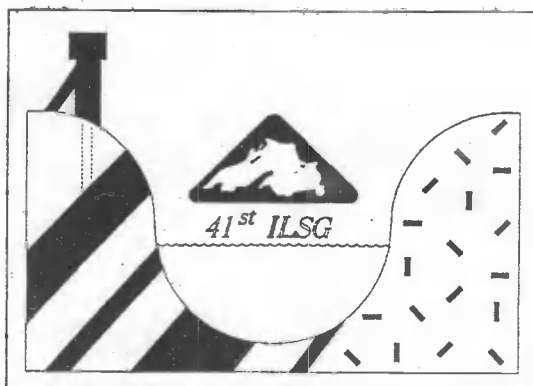

*Geology of the Schreiber Greenstone
Assemblage and its
Gold and Base Metal Mineralization*



**Institute on Lake Superior Geology
41st Annual Meeting, May 13-18, 1995
Marathon, Ontario**

**Proceedings Volume 41: Part 2c
Field Trip Guidebook**



Geology of the Schreiber Greenstone Assemblage and its Gold and Base Metal Mineralization

by

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Division, Metall Mining Corporation)***

***Frontispiece: Trip to the Empress Gold Mine, Syine Township, July 29, 1916
(photograph courtesy of Msgr. G. Bourguignon)***

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The authors have tremendously benefitted from the work and ideas of countless government and industry geologists and prospectors that have worked on the North Shore. We wish the best of luck to those who follow.

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**Field Guide to the Schreiber Greenstone Assemblage
includes stop descriptions for:**

- ~ **STOP 1:** Steel River Turbidites
- ~ **STOP 2:** Steel River Komatiites/Pillowed Tholeiites
- ~ **STOP 3:** Terrace Bay Batholith
- ~ **STOP 4:** Gold Range Prospect
- ~ **STOP 5:** Winston Lake Mine

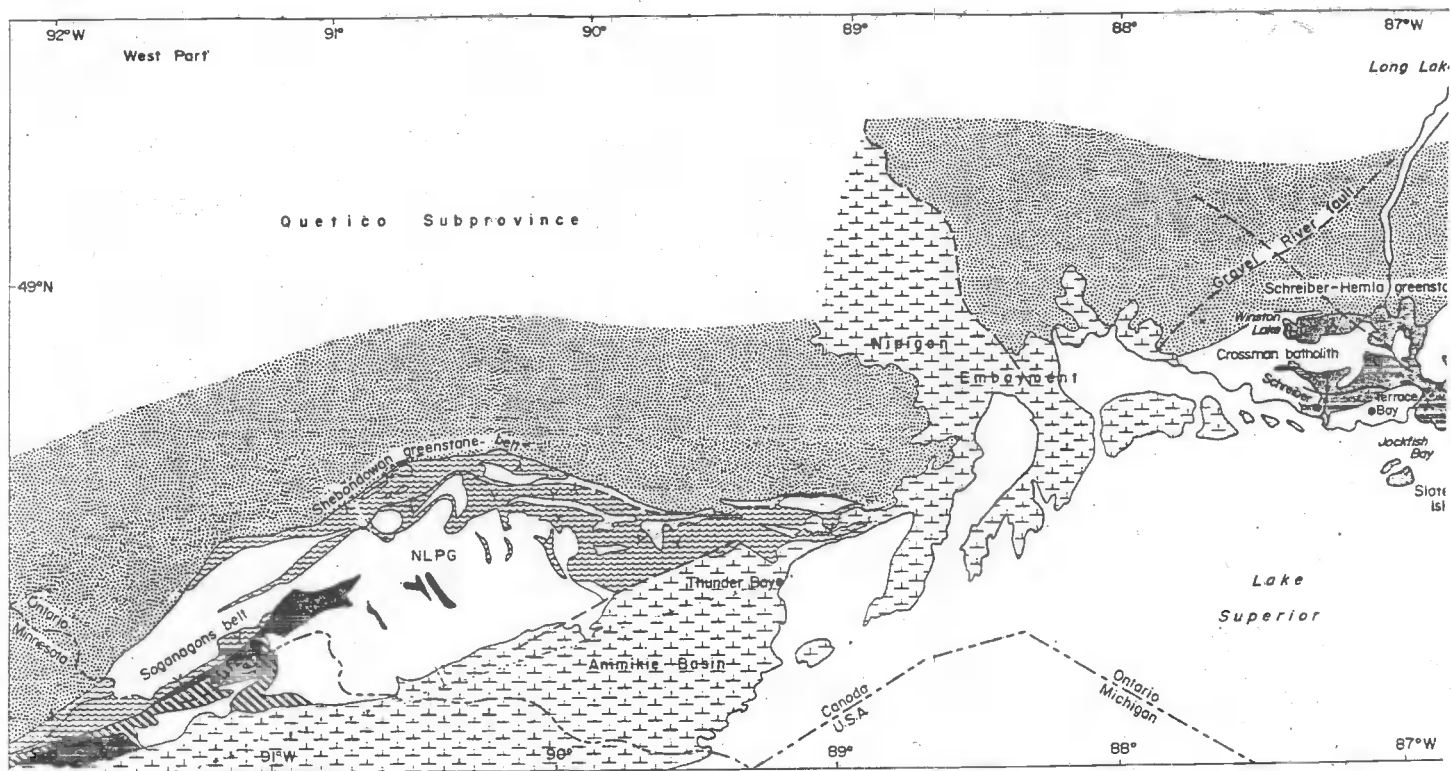
Road Log for Stops 1 - 5 (Marathon Starting Point)

<u>Total Kilometres</u>	<u>Landmark/Field Trip Stop</u>
0.0	Junction of Highways 17 and 626 (Marathon Turn-off)
33.9	Dead Horse Creek road turn-off
50.6	STOP 1: Steel River Turbidites
52.6	STOP 2A: Steel River Komatiites
53.2	STOP 2B: Steel River Pillowed Tholeiites
58.7	Coach House Motel
65.0	STOP 3: Terrace Bay Batholith
79.0	Tourist Information Centre, Terrace Bay
88.5	Turn-off to STOP 4: Gold Range Prospect
92.6	Voyageur Restaurant/Service Station, Schreiber
101.7	Turn-off to STOP 5: Winston Lake Mine

INTRODUCTION

This field trip highlights the geology and mineral deposits of the western portion of the Neoarchean Schreiber-Hemlo greenstone belt. This segment, termed the Schreiber lithotectonic assemblage, extends from the western contact of the Mesoproterozoic Coldwell alkalic complex, west to Schreiber and north to the Big Duck Lake area (Figures 1 and 2). It comprises a large portion of the shoreline of Lake Superior and the Slate Islands. The Trans-Canada Highway (Highway 17) provides access to the southern part of the area and a number of excellent roadside exposures of greenstone belt rocks. A number of field guides, including those of Pye (1969), Schnieders et al. (1991) and Sabina (1991) describe various aspects of the general geology. Other guides, reports and papers will be referenced in describing individual stops and/or areas.

Please note that many of the field trip stops located on the side of Highway 17 do not provide adequate parking/pull-off areas. **Extreme caution must be exercised when stopping, parking and visiting these sites.** Permission is required from property owners when visiting the Gold Range and Winston Lake Mine properties. Please contact the Resident Geologist's Office, Schreiber-Hemlo District, Thunder Bay, for current information regarding property ownership at (807) 475-1331.

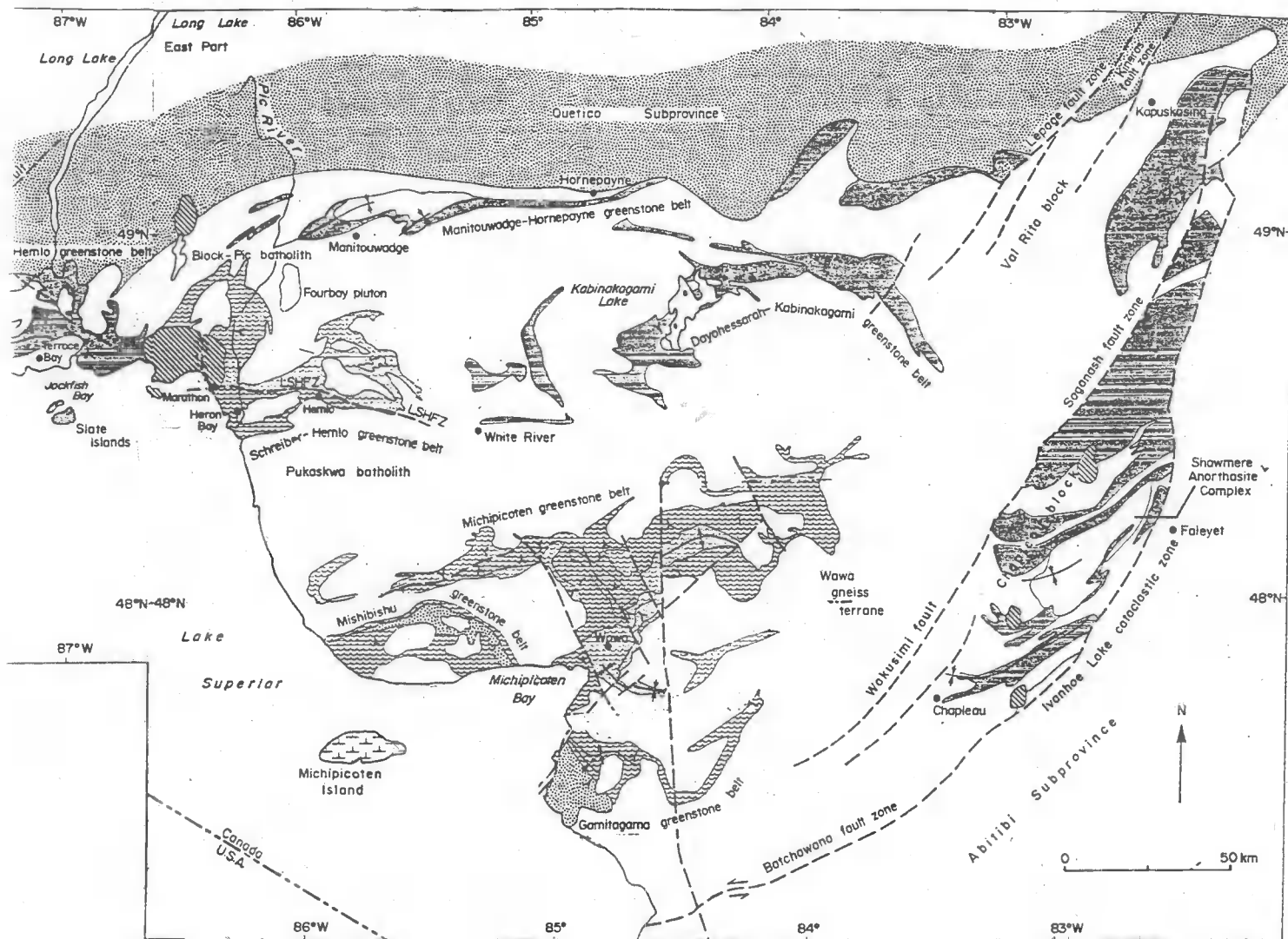


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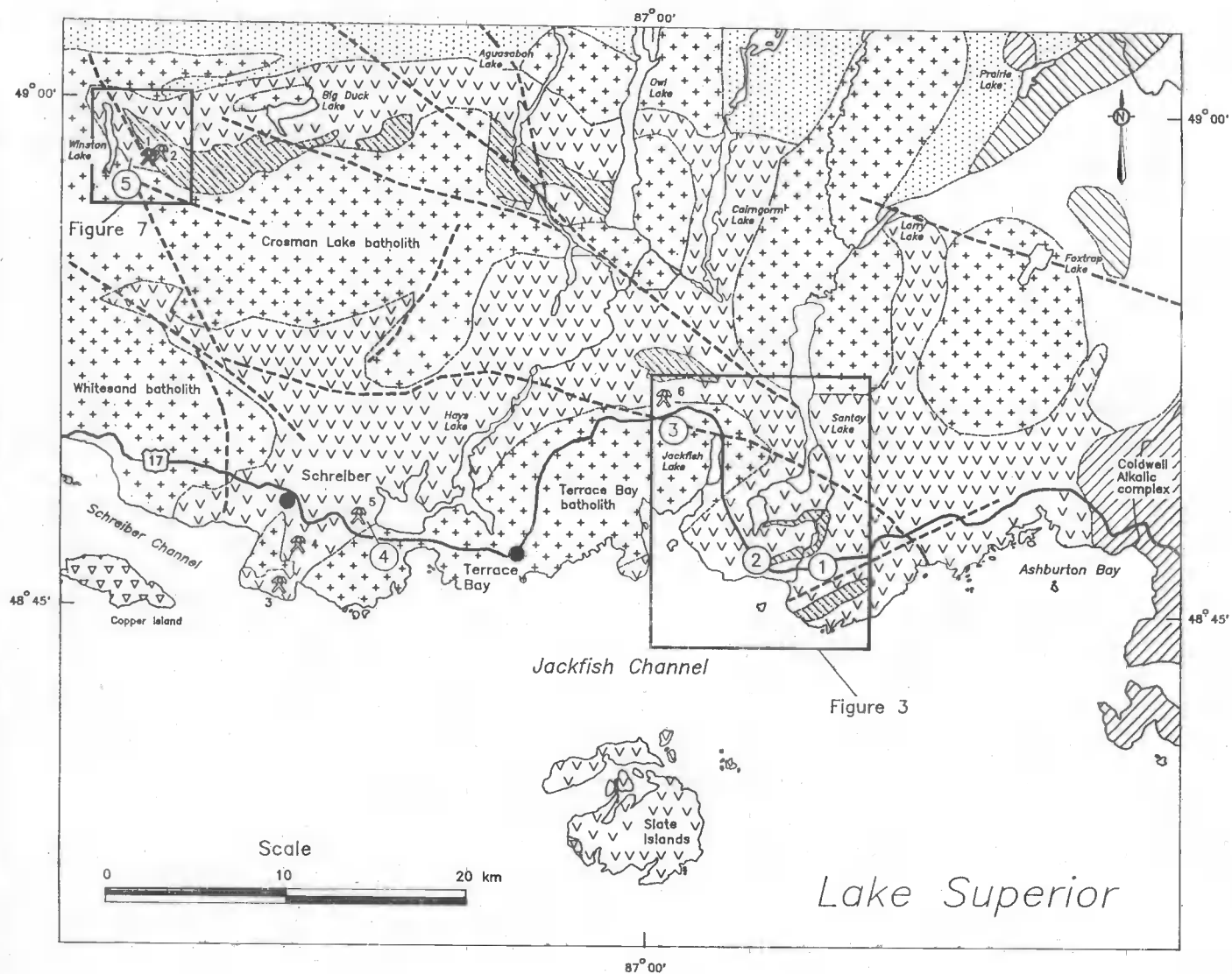
- | | | | | | |
|--|--|--|---|--|---|
| | Proterozoic cover: Animikie Basin, Nipigon Embayment | | Metavolcanic and metasedimentary assemblages (2.73 to 2.70 Ga): Heron Bay, Gamitagama, Catfish, Greenwater | | Geological boundary |
| | Proterozoic intrusions: Port Coldwell alkalic complex | | Metavolcanic assemblage: Saganagan assemblage | | Fault and/or shear zone; arrow indicates sense of direction |
| | Granitic rocks (large areas between, and small plutons within, greenstone belts) | | Metavolcanic and metasedimentary assemblages (2.77 to 2.70 Ga, probably 2.77 to 2.75 Ga): Schreiber, Manitouwadge-Hornepayne, Chapleau, Dayohessarah-Kabinakagami | | Top direction |
| | Shebandowan assemblage, Knife Lake assemblage (~2.69 Ga) | | Metavolcanic assemblage (2.77 to 2.75 Ga): Hemlo, Wawa, Burchell | | Synform, antiform |
| | Metasedimentary assemblages (probably ~2.70 Ga): Mishi, Gargantua, Quetico | | Metavolcanic assemblage (2.77 to 2.75 Ga): Hawk | | International boundary |
| | | | | | LSHFZ Lake Superior-Hemlo fault zone |
| | | | | | NLPB Northern Light-Perching Gull Lakes batholithic complex |

Tectonic assemblage map of the Wawa Subprovince, showing the greenstone belts and their constituent assemblages, selected stratigraphic-facing data, major granitoid masses and faults.

Figure 1. (Williams et al. 1991)



Schreiber Assemblage 4



PROTEROZOIC



Carbonatitic-Alkalic Intrusive Rocks



Osler Group Mafic and Felsic Volcanic Rocks and associated conglomerate and arkose

ARCHEAN



Felsic Intrusive Rocks



Tonalitic to Granodioritic Gneisses



Mafic to Ultramafic Intrusive Rocks



Migmatized Supracrustal Rocks



Metasedimentary Rocks of the Quetico Subprovince



Mafic to Felsic Metavolcanic Rocks and associated Metasedimentary Rocks

SYMBOLS



Field Trip Stop



Geological Contact



Fault



Highway



Producing Mine

1. Winston Lake (Zn,Cu,Ag)



Past Producing Mine

2. Zenith/Zenmae (Zn,Cu)

3. North Shores (Au)

4. Davis Sulphur Ore (S)

5. Harkness-Hays (Au)

6. Empress (Au)

Figure 2. Regional geology of the Schreiber assemblage.

GENERAL GEOLOGY

Definition of Terms

The term *tectonic assemblage* as informally applied by the Ontario Geological Survey in the Ontario part of the Superior Province has been defined by Thurston (1991) as consisting of:

"stratified volcanic and/or sedimentary rock units built during a discrete interval of time in a common depositional or volcanic setting. The rock units typically share a common or dominant lithofacies; they may also share some additional attributes, such as structural, metamorphic, geochemical and geophysical features... An assemblage is typically bounded by faults, unconformities or intrusions."

The term *greenstone belt* refers to:

"elongate or belt-like, kilometre-scale areas of supracrustal rocks within granite-greenstone subprovinces, with tectonic or intrusive boundaries. Greenstone belts may consist of one or more *assemblages*. A subprovince generally consists of several greenstone belts." (Thurston 1991)

Regional Geology

The Schreiber lithotectonic assemblage comprises the western segment of the Neoarchean Schreiber-Hemlo greenstone belt of the Wawa Subprovince (Williams et al. 1991). It consists of

a number of narrow, arcuate segments of supracrustal rocks that are bounded and enclosed by granitoid bodies. Regional metamorphic grade ranges from upper greenschist facies to mid- to upper amphibolite facies near granitoid contacts. The majority of lithologic and structural information has been gleaned from regional scale mapping by Hopkins (1922), Harcourt (1939), Bartley (1939; 1942), Pye (1964), Walker (1967) and Carter (1988).

Supracrustal Rocks

Three major types of supracrustal rocks have been recognized by Carter (1988): (1) tholeiitic, mafic volcanics, (2) calc-alkalic, mafic to felsic volcanics, and (3) clastic and chemical sedimentary rocks.

Tholeiitic volcanic rocks comprise mainly massive to pillowed basalt, tuffs and related autoclastic breccias (**STOP 2B**). Basaltic komatiites have recently been recognized within tholeiite-dominated successions (**STOPS 2A, 2B**). Calc-alkalic, felsic rocks are dominated by fine to coarse pyroclastic units that attain significant thicknesses in the Prairie River to Rhumly Lake area and in the Winston Lake area (**STOP 5**). Sedimentary rocks consist mainly of wacke and slate of turbiditic origin and lesser, but significant oxide- and sulphide-facies banded iron formation (**STOP 1**).

Few geochronologic data are available from this part of the Wawa subprovince. A U-Pb zircon

date of 2723 ± 2 Ma was determined by Schandl et al. (1991) for host rhyolite at the Winston Lake Mine. A virtually identical age of 2720 ± 2 Ma (Davis et al. 1994) was derived from altered felsic volcanic rocks at the Geco Mine in the Manitouwadge greenstone belt. Monazites, interpreted as synmetamorphic, gave ages of 2677 ± 1 Ma and 2675 ± 1 Ma at Winston Lake and Geco, respectively (ibid).

Granitoid Rocks

The supracrustal rocks are intruded by and bounded by two main suites of Neoproterozoic granitoids: a gneissic tonalite suite, and a massive granite to granodiorite suite. Rocks of the gneissic tonalite suite, comprising foliated to gneissic tonalite to granodiorite with minor supracrustal inclusions, bound the greenstone belt to the northeast, south of Killala Lake. Similar rocks occur within Quetico metasedimentary rocks to the north. Williams et al. (1991) have considered that the tonalitic rocks may, in part, be synvolcanic with regard to the 2.77 to 2.70 Ga greenstone assemblages.

Massive granite to granodiorite intrusions comprise a more voluminous and perhaps more influential suite of rocks within and adjacent to the Schreiber assemblage. These so-called, "internal granitoids", are typically composite, ovoid intrusions that vary in size up to 25 km. They have relatively sharp contacts with the supracrustal rocks, characterized by assimilated

septa, xenoliths and hybridization, suggesting high-level emplacement. Walker (1967) mapped a narrow, amphibolite-facies contact aureole around the Terrace Bay batholith (**STOP 3**) and noted that some remnant supracrustal slivers had been metamorphosed to granulite-facies. A foliation or gneissosity is commonly developed in the intrusion parallel and adjacent to its contact with the country rocks.

Intrusions are composite, with lithologies ranging from dominantly granite and granodiorite, to quartz diorite, syenite, and quartz monzonite, accompanied by their gneissic equivalents and aplite and pegmatite dykes. These intrusions are considered to be syn- to post-tectonic and are probably correlative in age and emplacement style to those in the Hemlo assemblage to the east. Plutons in the Hemlo assemblage returned ages between 2678 and 2688 Ma (Corfu and Muir 1989). Examples within the Schreiber assemblage include the Terrace Bay, Crosman Lake and Whitesand batholiths.

Structural Geology

Despite a marked lack of stratigraphic facing determinations, recent structural studies suggest that there is likely a great deal of tectonic juxtaposition between supracrustal units in addition to ubiquitous, upright folding (Schnieders 1987; Carter 1988; Williams 1989). Facing reversals, conflicting younging directions, unit repetition, inhomogeneous deformation and thickening of

successions indicate that kilometre-scale folding and duplication by thrusting were significant (Williams 1989). Schnieders (1987) noted complex folding events, accompanied by large-scale faulting in the Steel River area. Deformation of original stratigraphy has resulted in a fragmentation of volcano-sedimentary successions and produced a pseudostratigraphy.

Williams (1989) and others have noted that, for the most part, the supracrustal rocks in the Schreiber assemblage display non-penetrative strain fabrics produced by rotation, without significant internal distortion. In marked contrast, discrete zones of strong deformation, such as the Jackfish-Middleton shear zone, are characterized by dip-slip style, steeply plunging, mineral and stretching lineations that are superimposed on tectonic layering or schistosity. Phyllites and slates, derived from volcano-sedimentary protolith, are locally carbonatized, sericitized and hematitized.

Quetico subprovince clastic sedimentary rocks are juxtaposed with the supracrustal and granitoid rocks of the Wawa subprovince along its northern boundary. The Quetico accretionary complex was likely contiguous with the Wawa subprovince at least since 2689-2684 Ma, and possibly since 2696-2689 Ma (Percival 1989). A U-Pb zircon provenance study of Manitouwadge belt wackes by Zaleski et al. (1995) placed a maximum age limit on deposition of 2693 Ma.

A variety of diabase dyke swarms intrude the granite-greenstone country rocks. These include the Paleoproterozoic Hearst (northwest-trending, 2454 Ma) and Marathon (north-trending,

2170 Ma) swarms, and Mesoproterozoic Pigeon River and Pukaskwa (north-northeast and northwest-trending, respectively; 1100-Ma) swarms (Osmani 1991).

Economic Geology

Metallic mineral deposits within the Superior Province of Ontario consist of: (1) those related to the tectonic setting of rock assemblages, and (2) those related to orogenic processes, superimposed upon rock assemblages (Fyon et al. 1991). Rocks of the Schreiber assemblage, like those in all granite-greenstone subprovinces, host examples of both types of mineralization.

The first category comprises those deposits that were formed during early tectonic and magmatic events, including syn-volcanic, base metal sulphide deposits. Volcanogenic, massive sulphide (VMS), zinc-copper-silver mineralization occurred in the bimodal, subaqueous volcanic succession at the Winston Lake Mine (**STOP 5**). The host rocks consist of mafic flows and felsic pyroclastic rocks. Similar rocks, characterized by the same distinctive major and trace element chemistry and hydrothermal alteration mineral assemblages occur in the Prairie River area, 45 km to the southeast (Schnieders and Smyk 1994). Lithologic, metallogenetic and temporal similarities that exist between the Winston Lake and Manitouwadge VMS camps may suggest an original stratigraphic connection.

Closely related to VMS deposits, oxide- and sulphide-facies banded iron formations locally occur within both volcanic and sedimentary successions, but have limited lateral and vertical extent. Magnetite, pyrrhotite and/or pyrite are intercalated with chert, wacke or pelite. Study of the Morley pyrite deposit, 3 km south of Schreiber, by Schnieders (1987) and Fralick et al. (1989) suggested that massive sulphide precipitation resulted both from the venting of hydrothermal fluids and activity of deep-water, organic mats.

Archean lode gold deposits, which exemplify the second, epigenetic type of mineralization, are typically associated with late tectonic elements such as regional deformation zones (Colvine et al. 1988). However, gold occurrences in the Schreiber assemblage, while commonly hosted by discrete, local structures, have no discernable association with major deformation zones. They are spatially, and perhaps genetically, related to felsic intrusive rocks on a variety of scales. The majority of gold occurrences in the Schreiber area lie at or near the contact of the Terrace Bay batholith (Marmont 1983), while the Big Duck Lake quartz porphyry serves as a locus for gold mineralization in that area (Pye 1964; Patterson et al. 1985). The majority of occurrences are quartz vein-hosted, narrow, high-grade deposits which have collectively produced several thousand ounces of gold (e.g. Gold Range prospect, **STOP 4**).

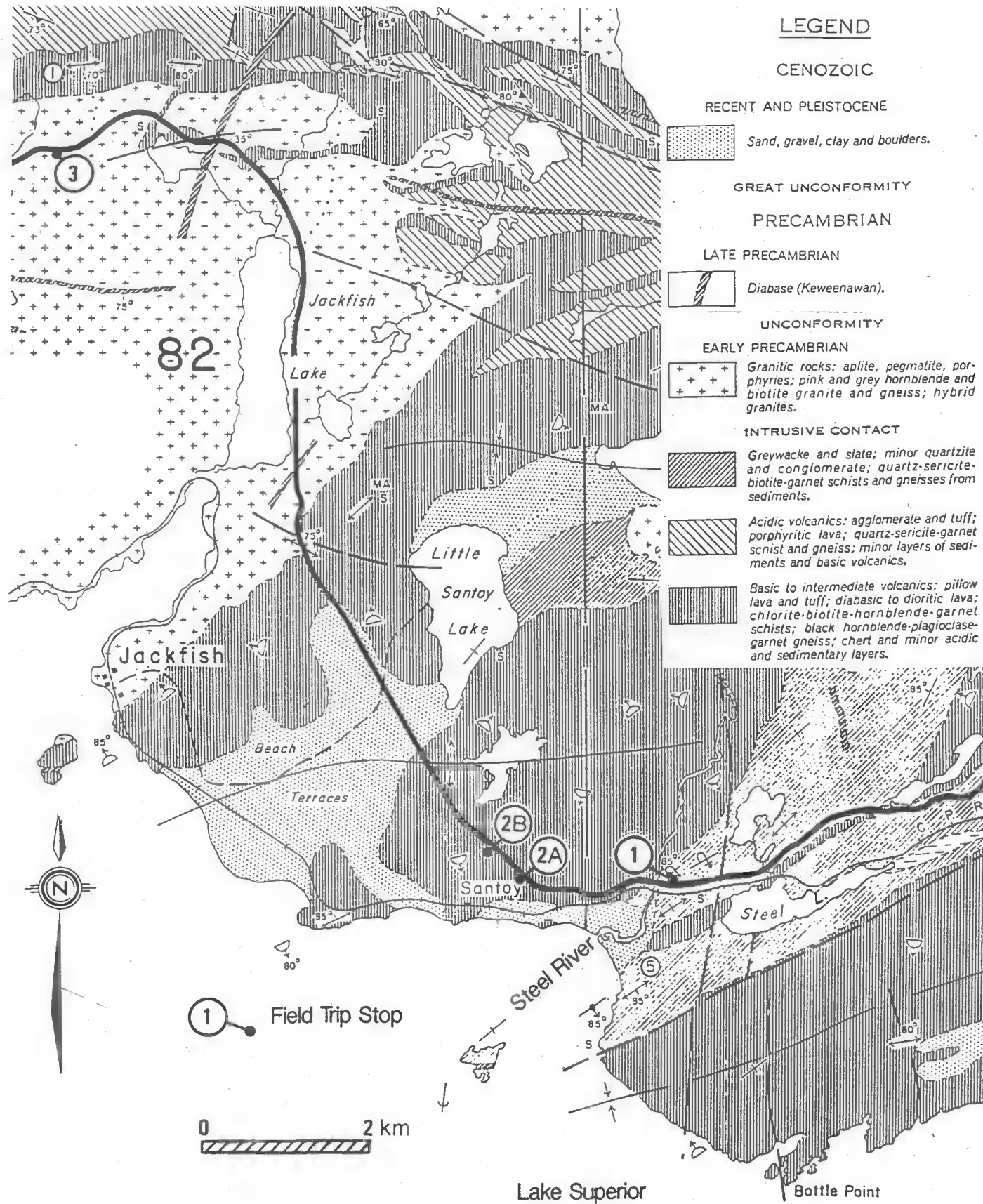


Figure 3. Geology and Stop Locations, Jackfish area; Geology from Walker (1956).

FIELD STOP DESCRIPTIONS: Stops 1 -5

STOP 1: Steel River Turbidites

STOP 2A: Steel River Komatiites

STOP 2B: Jackfish Pillowed Basalts

STOP 3: Terrace Bay Batholith

STOP 4: Gold Range Prospect

STOP 5: Winston Lake Cu-Zn Mine

STOP 1: STEEL RIVER TURBIDITES

This roadcut exposes clastic sedimentary rocks within a structured, submarine fan sequence associated locally with submarine volcanic rocks and metalliferous sedimentary rocks, including sulphide-facies iron formation (Schnieders 1987). As described by Schnieders (1987) and Fralick and Barrett (1991), the sedimentary succession here is dominated by A- and AB-turbidites, organized into upward (southward) coarsening and thickening, and fining and thinning sequences. These assemblages were thought to represent deposition on suprafan lobes and submarine channels, respectively (Schnieders 1987; Fralick and Barrett 1991)

Purdon (in progress) has recognized features ascribable to a submarine ramp environment in what he has termed the McKellar Harbour Sequence. These clastic sedimentary rocks, dominated by sandy turbidites, extend 16 km east to Middleton where they are truncated by the Coldwell alkalic complex. Constituent turbidites typically show only obscure ordering, transitional boundaries between subsequences and no evidence of channelized deposition. Local turbidites are laterally continuous; some units have been traced for over 1 km along strike. There is also a general thinning- and fining-upward trend within this sequence. In this context, the Steel River turbidites may represent channelized deposition on a small lobe on the larger, submarine ramp (R. Purdon, personal communication, 1995). Geochemical similarities between the Steel River rocks and the main part of the McKellar Harbour Sequence support a common provenance and similar tectonic setting.

Primary sedimentary features, such as graded bedding, scours and load casts, indicate a southerly younging direction. These features have been obscured and somewhat transposed along a foliation, oriented at about 20° to bedding. Schnieders (1987) has noted other features, such as parallel and convolute lamination, cross-bedding, flame structures, ripples, loaded ripples and rip-up clasts.

This locality is close to the western end of what Williams (1989) described as the Jackfish-Middleton/ McKellar Harbour shear zone. This northeast-trending zone lies between mafic volcanic rocks to the south and sedimentary rocks to the north, varying in width between 2 and 3 km. The biotite-in isograd and more northerly garnet-in isograd (Walker 1967) obliquely transect the shear zone. Phyllites derived from mafic volcanic and sedimentary rocks exhibit vertical stretching and mineral lineations, horizontal crinkle lineations and flat-lying, calcite-filled extension fractures. Steeply plunging, tight to isoclinal folds occur within the wackes, but fold limbs parallel a strongly developed slaty cleavage in the metapelites. Tectonic disruption, bed attenuation and conflicting kinematic and younging indicators characterize much of this zone (Schnieders 1987). Williams (1989) has suggested that an early dip-slip style of deformation was followed by dextral shear as evidenced by overprinting, Z-asymmetric folds and sub-horizontally plunging slickensides. Schnieders (1987) has suggested two separate folding events or a polyphase folding event in the Steel River area.

STOP 2A: STEEL RIVER KOMATIITES

This section of the local volcanic succession has been investigated because of the recent discovery of a spinifex-textured flow unit within pillowed, tholeiitic basalt, similar to pillowed units exposed 600 m northwest (**STOP 2B**). These two sections, while part of the same volcanic package, are remarkably different in terms of their lithologic and eruptive characteristics.

This 70 m detailed section (Figure 4) along the south side of the highway comprises a number of different flows/flow units which dip steeply (60°SE) and young to the southeast. Subsequent tectonic deformation, alteration and quartz-carbonate veining have obscured some of the primary features and relationships. Individual flow units, separated by sharp, locally sheared, contacts, range in thickness from approximately 1m to perhaps 20 m. These units comprise massive, locally pillowed, basalt, "isolate"- to "crowded"-pillow breccia and massive to spinifex-textured, basaltic komatiite. Individual flow units display marked geochemical variation.

Perhaps the most noteworthy lithologic unit is the spinifex-textured, basaltic komatiite. It is apparently a composite flow consisting of a massive, metapyroxenite(?) base, an oriented, plate spinifex-textured central unit and a finer-grained, randomly oriented, upper spinifex-textured portion. Serpentine-rich veins occur within the massive flow. Whole-rock geochemistry shows a progression from basaltic komatiite at the base to high-magnesium, tholeiitic basalt at the top of the flow (Table 1). Immediately above the contact with the massive komatiite, spinifex crystals

are oriented parallel to the contact. Less than a metre up from the contact, large (≤ 8 cm) crystals and sheaf-like aggregates are oriented at right angles to the contact and locally branch upwards in a plumose fashion. Coarse-grained spinifex gradually gives way to a finer-grained, more randomly oriented texture in which individual crystals are ≤ 0.8 cm long.

Incipiently pillowed, largely massive, non-magnetic, basalt flows are characterized by 2 to 4 mm, light green varioles which coalesce into lobate, amoeboid patches or may concentrate along irregular (synvolcanic?) stockwork fractures. Pillow forms are indistinct but are suggested by lobate variole pods and selvage-like patterns. Selvages are characterized by bands of coalescing varioles, and/or quartz $\pm$ hyaloclastite layer(s).

This unit may be related or transitional with an isolate pillow breccia, a massive flow unit with discrete, isolated or detached pillows and pillow fragments. "Crowded" pillow breccia contains a higher proportion of discernable pillows and pillow fragments ranging in size from 10 to 100 cm. Smaller pillows are spherical to bun-shaped, while larger counterparts are ovoid to mattress-shaped. Many of the larger pillows contain stacked, quartz-filled, "drain-away" cavities which represent successive stands of falling lava (cf. Wells et al. (1978). Hyaloclastite occurs in the interpillow spaces and within lenticular pods in seemingly more massive flow units. Autoclastic breccias occupy most flow contacts.

The spinifex-textured flow shows remarkable similarities with the serial textural variation

described by Pyke et al. (1973) in the Abitibi greenstone belt. Common subunits, in descending order, include: chilled, fractured and brecciated upper contact; upper, randomly oriented spinifex zone (KOM-3); lower, plate spinifex zone (KOM-1); foliated phenocryst zone (KOM-7) and a massive, ultramafic base (KOM-2,-5,-6).

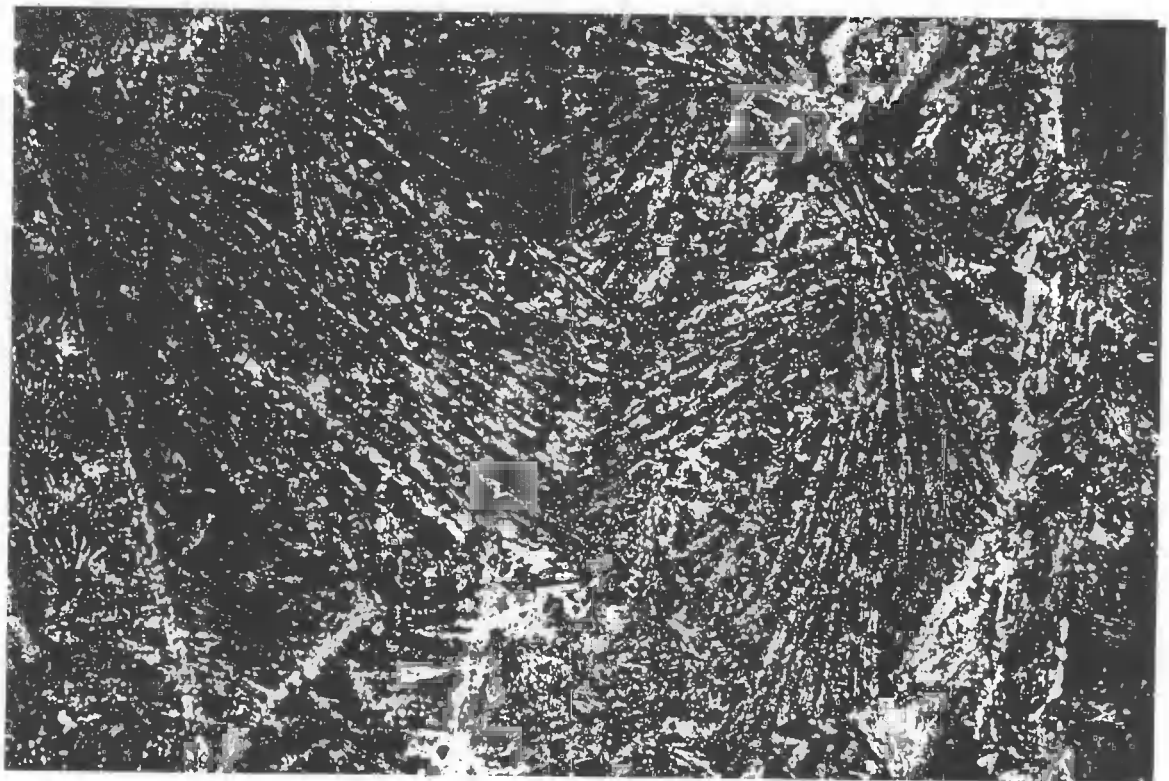
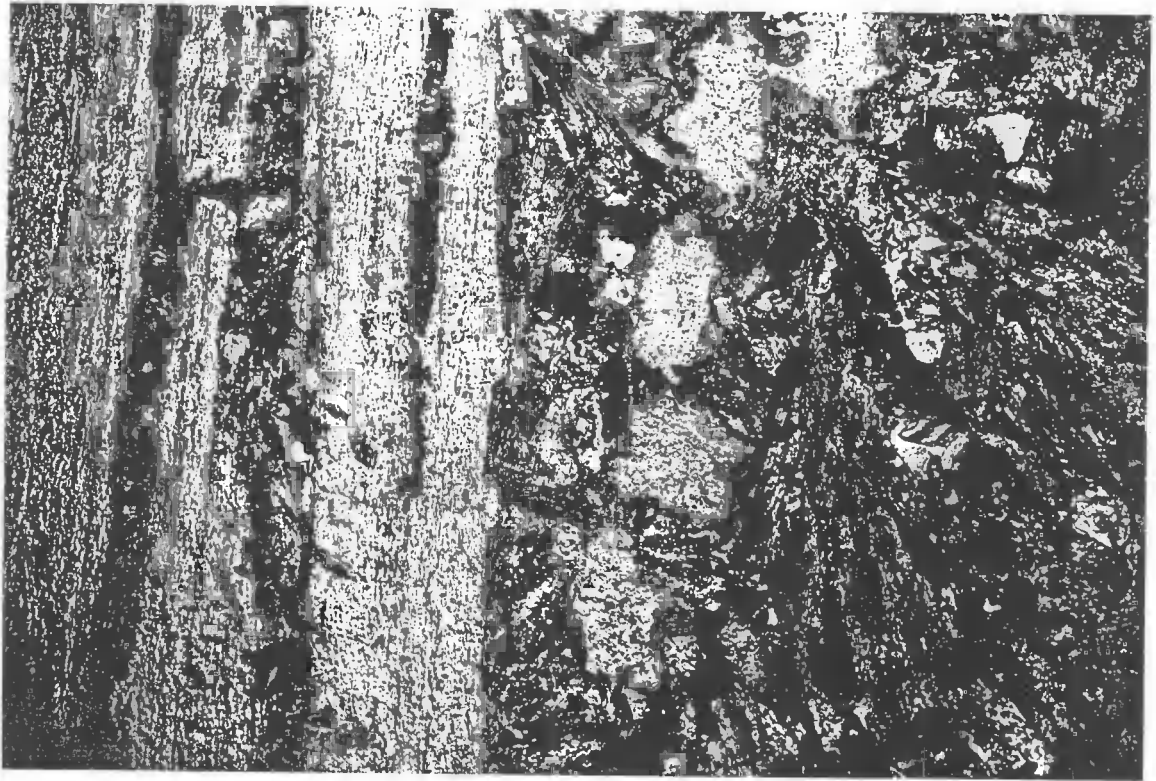
Thin section and X-ray diffraction analyses reveal that the constituent crystals in the spinifex are optically continuous, skeletal, branching grains of magnesio-hornblende and chlorite (clinochlore) (Plate 1). They are likely the alteration products of primary, magnesium-rich clinopyroxene. The matrix is a fine-grained matte of talc, serpentine, carbonate, chlorite and amphibole resulting from alteration and greenschist-facies metamorphism.

The massive, basal portion of the flow (samples KOM-2,-5,-6), interpreted as a metapyroxenite, consists of a very fine-grained, decussate to weakly foliated (parallel to flow contact), talcose, serpentinized matrix with minor amphibole, Fe-oxides and calcite. Relict, equant clinopyroxene(?) phenocrysts average 0.15 mm in size.

Foliated spinifex (KOM-7) occurs at the lower contact of the spinifex-bearing portion of the flow. It is characterized by subparallel, serpentine + talc $\pm$ calcite aggregates that have replaced acicular, 0.3 x 1.0 mm phenocrysts. Equant, blocky clinopyroxene phenocrysts (≤ 0.6 x 1.0 mm, averaging 0.15 to 2 mm square) are also evident. Phenocrysts and pseudomorphs are set in a finer-grained matrix of subparallel, 0.05 to 0.075 mm, acicular crystals and Fe-oxides.

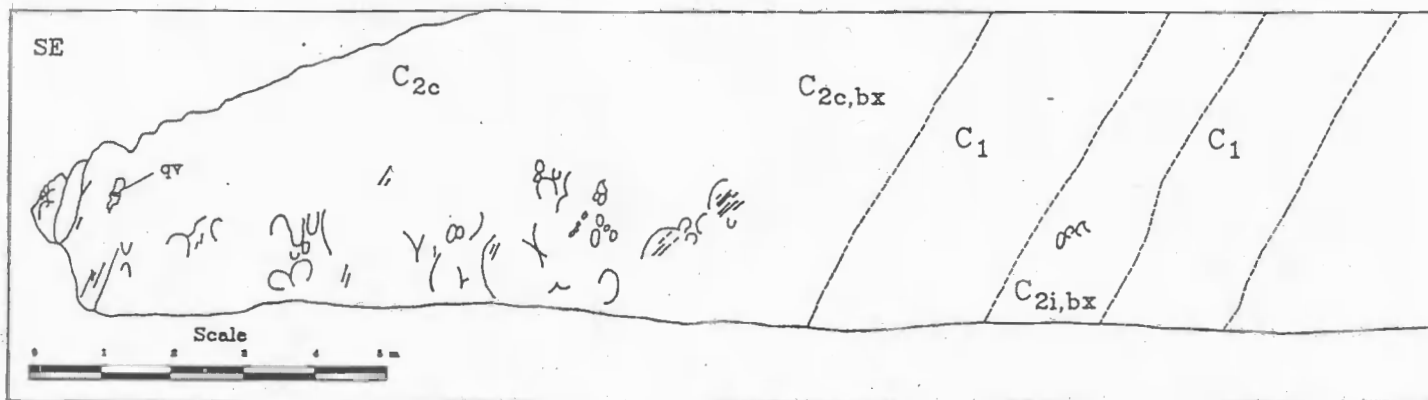
Plate 1. Photomicrograph (PPL) of optically continuous, branching and plumose
magnesio-hornblende and chlorite (clinochlore) in coarse, plate spinifex-textured,
basaltic komatiite (KOM-1), STOP 2A. Field of view is 4.0 mm.

Plate 2. Photomicrograph (PPL) of upper, randomly oriented spinifex-textured portion of flow
(KOM-3), STOP 2A. Field of view is 4.0 mm.

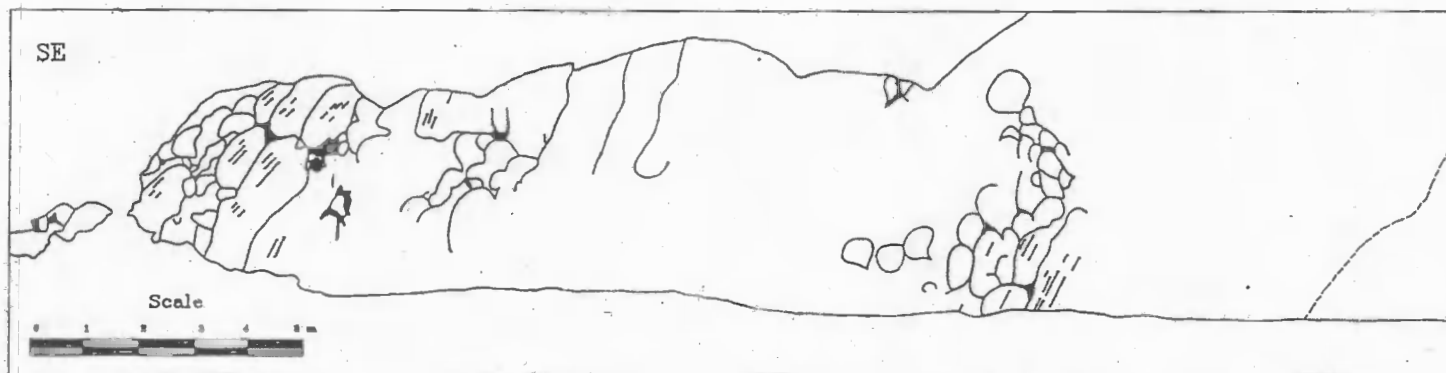


Schreiber Assemblage 21

STOP 2A



STOP 2B



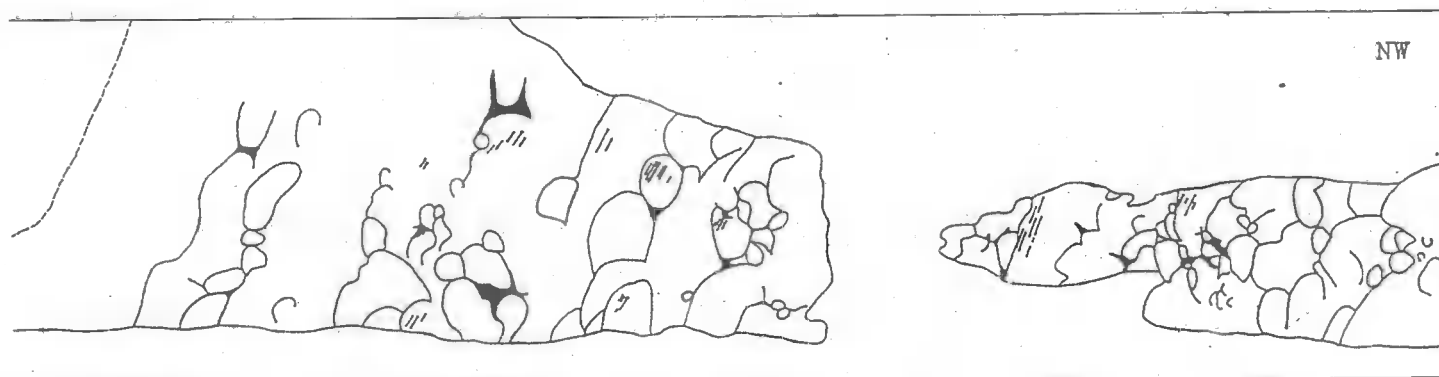
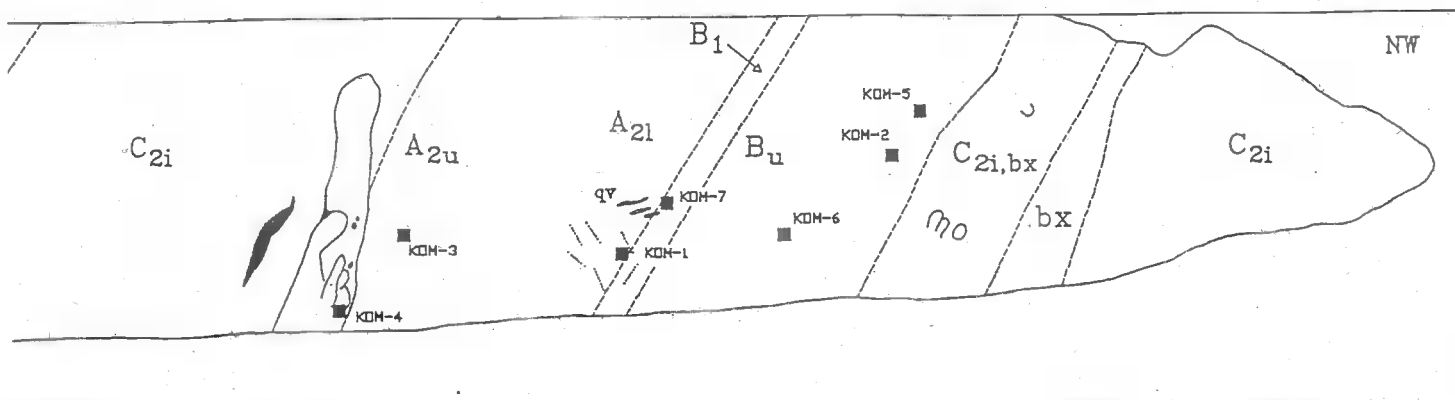
LEG.

Lithologic Units

- A₁: Chilled Zone (upper contact)
- A₂: Spinifex zone (A_{2u}: upper, randomly oriented zone)
(A_{2l}: lower, plate spinifex zone)
- B₁: Foliated spinifex zone
- B_u: Massive, ultramafic basal zone (unsubdivided)
- C₁: Massive basalt/basaltic komatiite

- C_{2c}: "Crowded" pillow basalt/basaltic komatiite
- C_{2i}: Incipiently pillowed basalt/basaltic komatiite
- bx: Autoclastic breccia (broken pillow/flow breccia)

Figure 4: Geological sketch maps, detailed flow cross-sections (looking southwest), stops 2A, 2B.



LEGEND

Symbols



Flow contact/internal subdivision



Pillow outline



Hyaloclastite



Drain-away cavities



Spinifex orientation



Sample location and number (e.g. KOM-1)



quartz +/- calcite vein/pod

Plate spinifex (KOM-1) is characterized by amphibole pseudomorphs of 0.15 to 0.2 mm, acicular crystals that occur in optically continuous aggregates up to 1.0 mm wide and in excess of 20 mm long. Amphibole-replaced crystals are separated by serpentinized crystals. Relict, subhedral pyroxene phenocrysts, equant to lathlike, reach lengths of up to 1.0 mm. The fine-grained matrix consists mainly of plumose to sheaf-like serpentine, with subordinate epidote (saussurite?).

The upper, spinifex-textured flow (KOM-3) consists of completely serpentinized, 0.05 x 1.0 mm, randomly oriented books of crystals in a devitrified glass matrix (Plate 2). Larger (0.3 x 4 mm) phenocrysts comprise approximately 5% of the rock and have been altered to serpentine + epidote + calcite.

The overlying basaltic komatiite flow (KOM-4) consists of a very fine-grained, decussate intergrowth of turbid amphibole and epidote. Pseudomorphs (after pyroxene) are equant and blocky and average 0.1 to 0.2 mm in size. Fe-oxides are notably rare. Pyroxene phenocrysts, comprising approximately 3% of the rock, range up to 0.6 mm in size and are invariably altered to magnesian chlorite (penninite) ± epidote ± serpentine.

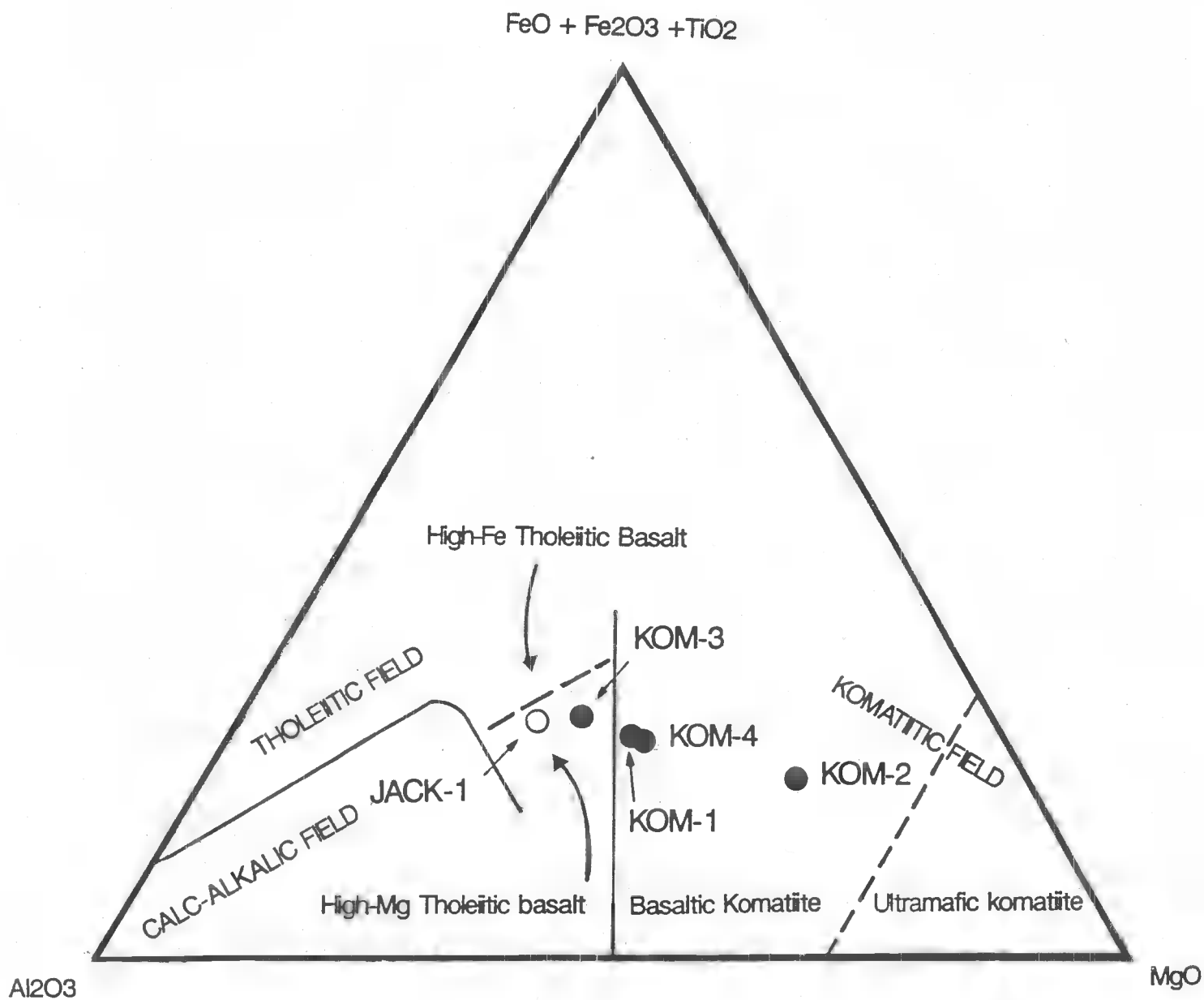


Figure 5: Jensen (1976) Cation Plot of Steel River mafic volcanic rocks.

Table 1. Geochemical Results, Tholeiitic and Komatiitic Basalts, STOPS 2A and 2B

Sample	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	TiO ₂	MnO	BaO	Cr ₂ O ₃	SrO	LOI	Total (%)
KOM-1	48.00	11.29	11.82	10.00	9.10	1.89	0.12	0.146	0.701	0.182	0.013	0.174	0.10	2.7	96.1
KOM-2	41.08	9.42	13.25	19.53	7.03	0.10	0.01	0.106	0.545	0.215	0.006	0.350	0.001	6.7	98.3
KOM-3	48.35	11.60	12.14	8.07	11.70	1.49	0.05	0.099	0.660	0.191	0.007	0.250	0.013	3.6	98.2
KOM-4	47.40	11.07	12.66	10.84	9.28	1.72	0.06	0.084	0.656	0.206	0.007	0.219	0.008	3.8	98.0
JACK-1	48.71	13.95	12.34	7.17	12.35	1.13	0.24	0.065	0.932	0.203	0.011	0.085	0.009	2.6	99.8
BRS-48	44.77	10.43	13.37	12.04	8.67	1.96	0.01	0.16	0.65	0.26				7.40	99.74 ¹
SRG-22	51.70	14.40	12.00	7.04	7.81	2.86	<.10		0.90	0.21					97.52 ²
SRG-14	45.70	13.00	11.10	11.80	7.74	2.18	0.24		1.12	0.18				5.00	98.06 ²
SRG-15	37.50	4.40	9.15	32.00	2.05	0.07	0.05	0.03	0.29	0.15				13.0	98.58 ²
Pyrox ^{1c}	46.27	7.16	11.45	16.04	14.08	0.92	0.64	0.38	1.47	0.16				1.26	99.83 ³
Perid ^{1c}	42.26	4.23	10.19	31.24	5.05	0.49	0.34	0.10	0.63	0.41				5.27	99.46 ³
Dunite	38.29	1.82	12.97	37.94	1.01	0.20	0.08	0.20	0.09	0.71				5.27	98.53 ³

Sample Descriptions:

- STOP 2A:
- KOM-1: Coarse, plate spinifex-textured, basaltic komatiite
 - KOM-2: Massive, basal metapyroxenite unit (basaltic komatiite)
 - KOM-3: Randomly oriented, fine-grained, spinifex-textured upper flow (high-Mg tholeiitic basalt)
 - KOM-4: Overlying, pyroxene-phyric, pillowed basaltic komatiite
- STOP 2B:
- JACK-1: Variolitic pillow, section rim to core (high-Mg tholeiitic basalt)
 - BRS-48: Ultramafic intrusion, Little Steel Lake [3 km east of STOP2A]¹
 - SRG-22: Massive, high-Mg tholeiitic basalt, Stoughton-Roquemaure Group, Abitibi Belt²
 - SRG-14: Massive, basaltic komatiite, Stoughton-Roquemaure Group, Abitibi Belt²
 - SRG-15: Pillowed, ultramafic komatiite, Stoughton-Roquemaure Group, Abitibi Belt²

¹from Schnieders (1987)

²from Jensen (1976)

³Average Major Element Compositions of Igneous Rocks (LeMaitre 1976)

STOP 2B: JACKFISH PILLOWED BASALTS

No trip would be complete without a pillow lava stop! However, not only does this stop exemplify well-preserved volcanic features it also represents one end of the deformation-metamorphism spectrum in the Schreiber assemblage. It represents the most unmetamorphosed (greenschist facies), undeformed supracrustal rocks in the area. By comparison, the rocks we see to the east along the highway are progressively more deformed, metamorphosed and altered.

This exposure, first mentioned by Walker (1967), affords an excellent, three-dimensional view of relatively undeformed, pillowed, high-magnesium tholeiitic basalt flows which dip steeply (70°SE) and young to the southeast. About one-half of the flow succession within the 60m detailed section (Figure 4) is pillowed; the remainder is relatively massive or shows some incipient pillow development. Where traceable, flow contacts are sharp and conformable with other, horizontal features such as drain-away cavities and lava tube surfaces. Flow morphology and thickness are not readily apparent because of the lack of reliable marker units and the limited exposure along strike. Internal features of the flows, however, are remarkably well-preserved and provide insight into the nature of the lava and its eruptive environment.

The pillow-forms vary from small, ellipsoidal, bun-shaped masses (50-100 cm) to large, flat, mattress megapillows (≥ 3 m) which are interpreted as lava tubes (nomenclature of Dimroth et al. 1978). Pillows are tightly packed and molded to one another, with little massive, interpillow

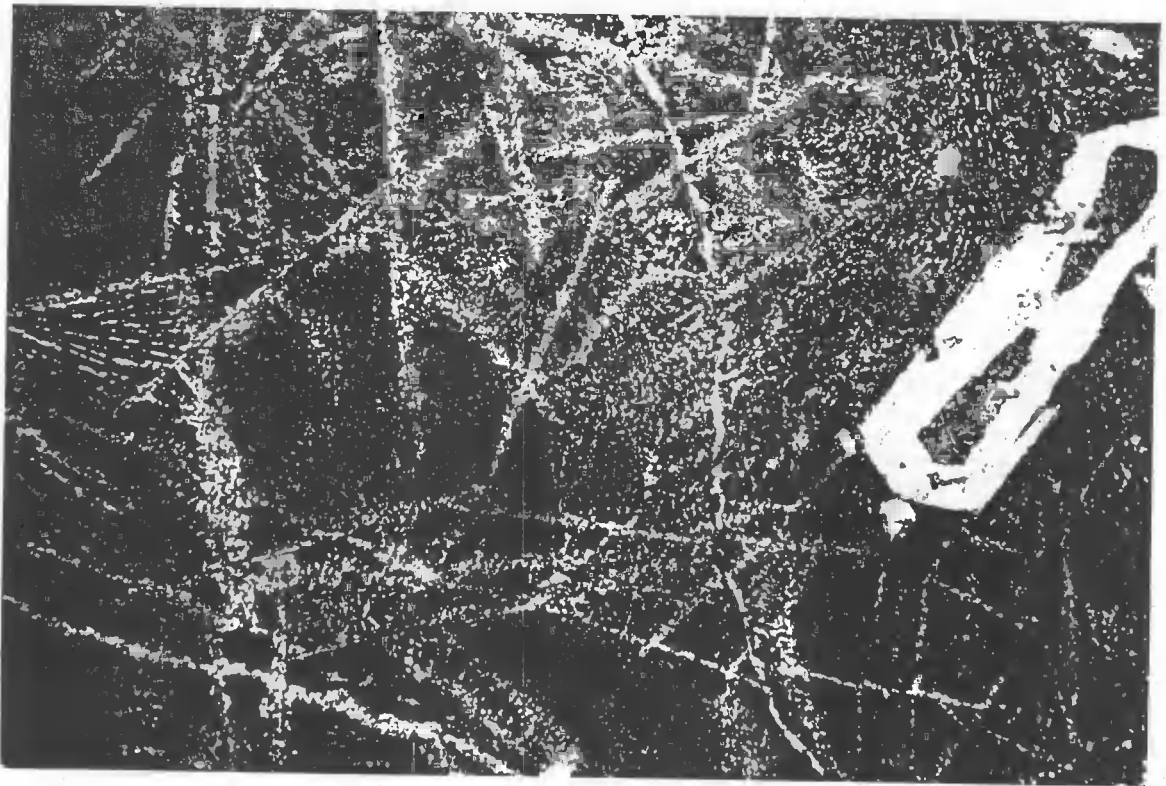
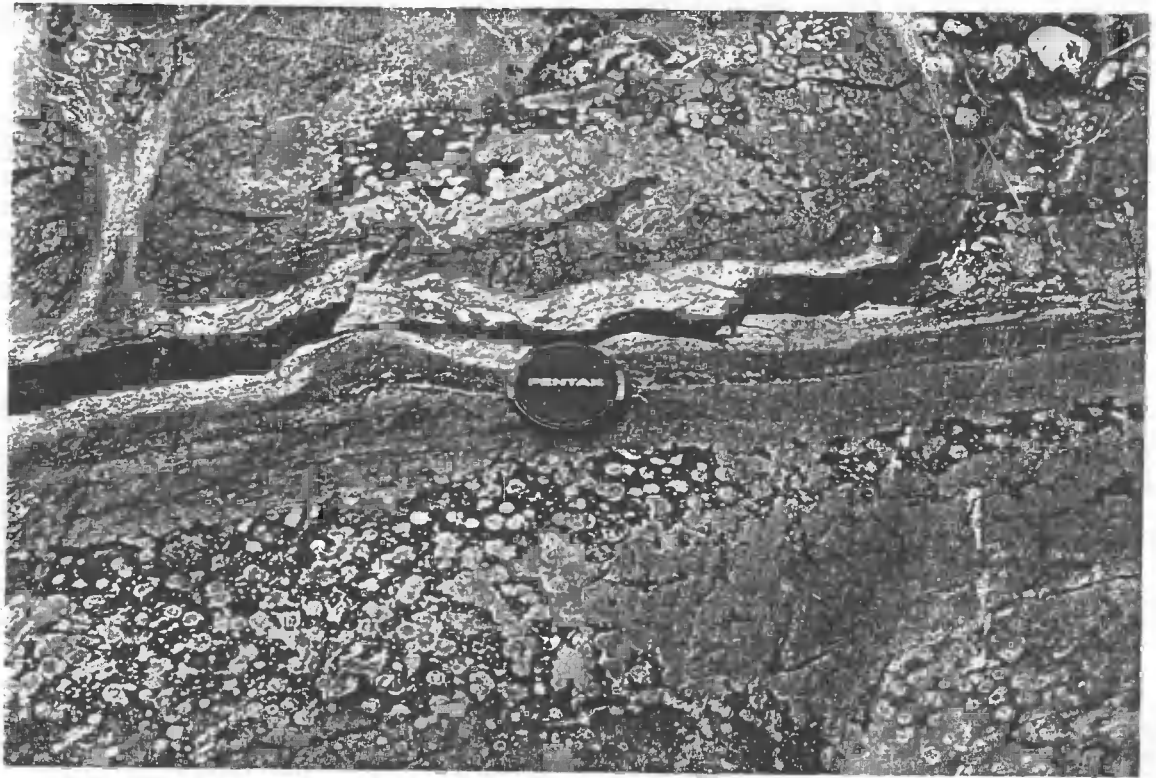
space. There is considerable size variation amongst pillows within the same part of the flow. Areas with rounded, bulbous pillow forms may represent flow tops (Wells et al. (1979). There is some evidence of lateral budding of pillows in the form of "neck-and-knob" development and re-entrants of chilled pillow crust, perhaps indicating too rapid chilling. Pillow imbrication is minimal.

Hyaloclastite is locally developed in the interpillow spaces. Autoclastic breccias are notably absent in this part of the succession but become volumetrically significant to the southeast (STOP 2A). Interflow sedimentary rocks, absent in this section, occur within stratigraphically lower flows to the northwest. Quartz-filled drain-away cavities or lava shelves provide excellent geopetal indicators. Individual pillows may contain up to 4 or 5 stacked cavities, which represent successive stands of falling lava (cf. Wells et al. 1979).

Although small, 2-4 mm, spherical vesicles and amygdules of quartz and calcite are evident, the local flow succession is characterized by the development of lime-green varioles. Smaller (≤ 2 mm) varioles tend to develop near pillow selvages while larger (≤ 10 mm) counterparts occur closer to the core of the pillow. They typically coalesce to form arcuate, somewhat concentric bands and pods along flow contacts, selvages and in pillow cores (Plate 3). In some examples, they comprise over one-half of the pillow. Some varioles display a concentric, macroscopic zonation between originally plagioclase-rich cores and more mafic, outer envelopes. Plagioclase crystals may project radially outwards from the otherwise fairly smooth, spherical variole margin.

Plate 3. Photograph of coalescing varioles in pillows, STOP 2B. Note hyaloclastite in interpillow spaces. Lens cap is 5 cm in diameter.

Plate 4. Photomicrograph (PPL) of reticulate plagioclase microlites and devitrified glass in variole (JACK-1), high-Mg basalt, STOP 2B. Note euhedral phenocryst of plagioclase(?), pseudomorphed by fine-grained quartz and epidote (dark patches near core). Field of view is 4.0 mm.



Local pillows are morphologically similar to spherulitic pillows described by Dimroth and Lichtblau (1979). They described a rim to core succession:

hyaloclastite → devitrified glass crust → zone of albite spherulites → isolated spherulites → coalescent spherulites → coarse, fibrous spherulites or dendrites → microlitic zone (core).

In thin section, the varioles consist of a glassy, altered groundmass which hosts a polygonal network of discrete, 0.02 to 0.04 mm wide, dendritic and plumose plagioclase microlites (Plate 4). Fe-oxides occur adjacent to the microlites. Subparallel, branching microlite arrays/intergrowths may occupy sections between larger crystals. These linear arrays are somewhat similar to quench-texture, skeletal olivine chains described by Gelinas and Brooks (1974) in Archean, high-magnesium tholeiites. The fine, fibroradial textures described by Fowler et al. (1987) are notably absent.

Conspicuous, subhedral to euhedral phenocrysts have been replaced by fine-grained quartz. They are typically ≤ 1 mm in diameter and occur both within varioles and in the more mafic groundmass. Quartz comprises coarser, polygonal mosaic-textured cores and finer-grained margins. Hollow crystal cores commonly host "islands" of epidote. Crystal habit and shape suggest that the original phenocrysts were plagioclase and/or olivine, both of which have similar cross-sections in orientations parallel to the c-axis. Quench olivine described by Gelinas and Brooks (1974) bears some striking similarity to the phenocrysts in question. They described hollow, quartz-replaced olivine euhedra in a matrix of plumose and branching clinopyroxene, with intervening calcic

plagioclase and devitrified glass. These quench textures were ascribed to rapid cooling (not necessarily supercooling) and are identical to those found in modern submarine lavas.

The greener (in hand specimen) areas between the varioles consist of coarse, polygonal chlorite aggregates with accessory, blocky epidote, quartz and Fe-oxides.

This section of subaqueous basalt flows was probably extruded in fairly deep water as suggested by low vesicularity and small vesicle size and sphericity, by the absence of significant volumes of pillow breccia (cf. Dimroth et al. 1978). The conformity of primary horizontal features suggests relatively flat depositional surfaces. Stacked megapillows are interpreted as successively emplaced flow lobes or lava tubes, each behaving as a single cooling unit. These tubes were perhaps feeders for overlying, pillowed sections. The lack of isolated, detached pillows may relate to relatively slow rates of spreading and lava production. However, laboratory experiments conducted by Gregg and Fink (1995) showed that pillows become larger and flatter as effusion rate and slope increase and/or cooling rate decreases.

The origin of varioles has been related to undercooling of the liquid during cooling (Fowler et al. 1987). Lava eruption temperatures of between 1300° and 1400° C have been suggested for basaltic komatiites and siliceous, high-Mg basalts (R. Keays, personal communication, 1994). In Archean tholeiites, varioles are spherulites produced by crystallization when nucleation is suppressed until the phase is well below its liquidus temperature; this textural development is due

to immiscibility. It is interesting to note that Fowler et al. (1987) stated that the textural development of varioles and komatiites are analogous in that both result from supersaturation brought about by supercooling.

STOP 3: TERRACE BAY BATHOLITH

This field stop is located near the northeastern contact of the Terrace Bay batholith, where it is in contact with predominantly mafic metavolcanic rocks, similar to those at Stops 2A and 2B. The contact lies along the base of a prominent, east-trending ridge of mafic metavolcanic rocks that lies approximately 800 m north of this highway stop.

The batholith is ovoid in plan view and extends for approximately 30 km from south of Schreiber to this vicinity. As described by Marmont (1984), the bulk of the batholith consists of massive, homogeneous, equigranular, medium-grained granodiorite. However, variations in texture, grain size, colour and composition are common, especially at and near intrusive contacts. Largely pristine and undeformed, the batholith may exhibit local, weakly developed mineral foliations and lineations near its margins. Marmont (1984) suggested that the lack of a chill margin, the presence of perthitic feldspar and the largely homogeneous, medium-grained texture suggest a relatively slow cooling history and a mesozonal emplacement level. The abundance of assimilated country rock xenoliths indicates that passive stoping was important.

A number of polymetallic, auriferous quartz veins, including the Mogotherium, Beaver Creek, Ferguson (Crystal Creek), Elgin/Siville-Ferrier and Mocan occurrences, occur in the vicinity. The largest of these, the Empress Mine (see Frontispiece), is located approximately 1 km north of this field stop, midway up the aforementioned metavolcanic ridge. Operated around the turn

of the century, this mine reportedly produced just over 100 ounces of gold. Base metal sulphides such as galena, chalcopyrite and sphalerite tend to characterize auriferous veins. The Ferguson occurrence is somewhat unique in that the minerals hessite (Ag_2Te), acanthite (Ag_2S), native bismuth, nuffieldite ($\text{CuPb}_2(\text{Pb,Bi})\text{Bi}_2\text{S}_7$) and an unidentified Cu-Bi-Pb-sulphide have been discovered there (Patterson et al. 1987; Kissin and McQuaig 1988). The possible role of the Terrace Bay batholith in epigenetic, Au-Cu-Mo mineralization is discussed prior to the description of Stop 4.

The granite exposed at this location is grey-weathering, equigranular, medium-grained and contains approximately 25% quartz, 40% potash feldspar, 25 to 30% oligoclase-andesine and 5% hornblende or biotite (Walker 1967). Minor constituents, in order of decreasing abundance, are sphene, apatite, fluorite, tourmaline, muscovite, epidote and magnetite. Molybdenite has been noted locally.

These glacially polished outcrops are characterized by numerous, partially digested, rounded to sub-rounded, mafic xenoliths. The xenoliths range in size from <1 to 15 cm, averaging 2 to 5 cm. Average abundance is in the order of ten xenoliths/m². Xenoliths range in composition from small, amphibole clots that presumably represent the refractive residuum left over from partial digestion, to larger, amphibole-phyric, diorite and mafic metavolcanic fragments. Xenoliths are recessively weathered, perhaps due to the presence of biotite. These xenoliths represent assimilated mafic metavolcanic country rocks and earlier, more mafic intrusive rocks

that pre-dated granitic intrusion. Marmont (1984) stated that the abundance of mafic enclaves is directly proportional with their proximity to the present batholith contacts and its upper/roof zone.

Hematitic alteration selvages have developed along cross-cutting fractures in the granodiorite.

Minor, glassy quartz veins are also present. Epidote $\pm$ chlorite occur on joint surfaces. The rock cut immediately east of the polished outcrops has followed a prominent, steeply dipping joint plane.

A composite, east-southeast-trending, Proterozoic diabase dyke intrudes the granite a short distance to the east and is exposed on both sides of the highway. This dyke is 1.2 m wide and dips steeply north to vertically. It is locally characterized by quartz-carbonate veinlets and clay alteration.

Gold Mineralization in the Schreiber Area

The Schreiber area first gained notoreity in 1851 when Terrace Bay became the site of the first molybdenite discovery in Canada (Geological Survey of Canada, Report of Progress, 1853-1856, p.40). Some of the earliest claim staking on the north shore took place on a gold property south of Schreiber in 1872, prior to the construction of the Canadian Pacific Railway. Early gold discoveries bewteen the mid-1890's and 1920 around Schreiber and north at Big Duck Lake were described by Hopkins (1922). This exploration ultimately led to surface and underground development on a number of small properties, resulting in a modest, collective gold production of approximately 3000 ounces. The largest producer, the North Shores Mine, yielded 2441 ounces at an average grade of 0.64 ounce Au per ton. Exploration and test milling have continued since mining activity lapsed in the 1930's.

Much of the following information has been gleaned from a variety of unpublished reports and articles archived in the Resident Geologist's Files, Schreiber-Hemlo District, Thunder Bay.

The vast majority of the more than 25 gold occurrences in the Schreiber area are hosted by discrete structures, usually composite, quartz $\pm$ carbonate veins. Vein orientations are generally subparallel to one another and to fault/joint sets in host rocks; *en echelon* and conjugate arrays are common. Auriferous structures are hosted by a variety of rock types, including supracrustal and felsic intrusive rocks. Veins are commonly localized along contacts and discontinuities.

Host rocks show little evidence of ductile deformation although some primary features may be somewhat flattened.

There is a strong spatial association between gold occurrences and felsic intrusive rocks (quartz- and quartz-feldspar porphyries, syenite and trondhjemite) as well as lamprophyre dykes.

Marmont (1984) investigated the occurrence of polymetallic, auriferous veins and Cu-Mo-bearing veins in and around the contact zone of the Terrace Bay batholith. Locally auriferous, sericite-chlorite-quartz-pyrite $\pm$ carbonate $\pm$ tourmaline alteration is commonly developed around veins, but is usually of limited lateral extent.

The vein-hosted nature of the gold suggests that mineralization took place in a brittle shear setting. Dilatancy in such an environment may have resulted chiefly from bulk, inhomogeneous flattening, perhaps related to compressive stress imparted by the enclosing Terrace Bay and Whitesand batholiths. Zones of competency contrast and pre-existing weakness (e.g. contacts, interflow sedimentary units, etc.) were important in the localization of shear zones and fractures. The close spatial association between felsic intrusive rocks, gold occurrences and hydrothermal alteration may reflect the fact that these rocks are loci for fracturing. It suggests that the hydrothermal activity which accompanied gold deposition may be related in part to late-stage events within these intrusions.

The two most important exploration criteria appear to be:

- (1) evidence of hydrothermal fracturing and alteration, and
- (2) rocks that are attributable to felsic magmatism, the late stages of which may often lead to the formation of hydrothermal ore deposits (Burnham and Ohmoto 1980).

A number of volcanic and intrusive igneous rocks sampled by Carter (1988) near Schreiber have alkalic, shoshonitic affinities. They can be geochemically classified (LeMaitre 1989) as latites, mugearites and biotite lamprophyre (kersantite), similar to those of the Timiskaming-like successions of the Shebandowan greenstone belt (summarized by Fyon et al. 1991). Pye (1969) referred to a package of conglomerate, quartzite and limestone mapped by Harcourt and Bartley (1939) south of Schreiber as Timiskaming. Hornblende-phyric, syenitic rocks are spatially associated with many gold occurrences in both areas, bearing similarity with syenite-hosted gold deposits in the Matatchewan and Kirkland Lake areas of eastern Ontario.

STOP 4: GOLD RANGE PROSPECT

Gold was discovered just before the turn of the century on a northeast-trending ridge of metavolcanic rock near the contact with the Terrace Bay batholith, 4 km east of Schreiber.

Several subsequent discoveries of auriferous quartz veins led to the development of the adjoining Otisse, Harkness-Hays and Gold Range properties.

The Gold Range prospect was first staked in 1917 and explored for several years. In 1922, two adits were driven into the hillside by the Jackson Development Co. Ltd. Newly incorporated Gold Range Mines Ltd. acquired the property in 1934, continued underground development and investigated the placer potential of the sand and gravel at the base of the hill. Overburden extracted from test shafts was treated with a Denver concentrator. Sampling of two shafts at one-foot intervals in 1936 returned averages of 0.04 ounce Au per ton to 17 feet and 0.10 ounce Au per ton to 22 feet, respectively. A tramway and a small mill were erected on site to handle high-grade vein ore. Ore was crushed, pulverized and roasted. Gold was recovered with amalgamation; tables were reportedly installed to produce a sulphide concentrate as well. The first gold brick (22 ounces), representing 40% of the total gold concentrates processed to that time, was poured in mid-1936. Gold Range Mines was subsequently succeeded by Rolac Mines. The property became inactive around 1941. It has been explored by various individuals and companies since then.

Local Geology

The property straddles the northern contact (trending 030°) of the Terrace Bay batholith with mafic metavolcanic rocks. This contact is locally obscured by deep glacial drift. The mafic metavolcanic rocks are locally pillowed and have been upgraded to amphibolite-facies within the contact metamorphic aureole of the batholith. Coarser-grained, mafic units have been interpreted as gabbros. Sulphide- and oxide-facies banded iron formation, wacke and conglomerate are intercalated with the mafic flows. Tracing of one iron formation across the Harkness-Hays, Gold Range and Otisse properties reveals tight to isoclinal folds (Holbrooke 1939; Resident Geologist's Files, Schreiber-Hemlo District, Thunder Bay).

In the vicinity of the main workings, a series of quartz-feldspar porphyry dykes intrudes the mafic metavolcanic rocks and strikes 030° and dips 20° to 40° northwest. Biotite-bearing, brown to black lamprophyre (kersantite?) dykes intrude all of the aforementioned rocks and are intimately associated with some of the veins.

Gold mineralization on the property is associated with a series of at least seven numbered, subparallel veins that strike north-northeast and dip steeply to the northwest (Figure 6).

Although all these veins were discovered on surface, only veins No.'s 1 and 2 were investigated and mined underground using three adits and short drifts.

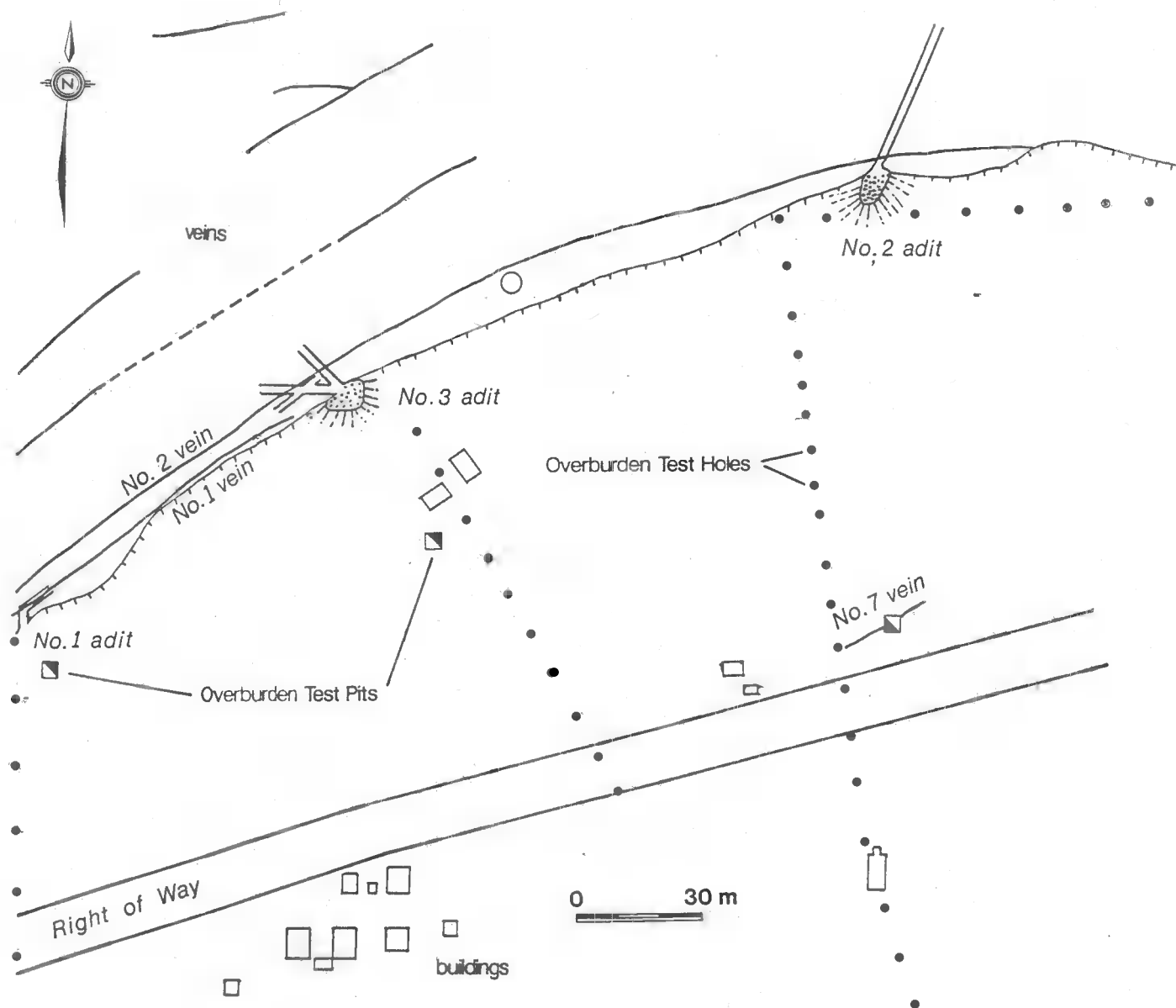


Figure 6. Sketch map of the Gold Range prospect (from Holbrooke 1939)

The veins are typically narrow (5 to 25 cm) but are remarkably persistent along strike. They may split and develop "horse-tail" structures that increase the vein width. Sub-parallel microveinlets are also common. The veins are rarely composite or crack-seal textured, but do contain septa and xenoliths of wall rock. Cockscomb textures are developed in drusy quartz and calcite. Vein breccias contain fragments of other vein gangue as well as altered wall rock. Slickensides are visible along vein margins.

Despite the narrow widths of the veins, hydrothermal alteration extends from the vein margins several centimetres into the wall rock. This alteration is manifested as a pale, grey to lime green zone that has a rusty weathered appearance (Plate5). Marmont (1984) has identified mineralogic zonation within the alteration envelope (from host towards vein):

[host] | sericite-biotite | sericite-carbonate-Mg(?) -chlorite | carbonate-Fe(?) -chlorite-quartz | [vein]
 | -----potassic alteration ----- carbonatization -----silicification----- |

Sulphides, predominantly pyrite, are ubiquitous, but are locally developed immediately adjacent to the vein itself. Altered zones are themselves commonly auriferous.

Coarse, visible gold occurs within quartz, but it also occurs as discrete grains within large (≤ 2.5 cm), euhedral pyrite crystals. The No.2 vein displays abundant pyrite euhedra where the vein is crosscut by a lamprophyre dyke. Gold-bearing tellurides, calaverite (AuTe_2) and sylvanite

((Au,Ag)Te₂), have also been noted. Accessory sulphides include pyrite, with lesser chalcopyrite, pyrrhotite, sphalerite, molybdenite and galena. Calcite, graphite, epidote and magnetite are also present. In addition, Sabina (1991) noted garnet, goethite and basaluminite (Al₄SO₄(OH)₁₀·4H₂O) on the adjacent Harkness-Hays property.

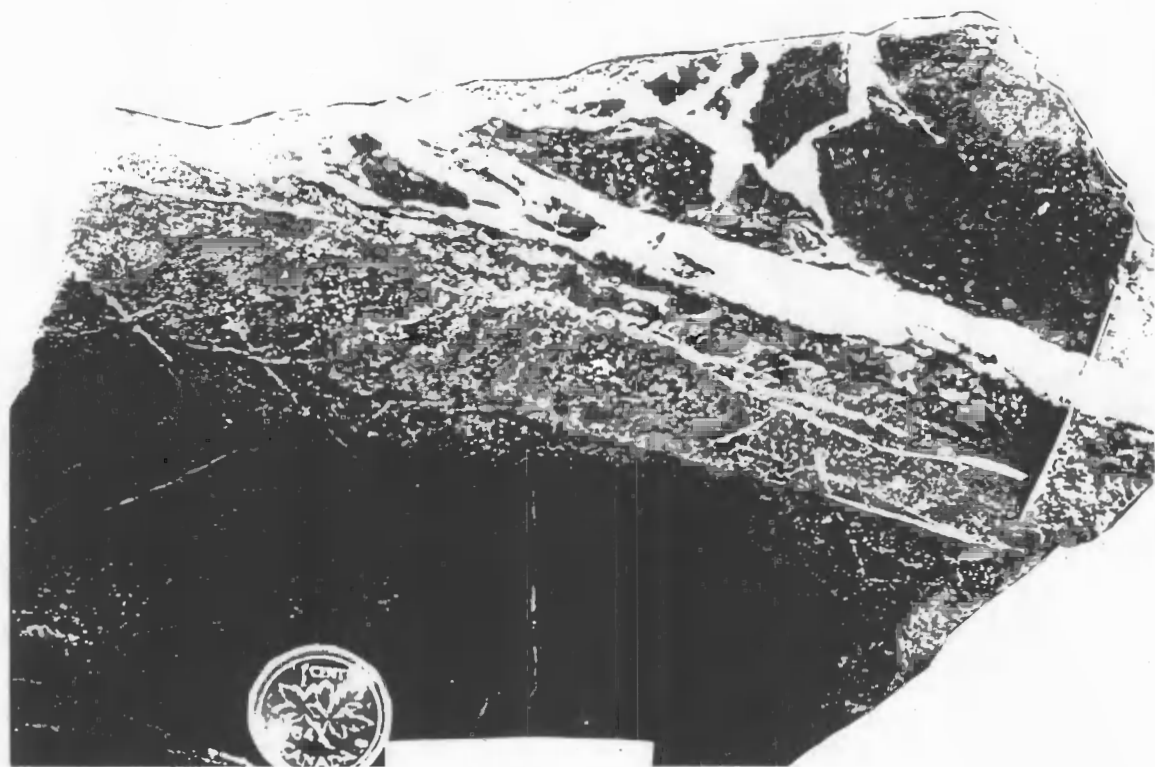


Plate 5. Alteration envelope around quartz vein in gabbro, Gold Range prospect (STOP 4).

Coin is 1.5 cm in diameter.

Sampling by Holbrooke (1939) of the No. 2 vein returned an average of 0.49 ounce Au per ton over 0.28 m for a length of 7.6 m. These results were probably typical of the best-mineralized sections of the veins. Typical grab samples of high-grade material have commonly returned between 5 and 20 ounces Au per ton. Silver values are about one-half that of the corresponding gold assays in these samples. Approximately 42 ounces of gold were eventually recovered during early mining operations.

Geology of the No. 7 Vein Shaft Area

The shaft exposed near the access road was sunk to a depth of 7.7 m to investigate the No. 7 vein. This vein, striking 040° and dipping 75° northwest, returned up to 0.98 ounce Au per ton over 0.36 m; most samples returned only trace amounts of gold (Holbrooke 1939). Harcourt (1939) reported that the vein was wider and carried gold at the shaft bottom. Visible gold was noted near the shaft bottom by the authors during a 1987 property visit. Diamond drilling and the stripping in the vicinity of the No. 7 vein were carried out in 1987 by Forerunner Resources Limited (now Beardmore Resources Limited).

The host rocks consist dominantly of equigranular gabbro that has been intruded and brecciated by dykes of pink granodiorite that extend off the main mass of the Terrace Bay batholith to the

east, across the road. In thin section, the unaltered gabbro contains plagioclase and pyroxene, including inverted pigeonite. Where altered adjacent to quartz veins, the original gabbroic texture has been replaced by a fine-grained matte of carbonate, sericite, quartz, epidote and pyrite. Coarse grains of visible gold have been noted in this altered zone.

Subparallel stringers of quartz, enveloped by conspicuous, rusty, carbonate-rich alteration haloes, are exposed at the shaft collar. Well-developed, orthogonal joint sets are also prominent. Dump material, extracted during shaft excavation and subsequent reclamation, has been piled nearby. Vein material with ubiquitous alteration is abundant in the dump.

STOP 5: WINSTON LAKE Cu-Zn MINE

Exploration and Mining History of the Winston Lake Mine

The exploration history of the Winston Lake Mine has been described by Balint et al. (1990) and Severin et al. (1990). The earliest exploration activity is largely gleaned from government reports and other documents (Resident Geologist's Files, Schreiber-Hemlo District, Thunder Bay).

Activity in the area dates back to the discovery and initial development of the Zenith Mine in 1879. High-grade (~45% Zn), sphalerite-rich, massive sulphide was mined on surface, hand-cobbed and shipped overland to a railway spur near Schreiber. Around the turn of the century, the Grand Calumet Mining Company Ltd. mined and concentrated approximately 2700 tons of ore. The property remained largely dormant until the 1960's when Zenmac Metal Mines Limited began shaft sinking, underground development and erected surface plant facilities.

Production from 1966 to 1970 totalled 164 000 tons of ore at a grade of 16.5% Zn.

In October, 1978, Corporation Falconbridge Copper (CFC) carried out reconnaissance geological and lithogeochemical surveys around the Zenith Mine in order to assess the exploration potential of this portion of the Big Duck Lake volcanic assemblage, previously mapped by Pye (1964).

Rocks previously interpreted as metasedimentary were recognized as hydrothermally altered, felsic metavolcanic rocks. The lithogeochemistry of these altered rocks was noted to be similar to

that of rocks at CFC's Sturgeon Lake Mine, primarily on the basis of sodium depletion and zinc enrichment. The delineation of an alteration zone 1200 m west of the Zenith Mine prompted CFC to acquire an option on the Zenith property and stake the ground around it.

In 1979 and 1980, detailed geological, lithogeochemical and geophysical (magnetometer, VLF-EM, and Max-Min II) surveys were conducted. Although geophysical results were disappointing, geological and lithogeochemical surveys succeeded in discovering zones of cherty, bedded ash within the calc-alkaline, felsic volcanic rocks and they further delineated the hydrothermal alteration zone. A geological model depicted the Zenith deposit as a raft of massive sulphide that had been stoped off of a larger, as yet undiscovered, felsic volcanic-hosted, sulphide deposit by a composite, gabbroic intrusion.

In 1981, eight diamond drill holes were completed, four of which tested the geological model. They intersected a cherty ash horizon that occurs at the top of the felsic volcanic pile, overlying the alteration zone, at the contact with the gabbro. Encouraging results included up to 0.5% Zn over 4.3 m. Subsequent borehole pulse EM surveys detected a strong, edge-type anomaly down-dip of the mineralized exhalite intersection.

In June, 1982, a follow-up drill hole intersected 2.1 m of massive sulphide (@ 1.10% Cu, 19.11% Zn, 22.2 g/t Ag and 0.73g/t Au) at the base of the gabbro sill, 300 m below surface.

Subsequent definition drilling and exploratory shaft sinking produced a reserve figure of 2 675 000 t grading 0.94% Cu, 17.81% Zn, 25.3 g/t Ag and 0.85g/t Au (Severin and Balint 1984). A production decision was delayed as the price of zinc fluctuated and development was suspended in 1985. Activity was renewed by Minnova Inc. and development ore was hoisted to surface throughout 1987. Original mineable reserves (all categories, including 20% dilution at zero grade) reported on November 1, 1987 were 3 076 339 tonnes at a grade of 1.00% Cu, 15.60% Zn, 30.87 g/t Ag and 1.02 g/t Au (Severin et al. 1990). The first concentrate was produced in January, 1988 and the mine's official opening took place in July, 1988. In May, 1993, Minnova Inc. merged with a wholly-owned subsidiary of Metall Mining Corporation.

Mine reserves as of January 1, 1995 stood at 733 306 tonnes at a grade of 12.05% Zn, 0.89% Cu, 26.82 g/t Ag and 1.647 g/t Au (G. Doiron, Metall Mining Corporation, personal communication, 1995). These estimates include proven, possible and potential ore with a 20% dilution at 0% grade.

Metall began drifting from the 615 m level of the Winston Lake Mine in August, 1993 in order to assess the Pick Lake upper zone deposit. This deposit was initially defined by surface drilling from the mid-1980's to 1992. The deposit consists of two thin, but continuous, massive sulphide sheets with a down-plunge length of 1400 m. The Upper Zone and Lower Zone average approximately 2.2 and 4.0 m in thickness, respectively. Potential reserves stand (as of January, 1995) at 1 147 442 t (20% dilution at 0% grade included) at 1.24% Cu, 20.05% Zn, 56.11 g/t Ag

and 0.33 g/t Au. Underground drilling in early 1995 will be used to determine the economic feasibility of mining the Pick Lake deposit.

Geology of the Winston Lake Mine

The local geology, particularly those aspects which are associated with volcanogenic massive sulphide, Cu-Zn mineralization, has been studied by the aforementioned authors, as well as Osterberg (1993), Osterberg and Morrison (1991), Severin and Balint (1984) and Thomas (1991).

The Winston Lake area lies within the northernmost portion of the Schreiber greenstone assemblage and the Wawa subprovince, near the boundary with the Quetico subprovince. Local metavolcanic, metasedimentary and associated intrusive rocks comprise a 4 km by 15 km package of rocks informally referred to as the Big Duck Lake greenstone belt (Balint and Severin 1984). These rocks are separated from the bulk of the Schreiber greenstone assemblage to the south by granitoid rocks of the Crosman Lake batholith. Several mapping projects covered the Big Duck Lake area, including those of Collins (1909), Hopkins (1915; 1921), and Bartley (1942). Gold was discovered at Big Duck Lake in 1906, leading to the subsequent discovery and exploration of over twenty gold and polymetallic occurrences for the next two decades. Activity in the "Duck Lake gold field", as it was then termed, peaked in the 1920's but has continued to the present.

The outer flanks of this part of the Schreiber assemblage have undergone upper greenschist to amphibolite grade regional metamorphism, typified by garnet and hornblende, while rocks in the core display quartz-chlorite-actinolite-albite assemblages typical of greenschist facies (Pye 1964). Pye (1964) also did a comprehensive investigation of the mineral deposits of the area in the course of his mapping.

Balint and Severin (1984) outlined the basic architecture of the supracrustal and associated rocks in the vicinity of the Winston Lake Mine (Figure 7):

(1) Winston Lake Sequence:

- ~ calc-alkaline, felsic and mafic metavolcanic and lesser metasedimentary rocks
- ~ predominantly lava flows with subordinate pyroclastic rocks

(2) Big Duck Lake Sequence:

- ~ overlies Winston Lake Sequence
- ~ predominantly tholeiitic basalt flows
- ~ flows intruded by Big Duck Lake quartz- and quartz-feldspar porphyry sills
- ~ separated from Winston Lake Sequence by a series of differentiated, tholeiitic, mafic to ultramafic sills

As a result of mapping and lithogeochemical sampling in the 1980's, subsequent base metal

exploration and associated research have been confined to the Winston Lake Sequence, which hosts the the Winston Lake, Zenith and Pick Lake deposits, as well as a number of surface, copper and zinc occurrences. Metall Mining Corporation conducted surface exploration and diamond drilling on their Cleaver Lake, Ciglen, Gesic, Pick Lake, Winston Lake and Zenith properties in 1994 (G. Doiron, Metall Mining Corporation, personal communication, 1995).

Physical volcanological studies by Osterberg (1993) and Osterberg and Morrison (1991) indicated that the footwall rocks to the Winston Lake Mine are dominated by interlayered successions of deep-water volcanoclastic, sedimentary and flow units. Footwall volcanic stratigraphy apparently developed as the result of cyclic accumulation of volcanoclastic and volcanic rocks in a subsiding, subaqueous, rift environment. A stratigraphic column depicting the lithologic subdivisions of the Winston Footwall Block (Osterberg 1993) is shown in Table 2. Volcanic rocks have been extensively intruded and block faulted.

Tectonic deformation features in local rocks have been described by Balint and Severin (1984), Osterberg (1993) and Williams (1989). Ductile deformation is typically manifested in flattening and foliation, as well as minor folds. The degree to which original stratigraphic and contact relationships have been modified by tectonism is still a matter of much debate.

Williams (1988, 1989) has described extremely deformed rocks of what he termed the Big Duck Lake shear zone. In his opinion, the ubiquity of tectonic layering precludes recognition of the

state of deformation and original lithologic relationships. Moreover, Williams (1988) interpreted the schistose contact between the hanging wall gabbro, the ore zone and altered footwall rocks **(Stop 5A)** as highly sheared, with slip directions generally down-dip of the schistosity, suggestive of thrusting and dip-slip tectonics.

Table 2. Stratigraphic subdivision of part of the Winston Footwall Block (from Osterberg 1993)

Winston Lake Horizon (WLH)

Winston Lake VMS Deposit (WLH-MS)

Mafic volcanic and intrusive feeder rocks (WLH-FR)

Mixed laminated ash and exhalative sedimentary rocks (WLH-CRT)^{5A}

Mafic lava flows (WLH-MA), including Footwall Flow (WLH-FWF)^{5B}

Upper Clastic Succession (UCS)

Clotted Rhyolite (CLR)^{5B}

Volcaniclastic and associated rocks (SIV)

Felsic tuffs (SIV-FT), Intermediate volcaniclastic rocks (SIV-VC)

Middle Flows Succession (MFS)

Synvolcanic felsic-derived volcaniclastic sedimentary and tuffaceous rocks (CT)^{5D}

Undivided mafic rocks (MA)

Middle mafic flow and associated rocks (MMF)

Camp Flow rhyolite and associated feeder dikes (QFF)^{5C}

Ladder basalt flow (LF)^{5E}

"Main" quartz-feldspar porphyry (QFP)^{5F}

(n.b. Superscripted numbers denote the Field Trip Stop which displays this unit.)

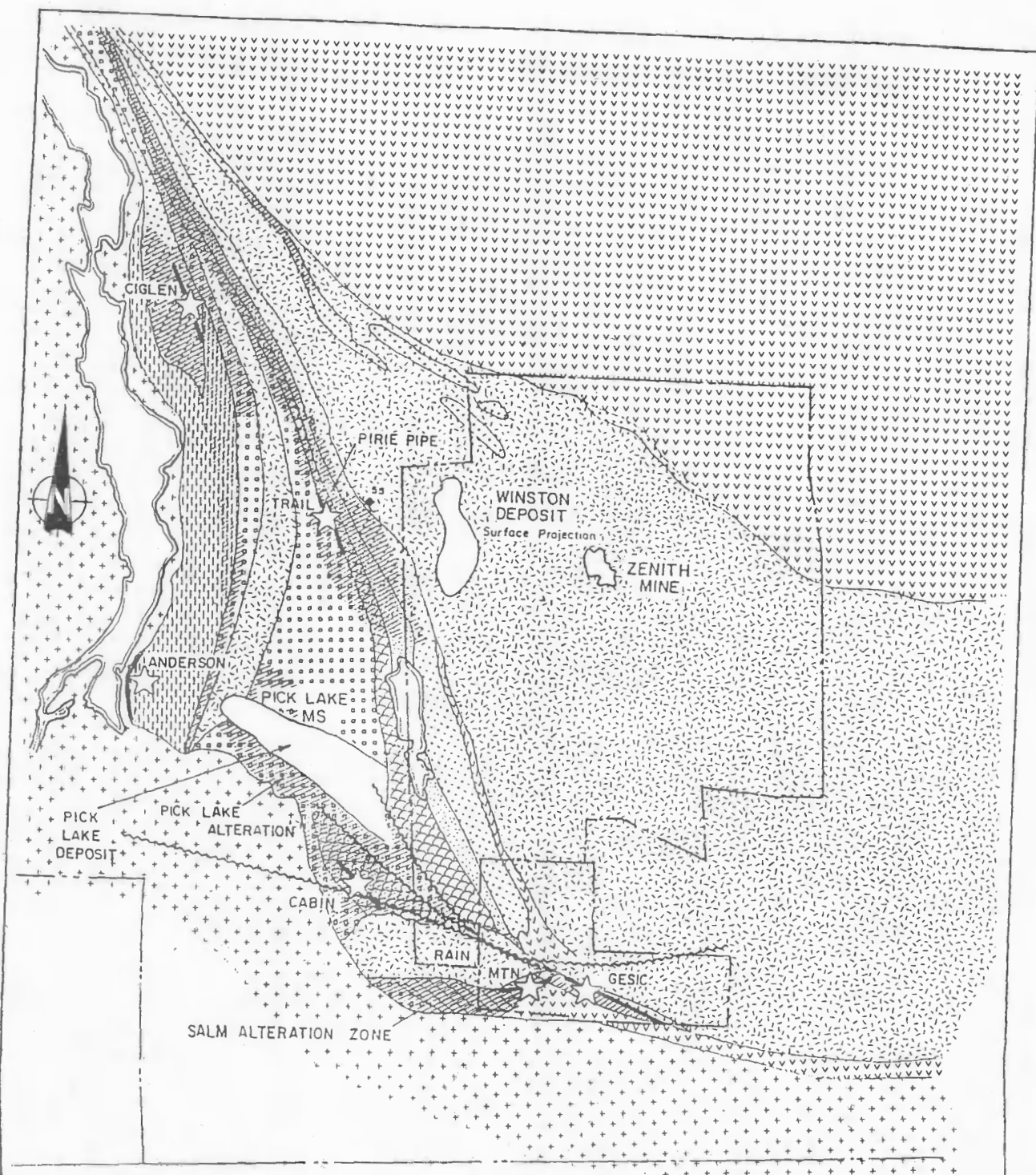


Figure 7. WINSTON LAKE AREA
GEOLOGY MAP

0 1 Km

- | | |
|---|---|
|  GRANITE |  FELSIC TO INTERMEDIATE VOLCANICLASTIC |
|  DIFFERENTIATED GABBRO SILLS |  QUARTZ FELDSPAR PHYRIC FLOW |
|  APHYRIC MAFIC FLOWS |  QFP FLOW / SUBVOLCANIC INTRUSION |
|  FELDSPAR PHYRIC MAFIC FLOWS |  META-SEDIMENTS WACKES & ARENITES |
|  ALTERATION |  MINERALIZED HORIZON |

Hydrothermal Alteration

The recognition of hydrothermally altered rocks at Winston Lake by CFC geologists in the late 1970's led to the acquisition of the property, prompted further exploration work and led ultimately to the discovery of the Winston Lake and other deposits. The occurrence of cordierite and orthoamphibole (anthophyllite/gedrite) or sillimanite was ascribed to syn-volcanic, hydrothermal metasomatism and subsequent, isochemical amphibolite-facies metamorphism. Osterberg (1993) has noted that approximately 50% of the footwall stratigraphy has been altered in sub-concordant to cross-stratal zones, presumably related to original, lithologic permeability. Other minerals that comprise the various alteration assemblages include tremolite-actinolite, biotite, muscovite/sericite, staurolite, chlorite, K-feldspar and quartz.

Hydrothermal alteration has greatly changed the primary lithogeochemistry. Mineralogic variation in altered rocks is reflected by variable enrichment of MgO, Fe₂O₃T, and K₂O, as well as depletion of CaO and Na₂O (Osterberg 1993; Severin and Balint 1984 (Figures 8A,B; Table 3); Severin et al. 1990). Osterberg (1993) noted that all major oxides, with the exception of TiO₂ and Al₂O₃, show significant mobility. Component changes, while similar in each alteration type, generally increase in the order: tremolite/actinolite ≤ biotite < sillimanite ± staurolite ≤ anthophyllite/gedrite (Osterberg 1993).

Osterberg (1993) has envisaged a multi-stage, syn-volcanic hydrothermal model at Winston

Lake that involves at least three distinct hydrothermal fluids, including:

- (1) seawater-based fluids that were primarily responsible for Mg-enrichment,
- (2) chemically evolved fluids that reacted with the rocks to produce stratiform zones of variable Fe-aluminous assemblages, and
- (3) metalliferous fluids that were base metal-rich and probably otherwise similar to chemically evolved fluids.

Schandl and Gorton (1991) identified REE-rich monazite and xenotime within chlorite-sericite-biotite alteration around the Winston Lake and other Precambrian massive sulphide deposits.

Intimate textural associations suggested that these REE-enriched phosphates and the alteration assemblage minerals co-precipitated from a common fluid at 2677 ± 1 Ma (U-Pb age of monazite, Schandl et al. 1991). This interpretation conflicts with the widely accepted model of synvolcanic alteration by stating that alteration represents a late, post-mineralization, metasomatic overprint.

A U-Pb zircon age of 2723 ± 2 Ma for the host rhyolite at Winston Lake was published by Schandl et al. (1991).

Table 3. Partial Whole Rock and Trace Element Geochemistry, Winston Lake Volcanic Rocks

Lithology	SiO ₂	Al ₂ O ₃	FeO ^T	MgO	CaO	Na ₂ O	K ₂ O	TiO ₂	Cu	Zn
WLH-FWF	48.7	15.25	8.49	6.94	7.89	4.06	0.75	1.01	94	35
WLH-FWF*	34.3	19.72	11.83	19.85	0.80	1.12	1.88	1.26	104	50
MMF	52.1	15.49	8.49	5.01	7.96	3.71	0.48	1.34	45	10
MMF*	51.2	14.69	10.00	11.57	0.11	0.54	1.39	0.89	109	43
F-IV	72.2	10.96	3.25	1.19	2.53	5.04	0.26	0.41	36	12
F-IV*	68.1	11.35	6.04	5.92	0.53	1.13	1.79	0.36	441	125
QFPRF	77.3	12.18	1.63	0.32	1.23	6.06	0.09	0.23	3	7
QFPRF*	74.9	10.32	3.63	6.19	0.62	0.47	1.13	0.27	83	17
LF	46.7	18.00	10.51	5.06	7.25	3.59	1.67	0.94	233	21
LF*	49.6	14.35	19.29	7.65	0.34	0.52	0.19	0.82	42	76
QFP	74.6	11.43	2.22	0.91	1.88	4.16	0.65	0.30	5	23
QFP*	79.9	7.86	5.60	2.64	0.06	0.06	2.03	0.27	20	58
Gabbro	50.9	14.30	11.60	7.94	11.10	1.85	0.30	0.76		
Pyroxenite	41.5	6.03	15.50	24.20	5.05	0.07	0.02	0.50		

Key to Abbreviations:

WLH-FWF Footwall Mafic Flow

F-IV Felsic-Intermediate Volcaniclastics

LF "Ladder" Mafic Flow

MMF Middle Mafic Flow

QFPRF Quartz-Feldspar-Phyric Rhyolite Flow

QFP Quartz-Feldspar Porphyry

Hydrothermally altered equivalents are marked with an asterisk (*).

Data from Severin and Balint (1984). Some abbreviations from Osterberg (1993).

Geochemical Changes with Alteration

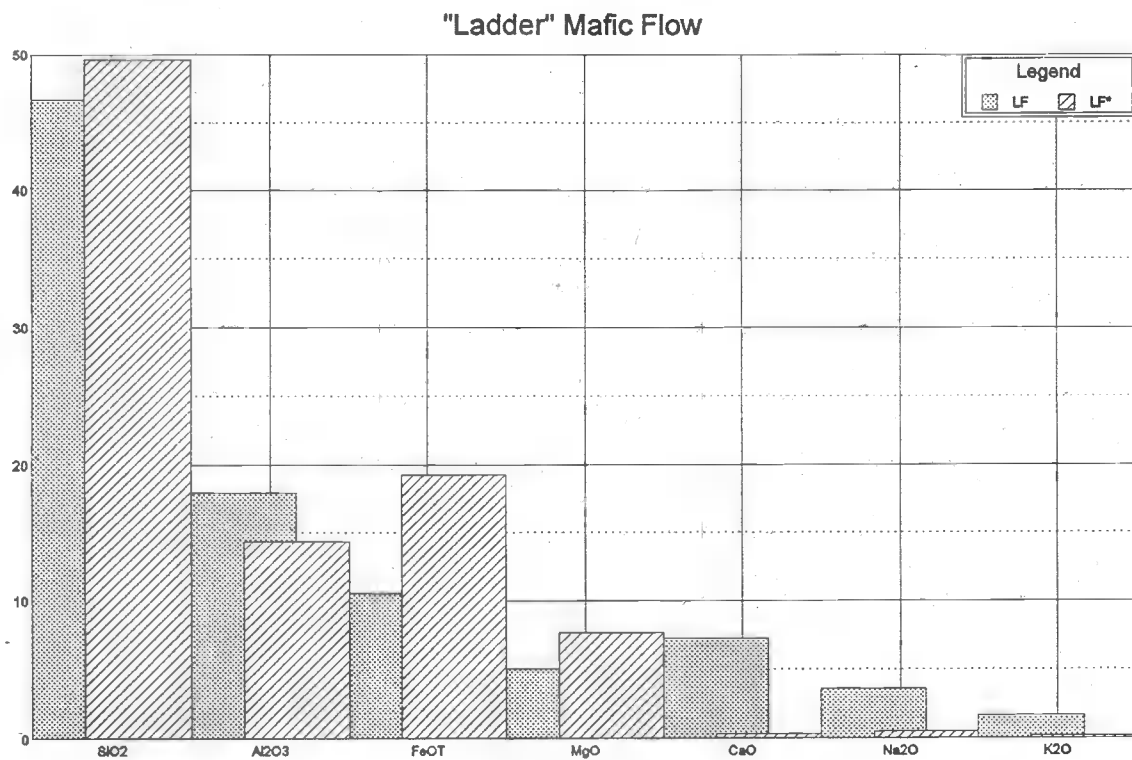


Figure 8A. Geochemical changes between unaltered (LF) and altered (LF*) rocks, "Ladder" mafic flow. Data from Severin and Balint (1984).

Geochemical Changes with Alteration

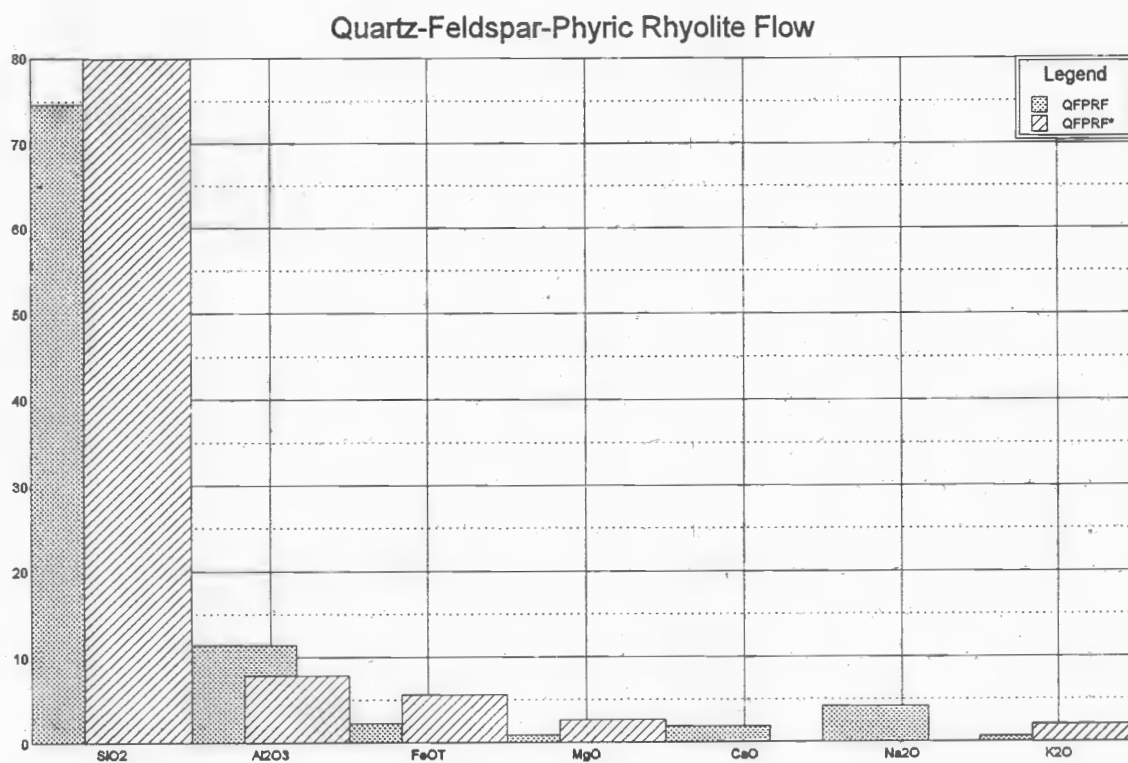


Figure 8B. Geochemical changes between unaltered (QFPRF) and altered (QFPRF*) rocks, quartz-feldspar-phyric rhyolite flow. Data from Severin and Balint (1984).

Massive Sulphide Ore

The ore zone at Winston Lake, as described by Severin et al. (1990) and Balint et al. (1990), varies in thickness from 2m to >20 m (horizontal), averaging 7m. Two main, apparently unzoned, ore types exist:

(1) "low-grade" (7-14% Zn):

- ~ massive to locally banded, fine- to medium-grained
- ~ homogeneous mix of sphalerite, pyrrhotite, pyrite, chalcopyrite
- ~ 10-20% included fragments (<1-5 cm)

(2) "high-grade" ($\leq 54\%$ Zn):

- ~ massive, medium- to coarse-grained sphalerite
- ~ locally banded with chalcopyrite and/or pyrrhotite

Less common metallic minerals include magnetite, marcasite, arsenopyrite, mackinawite and galena (Barr 1991). Bismuthinite (Bi_2S_3), gladite ($\text{CuPbBi}_5\text{S}_9$), galenobismutite (PbBi_2S_4) and anhydrite have also been identified by X-Ray diffraction analysis (Resident Geologist's Files, Schreiber-Hemlo District, Thunder Bay). Hessite (Ag_2Te), native silver and tellurobismuthite (Bi_2Te_3) have also been noted, as have the spinels franklinite, chromite and gahnite.

The thickest part of the ore zone corresponds to the thickest portion of the footwall alteration zone. There is no apparent zinc and copper zonation within the deposit, although there is evidence of remobilization on a small scale. A concentrically zoned, sulphide-filled cavity was discovered during mining operations in 1992 and has been interpreted as a sulphide chimney, akin to "black smokers" of modern oceanic hydrothermal systems. It consists of a chalcopyrite-rich core, a sphalerite zone and an outer zone of large selenite crystals. Sulphur isotope analyses of the massive sulphide and selenite-rich portions returned $\delta^{34}\text{S}$ values of -0.6 ‰ and +13.1 ‰, respectively (G. Doiron, Metall Mining Corporation, personal communication, 1995). Samples of massive sulphide and anhydrite from the Geco Mine, Manitouwadge, returned similar $\delta^{34}\text{S}$ values of +0.5 and +10.0 ‰, respectively (Franklin et al. 1981). Most Precambrian massive sulphide deposits yield ore sulphide values close to 0‰ (close to the "mantle" composition). Metamorphism precludes reasonable interpretation of data and isotopic disequilibria.

Osterberg (1993) proposed a metallogenetic model in which metalliferous fluids migrated through altered rocks and were trapped under impermeable CLR cap rock. Synvolcanic faulting allowed these fluids to migrate from the pressurized reservoir to the sea floor environment, resulting in the repeated precipitation of massive Zn- and Cu-sulphides.

Individual Stop Descriptions: Footwall Stratigraphy

The following stops exemplify both altered and unaltered footwall lithologies that structurally and stratigraphically underlie the Winston Lake massive sulphide deposit. These stops have been prepared and used on numerous field trips and therefore their descriptions have been largely gleaned from previous workers, including Balint et al. (1990), Severin and Balint (1984) and Severin et al. (1990). The stratigraphic and volcanological setting of the individual field stops has been described most recently and completely by Osterberg (1993), whose lithologic nomenclature (Table 2) will be adopted for these descriptions. Refer to Figures 9A and 9B for stop locations.

STOP 5A: Winston Lake Horizon / Hanging Wall Gabbro Contact

STOP 5B: Creek Copper Showing

STOP 5C: Altered Camp Flow Rhyolite

STOP 5D: Incipiently Altered Ladder Flow / Trail Showing

STOP 5E: Altered Pillowed Ladder Flow

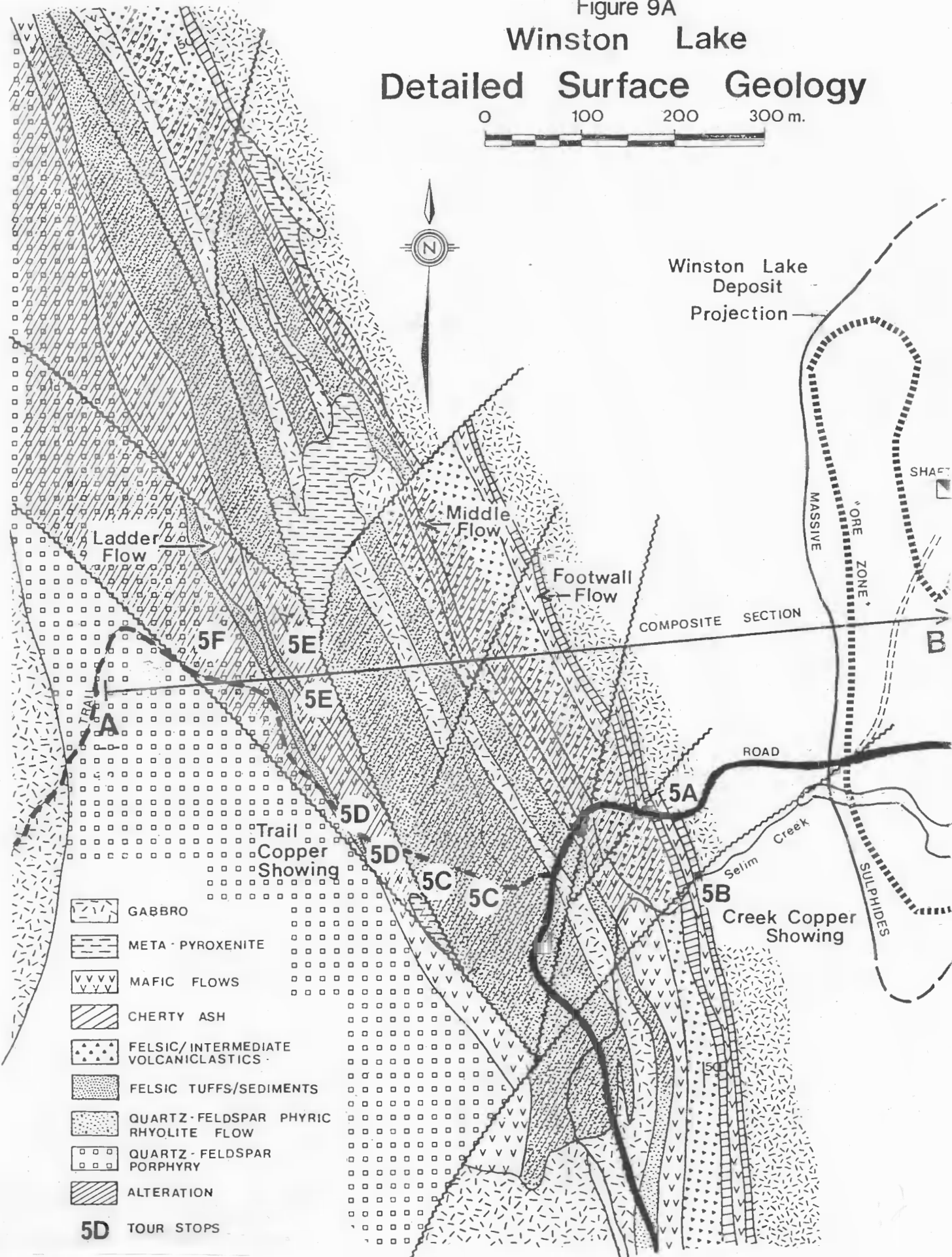
STOP 5F: "Main" Quartz-Feldspar Porphyry

Figure 9A
Winston Lake
Detailed Surface Geology

0 100 200 300 m.



Winston Lake
Deposit
Projection



- GABBRO
- META-PYROXENITE
- MAFIC FLOWS
- CHERTY ASH
- FELSIC/INTERMEDIATE VOLCANICLASTICS
- FELSIC TUFFS/SEDIMENTS
- QUARTZ-FELDSPAR PHYRIC RHYOLITE FLOW
- QUARTZ-FELDSPAR PORPHYRY
- ALTERATION

5D TOUR STOPS

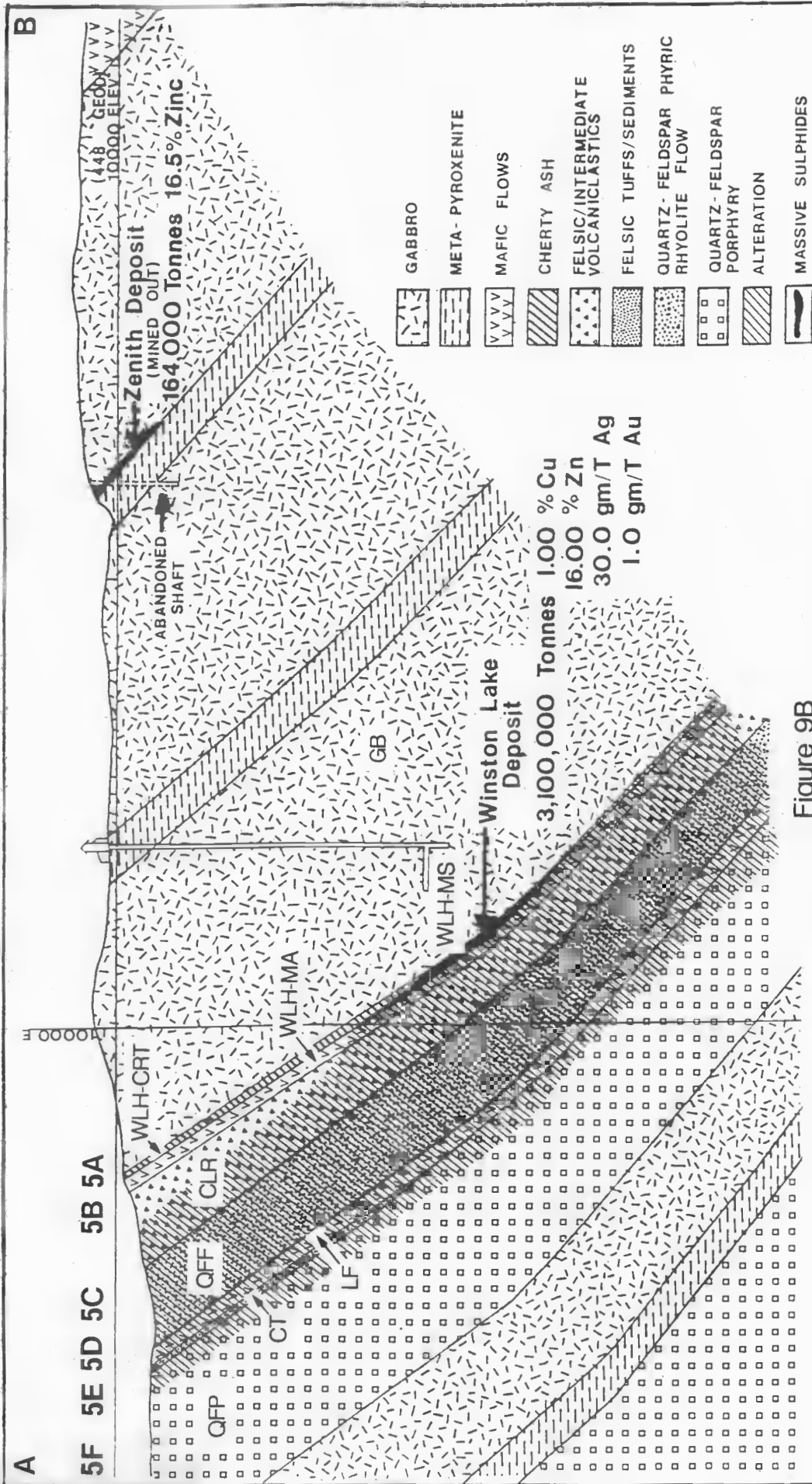


Figure 9B

Winston Lake Deposit COMPOSITE SECTION LOOKING NNW

STOP 5A: WINSTON LAKE HORIZON/ HANGING WALL GABBRO CONTACT

This stop lies at the top of the Winston Footwall Block (WFB) where it is in contact with gabbro of the Big Duck Sequence. The uppermost package of footwall rocks, the Winston Lake Horizon Succession (WLH), consists of volcanic and volcanoclastic rocks situated between the underlying Clotted Rhyolite (WLH-CLR) and overlying mafic flows and gabbro of the Big Duck Sequence. The Winston Lake massive sulphide deposit is hosted by the WLH rocks, approximately 450 m down-dip along this contact.

The WLH rocks at this site are interpreted as mixed laminated ash and exhalative sediments which are thinly laminated and locally folded (WLH-CRT). They appear as fine-grained, recrystallized rocks which range in colour from white to creamy yellow, light and dark green. Their mineralogy is dominated by quartz, plagioclase and lesser hornblende and a variety of accessory minerals. Felsic to mafic volcanoclastic/tuffaceous units predominate; minor cherty exhalites are also present. Pyrite and pyrrhotite dominate, comprising up to 20% of the rock locally. Near the Winston Lake deposit, sphalerite-rich beds and massive magnetite have been noted.

It has been noted by many observers that this exposure displays a great deal of hitherto undescribed deformation, manifested in a pervasive schistosity (locally crenulated), steeply plunging mineral lineations, chloritic shear planes and minor folds. It has even been suggested by Williams (personal communication, 1988) that these laminated rocks represent a mylonitized anorthosite that contains

very calcic plagioclase. There have also been suggestions of dip-slip movement and thrust contacts in this vicinity.

STOP 5B: CREEK COPPER SHOWING

This stop comprises a variety of lithologic units, sulphide mineralization and alteration-related features. It straddles the contact between rocks of the WLH and volcanoclastic rocks of the underlying Clotted Rhyolite (CLR). Outcrops on the east side of Selim Creek consist of alternating bands of mafic flows and thin, ashy sedimentary units. Gabbro outcrops approximately 10 to 15 m east of the creek. Volcanoclastic (CLR) rocks extend from this location south and west and host the pyrite- and chalcopyrite-bearing, Creek sulphide showing (gossan) on the access trail.

The mafic flows (WLH-MA) range in thickness from 2 to 33 m; most are between 4 and 10 m thick and uniform in thickness. They are typically fine- to medium-grained, aphyric, dark green-gray to black where fresh. Although primary features (pillows, sheet structures, hyaloclastite, autoclastic breccias) are rare, long, pillow-like structures have been noted at this locality. In the vicinity of the Winston Lake deposit, these mafic rocks have been altered to a cordierite-anthophyllite-biotite assemblage.

The CLR volcanoclastics exposed along the trail are heterolithic, containing both mafic and felsic

(quartz-phyric) elongate, flattened fragments ranging in size from 4 to 100 cm. Finely laminated sections are also present. The majority of the CLR has been interpreted as a felsic pyroclastic flow. Incipient hydrothermal alteration has affected the mafic component, smaller felsic fragments and ash component to produce a biotite-cordierite-anthophyllite assemblage. Relatively unaltered, felsic lenses may therefore be preserved in a dark, altered matrix, producing what has been locally termed a "pseudo-fragmental" texture that is not necessarily predicated upon a primary clastic protolith.

STOP 5C: ALTERED CAMP FLOW RHYOLITE

Felsic rocks of the Camp Flow rhyolite (QFF), thought to represent massive lava flows, outcrop on the access trail immediately west of the mine road. This unit is laterally extensive (>5 km) but relatively thin (50 to 200 m). Phenocrysts of quartz and plagioclase range in size from 1 to 3 mm and are set in a fine- to medium-grained, recrystallized, quartzo-feldspathic matrix. The recognition of individual flow units is precluded by shearing, recrystallization and hydrothermal alteration. Compositional banding developed in mafic minerals (biotite, hornblende, magnetite) may represent flow banding. Such banding is exposed in a roadside exposure across from the Cleaver Lake campsite.

Unaltered QFF rocks vary from tan to pale gray, while their altered counterparts may be bright white (sericite-rich) or brownish (biotite-rich). With increasing hydrothermal alteration these rocks may

contain:

- (1) Quartz - Muscovite - Biotite + Feldspar
- (2) Quartz - Cordierite - Sillimanite - Biotite + Staurolite + Garnet
- (3) Quartz - Cordierite - Anthophyllite + Sillimanite + Staurolite + Garnet

Where exposed along the trail, QFF rocks are variably altered. Large (≤ 2.5 cm) dark red porphyroblasts of garnet and smaller, honey-brown staurolite porphyroblasts occur in the more easterly outcrop. Fine-grained, whitish-pink andalusite porphyroblasts occur in a pervasively sericitized matrix at the outcrop west along the trail. Intense biotitization characterizes altered core samples at the site. It is notable that altered rocks containing in excess of 30% biotite (perhaps regarded as "mafic") still contain approximately 75% SiO_2 .

STOP 5D: INCIPIENTLY ALTERED LADDER FLOW / TRAIL SHOWING

The Ladder Flow (LF) is a 20 to 200 m thick series of mafic rocks consisting of thin sheet flows, thicker massive flows and flow lobes, pillow lava, pillow breccia and hyaloclastite. No obvious discernable facies relationships exist. Sharp contacts between different flow morphologies suggest compound lava flows. These lavas vary from fine-grained, dark grayish-green to medium- to coarse-grained, greenish-brown, altered equivalents.

At this location, dark green flows host 1 to 5 mm, lathlike plagioclase phenocrysts. Elongate pillows (feeders to lava lobes?) display local budding and re-entrant, hornblende-rich selvages.

Hyaloclastite, usually very rare, occurs as 10 to 20 cm wide, 1 to 5 m long, discontinuous zones between lobate, pillowed and massive flows. A flow breccia, consisting of 20%, 10 to 40 cm sub-rounded to sub-angular pillow fragments occur at the base of the LF.

The Trail copper showing consists of a pyrite-, pyrrhotite- and chalcopyrite-bearing, felsic interflow sedimentary unit (CT). It is exposed as patches of a rusty-weathering, laminated, siliceous rock.

Values of up to 6230 ppm Cu have been returned from this 0.15 m thick unit (Severin and Balint 1984). This unit occurs within mafic flows and between the "Main" quartz-feldspar porphyry (QFP) and mafic flows farther south along the trail. Garnet occurs within the altered base of this unit and is displayed along a steeply dipping outcrop surface which follows the undulating top of the underlying lava flow. The mafic lava flows on either side of the sedimentary unit are partially altered to anthophyllite-biotite-cordierite+garnet assemblages. Hyaloclastic units may be preferentially altered.

STOP 5E: ALTERED PILLOWED LADDER FLOW

This series of large outcrops provides an exceptional opportunity to view pervasively altered and

metamorphosed, undeformed, pillowed basalt flows. East-younging, metre-scale pillows have recessive-weathering, biotite-altered selvages. Pillow cores host coarse (≤ 5 cm) bladed to sheaf-like anthophyllite and blue-gray cordierite porphyroblasts (Figure 13). Anthophyllite and cordierite have undergone some retrograde alteration to chlorite + talc and pinitite, respectively. Siliceous material may occupy interpillow spaces. Further west, garnet has pervasively (up to 100% garnet + quartz) replaced primary, ovoid patches (selvages? lava tubes?) to produce coarse (≤ 3.5 cm) porphyroblasts, armored with biotite.

STOP 5F: "MAIN" QUARTZ-FELDSPAR PORPHYRY

The "Main" QFP, conformably overlain by mafic (LF) rocks, extends along strike for over 4.6 km and reaches an apparent map thickness of 1 km. It varies in appearance from tan to pinkish-gray to gray-brown. Unaltered QFP is remarkably homogeneous, massive to foliated, and contains 20 to 50% quartz phenocrysts and 1 to 25% lath-shaped, feldspar crystals. It has been interpreted, in part, as a subaqueous, felsic lava flow deposit. Alteration assemblages in the QFP include:

Quartz-Muscovite

Quartz-Biotite-Sillimanite

Cordierite-Quartz-Biotite-Sillimanite

Cordierite-Quartz-Anthophyllite

plus accessory staurolite, garnet, spinel, magnetite, zircon and rutile.

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