda area, are world-class deposits, and some geologists refer to such essentially syngenetic Archean deposits in many parts of the world as "Noranda-type". On the other hand, the vein deposits of the Cobalt area are now, unfortunately, much less significant; however, just after the turn of this century, they provided not only incredible riches to their discoverers and exploiters, but the profits from mining the Cobalt silver ores were instrumental in opening up the northern parts of the provinces of Ontario and Quebec. The Cobalt-area "5-element" deposits of silver with Bi, Co, Ni and As and the Noranda-area Cu-Zn-Ag-Au deposits may be examined in a short day's drive from Ottawa; the trip also provides the geologist with the opportunity to examine interesting physiographic and historical parts of Canadian terrain, in addition to the geology of this small part of the Canadian Shield.

The Canadian Shield in this part of the Provinces of Ontario and Quebec is dominated by the Superior Structural Province, a large array of greenstone belts, stitched together by the emplacement of large plutons of "granitic" rocks during the deformational and metamorphic episodes that culminated near the end of Archean time. Late brittle to ductile deformation zones transgress these volcanic, sedimentary and plutonic units and have spatially related, major gold mining camps, such as those around Val d'Or, and Kirkland Lake that we will skirt on our excursion. Much of the Archean volcanism in the greenstone belts occurred about 2.7 Ga ago, and volcanic rocks that make up most of the host rocks to the deposits in the Noranda area, as well as the greenstone terrain in the basement of the Cobalt area are of this approximate age. Weakly to strongly deformed sedimentary units comprise relatively minor amounts of the Archean succession in the areas that we will examine. As described in the part of this guide dealing with the Noranda segment of the tour, the volcanic rocks are part of the Noranda Subgroup of the Blake River Group, a major stratigraphic subdivision of the Abitibi Greenstone Belt. Correlation of the volcanic and sedimentary rocks of Archean age in the Cobalt area with those to the north and east (Figure 2; Tables 1 and 2) is made difficult because of the intervening granitic rocks, and the cover of essentially flat-lying Proterozoic sedimentary rocks of the Huronian Supergroup, the extensive sheets of Nipissing diabase (also Proterozoic) and some Paleozoic outliers that are confined to grabens and fault blocks of the Timiskaming Rift System.

The change from the typical Archean processes of oceanic volcanism, sedimentation, plutonism and deformation, revealed so distinctly in the rocks of the late Archean in the Noranda-Cobalt areas, to platformal sedimentation in the early Proterozoic of the Cobalt area makes this area an excellent laboratory for the study of supracrustal rocks of the Precambrian. The reader is referred to special paper 28 of the Geological Association of Canada (Evolution of Archean Supracrustal Sequences, edited by L.D. Ayres and others, 1985) for many papers dealing with these important aspects of Precambrian geology, and to special paper 16 also published by the G.A.C. (Volcanic Regimes in Canada, edited by W.R.A. Baragar and others, 1977).

NORANDA SEGMENT

Introduction and General Geology

The Noranda area in northwestern Quebec is one of Canada's premier base metal (and gold) mining camps. From 1920 when Ed Horne staked the property which became Noranda's Horne mine, to the present, 17 volcanogenic massive sulphide (VMS) deposits have been discovered. A purpose of this field trip is to examine some of the mines and showings of the Noranda

Table 1. Stratigraphic column for the Cobalt area, Ontario (after Donaldson and Munro 1982).

PHANEROZOIC	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	
PROTEROZOIC		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	
ARCHEAN		Diabase, minor lamprophyre	
		intrusive contact	
		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	
	Volcanic Rocks	Mafic to intermediate mafic flows and tuffs; felsic flows and pyroclastics; minor interflow sediments (mainly black shale and chert); iron formation.	

Table 2. Table of formations for the Noranda area, Quebec (from Gibson 1989).

EON (ERA)	CYCLE		FORMATION	MAP SYMBOL	PRINCIPAL LITHOLOGY
PHANEROZOIC					Sand, gravel, alluvium
Unconformity					
PROTEROZOIC					Diabase dikes
Intrusive Contact					
ARCHEAN	INTRUSIONS				Lamprohyre dikes
			Aldermac Syenite		Syenite plugs,dikes
			Dufault Pluton		Composite granodiorite intrusion
			Dalambert Pluton		Granodiorite
			Newbec Breccia		Hetrolithic diatreme breccia
				6	Diorite,gabbro sills and dikes
			Flavrian Pluton		Diorite,trondjemite,tonalite intrusions
			Here Diorite		Diorite,gabbro intrusions
	Intrusive Contact				
	NORANDA VOLCANIC COMPLEX	Cycle 5			Rhyolitic and andesitic flows/breccias
		Cycle 4			Rhyolitic and andesitic flows/breccias
		Cycle 3 MINE SEQUENCE HUNTER BLOCK FLAVRIAN BLOCK POWELL BLOCK	HUNTER BLOCK		
			Upper North Duprat Andesite	XI UNDA	Massive and pillowed andesitic flows
			Upper North Duprat Rhyolite	VII-X UNDR	Aphyric, feldspar porphyritic and quartz porphyritic rhyolitic flows
			Lower North Duprat Andesite	VII LNDA	Massive and pillowed andesitic flows
			Lower North Duprat Rhyolite	VI LNDR	Aphyric, feldspar porphyritic and quartz porphyritic rhyolitic flows
			Hunter Andesite	V H	Massive and pillowed andesitic flows
			FLAVRIAN BLOCK		
			Amulet Andesite	XI A	Massive and pillowed andesitic flows, minor tuff
			Waite/Millenbach Rhyolite	X W/M	Feldspar porphyritic and minor quartz porphyritic rhyolitic flows
			Waite/Millenbach Andesite	IX W/M	Massive and pillowed andesitic flows and minor tuff
			Amulet	VIII A	
			Amulet Upper Member	VIII Al	Silicified andesitic flows, minor rhyolite
			Amulet Lower Member	VIII Al	Feldspar and quartz feldspar porphyritic rhyolitic flows and minor breccia (Beecham Breccia) at base of unit
			Rusty Ridge	VII R	Massive and pillowed andesitic flows, minor rhyolitic breccias
			Northwest	VI N	Feldspar phyric rhyolitic flows
			Cranston Member	VI NC	Quartz feldspar porphyritic rhyolitic flow
			Flavrian	V F	Massive and pillowed andesitic flows
			Ansil Member	V FA	Quartz feldspar porphyritic rhyolitic flow
			POWELL BLOCK		
			Powell Andesite	XI P	Massive and pillowed andesitic flows
			Quemont Rhyolite	X Q	Aphyric and quartz-feldspar porphyritic rhyolite
			Joliet Rhyolite	VI J	Feldspar phyric rhyolitic flow
			Brownlee Rhyolite	VI B	Feldspar phyric rhyolitic flow
		Cycle 2			Rhyolitic and andesitic flows/breccias
		Cycle 1			Rhyolitic and andesitic flows/breccias

Roman numeral prefix indicates order of stratigraphic succession
Cycle 5 may be the stratigraphic equivalent of Cycles 2 or 3

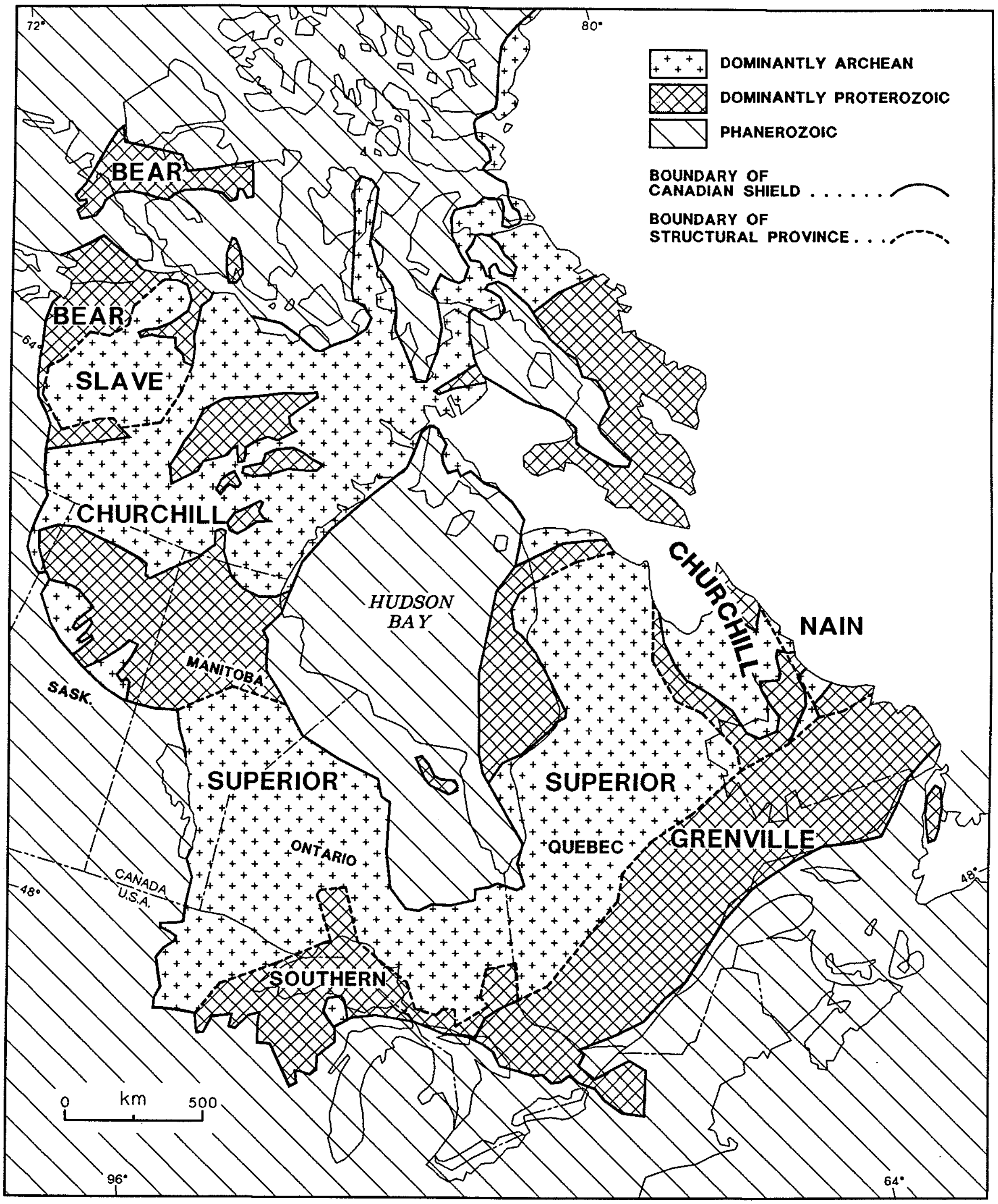


Figure 1. General geology of the Canadian Shield and the structural provinces after Ayres and Thurston (1985).

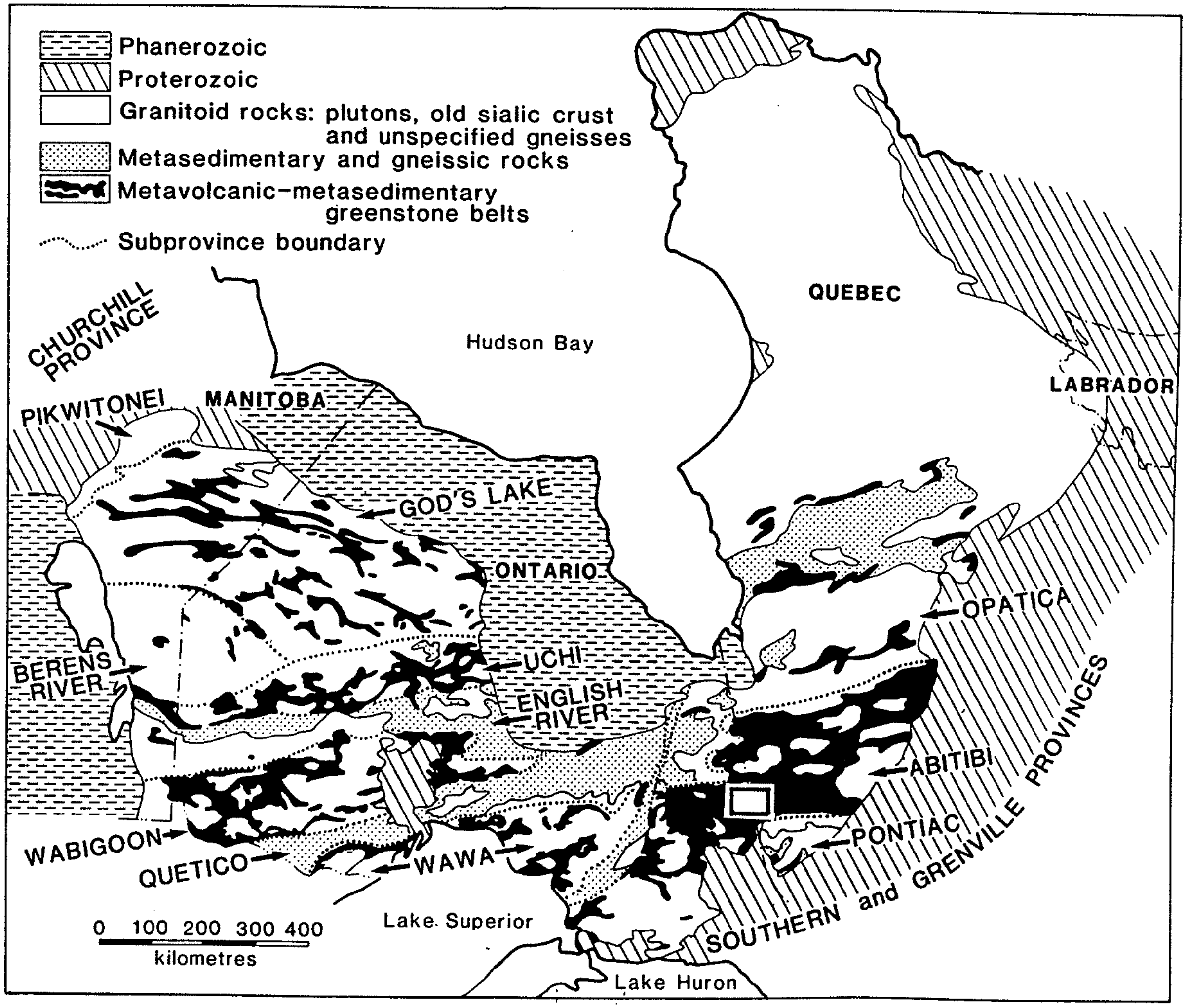


Figure 2. General geology of the Superior Structural Province and adjacent provinces showing the location of the Noranda and Cobalt areas (boxed area) after Ayres and Thurston (1985).

trip is to examine some of the mines and showings of the Noranda camp and more specifically to stress the interplay of volcanology, stratigraphy and structure in controlling the location of VMS deposits (Fig. 3).

Volcanic rocks of the Noranda area comprise the uppermost member of the Noranda subgroup, a division of the Blake River group within the Abitibi greenstone belt. Volcanic strata of the Noranda area consist of rhyolitic and andesitic flows and minor pyroclastic/epiclastic rocks that are gently folded and form an east-west trending, east-plunging antiform. This structure is bounded to the north, east and south by an arcuate zone of isoclinal folding (Spence, 1976 and Gelinas, 1977) and the major fault zones of the Porcupine-Destor and Cadillac-Bouzan "breaks" to the north and south respectively. Archean, synvolcanic granitic intrusive complexes and dioritic sills and dikes intrude volcanic strata. Metamorphic grade ranges from amphibolite facies in the contact aureole of the Lac Dufault Granodiorite to lower and sub-greenschist facies regional metamorphism.

Volcanic rocks of the Noranda area are interpreted to have formed a large shield-like volcano some 40-50 km in diameter (Spence and de Rosen-Spence 1976) that is in contact to the south with the sedimentary rocks of the Pontiac, Cadillac and Timiskaming groups some of which may be time equivalent (Dimroth, 1983). The Cadillac-Bouzan break, interpreted to be a re-activated synvolcanic fault, separates the sedimentary basin to the south from the volcanic rocks of the Noranda volcanic complex to the north.

Volcanic strata of the Noranda area are divided into 3 blocks that are bounded by major faults, as follows:

A) North Mine Sequence - includes volcanic strata north of the Hunter Creek Fault.

B) Central Mine Sequence-includes volcanic strata south of the Hunter Creek Fault and north of the Horne Creek Fault.

C) South Mine Sequence - includes volcanic strata south of the Horne Creek Fault and north of the Cadillac-Bouzan Break.

Central Mine Sequence Stratigraphy

The Central Mine Sequence strata are remarkably well preserved and well exposed (Gibson 1989; Paradis 1990). Although disrupted by numerous northeast and northwest striking faults, the volcanic rocks have suffered little penetrative deformation typically associated with greenschist-facies regional metamorphism elsewhere in the region. Volcanic strata in the tour area comprise alternating subaqueous andesitic and rhyolitic flows with less than 5% pyroclastic and epiclastic rocks. From oldest to youngest, and from west to east, formations encountered during the tour include the Flavrian, Northwest, Rusty Ridge, Amulet, Millenbach-Waite Andesite, Millenbach - Waite rhyolite and Amulet Andesite formations. Formations strike north-northeast, are gently folded about east-west trending axes, and dip from 5-55° to the east (Fig. 4).

The Central Mine Sequence strata (Fig. 5) represent the infilling of a primary volcano-tectonic depression or cauldrons (Dimroth et al., 1982; Gibson, 1989). Hydrothermal vents are coincident with volcanic vents and both show a strong spatial association to major synvolcanic faults which were active at various stages during successive collapse of the Noranda cauldrons.

VMS deposits (Gibson 1989, Gibson and Watkinson 1990), although prominently clustered above the Amulet formation are scattered throughout more than 2000m of strata; within individual deposits, massive sulphide lenses are stacked over vertical distances approaching 300 m (Amulet Upper and Lower A). VMS deposits are of the proximal type and are located within both rhyolitic and andesitic vent areas that are localized along synvolcanic faults.

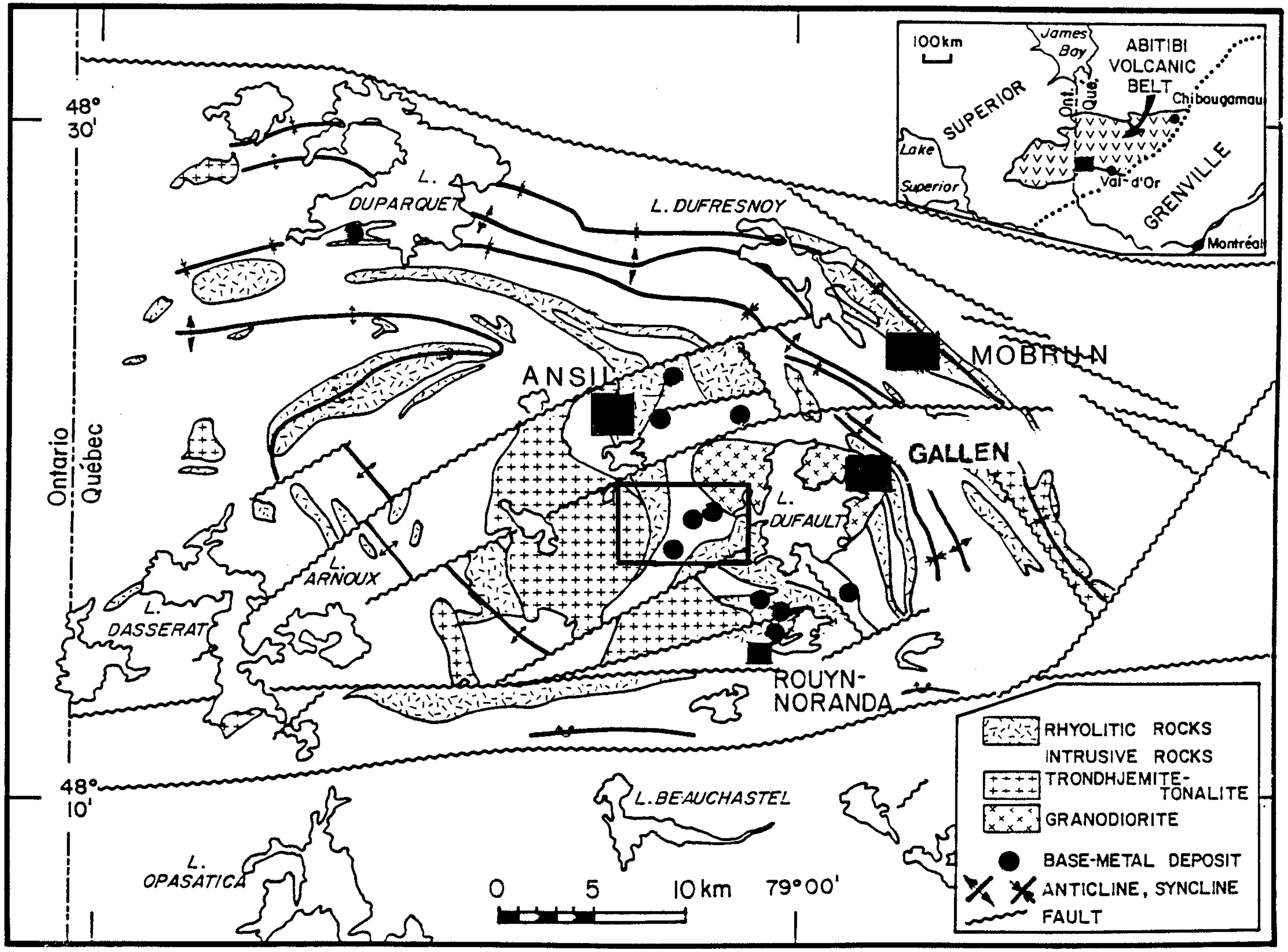


Figure 3. General geology of the Noranda area showing locations of the Ansil, Gallen and Mobrun Mines and the area of Figure 4.

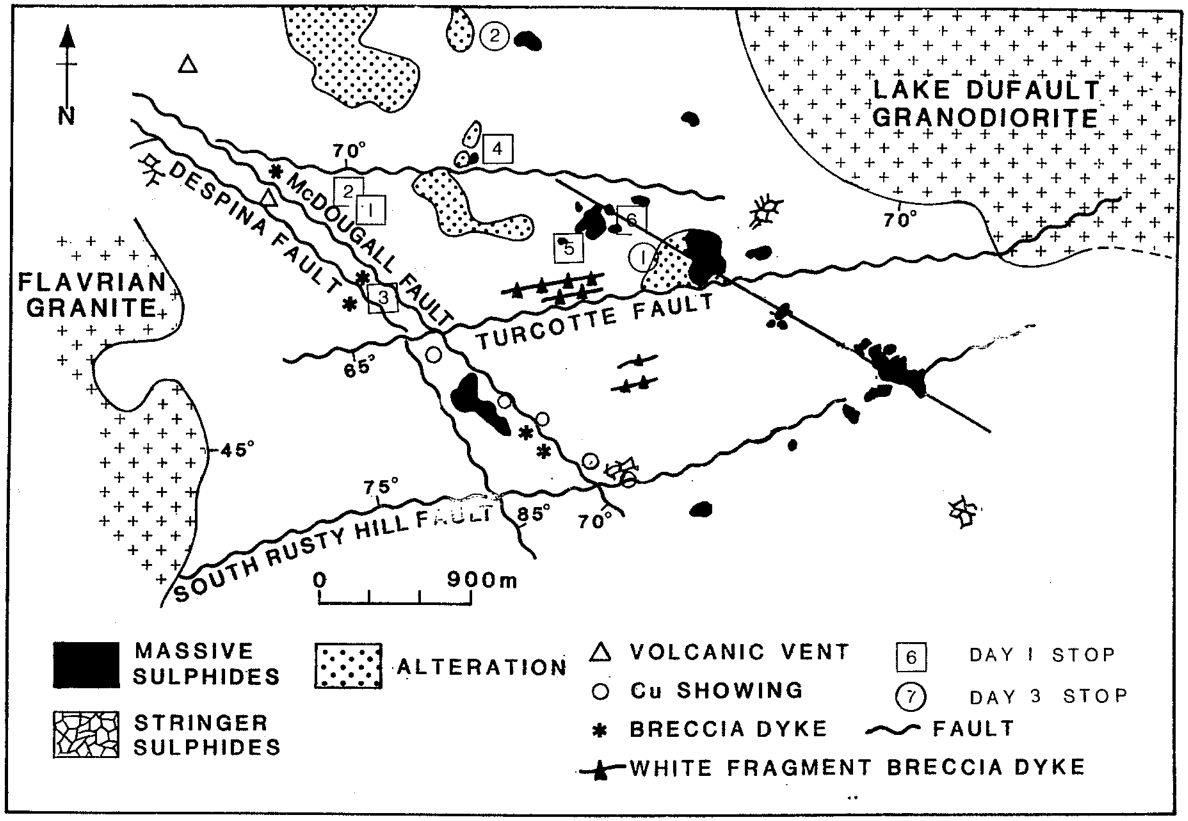


Figure 4. The Amulet area showing the projection to the surface of some massive sulphide deposits in volcanic rocks (white), areas of intense alteration, major synvolcanic faults, granitic rock complexes and stop locations after Knuckey et al. (1982).

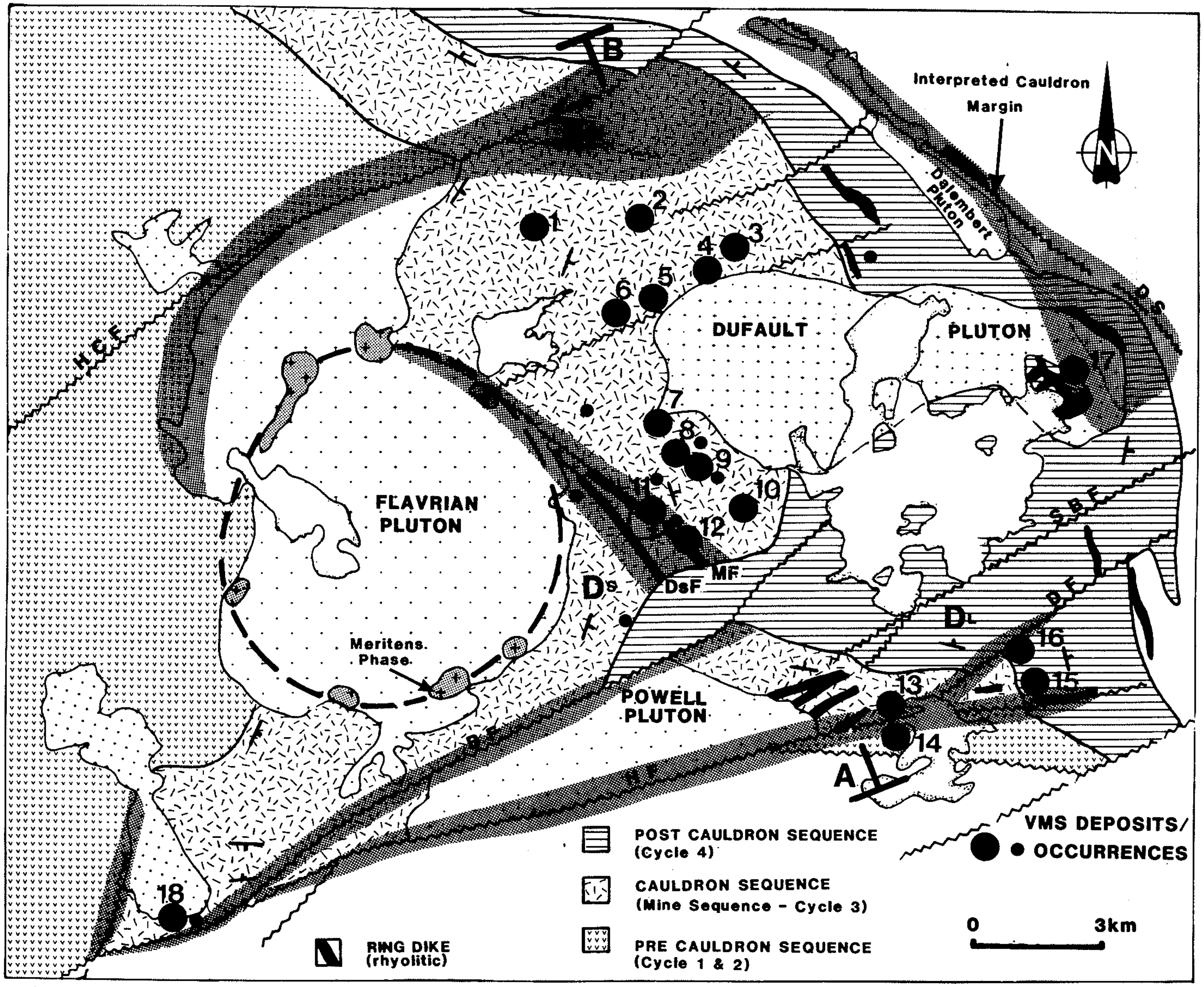


Figure 5. Distribution of the Cauldron Sequence or Mine Series volcanic rocks with their volcanogenic massive sulphide deposits and occurrences, pre- and post-cauldron successions and inferred limits of the cauldrons. Numbers adjacent to the deposits are those given in Table 3. A-B is the approximate position of the structural cross section in Figure 6. HCF - Hunter Creek Fault, HF - Horne Creek Fault, BF - Beauchastel Fault, DSF - Despina Fault, MF - McDougall Fault, DF - Deldona Fault, SBF - Southbay Fault, DS - Dalembert Fault, CF - Cranston Fault. From Gibson (1989) and Gibson and Watkinson (1990) with permission of CIMM.

Characteristics of Noranda-Type VMS deposits

Noranda-Type VMS deposits are proximal deposits that consist of a concordant lens of massive sulphide (>50% sulphides) overlying a discordant stockwork zone of sulphide stringer mineralization within a pipe-like envelope of altered rock.

The tonnage and grade of VMS deposits in the Mine Sequence and in stratigraphically younger and older formations are summarized in Table 3. Deposits consist either of a single massive sulphide lens and stringer zone, or of multiple lenses. The best example of the latter is the Millenbach deposit, which contained 15 individual massive sulphide lenses that ranged in size from 4,000 tons to 1.8M tons (Knuckey et al. 1982).

THE MASSIVE SULPHIDE LENS

Morphology, Textures, Structures and Mineral/Metal Zoning

A typical massive sulphide lens has a shape that varies from steep-sided cones with slopes of up to 45^0 to flat lensoid bodies with slopes of $<5^0$.

The textures, structures and mineral zoning within an individual massive sulphide lens have been described, for example, by Simmons (1973) and Knuckey et al. (1982). A typical lens at Millenbach consists of an inner discordant cone or spine that sits directly above the stringer zone and narrows toward the top of the lens. The spine consists of massive, fine to coarse-grained pyrrhotite with irregular patches and elongate vertical bands of chalcopyrite with minor pyrite and sphalerite. Surrounding the spine is either massive or crudely banded sulphide or a framework-supported sulphide breccia or "in situ" brecciated massive sulphide; matrix separating fragments is typically massive pyrrhotite, chalcopyrite and pyrite. Fragments as large as 3m across are angular to subrounded and consist of fine- to coarse- grained massive sphalerite, or weakly banded pyrite-sphalerite with minor pyrrhotite and chalcopyrite and massive chalcopyrite. Banding in fragments is discontinuous and lensoidal. The flanks of the sulphide lens consist of coarse-grained, crudely bedded and well-bedded sulphide that thins toward the top and centre of the sulphide lens. Thinly bedded to laminated pyrite and alternating pyrite-sphalerite beds which range from 1 mm to >15 cm in width often occur along the flanks of some lenses. Thin beds composed of pyrite framboids (up to 1.5 cm in diameter) with interbeds of tuff may occur locally within laminated sulphides along the fringe of the Corbet main lens.

The proportions of brecciated and massive sulphide in many deposits are unknown. In some deposits, such as Vauze, sulphide breccias (Main lens) deposited along the flanks of a rhyolitic dome constitute 75% of the massive sulphide lens. At Corbet, slumped and transported sulphide breccia also form a significant part of the ore.

Deposits are thus strongly zoned: pyrrhotite and chalcopyrite spines define a central core that grades laterally to pyrite and sphalerite-rich flanks and ultimately to pyritic fringes. Massive magnetite occurs as discrete zones at the base of the pyrrhotite-chalcopyrite rich core at both Ansil (Riverin et al. 1990) and Corbet (Watkins 1980).

THE STRINGER SULPHIDE ZONE

Morphology, Textures, Structures and Mineral Zoning

The stringer zone consists of sulphide veins which form a cross-cutting, discordant, anastomosing network within hydrothermally altered footwall rocks and occasionally in overlying hanging wall rocks. The zones have a crude circular or oval form in plan that is typically of smaller diameter than the overlying massive sulphide lens. In section they are pipe-like and crudely perpendicular to the basal contact of the massive sulphide lens.

Table 3. Grades and Tonnages of VMS Deposits Within the Noranda Volcanic Complex (after Gibson 1989).

Stratigraphic Position	Deposit	Massive Sulphide	Stringer Sulphide	Multiple Lenses	M/Tons	% Cu	% Zn	oz. Ag	oz. Au	Cu-Zn Ratio
1st Cycle	Four Corners		X							-
	Inmont		X							-
	Yvanex	X								Zn-rich
3rd Cycle Mine Sequence	Ansil (1)	X	X		2.1	7.18	0.57	0.80	0.06	92
	Vauze (2)	X	X	X	0.37	2.94	1.00	0.80	0.02	74
	Norbec (3)	X	X		4.35	2.77	4.50	1.40	0.02	38
	D-Zone (4)	INCLUDED WITH NORBEC (3)								
	East Waite (5)	X	X		1.65	4.10	3.25	0.91	0.05	56
	Old Waite (6)	X	X	X	1.24	4.70	2.98	0.63	0.03	61
	F-Shaft (7)	X	X		0.3	3.40	8.60	1.35	0.01	28
	C Deposits (8)	X	X	X	0.62	2.20	8.50	2.53	0.01	20
	Lower A (9)	X	X		5.17	5.10	5.20	1.29	0.04	49
	Upper A (9)	X	X		0.20	2.30	6.10	1.35	0.06	28
	#11 (9)	X	X		0.49	3.60	2.40	0.63	0.02	60
	Bluff (9)	INCLUDED WITH LOWER A								
	Millenbach (10)	X	X	X	3.92	3.46	4.33	1.64	0.03	44
	Corbet (11)	X	X	X	3.06	3.00	1.96	0.60	0.03	60
	D68 (12)	INCLUDED WITH CORBET								
	Quemont (13)	X	X		16.35	1.20	1.80	0.54	0.12	40
	Aldermac (18)	X	X	X	2.07	1.48	-	0.20	0.01	-
	Newbec		X		0.007	6 to 7				
	Fourcet		X							
	D-62	X								
	Moosehead	X	X							
	Dufault Zinc	X	X		0.50	-	<3.0	-	-	-
	South Rusty Hill		X							
	Bedford		X		0.09	0.89				
	Ribago	RECENT DISCOVERY - TONNAGE/GRADE UNCERTAIN								
	Aldermac	RECENT DISCOVERY - TONNAGE/GRADE UNCERTAIN								

Table 3. Grades and Tonnages of VMS Deposits Within the Noranda Volcanic Complex (con't)

Stratigraphic Position	Deposit	Massive Sulphide	Stringer Sulphide	Multiple Lenses	M/Tons	% Cu	% Zn	oz. Ag	oz. Au	Cu-Zn Ratio
4th Cycle	Deldona (16)	X			0.10	0.30	5.00	0.76	0.12	5
	Delbridge (15)	X	X		0.40	0.55	8.60	2.00	0.07	6
	Gallen (17)	X			3.25	0.07	4.77	0.63	0.02	2
5th Cycle	Mobrun[1]	X	?		3.00	0.62	2.30	0.60	0.50	21
	New Lens	TONNAGE/GRADE UNCERTAIN								
Uncertain	Magusi	X			4.11	1.20	3.60	0.90	0.03	25
	New Insco	X	X		1.15	2.11	-	0.50	0.03	-
	Horne (mined) (14)	X	X		60.26	2.20	-	0.40	0.17	-
	Horne #5[2]	X	X		144	1.0	0.9			52

(2) refers to former or operating mines and "uneconomic deposits" respectively.

[1] Some Cu-rich ore removed during earlier mining.

[2] Tonnage and grade of Horne #5 zone from Sangster (1980) and combined with mined tonnage.

Data from Boldy (1979) and unpublished compilations by D. MacNeil (Corp. Falconbridge Copper) and B. Bancroft (Noranda).

Contacts between sulphide stringers and overlying massive sulphide are gradational where sulphide veins ranging from <1 cm to 2.0 m in width increase in number and size laterally toward the core of the zone and upward toward the massive sulphide lens. Contacts with surrounding host rocks are gradational where sulphide-veined rocks grade within 1 to 3 m into non-mineralized host rocks often containing disseminated sulphides.

Stringer sulphides above deposits "connect" VMS lenses located at different stratigraphic intervals or are "blind" and end abruptly in overlying units. The Amulet 11 shaft, Lower A and Upper A deposits are connected by one stringer zone over a stratigraphic interval of 400 m and provide an excellent example of "stacked" deposits. Ore-grade stringers at the Ansil deposit continue above the massive sulphide lens for 300 m, and are an example of a "blind" stringer zone.

Stringer zones, like overlying massive sulphide, consist of a central core of chalcopyrite-pyrrhotite stringers which grades into a fringe of sphalerite-pyrite stringers. The pyrrhotite- and chalcopyrite-rich core grades into the overlying pyrrhotite-chalcopyrite core of the massive sulphide lens.

The stringer sulphide core generally constitutes "economic" stringer mineralization, with grades decreasing with depth. Economic stringers persist up to 150 m below massive sulphide and, at Norbec, for as much as 500m below the main sulphide lens. Stringer mineralization can contribute significantly to the tonnage of each deposit; at Millenbach, 52% of the ore mined was from stringer zones.

METAL ZONING

Metal Zoning in a Single Lens

Individual massive sulphide lenses have a concentric metal zonation where a copper-rich core grades outward into a zinc-rich fringe. This base metal zonation was first documented by Boldy (1968). Zinc-rich massive sulphide is also enriched in lead relative to the core zone. Precious metals tend to vary systematically within a deposit but not between deposits; at Millenbach higher gold and silver values occur in the copper-rich areas whereas at Corbet they are typical of zinc-rich areas (Knuckey et al. 1982).

Metal Zoning Between Lenses

In multi-lensed deposits, such as Millenbach and Amulet, the overall Cu/Cu+Zn content of individual massive sulphide lenses defines a crude "concentric" pattern of increasing copper content toward the main discharge areas marked by the Amulet Lower A and Millenbach Main lens (Knuckey et al. 1982).

The lower copper content of the Amulet Upper A deposit compared to the underlying Lower A deposit has been interpreted to reflect a vertical metal zoning resulting from an increase in the zinc content of the hydrothermal fluid with time (Spence and de Rosen-Spence 1975). The higher copper content of successively lower massive sulphide lenses located within the same alteration pipe (discharge conduit) is now interpreted as a product of dissolution and replacement of pre-existing sulphide in "older" deposits by continued ascent of hydrothermal fluids through the same conduit to form stratigraphically higher, younger deposits (Knuckey et al. 1982).

DISTRIBUTION OF VMS DEPOSITS WITHIN THE NORANDA SHIELD VOLCANO AND CAULDRON

Stratigraphic Distribution and Metal Zoning of VMS within the Noranda Shield Volcano

The distribution of VMS deposits in the Noranda Shield Volcano is illustrated in figure 5, and the stratigraphic position of these deposits summarized in figure 6.

By far the most significant cluster of economic VMS deposits occurs within the cauldron-filling

Mine Sequence (Cycle 3) where 17 VMS deposits and three new discoveries occur within 3000 m of volcanic strata. These deposits occur within and along the margins of the Noranda Cauldron (Gibson, 1989).

Pre-cauldron Formations

Pre-cauldron Cycles 1 and 2 do not contain an economic VMS deposit (Gibson, 1989). Cycle 1 does, however, contain the 4-Corners, Inmont and Ivanex deposits. The Inmont and 4-Corners deposits are chalcopyrite-pyrrhotite stringer zones and are interpreted as the erosional remnants of former VMS deposits. The Ivanex prospect is a well bedded zinc-rich, pyritic, transported massive sulphide lens without an underlying stringer zone.

Post Cauldron Formations

Post-cauldron Cycle 4 contains the Delbridge, Deldona and Gallen (West MacDonald) deposits and one prospect. Although not located within the cauldron filling Mine Sequence the Delbridge and Deldona deposits are located along the inferred south margin of the cauldron (Horne Fault) and the Gallen deposit occurs along the inferred east margin of the structure.

The zinc-rich, pyritic Deldona and Delbridge deposits (Delbridge No.#1 and 2 deposits (Boldy 1968) are located within a rhyolitic vent complex of the Delbridge Rhyolite formation. The Delbridge deposit is underlain by a Cu-rich stringer zone and chloritic alteration pipe. The Zn-rich, pyritic Gallen deposit occurs within a pendant of the South Dufault Rhyolite formation (Spence and de Rosen-Spence 1975) within the east body of the Dufault Pluton.

Post-cauldron Cycle 5 hosts the Zn-rich, pyritic Mobrun deposits. The stratigraphic position of the Mobrun deposits is uncertain; Dimroth et al. (1983) equated Cycle 5 with Cycles 1 and 2 whereas Gelinas et al. (1984) interpreted it to constitute the youngest units.

Metal Zoning of VMS Deposits within the Noranda Volcano

The Cu/Cu+Zn ratios for VMS deposits within the Noranda Shield Volcano (Table 3) were calculated from average grades which include both massive and stringer ore types and multiple lenses. The data indicate that:

1. The Mine Sequence is characterized by deposits that are distinctly copper rich. There is no systematic (vertical) variation in the Cu/Cu+Zn ratio of deposits located at different stratigraphic intervals within the Mine sequence. Deposits located at the C Contact are, however, distinctly zinc-rich.

2. Deposits located in post-cauldron Cycles are typically zinc rich and pyritic. Except for Delbridge, these VMS deposits do not have a well developed stringer zone.

3. Massive sulphide deposits within pre-cauldron Cycles, such as the Ivanex deposit are zinc-rich. Stringer zones at Inmont and 4-Corners are Cu-rich; however, the Cu-rich character of these zones does not indicate that they are remnants of Cu-rich deposits. For example, the zinc-rich Delbridge deposit is also underlain by a chalcopyrite-rich stringer zone (Boldy 1968).

CAULDRON SUBSIDENCE AND VMS DEPOSITS

The pronounced spatial and temporal relationship between VMS deposits to a large cauldron subsidence structure in Noranda has also been recognized in other VMS camps. Cauldron subsidence and volcanism represent an unique stage in the evolution of the Noranda Shield volcano not duplicated in pre- or post-cauldron formations (Gibson 1989). Cauldron formation is interpreted as a "focusing event" that restricted contemporaneous and "intense" structural, volcanic, plutonic and hydrothermal events to a small volume during a brief period in the evolution of the Noranda shield volcano. Numerous faults, continuously reactivated during subsidence and volcanism, provided access for recharge fluid (seawater) and acted as conduits for cross-stratal fluid flow for fluids from both deep and shallow aquifers and ultimately focused their discharge to form deposits both within and along the cauldron margins. Hydrothermal discharge peripheral to the cauldron would likely have been insignificant and of lower temperature compared to that within the cauldron.

VMS deposits formed during the onset of two cauldron subsidence cycles (Gibson 1989). This particular interval in cauldron development is one which combines maximum heat flow (following regional tumescence and intrusion) with greatest structural permeability (and reactivation) during volcanism and subsidence, and is therefore particularly favourable, but not exclusively so, for generating and sustaining a high-temperature hydrothermal system.

CONTROLS ON THE LOCATION OF VMS DEPOSITS WITHIN THE NORANDA CAULDRON

Stratigraphic Control

Volcanic reconstruction (Gibson 1989) indicates that economic deposits within the Noranda cauldron formed during active volcanism and subsidence at the onset of two cauldron cycles that were preceded and initiated by magma resurgence. The Corbet and Ansil deposits formed during a period of volcanism and subsidence that marked the onset of cauldron development during the first or earliest recognized cauldron cycle. Similarly, the Millenbach-D68, Amulet, Old Waite, East Waite, and Norbec deposits formed during a period of active volcanism and subsidence during onset of the second cauldron subsidence cycle. Small, Zn-rich deposits at the "C" contact (C, Dufault, Moosehead and F-Shaft deposits) formed during a hiatus in volcanism and subsidence between the two cauldron cycles. Similarly, the small Newbec deposit formed during a hiatus in volcanic activity which followed in-filling of the Noranda Cauldron.

The Quemont deposit, located along the south margin of the Cauldron, formed during an interval that spanned mineralization of both cauldron cycles. The large size of the Quemont deposit, which almost equals the combined tonnage of deposits within the cauldron, may reflect continued, uninterrupted hydrothermal discharge that, unlike the intra cauldron deposits, was not interrupted or forced to shift by contemporaneous volcanic activity.

Structural Control

Perhaps the most important and fundamental control on the location of VMS within the Noranda Cauldron is their location along synvolcanic faults and less well defined paleostructures or lineaments (Fig. 4 and 6). Synvolcanic faults, generated and reactivated during regional tumescence that preceded volcanism and subsidence provided cross-stratal permeability for ascending hydrothermal fluids and focused their discharge within the Noranda cauldron. Once established, these faults were continually reactivated and controlled the location of subsequent VMS deposits at different stratigraphic intervals. Synvolcanic faults also acted as conduits for ascending and commonly contemporaneous magma accounting for the common occurrence of deposits within rhyolitic and andesitic vent areas.

VMS deposits at Millenbach and D-68 (Fig. 7) occur at the base of, within, and on top of a growing rhyolitic ridge. The deposits occur along the length of the 2.0 km northeast trending rhyolitic ridge where they directly overlie the northeast trending feeder dike to the lower rhyolitic flow. The feeder dike defines the trace of a northeast striking radial fault (South Rusty Hill Fault) oriented perpendicular to the margin of the Despina cauldron. VMS deposits at D-68 (Ikingura et al. 1989) are situated at the southwest end of the rhyolitic ridge and immediately adjacent to the margin of the Despina cauldron.

The alignment of the Amulet C, Bluff, Lower and Upper A, Lac Dufault zinc and D-266 deposits and Millenbach main lens (Fig. 4) define a northwest-trending lineament, the Amulet-Millenbach lineament, which parallels the McDougall-Despina Fault located 1.5km to the south. The

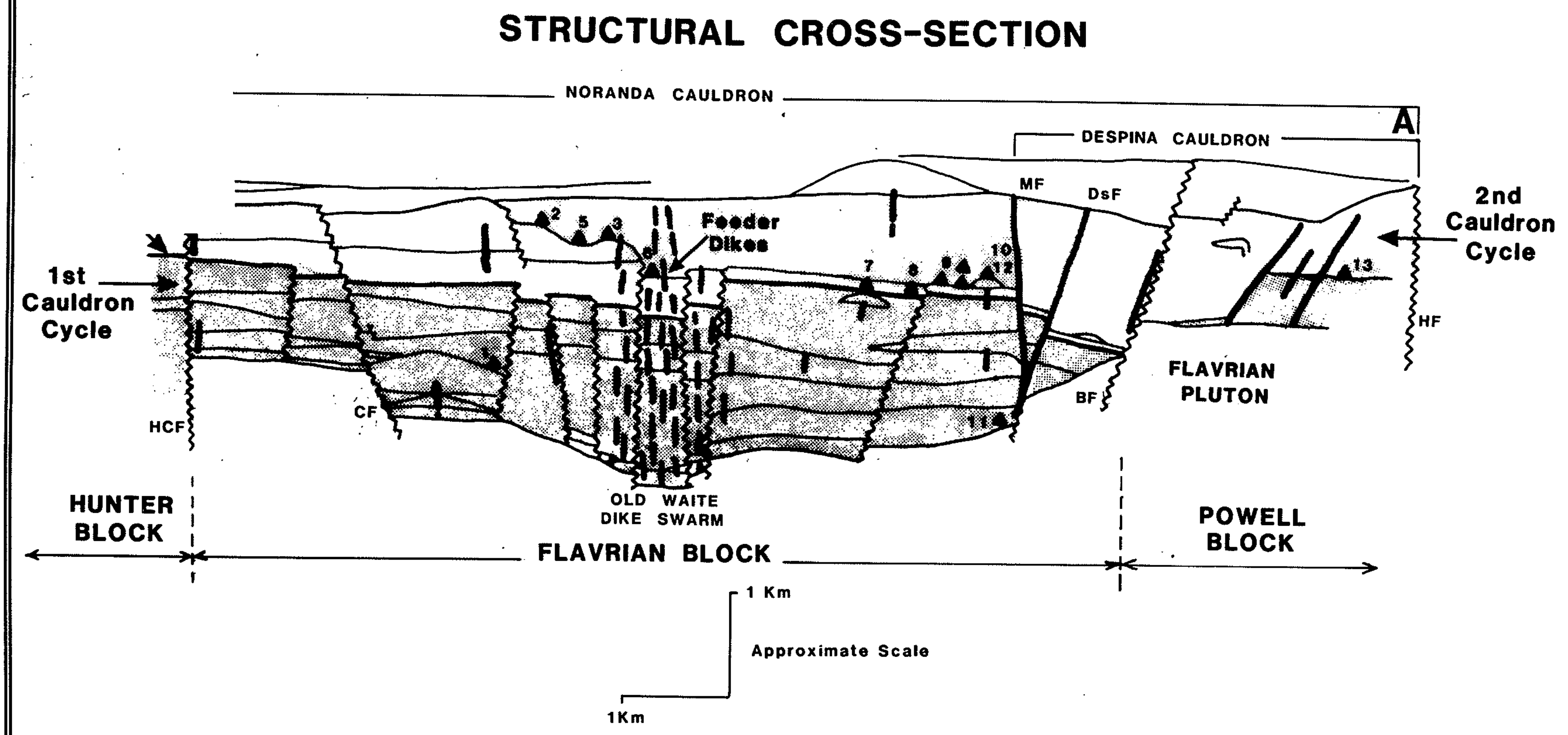
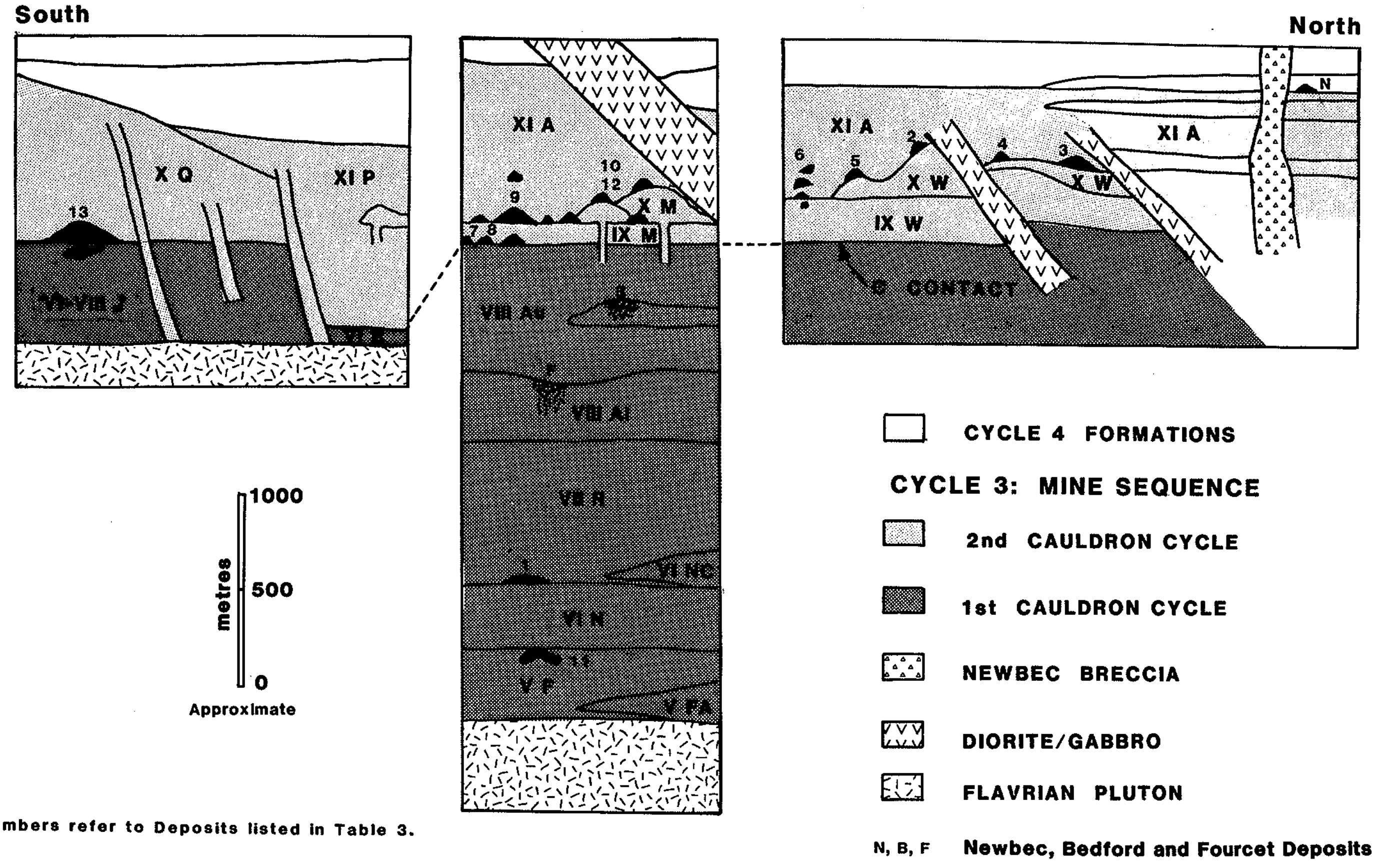


Figure 6a. a. Structural cross section of the Noranda Cauldron, and b. Mine sequence stratigraphy and VMS deposits. Abbreviations and numbers of deposits as in Figure 5 and Table 3 respectively. From Gibson (1989) and Gibson and Watkinson (1990) with permission of CIMM.

MINE SEQUENCE STRATIGRAPHY AND VMS DEPOSITS



Numbers refer to Deposits listed in Table 3.

Figure 6b.

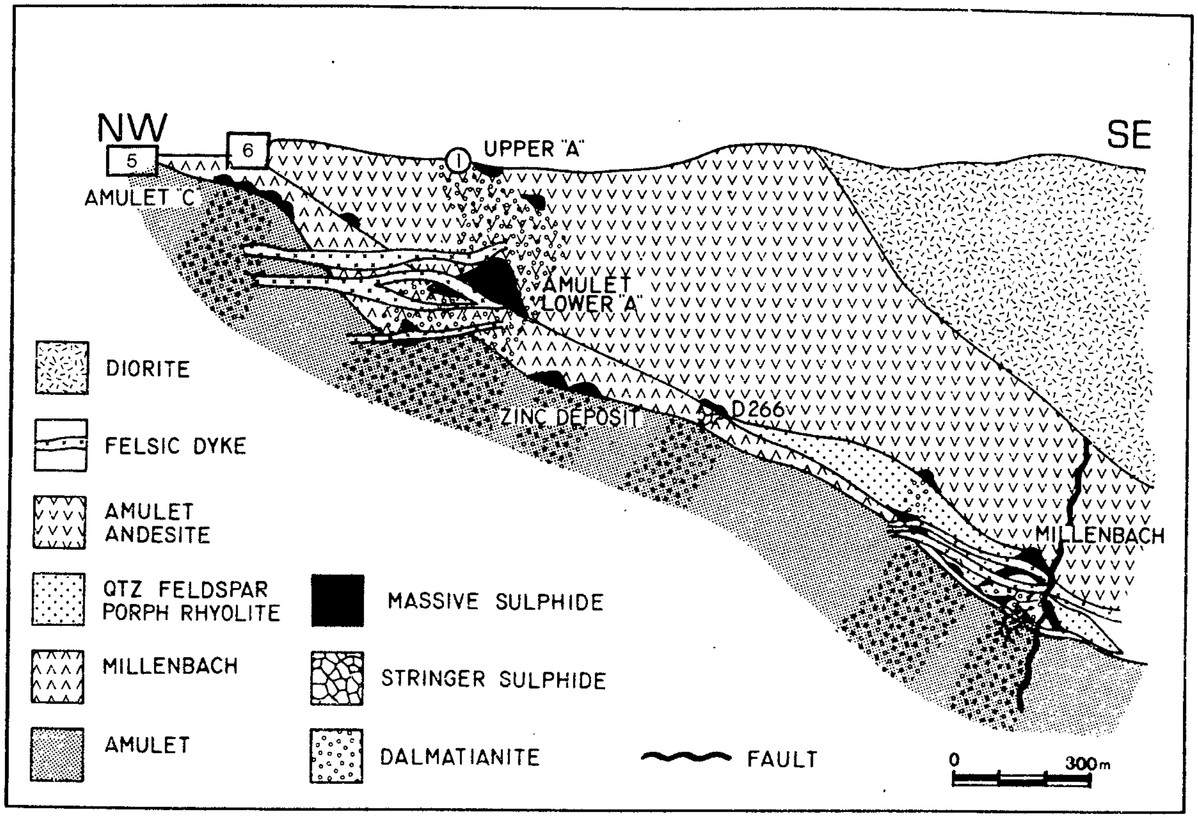


Figure 7. Cross section in the Amulet - Millenbach area showing the gentle dip of the volcanic strata, relationship of the deposits to the top of the silicified rocks of the Amulet formation, upper member, and to alteration pipes ("dalmatianite"), pillowed and massive units in the Millenbach and Amulet Andesite formations, and the locations of stops (see also Fig. 4) after Knuckey et al. (1982).

coincidence of the Amulet-Millenbach lineament with a feeding fissure for the Amulet Andesite formation suggests that the former may mark the position of a deep-seated structure. Deposits along this lineament occur over a 300 m stratigraphic interval indicating reactivation and continued ascent of hydrothermal fluids along this structure during volcanism and subsidence. The Amulet F deposit and D-62 lens lie on a northwest trending line, the F-shaft lineament, which parallels the Amulet-Millenbach lineament and McDougall-Despina Fault. The F-shaft lineament is interpreted to be similar to the Amulet-Millenbach lineament and collectively they are interpreted as parallel ring fractures developed along and parallel to the margin of the Despina cauldron (Gibson 1989).

The pronounced east-northeast alignment of the Old Waite, East Waite, D-Zone, Norbec and Newbec deposits parallels and is coincident with the east-northeast trend of the Old Waite dike swarm and Amulet Andesite feeding fissure, a graben-like andesitic fissure and subsidence zone within the centre of the Noranda cauldron. Synvolcanic faults and andesitic fissures, now represented by andesitic dikes, controlled the location of both volcanic vents and VMS deposits.

The Ansil deposit is located on the south flank of the North Rhyolite flow of the Northwest formation and north of the Old Waite dike swarm. The deposit is in part underlain by flows of the Rusty Ridge formation and is interpreted to have formed along the margin of an actively subsiding fault-bounded basin contemporaneous with andesitic eruptions of the Rusty Ridge formation.

In summary, VMS deposits have been discovered within and along the inferred west, south and east margins of the Noranda cauldron (Fig. 5), but to date, deposits have not been discovered along the north margin. Areas of alteration and sulphide concentrations do occur along the north margin and the absence of deposits may merely reflect minimal exploration, especially diamond drilling. There are, however, fundamental differences in the structural and volcanic history of the north and south margins that may have favoured the localization of deposits on the south margin. As illustrated in the reconstructed cross-section (Fig. 6) the south margin was more structurally active and characterized by greater subsidence, as suggested by the higher level of emplacement of the Flavrian Pluton, and less volcanism than the north margin.

ITINERARY

DAY 1: From the intersection of Murdoch Street and Saguenay Boul. in Noranda, proceed north on Highway 101 (Macamic Highway) for 8 km, turn left onto the Corbet Mine road and continue for 1.8 km to the first stop sign. Turn right onto the haulage road and proceed north for 1.6 km to the Bedford road (Second road on left, across from Amulet tailings). Drive 1.0 km west along the Bedford road and stop at the first beaver pond south of the road.

STOP 1: RUSTY RIDGE FORMATION AND BEECHAM BRECCIA

A. The Rusty Ridge formation consists of alternating flows of brecciated, ribbed, pillowed and massive andesite. Budding pillows, mega-pillows (lava tubes), and shattered collapsed pillows are located approximately 30 m from the top of the Rusty Ridge formation. The pillowed flow was intruded by a flow-banded, spherulitic rhyolite dike that is identical to other dikes that occupy the synvolcanic McDougall/Despina fault structure.

The top of the Rusty Ridge formation is marked by an amygdaloidal flow-top breccia containing angular, ribbed, andesite fragments in a matrix of silicified hyaloclastite and fine-grained quartz.

B. Beecham Breccia member is a distinctive unit that defines the base of the Amulet formation. The breccia is a laterally extensive unit which, in this area, has a thickness of 0.5-3 m increasing to the west where it may attain thicknesses in excess of 40 m adjacent to the McDougall fault.

Beecham Breccia consists of two distinct components: A., a breccia composed of variably silicified white fragments and andesitic fragments in a fine grained, quartz-rich matrix interlayered with b., a laminated, white-weathering, felsic, locally pyritic sediment reminiscent of Noranda "exhalative tuffs". The breccia component is restricted to an area within 1.5 km of the McDougall fault, whereas the laminated, exhalative component is regionally extensive.

The Beecham breccia is interpreted as a primary phreatomagmatic breccia associated with the onset of rhyolite volcanism, which was subsequently reworked and deposited by successive debris flows/turbidity currents (Gibson 1989).

STOP 2: LOWER AMULET RHYOLITE

The Amulet formation is divided into two members: an upper silicified member that ranges in composition from andesite to more siliceous compositions and a lower member composed of spherulitic rhyolitic flows (Gibson 1989; Gibson et al. 1983). At this locality the Lower Amulet member is represented by a spherulitic massive to flow-banded quartz amygdaloidal rhyolite flow. Quartz-amygdule zones (<0.4 m wide) outline irregular lobe forms (1 m to >10 m) within the flow. The chloritic alteration (strong Na depletion) which also accentuates the granular, spherulitic texture of the flow.

STOP 3: BUTTERCUP HILL

White-fragment breccia, so-called because of the striking white colour of the fragments (Gibson et al. 1989, Gibson 1989), occurs as dikes and localized deposits conformable to the top of the Amulet formation and within the lowermost andesitic flows of the overlying Millenbach Andesite formation (Fig. 8). Within the Noranda Cauldron, the Buttercup Hill breccias and numerous other breccia dikes are clustered within 2 km of the synvolcanic McDougall-Despina fault (Knuckey and Watkins 1982).

The breccias are interpreted to record a period of widespread hydrovolcanic explosions during magma resurgence prior to and during the onset of Millenbach Andesite volcanism. Buttercup Hill provides an unique cross-sectional exposure of a subaqueous, phreatomagmatic, explosion breccia deposit and its underlying feeder dikes. An origin is envisaged through successive, shallow, phreatomagmatic eruptions and emplacement as fluidized breccias. Silicification and sericitization, which predate and postdate emplacement of the breccias are described by Gibson and Watkinson (1979) and Lesher et al. (1986).

Stratigraphy of Buttercup Hill

The Amulet formation, upper member, is the basal stratigraphic unit exposed at Buttercup Hill. The upper member consists of variably silicified, andesitic flows. The Millenbach Andesite formation conformably overlies the Amulet upper member from which it is separated by the "C" Contact Tuff, a thin, plane-bedded deposit of ash and chert (Gibson 1989). The Millenbach Andesite formation consists of massive and pillowed andesitic flows and, near its base, local deposits of breccia as at Buttercup Hill (Gibson et al. 1989).

Amulet Formation, Upper Member

A green to white-weathering, plagioclase-porphyritic and amygdaloidal, silicified, andesitic flow of the Amulet upper member forms the base of the Buttercup Hill section. This flow is identical to others of the upper member and consists of massive columnar jointed andesite, overlain by a lobe and chloritized, vitrophyric flow-breccia facies (Gibson 1989).

Thick, massive and compound flows of the upper member are interpreted to be products of a brief, voluminous eruption

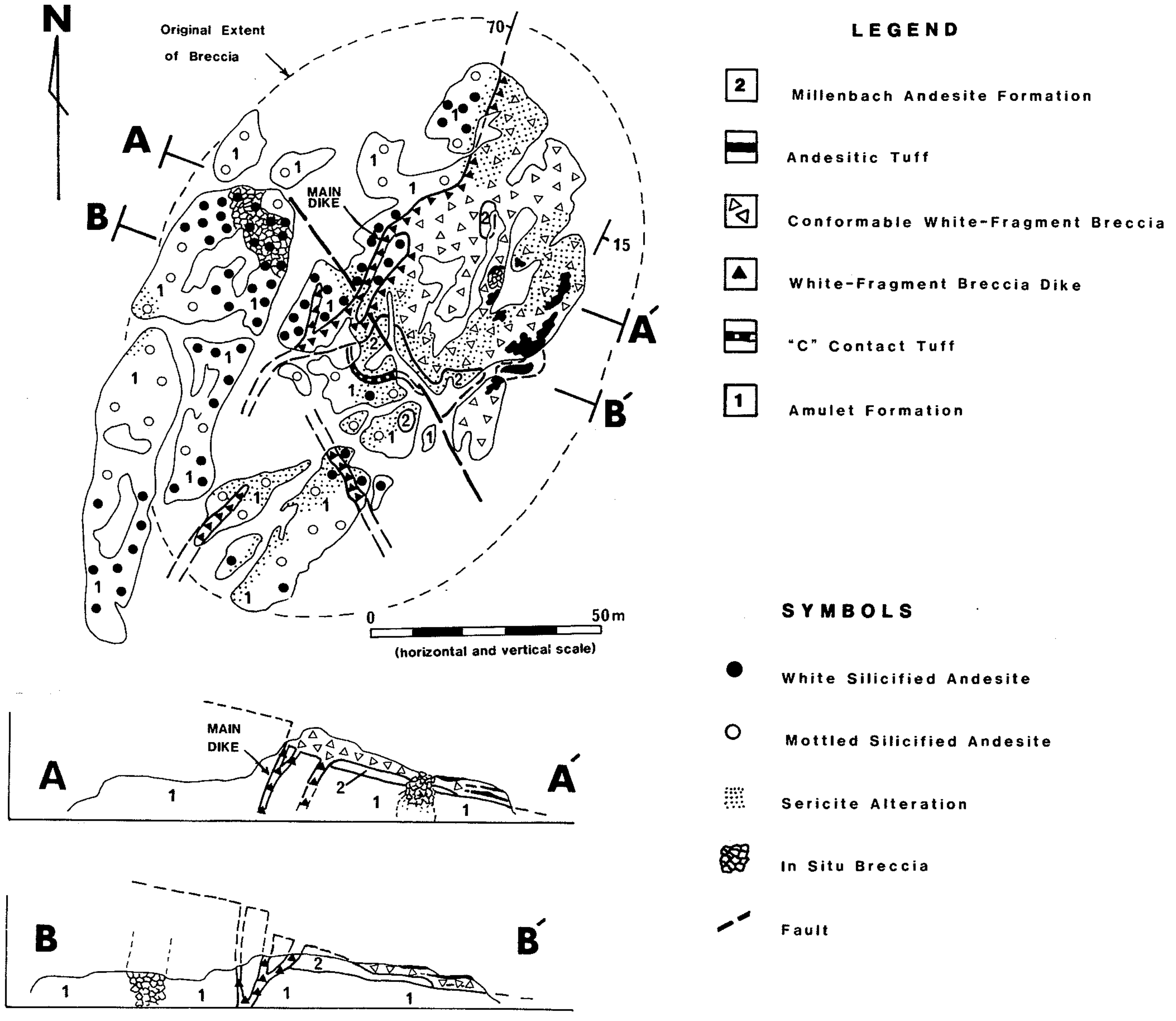


Figure 8. Geological map of Buttercup Hill area (Stop 3) and location of sections from Gibson (1989) and Gibson et al. (1989).

(approximately 40 km^3) that inundated underlying rhyolite (lower member) and resulted in a relatively flat and horizontal paleosurface (Gibson 1989).

"C" Contact Tuff

Extrusion of the Amulet upper member was followed by a period of quiescence characterized by deposition of fine, waterlain ash and widespread hot-spring activity to form the "C" Contact Tuff, a thin (<20 cm thick) deposit of laminated andesitic ash, grey chert, and pyrite. The tuff is plane bedded and dips shallowly (<10°) to the southeast.

Millenbach Andesite Formation

A rusty, brown-weathering, quartz-amygdaloidal and plagioclase-porphyritic, pillowed, andesitic flow marks the base of the Millenbach Andesite formation and conformably overlies the Amulet upper member and intervening "C" Contact Tuff. The andesitic flow is exposed immediately south of, and in windows through the overlying Buttercup Hill breccia. Contacts between the pillowed flow and overlying breccia are conformable and indicate a dip of <15° to the southeast.

Breccia Dikes

Breccia dikes at Buttercup Hill are identical to other breccia dikes which occur at the top of the Amulet upper member within 2 km of the McDougall-Despina Fault. The Buttercup Hill breccia dikes contain angular, equant, white fragments of silicified andesite in a fine-grained green, andesitic breccia matrix. The breccia dikes cross-cut all map units at Buttercup Hill except for the overlying, conformable breccia into which they merge (Fig. 9). White silicified fragments of the breccia dike and breccia deposit are derived from silicified andesite of the Amulet upper member to which they are identical in texture, mineralogy and composition.

Breccia dikes are chaotic, framework-supported intrusive breccias that contain fragments showing a complete size gradation from <0.1 mm to 0.35 m.

"IN SITU" Breccia Zone

A discordant, narrow (7 m wide X 22 m long), N40°W striking zone of "in situ" breccia cross-cuts silicified andesite northwest of the breccia dikes. "In situ" brecciation affects both lobes within the flow top breccia and underlying massive andesite.

Fragments produced by "in situ" brecciation are identical to fragments within the breccia dikes, overlying breccia and to underlying brecciated, silicified Amulet andesite exposed in "windows" within the breccia. The "in situ" breccia zone is interpreted as the roots of a northwest-trending breccia dike that contributed fragments to the overlying breccia which has subsequently been eroded. This zone of brecciation was also a locus of continued hydrothermal activity as indicated by chlorite alteration and sulphide deposition within the vein network matrix and adjacent fragment margins.

Buttercup Hill Breccia

The Buttercup Hill breccia is a localized (60m x 35m), <1m to 10m thick deposit which rests conformably on a pillowed flow of the Millenbach Andesite aformation and, where the latter is absent, directly on silicified andesite of the Amulet upper member. Although exposures of the breccia are now restricted to areas east of the breccia dikes, the original deposit was likely larger and thicker. Thin, discontinuous lapilli tuff beds separate virtually identical beds of coarse, blocky breccia. In total, the breccia contains five discontinuous depositional units. Fragments within the breccia matrix are identical to those within the breccia dikes.

Isolated "windows" reveal underlying intact and "in situ" brecciated silicified Amulet andesite and Millenbach andesite principally along the eastern edge of the outcrop where the breccia is thinnest. Where andesite within the "windows"

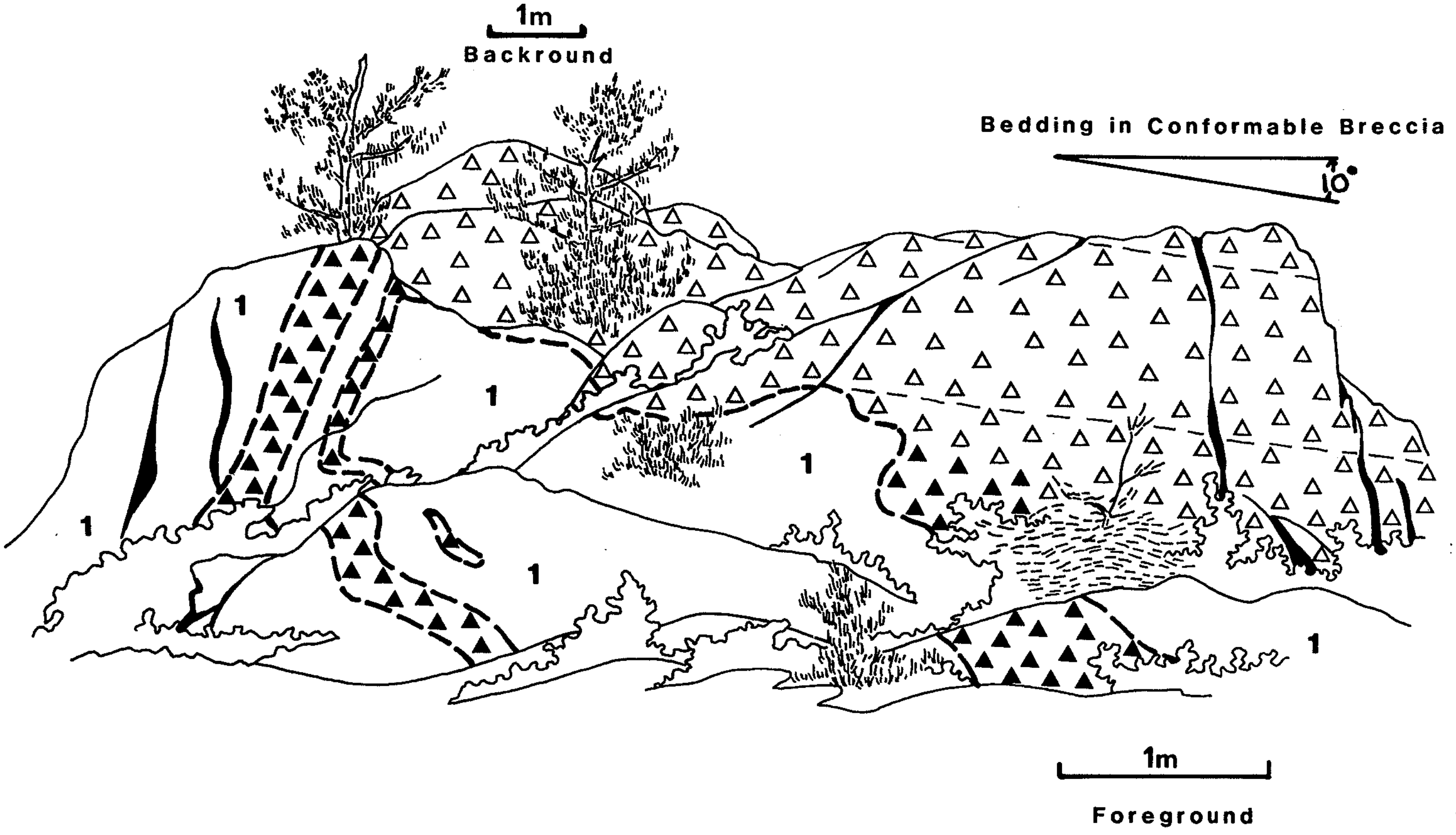


Figure 9. Sketch of the relationships of breccias and dikes on Buttercup Hill by C.D.A. Comba from Gibson (1989) and Gibson et al. (1989).

is intact, sharp contacts with the breccia are common and often marked by thin beds of laminated ash. Where andesite exposed within the "windows", is brecciated, fragments of silicified andesite or Millenbach andesite show every stage of separation and incorporation into the adjacent breccia. This gradational relationship between the breccia and "in situ" brecciated, shattered, underlying units indicates that fragments were not all emplaced via breccia dikes but that underlying units contributed directly to the overlying breccia.

STOP 4 MOOSEHEAD MASSIVE SULPHIDE OCCURRENCE

The C-Contact tuff marks the contact between the Upper Amulet member and the overlying Millenbach andesite. The C-Contact tuff is a pyritic ash tuff or "exhalite" that persists for a strike length of 8 km overlying the Upper Amulet member. Along this time-stratigraphic unit massive sulphides were mined from the Amulet F and C orebodies.

The unit at Moosehead Showing (Fig. 10) consists of massive and laminated pyrite and sphalerite with some andesitic ash tuff. At this location the exhalite is very irregular. Drilling 50 m to the south intersected few sulphides and only a narrow pyritic tuff. Trenching to the west along the base of the outcrop indicated a small lens of massive sulphide.

Underlying the C-Contact tuff, the Upper Amulet member outcrops a few metres to the northwest. The footwall volcanic rocks are spotted; this is the result of contact metamorphism of altered rocks by the Dufault pluton. Cordierite porphyroblasts having been retrogressed to chlorite, sericite and epidote. Pyrite is disseminated (up to 5%) and within quartz-epidote fractures.

The Millenbach andesite overlies the C-Contact tuff and outcrops to the southwest. The flows are basalt to basaltic andesite and consist of massive, pillowed and pillow-breccia flows. Pillow tubes are exposed on the southwest flank of the outcrop. The volcanic flows strike southeast and dip 30-40° to the east. Numerous fine grained mafic dykes cut southwest across the outcrop.

The dominant alteration mineral is chlorite up to 15% in pillow selvages and the more massive parts of the flows. In pillow selvages, vesicules or in fractures, a quartz-biotite-epidote assemblage is present. This fracture filling assemblage with the characteristically bleached margins is commonly referred to as "grid alteration".

STOP 5: AMULET C-OREBODY AND C-CONTACT EXHALATIVE TUFF

This stop is located 0.5 km south of the Bedford road (Fig. 4); park where the haulage road branches and climb the hill to the glory hole.

Continue east along haulage road for 0.3 km and park alongside large outcrop adjacent to, and south of the road. Walk 60 m south of the haulage road along the old mine road.

STOP 6: MAIN CONTACT EXHALATIVE TUFF - BLUFF EXPOSURE

The Main Contact exhalative tuff is a siliceous ash tuff marking the contact between the Millenbach Andesite and the overlying Amulet andesite. The thin to thickly laminated tuff contains 5% pyrite and lies approximately 70 m up-dip from the Bluff orebody and 450 m up dip from the Lower Amulet A orebody (Fig. 7). The Main Contact Tuff is not as extensive as the C-Contact Tuff; however, more ore has been produced from the Main Contact Tuff unit.

On leaving Stop 6 and 300 m along the haulage road to the east, note the well developed columnar jointing in the Amulet andesite.

DAY 2 STOP 1A: ANSIL MINE

The Ansil Mine of Minnova Inc. is about 12 km north of Rouyn-Noranda (Fig. 3). Production began in 1989 on reserves of 1.58 million tonnes grading 7.2 %Cu, 0.9 %Zn, 26.5 g/t Ag

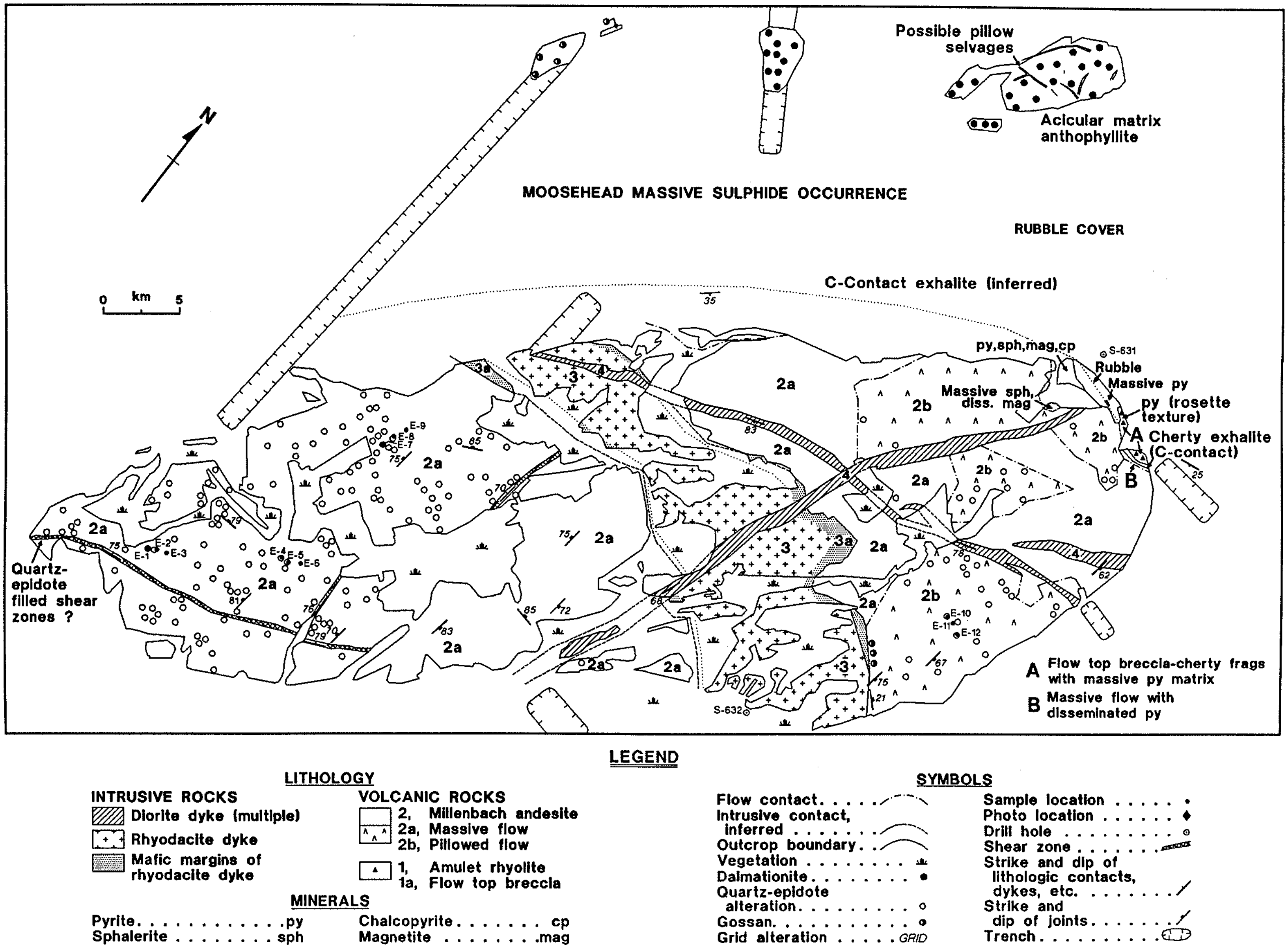


Figure 10. Geology of the Moosehead massive sulphide occurrence by T. Smith (Stop 4).

and 1.6 g/t Au (Riverin et al. 1990). The ore body consists of a massive sulphide lens at the upper contact of rhyolite of the Northwest formation and is overlain and partly enclosed by andesitic flows of the Rusty Ridge formation. Two pipe-like stringer zones characterized by chloritized rhyolite and mantled by diffuse, sericitized rhyolite underlie the main Cu-rich orebody. These merge at depth and have been traced downward 400m where the plunge changes to reflect a nearly original, horizontal conduit. Much of the stringer zone is stratabound. Massive sulphides comprise two thick, mound-like bodies that are connected by a thinner central part. Massive magnetite underlies and in part replaces massive sulphides and volcanic rocks of the deeper domal massive sulfide.

The rhyolitic rocks underlying and along strike from the Ansil deposit are parts of the Northwest formation; these rhyolitic rocks were erupted as flows and in their upper and distal parts as siliceous (exhalative) tuff, the Lewis tuff, and crystal tuff, related to the Cranston quartz-feldspar porphyritic rhyolite. The latter may be pyroclastic or debris from the submarine erosion of rhyolite domes; it interfingers with Ansil ore (Fig. 11).

Massive to pillowed andesitic flows of the Rusty Ridge formation overlie the tuffs and massive sulphide deposit, although one flow underlies one corner of the deposit. Cu-rich stringers with attendant stockwork-type alteration extend above the Ansil orebody; these have been traced as much as 300 m above the massive ore where they are characterized by veins and interpillow and vesicle fillings.

Riverin et al. (1990) envisage a very long-lived hydrothermal system that produced not only the typical Noranda-type massive sulphide deposit, but also the magnetite-rich rocks that invaded the lower part of one segment of the deposit, and the extensive alteration and Cu-rich sulphides in the hangingwall of the deposit. They attribute many of these features to high temperatures attained when the hydrothermal system was insulated from the modifying effects of seawater by a thick accumulation of andesite of the Rusty Ridge formation penecontemporaneous with the accumulation of the massive sulphide deposit.

STOP 1B: MOBRUN MINE

The Mobrun Mine of Ressources Audrey Inc. is located in Dufresnoy Township, 30 km to the northeast of Rouyn-Noranda (Fig. 3). It occurs in volcanic rocks of the Fifth Cycle (Spence and de Rosen Spence 1975), apparently in post-cauldron units (Gibson and Watkinson, 1990). The mine consists of two main lenses; the MAIN LENS (3.3 million tonnes of which 1.523 are economic at a grade of 0.80 %Cu, 2.44 %Zn, 30.19 g/t Ag, 2.2 g/t Au) was initially mined by open-pit, and the 1100 Lens, now under development, which contains 15 million tonnes of sulphides of which 10.4 are economic grading 0.76 %Cu, 5.43 %Zn, 37.4 g/t Ag and 1.35 g/t Au (Bouchard 1990).

Geological mapping (Fig. 12; MacRobbie and Watkinson 1990) of the Main Lens before open pit development revealed the stratigraphic footwall to consist of:

a) an intensely fractured and veined massive homogeneous felsic ash tuff >30 m in thickness.

b) an overlying <10 m thick sulphide-rich breccia below the Main Lens, which is restricted to the flanks of the orebody. The 7-35 m thick Main Lens was exposed over a 200 m strike length. The massive sulphide rock consists of fine-grained masses of recrystallized, brecciated, and locally colloform pyrite in a siliceous gangue. Minor disseminated chalcopyrite and whispy sphalerite aggregates are interstitial to pyrite. Nodular forms of radial fine-grained pyrite are present. Chalcopyrite is most abundant near the base of the thickest part of the lens, occurring interstitial to pyrite and as crosscutting chalcopyrite-pyrite-quartz-calcite veins. Vague banding is defined by fine-grained sphalerite, pyrite and minor

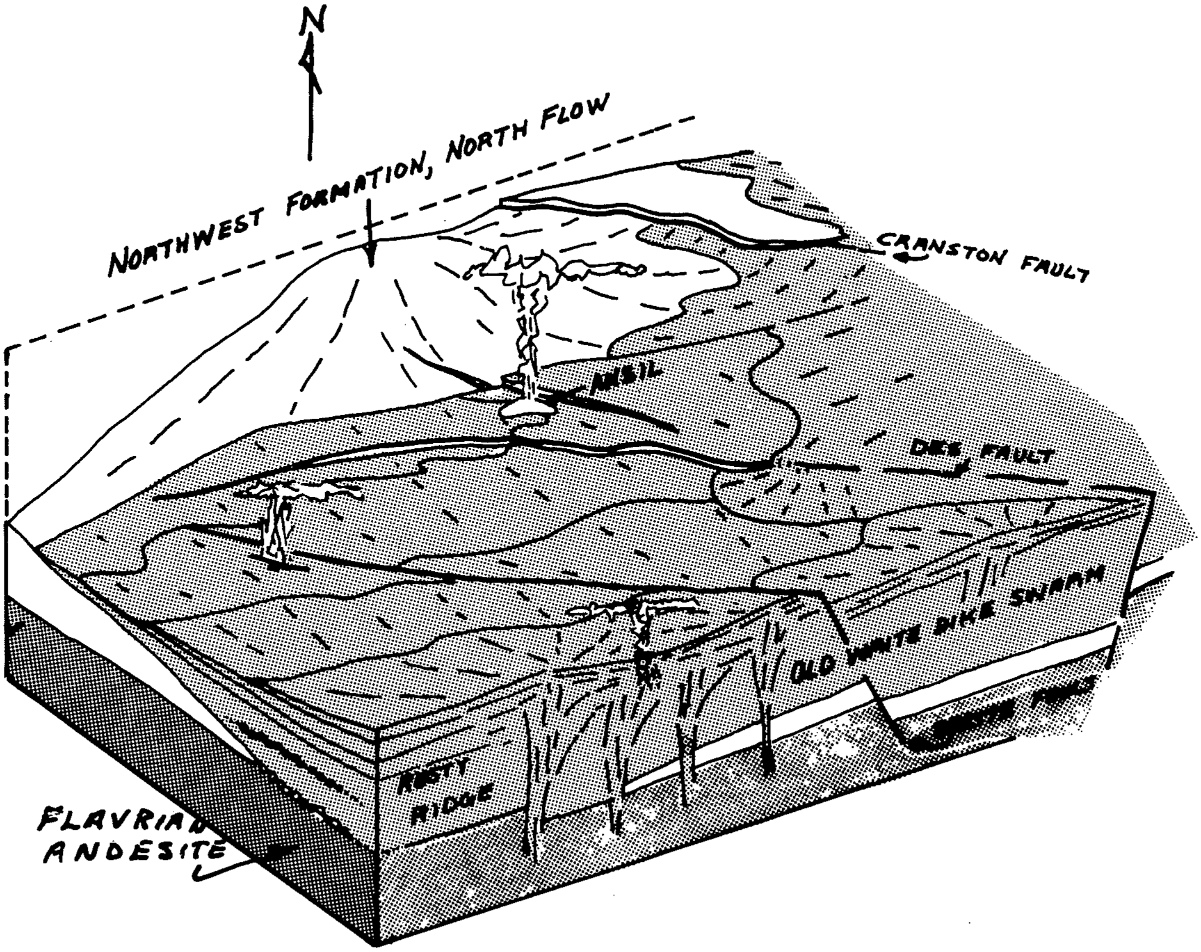


Figure 11. Cartoon of the volcanological environment of the Ansil Mine after Gibson (1989).

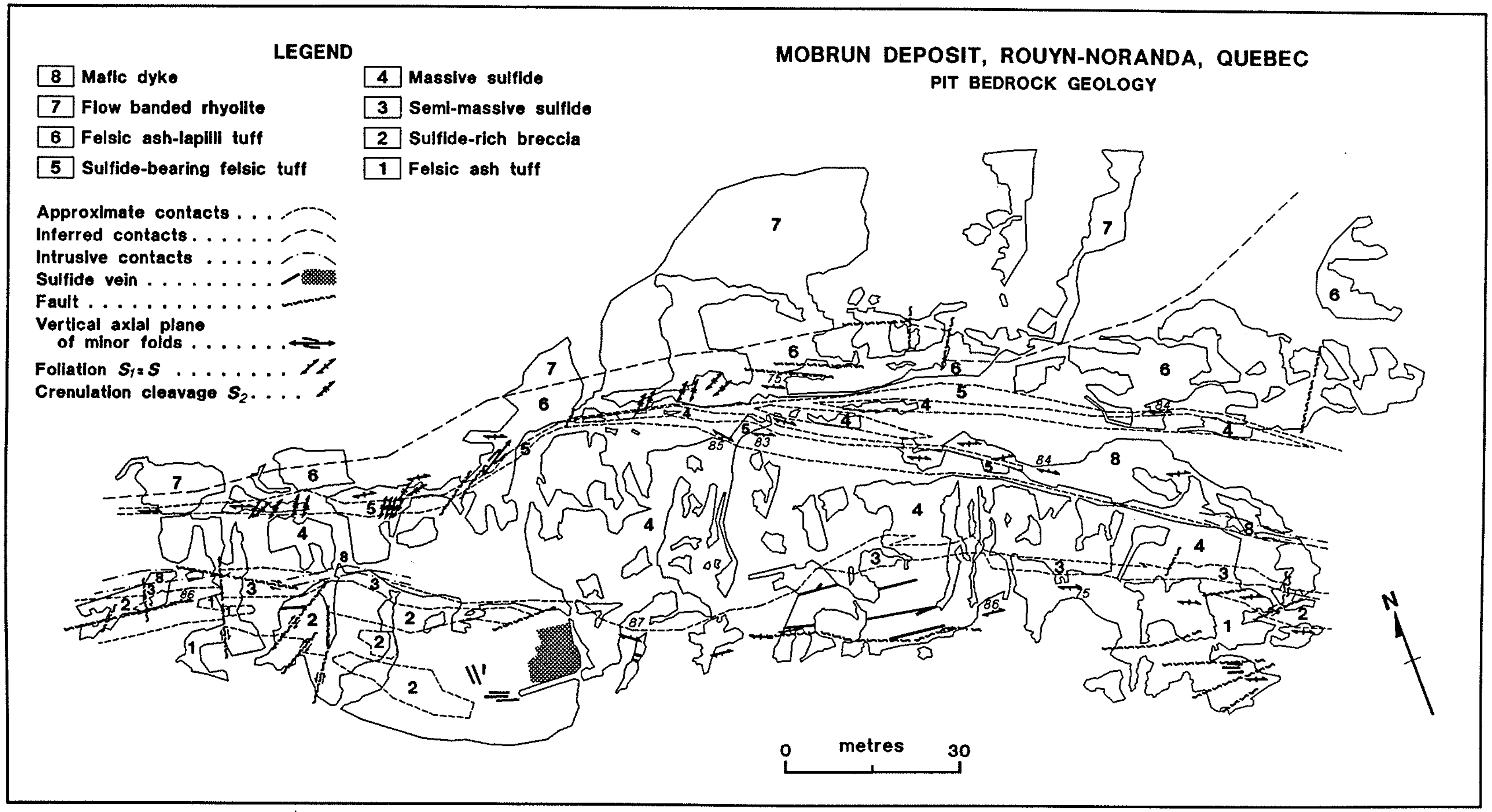


Figure 12. Geology of the pit area, Main Lens, Mobrun Mine, by P. MacRobbie (MacRobbie and Watkinson 1990).

chalcopyrite. A semi-massive sulphide rock containing 10-40% lithic fragments occurs at the base of the Main Lens.

The stratigraphic hangingwall to the Main Lens consists of:

a) a sulphide-bearing felsic ash tuff hosting several stacked massive sulphide lenses found northeast of the Main Lens. Notable is a single occurrence of a thin, discontinuous graphitic shale, with 40% pyrite as disseminations and 1.5-3.0 cm nodules.

b) a 3-40 m thick, medium to dark green, thinly bedded felsic ash-lapilli tuff overlies the sulphide-bearing tuff.

c) an overlying massive flow-banded rhyolite, >30 m thick.

A late, steeply dipping, dark green fine-grained mafic dyke cross cuts the earlier volcanic rocks.

Deposition as a series of hot pyroclastic flows, related to phreatomagmatic explosions is suggested by the presence of partially welded lapilli and spherulite-bearing tuffs. Continued hydrothermal and sporadic volcanic activity resulted in the stacking of three minor sulphide lenses in the sulphide-bearing fine ash tuff.

Hydrothermal alteration of the footwall rocks includes an early stage of strong pervasive silicification and a later stage of vein-related sericitization and minor pyritization and silicification. The footwall rocks at the erosion level of the open pit are not chloritized; however, underground work revealed a small stringer zone with chloritic units and Cu-rich sulphides (Bouchard 1990). The hanging wall strata are characterized by moderate sericitization and weak chloritization, best developed above the thickest part of the orebody. Tuffs between the stacked lenses are weakly chloritized. A late stage, weak carbonatization related to fracture permeability is evident as patchy calcite, vein fillings and replacement of feldspars.

North-south compression has produced a strong foliation parallel to bedding. Minor dextral shearing of less competent tuffs around the rigid sulphide lens produced crenulation cleavage, fault gouges and minor folds which are restricted to the north-west part of the pit adjacent to the Main Lens. Northeast trending conjugate faults with minor displacements are found at both ends of the pit.

The 1100 Lens (Bouchard 1990) is less well known; it is enclosed in a pyroclastic succession with rhyolitic and andesitic flows in the hangingwall. It is older and larger than the Main Lens and its associated satellite lens. Massive ore, composed of brecciated pyrite enclosing shreds and clusters of sphalerite and disseminated, very fine-grained chalcopyrite in the centre grades to sphalerite-rich fringes (with significant Au). This lens has a large stringer zone marked by strongly chloritized, pyritic volcanic rocks and is enriched in chalcopyrite and pyrrhotite.

<u>DAY 2 STOP 2</u>:

THE MINE GALLEN MASSIVE SULPHIDE DEPOSIT

Mine Gallen (formerly known as the West MacDonald deposit), 8 km NE of Rouyn-Noranda, Quebec (Fig. 3), is a pyritic Zn-rich deposit within a block of volcanic strata enclosed by the Lac Dufault granodiorite. Reserves were estimated to be 8.1 million tonnes of 3.36 %Zn, 0.08 %Cu, 2.4 g/t Ag and 0.06 g/t Au (Oeille 1949). Extensive trenching and drilling throughout the 1930s and 1940s resulted in a 5-year underground mining program (900 000 tonnes mined: 1955-59). Open-pit operations resumed in the 1980s and the deposit is currently under active redevelopment for further mining of the remaining ore.

Geological Setting

The lithological and structural setting of Mine Gallen (Fig. 13; McEwen and Watkinson 1982; McEwen 1987; Watkinson et al. 1990)) and other Noranda-area volcanogenic

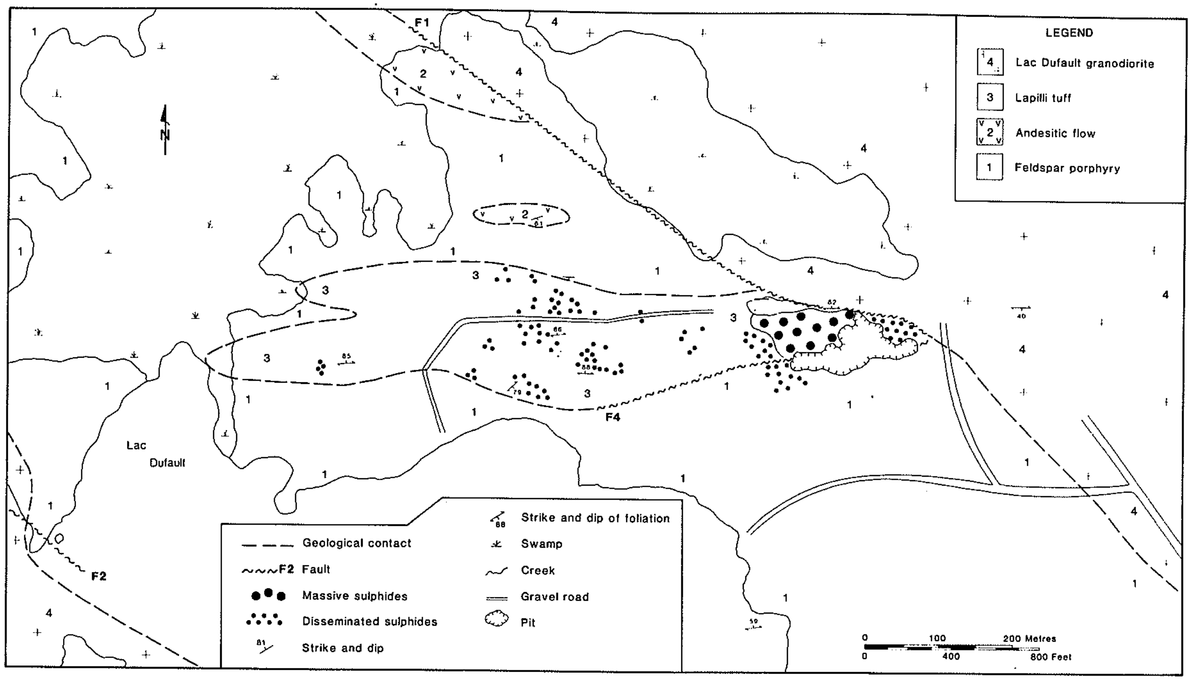


Figure 13. Simplified geological map (after McEwen 1987) of the Gallen open pit area (Watkinson et al. 1990; by permission of CIMM).

massive-sulphide deposits were reviewed by Gibson and Watkinson (1990). Mine Gallen lies within a 1 km by 0.7 km block of volcanic strata which appears to be in fault-contact with the Lac Dufault granodiorite.

Lithologies

The lapilli-tuff ranges from tuff to breccia without systematic variation and is essentially a monolithologic, andesitic unit. The unit is strongly altered with sericite and pyrite contents increasing toward the contact with the orebody. Foliation is defined by sericite and is consistently E-W.

The andesitic flow unit is composed of flows at least 4 m thick. Margins are scoriaceous; centres are massive and aphyric.

A feldspar-porphyritic intrusion cuts strata in the SE area and is intercalated with lapilli-tuff and flows in the N and W (sills 2 to 10 m thick). Adjacent to the orebody, the porphyry is a homogeneous, pervasive sericite and quartz assemblage; disseminated and patchy sulphide assemblages in the porphyry are pyrite-sphalerite-chalcopyrite, sometimes rimmed by chlorite and sericite.

Volcaniclastic debris occurs in the orebody as irregular masses with 1 to 10 mm laminae. Where this is matrix to pyritic blocks, soft-sediment deformational structures and lamina-free sediment are common.

Structural Setting and Deformation

The volcanic rocks enclosing the Gallen orebody are completely enclosed by outcrops of the Lac Dufault granodiorite. The northeastern and western contacts are faulted; other contact relationships are obscure because of insufficient outcrop. Fractures parallel the lineament that is interpreted as a major fault F-1 (Fig. 13). Other major faults are subparallel; F-2 occupies the contact of the western volcanic units and the granodiorite, whereas F-3 is in granodiorite. Fault F-4 is the boundary between massive sulphides and feldspar porphyry.

THE GALLEN OREBODY

The orebody, where exposed by overburden stripping, is a complexly brecciated, massive sulphide lens, 250 x 125 m, composed predominantly of massive pyrite with local sphalerite contents as high as 20 percent. Minor chalcopyrite and galena are also present as disseminations but mainly along cleavage planes. In the east and northeast, lapilli-tuff grades into the orebody with increasing sulphide content and correlative alteration of intense sericitization and weak chloritization. Irregular, anastomosing fractures (1 to 5 cm thick) are filled with pyrite, sphalerite and minor chalcopyrite forming a stockwork in the sulphidic lapilli-tuff. To the west, the orebody strikes into sulphidic lapilli-tuff but the contact area is poorly exposed.

The orebody is intensively and complexly brecciated to form dominantly "fragment-in-fragment" structures. This is made visible by variable grain size of pyrite and by sphalerite banding that define fragment boundaries at all scales.

The overall impression is one of blocky fracturing since sphalerite bands wrap around large to small blocks of massive pyrite. The same blocky fracturing was also accompanied by some 'soft-sediment' deformation; pull-apart textures are common in sphalerite bands that were apparently continuous. Infilling material may be massive sulphides or weakly banded sulphides. Some of the larger blocks are tilted, or show partial rotation that may be due to localized subsidence. This may also have led to deformation of bands.

The Gallen orebody occurs in a fault-bounded block of volcanic rocks, all of which are enclosed by the Lac Dufault granodiorite. Differences in dip and facing direction of the volcanic strata from those external to the granodiorite, and the low metamorphic grade of the alteration assemblage near and under the orebody, are compatible with rotation and transportation of the units after emplacement of the intrusion.

The volcanic rocks are flows, lapilli-tuffs and porphyries which are host to a brecciated massive sulphide body. The porphyritic rocks are subvolcanic intrusions. Sericite, pyrite and minor chlorite characterize altered equivalents of the host rocks. The volcanic rocks are intermediate in chemical composition and alteration is typical of that in other Noranda-area deposits with Na, Ca depletion and K and minor Mg enrichment. There is no strong Mg or Fe enrichment typical of "pipe" alteration.

The orebody consists largely of pyrite and as much as 20 percent sphalerite, with minor chalcopyrite and galena. There is no "stringer" ore, although an area at the footwall contact has some stockwork Cu-bearing sulphides within strongly altered lapilli-tuff. Most ore is a breccia of massive to banded pyrite-sphalerite cemented and healed by massive and complexly banded sulphide matrix and veins. The sulphide deposit grew at the seafloor as a sulphide mound similar to those on the modern seafloor in the Galapagos Rift (Watkinson et al. 1990).

DAY 3 STOP 1: UPPER A GLORY HOLE

The Upper and Lower Amulet A orebodies (Fig. 4) are two stacked massive sulphide lenses that are underlain by an extensive, well developed alteration pipe that plunges 60-70° to the west. The Amulet Upper A orebody was discovered in 1927 and the Amulet Lower A orebody subsequently found in 1938 while testing for more sulphides in the alteration pipe below the Upper A orebody.

The alteration surrounding the Amulet orebodies is distinctive. Below the massive sulphide lenses, there are alteration pipes consisting of chlorite-garnet-magnetite. Sulphide stringers in these pipes are enclosed by a chlorite-anthophyllite-cordierite zone characterized by cordierite-porphyroblasts in a chlorite-biotite-cordierite-anthophyllite groundmass. Outward and away from the pipe, a gradual transition is recognized by an increase in cordierite in a chlorite-biotite groundmass. A diffused halo of quartz-epidote-pyrite alteration extends into the country rock.

The spotted or maculose textures in these volcanic rocks is referred to as 'dalmatianite' or 'spotted dog'. This well developed texture is common to all the massive sulphide deposits in the Waite-Amulet-Millenbach area and may be recognized in areas with no known massive sulphide deposits.

Points of note near the Upper A glory hole are:-

1) An exhalative tuff found on strike from the Upper Amulet A orebody is exposed in a trench along the Corbet Mine road. This is a discontinuous pyritic unit that occurs between pillowed flows of the Amulet Andesite formation.

2) Near the Glory hole there is an excellent view of the Noranda smelter to the south and Minnova's Norbec Mill to the northeast. The low depression occupied by Lac Dufault to the east marks the extent of the Lac Dufault Granodiorite. Well developed dalmatianite is present around the glory hole and faint pillowed margins may be recognized through the intense cordierite spotting. These porphyroblasts are now retrograded to a chlorite-biotite assemblage in a fine-grained hornfels of biotite, chlorite, sericite, anthophyllite and talc.

3) Away from the main pit area the pillowed and massive Amulet Andesite flows are rusty with up to 10% pyrite both disseminated in massive parts of the flows and locally concentrated in pillow selvages. Chlorite and recrystallized quartz are also present in pillow selvages.

DAY 3: STOP 2
F-shaft area alteration pipes

This stop (Fig. 4) is designed to illustrate the volcanic rocks on either side of the "C-contact tuff", and the outcrop of a Cu-rich stringer zone, all of which have been metamorphosed in the contact aureole of Lac Dufault granodioritic intrusion.

Leave the haulage road that overlies the contact of the Lac Dufault granodiorite and walk to the west, climbing over outcrop areas of pillowed and massive flows of the Amulet Andesite and Millenbach Andesite (Fig. 14). There are some small tuff units between flows, and some tuff and pillowed flows are pyritic, indications of the weak hydrothermal system. Continuing to the west we encounter some weakly silicified pillowed flows, and increasing incidence of intrusion of dikes and sills (Fig. 15); this is correlative with increasing proximity of the "C-contact" and the F-Shaft fault.

Crossing the "C-contact" that has been trenched, and that is the stratigraphic equivalent of the mined-out Amulet F deposit, we find an intensely altered rhyolite of the Amulet Formation (upper member). To the west, this unit reveals spotted alteration ("dalmatianite") composed of subhedral patches to euhedral crystals of cordierite. In the vicinity of the pit, the rock is composed of cordierite, quartz and chalcopyrite, representing the core of a stringer zone. This stringer zone plunges to the west, and represents a pipe that fed a massive sulfide deposit now removed by erosion. Drilling in the area has revealed that there may have been many small pipes, at one time connected to a major conduit that fed massive sulphide accumulations.

The cordierite-bearing pipes in the F-shaft area are mineralogically zoned, with cores of cordierite + anthophyllite + Mg-rich chlorite + quartz + chalcopyrite (plus magnetite + pyrrhotite), ranging outward to more biotitic, pyritic and sphalerite-rich assemblages. This is compatible with the assemblages described by Riverin and Hodgson (1983), having been generated during contact metamorphism of chloritic and sericitic alteration zones in the Millenbach Mine.

COBALT SEGMENT

Introduction

The Cobalt silver mining camp (Fig. 16) has produced approximately 500 million ounces (10631 tonnes) of silver from high-grade Ag-Bi-Co-Ni-As veins. The local geology and the ore veins have been described by many workers, including Miller (1913), Knight (1924), Thomson (1957; 1960a, b, c; 1961a, b, c, d) and Berry (1971). The general geology of the Cobalt area has been reviewed by Owsiacki and Lovell (1984), Donaldson and Munro (1982) for Field Trip Guidebooks to the Cobalt area. Much of the pertinent detail on the Cobalt area rocks and silver deposits, however, is the result of many years of mapping by Robert Thomson for the Ontario Department of Mines; his coloured geological maps and preliminary reports provide a wealth of information on the camp. Abundant petrographic and mineralogical data are summarized in a group of papers edited for the Canadian Mineralogist by L.G. Berry (1971). More recent data, especially concerned with the geochemistry and isotopic geochemistry of the silver veins and their immediate host rocks, are found in a special issue of the Canadian Journal of Earth Sciences (1986).

The Cobalt area is underlain predominantly by Precambrian rocks of the Superior and Southern Structural Provinces. A small outlier of Paleozoic strata is exposed at the northern end of Lake Timiskaming (**Fig. 16**).

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, Early Proterozoic sedimentary rocks of the Huronian Supergroup.

Huronian strata are exposed in the northeastern part of the Southern Province termed the Cobalt Embayment.

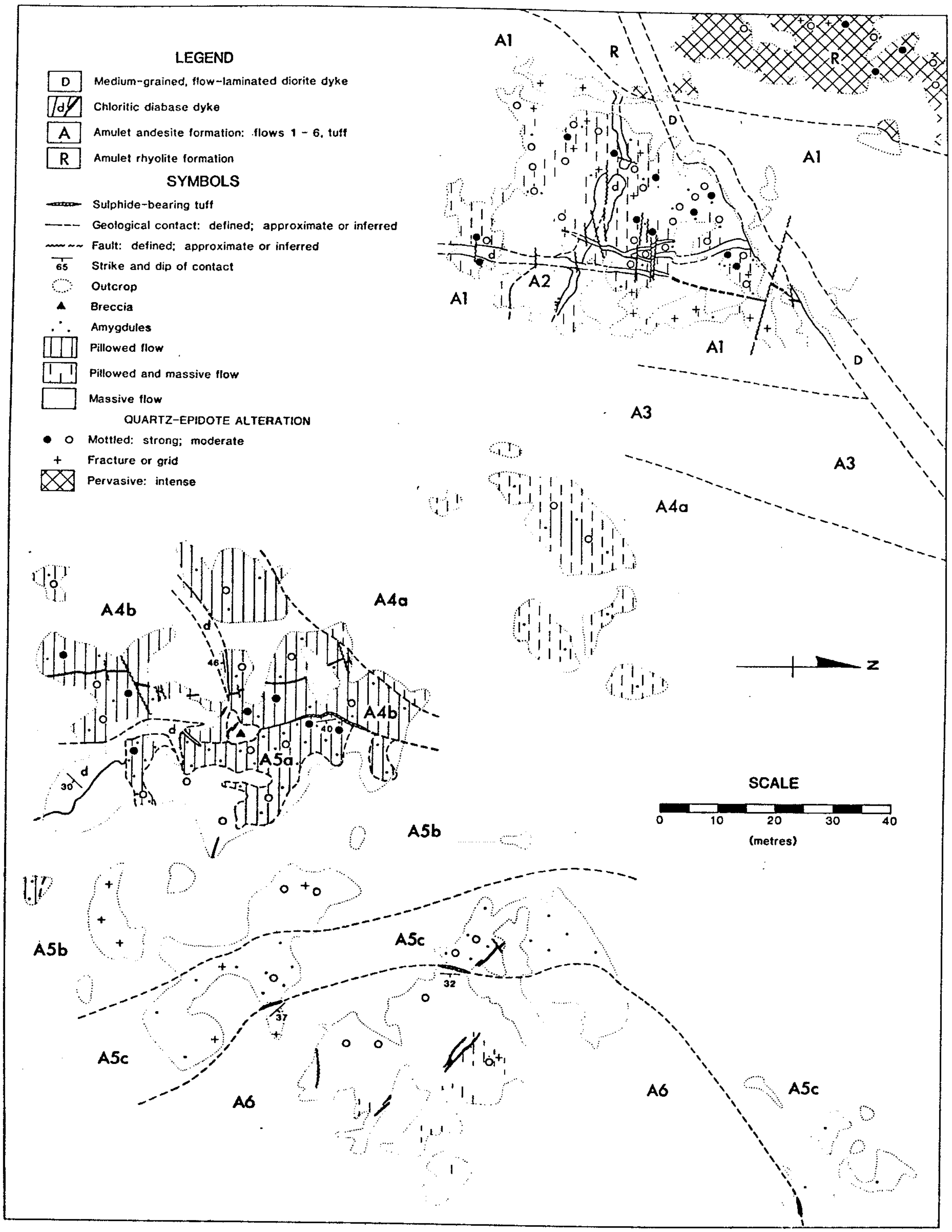


Figure 14. Geological map of volcanic rocks of the Millenbach and Amulet Andesite formations, F-Shaft area (Stop 2, Day three) from Buck (1981).

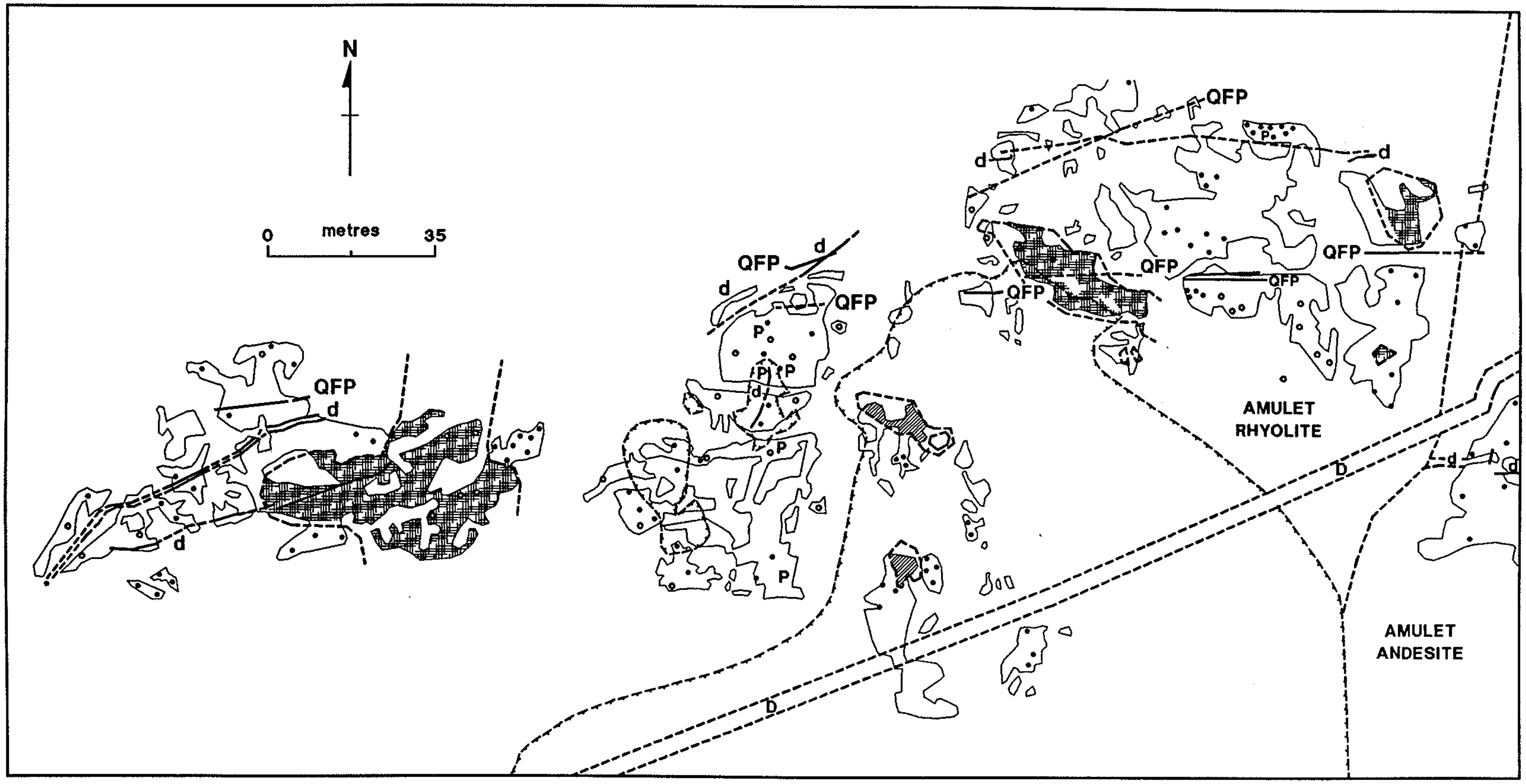


Figure 15. Geological map of part of the upper member, Amulet formation in the F-Shaft area from Buck (1981).

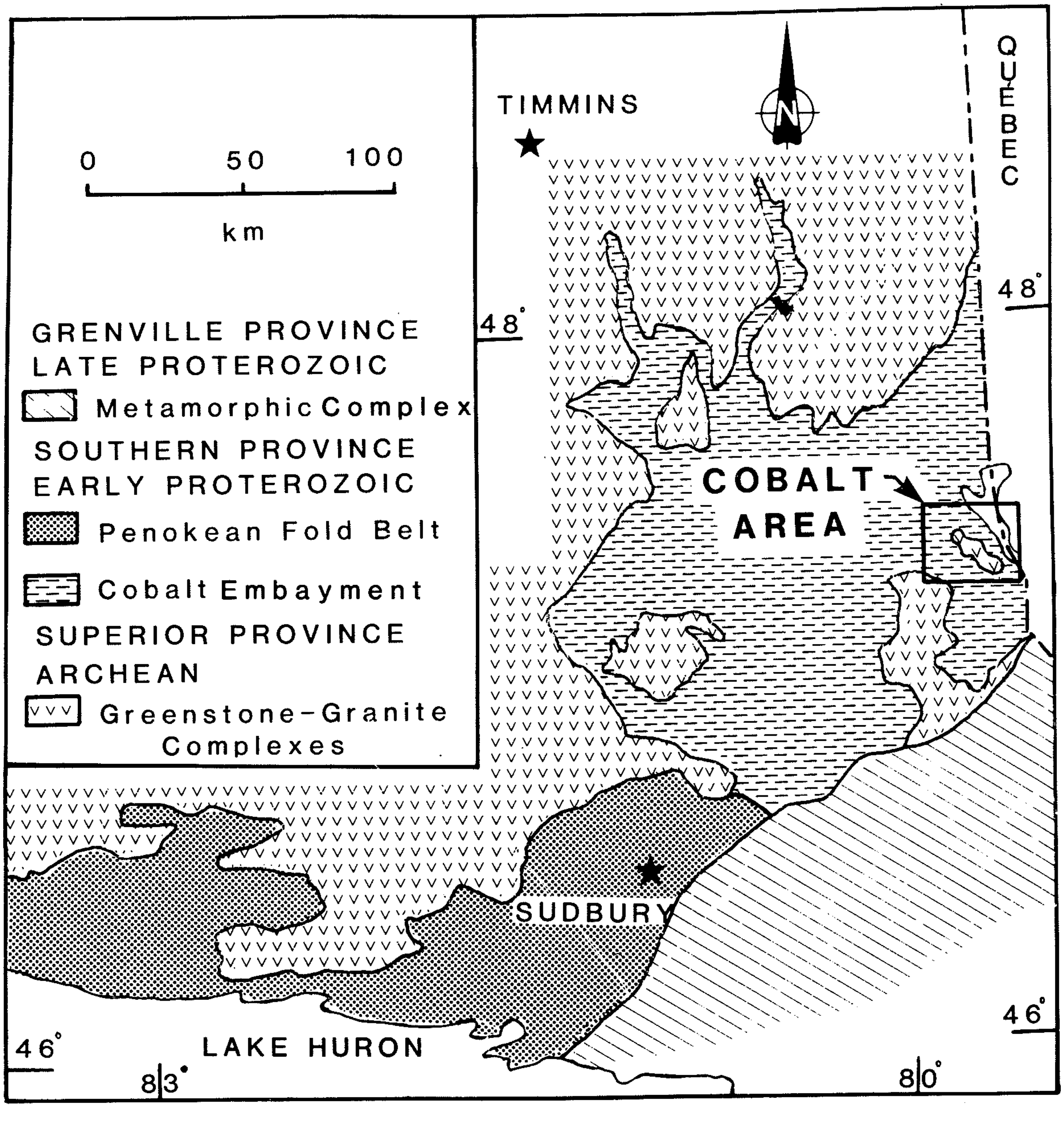


Figure 16. General geology and location of the Cobalt area, Ontario from Goodz (1985).

There is no evidence that the embayment is a separate 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. 1986) in the Gowganda area.

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

Six silver producing areas occur along the north and east margins of the Proterozoic succession, predominantly of the Cobalt group which represents a basinal structure. The Cobalt camp is the richest and most important of these areas.

Archean rocks

Archean rocks are exposed as inliers within the surrounding Proterozoic strata. The basement topography was extremely irregular with relief as much as 1000 m. The oldest rocks are composed of andesitic to basaltic volcanic rocks, interflow sedimentary, and minor volcaniclastic rocks. The volcanic rocks are primarily fine-grained, green, massive and pillowed flows. Pillows are usually well preserved and commonly contain 1-2% sulphides in the selvages. The Archean volcanic succession consists primarily of tholeiitic, massive to pillowed andesitic flows with associated autoclastic and hyaloclastic units. Rhyodacitic tuffs and quartz-feldspar porphyry comprise a very minor part of the succession. Conformable volcanogenic and epiclastic interflow sedimentary rocks (ISR) commonly delineate flow units (Fig. 17; Smyk 1987; Smyk and Watkinson 1990). Interflow sedimentary rocks usually occur as thin (<40 m thick) units intercalated with volcanic flows. Despite their relative paucity in many areas, they commonly are laterally continuous over several hundred metres. Accumulations up to 400 m thick occur near the northern end of Sasaginaga Lake, around Clear Lake and at the southwest end of Cross Lake. Contacts with the enclosing volcanic rocks are usually distinct. Facies interpretation based on sedimentological and field relationships indicate that most ISR are turbidites.

Local strata apparently reflect successive, cyclical, submarine extrusive and sedimentation events. Original stratigraphic relationships and lateral continuity were modified by turbidite scouring of unconsolidated volcanic fragmental, exhalative and/or pelagic deposits and the resultant juxtaposition of turbidites upon these units. The close spatial association between ISR and volcanic rocks, the predominance of volcanic detritus and the presence of resedimented volcaniclastic units suggest that sedimentation and volcanism were in part contemporaneous.

One of the most noteworthy features of the Archean volcanic-sedimentary rocks in the Cobalt area is the abundance of sulphide deposits. Patterson (1979) reported that 68 of 74 local silver mines entered base metal sulphide-rich Archean volcano-sedimentary rocks. Sulphides occur in lenses and layers in tuffs and cherts and at flow contacts, as matrix infillings in pyroclastic and autoclastic breccias, in pillow selvages and interpillow spaces, and as disseminated grains, fracture fillings and stockwork zones in mafic to intermediate flows. Closely associated silicification, chloritization and minor carbonatization are considered to be synvolcanic, hydrothermal alteration features (Dillon-Leitch 1980; MacRobbie 1986).

Syngenetic sphalerite, chalcopyrite, pyrite, pyrrhotite and galena typically occur as disseminated grains to massive, stratiform bodies intercalated with

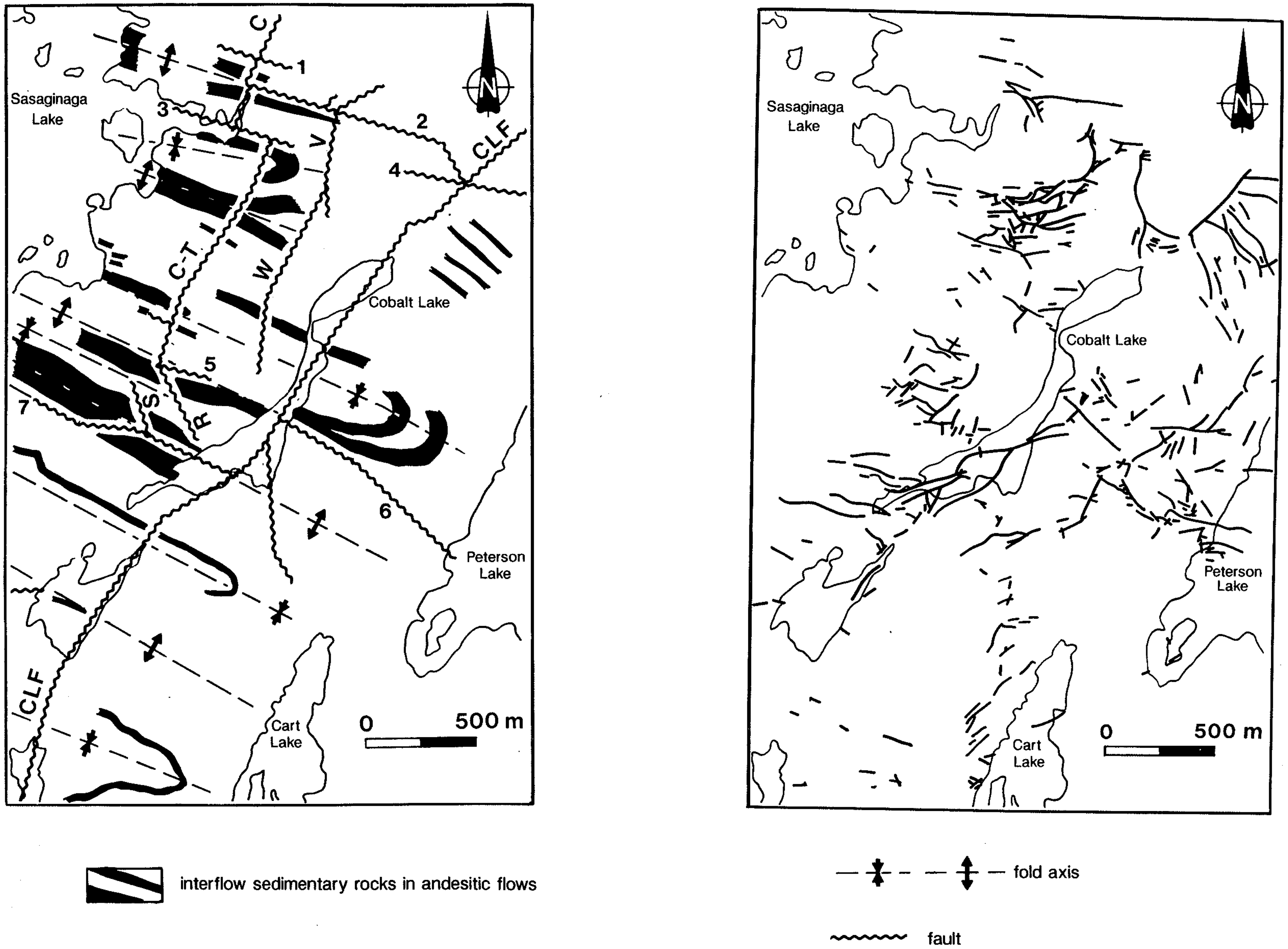


Figure 17. a. Archean geology and b. locations of silver veins in the area of the Cobalt townsite from Smyk (1987) and Smyk and Watkinson (1990).

chert and other ISR in close association with base metal sulphide deposits in the enclosing volcanic rocks. Chlorite, predominantly prochlorite and pycnochlorite, is invariably intergrown with sulphides. Fe-sulphide-rich shales have been the focus of some interest in the past because they have been found in spatial association with silver veins. The pyrite and marcasite take on a variety of shapes, including: banded to colloform, lenticular to reniform and nodular to botryoidal.

Within local volcano-sedimentary rocks, textures and fabrics have been developed as the result of metamorphic recrystallization, deformation and the replacement and mobilization of pre-existing sulphides. Recrystallization is manifested as changes in mineral morphology and grain size. Basement sulphides are pervasively annealed, displaying granoblastic polygonal mosaic textures which may be used to distinguish them from vein sulphides (e.g. Goodz et al. 1986b). Porphyroblasts of arsenopyrite, pyrite and magnetite occur in foliated rocks, commonly developing caries and sieve textures with inclusions.

Deformational textures, such as brittle fracturing, brecciation and cataclasis, are commonly displayed by pyrite. Boudins and sulphide schlieren occur in zones of flattening or shearing. Quartz-filled strain shadows develop on pyrite nodules. Chalcopyrite may display deformation twinning and undulose extinction.

Interflow sedimentary units occur between flows and range up to 100m in thickness. Individual bands may contain a combination of chemically precipitated (exhalative) cherts rich in pyrite, pyrrhotite, carbonaceous material, sphalerite, galena and chalcopyrite, and clastic sediments including laminated siltstone and massive to thick-bedded wacke and tuff.

Timiskaming-type clastic sedimentary rocks underlie much of the area immediately north of Cobalt. Steeply dipping beds of conglomerate, lithic sandstone and minor argillite and greywacke are moderately sorted and extensively crossbedded. The stratigraphic relationship to the volcanics is obscure, as is the case in many parts of the Shield.

Both volcanic and sedimentary rocks were intruded by large granitic plutons. Mafic, ultramafic and felsic dikes were emplaced both before and after this event.

Proterozoic rocks

Sedimentation during the Proterozoic was preceded and followed by lengthy periods of erosion. In the Cobalt area, only the Gowganda and Lorrain Formations of the Cobalt Group are preserved. The Gowganda Formation has locally been divided into two Members; the Coleman and Firstbrook. The Coleman Member consists of diamictite or mixtite sheets which are intercalated with lesser volumes of sandstone, thinly laminated siltstone and argillite. These sedimentary rocks display a variety of features indicative of glacial origin (Rainbird, 1980). The Firstbrook Member is composed predominantly of thinly laminated maroon and green argillite and siltstone.

Firstbrook sedimentary rocks grade rapidly upward through a transition zone of wackes and quartz arenites (Owsiacki, 1982) to an extremely thick sequence of arkose. These arkoses are commonly cross-bedded and make up the bulk of the Lorrain Formation.

Nipissing diabase was intruded at about 2219 Ma predominantly as extensive sheets (sills, cone sheets and dikes). Where intruded as a sill, the diabase takes the shape of basins and domes (Petruk et al. 1972).

The diabase, in sheet form, maintains a relatively uniform thickness of 300-355 m. In all instances the sheets are differentiated into relatively consistent zones (Hriskevich 1968). Both top and bottom exhibit narrow (<10 cm), bleached margins which bound fine-grained quartz diabase. The lower quartz diabase is transitional upward into a zone of medium-grained, massive hypersthene diabase. This zone in turn grades upward to varied texture diabase. The latter is characterized by irregular volumes of pegmatitic material in a matrix of similar composition (Owsiacki 1982) and may comprise the upper third of the sill. Granophyric diabase, granophyre and aplite commonly occur in this part of the sill.

Debate has raged for over eighty years as to the origin of the silver veins and their metal source. As discussed by Jambor (1971b) the main genetic theories involved: (1) a deep-seated, parental magma source, (2) distillation of metals from Archean rocks initiated by Nipissing diabase intrusion, and (3) a direct Nipissing diabase source. Based on the close spatial and temporal relationship between the diabase and the silver veins, it has been widely acknowledged that the diabase provided favourable sites of structural permeability for vein formation and served as a heat source for Proterozoic formation brines to create a hydrothermal system which mobilized metals from all rock types. However, a genetic link between diabase and veins remains unresolved.

The strong spatial association of Archean strata and Proterozoic silver veins was initially attributed to structural factors (Miller 1913; Knight 1924). The development of isoclinal folds and parallel, steeply dipping faults has strongly influenced the distribution of silver veins (Fig. 17). Knight (1924) described veins occurring within these faults and within interflow sedimentary rocks parallel to them. Thomson (1961a) regarded the position of interflow sedimentary units to be the most important factor in determining the location of vein sets. Smyk (1987) has listed 42 mining properties on which veins and faults are spatially associated with interflow sedimentary rocks. Nichols (1988) has listed approximately 50 veins which are subparallel to the strike of Archean rocks.

STRUCTURAL GEOLOGY

The volcanic-sedimentary succession was deformed into steeply plunging, tight to isoclinal folds (Thomson 1961b, Smyk and Watkinson 1990). In the area around the town of Cobalt, these folds have northwest-trending axes (Fig. 17).

Foliation is commonly developed in pelitic sedimentary rocks and is axial planar to minor folds. Planes of bedding transposition have developed in wackes. Steeply dipping faults have developed parallel to the folded limbs, predominantly within narrow interflow sedimentary units and along contacts with the enclosing volcanic rocks. Ductile shear zones display boudinage, shear banding, schistosity and passive rotation of early planar features. Lamprophyre and other mafic dykes may delineate zones of faulting and shearing.

Some northwest-trending faults in the area extend for hundreds of kilometres. Lovell and Caine (1970) interpreted the faults as part of a major rift valley centred on Lake Temiskaming. Displaced blocks of Paleozoic sedimentary rocks provide evidence for Post-Silurian movement. A weaker, northeast-trending set of faults is also developed over a broad area. These structures are cross-cut in places by silver-bearing ore veins (Jambor, 1971a).

All silver veins occur in small faults, fissures and joints which may be related to major faults (Petruk 1971; Wilson 1985). The localization of ore in shoots is apparently related to structures such as a major unconformity, faults, and geologic contacts (Fig. 17 and 18).

The data of Smyk and Watkinson (1990) compatible with sulphide remobilization from Archean rocks into Proterozoic, vein-bearing structures, presumably during a tectonic event which pre-dated and/or accompanied the development of the veins. Sulphide remobilization was accompanied by sulphide deposition and replacement in permeable Archean and Proterozoic rocks. Wilson (1986) has noted mineralogic, textural and

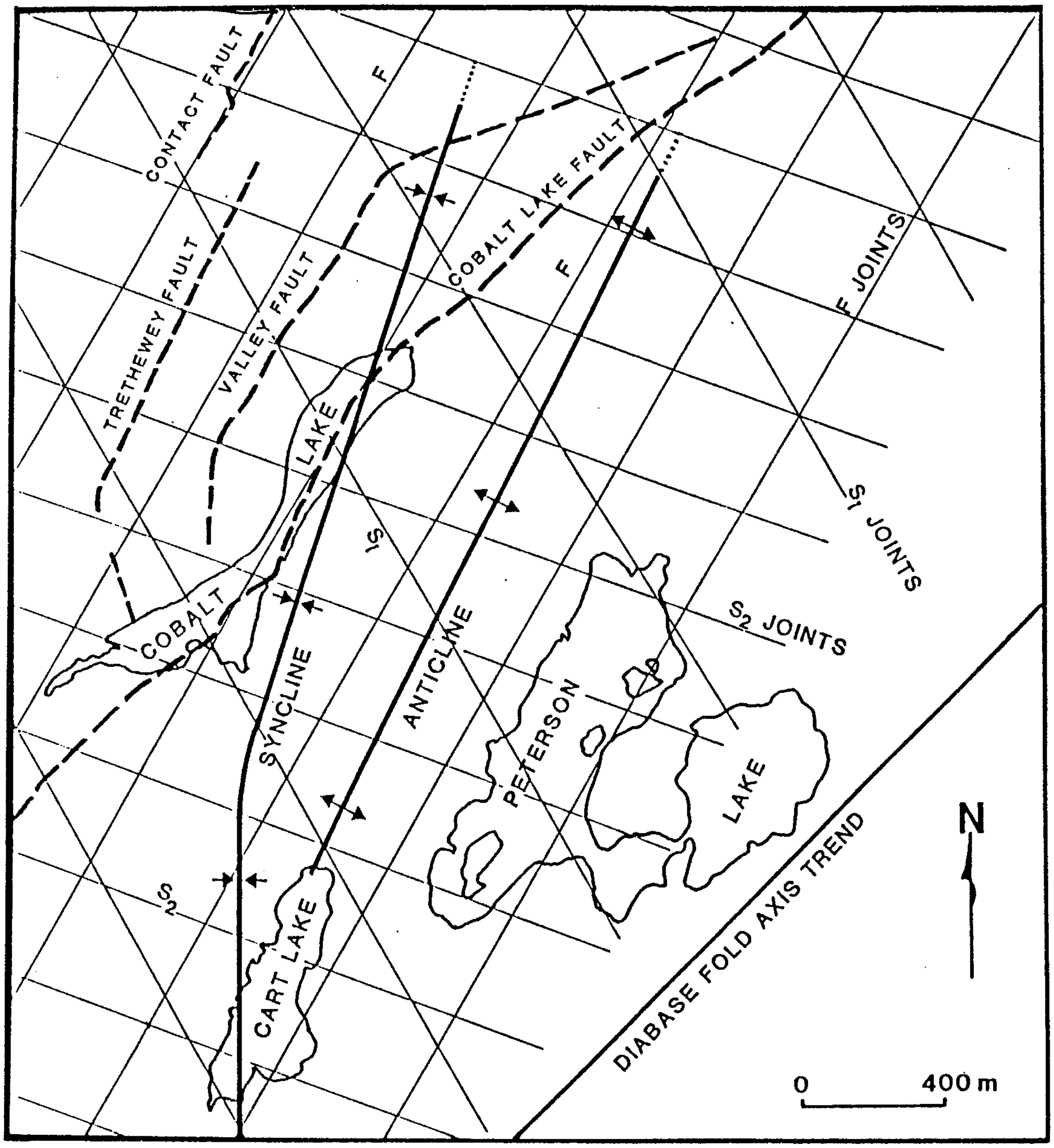


Figure 18. General structures in the Proterozoic rocks of the Cobalt area from Wilson (1986).

S-isotopic similarities between these sulphides in Archean rocks and those in the Proterozoic sedimentary rocks. Pb-isotopic data (Thorpe et al. 1986) offer no definite source for vein metals and infer a post-vein remobilization event. Pre-existing basement sulphides may have contributed sulphur, base metal and perhaps Co, Ni and As, as proposed by Goodz et al. (1986a,b) and Watkinson (1986).

DAY 4: STOP 2 VEIN 65 SULPHIDES AND NIPISSING HILL

From the discovery site of silver veins in the Cobalt area (Fig. 19), drive south on the Coleman Road to the third turn off to the right. Walk along the road to a small clearing beyond the power line where the mafic volcanic rocks of Archean age outcrop. Examine a trench of vertically dipping Cu-Zn-Pb sulphide minerals. This is known as Vein 65 (Fig. 20), and is regarded by some geologists as a sulphide-rich extension of typical silver veins. In fact, this, as are many other occurrences of sulphides in the Cobalt mining camp, is on strike with, and probably was overlain by a vertical Ag vein. This type of sulphide occurrence is reinterpreted as volcanogenic massive sulphide in the amassive and pillowed volcanics of the Archean (Watkinson 1983). Many of these sulphide units are enclosed or grade into tuff and siliceous sedimentary rock of the Archean (interflow sedimentary rocks; Smyk and Watkinson 1990).

Continue toward the southwest, crossing pillowed volcanic rocks, more-or-less chlorite-spotted, until the Proterozoic conglomeratic rocks are traversed. Examine the unconformity between Archean massive and pillowed volcanic rocks and lamprophyric dike and the overlying, subhorizontal basal breccia and mixtite rocks of the Coleman member, Gowganda Formation. Follow the unconformity across the tailings area, noting a small quartz-feldspar porphyritic unit in the Archean, and examine the Archean volcanic and sedimentary rocks of Nipissing Hill (Fig. 21). Younging directions are quite clearly different in this area, than at the earlier part of the stop. Examine the basal breccia and Coleman units just above the unconformity. The Archean and Proterozoic rocks exposed on Nipissing Hill are variably altered (spotted) because of their proximity to the contact with the Nipissing Diabase (eroded, but presumably was just above the present erosion surface). It is also possible that the intensity of alteration could reflect the degree to which the volcanic rocks just beneath the unconformity had been weathered prior to the early Proterozoic sedimentation.

DAY 5: GOWGANDA FORMATION (COLEMAN MEMBER) AND NIPISSING DIABASE

At this stop (Fig. 19) we will examine the intrusive contact of Nipissing diabase with conglomeratic rocks of the Coleman Member of the Gowganda Formation. Conglomerate at this outcrop contains interbeds and lenses of wacke and mudstone. The flat outcrop surface is essentially a bedding surface where differential erosion reveals minor draping of muddy units over large boulders of a variety of rock types including granitic rocks (some massive, some gneissic, some rapakivi-textured), volcanic and metavolcanic rocks and Temiskaming-type sedimentary rocks. Many boulders are fractured possibly as a result of frost shattering (Donaldson and Munro 1982). Dips in the area vary from horizontal to about 15 degrees with proximity to the diabase contact. The contact itself dips rather conformably (approximately 20 degrees to the southeast).

The diabase is very fine-grained at the contact, but because of the faulting that has occurred at the stop site, the diabase is chloritic. Across the road, the diabase is fine- to medium-grained and cylindrical joints (Eakins 1961) are apparent that represent spiral jointing splays from some rectilinear joint sets. In some areas near Gowganda, these tangential, rectilinear joints have potential for silver deposits. Some of these are filled with quartz, chlorite and carbonate minerals, and some reflect the occurrence of potential silver-

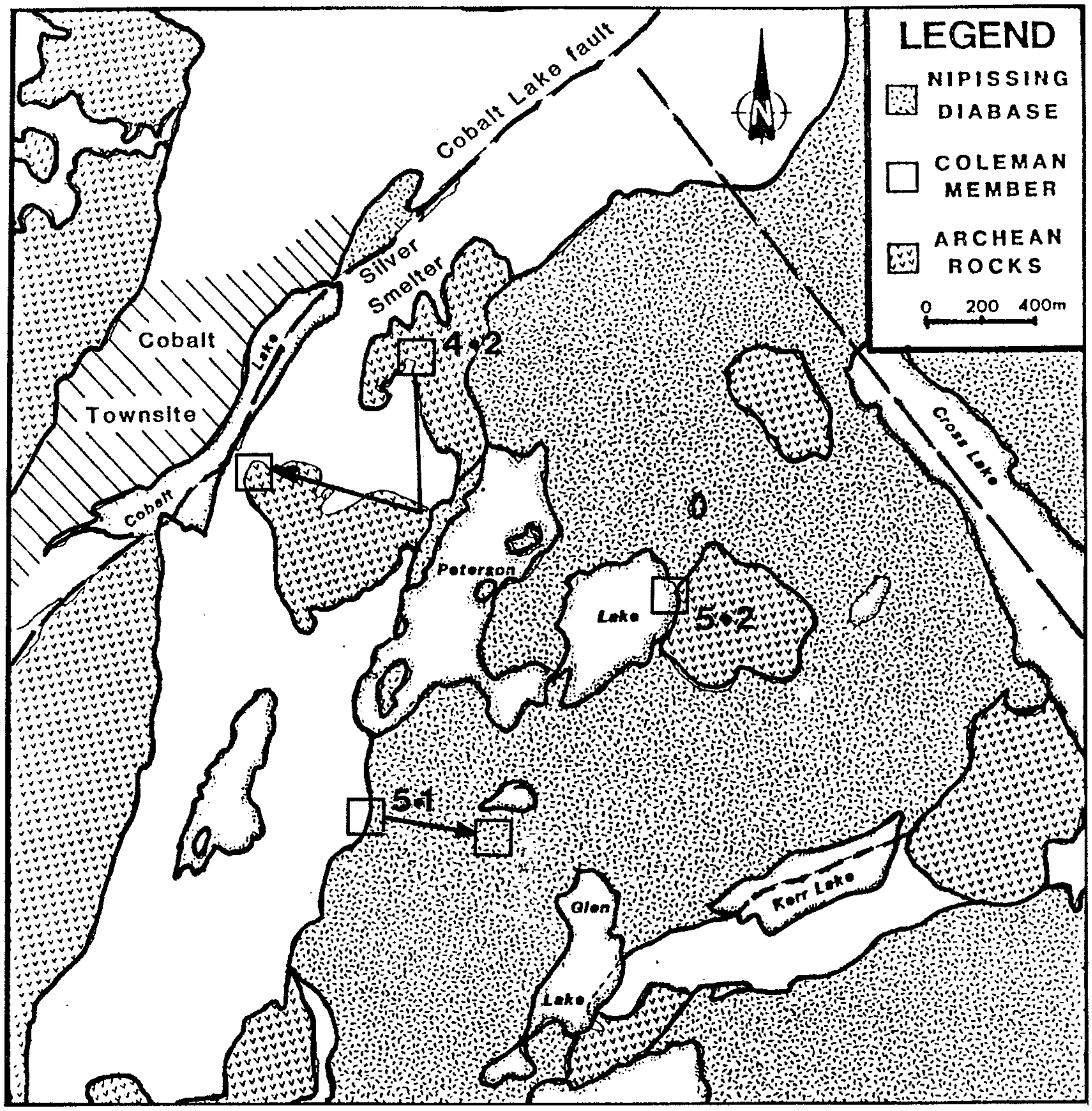


Figure 19. General geology of the Cobalt area and stop locations, after Wilson (1986).

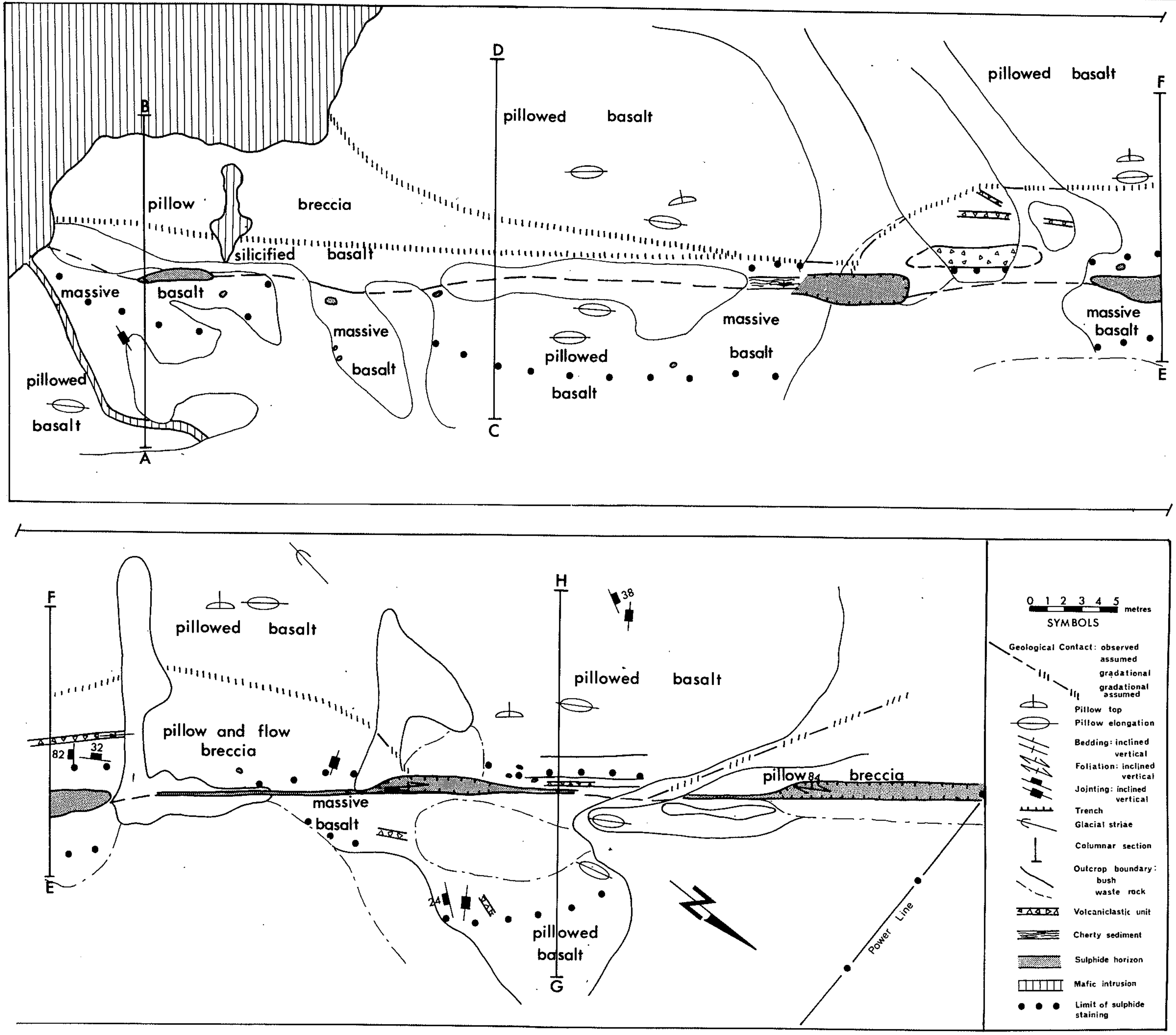


Figure 20. Geology of the Vein 65 area on Nipissing Hill from P. Whittaker and P. Jones.

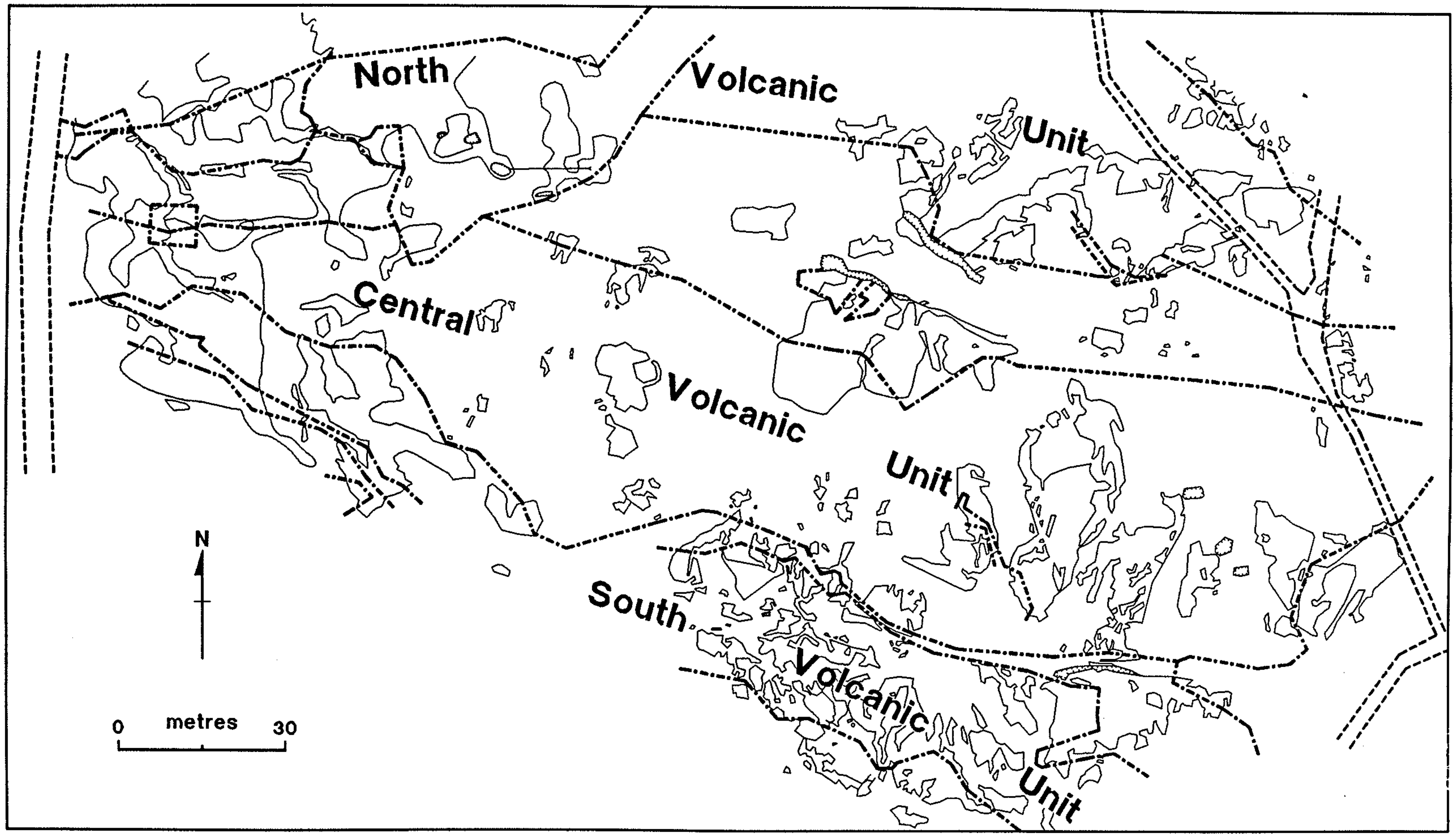


Figure 21. General geology of the Nipissing Hill South area by M. Smyk and P. MacRobbie (MacRobbie 1986).

bearing veins in the Gowganda and Archean rocks beneath the diabase contact. Climbing the hill of diabase reveals the appearance of hypersthene phenocrysts and the disappearance of the cylindrical joints. At the top of the hill is the abandoned site of the Little Nipissing Mine, Number 3 shaft. Silver ore was extracted from veins below the Gowganda - Nipissing diabase contact. Pits blasted in the medium-grained hypersthene diabase followed narrow carbonate-bearing veins with wide alteration envelopes.

STOP 2 (FIG. 19) PROVIDES A SAMPLING OF THE UPPER PART OF THE DIFFERENTIATED NIPISSING DIABASE.

Medium- to coarse-grained, granophyric diabase contains irregular, pegmatitic pods of late differentiate with amphibole crystals in excess of 10cm. At the edge of Peterson Lake, dikes of late-crystallizing magma have cut across the upper chilled diabase. Dikes have comb textures and miarolitic cavities. The rocks above the upper contact are Archean volcanic and sedimentary units.

THE LANGIS MINE

The Langis Mine (Agnico-Eagle Mines Ltd.), formerly known as the Casey Mine is located about 10 km northeast of New Liskeard, Ontario. Although it is not in the main part of the Cobalt Mining Camp, it shares many similarities with those deposits. At present new development is underway at the Penna Shaft, the site of the underground excursion. Formerly, the production was from other shafts; 2.8 million ounces was produced from 1908-1922 and 7.1 million ounces from 1956-1968 (Thomson 1965, Owsiacki and Lovell 1984). Agnico-Eagle Mines Ltd. have been producing ore from the mine sporadically since 1983.

REGIONAL GEOLOGY

The Langis Mine occupies a window into the Precambrian rocks through cover of Paleozoic sedimentary rocks and overlying Pleistocene clay deposits. The Archean basement is composed of mafic volcanic flows, fragmental and sedimentary rocks that are now subvertical and intruded by mafic dikes and a syenitic plug.

The Proterozoic succession unconformably overlying the Archean rocks is composed of conglomerates, mixtites, argillites of the Coleman Member, Cobalt Group, Huronian Supergroup. As is typical of Cobalt-area mine geology, the early Proterozoic rocks are intruded by subhorizontal Nipissing Diabase. There is a variety of pre- and postdiabase faulting, much of which controls the location of the steeply dipping silver veins.

SILVER VEINS

Veins of five-element type are subvertical fracture fillings of carbonate minerals (mainly calcite, minor dolomite) with lesser amounts of quartz and chlorite. The veins are irregular to straight, single or multiple, parallel and nonparallel arrays, mainly in the Coleman member.

Metallic minerals are complicated assemblages of nickel-cobalt-iron arsenides, diarsenides, triarsenides and sulfarsenides. Silver occurs as the native element or alloys with antimony, and as ruby silver minerals. It occurs as horns, slabs, flakes of leaf silver along late fractures, sometimes perpendicular to the main vein-trend, but commonly as disseminations in the complex arsenide intergrowths.

Ore-grade veins are difficult to trace, as their Ag content varies considerably over very short distances. Obviously, such narrow and irregular veins are even more difficult to explore for. Generally they are found beneath the intrusive contact of the Nipissing Diabase and above the unconformity. However, veins may extend tens of metres into both these units. Much of the recent exploration for veins under the Paleozoic and Pleistocene cover has taken advantage of the geophysical expression of the carbonaceous and sulfidic interflow sedimentary units in Archean volcanic successions; there is often a striking spatial (and perhaps genetic) relationship of the Proterozoic veins to the interflow sedimentary rocks, or to zones of deformation that are concentrated in them (Watkinson 1985, Smyk and Watkinson 1990).

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