New Nouveau Brunswick

GUIDEBOOK TO THE

METALLOGENY OF THE BATHURST CAMP

[FIELD TRIP #4]

edited by
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With Contributions From:

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Individual contributions should be referenced according to the following example:

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EDITOR'S PREAMBLE

Since the discovery of the Brunswick No.12 deposit in April of 1953, a lot of exploration has been conducted in the Bathurst Mining Camp. In the eary days, many near-surface deposits were found utilizing geochemical and geophysical methods, but since 1970 only a handfull of new discoveries have been made. Other deposits must exist because the Camp is like an iceberg with 90% of its mass below surface.

However, in order to find deposits below the "waterline", i.e. the limit of detection by standard exploration techniques, the stratigraphy and structure of the Camp must be thoroughly understood. In this regard, a significant breakthrough occurred when a formal subdivision of the Tetagouche Group was established and extended to the entire Camp (cf. van Staal and Fyffe 1991; van Staal *et al.* 1992). Recognition of the structural complexity (Helmstaedt 1973; van Staal 1985,1986) and the tectonic setting (van Staal 1987) were equally important steps forward. [See p.21-28 for references]

The purpose of this fieldtrip is to give participants an understanding of the geological setting of the massive-sulphide deposits in the Bathurst Camp. Deposits in different stratigraphic and structural settings will be visited to illustrate similarities and differences among them.

There are eight separate papers and two appendicies in this guidebook; each paper has different authorship. The first paper by McCutcheon *et al.* gives a stratigraphic and structural overview of the Camp. The next three papers are focused on the Heath Steele - Stratmat area; the paper by Wilson describes the geology surrounding the deposits, whereas the papers by Hamilton *et al.* and Hamilton and Park are specific to the Heath Steele and Stratmat deposits, respectively. The fifth paper by Luff *et al.* describes the Brunswick No.6, No.12 and Austin Brook deposits. The sixth, by Lentz and Langton, describes the geology of the Key Anacon deposit. The last two, by Cavellero and Burton, describe the Caribou and Murray Brook deposits, respectively. An attempt has been made to pull together all the relevant literature on each topic so that the reference lists in each paper should be relatively complete.

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STRATIGRAPHY, TECTONIC SETTING AND MASSIVE-SULPHIDE DEPOSITS OF THE BATHURST MINING CAMP, NORTHERN NEW BRUNSWICK

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INTRODUCTION

The following description provides an overview of the stratigraphic and structural relationships of rock units in the Bathurst Camp with emphasis on the setting and genesis of the massive-sulphide deposits. Much of this description is extracted from published papers and other field guidebooks (see References), but some of it is based on previously unpublished data. The road log at the end of this description gives details about specific stops and/or stratigraphic sections that will be visited on the first day. Appendix I contains four road maps that show the locations of the detailed maps referred to in the road logs, whereas Appendix II comprises Lexicon-style descriptions of various formations in the Bathurst Camp.

REGIONAL SETTING

New Brunswick encompasses three of the five tectono-stratigraphic zones in the northern Appalachians, which have been defined by Williams (1979). These are, from south to north respectively, the Avalon, Gander and Dunnage zones (Fig. 1); the latter two zones constitute a Central Mobile Belt (CMB). The Gander Zone is generally thought to represent a Lower Palaeozoic west-facing passive margin, whereas the Dunnage Zone represents the vestiges of a back-arc basin plus one or more island arcs (van Staal and Fyffe 1991; Fyffe *et al.* 1990; Fyffe and Swinden 1991). The Miramichi Highlands (Fig. 1) is the principal area where Cambro-Ordovician rocks of the Gander and Dunnage zones are exposed in the province.

STRATIGRAPHY

The rocks in the Bathurst Camp, part of the northern Miramichi Highlands, have been separated into three groups (Fig.2), namely Miramichi, Tetagouche and Fournier (van Staal and Fyffe 1991; van Staal *et al.* 1992). The Tetagouche Group conformably to disconformably overlies the Miramichi Group and is structurally overlain by the Fournier Group. The Tetagouche Group hosts most of the massive-sulphide deposits, and therefore is the only group that is described in detail below.

The Lower Ordovician to Cambrian(?) Miramichi Group comprises a monotonous sequence of quartz wacke and slate of unknown thickness, which probably represents a flysh apron on the Avalon continental margin (Rast and Stringer 1974; van Staal and Fyffe 1991). Slate is more abundant and graphitic in the upper part (Knights Brook Formation) of the group than in the lower part (Chain of Rocks Formation). The Miramichi Group constitutes the Gander Zone in northern New Brunswick (van Staal and Fyffe 1991).

The Middle to Late Ordovician Fournier Group is divided into the Sormany and Millstream formations. The older Sormany Formation comprises pillow basalts and minor gabbro. These basalts are mainly primitive

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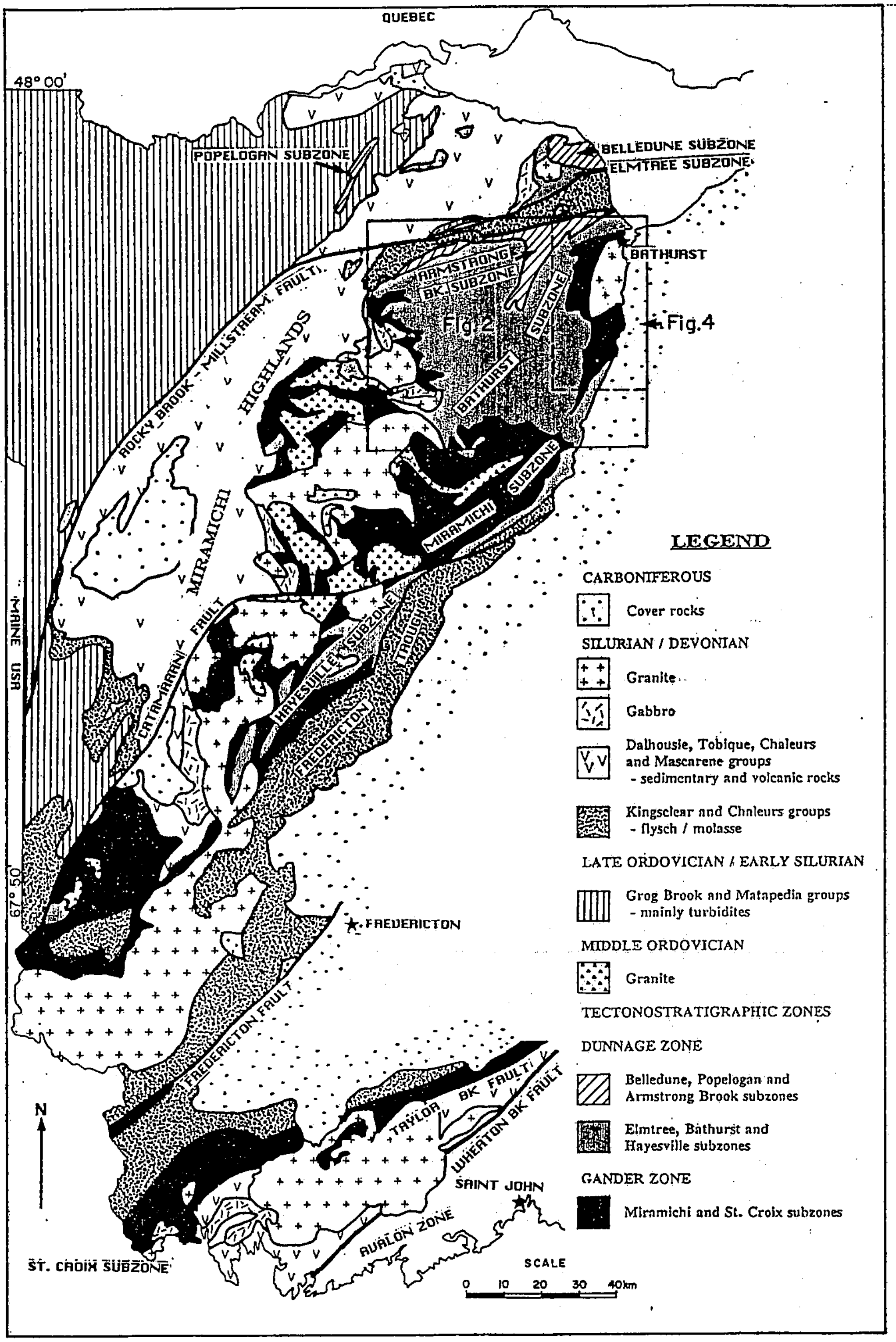

Figure 1. Simplified geological map of western New Brunswick showing the distribution of the Dunnage and Gander rocks. The various subzones are also shown (from van Staal and Fyffe 1991).

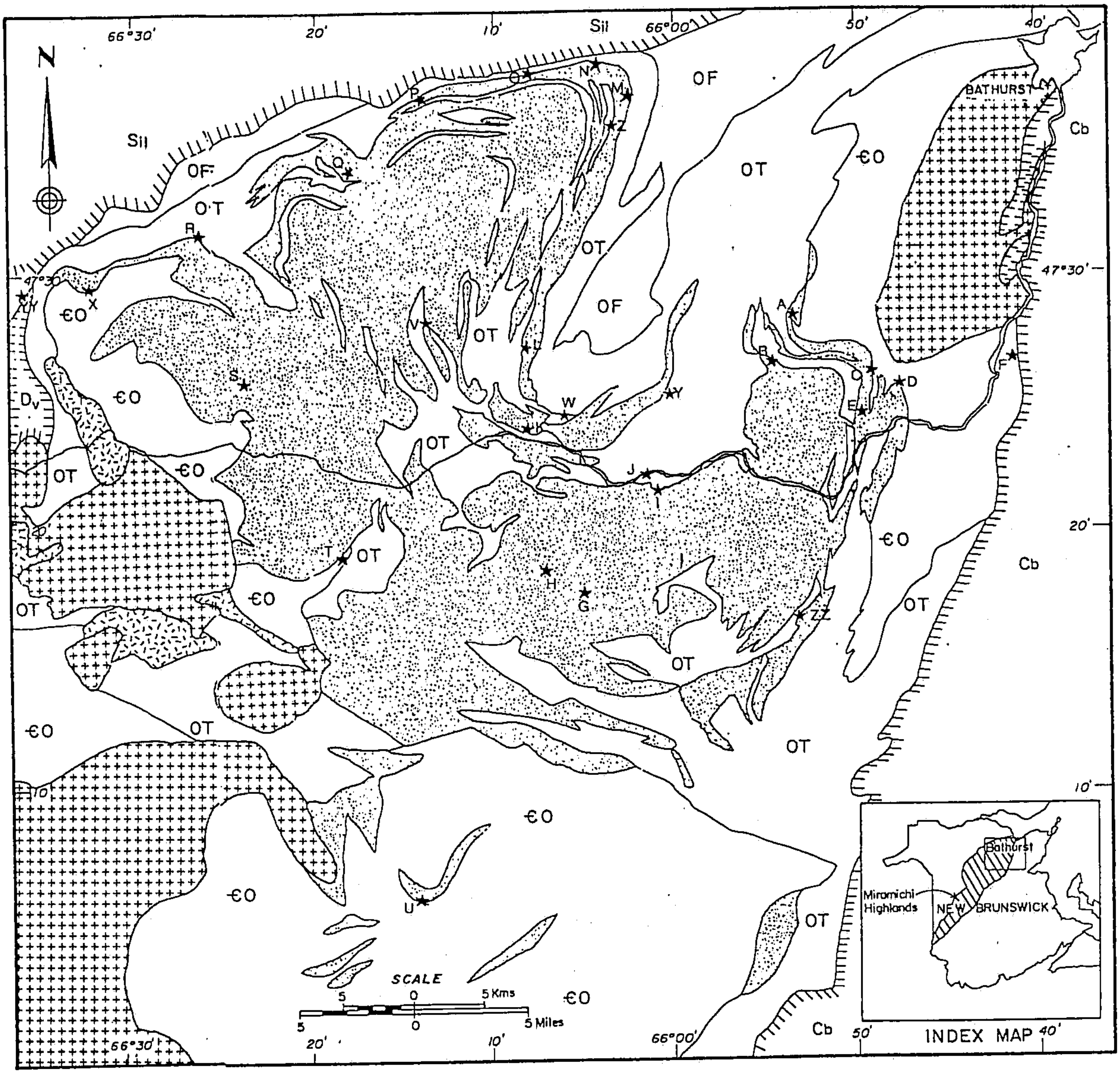

Figure 2. Simplified geological map of the Bathurst Mining Camp showing the locations of selected deposits (modified after McCutcheon 1992). Legend: Cb = Carboniferous sedimentary rocks, Dv = Devonian volcanic and sedimentary rocks, Sil = Silurian sedimentary rocks, OF = Ordovician Fournier Group (mafic volcanic rocks), OT = Ordovician Tetagouche Group (stippled = felsic volcanic rocks, unstippled = sedimentary and/or mafic volcanic rocks), CO = Cambro-Ordovician Miramichi Group (sedimentary rocks), crosses = felsic intrusions, dashes = mafic intrusions, stars = mineral deposits as follows: A. Brunswick No.12, B. Headway, C. Fab, D. Knights Brook (Maritime Mining), E. Brunswick No.6, F. Key Anacon (New Larder "U"), G. Heath Steele "A1", H. Stratmat, I. Nepisiguit "B", J. Nepisiguit "A", K. Wedge, L. California Lake, M. Armstrong "A", N. Rocky Turn, O. Orvan Brook (New Calumet), P. McMaster, Q. Caribou, R. Murray Brook, S. Devils Elbow, T. Halfmile Lake (Texas Gulf), U. Chester (Clearwater), V. Strachens Lake, W. Canoe Landing Lake, X. Restigouche, Y. Willett, Z. Armstrong "B", YY. Portage Brook, ZZ. Captain.

tholeiites with MORB-like compositions but they also show compositions intermediate between MORB and oceanic-island basalts, reflecting their oceanic back-arc depositional setting (van Staal *et al.* 1991). The conformably overlying Millstream Formation consists of lithic and feldspathic wackes and slate with minor intercalated limestone and basalt. The contact between the Fournier and Tetagouche groups is a zone of high strain, which represents a ductile thrust characterized by blueschist along 70 km of its length (van Staal *et al.* 1990). The Fournier Group is completely allochthonous upon the Tetagouche Group; together the two groups constitute the Dunnage Zone in the northern Miramichi Highlands.

The Middle to Late Ordovician Tetagouche Group comprises five formations (van Staal *et al.* 1992): Patrick Brook (PB), Vallée Lourdes (VL), Nepisiguit Falls (NF), Flat Landing Brook (FLB), and Boucher Brook (BB) in ascending stratigraphic order, more or less (Figs.3 and 4). The PB and VL formations are

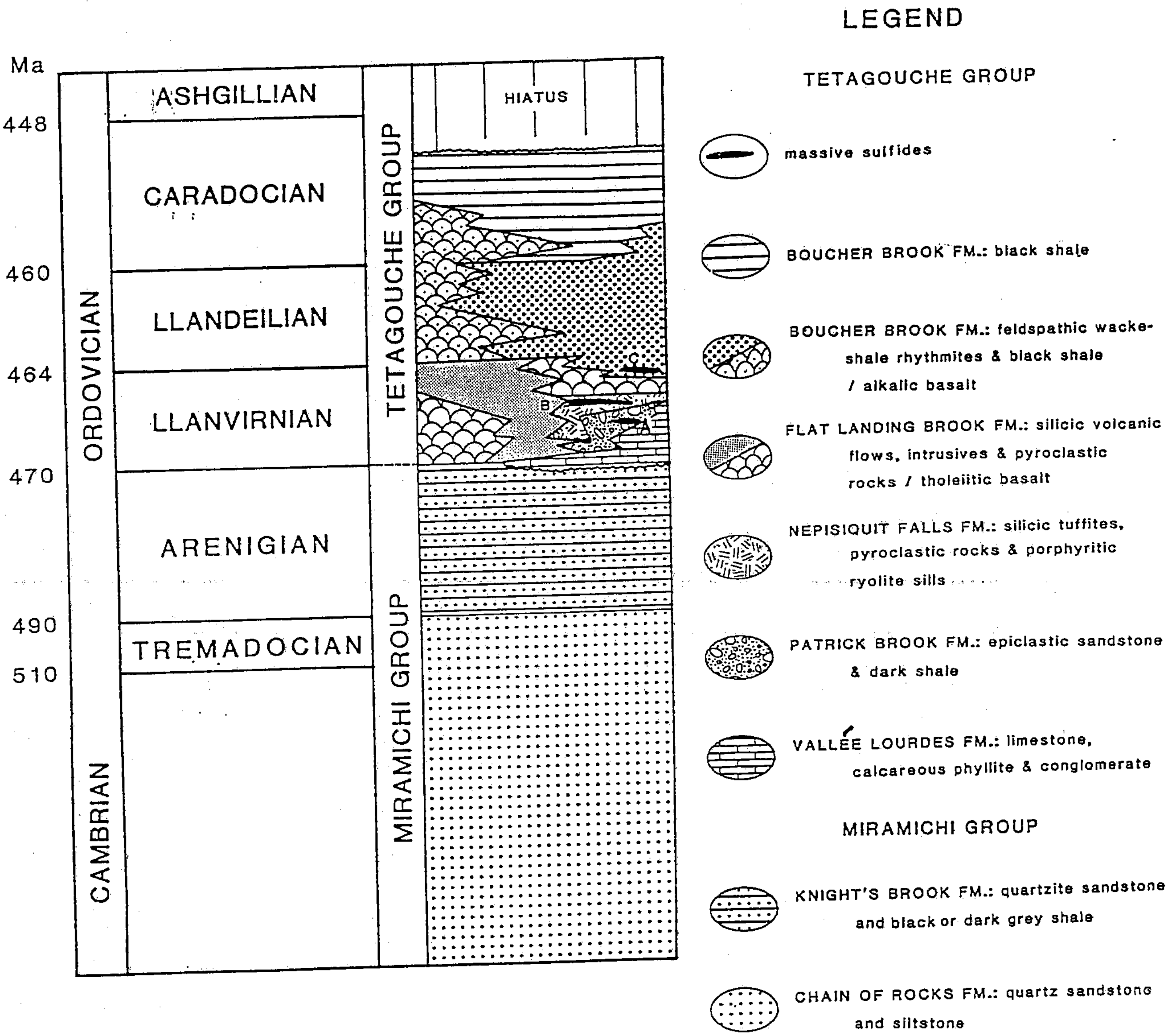

Figure 3. Schematic stratigraphic column showing the internal stratigraphy of the Tetagouche Group (from van Staal *et al.* 1992).

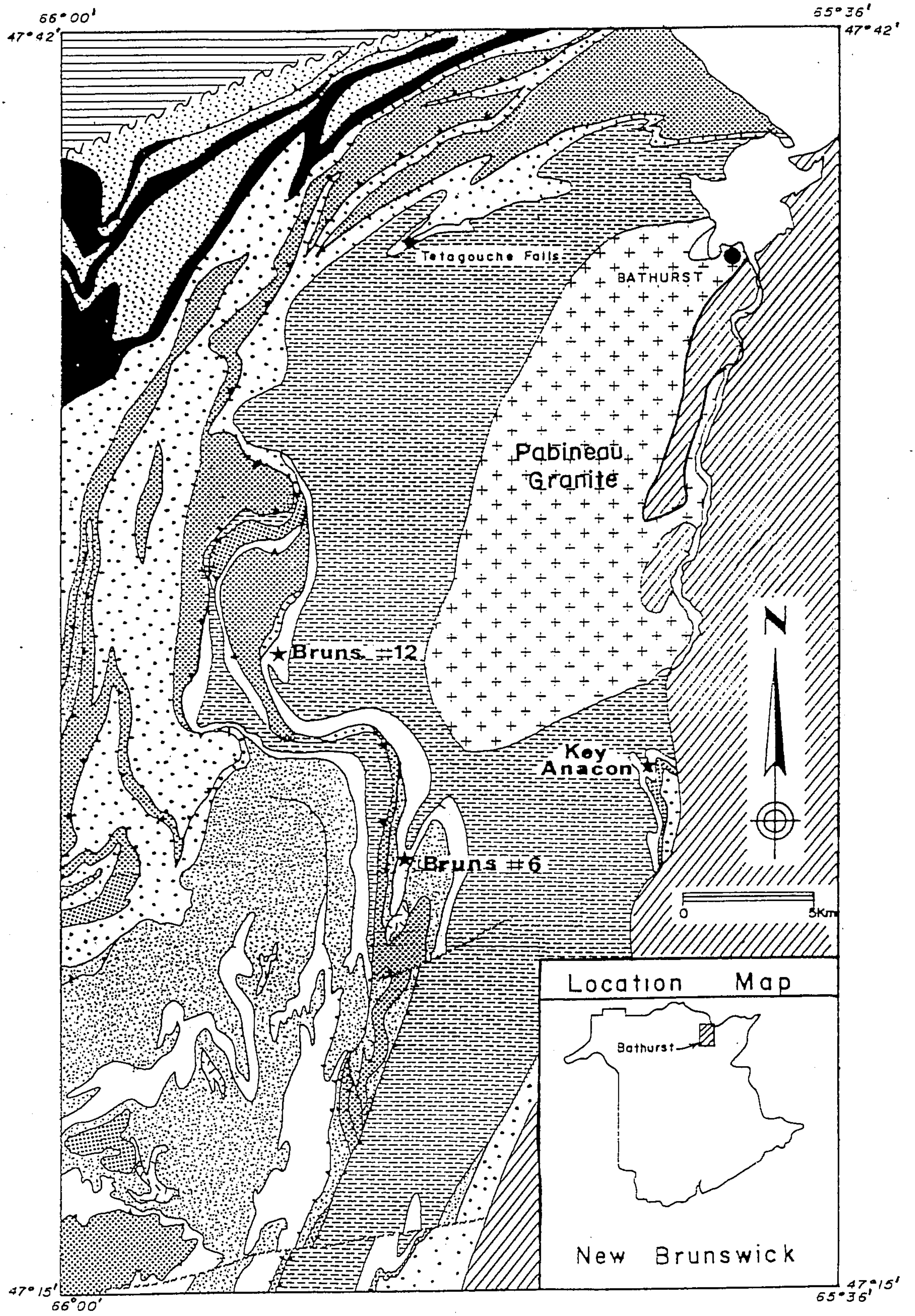

Figure 4a. Geological map of the eastern part of the Bathurst Mining Camp (modified after Langton 1991).

LEGEND

Carboniferous cover

DEVONIAN

Pabineau granite

SILURIAN

Chaleurs Group

ORDOVICIAN

Gabbro and diabase

FOURNIER GROUP

Mainly thickly bedded dark grey shales and lithic wacke.

Tholeiitic basalt.

TETAGOUCHE GROUP

Boucher Brook Formation: thinnly bedded, dark grey, phyllitic shale and siltstone.

Boucher Brook Formation: alkaline basalt and minor tholeiitic basalt.

Flat Landing Brook Formation: aphyric and quartz$\pm$feldspar phyric felsic volcanic rocks.

Nepisiguit Falls Formation: quartz and feldspar crystal-rich volcaniclastic and volcanic rocks, and fine-grained sedimentary rocks.

ORDOVICIAN (and CAMBRIAN?)

MIRAMICHI GROUP

Interbedded greenish grey, quartz-rich sandstone, light grey to dark grey shale, quartz wacke, and black shale.

SYMBOLS

geological contact

fault

thrust fault

Figure 4b. Legend for Figure 4a.

sedimentary units that occur locally at the base of the group. The conformably overlying NF and younger FLB formations form a thick felsic volcanic pile and constitute the most voluminous part of the group. The felsic volcanic pile ranges in composition from dacite to rhyolite (Whitehead and Goodfellow 1978; van Staal 1987; van Staal *et al.* 1991). Sedimentary and mafic volcanic rocks of the BB Formation conformably overlie the FLB Formation in the type area. A sixth unit of mafic volcanic and minor sedimentary rocks, called the Canoe Landing Lake (CLL) Formation, is in thrust contact with the type-BB Formation. However the CLL appears to be coeval with, and therefore laterally equivalent to, most of the above units because it is overlain by rocks that are lithologically identical to the Boucher Brook. Therefore, the CLL is considered to be part of the Tetagouche Group (van Staal *et al.* 1991). Each formation is described below and in Appendix A.

The Vallée Lourdes (VL) Formation (van Staal *et al.* 1988) generally comprises thin- to medium- bedded, greenish grey, calcareous siltstone and limestone; however, siliciclastic limestone (calcarenite to calcirudite) and/or calcareous sandstone predominates in places. This unit occurs intermittently as lenses at the base of the Tetagouche Group, and can be in conformable or disconformable contact with the underlying Miramichi Group. At one locality on Tetagouche River, the disconformity is marked by a thin bed of conglomerate, which contains quartzite and slate pebbles of the Miramichi Group. This unconformable contact probably formed in response to lithospheric doming associated with the onset of back-arc rifting during the middle to late Arenigian (van Staal and Fyffe 1991). Brachiopods (Fyffe 1976; Newman 1984) and conodonts (Nowlan 1981) indicate a middle Arenigian to early Llanvirnian age for this formation. These ages confirm that the overlying felsic volcanic pile is mainly Llanvirnian in age, as deduced from U-Pb geochronology (Sullivan and van Staal 1990; van Staal and Sullivan 1992).

The Patrick Brook (PB) Formation has not been formally defined, but it has been referred to since 1991 (c.f. de Roo and van Staal 1991; van Staal and Fyffe 1991; van Staal *et al.* 1991) and lithologic descriptions have been published (Rice and van Staal 1992; van Staal *et al.* 1992). The PB Formation, as originally described, comprises dark grey to black slate and very fine-grained to medium-grained dark grey sandstone that characteristically contains clear to smoky grey, vitreous, volcanic-quartz phenoclasts (commonly >5%). These rocks were recognized in several exposures along the Tetagouche River, from the mouth of Patrick Brook to below Tetagouche Falls. This unit was perceived to be lithologically transitional between the underlying Knights Brook and overlying Nepisiguit Falls formations.

Recently, Langton and McCutcheon (1993) have argued that a more rigorious definition of the PB Formation is needed for the following reasons: 1) Some wacke beds in the Knights Brook Formation are dark grey to black; 2) Volcanic-quartz phenoclasts occur in the Chain of Rocks, Knights Brook, Patrick Brook, Nepisiguit Falls, and Boucher Brook formations. They are notably more abundant in the Patrick Brook than in the Knights Brook or Chain of Rocks formations, but are most abundant in the Nepisiguit Falls Formation, where K-feldspar phenoclasts may be equally or more abundant; 3) The basal contact of the Nepisiguit Falls Formation at the type section is abrupt; K-feldspar phenoclasts are absent in the underlying rocks of the Knights Brook Formation, indicating that the onset of volcanism was also abrupt; 4) Many wacke beds in the PB Formation do not contain volcanic-quartz phenoclasts; 5) Both the wackes and and slates in the PB Formation can contain quartz phenoclasts. Therefore, Langton and McCutcheon recommended that a unit containing greater than 10% wacke or volcaniclastic beds in grey to black slate should be mapped as follows: a) as PB Formation if dark grey to black-weathering wacke (+/- volcanic quartz) predominates, b) as Knights Brook Formation if light grey to white-weathering wacke is most abundant but constitutes less than 50% of the unit or c) as distal Nepisiguit Falls Formation (see below) if the associated wacke beds contain greater than 10% K-feldspar and tufflavas are absent. If this recommendation is adopted, then some rocks now assigned to the PB Formation must be reassigned to the Nepisiguit Falls Formation.

The Nepisiguit Falls (NF) Formation consists of medium- to coarse-grained, quartz-feldspar-rich volcaniclastic rocks interlayered with quartz-feldspar porphyritic (2-15 mm) tufflavas and/or subvolcanic sills and fine-grained, greenish grey sedimentary rocks. Light to dark greenish grey, chloritic mudstone and iron formation (including massive sulphides) generally occur at, or near, the top of this formation and together constitute the "Brunswick Horizon".

The crystal-rich (10%-50%) NF rocks have been called "augen schists" because of the anastomosing nature of the cleavages around the crystals and less-altered microlithons. The quartz- and quartz-feldspar varieties are commonly referred to, respectively, as quartz-augen schist (QAS), and quartz-feldspar-augen schist (QFAS). The terms QAS and QFAS are non-genetic, although most QAS occurs where hydrothermal alteration and deformation have obliterated feldspar (Juras 1981; Nelson 1983; Lentz and Goodfellow 1992a, 1993a).

Primary features such as cross-bedding, graded beds, and a high percentage of rounded crystals (granular texture), indicate that much of the QFAS is volcaniclastic, i.e. the tuffite of Schmid (1981), which contains between 25 and 75% juvenile pyroclastic material. This type of QFAS probably resulted from explosive underwater eruptions that were deposited as cold debris flows (see Stix 1991), the "subaqueous, water-transformed pyroclastic flow deposits" of Cas and Wright (1991). However, some QFAS is clearly the product of igneous depositional processes and lacks any evidence of reworking because the rocks typically contain less than 30% phenocrysts and have a "glassy", cryptocrystalline groundmass. The near absence of magmatically broken crystals indicates that the emplacement mechanism was non-explosive, but the lack of carapace breccias and hyaloclastites is atypical of subaqueous lava flows. In the past some of these rocks were mistakenly identified as quartz-feldspar porphyries (QFP), i.e. intrusions. However, most of this type of QFAS was probably extruded subaqueously from volatile-rich magma that remained non-explosive because of the confining pressure of the overlying water column. Notably, rocks with characteristics intermediate between tuffs and lava flows (tufflavas) have been described elsewhere (Cas 1978; Creaser and White 1991). In many places, it is difficult to distinguish volcanic from volcaniclastic rock because deformation has obliterated primary textures, i.e. the relative amounts of primary and reworked material are uncertain.

The NF Formation has been divided into proximal (Grand Falls Member) and distal (Little Falls Member) facies by Langton and McCutcheon (1993). The Grand Falls Member consists of interbedded medium to coarse-grained, quartz-feldspar-phyric volcaniclastic rocks and tufflavas (or hypabyssal sills) with some associated greenish grey sedimentary rocks, whereas the Little Falls Member consists of greenish grey hyalotuff and fine- to medium-grained, quartz-feldspar-phyric volcaniclastic rocks interbedded with dark grey slate; tufflavas are absent. A U-Pb zircon age of 469 $\pm$ 2 Ma was obtained from rocks of the Grand Falls Member and an age of 471 $\pm$ 3 Ma was obtained from the Little Falls Member (van Staal and Sullivan 1992).

The Flat Landing Brook (FLB) Formation comprises aphyric to feldspar-phyric ($\pm$ quartz) rhyolitic flows, hyaloclastites, crackle breccias and minor sedimentary rocks, including iron formation, and basalt. In the past, many of these rocks were interpreted as pyroclastic deposits, but now they are considered to be the products of lava flows (van Staal 1987; McCutcheon *et al.* 1989; Langton and McCutcheon 1990; Wilson 1990). Feldspar $\pm$ quartz phenocrysts are small (1 to 3 mm) and constitute less than 10% of the rocks; the matrix is cryptocrystalline. The large areal extent and sparsely porphyritic nature of the lava flows suggests that their parent magma was very fluid.

Chemically, the FLB volcanic rocks are slightly different than those in the NF Formation. The major-element contents of the two units are similar but the FLB has slightly higher amounts of heavy-rare-earth elements, Zr, Nb, Y and Th (Table 1). In particular, Th/Yb versus Ta/Yb ratios are lower in the FLB Formation than in the NF Formation (Langton 1991). The higher abundance of high-field-strength elements in the FLB Formation is probably related to two-stage partial melting of a single lower-crustal source area (Lentz and Goodfellow 1992b). The U-Pb zircon age of 465 $\pm$ 1.6 Ma from the top of the FLB rhyolite (van Staal and Sullivan 1992) indicates a maximum time gap of 7 million years between the deposition of the NF and FLB formations, thus allowing time for two melting episodes to occur.

Table 1. Average compositions, including major- and trace-element data, of various felsic rock units in the Tetagouche Group. Modified after Lentz and Goodfellow (1992b); 1, 2, & 3 - Brunswick No. 6 footwall (QFAS, QAS) and hanging-wall rhyolites (HWR) from McCutcheon (1990), 4 & 5 from van Staal et al. (1991), 6 from Connell & Hattie (1990); 7 & 8 from Langton (1991); n = number of samples; $\pm = t_{0.25}s/\sqrt{n}$ is a 95% confidence interval (Le Maitre 1982); Fe_2O_{3T} denotes total Fe reported as Fe_2O_3; - no analysis.

Sample	QFAS		QAS		HWR		Rhyolite		Dacite		Felsic		QFAS		Rhyolite	
	1		2		3		4		5		6		7		8	
n	6		16		7		13		11		7		11		12	
SiO_2 wt.%	71.5 ±	0.4	68.4 ±	2.5	73.9 ±	2.5	74.9 ±	1.4	70.0 ±	2.0	77.3 ±	2.8	73.0 ±	2.7	74.6	2.6
TiO_2	0.52	0.02	0.62	0.09	0.40	0.18	0.28	0.07	0.45	0.14	0.21	0.03	0.37	0.10	0.34	0.12
Al_2O_3	13.47	0.41	12.84	1.05	12.73	0.86	12.61	1.13	14.28	0.74	10.14	1.19	13.25	0.93	12.81	1.97
Fe_2O_{3T}	3.45	0.43	9.91	2.38	2.95	1.09	1.85	0.07	3.53	1.19	3.54	2.91	4.26	0.81	4.49	0.84
MgO	1.81	1.17	1.72	0.36	1.01	0.35	0.64	0.50	1.04	0.42	0.48	0.57	1.29	0.65	1.22	0.50
MnO	0.06	0.01	0.06	0.02	0.08	0.05	0.01	0.01	0.05	0.02	0.07	0.10	0.01	0.02	0.05	0.04
CaO	0.45	0.19	0.18	0.03	0.72	0.77	0.27	0.11	1.27	0.69	0.75	0.86	0.43	0.58	0.31	0.28
Na_2O	2.61	0.35	0.30	0.76	3.41	1.20	1.97	0.69	3.38	1.55	1.98	1.44	2.41	0.77	1.66	0.98
K_2O	4.11	0.15	2.25	0.30	3.34	2.11	5.73	1.74	3.31	1.61	3.42	1.55	3.94	1.03	4.19	1.32
P_2O_5	0.17	0.01	0.17	0.01	0.10	0.05	0.11	0.04	0.18	0.05	0.06	0.03	0.09	0.05	0.06	0.05
H_2O	1.4	0.1	3.2	0.45	1.2	0.5	1.20	0.49	1.99	0.65	0.86	0.50	1.40	0.45	1.24	0.36
CO_2	-	-	-	-	-	-	-	-	-	-	0.51	0.77	0.02	0.03	0.13	0.20
S	-	-	-	-	-	-	0.03	0.03	0.01	0.01	1.40	1.26	-	-	-	-
Total	99.6		99.7		99.8		99.6		99.5		100.8		100.5		101.1	
Zr ppm	203 ±	22	249 ±	43	314 ±	53	191 ±	23	227 ±	70	220 ±	98	163 ±	31	293	105
Ba	808	53	396	60	892	588	681	131	544	158	730	423	756	201	814	390
Rb	145	14	122	12	128	70	162	41	129	50	151	53	129	23	145	34
Sr	70	19	46	69	117	80	47	10	124	64	46	35	62	34	29	17
Y	16	2	7	2	54	25	51	7	60	19	42	27	45	11	50	17
Nb	14	5	14	6	26	7	14	3	14	3	17	7	11	5	26	12
Th	14.2	0.7	14.9	1.9	19.7	1.8	15.4	5.8	13.0	6.0	13	5	12.3	1.7	16.5	2.6
Cu	14 ±	2	7 ±	8	7 ±	3	11 ±	12	42 ±	27	24 ±	39	3 ±	3	4	5
Pb	27	8	14	18	19	9	19	8	20	11	87	98	17	20	27	39
Zn	68	10	53	31	88	18	41	10	59	16	100	98	26	17	159	244
Ni	11	1	9	3	9	6	7	8	5	2	3.7	1.2	8	4	3	2
Cr	16	2	13	62	13	6	19	10	21	12	34	5	17	4	11	4
V	44	9	57	14	23	18	24	17	42	27	14	4	41	16	32	18
Sb	0.3	0.2	1.0	0.4	0.9	0.6	-	-	-	-	4.7	5.6	0.6	0.2	0.8	0.6
La	38.0	3.4	44.4 ±	8.9	49.1 ±	10.9	35.5 ±	10.4	31.5 ±	10.9	-	-	29.6 ±	11.3	47.2	16.2
Ce	80.0	7.2	90.8	13.6	101.5	23.0	64.5	14.1	65.2	22.7	-	-	62.5	16.0	98.9	25.8
Nd	37.6	2.4	43.6	7.6	47.9	11.4	47.1	8.4	42.2	12.8	-	-	28.6	9.5	45.3	14.3
Sm	6.6	0.4	7.7	1.4	9.7	2.9	8.9	-	15.7	-	-	-	5.64	1.52	9.0	2.9
Eu	1.03	0.07	1.07	0.1	1.19	0.35	1.0	-	0.4	0.9	-	-	0.84	0.30	1.47	0.63
Gd	5.4	0.3	5.8	1.1	1.37	0.54	8.9	-	17.4	-	-	-	5.0	1.3	8.1	2.6
Dy	4.2	0.3	3.6	0.6	8.0	3.0	8.4	-	18.6	-	-	-	4.7	1.0	7.8	2.2
Yb	1.6	0.2	2.2	2.1	4.7	1.6	4.4	-	11.3	-	-	-	2.21	0.44	4.72	1.12
Lu	0.28	0.04	0.22	0.03	0.70	0.24	-	-	-	-	-	-	0.35	0.07	0.75	0.17

At or near the base of the FLB Formation there can be an Algoma-type iron formation, and there is at least one sulphide-bearing sedimentary unit within this formation. For example, rhyolite directly overlies magnetite-hematite iron formation at the Narrows on Nepisiguit River (see Stop# N-8), whereas the Stratmat massive-sulphide deposits are within a fine-grained sedimentary unit that appears to be in the lower part of the FLB Formation.

Locally, minor amounts of tholeiitic basalt are intercalated in the FLB Formation. Enrichment in light-rare-earth elements within the basaltic rocks indicates a continental within-plate environment of deposition (van Staal *et al.* 1991). The basaltic rocks are mainly massive flows but there are also tuffs, sills, breccias and agglomerates. Pillows, which are common in other basalts of the Tetagouche Group, are rare or absent suggesting a subaerial environment of deposition for at least some of these rocks.

The type Boucher Brook (BB) Formation conformably overlies the FLB Formation (Figs. 3 and 4) and mainly consists of thinly bedded, bluish grey, fine-grained wacke and siltstone, which grade upward into homogenous black slate. However, outside the type area, alkali basalt can constitute the main rock type in this formation. Near the contact with the FLB, the wacke appears to be feldspathic but the "feldspar" actually consists of small fragments of white-weathering rhyolite. Furthermore, at or near this contact, dark grey to red metalliferous slate commonly occurs, locally with economic concentrations of base-metal sulphides (e.g. the Caribou and Wedge deposits). The underlying rhyolite has yielded U-Pb ages of 466 $\pm$ 5 Ma and 465 $\pm$ 1.6 Ma (Sullivan and van Staal 1990; van Staal and Sullivan 1992), whereas black slate near Bathurst, considered to be part of the BB Formation (van Staal and Langton 1990a, 1990b), yielded Llandeilian to Late Caradocian graptolites (Dean in Skinner 1974, p.43; van Staal *et al.* 1988). Notably, much of the lithogeochemical data reported by Connell and Hattie (1990) on exhalative rocks from the Bathurst Camp (Table 2) is from the Boucher Brook Formation.

Three different, low-chromium (<200 ppm), alkali-basalt suites have been distinguished in the BB Formation (van Staal *et al.* 1991). Each suite contains pillow basalt, breccia and hyaloclastite, with interflow chert and red metalliferous slate; locally, trachyandesite and comendite are present. Most of the interlayered sedimentary units comprise thinly bedded turbidites that resemble those in the type section, but minor limestone occurs in at least two localities near Camelback Mountain. This limestone yielded early to middle Caradocian conodonts (Nowlan 1981). Also, a trachyandesite near Bathurst yielded a U-Pb zircon age of 457 $\pm$ 1 Ma (van Staal *et al.* 1991).

The Canoe Landing Lake (CLL) Formation comprises two basalt suites. One suite consists of high-chromium (>200 ppm) alkali basalt with intercalated red slate, chert and rare felsic volcanic rocks, whereas the structurally overlying suite is composed of tholeiitic pillow basalt with intercalated alkali basalt, red slate and chert. A small rhyolite body within the lower suite yielded a U-Pb age of 472 $\pm$ 4 Ma (van Staal *et al.* 1991). The basal contact of the alkalic suite with BB rocks is a thrust, but BB-type sedimentary rocks also conformably overlie this suite. Similarily, the basal contact of the tholeiitic suite is interpreted as a major thrust that is marked by the presence of a narrow zone of phyllonite (van Staal 1986) and the upper contact is conformable with BB-type sedimentary rocks.

STRUCTURE

The structural geometry of the Bathurst Camp reflects an interference pattern produced by polyphase deformation, something that was first recognized by Skinner (1956). Helmstaedt (1973) recognized three, and locally four, phases of deformation in the Camp, but detailed analysis by van Staal and co-workers has shown that there are five groups of folds, which have been designated F_1 to F_5 based on overprinting relationships. The first two groups of folds are responsible for most of the

Table 2. Average compositions, including major- and trace-element (in ppm unless indicated otherwise) data, of iron-rich rocks in the Bathurst Mining Camp. Data from Connell & Hattie (1990); n = number of samples; x = mean, 1s = 1 standard deviation; Fe_2O_{3T} denotes total Fe reported as Fe_2O_3; * total does not include Al_2O_3 content.

	FELSIC TUFF		"BASIC IF"		RED ARGILLITE		MAROON CHERT		GREEN SLATE		IRON FM.		BLACK SLATE		C-O MAROON SLATE	
n	10		9		52		14		30		113		104		7	
	x	1s	x	1s	x	1s	x	1s	x	1s	x	1s	x	1s	x	1s
SiO_2 wt.%	75.0±	7.7	40.5±	17.0	65.9±	10.2	75.0±	9.9	68.2±	11.3	30.2±	14.8	69.5±	11.8	58.8 ±	3.1
TiO_2	0.25	0.11	3.14	2.73	0.54	0.45	0.30	0.19	0.39	0.21	0.42	0.71	0.64	0.39	0.90	0.09
Al_2O_3	10.76	1.98	-	-	8.99	3.76	5.91	4.17	7.63	3.43	-	-	11.12	5.37	18.67	1.57
Fe_2O_{3T}	3.63	2.95	19.85	12.38	12.83	5.30	10.97	6.99	12.10	7.74	47.4	18.7	7.15	4.22	8.27	1.05
MgO	1.45	2.72	4.52	2.88	1.42	0.66	1.08	1.14	1.51	1.16	1.90	1.89	2.04	1.40	2.21	0.41
MnO	0.11	0.13	1.62	3.28	2.13	1.70	1.50	1.61	2.18	1.79	2.71	2.43	0.45	0.97	0.11	0.08
CaO	0.65	0.78	7.17	4.49	1.20	1.97	0.43	0.26	0.61	0.72	3.72	1.97	0.91	1.03	0.52	0.45
Na_2O	1.43	1.56	1.06	1.28	1.08	1.10	1.53	1.54	0.36	0.86	0.59	1.02	0.84	1.01	1.22	0.61
K_2O	3.31	1.56	1.65	1.21	2.06	1.14	0.98	1.05	1.55	1.50	0.79	1.25	2.46	1.34	5.11	0.85
P_2O_5	0.11	0.10	0.98	0.94	0.23	0.14	0.14	0.11	0.34	0.40	1.87	1.12	0.15	0.15	0.12	0.02
H_2O	1.0	0.6	3.7	2.7	1.7	0.8	0.7	0.7	2.3	1.3	2.4	1.8	2.0	1.1	2.6	0.75
CO_2	0.74	0.94	3.62	3.73	0.73	1.46	0.21	0.31	1.42	1.85	4.73	4.26	0.42	1.23	0.01	0.00
S	1.2	1.3	0.01	0.01	0.03	0.09	0.01	0.01	0.60	1.92	1.12	2.28	0.93	1.42	0.01	0.00
Total	99.6		87.8*		98.8		98.8		99.2		97.9*		98.6		98.6	
F ppm	550	440	895	415	528	237	353	307	567	390	1398	1495	524	253	613	68
Ba	966	993	919	871	1053	972	556	524	1769	4870	866	2414	1170	1834	697	92
Rb	160	64	71	39	119	68	53	51	85	67	58	69	143	76	296	47
Sr	37	35	161	65	65	105	49	57	37	30	69	72	70	68	61	35
Li	14	20	17	16	15	10	11	8	29	25	8	15	39	26	18	15
Zr	191	103	378	444	100	70	93	113	100	65	40	85	116	68	194	41
Y	39	26	55	61	25	11	19	14	24	16	9	14	28	15	31	7
Nb	17	7	43	17	26	12	21	10	23	7	35	17	21	9	24	8
Th	12.2	4.7	2.8	1.4	7.4	3.1	5.6	4.7	7.3	3.8	3.7	3.3	7.9	4.3	12.7	2.1
Ni	6	6	48	42	70	37	44	36	61	44	49	192	69	50	46	7
Cr	5	7	76	109	31	26	22	29	30	20	29	58	74	50	67	24
V	25	27	238	137	88	49	72	63	92	68	152	89	213	299	128	21
Co	4	5	43	16	74	54	50	48	67	57	20	32	26	26	23	4
Cu	23	35	43	33	48	44	45	67	90	151	165	533	61	41	16	11
Pb	120	150	344	863	46	33	31	26	281	688	1475	1165	21	18	17	15
Zn	135	134	229	165	89	43	48	35	475	1401	907	1369	106	64	126	14
Cd	0.9	0.2	0.5	0.0	0.5	0.1	0.5	0.0	1.5	3.4	1.6	2.0	0.8	0.6	0.5	0.0
Ag	0.2	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.4	0.9	1.2	3.1	0.3	0.0	0.3	0.0
Au ppb	8	9	1	1	4	9	3	4	6	8	7	19	5	7	3	3
Sb	4.9	5.8	1.3	1.4	4.8	4.4	3.1	2.5	7.6	12.7	2.9	6.8	5.7	7.4	1.2	0.6
As	165	244	29	51	16	19	17	19	68	103	258	744	32	42	4	2
Sn	5	2	80	170	2	1	2	1	3	4	60	61	4	6	4	1
Mo	2	2	1	1	1	5	1	1	2	3	33	45	12	21	1	1
Bi	0.6	0.2	0.7	0.6	0.5	0.1	0.6	0.4	0.7	0.7	4.9	15.8	0.6	0.8	0.5	0.0

complex geometry (van Staal and Williams 1984; van Staal *et al.* 1988; de Roo *et al.* 1990, 1991; de Roo and van Staal 1991, 1993).

The earliest deformational event (D_1) is represented by steeply inclined to recumbent, non-cylindrical folds (F_1) with an axial-planar, layer-parallel transposition foliation (S1), and generally a stretching lineation (L_1). The D_1 fabric elements are interpreted to have formed in the Late Ordovician to Early Silurian as a result of imbrication in a northwest-dipping subduction complex (van Staal *et al.* 1992). They are typically concentrated in narrow zones of high strain (phyllonites or mylonites) that cross-cut stratigraphy and represent major thrust faults (van Staal *et al.* 1990; de Roo and van Staal 1993).

During the second phase of deformation (D_2) S_1 was reoriented into a near-vertical attitude by tight to isoclinal F_2 folds, which are interpreted to have formed in the Late Silurian (de Roo and van Staal 1993). The plunge of F_2 folds is generally shallow, but locally changes from shallow to steep, largely because of the influence of existing F_1 closures. Thus, changes in attitude of F_2 hinges provide a method of detecting macroscopic F_1-folds. The S_2 clevage is moderately to well developed and generally steeply-dipping. Along the limbs of the F_2 folds, S_1 and S_2 are sub-parallel and may form a composite S_1/S_2 cleavage (S_{MAIN}). The S_1 and S_2 cleavages are the dominant fabric elements throughout the area.

The D_1 and D_2 structures are refolded by open to tight, recumbent F_3 folds that are probably related to extensional collapse (van Staal and Fyffe 1991; de Roo and van Staal 1993). Where D_3 was intense, S_1 and S_2 were re-oriented to shallow-dipping attitudes, producing so-called flat belts (de Roo *et al.* 1990; de Roo and van Staal 1991). The areas that were relatively unaffected by F_3 folds are called steep belts. In the past, i.e. pre-1985, the D_3 fabric elements were considered to be part of the D_5 event (cf. van Staal and Williams 1984). Thus, in the older literature, some large-scale F_5 folds, such as the Pabineau synform and antiform, are called F_3 structures.

All earlier structures are refolded by F_4 and F_5 folds, but overprinting relationships between these two are rarely seen (van Staal 1987). These folds range in scale from millimetres to kilometres, and produce dome and basin structures. They include the Pabineau synform and antiform (van Staal and Williams 1984), the Nine Mile synform and the Tetagouche antiform (van Staal 1986, 1987). F_4 and F_5 are interpreted to result from dextral transpression in the northern Appalachians during the Middle Devonian.

TECTONIC SETTING

Many years ago Pajari *et al.* (1977) proposed that the Tetagouche volcanic rocks represent the remnants of an ensialic arc formed above an eastward-dipping subduction zone. However, the chemical compositions of the mafic volcanic rocks are not consistent with an arc setting, but instead are more typical of a rift environment (van Staal 1987; van Staal *et al.* 1991). Therefore, van Staal (1987) proposed a back-arc-basin model. In this model, most of the Tetagouche volcanic rocks represent basin-margin deposits laid down on rifting continental crust, whereas the Fournier Group rocks represent oceanic crust that formed during spreading of the basin. Radiometric dates show that the Fournier oceanic crust is slightly younger than the Tetagouche Group volcanic rocks, consistent with an ensialic back-arc basin model. The development of this back-arc basin is illustrated schematically in Figure 5.

This back-arc basin started to close in the Late Ordovician by northwest-directed subduction (van Staal 1987) that lasted at least until the Early Silurian (van Staal *et al.* 1990). The rocks of the northern Miramichi Highlands are thought to have been assembled in the subduction complex, i.e. Tetagouche Group rocks were underplated to the oceanic part (Fournier Group) of the accretionary wedge when the leading edge of the continental margin descended into the subduction zone. Closure of this basin culminated with the obduction of trench-blueschist onto the former margin of the basin. The time of closure is constrained by the following: 1) Ar^{40}/Ar^{39} dating of crossite and phengite from blueschist at the structural base of

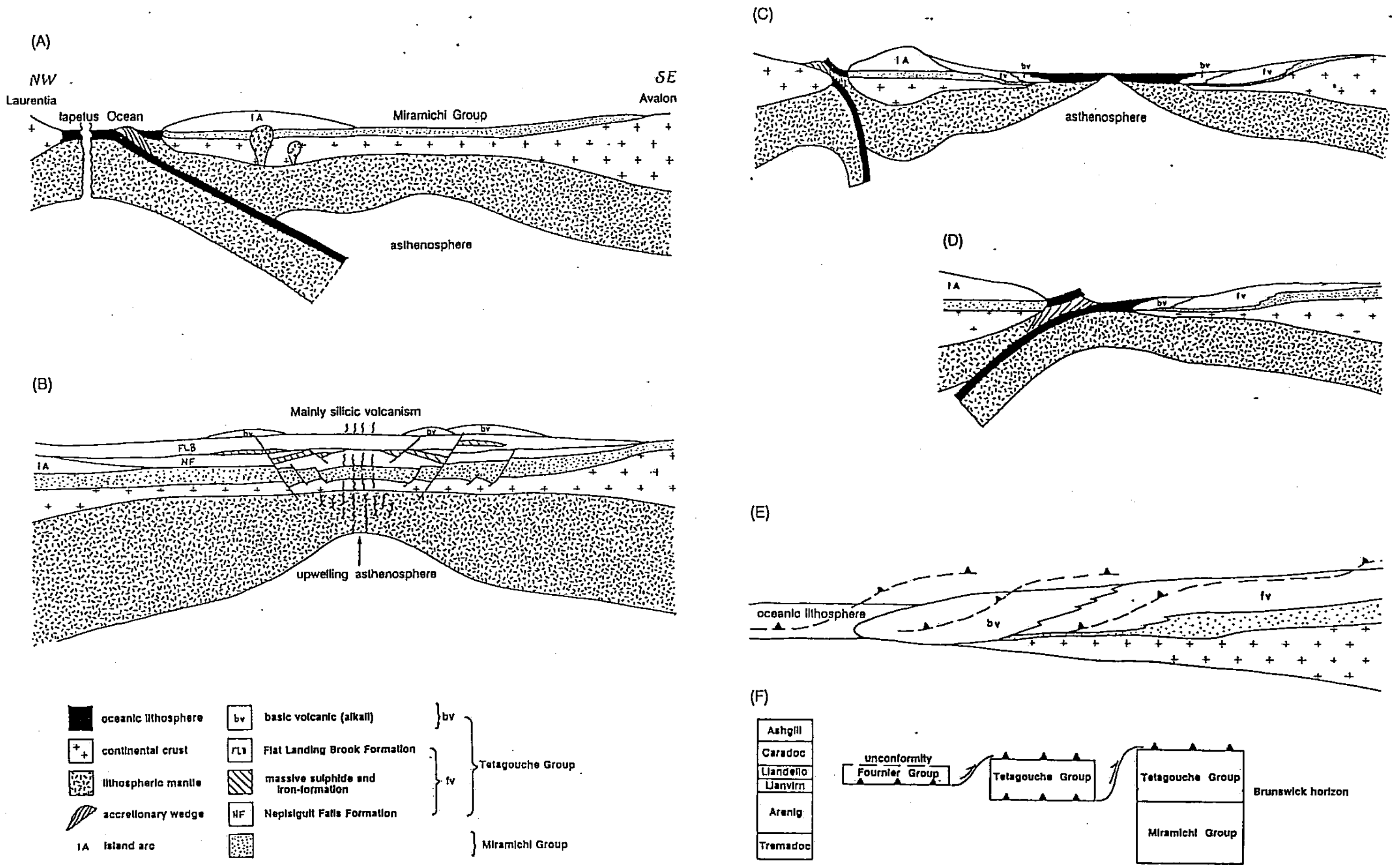

Figure 5. Schematic diagrams illustrating the development of the Middle Ordovician back-arc basin, in which the Tetagouche Group was deposited.

the Fournier Group yielded ages ranging from 453 $\pm$ 6 Ma to 416 $\pm$ 6 Ma, with the most precise age of blueschist metamorphism being 447 $\pm$ 6 Ma (van Staal *et al.* 1990); 2) the youngest rocks of the Tetagouche Group involved in the D_1 thrusting are late Caradocian (Riva and Malo 1988); and 3) Fournier Group rocks are unconformably overlain by Early Silurian (Llandovery) conglomerates of the Chaleur Group. Within this tectonic scenario, D_1 and M_1 are seen as the products of the subduction-related closure of the oceanic basin (Fig.5). Post-D_1 ductile deformation resulted from the subsequent oblique, more or less continuous collision between Laurentia and Avalonia, which ended in the Lower Devonian.

MASSIVE-SULPHIDE DEPOSITS

The Tetagouche Group is characterized by an anomalous abundance of Zn-Pb-Cu massive-sulphide deposits. At least 35 deposits and about 100 occurrences are known (McCutcheon 1992). At present, base metals are mined from the Brunswick No.12, CNE and Heath Steele deposits, whereas Brunswick No.6, Wedge and Caribou are past producers (Fig. 2). Gold and silver were extracted from gossan overlying the Murray Brook, Caribou and Heath Steele deposits, and in the early part of this century (Belland 1992) the iron formation in the hanging wall of the Austin Brook massive-sulphide deposit was mined for iron.

Massive-sulphide deposits occur in several stratigraphic positions within the Tetagouche Group. Many are closely associated with felsic volcaniclastic rocks of the Nepisiguit Falls Formation; others are in the lower sedimentary part of the Boucher Brook Formation and a few are within the Flat Landing Brook Formation. Previously, three groups of deposits were recognized in the first two units (van Staal and Williams 1984; van Staal 1986).

The stratigraphically lowest deposits occur within the Nepisiguit Falls Formation, at or near the contact with the underlying Patrick Brook Formation and are typified by the Heath Steele orebodies. The host rocks are greenish grey to dark grey mudstones that are interbedded with fine- to medium-grained volcaniclastic rocks. Besides Heath Steele (de Roo *et al.* 1991), this set includes the Halfmile Lake (Adair 1992) and FAB (Lentz and Goodfellow 1993b) deposits. The Key Anacon (Saif *et al.* 1978; Irrinki 1992), Chester (Irrinki 1986) and Murray Brook (Rennick and Burton 1992) deposits were included in this group by van Staal *et al.* (1992) but Key Anacon clearly belongs to group 2 and the latter two are also stratigraphically higher.

A second group of deposits occurs in greenish grey mudstones at or close to the contact between the Nepisiguit Falls and Flat Landing Brook formations, i.e. the so-called Brunswick Horizon. These Brunswick-type deposits generally are associated with Algoma-type iron formation (McAllister 1960; Davies 1972). Included in this set are the Brunswick No.12 (Luff 1975), Brunswick No.6 (Boyle and Davies 1964), Austin Brook (Boyle and Davies 1964; Davies 1972), Flat Landing Brook (Troop 1984), CNE (Whaley 1992) and Key Anacon deposits.

A third group of deposits occurs within the Flat Landing Brook Formation. Mudstones that are interbedded in the volcanic pile host some deposits; others are in rhyolitic rocks. This group includes Stratmat (Hamilton 1992), as well as others that are not described in the literature, namely Consolidated Morrison, Taylor Brook Road, Louvicourt and Coulee.

A fourth group of massive-sulphide deposits occurs in grey phyllites of the Boucher Brook Formation, generally close to the contact with underlying felsic volcanic rocks of the Flat Landing Brook Formation (van Staal 1986), and is typified by the Caribou deposit (Roscoe 1971; Davis 1972; Cavalero 1990). This group includes the Nepisiguit A,B,C, Nine Mile Brook, Canoe Landing Lake, Wedge and Orvan Brook deposits (Fig. 2). However, where the Flat Landing Brook Formation is absent, it is not always possible to distinguish this group from the second, e.g. Key Anacon.

The stratigraphic division is, in part, supported by isotope data. Sulphur isotopes (Table 3a; Fig. 6) show that deposits hosted by Nepisiguit Falls and Flat Landing Brook rocks, i.e. deposit groups 1, 2 and 3, have higher $\delta^{34}S$ values than those hosted by Boucher Brook rocks. Similarily, $^{207}Pb/^{206}Pb$ ratios (Thorpe *et al.* 1981; Table 3b; Fig. 7) from deposits hosted by Boucher Brook rocks (group 4) are generally higher than those in deposits from older units (groups 1, 2 and 3); furthermore, most of the deposits in the Nepisiguit Falls Formation (groups 1 and 2) were derived from rocks of a higher μ value (Fig.7) than the rest. Notably, the Stratmat deposit (group 3) has lead and sulphur isotope values compatible with groups 1 and 2, suggesting that the lead for all three groups was derived from the same source. Also, the Murray Brook and Chester deposits belong to group 4, at least isotopically.

The deposits, which range in size from small showings to supergiants such as Brunswick No.12, comprise concordant, massive to disseminated bodies that mainly consist of pyrite, sphalerite, galena, chalcopyrite, magnetite and, in places, pyrrhotite. Other sulphides (particularly arsenopyrite), sulphosalts, and iron oxides occur in minor amounts.

Large-scale mineralogical and/or chemical zonation may be present, both vertically and laterally, in the deposits (Lusk 1969). For example, vertical zonation in the Brunswick No.12 deposit is ideally made up of four zones (Rutledge *in* McAllister and LaMarche 1972; Luff 1977; van Staal and Williams 1984; Luff *et al.* 1992). From footwall to hanging wall, these are: 1) a zone of massive to crudely-layered pyrite, with variable amounts of pyrrhotite, magnetite and chalcopyrite; 2) a zone of well-layered (cm to mm scale) pyrite, sphalerite and galena, with minor chalcopyrite and pyrrhotite; 3) a zone of massive pyrite with thin discontinuous layers or lenses of sphalerite and galena, and 4) iron formation. There is thus a decrease in the Cu-content between zone 1 and 3 and an apparent enrichment of Zn and Pb in zones 2 and 3. This zonation is also developed in the Brunswick No.6 and Austin Brook deposits, although the sulphide zonation is condensed in the latter (van Staal 1985). A decrease in Cu/(Pb+Zn) from stratigraphic footwall to hanging-wall has also been observed in the Caribou and Halfmile Lake deposits (Jambor 1979). Although this vertical zonation is not always fully developed, in part because of complications induced during deformation, it is interpreted as a pre-deformational feature (van Staal and Williams 1984) that can be used as a younging indicator (c.f. Large 1977; Stanton 1979). For example, the metal zonation in the Halfmile Lake deposit indicates that the orebody is tectonically inverted (Adair 1992).

Lateral zonation in the Brunswick-type (group 2) deposits is manifested by a transition from massive sulphides into Algoma-type iron formation, an association typical of VMS deposits worldwide (cf. Gross 1991). Several studies have focused on the relationship between massive-sulphide deposits and iron formations in the Bathurst Camp (Bhatia 1970; Davies 1972; Whitehead 1973; Saif 1980, 1983; Troop 1984; Peter and Goodfellow 1993). Saif (1980, 1983) subdivided iron-rich rocks in the Bathurst Mining Camp into five types, excluding the massive sulphides. These five types are: i) cherty magnetite (oxide facies); ii) Fe-rich chloritic rocks (silicate facies); iii) Fe-rich carbonate rocks (carbonate facies); iv) basic iron formation; v) Fe-rich maroon shales. The first three types are associated with Brunswick-type deposits and are described briefly below.

The oxide facies consists of alternating layers of hematite-magnetite and quartz, or jasper-rich layers and quartz, which give the rocks a banded appearance (Davies 1972; Saif 1980,1983). Commonly, this Algoma-type iron formation overlies, or passes laterally into, massive sulphides, either abruptly or gradationally, but it may also overlie, be interbedded with or pass gradationally into Fe-rich chloritic rocks along strike.

The silicate facies is a mudstone that consists mostly of chlorite, quartz, magnetite and/or pyrite with lesser amounts of biotite, stilpnomelane and Fe-Mn carbonates. Not all rocks of this facies contain enough iron (15% or more) to be true iron formations (Davies 1972), but on average, they contain about

Table 3a. Average $\delta^{34}S$ ‰ values for various deposits in the Bathurst Mining Camp; data recalculated from Tupper (1960); n = number of samples; 1s = one standard deviation. See Figure 2 for deposit locations.

DEPOSIT	GROUP	n	$\delta^{34}S$ ‰	(1s)
A - Brunswick No.12	2	18	16.0	1.4
B - Headway	1	1	16.5	
C - FAB	1	1	16.0	
C - FAB	1	1	14.6	
D - Knights Brook (Maritime Mining)	1	1	16.5	
E - Brunswick No.6	2	19	15.4	1.3
F - Key Anacon (New Larder "U")	2	12	14.2	3.3
G - Heath Steele "A1"	1	7	13.2	1.8
H - Stratmat	3	13	15.5	1.8
I - Nepisiguit "B"	4	9	6.8	4.6
J - Nepisiguit "A"	4	10	7.7	4.6
K - Wedge	4	7	10.0	1.8
L - California Lake	4	5	6.3	2.3
M - Armstrong "A"	4	7	5.9	3.7
N - Rocky Turn	4	1	8.6	
O - Orvan Brook (New Calumet)	4	4	8.6	1.8
P - McMaster	4	1	8.2	
Q - Caribou	4	28	7.7	1.8
R - Murray Brook	4?	10	10.9	1.8
S - Devils Elbow	2	13	11.8	2.3
T - Halfmile Lake (Texas Gulf)	1	9	13.7	1.3
U - Chester (Clearwater)	4?	10	9.5	1.8

Table 3b. Lead isotope values for various deposits in the Bathurst Mining Camp. Unpublished data from the lead isotope computer file at the Geological Survey of Canada (Thorpe, written communication 1992). Dr. R. Thorpe was supplied samples by Drs. J. Jambor, F.M. Vokes, D.F. Sangster, and G.A. Gross, which were analysed under contract by the Geological Survey of Canada. See Figure 2 for deposit locations.

DEPOSIT	Group	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
A - Brunswick No.12	2	18.187	15.649	38.100
E - Brunswick No.6	2	18.277	15.663	38.219
E - Austin Brook	2	18.247	15.658	38.140
F - Key Anacon (New Larder "U")	2	18.247	15.658	38.140
G - Heath Steele "A1"	1	18.199	15.652	38.124
H - Stratmat	3	18.207	15.641	38.116
K - Wedge	4	18.275	15.662	38.198
M - Armstrong "A"	4	18.287	15.655	38.166
N - Rocky Turn	4	18.319	15.668	38.269
O - Orvan Brook (New Calumet)	4	18.305	15.653	38.195
Q - Caribou	4	18.276	15.654	38.187
R - Murray Brook	4	18.309	15.669	38.219
T - Halfmile Lake (Texas Gulf)	1	18.217	15.659	38.152
U - Chester (Clearwater)	4	18.302	15.659	38.215
V - Strachans Lake Bk.	4	18.223	15.649	38.119
W - Canoe Landing Lake	4	18.243	15.653	38.191
X - Restigouche	3	18.241	15.648	38.163
Y - Willett showing	4	18.295	15.651	38.186
Z - Armstrong "B"	4	18.298	15.660	38.233
YY - Portage Lakes	4	18.230	15.647	38.143
ZZ - Captian	2	18.279	15.657	38.161

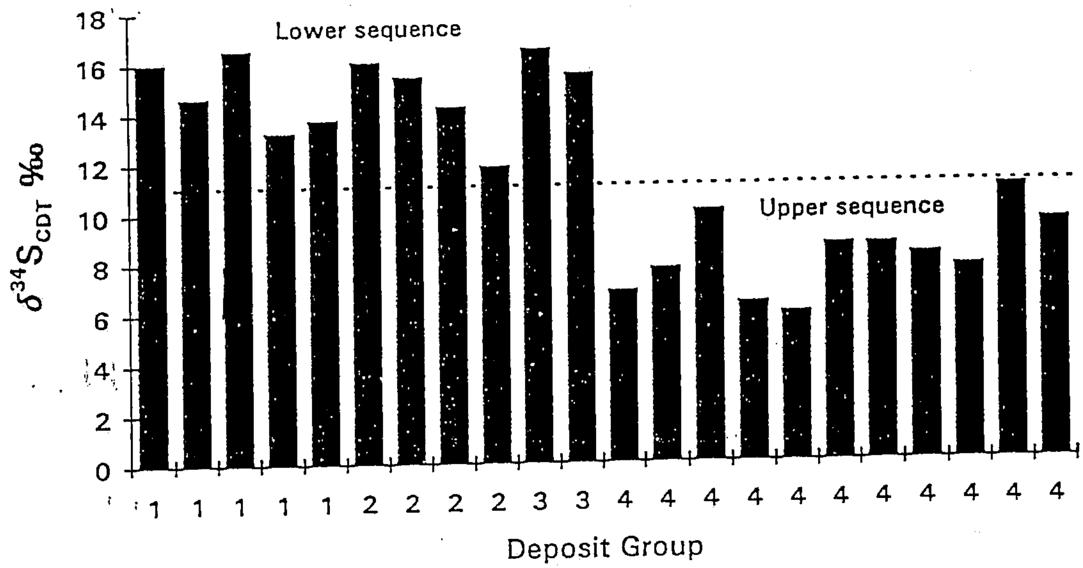

Figure 6. Average sulpur isotope compositions of massive sulphide deposits in the Bathurst Camp subdivided into 4 groups as described in text (See Table 3a).

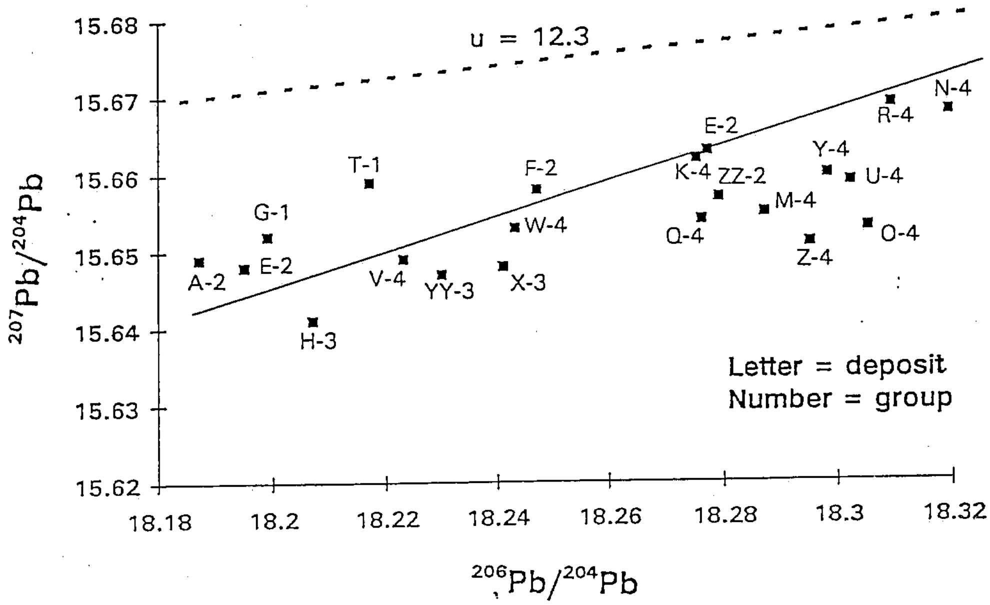

Figure 7. Lead isotope compositions from various massive sulphide deposits in the Bathurst Camp (See Table 3b).

30% chlorite (Saif 1980). The chlorite is typically iron-rich (Davies 1972; Juras 1981; van Staal 1985; Lewczuk 1990; Luff *et al.* 1992). Similar rocks underlie the massive-sulphide deposits, where they commonly contain disseminated and stringer sulphides (pyrite-pyrrhotite-chalcopyrite), and are sometimes referred to as the footwall iron-formation (Bhatia 1970; van Staal and Williams 1984). In contrast to the oxide iron-formation, which originated entirely as hydrothermal chemical-sediment, the silicate-facies has a significant volcaniclastic component (cf., Davies 1972; Whitehead, 1973; Graf 1977; Peter and Goodfellow 1993). However, it is not clear to what extent hydrothermal alteration has modified the original character of the footwall iron-formation, i.e. if it mainly represents chemical sediment or if it is largely the product of sub-seafloor alteration.

The carbonate facies is not areally extensive and generally occurs within the other two facies as medium to thick (5-10 mm) lamina of light grey and buff Fe-carbonate. The rocks predominantly consist of a cryptocrystalline mixture of carbonate and quartz with subordinate chlorite.

The Caribou-type (group 4) deposits do not contain a laterally extensive iron formation, but lateral zoning is manifested in the Caribou deposit by a decrease in magnetite, Cu, Zn, Pb and Ag from the west limb of the Caribou fold, around the nose to the east limb (Jambor 1979). Elsewhere in the Boucher Brook Formation, basic iron-formation and red, relatively Fe/Mn-rich slate (RMS) and chert occur. These rocks constitute types (iv) and (v) of Saif's (1980) iron-rich rocks, respectively. The term "basic" iron-formation is used to describe alternating magnetite- and chlorite-rich bands hosted in mafic volcanic rocks (Saif 1980) and represent chemical sediments and/or hydrothermally altered lavas. Notably, the RMS has higher Ni, Cr, V, and Co contents than any of the iron-rich rocks in the felsic volcanic pile (see Table 2) and is generally associated with mafic volcanic rocks. However, these kinds of iron-rich rocks have not been found in contact with, or in close proximity to, Caribou-type sulphides.

The major-element data from outcrop and drill-core samples obtained by Saif (1980) are summarized in Table 4a. On average, the silicate iron-formation has the highest Al_2O_3, MgO and Na_2O but the lowest Fe_2O_3 and MnO; the oxide iron-formation has the highest Fe_2O_3, FeO and P_2O_5 but the lowest SiO_2, TiO_2, Al_2O_3, MgO, Na_2O and K_2O; the carbonate iron-formation has the highest TiO_2, MnO, CaO, CO_2 and S, whereas the Fe-rich shale has the highest SiO_2 and K_2O but the lowest FeO, CaO, P_2O_5, CO_2 and S. It is also interesting to compare the average chemical compositions obtained on Algoma-type iron-formations (Gross and McLeod 1980) with data obtained by Saif (1980). However, the data presented by Gross and McLeod (1980) represent a compilation from many areas (dominantly Archean iron-formations), so some differences are expected, as shown in Table 4b.

It has been shown that the variation in Mn/Fe ratio within iron-rich rocks is potentially useful as an indicator of proximity to ancient hydrothermal vent-complexes (cf. Bonatti *et al.* 1972; Whitehead 1973; Goodfellow 1975). Low Mn/Fe ratios are proximal, whereas high Mn/Fe ratios are distal. However, from Tables 4a and 4b, it is clear that there are variations in the Mn/Fe ratio among the different types of iron-rich rocks, and more importantly, among iron formations of the same type from one area to another, because of their relative affinities for manganese. Therefore, absolute values of the Mn/Fe ratio are less meaningful than relative values within a single exhalative unit, when it comes to assessing the proximity to a massive-sulphide deposit.

GENETIC MODELS

The Tetagouche Group in the Bathurst Mining Camp contains an abundance of massive-sulphide deposits. The lower part of this group was deposited during the initial (ensialic stage) opening of a back-arc basin at the leading edge of Avalonia (Fig.4). Within these Middle Ordovician

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ROAD LOG FOR STRATIGRAPHY OF THE TETAGOUCHE GROUP

Depart from Keddys Hotel and proceed south on King Avenue; at the overpass above Highway (Hwy) 11, this street becomes Route 430. This is the starting point of the road log.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Drive south on Route 430.
4.7	4.7	Junction with road to Pabineau Falls; bear right on Route 430.
11.6	16.3	Junction with Route 360 to Allardville; continue straight on Route 430.
6.8	23.1	Junction with road to Brunswick No.12 Mine; bear left on Route 430.
0.6	23.7	Junction with road to Bathurst Mines (Nepisiguit Falls); continue straight.
1.2	24.9	Junction with dirt road to Brunswick No.6 Mine; turn left.
1.7	26.6	The road crosses Knights Brook at this point. The large outcrop in the edge of the trees west of the road, and on the north side of the brook, consists of quartz wacke and grey slate of the Miramichi Group. Well developed F_2 folds and S_2 cleavage are overprinted by S_4 (trending 050°) and S_5 (trending 120°) cleavages in this outcrop.
2.0	28.6	The stop sign at the forks in the road overlooks the Nepisiguit Falls dam and power generating station. Bear left and drive down to the parking lot by the dam. The outcrops in this area constitute the type section of the Nepisiguit Falls Formation. The roadbed that parallels the Nepisiguit River is all that remains of the Northern New Brunswick and Seaboard Railway line to the old Austin Brook Iron Mine. Walk west (upriver) along this roadbed about 450 m, past STOP NF-3 and STOP NF-2, to STOP NF-1 (Fig.T1).

STOP NF-1:

Outcrops of massive, aphyric rhyolite occur along the hillside northwest of the roadway. About 600 m farther up the road, just past the Nepisiguit Sport Lodge, there is a roadcut where rhyolitic hyaloclastites and minor sedimentary rocks occur with massive rhyolite. All these rocks are part of the Flat Landing Brook Formation.

Return to roadway and walk back towards the dam about 50 m.

STOP NF-2:

The outcrop in the ditch where the culvert crosses the road contains the contact between massive rhyolite of the Flat Landing Brook Formation and chloritic iron formation of the Nepisiguit Falls Formation. Note the contrast in cleavage development in these two rock types. The chloritic iron-rich rocks outcrop intermittently along the ditch for 100 m or more, and constitute the "Brunswick Horizon". Some of the chloritic rocks are magnetic and/or manganiferous reflecting their original, chemical-sedimentary character, whereas others exhibit remnant volcaniclastic textures indicating that they are the product of hydrothermal alteration.

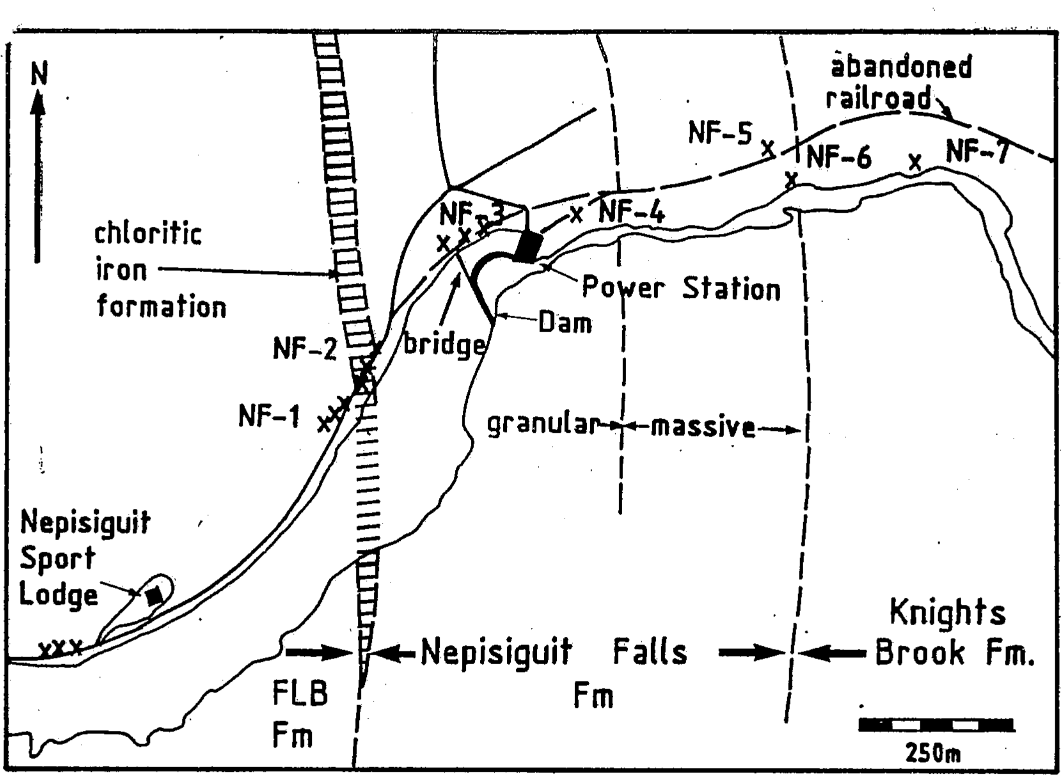

Figure T1. Simplified geological map of the Nepisiguit Falls area showing stop locations. The location of this map in the Bathurst Mining Camp is shown on the Nepisiguit Falls (21 P/5) road-map in Appendix I.

Walk back towards the dam along the old railway roadbed to the point where the bridge crosses to the dam. Turn left along the path that goes up the hill and proceed to the small glaciated outcrop in the path.

STOP NF-3: Granular texture is apparent in this outcrop of quartz-feldspar-augen schist (QFAS), which predominantly consists of juvenile volcaniclastic material with a few accidental lithic fragments. This type of QFAS constitutes part of the proximal volcaniclastic facies of the Nepisiguit Falls Formation. By comparing this outcrop with the two closer to the parking lot, one can detect variations in the grain size and abundance of quartz and K-feldspar phenoclasts. In the water-polished outcrops at the foot of the dam, thick crudely-graded beds can be seen. These rocks are interpreted as cold debris flows rather than hot pyroclastic deposits.

Walk past the vehicles and downriver along the railroad bed about 100 m. Turn right onto the trail that leads down to the foot of the power station.

STOP NF-4: In the first part of the rock-cut on the right, a thin layer of hyalotuff caps fining-upward QFAS. This hyalotuff represents fine-grained glass particles that separated from the crystal-rich debris flow during its emplacement, and then settled from the water column before deposition of the next flow. These hyalotuff beds are rare in the proximal facies of the NF Formation but predominate in the distal facies.

Return to the old railroad bed and proceed downriver another 200 m.

STOP NF-5: The roadcut on the left is massive QFAS, which consists of large quartz and K-feldspar phenocrysts (up to 1.5 cm) in a cryptocrystalline groundmass. This type of QFAS lacks the microcrystalline groundmass of an intrusive porphyry, but has characteristics intermediate between lava and pyroclastic flows. Therefore it is interpreted as tufflava. Such rock constitutes the lower half of the Nepisiguit Falls section in this area.

Continue along roadway approximately 20 m to the gully on the right, which contains the remains of an old car. Follow the path down the right side of the gully to the outcrop.

STOP NF-6: The basal contact of the NF Formation is exposed in the outcrop halfway up the right side of the gully. The contact is conformable with some interbedding of volcanic and sedimentary rocks. The top of the underlying Knights Brook Formation consists of chloritic siltstone that is in contact with a one-meter-thick chloritic QAS layer. The QAS is overlain by a 45-centimeter-thick quartz wacke bed; itself overlain by more QAS that grades upward away from the contact into QFAS. The QAS is interpreted as QFAS from which the K-feldspar phenocrysts were lost because of alteration.

Return to the roadway and continue downriver approximately 300 m to the point where the road widens. Follow the beaten path up over the bank on the right and down to the river.

STOP NF-7: Rusty-weathering quartz wacke and grey slate of the Knights Brook Formation (Miramichi Group) are exposed near the river. Small (< 1 mm) volcanic-quartz eyes are present locally and S_2 cleavage is well developed.

Return to the roadway and then back to the power station. Drive back the same route to the junction with Hwy 430. Reset the road log to zero.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Turn left and drive west on Route 430, which is a gravel road from this point.
1.6	1.6	The road on the right intersects the paved road to Brunswick No.12 and leads to Stone Consolidated's sawmill.
0.4	2.0	At this point Route 430 crosses the haulage road between Brunswick No.6 and No.12 mines.
5.3	7.3	Junction with Nine Mile East Road on the right; continue straight on Route 430.
0.7	8.0	Outcrop on the right side of the road is reddish grey, massive aphyric rhyolite

Distance (in km)	Cumulative Distance	Description
		of the Flat Landing Brook Formation. The surrounding area within about a 2 km radius constitutes the type-area of this formation.
1.2	9.2	Turn left on the Flat Landing Brook haulage road.
2.3	11.5	Outcrop on the left (north) side of the road contains magnetite-hematite iron formation in Flat Landing Brook rhyolite. Not far past this outcrop, the road deteriorates.
1.3	12.8	Y-intersection with the road to Flat Landing Brook; bear right toward The Narrows and continue east. Ignore side roads.
2.2	15.0	The road turns sharply left, toward the north-northeast, just past a side road on the right.
0.2	15.2	The large glaciated outcrop on the right is massive rhyolite of the Flat Landing Brook Formation.
1.8	17.0	At the fork in the road, shown in Figure T2, bear right.
0.2	17.2	The outcrop in the road, also shown in Figure T2, is FLB rhyolite.
0.3	17.5	Turn left into the clearing and park. Follow the trail at the south end of the clearing down over the hill approximately 100 m to the outcrop on the left.
STOP N-1:		The depositional contact between massive QFAS (tufflava) and grey fine-grained sedimentary rocks is exposed in the low outcrop beside the trail. Grading in thin volcaniclastic layers near the contact indicates that the ridge-forming QFAS overlies the sedimentary rocks. The quartz and K-feldspar phenocrysts (1-5 mm) are not as large as those in the type section. Whether the sedimentary rocks are part of the Nepisiguit Falls Formation or part of the Miramichi Group is unclear because of the paucity of outcrop.
		Continue east along the trail approximately 100 m to the low ridge; climb to the crest of this ridge another 50 m farther along.
STOP N-2:		Along the ridge crest, there are several outcrops consisting of dark grey slate with thin beds of white-weathering quartzose sandstone. Mesoscopic F_2 folds in these outcrops plunge to the north even though the megacsopic F_2 fold at the river plunges south; this indicates that there is an F_1 fold closure not far below the surface. About 50 m farther east, just beyond the edge of the old clearcut, there is an outcrop that contains mesocopic F_1 folds refolded by F_2; the F_1/F_2 interference pattern mimics the megascopic fold pattern.
		Continue eastward along the ridge approximately 150 m to Nepisiguit River. Walk downriver along the waterline to the first outcrop.
STOP N-3:		Both the lower and upper contacts of a 10-m-thick, massive QFAS layer are exposed. Bedding and cleavage are oblique to one another. The dark grey to

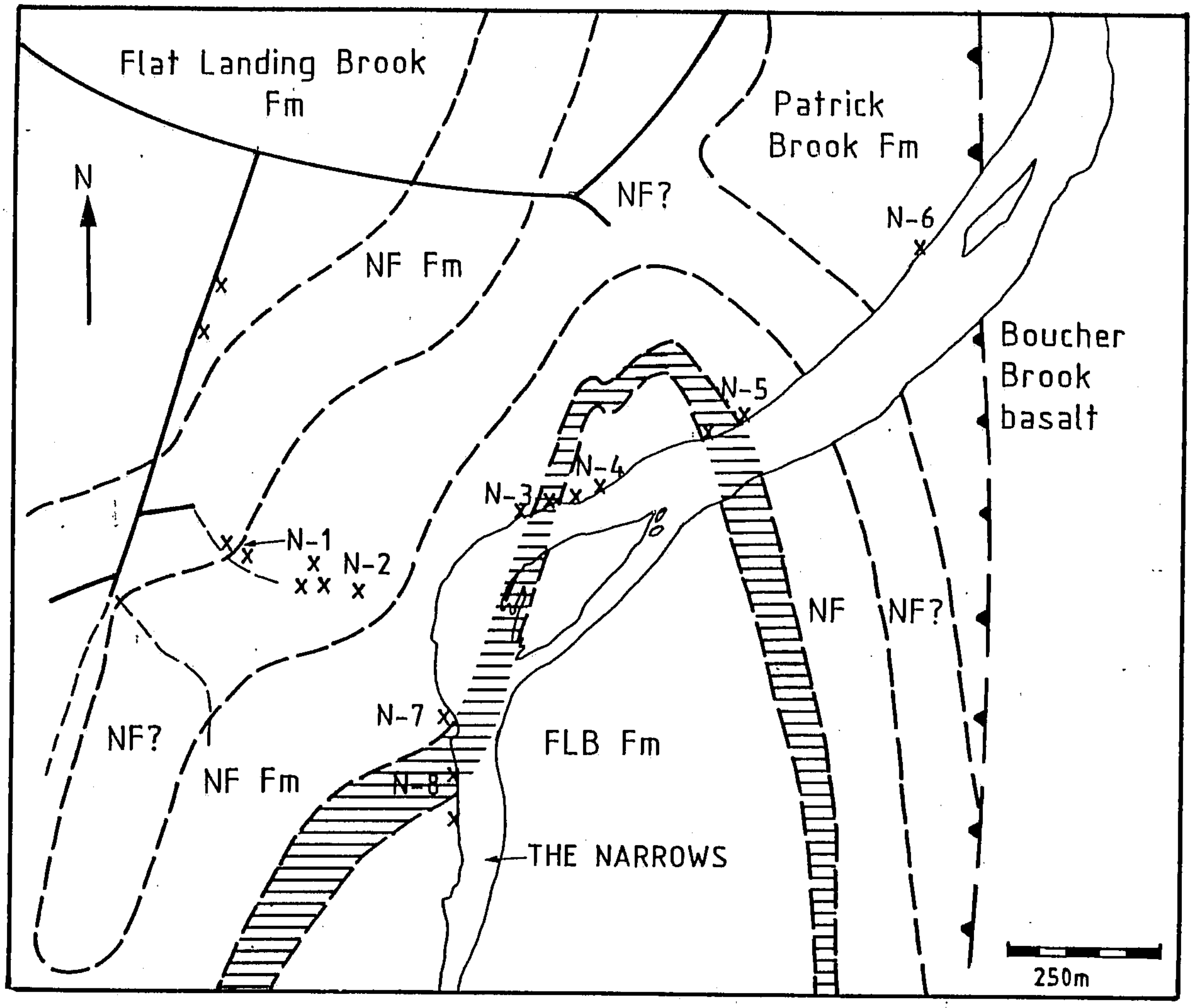

Figure T2. Simplified geological map of The Narrows area showing stop locations. The location of this map in the Bathurst Mining Camp is shown on the Nepisiguit Falls (21 P/5) road-map in Appendix I.

brownish grey sedimentary rocks that immediately overlie this QFAS (near the large pine tree) are manganiferous and in places magnetic. They constitute the "Brunswick Horizon" at this locality. Toward the top (downriver) of this sedimentary unit there is a thin layer of black rhyolite.

Walk northeastward (downriver) along the shoreline another 50 m to the next stop (Fig.T2).

STOP N-4:

Pseudo-fragmental greenish grey rhyolite of the Flat Landing Brook Formation occupies the core of a southerly plunging, macroscopic F_2 syncline. The apparent feldspars (white) and fragments (black) are the product of partial devitrification of massive rhyolite, which occurred shortly after it was deposited.

Continue downriver along the shoreline another 300 m to the low-relief outcrops at the waterline.

STOP N-5: Although the contact is not exposed, the boundary between pseudo-fragmental rhyolite of the FLB Formation and manganiferous sedimentary rocks of the NF Formation occurs within the group of scattered outcrops in this area. Also an orthogonal relationship between the S_1 and S_2 cleavages can be seen in the mesocopic folds that occur locally.

Continue northeastward another 500 m to the large outcrop on the bank away from the water.

STOP N-6: Graphitic slates with quartz eyes (1 mm) constitute the entire outcrop. These rocks are assigned to the Patrick Brook Formation and constitute the base of a nappe that overlies Boucher Brook basalts to the east (Fig.T2).

Return to STOP N-3 and from there proceed south along the shoreline approximately 300 m to the mouth of the small brook.

STOP N-7: Granular (volcaniclastic) QFAS is interbedded with greenish grey siltstone in the outcrop at the mouth of the brook. These beds are overlain by the same manganiferous sedimentary rocks that occur at STOP N-3.

Continue upriver along the shore another 50 m.

STOP N-8: At this locality magnetite-hematite iron formation, at the top of the same sedimentary unit seen at the last stop, is in contact with rhyolite of the FLB Formation.

Return to STOP N-7 and proceed downriver along the shore 200 m; turn west and go up over the bank for about 200 m to STOP N-2 and thence back to the vehicles along the same trail used to get there. Retrace the same route back to Route 430. Reset the road log to zero.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Turn left and drive west on Route 430.
4.0	4.0	Turn right (north) on Nine Mile West road.
5.6	9.6	Turn left into the borrow pit (Fig.T3) beside the road and park.

STOP B-1: Dark grey to black siltstone and lithic wacke of the Boucher Brook Formation constitute the floor of this pit. At the eastern end, there is a layer of lithic wacke containing what appears to be white-weathering feldspar grains; however, the grains are actually small fragments of rhyolite, presumably from the underlying Flat Landing Brook Formation.

Walk southeast (uphill) about 100 m along the Nine Mile West road to the first trail on the left. Follow this trail to the end (150 m) and then follow the cut line northward another 150 m to Nine Mile Brook.

STOP B-2: In the large outcrop on the opposite side of the stream, the depositional contact between Flat Landing Brook Rhyolite and Boucher Brook sedimentary rocks is

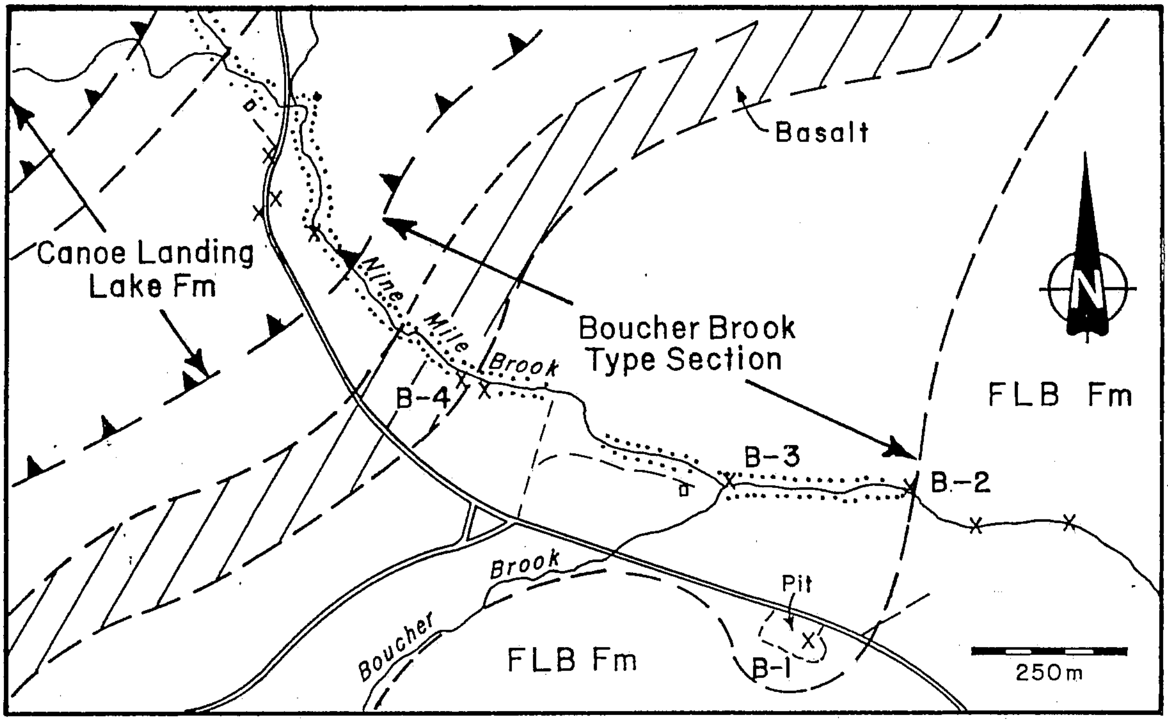

Figure T3. Simplified geological map of the Boucher Brook area showing stop locations. The location of this map within the Bathurst Mining Camp is shown on the California Lake (21 O/8) road map in Appendix I.

exposed. Reddish grey, manganiferous slate occurs at the contact. Rhyolite outcrops downstream from this contact are sericitic and pyritized. Upstream for over 200 m, outcrop is almost continuous and consists of nothing but grey siltstone with well developed cleavage(s).

Return to vehicles and drive northwest about 600 m to the junction with the Theriault road. Turn right (north) and park in the clearing on the left (100 m). Walk (about 300 m) in the driveway that parallels the stream past the cabins to the confluence of Boucher and Nine Mile brooks.

STOP B-3:

The outcrop on the opposite side of Nine Mile Brook consists of dark grey siltstone with minor sulphides, mostly pyrite. A diamond-drill hole collared approximately 400 m to the southwest, between Boucher Brook and the Theriault road, contained a 2.8 m intersection grading 2.4% Pb.

Return to the vehicles and walk past them on the trail to the right. Either walk down the trail to the brook (100 m) and then up the brook for 100 m, or traverse north-nortwesterly through the bush to the brook (about 150 m).

STOP B-4:

There are two low-relief outcrops along the south bank of the brook at the waterline, which are approximately 50 m apart. The first consists of highly deformed, dark grey slate and siltstone, whereas the second comprises basalt with interbedded greenish grey volcaniclastic rocks. The contact between the contrasting lithologies in the two outcrops is considered to be conformable and that both are part of the Boucher Brook Formation. Another 250 m farther upstream is the thrust contact with the Canoe Landing Lake Formation.

Return to the vehicles and drive back to Bathurst via Route 430.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	At the overpass with Hwy 11 turn north towards Campbellton and reset the road log to zero.
7.6	7.6	Exit right 600 m past the Vanier Boulavard overpass (Exit 310).
0.4	8.0	Turn left (west) at the Stop Sign onto Route 315.
1.9	9.9	Junction with Route #322; bear left on Route 322.
0.7	10.6	Junction with the road to North Tetagouche; bear left (straight) on the North Tetagouche road.
6.8	17.4	Turn left (south) at the driveway into the field (about 200 m past the end of the paved road) and follow the driveway across the field (another 200 m) to the turn-around overlooking the river (Fig.T4). Park and follow the steep path down to the river's edge. Walk downriver (east) about 100 m to the first stop.

STOP LF-1:

Steeply north-dipping Vallée Lourdes limestone is depositionally overlain by black pyritic slate that is in turn overlain by fine-grained, greenish grey volcaniclastic beds of the Nepisiguit Falls Formation. On the opposite (south) side of the river, the disconformable contact between the Vallée Lourdes and underlying Miramichi Group is exposed when the water-level is low. The base of the Vallée Lourdes is marked by a pebble conclomerate with quartzite clasts. Approximately 25 m upriver, along the north side, there are large blocks of coarse-grained volcaniclastic rock, which have fallen down from the cliff above. Note the abundance of quartz and K-feldspar, as well as the tiny slate fragments in these blocks. This rock type occurs as lenses in the fine-grained volcaniclastics, as will be seen at STOP LF-3.

Return upriver to STOP LF-2; note that you are walking parallel to strike.

STOP LF-2:

The flat outcrop at the top of Little Falls is directly on strike with the limestone at the previous stop. However, it consists of siliciclastic limestone and/or medium to coarse-grained, calcareous sandstone. Cross-bedding and scours filled with granule conglomerate, containing quartzite clasts, indicate that the section youngs to the north. The rocks contain numerous quartz and K-feldspar grains; they pass upward into more typical Vallée Lourdes limestone that is overlain by black slate as at STOP LF-1.

Continue upriver about 150 m to the next stop; again note that you are walking parallel to strike.

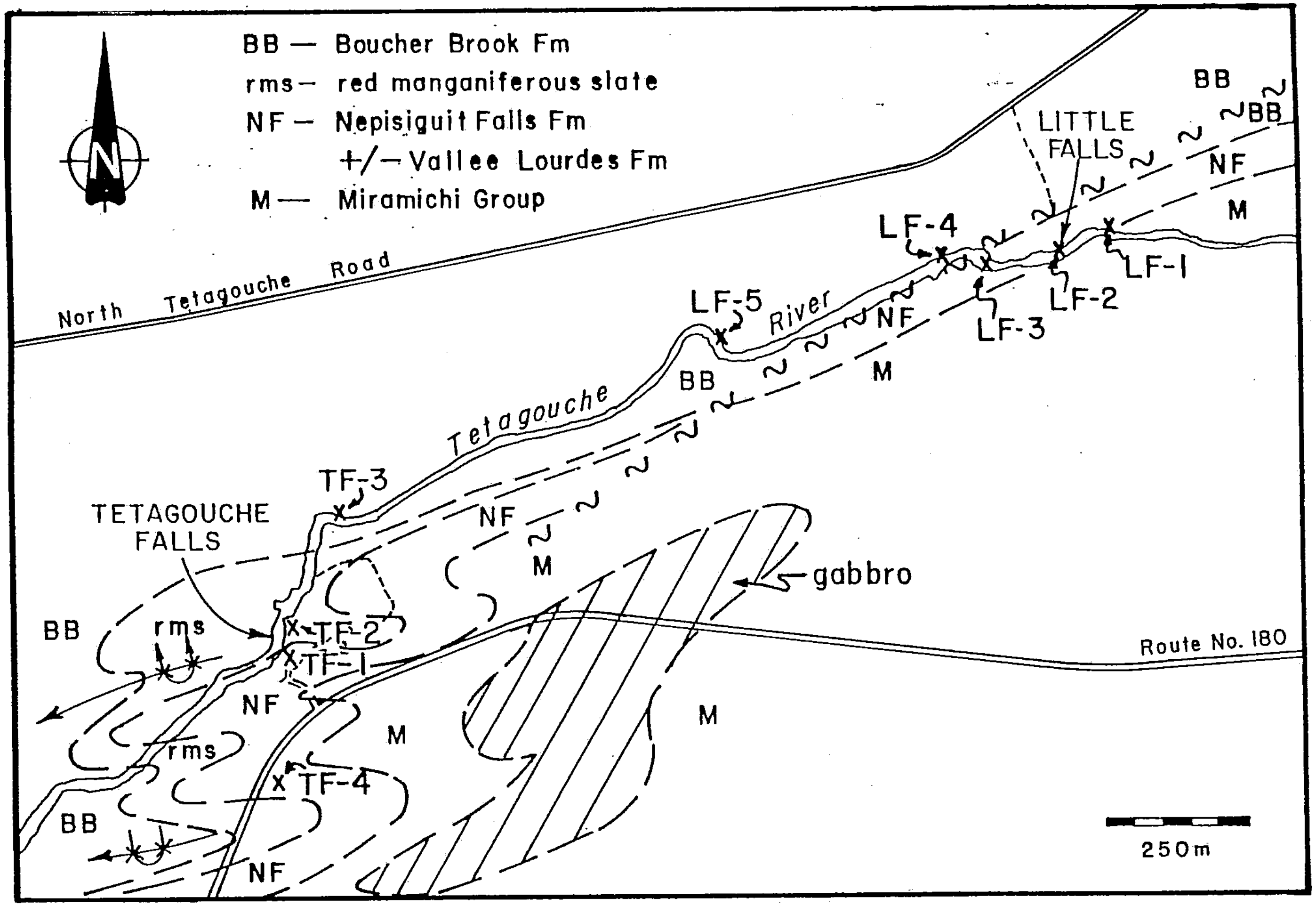

Figure T4. Simplified geological map of the Little Falls - Tetagouche Falls area showing stop locations. The location of this map in the Bathurst Mining Camp is shown on the Bathurst (21 P/12) road map in Appendix I.

STOP LF-3:

The large outcrop at the bend in the river constitutes the reference section for the Little Falls member (cf. Langton and McCutcheon 1993) of the Nepisiguit Falls Formation. The section exposed in this outcrop is approximately 30 m thick and consists of fine-grained, greenish grey volcaniclastic beds that grade upward into, and/or are interlayered with, greenish grey hyalotuff and dark grey siltstone. Toward the top of the section, there are lenses (channels) of coarse-grained volcaniclastic rock like that in the large blocks seen near STOP LF-1. The coarse-grained lenses represent the crystal-rich parts of individual debris flows, from which the fine-grained glass (hyalotuff) was winnowed during transport downslope. The Little Falls Member appears to grade upward through dark grey siltstone into black, graphitic slate. However, there is a sub-vertical fault separating the slate from the siltstone.

Continue upriver another 50 m.

STOP LF-4:

The orange to reddish brown outcrop, which juts into the river is an altered felsite dyke. This dyke occupies and is dismembered by the fault that parallels this section of the river. Parts of the dyke can be seen within the graphitic slate in the cliff face and other parts (knockers) occur in the tectonic mélange beneath the water. About 50 m farther along, there are minor folds in black slate adjacent to the fault zone, which trend approximately 210°, whereas the fault trends about 250°. In the cliffs north of the river, there are light grey, locally calcareous, siltstones of the Boucher Brook Formation, but to the south of the river, there are volcaniclastic rocks of the Nepisiguit Falls Formation.

Continue upriver another 400 m.

STOP LF-5:

The large outcrop at the bend in the river comprises very thinly bedded to laminated siltstone and slate of the Boucher Brook Formation. Bedding-cleavage relationships are well displayed in this outcrop.

If the waterlevel is low, you can continue upriver approximately 750 m to STOP TF-3; otherwise return to the vehicles and drive back the same route to the Vanier Boulevard overpass (Exit 310) on Hwy 11. Reset roadlog to zero.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Take Exit 310 and turn left (west) on Route 180.
9.8	9.8	Turn right (north) into the Provincial Picnic Area at Tetagouche Falls. Park and walk past the hand-pump to the fenced look-off point (Fig.T4).

STOP TF-1:

The outcrop at the look-off comprises altered volcaniclastic rocks of the Nepisiguit Falls Formation, which are in contact (beyond the fence) with red manganiferous slate. These rocks are sitting on the overturned limb of a tight, westward-plunging syncline that underlies the gorge; the same contact, but on the upright limb, can be seen near the entrance to the adit at the bottom of the gorge and on the opposite side of the river. The manganiferous slate can either be considered to sit at the top of the Nepisiguit Falls Formation, i.e. Brunswick Horizon, or at the bottom of the Boucher Brook Formation because there are no Flat Landing Brook rocks present. However, elevated Co, Ni and Cr values in one sample of maroon slate from this area (cf. Connell and Hattie 1990) suggests a Boucher Brook affinity.

Walk to the eastern end of the parking lot, about 100 m, and follow the well-beaten path down to the river, approximately 300 m. Walk upriver along the waterline toward the falls.

STOP TF-2: Thinly layered green and maroon slates with parasitic folds and southerly dipping cleavage are exposed in the outcrops along the bank. The metal construction and concrete abutments represent the remains of a 9 m (30 foot) dam and electical-generating facility that was abandoned in 1921; until then this facility provided electricity to Bathurst (Wright 1950). If the waterlevel is low, you can wade across the foot of the pool below the falls to see the depositional contact between the slate and fine-grained volcaniclastic rocks near the entrance to the old adit. This is the upright limb of the northward-overturned syncline mentioned above. The adit dates from the last century when attempts were made to mine manganese in this area (Wright 1950); the last serious exploration for manganese on this property was conducted by the Canadian Manganese Mining Corporation in the mid-1950's, when geophysics, trenching and extensive diamond drilling were carried out.

Walk downriver along the north shoreline approximately 200 m.

STOP TF-3: The large outcrop at the bend in the river consists of very thinly bedded, grey siltstone and slate of the Boucher Brook Formation. These rocks are similar to those seen farther downriver at STOP LF-5.

Return to the parking lot and walk to the large outcrop along Route 180, which is across the road from the entrance to the picnic area about 150 m southwest.

STOP TF-4: Fine to coarse-grained volcaniclastic rocks are interlayered in this outcrop. The beds dip steeply to the south and are right-way-up as indicated by fining-upward-depositional units. However, diamond-drill records show that this is the upright limb of a northward-overturned anticline.

Return to Bathurst.

GEOLOGY OF THE HEATH STEELE-SOUTH LITTLE RIVER LAKE-ISLAND LAKE AREA, BATHURST CAMP, NEW BRUNSWICK

R.A. Wilson[4]

This part of the Heath Steele field trip will be spent exploring Tetagouche Group stratigraphic relationships outside of the immediate mine area. Figure HS-1 shows the location of the area; most of the exposures to be visited are located south of the mine (Fig.HS-2) and include rocks belonging to (from oldest to youngest) the Nepisiguit Falls, Flat Landing Brook and Boucher Brook formations (van Staal and Fyffe 1991). At Heath Steele, mineralization is hosted by volcanic and sedimentary rocks of the Nepisiguit Falls Formation, which occupy the core of a large F_1 antiform with an axis that strikes ENE-WSW in the mine area. North of Heath Steele, crystal-rich tuff/tufflava and/or tuffite of the Nepisiguit Falls Formation (also known as quartz-feldspar porphyry or quartz-feldspar augen schist) is conformably overlain by aphyric and feldspar-phyric rhyolite of the Flat Landing Brook Formation, indicating that the sequence youngs to the north. Flat Landing Brook rhyolite is also exposed on the east side of the backfill quarry south of the "B" Zone (Fig.HS-3), where it occurs on the southern limb of the F_1 fold. This southern limb is truncated by the Heath Steele fault, such that there is no rhyolite west of the quarry, on the north side of the fault.

South of the Heath Steele fault, Nepisiguit Falls Formation crystal tuff/tufflavas (unaccompanied by sedimentary rocks) are similarly conformably overlain by Flat Landing Brook rhyolites, and the sequence again youngs to the north. Yet farther south (south of the Tailings Lagoon), a zone of high strain separates these latter rocks from a third north-younging sequence. This sequence consists of Flat Landing Brook rhyolites overlain by alkalic, pillow basalts typical of the Boucher Brook Formation, and thus represents a substantially younger fragment of the stratigraphic succession. These truncations and repetitions of north-younging sequences are interpreted as imbricate thrust slices. From north to south, successively younger slices of the Tetagouche Group stratigraphy are preserved, and within these three slices, geological features characteristic of the three main mineralized horizons in the Tetagouche Group are found, these being the Heath Steele (or Brunswick), Stratmat and Caribou horizons, from oldest to youngest, respectively. The structural geology of the area is described in detail by de Roo *et al.* (1990), de Roo *et al.* (1991), and Williams and McAllister (1989).

At Heath Steele, the mine sequence documents periodic extrusion of quartz-feldspar crystal tuff/tufflava alternating with periods of normal sedimentation and, locally, exhalative activity. Mineralization typically occurs at or near the contact between the volcanic and sedimentary members of the Nepisiguit Falls Formation. Evidence for a pyroclastic origin for the quartz-feldspar-rich rocks includes large lateral extent but limited thickness of units, local internal bedding structures, gradational contacts with overlying tuffaceous (epiclastic) sedimentary rocks, and, in places, broken phenocrysts (Wilson 1992a). Locally, these rocks contain evidence of reworking and may be classified as tuffites. However, bubble-wall shards are extremely rare and pumice fiammé and lithic fragments are apparently absent. The absence of shards and fiamme may be a result of their destruction by post-emplacement alteration or dynamic metamorphism; alternatively, the lack of normal criteria for a pyroclastic origin may indicate relatively low-energy eruptions of volatile-poor magma. As the Nepisiguit Falls Formation was emplaced underwater (McCutcheon *et al.* 1993), rapid vesiculation may have been inhibited by the confining pressure of the overlying water column, thus reducing explosivity (*cf.*, Cas 1992).

Sedimentary rocks of the Nepisiguit Falls Formation include quartzose and feldspathic wackes, argillaceous siltstones, shales, local quartzose sandstone, massive sulphides, and iron formation. The clastic rocks are typically medium to dark green in colour, locally sericitic and commonly moderately to highly chloritic; maximum chloritization occurs in proximity to massive-sulphide bodies, where they are referred to as "chloritic tuff".

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[4] *New Brunswick Department of Natural Resources and Energy, Geological Surveys Branch, P.O. Box 6000, Fredericton, N.B., E3B 5H1.*

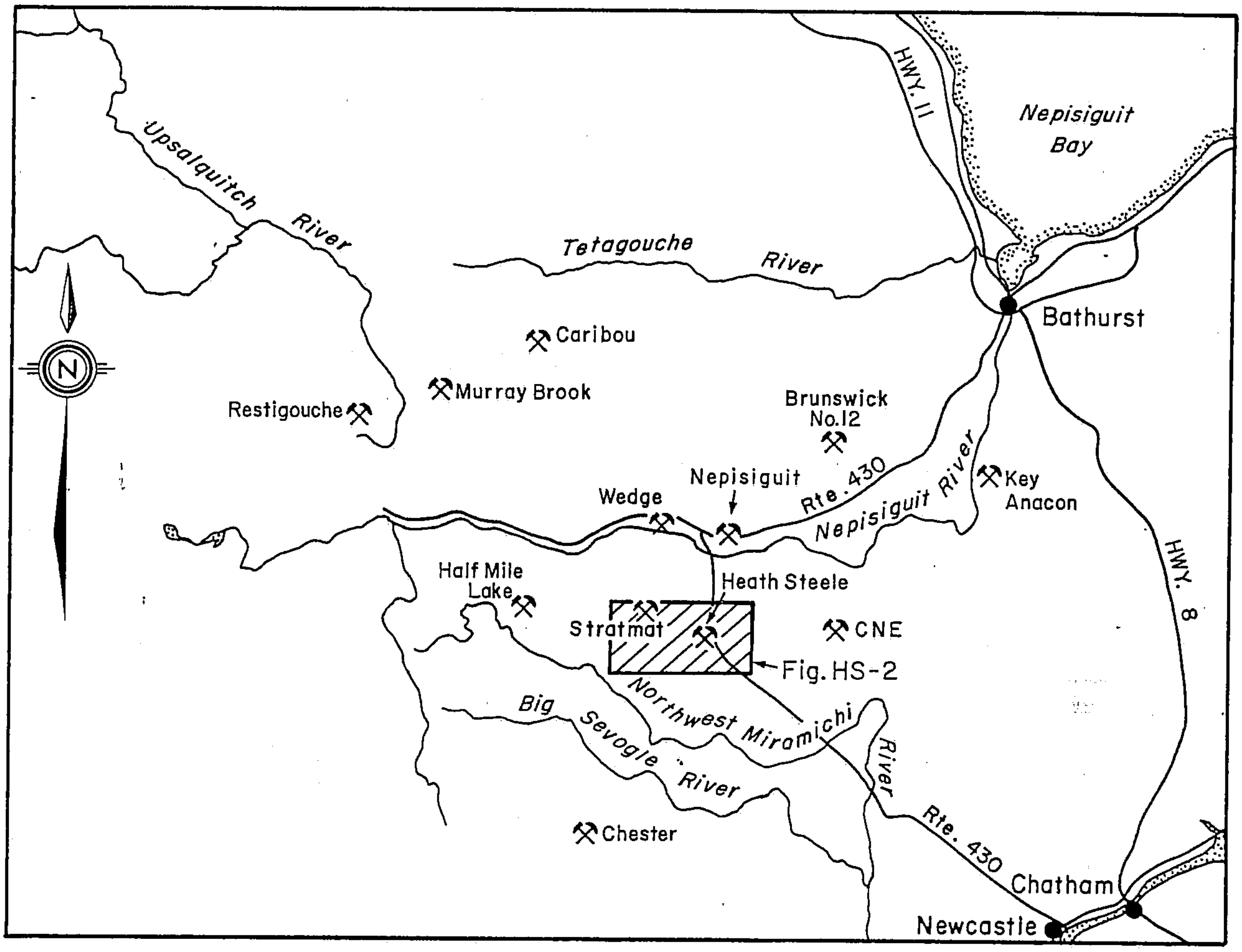

Figure HS-1. Location map for Heath Steele field excursion.

The Heath Steele horizon can be traced southwest from the mine, where it is folded around the northwest-trending axis of a major F_2 fold. The Mowat and Satellite prospects are located near the closures and along the flanks of minor F_2 folds southeast of North Little River Lake. With increasing distance from Heath Steele, there is a decrease in the proportion of crystal tuff/tufflava, relative to sedimentary rocks, in the Nepisiguit Falls Formation. Near Moose Brook, west of the granite body at South Little River Lake (Fig.HS-2), sideritic iron formation has been noted in drill core of Nepisiguit Falls sedimentary rocks.

The Flat Landing Brook Formation consists primarily of aphyric or feldspar-phyric rhyolite flows and domes, plus minor felsic hyaloclastites and pyroclastic rocks, thin units of interflow sedimentary rocks and local alkalic and tholeiitic, subvolcanic, mafic intrusions. Spherulitic and perlitic textures, indicating an originally glassy state, are developed in a large proportion of the felsic rocks. Pseudo-fragmental (lapilli-like) textures are locally produced by devitrification and alteration of glassy rhyolites (*cf.* Allen 1988). In high-strain zones, false ignimbritic textures may be created by extreme attenuation of pseudo-fragments, spherulites and/or phenocrysts (Wilson 1992b). However, deformation of the Tetagouche Group is markedly heterogenous (*e.g.* van Staal 1987; van Staal and Langton 1990), such that primary textures and structures in felsic volcanic rocks are locally undeformed and very well preserved, which has greatly aided the interpretation of modes of emplacement.

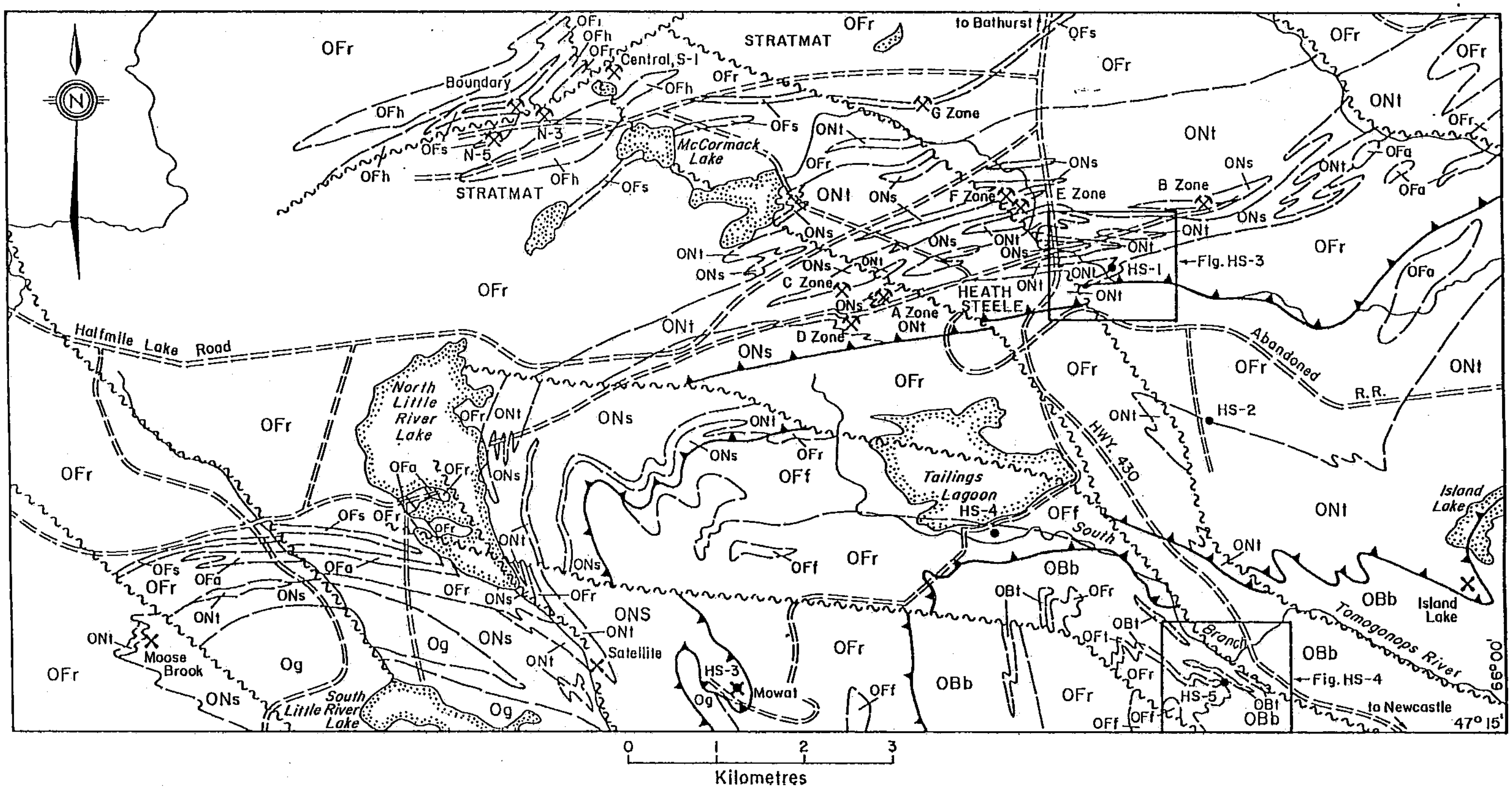

Figure HS-2a. Geological map of the Heath Steele area showing stop locations. Legend is on next page.

ORDOVICIAN

Og	South Little River Lake granite: leucocratic, foliated, granophyric
	Tetagouche Group
OBb OBt	*Boucher Brook Formation:* Massive to pillowed basalt (Brunswick alkalic basalt), plus minor brick-red chert, or cherty iron formation (OBb); quartz-feldspar crystal tuff (OBt)
OFr OFa OFt OFf OFs OFh	*Flat Landing Brook Formation:* Mainly aphyric and feldspar-phyric rhyolitic flows, minor dacitic flows, commonly perlitic or spherulitic; minor pyroclastic rocks, hyaloclastites and sedimentary rocks (OFr). Includes alkalic gabbro (OFa); quartz-feldspar crystal tuff (OFf); tholeiitic gabbro and massive basalt (Forty Mile Brook tholeiite - OFf); sedimentary rocks (green to grey shale, siltstone, feldspathic wacke - OFs); felsic hyaloclastites, minor aphyric or feldspar-phyric rhyolite (OFh).
ONt ONs	*Nepisiguit Falls Formation:* Quartz-feldspar crystal tuff (quartz-feldspar augen schist in many cases), plus minor "quartz-eye" tuff, quartzo-feldspathic epiclastic rocks (tuffites) and chloritic feldspathic wackes (ONt); shale, siltstone, feldspathic wackes, quartzose wackes and sandstones, commonly chloritized, plus minor quartz-feldspar crystal tuff, epiclastic rocks and massive sulphides (ONs).

SYMBOLS

— —	Geological contact
∿ ∿ ∿ ∿	Fault
▲—▲	Thrust fault
⚒	Massive sulphide deposit (significant tonnage)
✕	Massive sulphide occurrence
●	Stop Location

Geology by R.A. Wilson, 1992

Figure HS-2b. Legend for Figure HS-2a.

Felsic hyaloclastites occur as carapaces of monomict fragmental rocks marginal to some flow units. These rocks are produced by quench shattering (thermal strain) in combination with brittle fracturing of the partially solidified border zones of actively moving flows (*cf.* de Rosen-Spence *et al.* 1980).

The top of the Flat Landing Brook Formation is, in places, marked by a quartz-feldspar-rich tuff/tufflava, of variable thickness, which is remarkably similar in hand specimen to the crystal tuff/tufflavas of the Nepisiguit Falls Formation. The Flat Landing Brook crystal tuff/tufflavas are chemically similar to the rhyolites, however, and both can be distinguished from the Nepisiguit Falls crystal tuff/tufflavas on the basis of higher Nb, Y, Zn, Sc, V, Hf, and especially ΣREE (Wilson in press).

Sedimentary and felsic volcanic rocks of the Flat Landing Brook Formation host and enclose, respectively, scattered sulphide deposits and occurrences, the most important being the Stratmat deposits. Mineral occurrences in the Flat Landing Brook Formation can only be tentatively correlated because of poor control on the internal stratigraphy of this unit. Felsic hyaloclastites are commonly spatially associated with mineralization, which is hosted by relatively thin sedimentary units, comprising feldspathic wacke or hyalotuff, siltstone and mudstone. The intimate association with felsic lavas and breccias suggests that the "Stratmat horizon" deposits and occurrences more closely resemble typical Kuroko deposits than do most of the sulphide deposits in the Bathurst Camp.

The transition from the Flat Landing Brook Formation to the Boucher Brook Formation is commonly complex, and marked by different depositional histories in different places. Regionally, the Boucher Brook Formation consists mainly of sedimentary rocks (including dark grey to black slates, greywackes, lithic wackes containing volcaniclastic material, and exhalite composed of brick-red to purple-grey manganiferous slate, siltstone and chert) and mafic volcanic rocks (Brunswick-type, massive to pillowed, alkalic basalts). Southeast of the Tailings Lagoon, at Heath Steele (Fig.HS-2), Flat Landing Brook Formation rhyolites are conformably overlain by a Boucher Brook Formation sequence consisting predominantly of pillow basalt. However, a detailed traverse across the contact reveals a more complex history, with discontinuous or local deposition of crystal tuff, basalt, and red cherty exhalite between the rhyolite and the main body of overlying basalt. Three distinct, relatively thin units of crystal tuff have been identified within this sequence, one immediately overlying the rhyolite at the top of the Flat Landing Brook Formation, and two interbedded with pillow basalt (Wilson 1992a). The succession of rhyolite, crystal tuff, basalt and exhalite at the contact between the Flat Landing Brook and Boucher Brook formations is a typical Caribou horizon sequence, and therefore, this area south of the Tailings Lagoon should be prospective for mineral deposits.

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ROAD LOG FOR FIELD EXCURSION IN THE HEATH STEELE AREA

The locations of field stops in the Heath Steele area are shown on Figure HS-2. The road log starts at the Heath Steele gate/security office on Route 430.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	At the end of asphalt by the security office, bear right and proceed north on Route 430.
1.0	1.0	50 m south of the intersection with the B-Zone haulage road, turn left onto the dirt road that runs parallel to the haulage road.
0.1	1.1	Bear right at the fork in the road and pass under the elevated pipeline.
0.7	1.8	Park in large quarry on north side of road.
STOP HS-1:		Both the Nepisiguit Falls and Flat Landing Brook formations are exposed in this backfill quarry southwest of the B-Zone (Fig.HS-3). This stop affords an opportunity to examine a section of the Nepisiguit Falls Formation that has not undergone the intense alteration seen around the Heath Steele sulphide deposits. The rocks are highly strained, however, and the prominent fabric seen here is a result of D_1 (thrust-related) deformation. A relatively thin bed of siltstone and feldspathic wacke is underlain by quartz-feldspar crystal tuff/tufflava and overlain by light grey-green, tuffaceous-looking rhyolite. The sedimentary rocks and crystal tuff/tufflava are assigned to the Nepisiguit Falls Formation, whereas the rhyolites belong to the Flat Landing Brook Formation. The granular/tuffaceous appearance of the rhyolite probably results from extreme attenuation of tectonically produced microlithons, comparable to those at Brunswick No.6 (cf. Luff *et al.* this volume), which resemble flattened pumice or lithic clasts. The crystal tuff/tufflava occupies the core of a steeply plunging antiform that closes in the centre of the quarry. The sedimentary bed thickens from the south limb toward the nose, and widens out on the north limb, where it and the underlying tuff/tufflava, appears to become progressively more chloritic. In this area, the feldspar phenocrysts are partly to completely obliterated producing a quartz-augen schist.
0.8	2.6	Return to Route 430; turn left (south).
1.65	4.15	Turn left (northeast) on gravel road (abandoned railroad) just past the Heath Steele security gate.
1.35	5.5	Turn right (south) on gravel road.
0.2	5.7	Continue south at four-way intersection.
0.8	6.5	Park and walk 200 m east through clear-cut to large area of outcrop on the crest and slope of low hills.

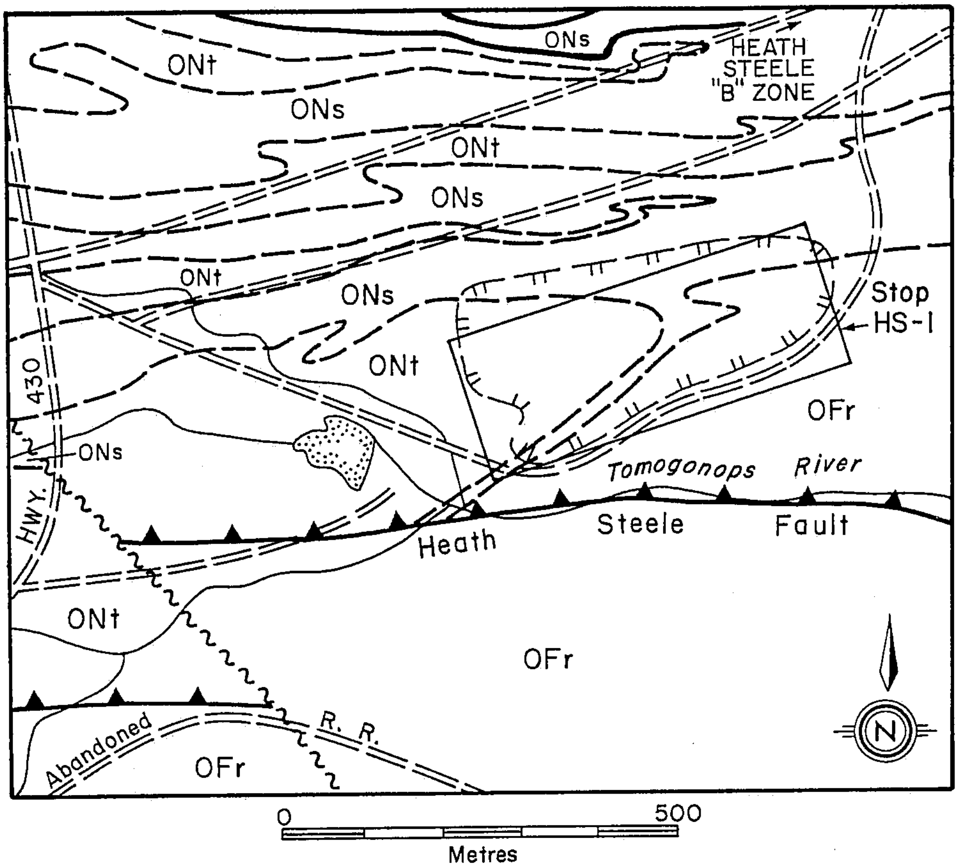

Figure HS-3. Geological map of the area in the vicinity of the quarry (STOP HS-1), southwest of B-Zone. See Figure HS-2 for legend with the following additions: heavy solid line = massive sulphides, broken line with double ticks = quarry limit.

STOP HS-2:		A sharp contact between quartz-feldspar crystal tuff/tufflava of the Nepisiguit Falls Formation and light green aphyric rhyolite of the Flat Landing Brook Formation is exposed; this contact can be traced around the nose of minor F_2(?) folds. No sedimentary rocks are interbedded with the crystal tuff/tufflavas here as is the case in the Heath Steele area. An ash-flow origin for the crystal tuff/tufflava is suggested by good examples of what appear to be primary layering seen in some of the copious exposures.
2.35	8.85	Return to Route 430; drive straight across and bear left at sand pile 50 m west of the highway.
0.9	9.75	Bear right at fork in road, drive onto tailings dam.
2.0	11.75	Turn left off tailings dam, keep right at the fork in the road.
0.8	12.55	Keep right at fork in road.

Distance (in km)	Cumulative Distance	Description
0.8	12.55	Keep right at fork in road.
0.8	13.35	Continue straight ahead at intersection with new logging road.
2.0	15.35	Bridge over small brook.
1.0	16.35	Stop at filled-in trench on either side of road; walk 50 m north along trench to outcrops.
STOP HS-3:		This is the Mowat base-metal occurrence. Sedimentary and volcanic rocks (chloritic metasedimentary rock and quartz-feldspar crystal tuff/tufflava) represent the southwestward extension of the Heath Steele horizon. However, no massive sulphides are visible on the surface.
4.6	21.0	Return to tailings dam; turn right on road at top of tailings dam.
0.3	21.3	Turn right; drive down to foot of tailings dam and continue straight into old quarry.
0.3	21.6	Park at rusty outcrop on right side of road beside pond.
STOP HS-4:		On the right (south) side of the road at the edge of a pond occupying a depression in the quarry, is an exposure of yellowish grey, sericitic, pyritiferous rhyolite. On the left side of the road, at the edge of another pond about 50 m back toward the tailings dam, schistose rhyolite and chloritic, quartz-veined mudstone both locally contain considerable pyrite. These lithologies are similar to some of those at Stratmat, although brecciated rhyolites do not appear to be present. This sedimentary band may be correlative to the Stratmat "horizon".
0.3	21.9	Return to tailings dam; turn right at the top of tailings dam.
1.7	23.6	Take a sharp right at Y-intersection.
1.5	25.1	Intersection with Route 430; turn right.
1.75	26.85	Turn right at old logging road.
0.9	27.75	Park and walk 300 m south on trail to outcrops.
STOP HS-5:		The Flat Landing Brook Formation/Boucher Brook Formation contact is exposed in this area (Fig.HS-4). A sequence of schistose aphyric rhyolite, quartz-feldspar crystal tuff, iron formation and basalt will be examined. The crystal tuff is quite variable in terms of the size and abundance of crystals that it contains. The lithologies present and their stratigraphic position allow a correlation with the Caribou horizon to be made; however, no mineralization has as yet been encountered here.
		End of trip; return to vehicles.

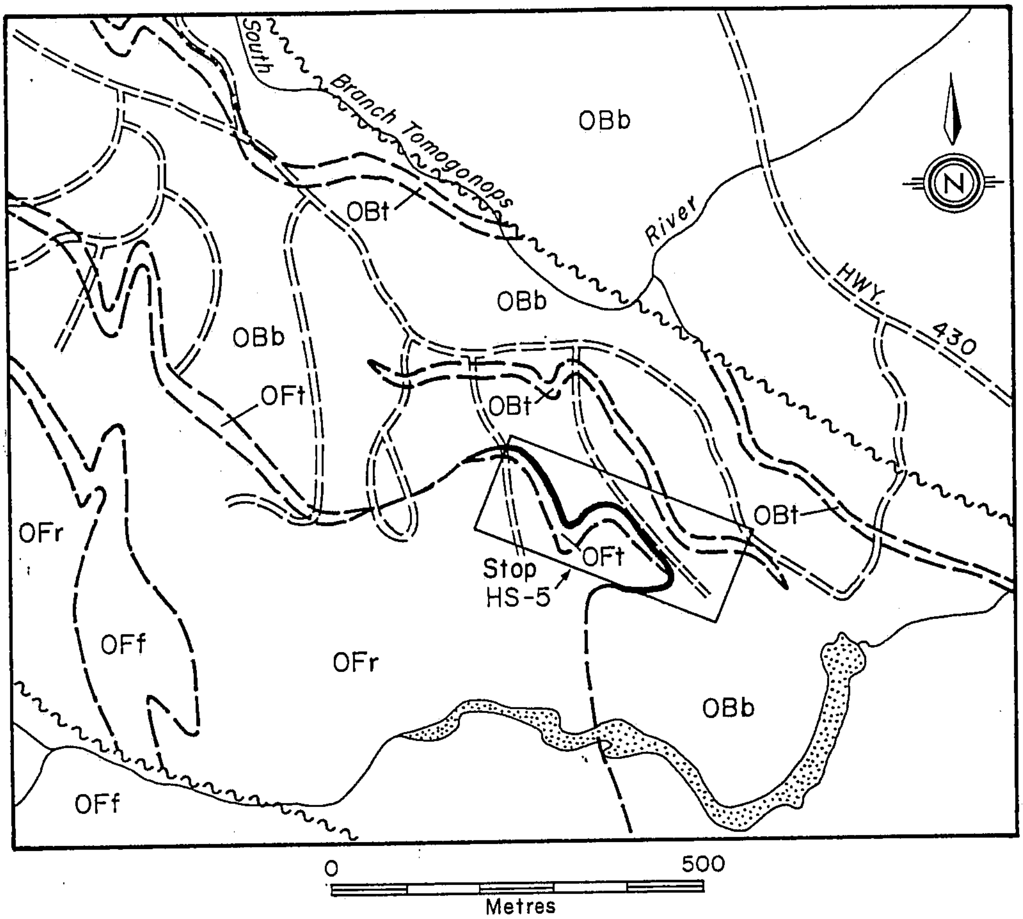

Figure HS-4. Geological map of the area around STOP HS-5. See Figure HS-2b for legend with the following addition: heavy black line = red to pink, cherty exhalite.

GEOLOGY OF HEATH STEELE MINES, BATHURST CAMP, NEW BRUNSWICK

Art Hamilton[1], *Adrian Park*[2] *and Chris Moreton*[3]

INTRODUCTION

The Heath Steele property is located approximately 65 kilometres southwest of Bathurst and 50 kilometres northwest of Newcastle in northern New Brunswick (see Fig.HS-1 of Wilson, this volume). Heath Steele Mines is jointly owned by Brunswick Mining and Smelting Corp. Ltd. and Noranda Minerals Inc. All of the massive sulphide deposits in the central part of the Heath Steele property (Fig.H1) occur within the Nepisiguit Falls Formation (van Staal and Fyffe 1991) of the Tetagouche Group (Skinner 1974). The latter predominantly consists of polydeformed felsic and mafic volcanic rocks along with associated sedimentary rocks (see Fig.HS-2 of Wilson). Although the enclosing host rocks and the sulphide deposits are metamorphosed to at least the lower greenschist facies the protolith can still be determined with some certainty. Therefore, the prefix 'meta' is omitted from the rock nomenclature.

HISTORY

Ore deposits at Heath Steele were discovered shortly after the 1952 discoveries of the Brunswick No. 6 and No. 12 deposits. At that time the International Nickel Company (INCO) had developed a new airborne electromagnetic instrument and, under an agreement between INCO and AMAX (formerly American Metals), an airborne survey was carried out in 1953 over a large portion of the Bathurst-Newcastle District. Numerous anomalies were detected in the Heath Steele area and the follow-up, ground-electromagnetic and soil-geochemical surveys highlighted targets that were diamond-drilled in 1954. This drilling led to the discovery of the ACD, B and E zones (Fig.H1). In fact, the discovery of the A-Zone massive sulphide deposit at Heath Steele was the first in the world using the airborne electromagnetic method (see 'The Discoveries' p.161-162).

Mining began in 1957 but ceased in 1958 due to metallurgical problems and low metal prices. Mining operations resumed in 1962 and lasted until 1983 when low metal prices forced another shutdown. Production during this period included 508 000 tonnes from the A-Zone, 150 000 tonnes from D-Zone and 15 794 000 tonnes from B-Zone. Most of this production came from underground although some ore was recovered from open pit workings at A and B zones. Six thousand tonnes of ore were mined at the C-Zone in 1975 as part of an underground exploration program. The average production grade prior to the 1983 shutdown was 1.70 % Pb, 4.62 % Zn, 0.99 % Cu and 63 g/t Ag. Following the 1983 mine closure, 178 000 tonnes of gold-bearing gossan ore were processed with an average grade of 4.8 g Au/t and 175.5 g Ag/t. The gossan had been stockpiled from earlier mine development when it had been removed from the surface of the B-Zone open pit. Enrichment of Au and Ag in the gossan had been documented by Boyle (1979) who found limonite and wad gossan with 25 times more Au (1.5 ppm Au) and 6 times more Ag (143 ppm) than the primary ore (0.06 ppm Au, 23 ppm Ag). Similarly, the supergene ore graded 0.5 ppm Au and 96 ppm Ag, approximately 8 and 4 times higher, respectively, than the primary ore.

In 1986 the Stratmat property (Fig.H1) was acquired from Cominco; when the mill was put back into production in 1989 ore was scheduled to be mined from the Boundary-Zone, B-Zone and E-Zone. The Boundary-Zone straddles the boundary of the Stratmat property and the Heath Steele lease. Subsequently, a production decision was made not to mine the E-Zone so that all of the early mill feed came from the other two zones. In 1990, it was

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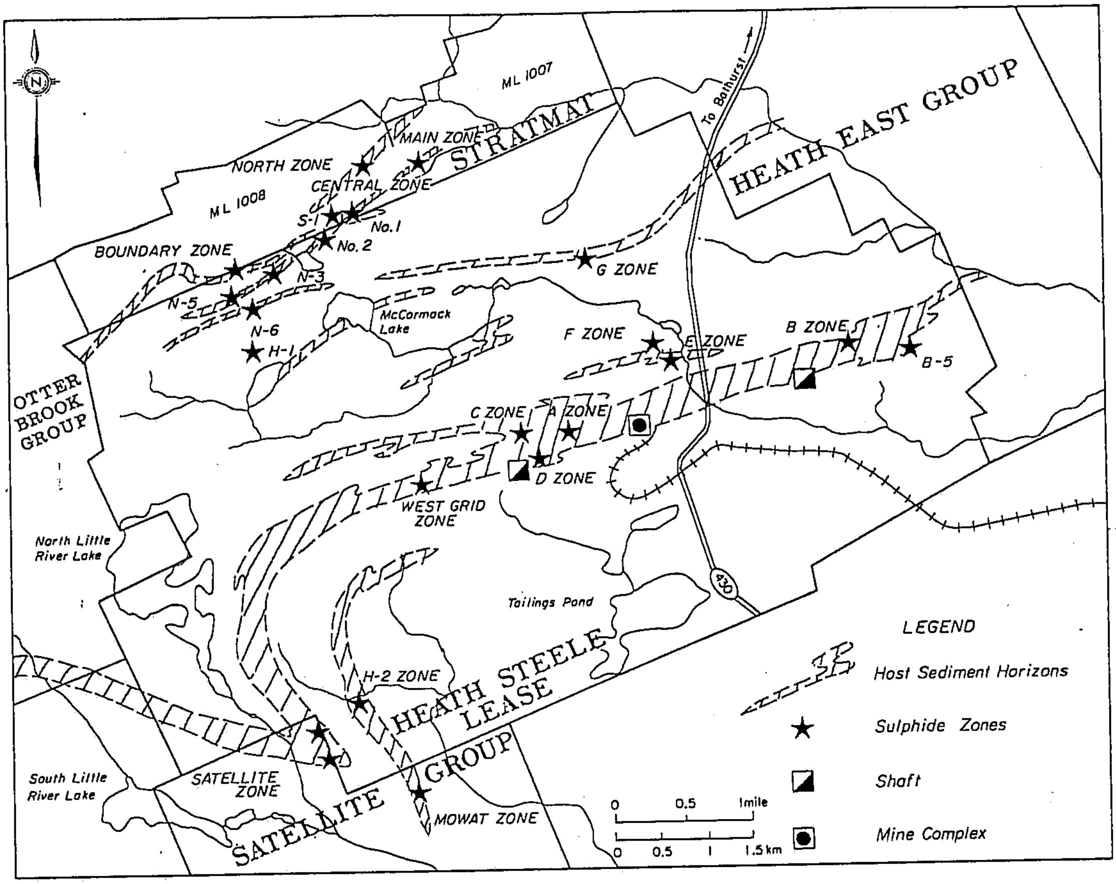

Figure H1. Location map showing the boundaries of the Heath Steele lease and the Stratmat property (from Hamilton 1990).

decided to mine the upper part of the C-Zone via a ramp that had been used to access underground ore at the A-Zone. Mine development was started in May 1992 and the first stope was recovered early in 1993. Production from 1989 to 1992 included 10 387 600 tonnes from the Boundary and nearby N-5 zones, 2 126 800 tonnes from the B-Zone and 20 000 tonnes from the C-Zone with an average grade of 2.54% Pb, 6.78% Zn, 0.52% Cu and 61 g Ag/t. Ore reserves at January 1, 1993 totalled 3 943 000 tonnes grading 2.00% Pb, 6.76% Zn, 0.89% Cu and 66 g Ag/t. An additional 18 311 000 tonnes of geological reserves with an average grade of 2.65% Pb, 7.52% Zn, 0.45% Cu and 49 g Ag/t, located in the vicinity of Heath Steele Mines, are considered to have mineable potential.

At least five major mineralized zones occur in the Heath Steele area, the largest of which is the B-zone (Table 1). The B-Zone is currently being mined along with portions of the C-zone. The Heath Steele field trip will include a surface tour of the A-Zone pit and an underground tour of active development headings at the C-Zone.

Table 1. Cumulative production statistics 1962 - 1992.

Zone	Tonnes	Pb (%)	Zn (%)	Cu (%)	Ag (g/t)
A-Zone	508,000	2.98	7.60	0.70	97
B-Zone	17,920,600	1.73	4.67	0.96	63
C-Zone	26,200	1.20	5.78	0.44	37
D-Zone	149,600	2.54	9.61	0.36	84
Stratmat	1,037,600	3.03	8.25	0.35	44

STRATIGRAPHY

The massive sulphide deposits at the B, ACD and E zones are concordant with the enclosing sedimentary and volcanic host rocks of the Nepisiguit Falls Formation (Wilson this volume; McCutcheon *et al.* this volume). In general, the lithologies have an east-west strike and dip steeply towards the north. The interpreted stratigraphic (ie.pre-tectonic) footwall to the massive sulphide deposits consists of fine- to coarse-grained sedimentary rocks locally containing fine- to medium-grained volcanic phenoclasts. Quartz-feldspar crystal tuffs/tufflavas overlie the sulphide deposits or their associated iron formations. This stratigraphy (Fig.H2) is simplified from earlier interpretations by McBride (1976) and Moreton and Williams (1986), because the crystal tuffs/tufflavas that occur to the south of the B-Zone are considered to be a structural repetition of those to the north at the ore horizon.This interpretation is based on the results of trenching a fold nose (F_2) to the east of the B-Zone (de Roo *et al.* 1991), and has significant implications for exploration along the sedimentary rock-crystal tuff/tufflava contact in the structural footwall of the B-Zone.

This sequence of rocks is bounded to the south by an east-west striking fault (Fig.H3; also Fig. HS-2 of Wilson), called the Heath Steele Fault by de Roo *et al.* (1991). This fault zone separates the mine sequence from rhyolitic rocks of the Flat Landing Brook Formation. To the north of the mine sequence, there is another large area of Flat Landing Brook rhyolitic rocks. Because the geology to the north and south of the mine sequence is similar, the structure was originally described as a broad antiform by Dechow (1960). However, this simplistic structural model has been superseded by that of Moreton (1993). Although Dechow (1960) interpreted the mine sequence in the B-Zone area as a south-younging succession, McMillian (1969), Whitehead (1973), McBride (1976) and Owsiacki (1980) all suggest that the sequence is north-younging in the vicinity of the B-Zone.

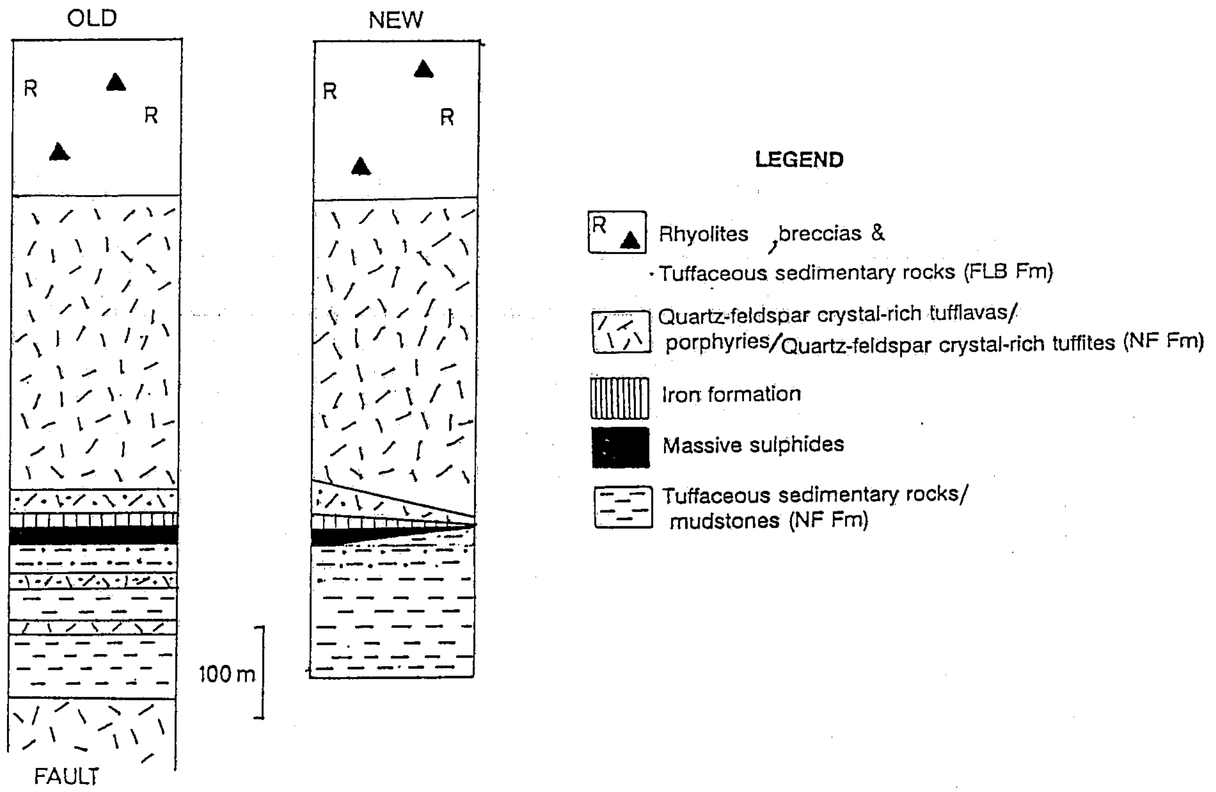

Figure H2. Idealized columns comparing the old (modified after McBride 1976; Moreton and Williams 1986) and new (de Roo *et al.* 1991) versions of the tectonostratigraphy at Heath Steele.

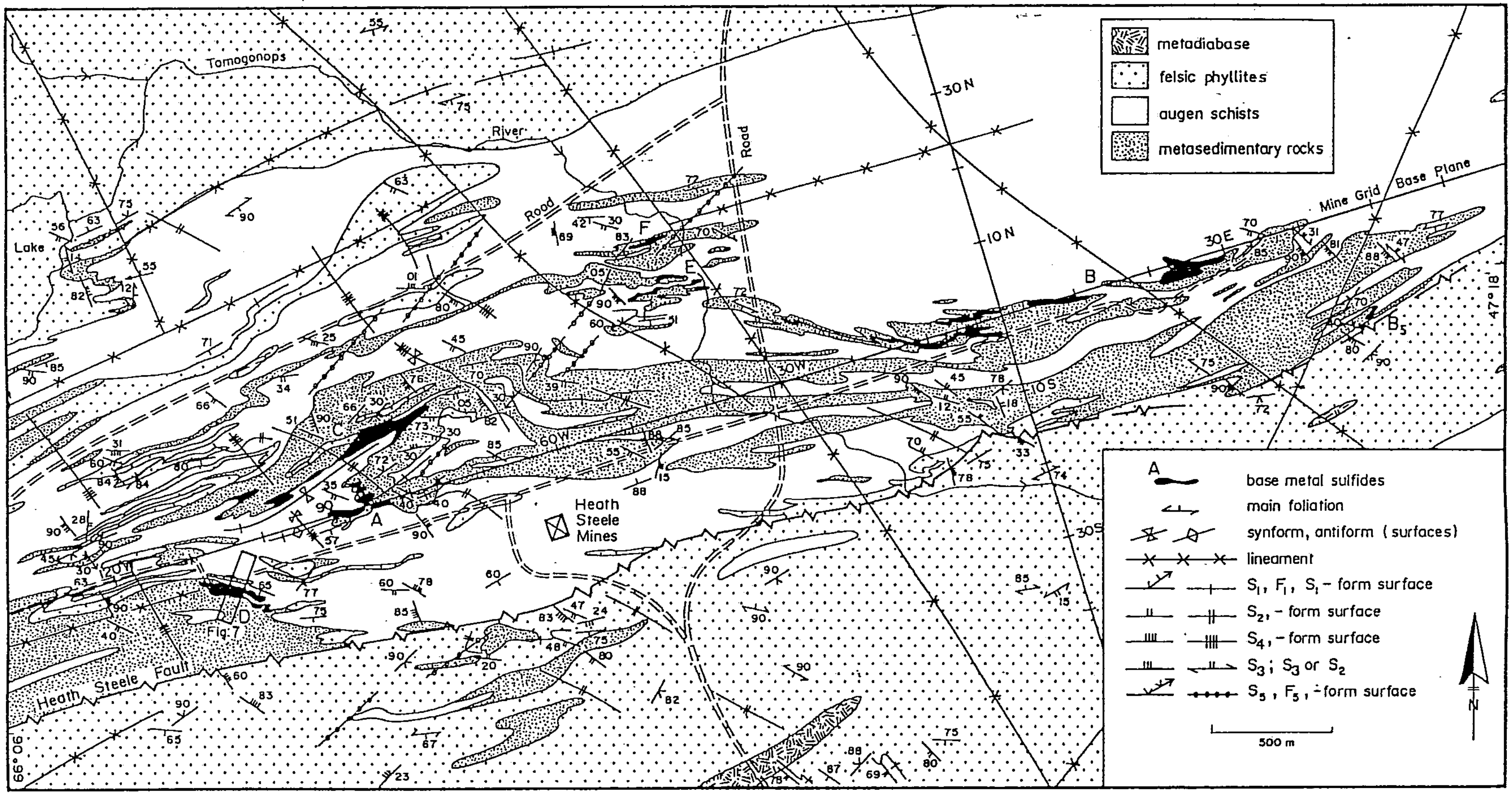

Figure H3. Structural map of the southeastern part of the Heath Steele Mining Lease (from de Roo *et al.* 1991).

STRUCTURE

Detailed structural analysis in the Heath Steele area by McBride (1976), de Roo *et al.* (1990, 1991) and Moreton (1993) indicates that there are at least five deformation events. These are described briefly below.

First deformation: The first deformation event is characterized by tight to isoclinal recumbent folds (Moreton, 1993) that have sheath-like profiles and therefore formed in a high-strain environment. Both outcrop- and mine-scale examples of F_1 folds have been documented by Moreton (1993) and their presence helps to explain some of the reversals in the younging directions as well as the repetition of hanging wall units in the structural footwall. Using the relationship of cleavage (S_1) to bedding in a limited number of exposures in the B-Zone, McBride (1976) concluded that the first deformation event was characterized by north-northwest facing recumbent folds (F_1). In contrast, Moreton (1993) suggested that the vergence of the F_1 folds is towards the southeast. This direction is compatible with the paleotectonic model of van Staal (1987) which suggests that southeast-directed tectonic transport (obduction) was prevalent in this part of the Camp during the Late Ordovician.

In the ACD-Zone, Owsiacki and McAllister (1979) could only document the four youngest deformation events. It was suggested by them that D_1 features may be absent because of the masking effects of later deformations.

Second deformation: In the vicinity of the B-Zone deposit, the second deformation event (D_2) is characterized by northerly-overturned, open to tight folds of the earlier layering (Figs.H4 and H5). In general, the F_2 folds have a moderate westerly plunge and a moderately south-dipping (45°), axial planar foliation. The intensity of the S_2 foliation is such that it generally obliterates the S_1 cleavage by transposition, producing a composite S_{1-2} schistosity. Moreton and Williams (1986) and de Roo *et al.*(1991) suggested that, in a broad sense at least, the enveloping surface to the F_2 folds defines the tabular nature of the sulphide deposit. On a larger scale (kms), the B-Zone deposit lies on the short limb of an overturned F_2 fold. In contrast to the B-Zone, the F_2 folds at the A and C zones are sheath folds whose X-axes plunge west-southwest, west or east-northeast, at a variety of angles, because of their curvilinear hinge lines. The strike of S_2 is variable, ranging in orientation from 050° to 120°, mainly because of the effects of the younger deformations.

Third, fourth and fifth deformations: The younger deformation events are characterized by open folds of the main S_{1-2} composite foliation. Horizontal folds with flat to shallowly dipping axial surfaces (F_3 or F_H, de Roo *et al.* 1990, 1991) define the third deformation and account for much of the variability in the strike and dip of S_2. The fourth and fifth deformations have steeply dipping (subvertical) axial surfaces and northwest- or northeast-plunging (respectively) fold axes. These two fold generations can be considered to define a conjugate pair at B-Zone. At C-zone a clear F_4-F_5 interference pattern is seen. In most cases, the axial plane foliation is a fracture cleavage that may contain remobilized quartz and base metals.

MASSIVE SULPHIDES

Broad relationships in base-metal zoning and iron formation location, as well as abundant feeder-zone type rocks, suggest that the massive sulphides are syngenetic, and accumulated from exhalative solutions in subaqueous basins (Lusk 1969; Whitehead 1973; Wahl 1978; Lusk 1992). This model contrasts with the earlier suggestion by Dechow (1960) that these deposits are epigenetic, although de Roo *et al.* (1991, 1992) have resurrected this model.

B-Zone: As with other volcanic-associated massive sulphide deposits three distinct sulphide zones can be mapped-out: massive pyrite, banded pyrite-sphalerite-galena and a pyrrhotite-chalcopyrite fragmental ore. Massive pyrite bodies are generally fine-grained and commonly contain bands of chlorite, quartz and magnetite. The banded pyrite-sphalerite-galena facies consists of alternating pyrite-rich and sphalerite-galena-rich layers. The fragmental ore contains rounded to subangular sulphide (generally pyrite) and lithic fragments hosted by a chalcopyrite-bearing pyrrhotite-rich matrix. The fragmental ore occurs mainly along the footwall of the B-Zone (and in the ACD-Zone) although it locally transgresses the sulphide body in several places when it is folded by F_2 folds (Figs.H3 and H4).

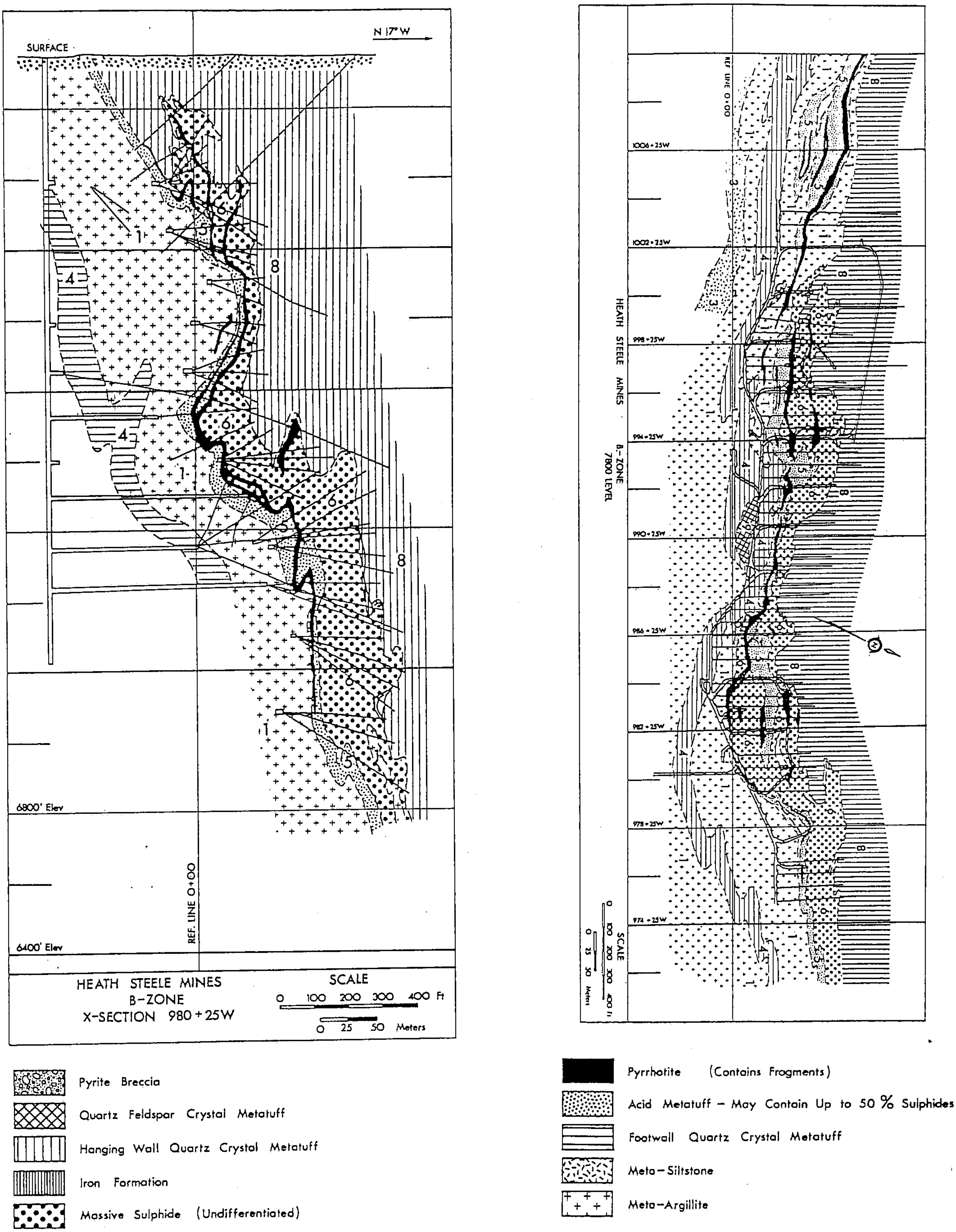

Figure H4. Geological plan of the 7800 level at B-Zone, together with a cross section at 980 + 25W. Diagrams from McDonald (in Davies *et al.* 1983).

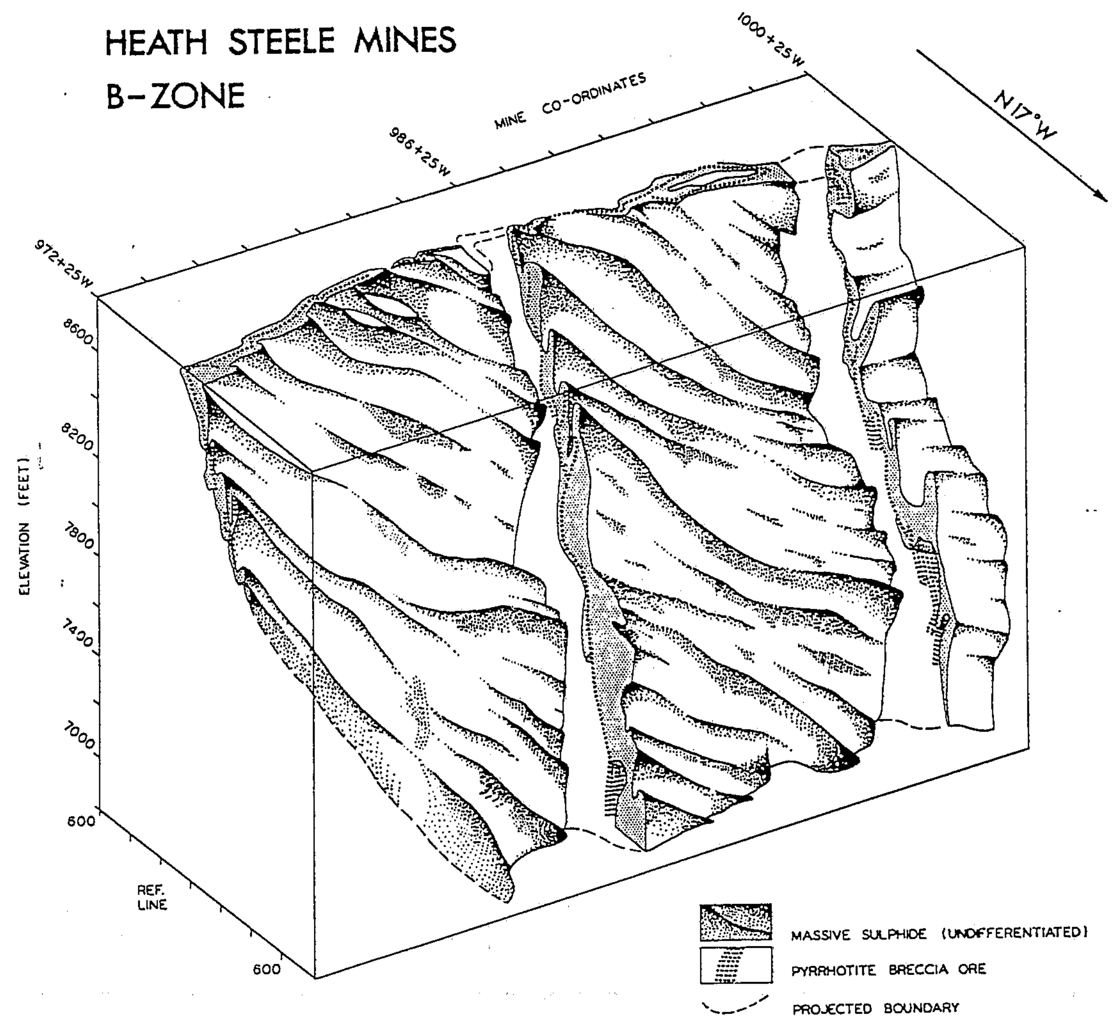

Figure H5. Block diagram of the Heath Steele B-Zone showing the orientation of F_2 folds. The co-ordinate system is the same as in Figure H4. Diagram from McDonald (in Davies *et al.* 1983).

In some areas the breccia appears to both overlie and underlie the lead-zinc ore, but in other places, it appears to cross cut the zoning. Owsiacki and McAllister (1979) suggested that the fragmentation was volcanic-related so that the deposit formed by soft-sediment slumping of the sulphides. McDonald (1983) and Moreton (1993), on the other hand, suggest that D_1 thrusting was responsible for creating the breccia because it transgresses the massive sulphide deposit, occupies D_2 hinge zones, and contains clasts of deformed rocks including pyrite.

Silicate (chlorite-rich), carbonate (ankerite-siderite-rich), and oxide (magnetite-rich) facies iron formations have been recognized at B-Zone. Thinly layered iron formation may overlie, be marginal to or be intercalated with massive sulphides, although the latter case probably is due to F_1 and F_2 folding. Cherty beds are often intercalated with the various iron formation types, and metamorphic biotite, chlorite and/or stilpnomelane have all been recognized in the iron formation (McMillan 1969). McMillan (1969) stated that the most common silicate within the iron formation was chamosite, although McBride (1976) determined that it was diabantite by X-ray diffraction. Fine-grained, concentrically zoned siderite in the carbonate-facies iron formation were interpreted as oolites by both McMillan (1969) and McBride (1976). If this interpretation is indeed correct, it might indicate a shallow water environment for the formation of the sulphide deposits although this remains to be investigated. A change from a reducing depositional environment in the vicinity of the massive sulphides, to an oxidizing environment away from them, has been demonstrated by both Wahl (1976) and Whitehead (1973) using the Mn/Fe ratio. In particular, the ratio increases with increasing oxidation.

Mineralogically, the B-Zone ore is dominantly composed of pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, arsenopyrite, tetrahedrite, and Ag-bearing Pb-Bi-Sb sulfosalts. From Chen and Petruk (1980) the grade, mineralogy and benefaction of this ore, for August 1977, was as follows: the average feed was 1.25 % Cu, 1.64 % Pb, 4.34 % Zn, 0.009 % (90 g/t) Ag with 35.55 % Fe, 2400 ppm As, <500 ppm Sb, 50 ppm In, 500 ppm Bi, <100 ppm Cd, 1065 ppm Co, 860 ppm Sn, <4 ppm Hg, < 1.1 ppm Au.

Proven and probable ore reserves for the B-Zone at December 31, 1992 were 2 167 000 tonnes of 2.22% Pb, 5.98% Zn, 1.04% Cu and 68 g Ag/t. In addition, probable geological reserves were estimated at 1 097 000 tonnes of 1.54% Pb, 4.15% Zn, 1.57% Cu and 73 g Ag/t.

ACD-Zone: This zone comprises A, C and D parts that are separated at surface, but subsequent work has shown that the three parts probably belong to one continuous exhalative unit, hence the term ACD-Zone. However, on a detailed plan each part is called a zone (Fig.H6). The A and C parts define a semi-continuous massive sulphide body that covers a strike length close to a kilometre, and can be traced to greater than 400 m below surface (Fig.H7). The ACD-Zone is at least as structurally complex as the other deposits on the mining lease. Isoclinal F_1 sheath folds that are refolded by F_2 folds account for much of the complexity in the ACD-Zone (de Roo *et al.* 1991).

The sulphide ore bodies of the A and C zones occur in chloritic phyllite or slate units; their geometry is dominated by large F_2 sheath folds. The A-pit is in the nose of an upward-closing F_2 sheath fold and the C-1 zone occupies a similar structure to the north (Fig.H6). These antiformal culminations are elongate, doubly plunging features with an F_4 interference imposed (Fig.H6). The F_4 folds plunge 10° to 45° to the west or west-southwest. The F_2 folds have extremely curvilinear hinge-lines, some being true sheaths, whose long axes plunge to the southwest. A composite foliation (S_{1-2}) defines their axial planes. A strong and persistent mineral (stretching) lineation ($L^m{}_2$) consistently plunges to the southwest, lying in the foliation. Variations in strike and dip of the main composite schistosity (S_{1-2}) is attributed to post-F_2 deformation, particularly F_4 folding.

The C-1 zone lies in a F_2 sheath, near the upper contact of a a thick sedimentary unit composed of interbedded argillite and siltstones, which are now chloritic slates and phyllites (Figs.H5, H6 and H7). Within this sequence there are discontinuous lenses of quartz and quartz-feldspar crystal tuff/tufflava that have been interpreted as structural repetitions of the hanging wall by F_1 sheath folds (de Roo *et al.* 1991) similar to that of the porphyritic rocks in the structural footwall of the B-Zone. Immediately below the sulphide body is a thin, intermittent layer of acid tuff, containing bands of pyrite and pyrrhotite.

The C-zone exhibits some lateral base-metal zoning. In particular, the north limb of the F_2 fold is a copper-rich fragmental ore, whereas massive pyrite and banded pyrite-sphalerite-galena ores tend to be restricted to the hinge areas of parasitic F_2 folds. Oxide- and silicate-facies iron formation occur along the south limb of the main synformal structure.

Proven and probable ore reserves for the ACD-Zone at December 31, 1992 were 1 563 000 tonnes of 1.51% Pb, 7.71% Zn, 0.76% Cu and 66 g Ag/t. In addition, probable and possible geological reserves were estimated at 2 621 000 tonnes of 2.16% Pb, 7.56% Zn, 0.71% Cu and 71 g Ag/t.

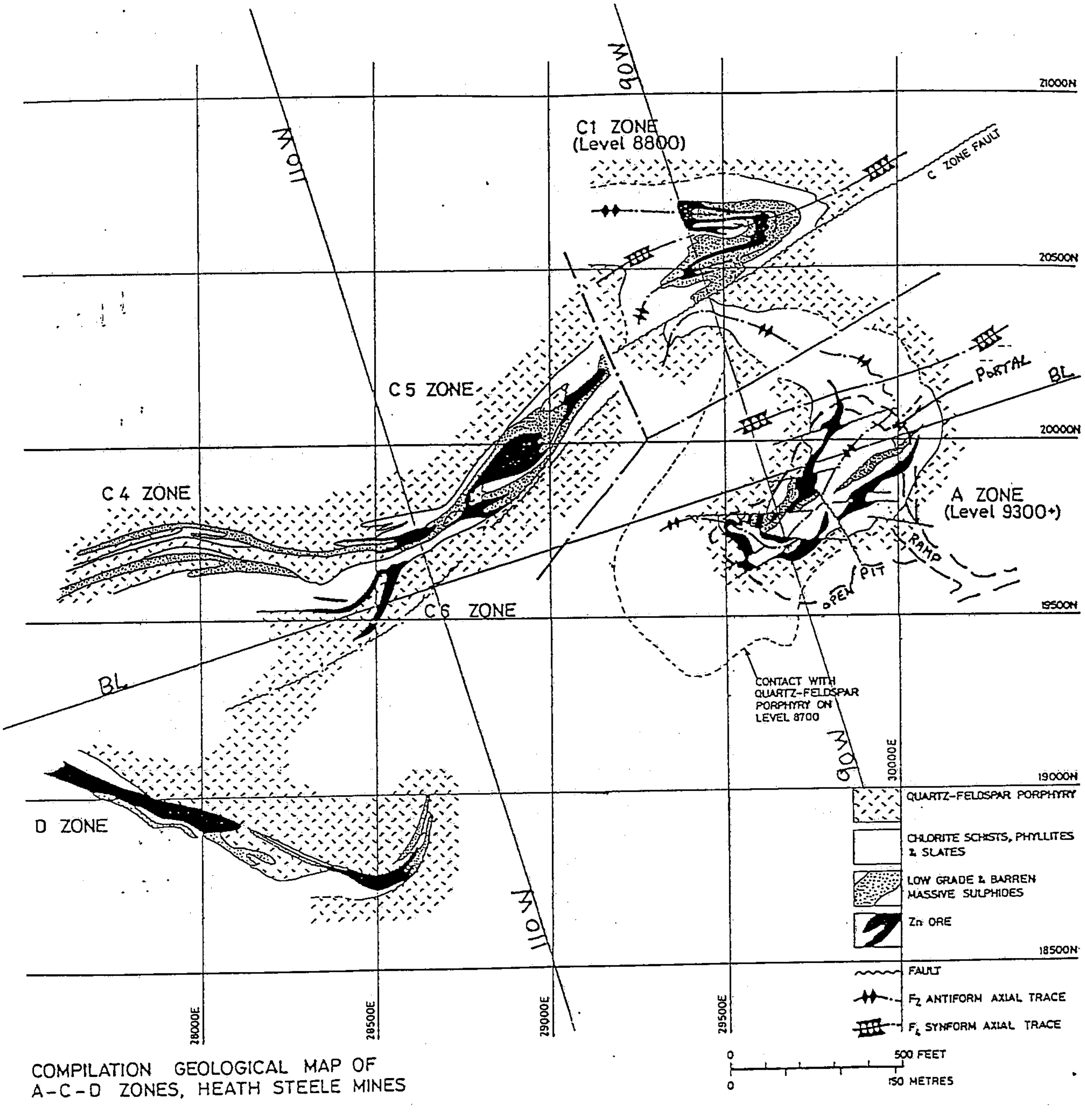

Figure H6. Detailed geological map of the A, C and D zones at Heath Steele. The lines labelled BL, 90W and 110W refer to the mine grid shown in Figure H3.

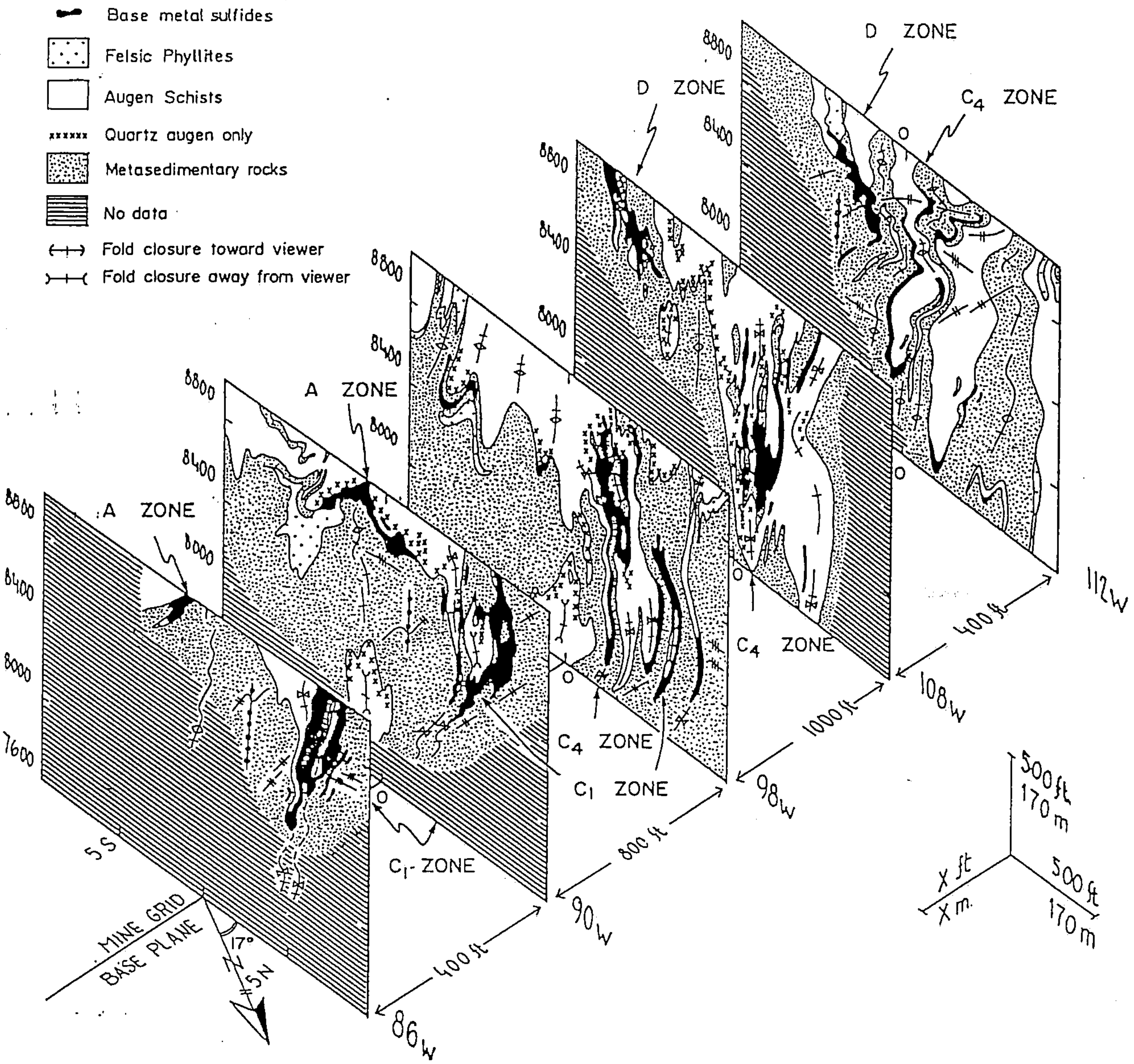

Figure H7. A fence of five cross sections through the ACD-Zone looking southwest; the section numbers, e.g. 90W, refer to the section location on the mine grid in Figure H3. Diagram from de Roo *et al.* (1991).

E-Zone: The E-Zone, located midway between the B and ACD zones, initially appeared to belong to a common stratigraphic horizon but, detailed mapping and trenching by Moreton (1993) has shown that the B and E-Zones are not connected at surface. Nevertheless, it is true that the enclosing metasedimentary and metavolcanic rocks closely resemble those of the B-Zone, and it is speculated that the two deposits connect at depth.

In general, the main sulphide body strikes east-west and dips steeply south. This dip direction contrasts sharply with the northerly dip of the B-Zone. Both the sulphides and the enclosing rocks are tightly folded and appear to plunge west. Although internal base-metal zoning is highly disrupted, the distribution of banded iron formation suggests that the stratigraphic sequence is overturned towards the north. Within the sulphide deposit itself, a fragmental pyrrhotite ore lies concordant with the enclosing rocks. Similarly, a pyrite breccia zone, consisting of blocks of solid sulphide embedded in a sandy, porous pyrite matrix, forms a planar crosscutting feature. This planar configuration indicates that the breccia formed during late-stage faulting.

Probable and possible geological reserves at E-Zone were estimated at 2.14% Pb, 4.82% Zn, 1.18% Cu and 79 g Ag/t.

ALTERATION

Quartz-feldspar crystal tuff/tufflava and sedimentary rocks in the structural footwall of the Heath Steele massive sulphide deposits are altered in proximity to the deposits. Alkali feldspar is altered to a chlorite-sericite assemblage although in some instances albite may still be present (Wahl 1978). The altered crystal tuff/tufflava is referred to as quartz porphyry because of the absence of feldspar. Under most of the deposits, there is a relatively thin unit of sericite schist/phyllite that is variably pyritic. This unit is commonly known as an 'acid tuff', referred to earlier, because of its lateral continuity but it probably represents an alteration of the footwall sedimentary unit (Wahl 1978). Some of the most intense alteration in the area is associated with the C-zone orebodies, both in the hanging wall and the footwall rocks (Wahl 1978), i.e. "quartz porphyries" are particularly abundant in the C-zone.

Using discriminant analysis, Whitehead and Govett (1974) found that Pb was higher in the hanging wall rocks above the ore zones, whereas there is no apparent distinction between the hanging wall and footwall Pb contents away from the ore zone. Whitehead (1973) also found that the Mn/Fe ratio was low in the footwall of the ore zone but high in the iron formation and in the immediate hanging wall rocks; in general, low Mn/Fe ratios are distal with respect to the sulphides. Although interpreted from a paleoenvironmental perspective, the above information shows that the footwall alteration was more reducing than the hanging-wall alteration. Such geochemical data was used by Whitehead (1973) and Whitehead and Govett (1974) to support the generalized north-younging direction of the B-Zone. In another geochemical study of the Heath Steele deposits, Wahl (1978) showed that the Fe, K and Mg values were enriched but Na and Ca depleted in the alteration zones relative to determined background values. In addition to the major elements, Cu, Pb, Zn, Co, Ag, Cr, and P increase during alteration.

ACKNOWLEDGEMENTS

Numerous discussions with geologists from Heath Steele Mines and Noranda Exploration Ltd. have been helpful in developing an understanding of the geology of the Heath Steele mine area. The manuscript benefitted from reviews by Dave Lentz, John Langton and Steve McCutcheon.

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STOP DESCRIPTIONS AT THE ACD-ZONE, HEATH STEELE MINE

STOP H-1: Glaciated outcrops north of the A-Zone open pit (Location 1 in Fig.H8). The rocks here are chlorite-rich and quartz-chlorite-rich phyllites representing fine-grained turbidites or metagreywackes. Relics of primary bedding and graded bedding are preserved. The glaciated surface is at a high-angle to the stretching lineation, but F_2 and F_4 folds can be seen along the western edge of the outcrop. F_4 folds are responsible for the variations in strike of the bedding and foliation.

Bedding is preserved as quartz-rich layers, and graded bedding is evident locally on the gradational contacts between the quartz-rich material and the chloritic phyllite. In these quartzose layers, darker segregations mark the S_1 component of the S_{1-2} composite foliation. Only in the quartz-rich layers can it be distinguished from the earlier S_1 fabric.

F_4 folds are open structures plunging towards the west southwest, with a nearly vertical crenulation cleavage in their axial planes. On surfaces parallel to S_2 the intersection lineation L^2_4 lies very close to the mineral lineation (L^m_2).

STOP H-2: East side of the A-Zone open pit from the ramp to the portal (Location 2 in Fig.H8). This continuous outcrop provides a section (Fig.H9) through part of an F_2 major fold refolded by an F_4 structure. It also cuts through a typical portion of the tectonic stratigraphy common to the A and C zones (Fig.H8). At the top of the ramp the rock is quartz-alkali-feldspar porphyry/tufflava, the unit that forms both the hanging wall and footwall to the A and C zone ores. The unit is weakly foliated and consists of alkali feldspar and quartz phenocrysts (phenoclasts) in a fine-grained matrix dominated by quartz and sericite. Toward its contact with the metasedimentary rocks, this unit becomes more strongly foliated (S_2) and the phenoclasts have quartz beards defining the L^m_2 mineral stretching lineation. S_2 is defined by sericite- and chlorite-rich seams. At the contact, the rock is a chlorite schist with quartz and alkali feldspar phenoclasts and a strong lineation. Below the lower contact of the quartz-alkali feldspar porphyry/tufflava on the pit wall occurs 10 metres of "chaotic" chlorite schist (Fig.H9). The rock is a deformed tectonic mélange with a strong foliation. Deformation in this unit is extremely heterogeneous, varying from schistose with a weak lineation to a rodded quartz-rich, chloritic L-tectonite. Lithologies in this unit are diverse, dominated by coarse chlorite or chlorite-quartz schist and material that looks like extremely schistose porphyry/tufflava. The entire assemblage is cut by pyrrhotite-chalcopyrite veins, barren quartz veins and veins of quartz-chalcopyrite. Veins exhibit varying states of deformation from boudinaged sheets parallel to S_2 to discordant veins that crosscut S_2. En echelon vein arrays are also common. One unusual vein type is, for the most part, concordant with S_2, though boudinaged and locally mylonitic, but in places, connects with polyphase breccias that are discordant to S_2. The clasts in the breccia are chlorite-schist (or chlorite-sericite schist), vein quartz and sulphides, whereas the matrix consists of coarse-grained quartz, commonly with chalcopyrite. This unusual vein-type appears to represent localized brittle fracturing during the overall ductile D_2 deformation event. High fluid pressures seem to have been ubiquitous at this time with mass transfer an important process.

Beneath the "chaotic" chlorite-schist zone, the rocks vary from a green, pure chlorite rock, through a black, fine-grained sulphide-rich slate, to a coarse-grained phyllite with abundant quartz layers and variable amounts of pyrite (Fig.H9). Though no in situ ore remains in the A-Zone pit wall, these are the lithologies that host the sulphides.

Through most of this section, the composite S_{1-2} is the dominant fabric, although locally S_1 and/or lithological layering is/are preserved. Near the portal, a vertical crenulation cleavage (S_4) is axial planar to the F_4 antiform seen over the portal itself. Locally, a nearly horizontal cleavage and fracture are important, representing S_3. S_3 and S_4 represent the fabrics termed S_{II} and S_V in de Roo *et al.* (1990). Their cross cutting relationships are not clear in the pit but can be observed underground.

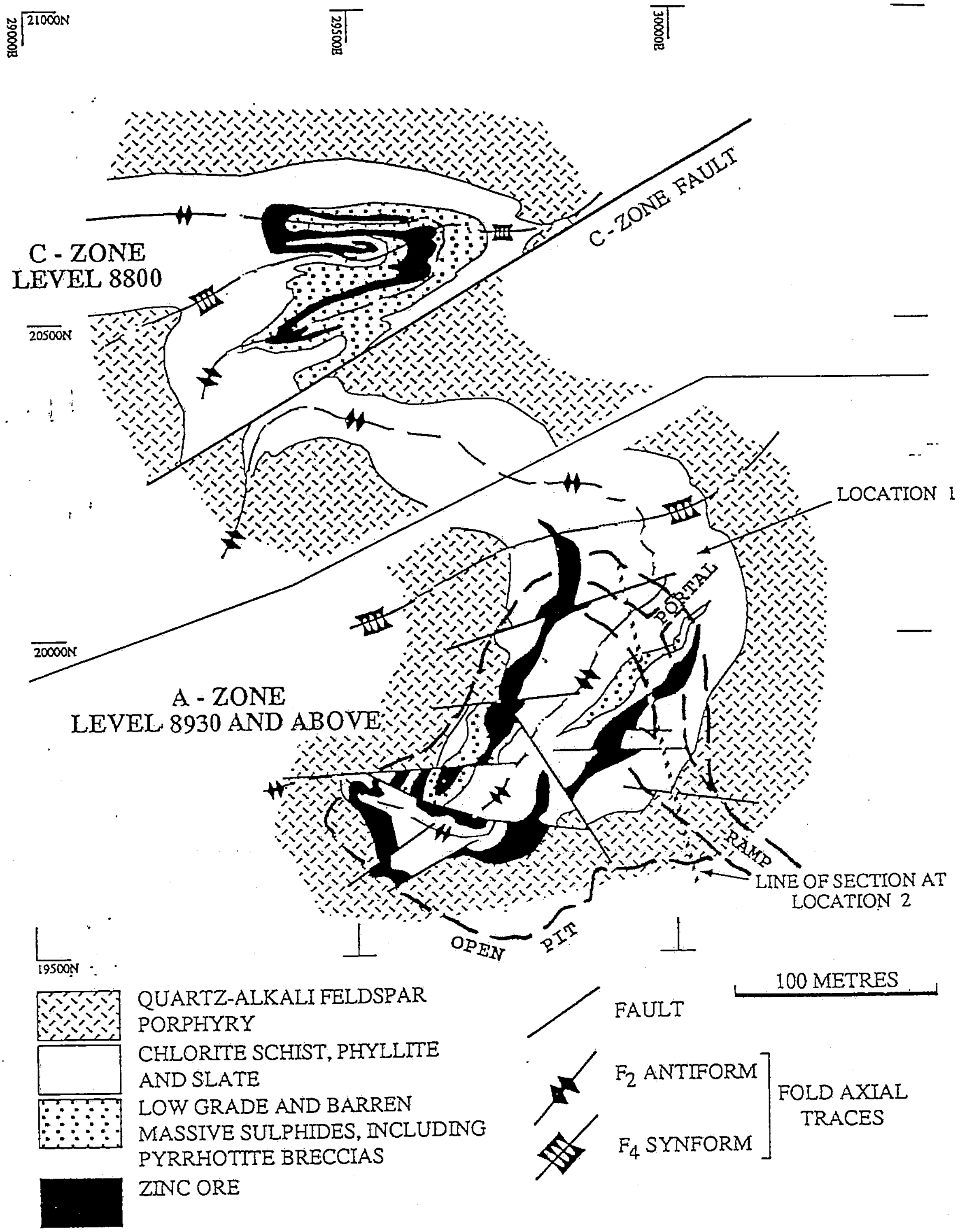

Figure H8. Geological plan of the A-Zone sulphide bodies with pit outline and adjacent C-1 Zone sulphide deposit (Park 1992, unpublished report). Note section for location H-2 (Figure H9).

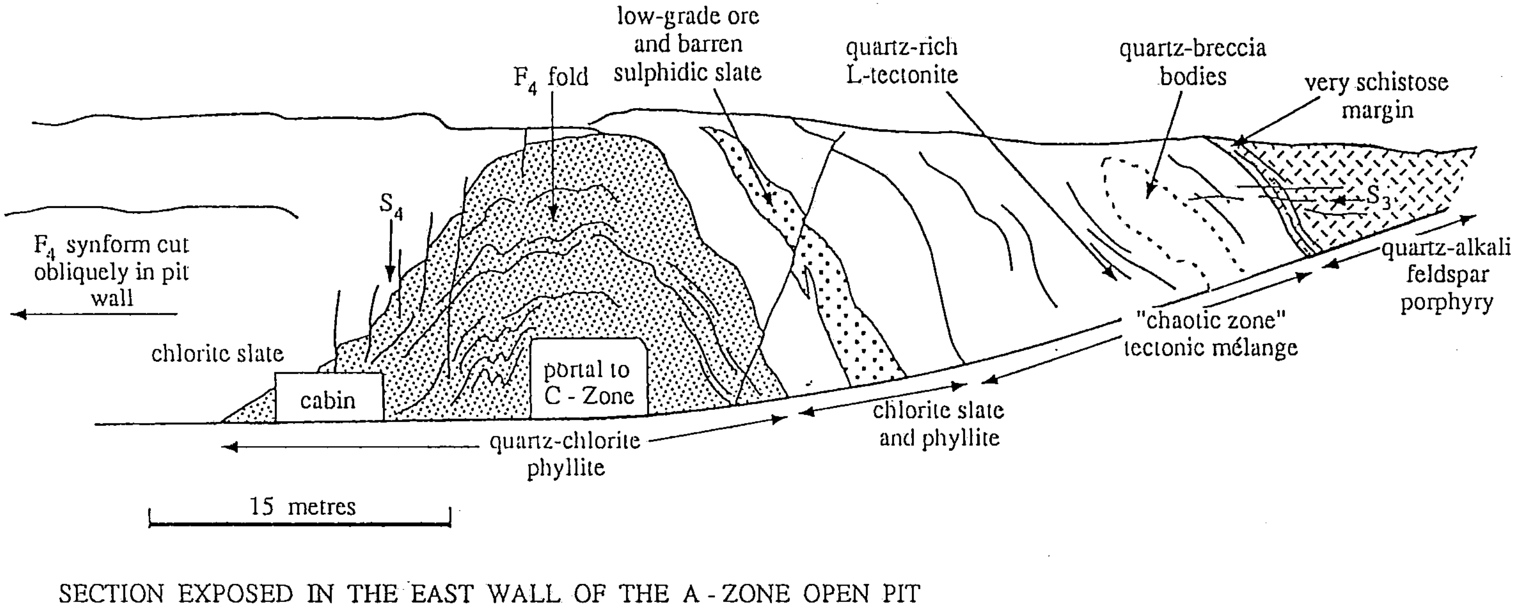

Figure H9. Section exposed in the northeast wall of the A-Zone open pit (see Figure H8 for location).

STRATMAT BOUNDARY AND HEATH STEELE N-5 ZONES, NORTHERN NEW BRUNSWICK

Art Hamilton[1] *and Adrian Park*[2]

INTRODUCTION

The Boundary deposit straddles the Heath Steele-Stratmat property boundary, and the N-5-Zone lies wholly on the Heath Steele Lease (see Fig.H1 of Hamilton *et al.*, this volume). Heath Steele Mines is owned jointly by Brunswick Mining and Smelting Corp. Ltd. and Noranda Minerals Inc.

In 1989, following the completion of a feasibility study, the Boundary and N-5 deposits were put into production. At that time, underground mining of B-Zone was resumed, and the current total production is 2700 tonnes/day (tpd). Reserves at the Boundary and N-5 zones were depleted in June 1993, after mining 1,136,900 tonnes with an average grade of 2.98% Pb, 8.11% Zn, 0.35% Cu and 44 g/t Ag. Both deposits were mined by a combination of open-pit and underground methods.

The Boundary and N-5 zones, although discovered in the early 1960's, did not achieve production until the late 1980's. Development was hindered by the divided ownership and relatively small size of the reserves. Viability of the present operation depends largely on concurrent production from these and other deposits in the Heath Steele area. Re-interpretation of the structure of the Boundary Zone by Noranda Exploration in 1984 identified a potential for significant, shallow open-pit reserves lying on the crest of a large-scale antiform; the potential was subsequently confirmed by diamond drilling, and a simultaneous review of previous metallurgical testwork encouraged development.

HISTORY

The Stratmat property was staked in 1954 by Stratmat Limited (a wholly owned subsidary of Strategic Materials Ltd.) during the original staking rush in the Bathurst Camp. Airborne and ground electromagnetic surveys and soil geochemical surveys on the Stratmat property between 1954 and 1956, and subsequent diamond drilling in 1956, led to the discovery of the Main Zone (see Fig.H1 of Hamilton *et al.*, this volume). In 1959, Cominco Ltd. purchased the property (Rhodes 1978) and outlined a weak electromagnetic anomaly and a coincident geochemical anomaly in 1960 (Rhodes 1978). Subsequently, diamond-drilling in 1961 intersected the Boundary-Zone. In 1964, several I.P. anomalies were drilled leading to the discovery of the N-5 and N-3 zones by Heath Steele Mines.

After an option agreement was reached with Cominco in 1986, exploration work on the Stratmat property by Noranda Exploration Ltd. continued outlining significant reserves amenable to open-pit mining at the Boundary-Zone. The nearby S-1 deposit was first drilled by Noranda in 1988 to test the sedimentary horizon at depth in the Central Zone (see Fig.H1 of Hamilton *et al.*, this volume). Probable and possible geological reserves for S-1 Zone are 4.9 million tonnes of 2.82% Pb, 6.74% Zn, 0.44% Cu, and 50 g/t Ag.

STRATIGRAPHY

The rocks of the mine area have been divided into three informal units (Figs.S1 and S2); 1) the *southwall sequence* that forms the footwall of the ore zone, 2) the *sedimentary sequence* that contains the ore zone, and 3) the *northwall sequence* that forms the hanging-wall of the deposit (Dahn et al. 1987, Rhodes 1978). Stratigraphic relationships are based on observations of drill-core and rock exposures.

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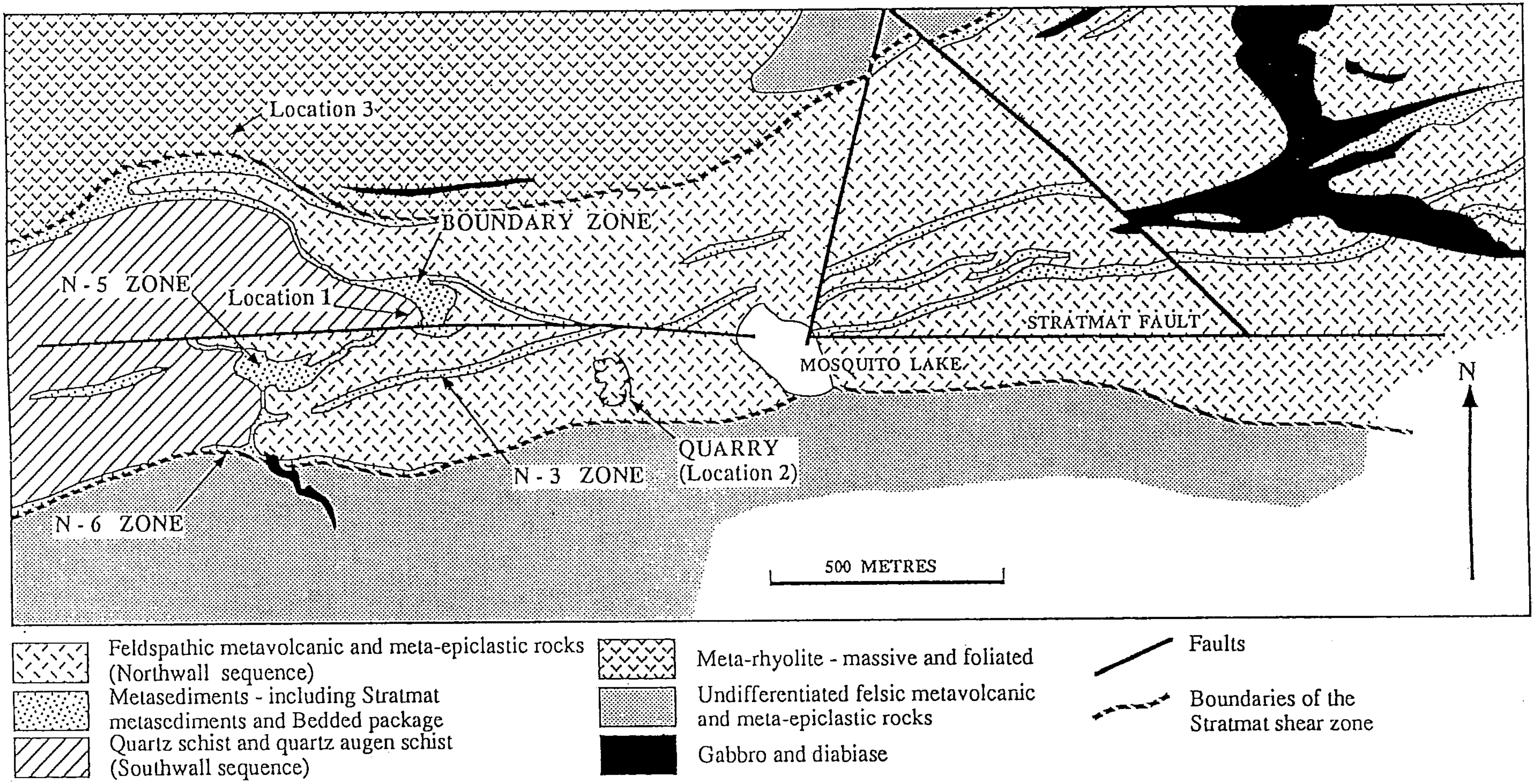

Figure S1: Simplified geological map of the area around the Boundary and N-5 zones showing Stop Locations.

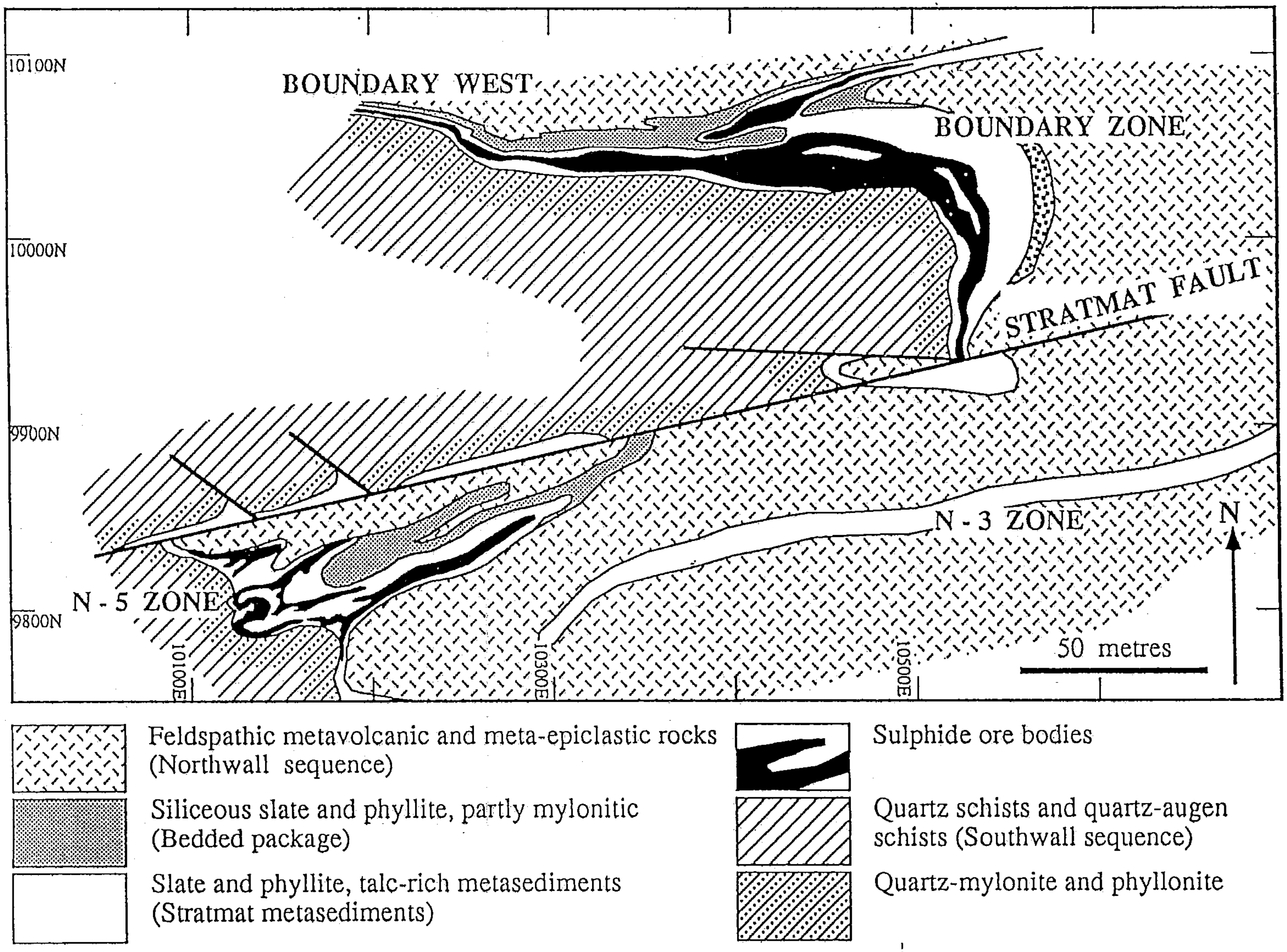

Figure S2: Detailed geological map of the area near the Boundary and N-5 zones (from Park 1992).

Footwall Rocks: The presumed oldest rocks of the sequence, the *southwall fragmentals*, consist predominately of white to pale grey, fine- to extremely fine-grained siliceous fragments ranging from < 1 mm to > 10 cm. The fragments vary from closely packed to sparse within a phyllosilicate-rich matrix. Locally, the "matrix" occurs interbedded with fine-grained siliceous or "cherty" layers that vary in thickness from centimetres to metres. Thin-section study by Dahn et al. (1987) revealed that the phyllosilicates are muscovite, chlorite, and minor biotite; furthermore, a possible exhalative origin for the fine-grained siliceous rock (i.e. chert) was proposed.

In the mine area, the *southwall fragmentals* contain an average of 2% to 4% disseminated pyrite, as well as minor sphalerite, galena, and chalcopyrite. The sulphides generally occur within the phyllosilicate-rich matrix or layers, but minor fine-grained sulphides also occur within the siliceous fragments or layers. Local coarse-grained stringers of pyrite chalcopyrite-sphalerite-galena are present near the top of this unit.

The *southwall fragmentals* also are referred to as "coarse acid fragmentals", "lapilli tuffs", and "bedded or siliceous tuffs". They represent fragmental rhyolitic rocks and are assigned to the Flat Landing Brook Formation (see Wilson, this volume). The fragmental fabric probably results from phreatic fragmentation preceding chert and argillaceous sediment deposition. Tectonic cataclasis during the intense D_1 and D_2 events caused further brecciation, enhancing the fragmental texture.

Massive sulphides and associated sedimentary rocks: The ore-bearing *sedimentary sequence*, commonly referred to as phyllites, gradationally overlies the *southwall fragmentals*. The basal unit of the sequence is a chert-rich layer that grades upward into dull greenish grey, fine-grained, siliceous phyllites, and eventually into less-siliceous phyllite. The chert unit may be a relatively undeformed equivalent of the siliceous fragmental rocks. The mineralogy of the phyllitic rocks is predominately quartz-muscovite-chlorite (Dahn et al. 1987), but talc-chlorite and muscovite contents increase and quartz content decreases toward the ore zone. Disseminated pyrite-sphalerite-galena-chalcopyrite averages 2% to 4% in the immediate footwall sedimentary rocks, with increasing grade towards the ore. Coarse-grained sulphide stringers occur locally in the footwall sedimentary rocks. If these represent a stringer-sulphide feeder zone, it is highly attenuated and transposed into virtual parallelism with the stratigraphy.

The ore consists of disseminated and massive sphalerite-galena-pyrite and chalcopyrite. The sulphides are fine- to medium-grained but coarser than typical massive sulphides in the Bathurst Camp. The Boundary and N-5 deposits have a relatively low iron content, averaging 15% to 20% pyrite, and have an abundance of talc and chlorite associated with the ore. The talc occurs as discrete layers in the ore and is disseminated in the phyllites that are directly associated with the ore. Disseminated mineralization, commonly of ore grade, occurs in the phyllitic sedimentary rocks, as well as in the talc layers that locally grade into layers of massive sulphides.

A layer of massive pyrite-chalcopyrite, typically < 1 m thick, occurs locally on the footwall side of the ore zone. Copper grades in this unit average 1% to 2%, although 10% grades do occur. The copper-rich layer may be in contact with, or grade into pyrite-poor massive sphalerite-galena ore that locally is up to a few metres thick (grades average 5% to 15% Pb and 15% to 35% Zn). Muscovite, talc, chlorite, quartz and carbonate occur as gangue constituents with the sulphides. Many of the Cu-rich and Pb-Zn-rich massive-sulphide layers are separated by talcose or phyllitic sedimentary rocks that commonly have disseminated ore-grade mineralization. A carbonate layer is locally associated with the ore and generally contains disseminated sulphides. Calcite is the most common carbonate, but ferroan dolomite and siderite also are present.

Directly overlying the ore is a pyritiferous sedimentary layer, up to several metres thick, that is similar to the greenish grey phyllites of the footwall.

Hanging-wall: The *northwall sequence* is presumed to be the youngest in the mine stratigraphy. The dominant facies is a feldspar-rich fragmental rhyolite with pseudo-pyroclastic textures. Typically, the feldspars are set in a siliceous matrix with muscovite, and minor chlorite, biotite and pyrite (Dahn et al. 1987). Lapilli-sized fragments occur in a very fine-grained matrix that resembles tuff or hyalotuff. These rocks are typical of the Flat Landing

Brook Formation.

A unit referred to as the *bedded package* (Figs.S2, S3 and S4) has been included as a subunit of the *northwall sequence*. This unit, which contains thin ore lenses, overlies the main ore lens near the crest of the large-scale antiform at the Boundary deposit. The rocks are mesoscopically similar to the *southwall fragmentals*, although there are local occurrences of northwall crystal tuff within the unit. The exact stratigraphic relationship of the *bedded package* to the rest of the section is not clear. It is possible that D_1 fault stacking has "mixed" southwall and northwall rocks.

STRUCTURE

Complex folding and shearing are generally more intense within the sedimentary sequence that hosts the ore than in the northwall or southwall units. The sulphide orebodies in the Stratmat Boundary and Heath Steele N-5 zones both lie in the Stratmat shear zone, a major vertical structure that trends slightly north of east (Fig.S1). The zone of high strain that marks the surface expression of the shear zone is at least one kilometre wide, and the sulphide ore bodies occur in metasediment enclaves approximately in the centre of the structure. The *northwall sequence* comprises porphyritic feldspathic metavolcanic schists and gneisses (Figs.S2 and S3), commonly with breccia textures, and forms the hanging wall. The *southwall fragmentals* form the footwall succession, comprising quartz-augen and quartz-sericite schists. The metasedimentary enclaves (Stratmat metasediments of the mine stratigraphy) define F_2 sheath folds within the *northwall sequence*. Other lithologies include tectonic mélange, talc and talc-carbonate schist, quartz-mylonite and phyllonite, and the massive sulphide and sulphide-silicate gneisses that constitute the ore deposits (Figs.S2 and S3). The "*bedded package*" in the mine terminology consists of *southwall fragmentals* that are tectonically juxtaposed (mixed?) with rocks of the *northwall sequence* (Fig.S4).

All the rocks in the Stratmat shear zone are extremely deformed metamorphic tectonites, dominated by a composite schistosity (S_{0-1}), in which relics of primary layering are extremely rare. A second schistosity, S_2 is axial-planar to the F_2 sheath folds, and is sub-parallel to the composite schistosity, except in the F_2 fold closures, where it can be distinguished from S_{0-1}. Two mineral lineations, defined by microboudins, quartz-beards on porphyroclasts and elongate mineral aggregates, lie in the planes of the two schistosities ($L^m{}_1$ and $L^m{}_2$), but can only be distinguished as separate fabric elements in the closures of the F_2 folds. Elsewhere, they constitute a single stretching lineation, consistently plunging steeply to the southwest or south-southwest. Kinematic indicators show that the overall sense of shear in this zone is north side-up, consistent with the vergence of the F_2 folds (Figs.S3 and S4).

The sulphide orebodies are statabound only in the sense that they are within the Stratmat *sedimentary sequence*; however, deformation is so extreme that whether or not they were originally strataform is unknown. The bodies are now elongate parallel to the stretching lineation in the plane of the S_{0-1} foliation. Attenuations or discontinuities in the ore layers typically occur in directions parallel to S_{0-1}, but at right angles to the stretching lineation. The N-5 Zone is located along an F_2 limb, close to the hinge area (Figs.S3 and S4).

DISCUSSION

The Boundary and N-5 deposits occupy a different belt than the B-Zone and other deposits in the central part of the Heath Steele property. The deposits in the Stratmat belt are hosted by sedimentary rocks of the Flat Landing Brook Formation and have many attributes similar to others deposits in the Camp that occupy a similar stratigraphic position (cf. McCutcheon *et al.* this volume). Deposits in the Stratmat area, with the exception of the Main and N-3 zones, have relatively low pyrite contents (15% to 20%), are coarser grained, and have variable amounts of talc associated with the ore. Deposits along the Heath Steele belt average 50% to 80% pyrite and pyrrhotite, and several are overlain by, or have inter-layers of, magnetite. With the exception of the Main Zone, oxide iron-formation has not been identified in the Stratmat area.

The structural complexity intensifies with proximity to the ore lenses, probably because deformation was partitioned into the less competent sulphides and their sedimentary host rocks. D_1 is characterized by layer-parallel shear zones,

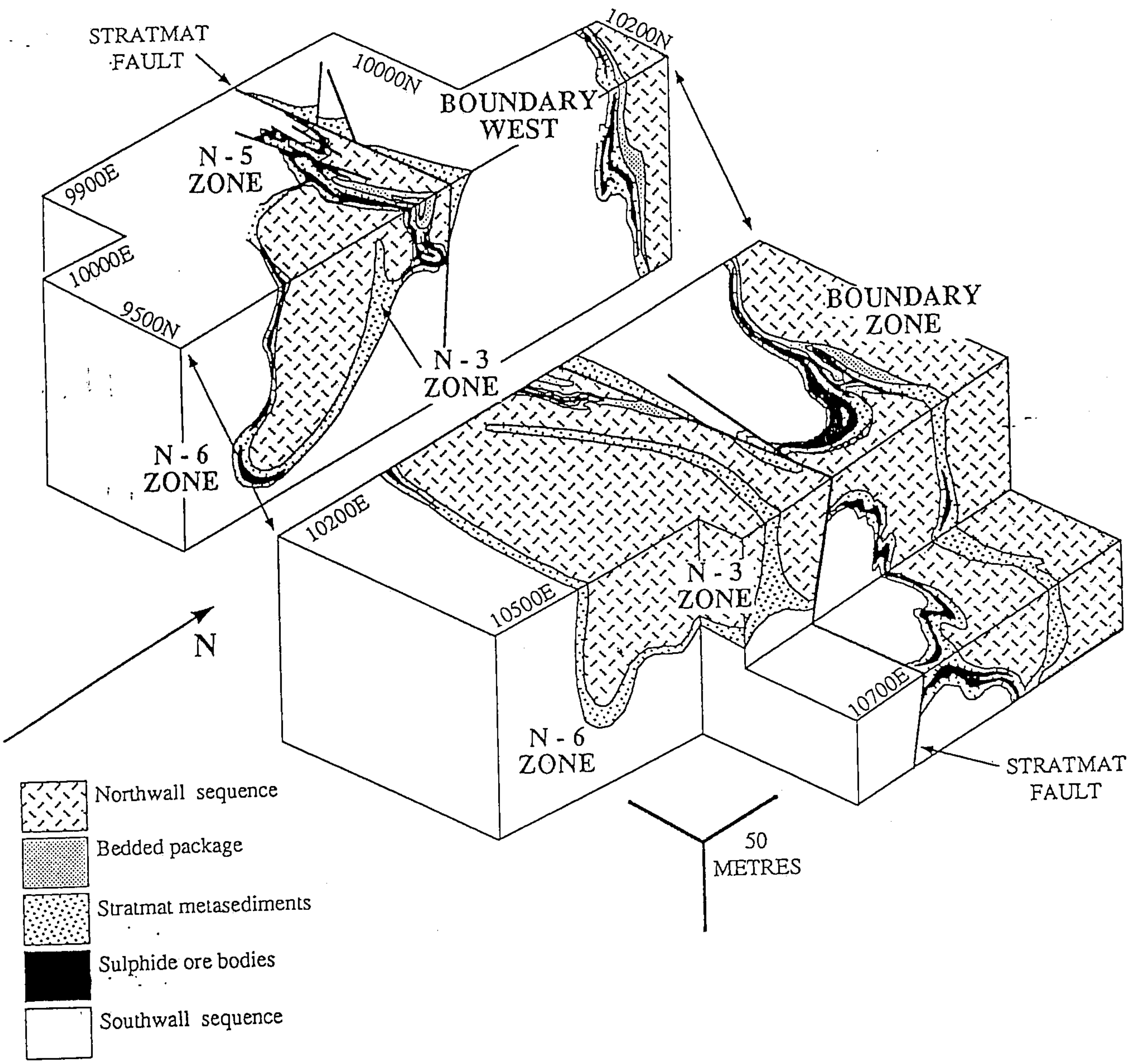

Figure S3. Block diagram of the geology of the Boundary and N-5 deposits separated and displaced by the Stratmat Fault. (after Park 1992, unpublished report).

recumbent folds, and local sheath folds. The overall morphology of the deposits, however, is chiefly controlled by large-scale F_2 folds. Structural models of the complex deformation play an important role in the mine-scale interpretations, as well as in the ongoing exploration effort in the Heath Steele area.

ACKNOWLEDGEMENTS

Numerous discussions with geologists from Noranda Exploration and Heath Steele Mines have been helpful in developing an understanding of the geology of the Heath Steele mine area. The manuscript benefitted from reviews by Dave Lentz, John Langton, Steve McCutcheon and Chris Moreton.

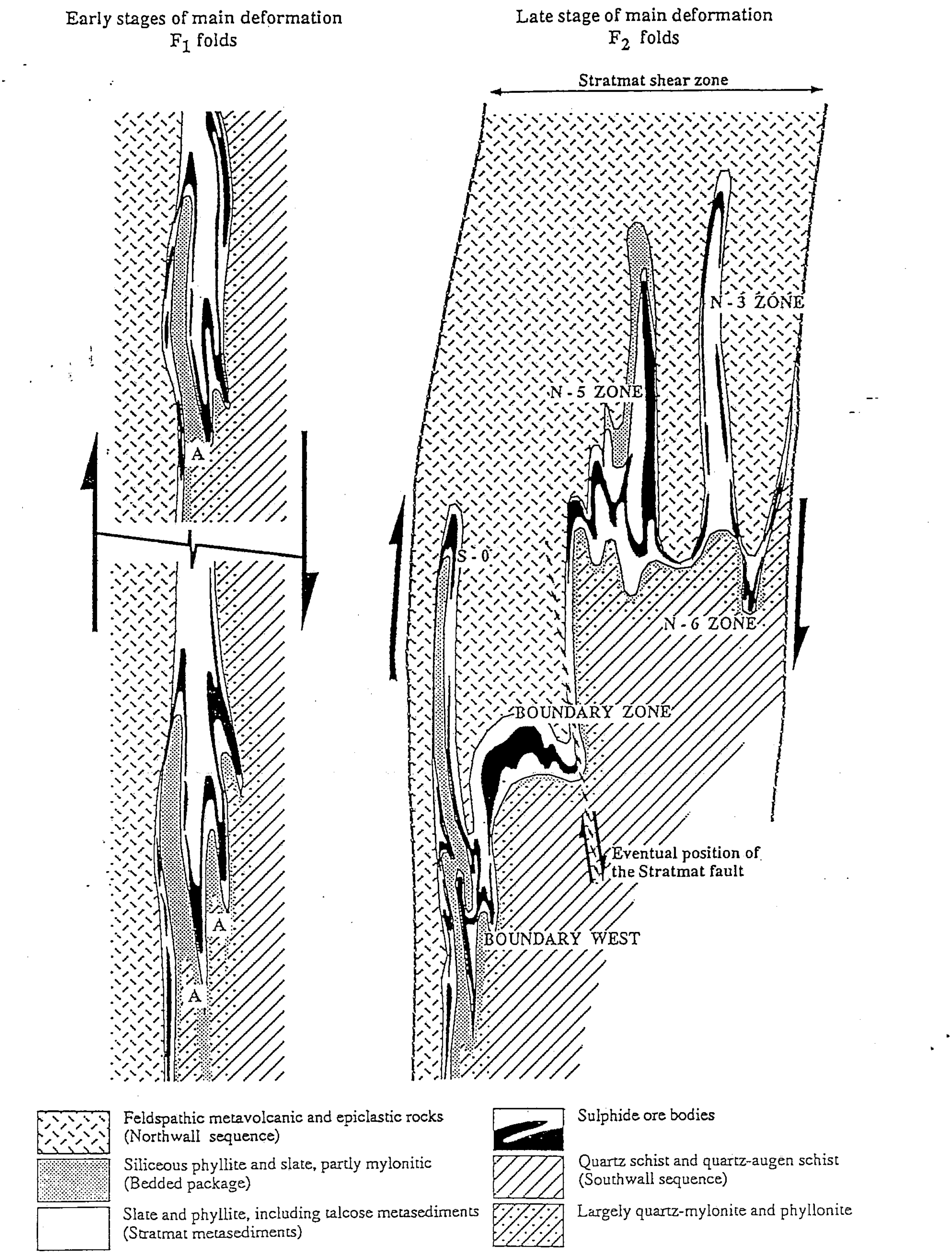

Figure S4. Schematic cross section, Stratmat shear zone showing the distribution of the various sulphide deposits.

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STOP DESCRIPTIONS IN THE STRATMAT AREA

STOP S-1: (Location 1 in Fig.S1). The ramp of the Stratmat open-pit transects the footwall (*southwall sequence*) of the Boundary Zone ore (Figs.S1 and S2). The predominant lithology is mylonitic or phyllonitic, pyrite-rich, quartz-augen and quartz-sericite schists. The most quartz-rich material is nearly pure quartz-mylonite with a strong mineral lineation (L^m_1 or L^m_2). In the pyritic material this lineation is defined by quartz-beards on pyrite (locally sphalerite) porphyroclasts. Veinlets of sphalerite and galena, with or without chalcopyrite, are common and usually parallel or sub-parallel to the composite foliation (S_{0-1}).

Quartz-vein development occurred throughout the D_1 and D_2 events. Early-formed veins are almost completely transposed into the composite schistosity, preserved as quartz-mylonite layers with rare discordant relationships to foliation. Later veins retain more relict disordant relationshis, but are still in part mylonitic. The latest veins are almost completely discordant and not mylonitic. These quartz veins may contain chalcopyrite and traces of sphalerite. One group of syn-tectonic veins bears a distinctive pink microcline feldspar.

Much of the quartz, and in some lithologies all of the quartz, appears to have once been vein material, or infillings of pressure shadows around pyrite grains. The protolith for most of the mylonite and phyllonite in the footwall appears to have been a relatively quartz-poor pyritic sericite rock.

Farther from the ore-footwall contact the lithologies are less mylonitic and earlier textures are preserved in patches. These include the "fragmental" breccia-like textures of the typical *southwall fragmentals*. Typically feldspar free, there are minor layers of fragmental, quartz-augen rock with pink microcline porphyroclasts or relict phenocrysts, that may be found in the wall above the middle part of the ramp, just above the bend.

STOP S-2: (Location 2 in Fig.S1). In the small quarry south of the portal, all the rocks (Fig.S1) are *northwall sequence* metavolcanic schists and gneisses in the hanging wall of the N-5 and N-3 zones. The predominant lithology is a breccia with pale clasts in a darker matrix. The color contrast results from modal variations in quartz and chlorite content. A small body of fine-grained quartzo-feldspathic gneiss runs through the middle of the quarry and may represent a granophyric felsite intrusion, though its boundaries are now parallel to the S_{0-1} composite foliation.

The ice-smoothed rock surfaces are almost perpendicular to the stretching lineation, and when viewed in this aspect, the rock appears to be only weakly foliated. However, the exposures that permit a 3-D view of the structure show how misleading this can be. On surfaces parallel to the foliation the pale breccia clasts are elongate with aspect ratios ranging from 5:1 to more than 10:1. On vertical surfaces perpendicular to the foliation the aspect ratios may be even larger. These shapes define a prolate strain ellipsoid with some flattening in the foliation. Notice particularly, how, in a vertical section cut perpendicular to foliation (close to the view seen in drill-core), the deformed breccia can look like a banded metasedimentary rock. This location demonstrates how easily these deformed porphyritic metavolcanic rocks can be misinterpreted, especially in restricted outcrop or in drill-core.

STOP S-3: (Location 3 in Fig.S1). Outcrops in the old roadways north of the waste dumps, and close to the northern boundary of the Stratmat shear zone, are on the margins of a metarhyolite dome (Fig.S1). The rock is a deformed metarhyolite. As at Location 2, the stretching lineation is nearly vertical. Much of the ice-smoothed material appears to be only weakly foliated, and dominated by an anastomosing parting. In fact, the rocks are L-tectonites, in which the strain ellipsoid is prolate with little or no flattening component perpendicular to the S_{0-1} composite foliation. Unlike the breccia at location 2, there are no strain markers here. On sections parallel to the foliation, a strong lineation, locally a rodding, is apparent. On vertical sections perpendicular to the foliation C-C' structures (shear bands) are evident. Once again, if observations are restricted to one or two dimensions, misinterpretation is possible.

THE BRUNSWICK NO. 12 AND NO. 6 MINES, BATHURST CAMP, NORTHERN NEW BRUNSWICK

W. M. Luff[1], D.R. Lentz[2] and C. R. van Staal[3]

INTRODUCTION

The Brunswick No. 12 and 6 massive-sulphide deposits are located 27 km southwest of Bathurst, New Brunswick and situated about 10 km apart; the Austin Brook Iron Mine is approximately 1 km south of Brunswick No.6 (Fig.1). The massive-sulphide deposits and associated iron formation known as the "Brunswick horizon", occur near the upper part of the Nepisiguit Falls Formation (Figs.2 and 3) of the Tetagouche Group.

Since formal subdivision of the Tetagouche Group is a relatively recent phenomenon (cf. van Staal and Fyffe 1991), names such as the Nepisiguit Falls Formation are generally not used by the mine geologists. Instead, the long-established mine nomenclature continues to be applied to the rock units in the mine sequence. Consequently, both the mine terminology and the formal nomenclature are used in the stratigraphic description that follows. Furthermore, all rocks within the Bathurst Camp are metamorphosed, but the pre-metamorphic protolith can generally be identified. Therefore, pre-metamorphic rock names are used herein, in addition to the well known metamorphic abbreviations used by Brunswick mine geologists.

HISTORY

The Austin Brook hematite-magnetite-rich iron formation was discovered in 1897 by a local prospector Mr. William Hussey. Approximately 160 000 tonnes of ore were mined between 1911 and 1913 by the Canadian Iron Corporation. The Austin Brook deposit was reopened by the Dominion Steel and Coal Company in 1942 and produced approximately 130 000 tonnes before closing a year later (Belland 1992).

The Brunswick No. 6 deposit was intersected by three diamond-drill holes in 1907, while investigating the Austin Brook iron mine's third zone, located 0.8 km to the north of Austin Brook (Young 1911). However, the No. 6 sulphide deposit was not recognized as such until late in 1952. Prior to this, in 1951, interest in sulphur led to renewed exploration of the Austin Brook area by Brudon Enterprises Limited. Dr. G.S. Mackenzie was contracted to evaluate the property for Brudon and with the help of his graduate student, Mr. A.B. Baldwin, recognized that the potential for base-metal sulphides. Based on the recommendation of P.W. Meahan, and Dr. G.S. Mackenzie's report to Brudon Enterprises, the M.J. Boylen Prospectors Group optioned the Austin Brook property in mid-1952 and immediately began the diamond drilling program, which was outlined in MacKenzie's report to Brudon Enterprises (McCutcheon *et al.* 1993). At the same time, a vertical-loop electromagnetic (EM) survey was also initiated at the recommendation of Mr. Robert J. Issacs, chief mining engineer for M.J. Boylen. Subsequent drilling of strong EM anomalies led to the discovery of the No. 6 sulphide body, after the first eleven holes had been drilled in the Austin Brook deposit. The discovery hole was completed on October 25th, 1952; within six days of the discovery, Brunswick Mining and Smelting Corporation Ltd. was formed.

Geological Survey of Canada airborne magnetic maps (1951) helped delineate the regional trend of lithological units and resulted in extensive staking of magnetic anomalies in 1952-53. The Brunswick No. 12 deposit was discovered in the spring of 1953 on the Anacon-Leadridge group of claims, an M.J. Boylen company, while drilling a strong electromagnetic anomaly (MacKenzie 1958).

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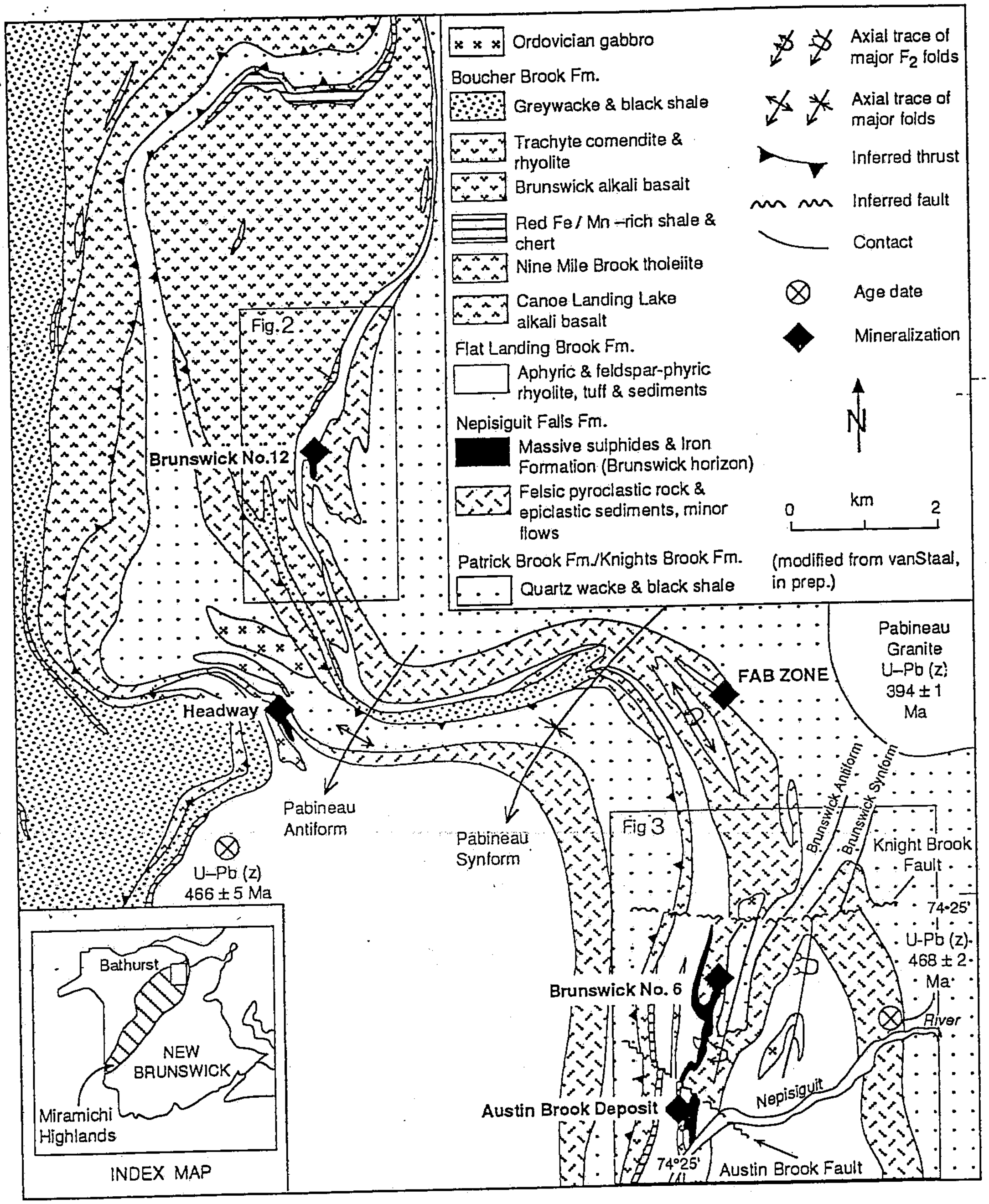

Figure 1. Geological map of the Brunswick No. 6 and 12 areas (modified after van Staal in prep.). The areas covered by Figure 2 and Figure 3 are also shown.

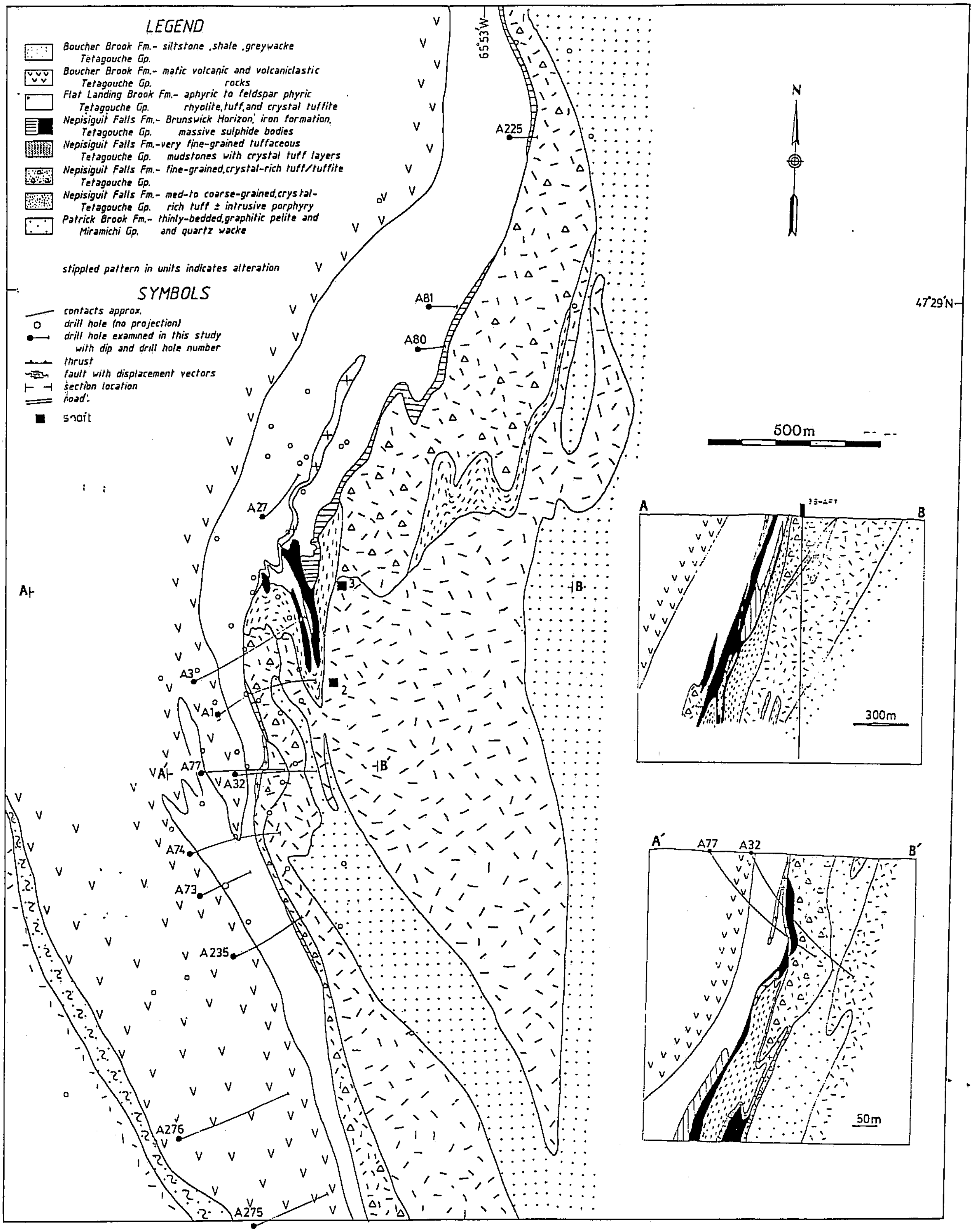

Figure 2. Simplified geological map and cross sections in the vicinity of the Brunswick No. 12 deposit (after Lentz and Goodfellow, in prep.). See Figure 1 for location of this map area.

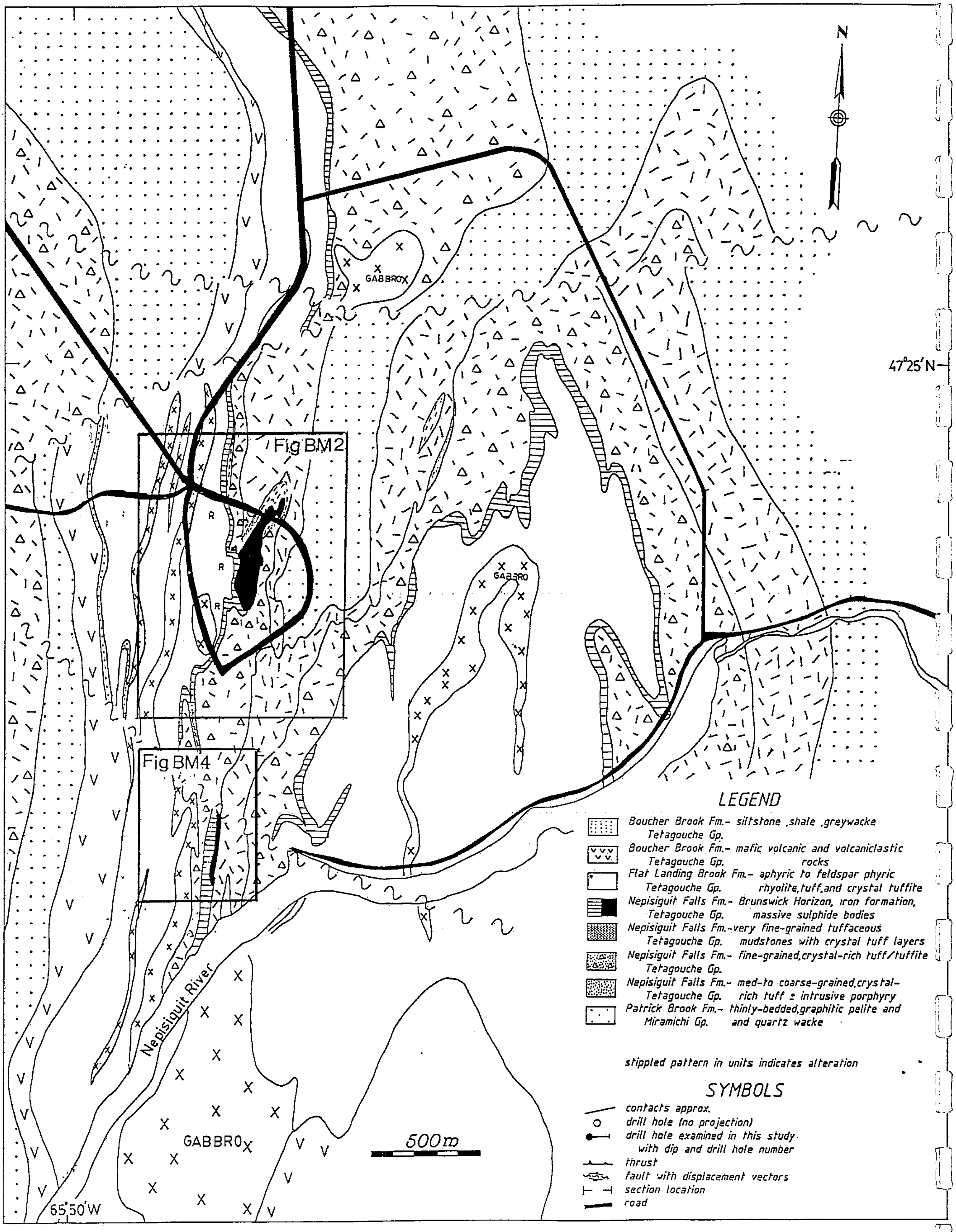

Figure 3. Regional geology around the Brunswick No. 6 and Austin Brook mines. See Figure 1 for location of this map area. The insets show the locations of Figure BM2 and Figure BM4.

STRATIGRAPHY

The mine stratigraphy and the regional stratigraphy of Fyffe and van Staal (1991) are shown in Figure 4. The oldest rocks in the Brunswick mine sequence, "graphitic older metasedimentary rocks" (OM), belong to the Patrick Brook and/or Knight's Brook formations and comprise intercalated graphitic to carbonaceous slate and quartz wacke. The contact with the overlying Nepisiguit Falls Formation is commonly tectonized but appears to be conformable.

Above the Patrick Brook rocks (OM) are "quartz-feldspar-augen schist" (QFAS), "quartz-augen schist" (QAS), "metasedimentary rocks" (M), "crystal tuff" (CT) and "footwall metasediments" (FW), in ascending stratigraphic order (Figs.4, 5, 6 and 7); all of these units belong to the Nepisiguit Falls (NF) Formation. At the Brunswick No. 12 deposit, most of the QFAS is relatively homogeneous with a cryptocrystalline groundmass (Lentz and Goodfellow 1992a). In general, quartz and feldspar are coarse grained (3-10 mm) and constitute 20 to 40 vol. % of the rock. This massive type of QFAS is considered to be a pyroclastic flow (Lentz and Goodfellow 1992a) or tufflava (Langton and McCutcheon 1993) rather than intrusive porphyry. At Brunswick No. 6 massive QFAS constitutes the lower part of the NF Formation. Granular or volcaniclastic QFAS, locally with interbeds of crystal tuff (CT) and/or sedimentary rocks (M), overlies the massive type and contains a high percentage of rounded crystals, i.e. tuffite; locally magmatically broken crystals and possibly relict pumice fragments (Juras 1981; Nelson 1983; Lentz and Goodfellow 1992a) are preserved. Granular QFAS probably represents cold debris flows of juvenile pyroclastic material. In many places, it is difficult to distinguish massive from granular QFAS because alteration and deformation have obliterated primary textures, i.e. the relative amounts of primary and reworked material are uncertain. In the mine area, the massive QFAS unit is thicker than elsewhere along strike, and may in part be a primary feature enhanced by structural thickening rather than resulting from structural thickening alone.

The QAS is a fine- to medium-grained rock with approximately 20 to 30 volume percent quartz crystals having an average grain size between 3 and 4 mm. The QAS probably was not deposited as such but was originally granular QFAS and/or CT. McCutcheon (1990 1992) proposed an epiclastic origin for the QAS at Brunswick No.6 based on the absence of feldspar, the sphericity of quartz, the high proportion of quartz to matrix, and the regional distribution of this rock type. However, the fact that massive QFAS (tufflava) is converted to QAS in the hydrothermal alteration zone beneath the Brunswick No. 12 deposit (Juras 1981; Lentz and Goodfellow 1992a) strongly suggests that most QAS is the result of seawater- and/or vent-related alteration of existing QFAS.

A laterally-continuous, fine-grained (1-2 mm) crystal tuff (CT) of variable thickness overlies QFAS at Brunswick No.12. The crystal tuff contains crystal shards and remnant pumice fragments (Juras 1981; Nelson 1983) and is a fine-grained variety of granular QFAS. Fine-grained, chlorite-sericite-rich footwall sedimentary rocks (FW) with minor tuffite lenses occur in the immediate footwall to the No. 12 deposit. The footwall sedimentary rocks appear to be laterally equivalent to this crystal tuff (CT) and originally may have contained a significant amount of fine-grained glass that settled from the water column. Near the contact with massive sulphides, these rocks are highly chloritic.

Massive-sulphide deposits and associated iron formation (SPP, SPPC, SO, SP and IF in Figs.4, 5, 6 and 7), commonly referred to as the "Brunswick Horizon", overlie the footwall sedimentary rocks (FW) and constitute the top of the Nepisiguit Falls Formation. At Brunswick No. 12, massive sulphides, capped by iron formation, overlie the thickest accumulation of footwall sedimentary rocks (FW) but along strike iron formation commonly directly overlies crystal tuff (CT). At No. 6, a similar relationship is evident. The spatial association of footwall sedimentary rocks with massive-sulphide deposits probably means that the sulphides accumulated in second- or third-order basins that were fault bounded. The upper contact of the NF Formation, and base of the FLB Formation, is placed at the top of the iron formation along the Brunswick Belt (van Staal 1992) because it marks the a major change in the type of volcanism and forms a well-defined marker horizon.

The massive sulphides form an integral part of an Algoma-type iron formation (IF) that can be divided into five facies: 1) sulphide, 2) oxide (hematite-magnetite), 3) silicate (chlorite), 4) carbonate (siderite) and 5) chert (cf. Saif 1980). The carbonate and chert (pyrite) facies are most closely associated with the massive sulphides at the

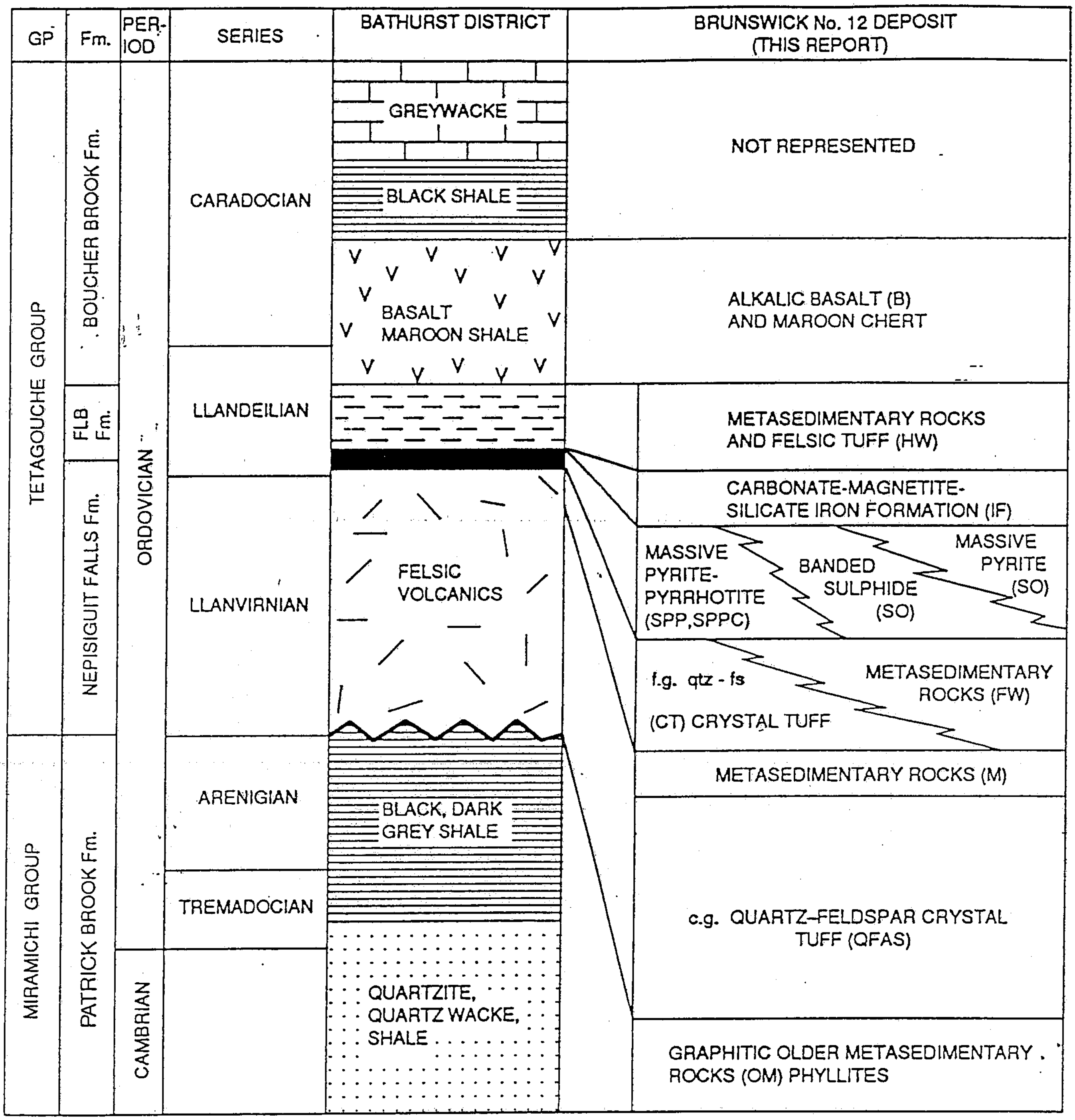

Figure 4. Stratigraphic section in the Brunswick No. 12 deposit (modified after Luff *et al.* 1992) compared to the regional stratigraphic section of van Staal and Fyffe (1990).

Brunswick No. 12 deposit, whereas the oxide facies is most prevalent at the Austin Brook deposit. The sulphide, oxide, carbonate, and chert facies of this Algoma-type iron-formation have very delicate, rhythmic layering typical of a chemical precipitate, but the silicate facies has moderate to poorly developed layering. In general, the various facies of iron formation are gradational into one another. To a large degree, the silicate-facies represents an allochemical sedimentary dilution of a metalliferous chemical sediment (cf. Bhatia 1970; Davies 1972; Saif 1980; Saif 1983; Peter and Goodfellow 1993). The consistent superposition of iron formation on massive sulphides and the lateral facies changes away from the sulphide deposits are indicative of changes in the physio-chemical environment of deposition within a basin.

The immediate hanging-wall rocks (HW in Figs.4, 5, 6 and 7) at the Brunswick No. 6 and No. 12 deposits belong to the Flat Landing Brook (FLB) Formation, but the sections differ from one deposit to another (van Staal and Williams 1984; McCutcheon 1990, 1992). At Brunswick No. 12, the FLB Formation consists of light to dark grey, fine-grained sedimentary rocks and interbedded acid hyaloclastite (hyalotuff) with minor massive rhyolite and associated breccia. However, at Brunswick No. 6, this formation is predominantly massive rhyolite and breccia with minor hyalotuff and sedimentary rocks.

Above the hanging-wall rocks (HW) at both No. 6 and 12, there is a "basic volcanic" (B) sequence (Figs.4, 5, 6 and 7) that is assigned to the Boucher Brook (BB) Formation. The sequence consists of massive to pillowed alkali basalt (locally magnetic), pillow breccia and hyaloclastite (van Staal 1987, van Staal *et al.* 1991) with thin units of interbedded sedimentary rocks; commonly dark grey siltstone but also red or green, in places magnetic, Fe/Mn-rich slate and chert (RMS). At both No.6 and No.12, there is a RMS unit delineated at the base of the basalt pile (Fig 1); however, RMS also occurs intermittently throughout the pile in association with altered magnetic basalts. For many years, these rocks have been loosely referred to as "basic iron formation" by exploration geologists (Whitehead and Goodfellow 1978; Saif 1980).

A composite mafic and felsic, quartz-feldspar porphyry dyke cuts the Brunswick No. 12 ore body and enclosing rocks of the NF and FLB formations (Figs.5, 6, and 7). The dyke contains fine- to medium-grained albite, K-feldspar, and quartz hosted in a compositionally-similar, microcrystalline (margins) to fine-grained matrix (core). Disseminated carbonate and pyrite constitute less that a few percent of the mode. There is some evidence of hydrothermal alteration along the margin (< 1 m) of the dyke. However, the dyke has retained some evidence of β quartz indicating that it was subvolcanic, possibly related to the alkali rhyolites (comendites) in the Boucher Brook Formation. At surface, the dyke occurs predominantly in the hanging-wall rocks north of the West ore zone, but at the 1125 m level, it occurs in footwall sedimentary rocks and from the 575 m - 1000 m levels, it cuts massive sulphides. The dyke has a weakly developed S_1 fabric that is deformed by F_2 folds. This shows that the dyke was emplaced before the D_1 deformation. Evidently, the dyke is thicker in the hinges of the F_2 folds having been attenuated along the limbs. The existence of a post-ore and pre-deformation intrusion within the mine sequence shows that there was limited remobilization of sulphides after they were deposited (Lentz and van Staal 1992).

The hanging-wall rocks of the No. 6 mine are intruded by a southwesterly plunging body of tholeiitic gabbro (Group "C" gabbro of van Staal 1987). A similar gabbroic body was intersected in the hanging-wall sequence during underground drilling to the north of the No. 12 mine (1000 m level). Interestingly, the gabbros are not the intrusive equivalents of the BB basalts because the latter are alkaline in composition. Numerous unmineralized and weakly altered gabbroic dykes intrude the FAB mineralized zone near the contact between the Patrick Brook or Knight's Brook and Nepisiguit Falls formations (Lentz and Goodfellow 1993a).

STRUCTURE

Detailed structural analysis of the Brunswick No. 6 and No. 12 mines and surrounding areas (van Staal and Williams 1984; van Staal 1985) has shown that the deformational history and geometries of the two orebodies are essentially the same. At both deposits, the host rocks and sulphides exhibit tight F_1 and F_2 folds with well developed axial planar cleavage (S_1 and S_2). Both deposits occur in large asymmetrical F_2 fold hinges that show a marked

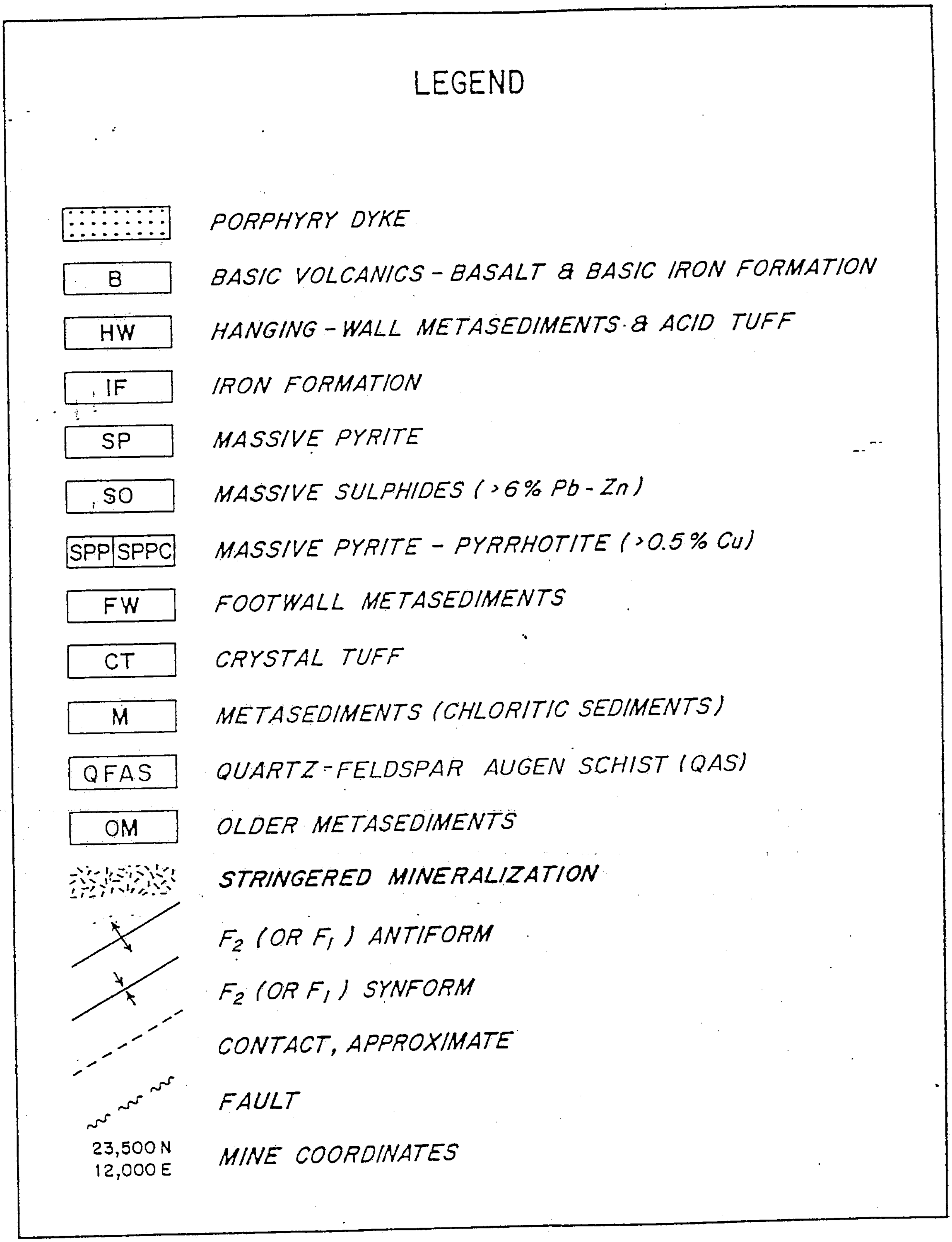

Figure 5. Legend for the geological plan (Fig.6) and section (Fig.7) of the Brunswick No. 12 massive-sulphide deposit (modified after Luff *et al.* 1992).

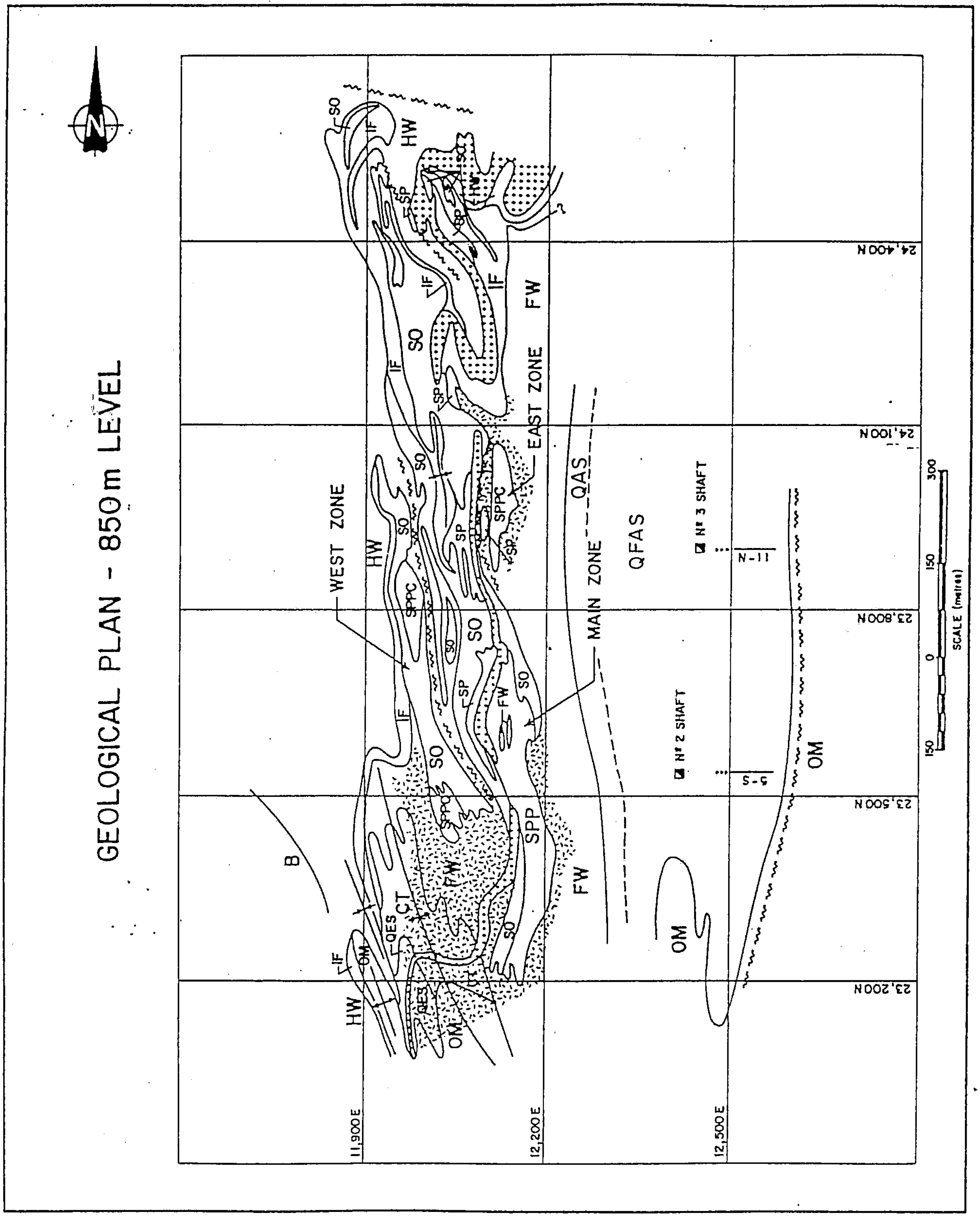

Figure 6. Geological map of the 850 metre level (2800 ft) of the Brunswick No. 12 massive-sulphide deposit. The field excursion begins on this level at the No. 3 shaft and proceeds along the drive into the FW sedimentary rocks, and then north into the East ore zone (modified after Luff *et al.* 1992).

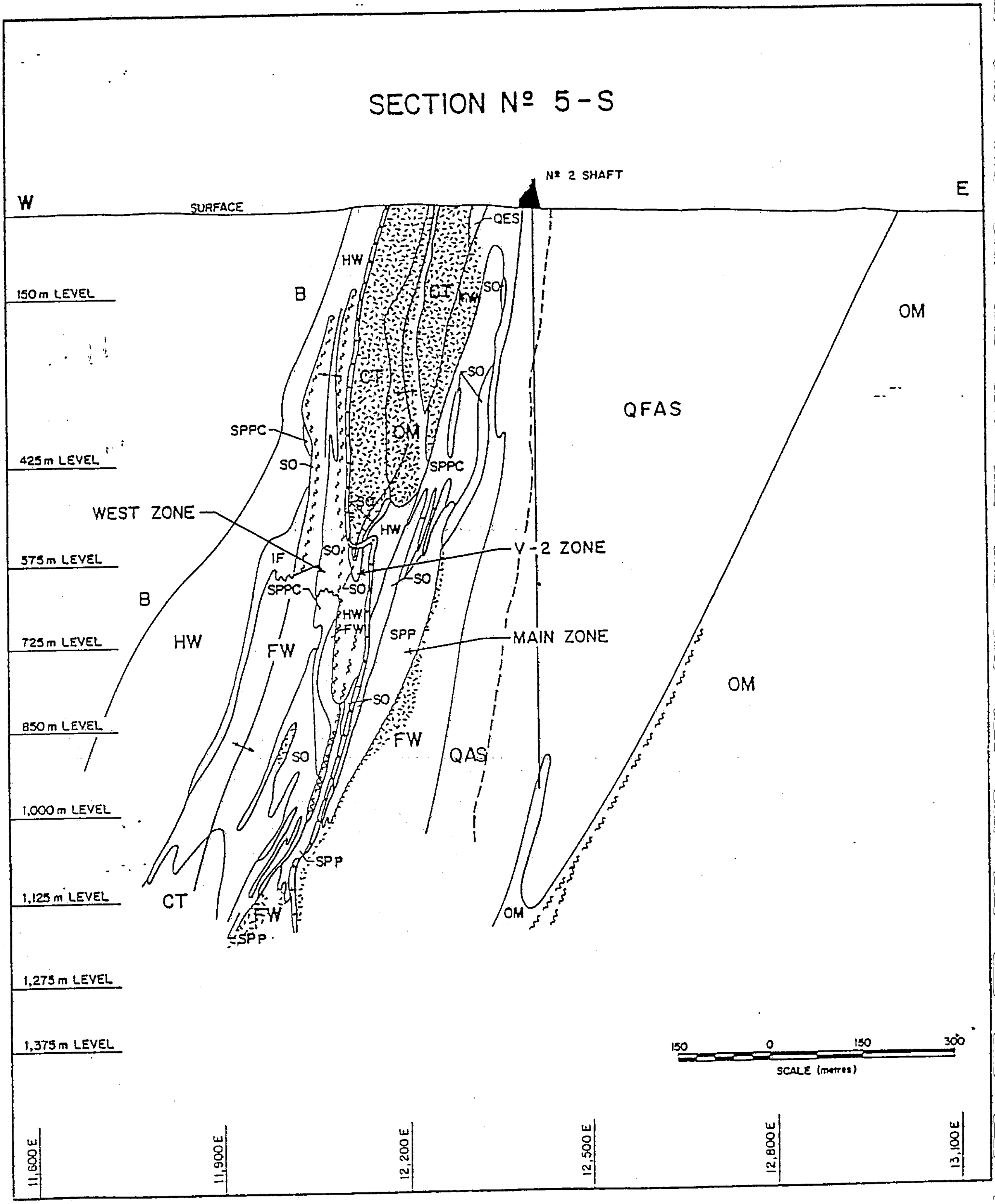

Figure 7. East-west cross section through the Brunswick No. 12 deposit at 5-S (see Fig.6 for location).

variation in plunge resulting from the influence of the earlier (F_1) fold closures (Figs.8 and 9). Massive sulphides in the Brunswick No. 12 mine occur in four major zones; the Main Zone, the East Zone, the West Zone, and the V-2 zone (Figs.6 and 7). These zones coelesce below the 850 m level, where F_2 folds impinge upon an F_1 fold hinge causing structural thickening of the metalliferous rocks. The attenuation of alternate limbs of tight to isoclinal (F_2) folds results in an en echelon pattern of tabular sulphide bodies, something that is evident in the block diagrams (Figs.8, 9 and 10). Numerous intrafolial, isoclinal F_1 and F_2 folds in the sulphide bodies attest to intense transposition and the marked boudinage of the porphyry dyke, where it transects the massive sulphides (Figs.6 and 7), is another indication of the high strain that the sulphide bodies have undergone.

On the basis of the regional stratigraphy, metal zonation, and the stratigraphic position of the iron formation with respect to the sulphides, the F_2 folds can be divided into upward- and downward-facing structures. For instance, the steeply south-plunging, Z-shaped fold in the Brunswick No. 12 mine is downward-facing at surface (van Staal and Williams 1984). The plunge of this fold changes by more than 90°, passing through the vertical and then the horizontal to become shallowly south plunging and upward facing at depth (Fig.8). The trace of the F_2 fold plunge, drawn in a section parallel to the axial plane of the F_2 fold, defines a large overturned F_1 fold (Fig.11). The large-scale geometries of both the Brunswick No. 6 and 12 mines, which define overturned, asymmetrical basins, are therefore interpreted as interference structures between F_1 and F_2 folds. Cross-sections parallel to the F_2 axial surfaces show that the metal zoning in both the No. 12 (Fig.11) and No. 6 (Fig.12) deposits is affected by F_1 folds and indicate that the zoning predates the earliest deformation. All other structural data indicate that the mineralization, with the exception of some remobilized material, has been affected by the earliest deformation recorded in the country rocks. The structural evidence is thus compatible with a volcanogenic-exhalative origin of the ores. However, primary features, such as the stringer-sulphide zone and associated alteration, are partially obliterated by deformation and metamorphism. At least some of the cross-cutting sulphide veinlets are parallel to S_2 (van Staal and Williams 1984) and, therefore, cannot be original stockwork stringers. However, some of the sulphide veinlets are folded and probably represent re-oriented stringers of an original stringer-sulphide zone.

The form-surface map of the Brunswick No. 6 deposit (Fig.13) shows the relationship between the two predominant tectonic fabric elements (S_1 and S_2). The S_1 fabric is generally a differentiated (solution) cleavage represented by thin recessive-weathering phyllosilicate layers; this cleavage is refolded by F_2 folds with a penetrative axial-planar S_2 foliation. However, prior to van Staal and Williams (1984), the relative ages of these two cleavages had been misinterpreted. This is because the S_2 fabric appears to be crenulated by S_1, when in fact it is refracted by the phyllosilicate layers, which are compositionally different from the rest of the rock. The situation is analogous to cleavage refraction in a sandstone-slate sequence.

Overprinting relationships among folds are more common in the iron formation, particularly at the Austin Brook deposit, than in other rock units. Fine-scale layering in hematite-magnetite iron formation outlines F_1 folds that are refolded by F_2 and F_3. Originally, these folds were attributed to soft-sediment deformation but the consistency in fold relationships, pointed out by van Staal (1985), does not support this hypothesis. The outcrop-scale F_1 and F_2 fold interference patterns mimic the megascopic structures in the Bathurst Camp.

MASSIVE SULPHIDES

Production of ore from the No. 6 deposit began in 1966 and ceased operation in 1983 after producing 12 125 000 tonnes of ore grading 5.43% Zn, 2.16% Pb, 0.39% Cu and 67.0 g/t Ag (Table 1). Mining began at the No. 12 deposit in 1964 and currently (1992) has mineable ore reserves of 60 787 000 tonnes grading 8.99% Zn, 3.59% Pb, 0.32% Cu, and 101.6 g/t Ag (Table 1).

The No. 12 deposit comprises four zones (West, Main, East and V2) that merge at depth. The West Zone generally has the highest base-metal grades, whereas the Main Zone comprises the bulk of the deposit. The massive sulphides at both deposits are divisible into three compositional units: 1) massive pyrite containing minor amounts of sphalerite and galena, and minor to significant amounts of chalcopyrite, pyrrhotite, and magnetite (SPP or SPPC); 2) banded

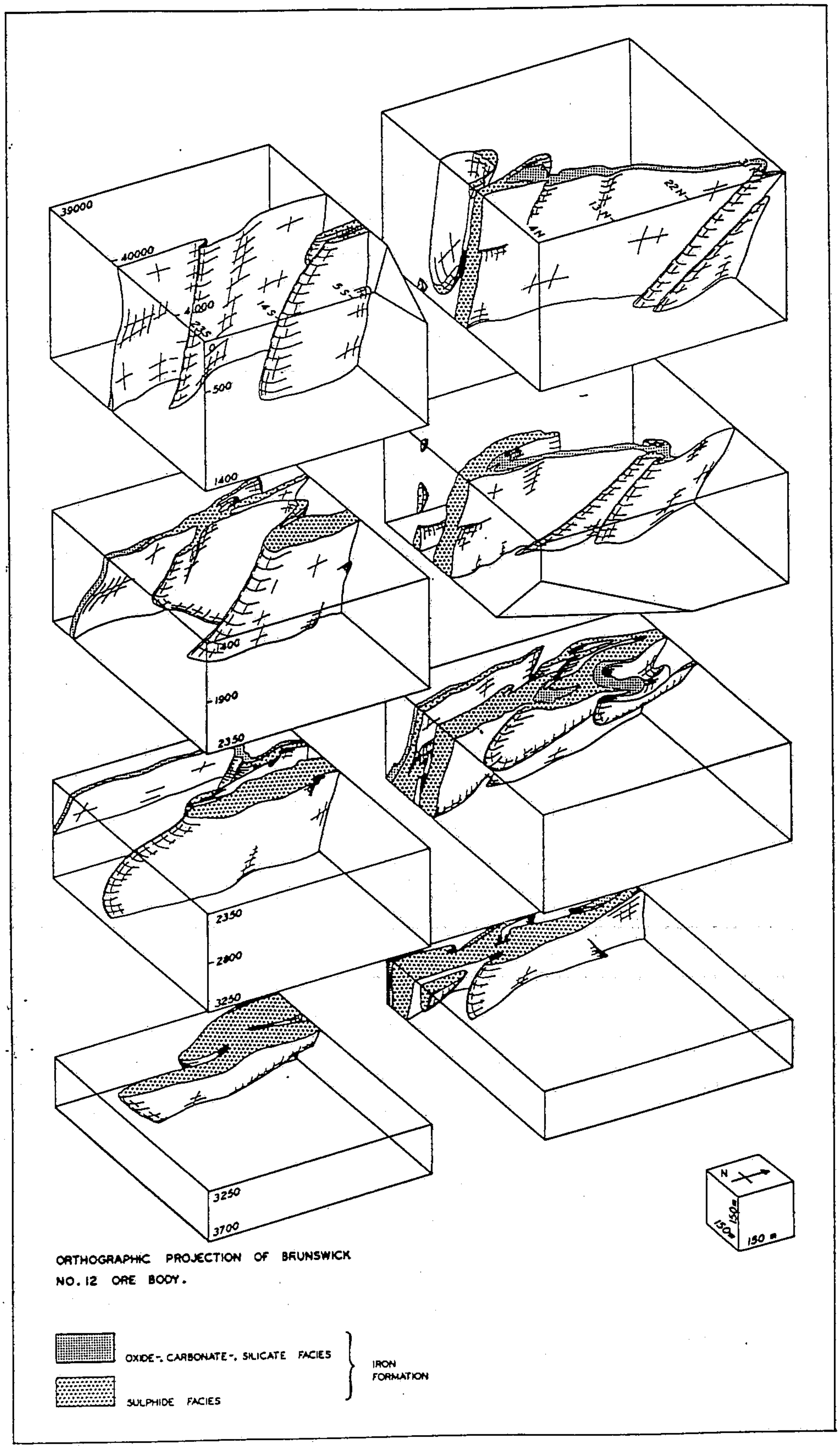

Figure 8. Block diagram of the Brunswick No. 12 orebody (after van Staal and Williams 1984).

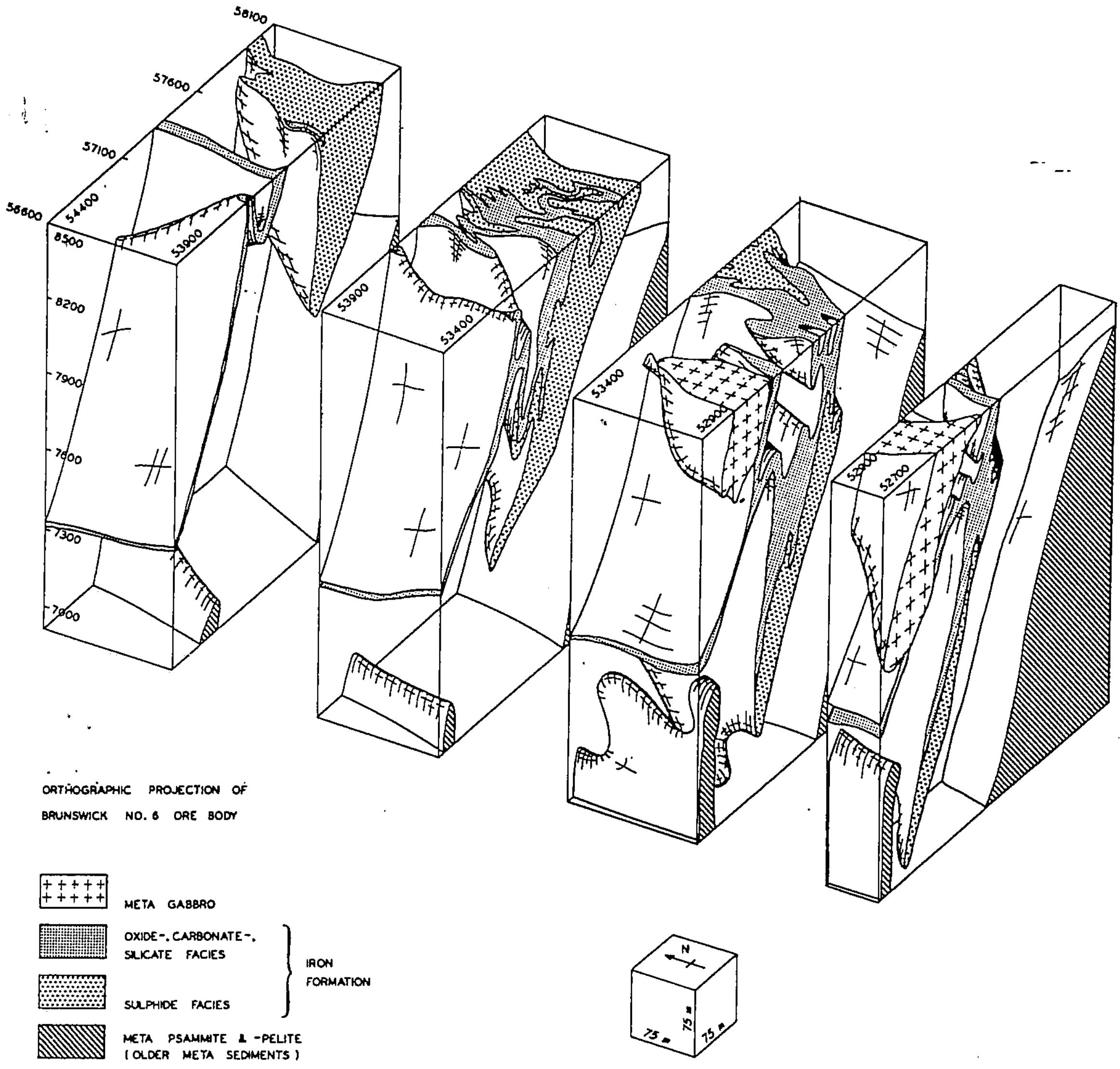

Figure 9. Block diagram of the Brunswick No. 6 orebody (after van Staal and Williams 1984). The grid lines tie the block diagram to Figure BM2 in the road log.

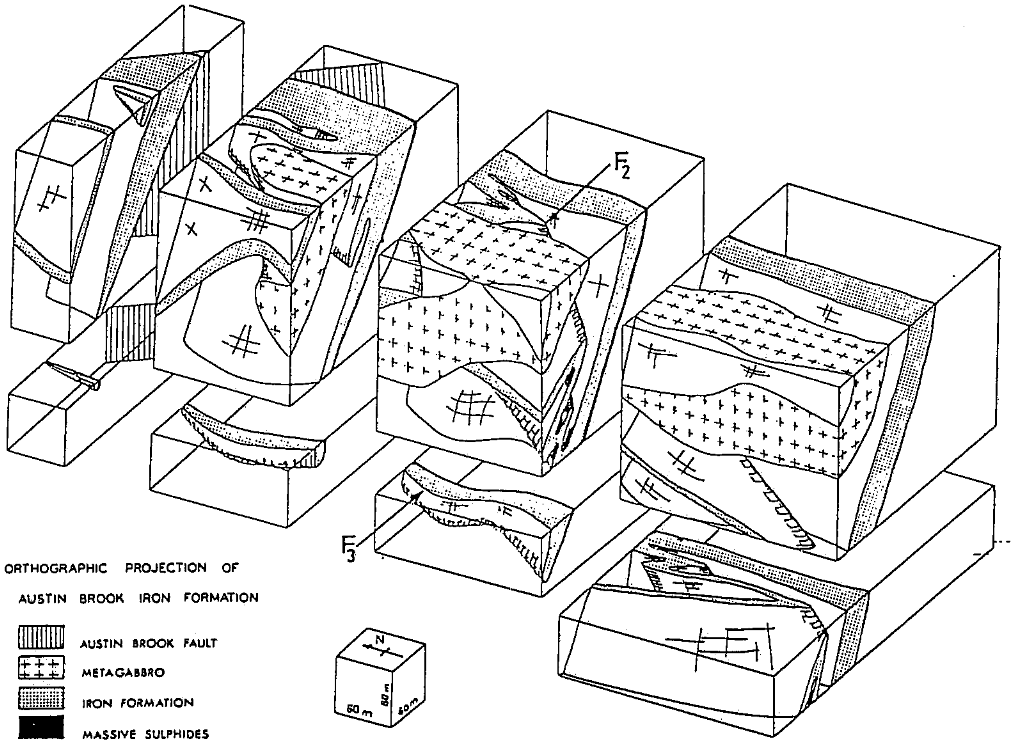

Figure 10. Block diagram of the Austin Brook iron deposit (after van Staal 1987). The grid lines tie the block diagram to Figure BM4 in the road log.

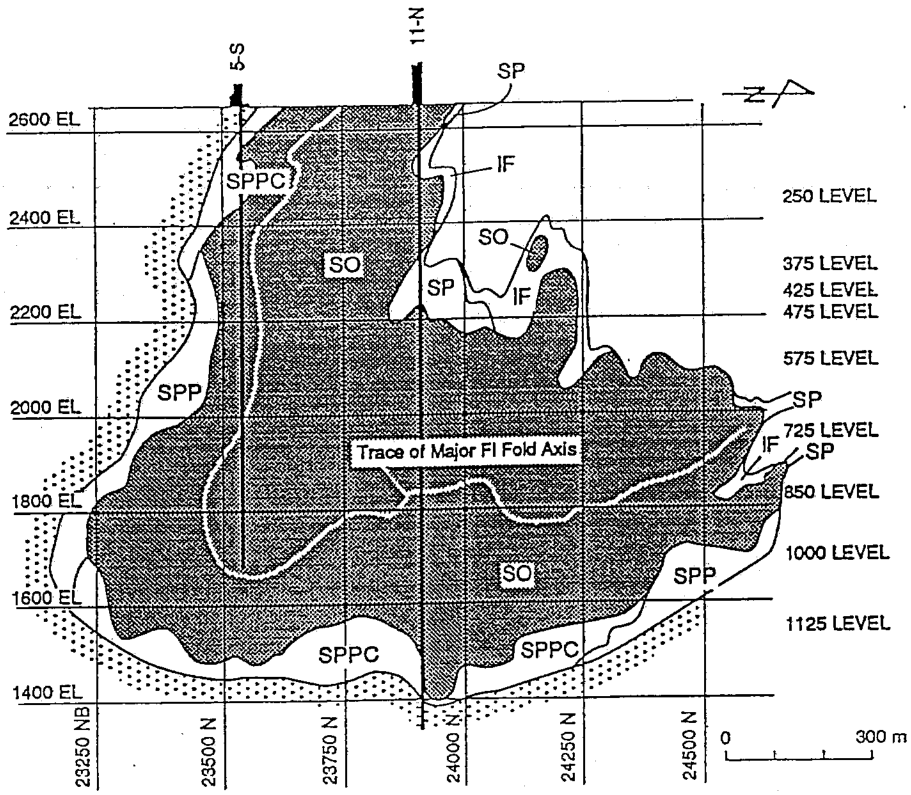

Figure 11. Longitudinal section, Main Zone, Brunswick No. 12 ore body parallel to an F_2 axial plane (after Luff *et al.* 1992). Abbreviations are in Figure 5.

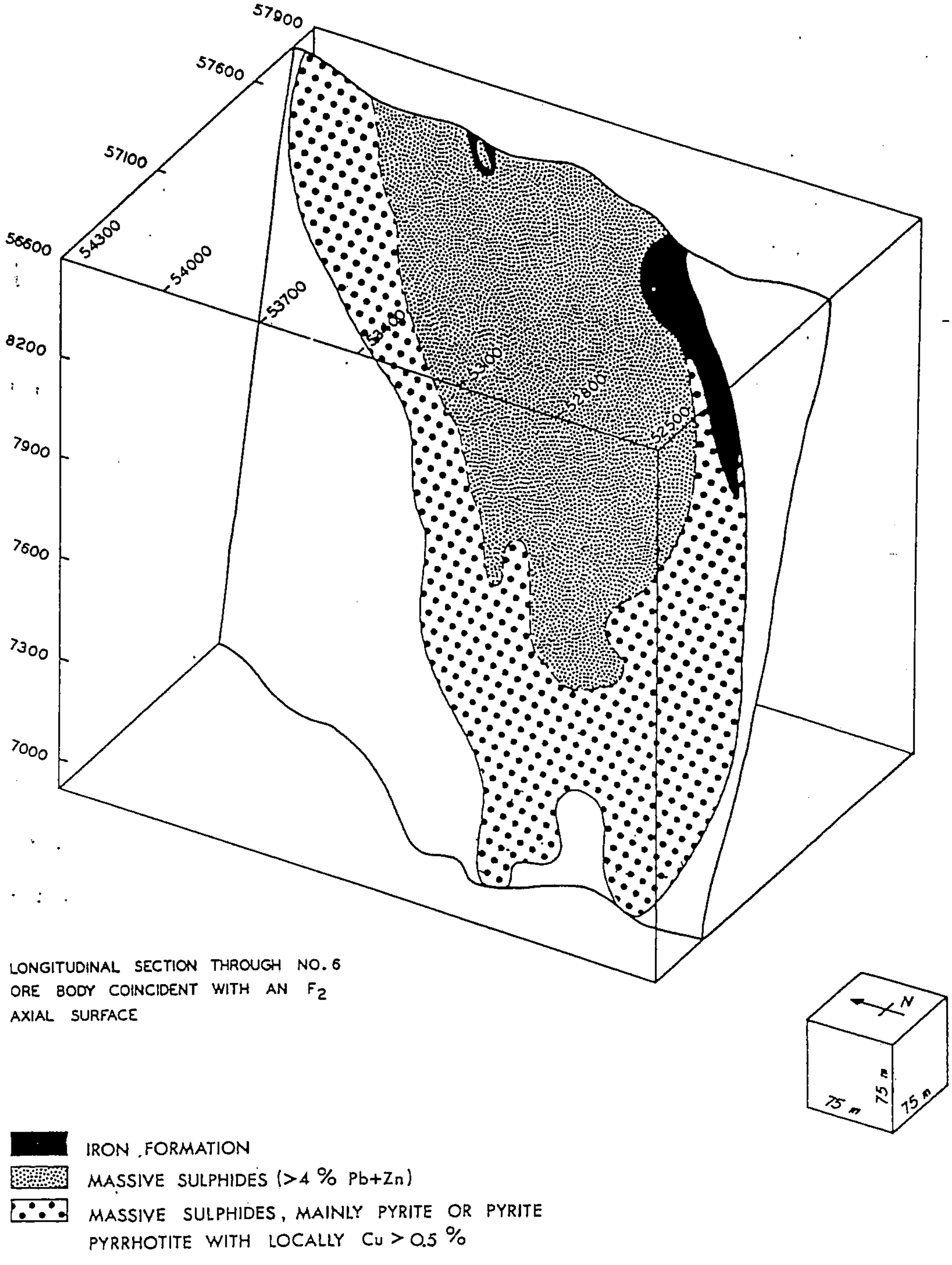

Figure 12. Longitudinal section of the Brunswick No. 6 orebody parallel to an F_2 axial plane (after van Staal and Williams 1984).

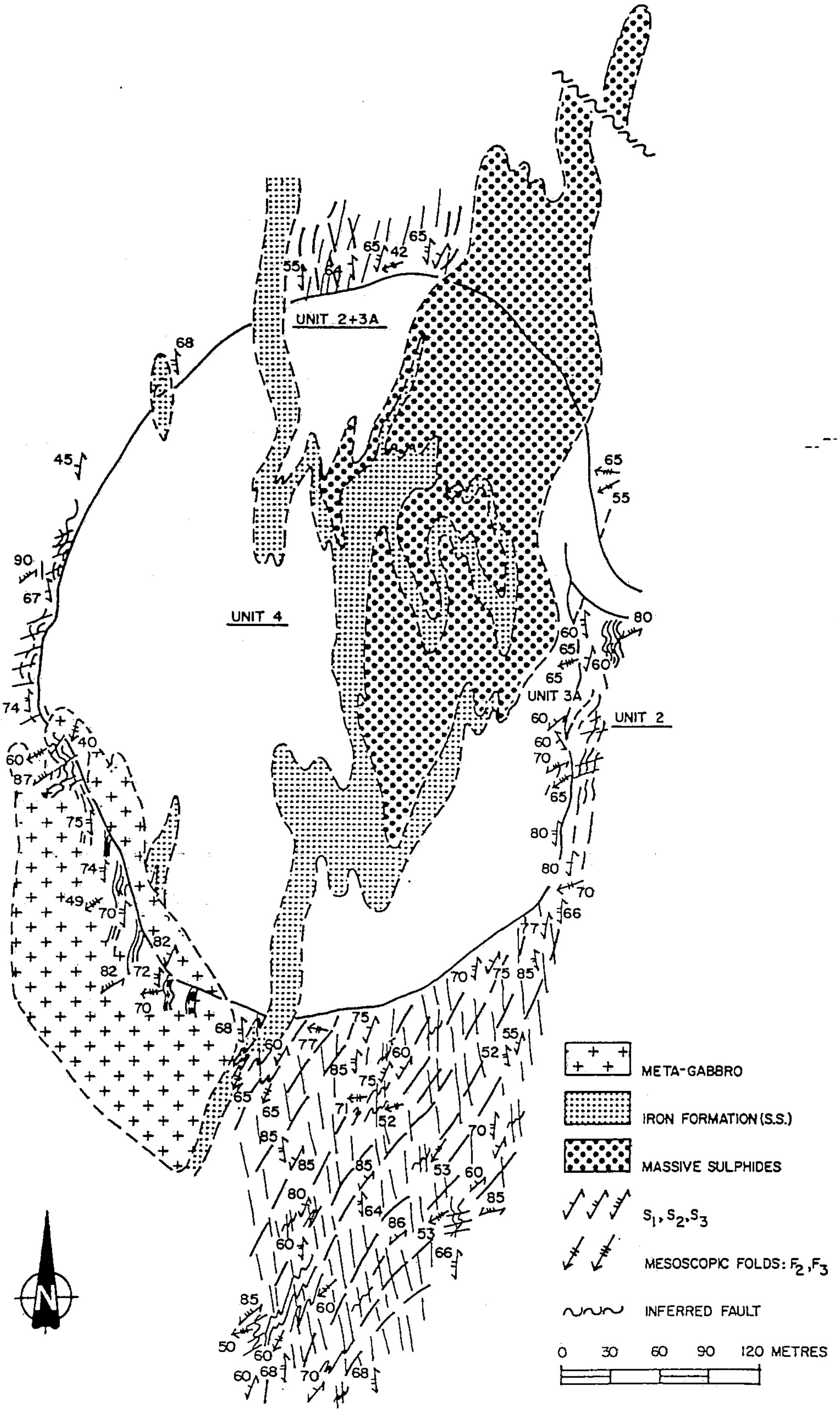

Figure 13. Surface geology with form-surface map of the Brunswick No. 6 orebody before open pit mining (after Boyle and Davies 1964 and van Staal and Williams 1984).

BRUNSWICK MINING AND SMELTING PRODUCTION

YEAR	No.12 Mine Tonnes	%Pb	%Zn	%Cu	g/tAg	No. 6 Mine Tonnes	%Pb	%Zn	%Cu	g/tAg	No. 6 & No. 12 Mines Tonnes	%Pb	%Zn	%Cu	g/tAg
1964	877,000	4.06	9.46	0.30	89.00						877,000	4.06	9.46	0.30	89.00
1965	1,504,000	3.96	9.51	0.30	95.00						1,504,000	3.96	9.51	0.30	95.00
1966	1,497,000	3.64	9.26	0.22	76.00	273,000	2.75	6.19	0.35	59.00	1,770,000	3.50	8.79	0.24	73.00
1967	1,514,000	3.47	9.07	0.29	82.00	786,000	2.93	5.96	0.40	61.00	2,300,000	3.29	8.01	0.33	75.00
1968	1,564,000	3.38	8.56	0.27	66.00	892,000	2.47	5.66	0.35	52.00	2,456,000	3.05	7.51	0.30	61.00
1969	1,538,000	3.04	8.05	0.33	73.00	974,000	2.28	5.78	0.35	64.00	2,512,000	2.75	7.17	0.34	70.00
1970	1,343,000	2.93	7.54	0.32	75.00	999,000	2.12	5.86	0.33	63.00	2,342,000	2.58	6.82	0.32	70.00
1971	1,421,000	3.25	8.11	0.30	84.00	768,000	2.11	5.76	0.36	64.00	2,189,000	2.85	7.29	0.32	77.00
1972	1,365,000	3.62	9.10	0.28	96.00	1,593,000	2.05	5.48	0.37	72.00	2,958,000	2.77	7.15	0.33	83.00
1973	1,701,000	3.43	8.58	0.34	96.00	1,317,000	2.02	4.98	0.35	75.00	3,018,000	2.81	7.01	0.34	87.00
1974	1,429,000	3.58	8.00	0.35	89.00	953,000	2.03	4.65	0.41	65.00	2,382,000	2.96	6.66	0.37	79.00
1975	1,982,000	3.54	8.48	0.36	91.00	1,126,000	1.93	4.94	0.50	68.00	3,108,000	2.96	7.20	0.41	83.00
1976	1,473,000	3.53	8.63	0.32	96.00	774,000	1.60	4.41	0.50	68.00	2,247,000	2.87	7.18	0.38	86.00
1977	2,456,000	3.51	8.70	0.31	91.00	678,000	1.70	4.65	0.58	61.00	3,134,000	3.12	7.82	0.37	85.00
1978	2,685,000	3.77	9.31	0.28	97.00	373,000	2.07	5.85	0.39	72.00	3,058,000	3.56	8.89	0.29	94.00
1979	2,722,000	3.71	9.13	0.30	97.00	249,000	2.60	6.78	0.41	78.00	2,971,000	3.62	8.93	0.31	95.00
1980	1,746,000	3.61	8.90	0.31	99.00	102,000	2.75	7.18	0.31	75.00	1,848,000	3.56	8.81	0.31	98.00
1981	3,401,000	3.51	8.75	0.35	98.00	22,000	2.69	7.38	0.14	84.00	3,423,000	3.50	8.74	0.35	98.00
1982	3,535,000	3.64	9.04	0.31	102.00	99,000	3.15	8.62	0.15	94.00	3,634,000	3.63	9.03	0.31	102.00
1983	3,264,000	3.56	9.00	0.30	99.00	147,000	2.57	6.90	0.52	86.00	3,411,000	3.52	8.91	0.31	98.00
1984	3,560,000	3.57	8.91	0.32	100.00						3,560,000	3.57	8.91	0.32	100.00
1985	3,312,000	3.52	8.77	0.32	101.00						3,312,000	3.52	8.77	0.32	101.00
1986	3,409,000	3.54	8.68	0.34	101.00						3,409,000	3.54	8.68	0.34	101.00
1987	3,447,000	3.56	8.94	0.37	104.00						3,447,000	3.56	8.94	0.37	104.00
1988	3,494,000	3.58	8.85	0.36	105.00						3,494,000	3.58	8.85	0.36	105.00
1989	2,983,000	3.56	8.93	0.39	110.00						2,983,000	3.56	8.93	0.39	110.00
1990	2,255,000	3.39	8.90	0.36	101.00						2,255,000	3.39	8.90	0.36	101.00
1991	2,531,000	3.26	8.41	0.42	102.00						2,531,000	3.26	8.41	0.42	102.00
1992	3,874,000	3.30	8.68	0.38	109.00						3,874,000	3.30	8.68	0.38	109.00
Total	67,882,000	3.52	8.80	0.33	97.00	12,125,000	2.16	5.43	0.39	67.00	80,007,000	3.31	8.28	0.34	92.00

W.Luff

Table 1. Brunswick Mining and Smelting Pb-Zn-Cu-Ag production for No. 6 and 12 Mines, 1964-1992.

pyrite-sphalerite-galena with minor chalcopyrite and pyrrhotite (SO), the latter two minerals becoming more abundant below the 850 level and 3) massive pyrite comprising very fine-grained pyrite, with minor sphalerite, galena and chalcopyrite (SP). Minor arsenopyrite and tetrahedrite are disseminated throughout the massive sulphides. Although all the sulphides are annealed to some degree, fine-scale layering of the sulphides, accentuated by different mineral proportions, is apparent. There is some layering preserved in boudinaged, massive, pyrite-rich zones (SP), which may be primary. This is because the pyrite probably behaved more competently than the other sulphides, although this remains to be tested. However, the layering within the main ore zones is probably modified by deformation (van Staal and Williams 1984).

The mineralogy and textural features of the ore have been described in considerable detail (Lea and Rancourt 1958; Aletan 1960; Roy 1961; Sutherland 1967; Boorman 1968; Fuller 1968; Sutherland and Halls 1969; Boorman 1975; Owens 1980; Laflamme and Cabri 1986a; Laflamme and Cabri 1986b; Luff 1986). Accessory minerals include boulangerite, bournonite, enargite, cassiterite, stannite, marcasite, tennantite, freibergite, rare native bismuth and bismuthinite, and native gold (Lea and Rancourt 1958; Stanton 1959; Aletan 1960; Boorman 1975; Petruk and Schnarr, 1981). In addition to the primary ore assemblage, secondary ore minerals (supergene) include covellite, chalcocite, bornite, native copper and native Ag.

Petruk and Schnarr (1981) have detailed the major and trace consituents of the ore and mill products for metallurgical purposes. They reported a feed grade of 0.18 % Cu, 4.49% Pb, 9.03 % Zn, 28.71 % Fe, 0.19 % As, 105 ppm Ag, 500 ppm Sb, 70 ppm In, 60 ppm Bi, 980 ppm Sn, and 9 ppm Hg. Luff (1986) reported an average of 0.5 g/t Au with higher grades associated with the cherty Pb-Zn ore and cherty pyritiferous iron formation. Lentz *et al.* (1993) report an average between 0.55 and 0.7 g/t Au for the ore with some ore zones as high as 2.25 g/t Au.

HYDROTHERMAL ALTERATION

At the Brunswick No. 12 and No. 6 deposits, the hanging-wall rocks have considerably less alteration and sulphide veining than the footwall rocks (Pearce 1963; Goodfellow 1975a, b; Juras 1981; Nelson 1983; Luff *et al.* 1992; Lentz and Goodfellow 1992a). Most of the stringer sulphide mineralization and related Fe-rich chloritic and siliceous alteration in the footwall rocks are probably related to a zone of hydrothermal discharge, which formed beneath the massive-sulphide deposit. The spatial association of the stringer-sulphide zone with the Cu-rich part of the orebody is an additional piece of evidence for the existence of a feeder pipe (Luff *et al.* 1992). However, the original cross-cutting geometry of the stringer zone has largely been obliterated because everything has been structurally transposed into near-parallelism with the composite $S_{(1-2)}$ fabric, at least at the mine-scale.

Lentz and Goodfellow (1993c) subdivided the alteration at Brunswick No. 12 into four zones based on their petrographic features and attempted to characterize them geochemically. The most distal alteration facies (zone 4) is manifested by the replacement of K-feldspar phenoclasts by chessboard albite, phengite, Mg chlorite, and quartz. These rocks are slightly enriched in Na, Fe, Mn, S, CO_2, base metals, and possibly Mg, and depleted in K, Ca, Ba, and Sr. Zone 3 alteration (proximal-distal) is characterized by the replacement of albite by Fe-Mg chlorite, phengite, and quartz. This zone is enriched in Fe, Mn, S, CO_2, and base metals at the expense of Na, Ca, K, Ba, Rb, Sr, and La. In Zone 2 (vent area), the Fe/(Fe+Mg) ratio and the amount of chlorite and sulphide veins/disseminations increases. Zone 1 (vent-proximal) is manifested by pervasive, Fe-rich chloritic and heterogeneous silicic alteration that is intimately associated with the sulphide-stringer zone. The least-altered rocks (zone 4) have typical seafloor-keratophyric alteration. Therefore, the other alteration zones that are superimposed reflect the interaction of buoyant, high-temperature, weakly acidic, Fe-rich fluids with the keratophyrically altered footwall units.

The sulphide-vein networks are well preserved in the silicified parts of Zone 1, which behaved more competently than other footwall rocks during deformation. In the Discovery Hole (A1), which intersects the zone of most intense stringer mineralization, Lentz and Goodfellow (1993b) found that there is some evidence for syngenetic/diagenetic sulphide textures. In particular, there are primary intergrowths of pyrite-arsenopyrite, although the rims of the arsenopyrite seem to have re-equilibrated with the rest of the sulphide assemblage during metamorphism. A detailed analysis of the trace-element distribution in hole A1 shows that all the ore-forming elements are depleted with respect to the average bulk ore composition (Lentz and Goodfellow 1993c). Co, Cu, and As were found to be enriched in the core of the stringer system near the base of the massive-sulphide deposit.

The quartz-augen schist (QAS) that occurs in the footwall is the product of feldspar-destructive hydrothermal alteration, mainly of the fine- to coarse-grained granular volcaniclastic rocks (CT and QFAS). It forms a much broader alteration halo than the stringer sulphide zone (Lentz and Goodfellow 1992a,c) and consequently may be used as an exploration tool to help find Brunswick-type massive sulphide deposits that are stratigraphically higher in the pile. How far below and/or laterally away from a deposit the QAS extends, is dependent on the original permeability of the footwall rocks. Furthermore, if there are impermeable beds or units in the footwall stratigraphy, one should expect to find semi-conformable alteration zones.

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ROAD LOG FOR EXCURSION IN THE BRUNSWICK MINES AREA.

Depart from Keddy's Motel and proceed south on King Ave; at the overpass above Highway (Hwy) 11, this street becomes Route 430. This is the starting point of the road log.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Drive south on Route 430.
4.7	4.7	Junction with road to Pabineau Falls; bear right on Route 430.
11.6	16.3	Junction with Route 360 to Allardville; continue straight on Route 430.
6,8	23.1	Junction with road to Brunswick No.12 Mine; bear left on Route 430.
4.2	27.3	Brunswick No. 12 Mine parking lot. Clear security and proceed to the mine dry to get underground gear. Assemble at Shaft No.3 for the underground tour, all stops will be on the 850 m level and are labelled A through M (Fig.BM1).

STOP 12-A: Quartz-feldspar-augen schist (QFAS) occurs from the cage for 250 m along the main drive. These are the least-altered footwall rocks in the mine area. This coarsely porphyritic, crystal-rich rock probably originated as a subaqueous tufflava, i.e. a non-explosive pyroclastic-type flow.

STOP 12-B: Contact zone between quartz-augen schist (QAS) and QFAS; the QAS is interpreted as an alteration product of the QFAS, with the feldspars altering to micas and quartz.

STOP 12-C: Weak to moderately altered footwall sedimentary rocks (FW) with the S_1 S_2 composite foliation that is orthogonally cut by a weak S_5 cleavage.

STOP 12-D: Contact between moderately altered FW sedimentary rocks and massive pyrite with minor Pb-Zn layered ore (tectonic or primary layering?).

STOP 12-E: Siliceous-sulphide stringer veins hosted in a silicified and chloritized FW sedimentary rock. Very fine-grained siliceous losenges are tectonically dismembered. The S_1 foliation and the stringer veins are folded by F_2 folds.

STOP 12-F: Contact between footwall sedimentary rocks and massive pyrite, tectonically thinned, grading up into thin-layered pyrite-magnetite-chlorite iron formation.

STOP 12-G: Contact between porphyry dike and iron formation. This dyke also cuts the siliceous and sericitic hanging-wall sedimentary rocks.

STOP 12-H: Contact between porphyry dike and iron formation with F_2 folds evident in the iron formation.

STOP 12-I: Folding in iron formation with fold plunge (F_2).

STOP 12-J: Semi-massive pyrite zone hosted in iron formation.

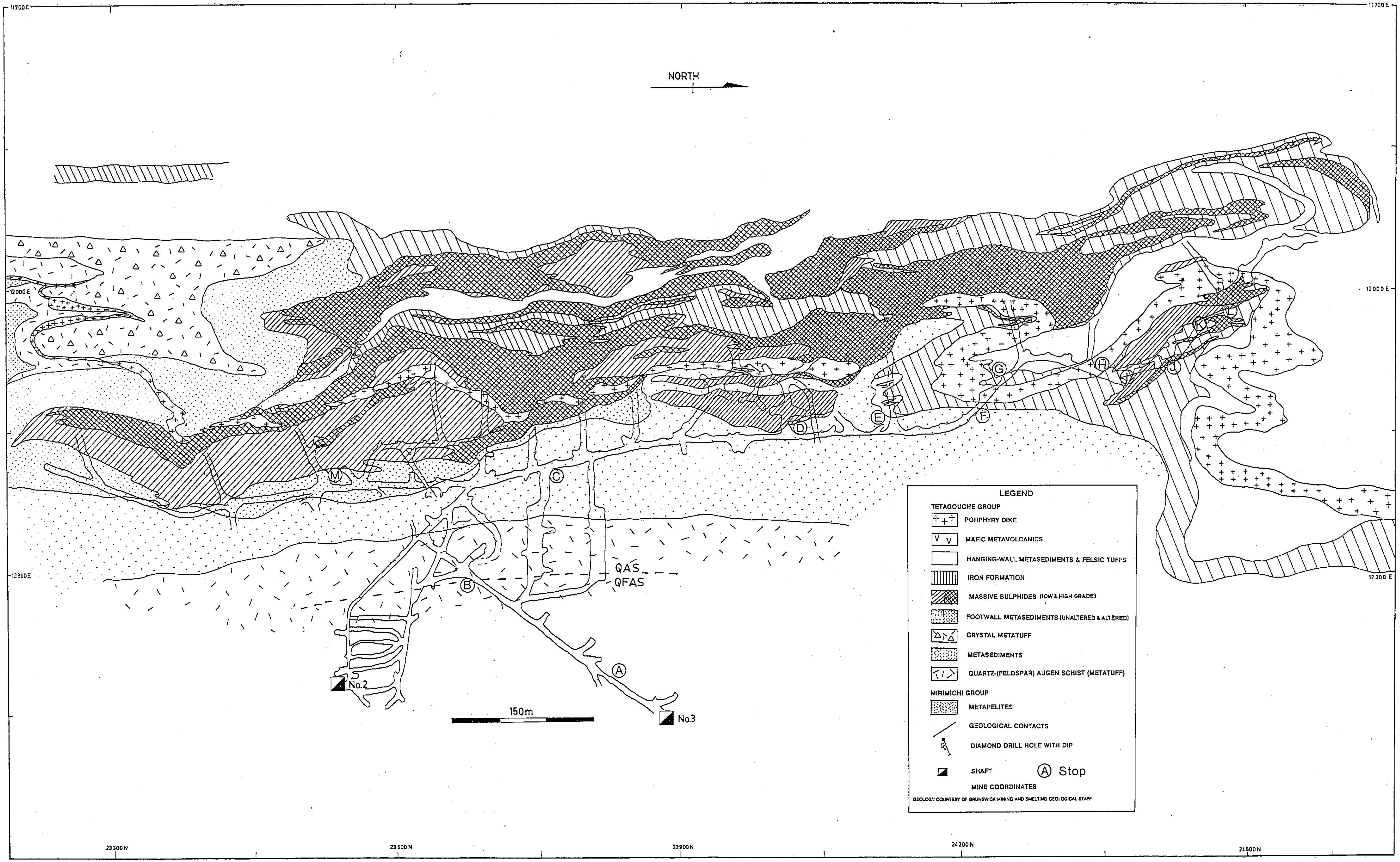

Figure BM1. Simplified geological map of the 850 level, Brunswick No. 12 Mine showing stop locations. This is an enlarged version of the same map shown in Figure 6.

STOP 12-K: Fine- to coarse-grained barite associated with pyritiferous chloritic iron formation. This is one of the few barite occurrences in the mine.

STOP 12-L: High-grade Pb-Zn ore lens near the core of a large-scale F_2 fold. The ore lenses in this area are hosted in thick chloritic iron formation and altered footwall sedimentary rocks (?)

Walk back along the drift, about 230 m past Stop C, to the last stop.

STOP 12-M: Moderately altered FW sedimentary rock with irregularly developed stringer sulphide veins in contact with the Cu-rich pyrrhotite-pyrite mineralization. Siliceous and chloritic alteration are evident in the footwall with veins hosted in both alteration types.

Return to surface and get changed for lunch.

Distance (in km)	**Cumulative Distance**	**Description**
0.0	0.0	Afternoon: board vans and re-set road log. Drive back the Brunswick No. 12 road
4.2	4.2	Junction with Route 430; turn right (west).
0.6	4.8	Junction with road to Bathurst Mines (Nepisiguit Falls); continue straight.
1.2	6.0	Junction with dirt road to Brunswick No.6 Mine; continue straight.
1.6	7.6	Brunswick No.6 open pit; drive around the east side to the buildings and park (Fig.BM2). Follow the trench from the liming tower to the ramp into the pit.

STOP 6-1: Pyritiferous, chlorite-sericite-rich footwall sedimentary rocks are exposed in the trench and near the top of the haulage ramp. A strongly developed S_1S_2 composite fabric is evident. Fabric-parallel, stringer-sulphide veins increase in abundance towards the massive sulphide zone on ramp.

Return to the top of the ramp and walk south along the pit perimeter [KEEP BACK FROM THE EDGE] approximately 150 m.

STOP 6-2: Light- to medium-green, sericitic ($\pm$ chlorite) quartz-augen schist that was originally quartz-feldspar-rich tuffite (volcaniclastic rock). There is vitreous volcanic quartz and milky quartz $\pm$ mica that represents replaced feldspar porphyroclasts. STOPS 3 and 4 illustrate the effects of alteration on the feldspars and partial replacement by secondary quartz.

Walk southeast about 200 m to the rusty outcrop that stands out in the grassy area, the former site of a tailings pile.

STOP 6-3: In this outcrop, quartz-feldspar-augen schist (QFAS), originally tufflava or subvolcanic porphyry, can be seen with feldspar in intermediate stages of alteration to mica. The S_1S_2 fabric is moderately well developed in the rock.

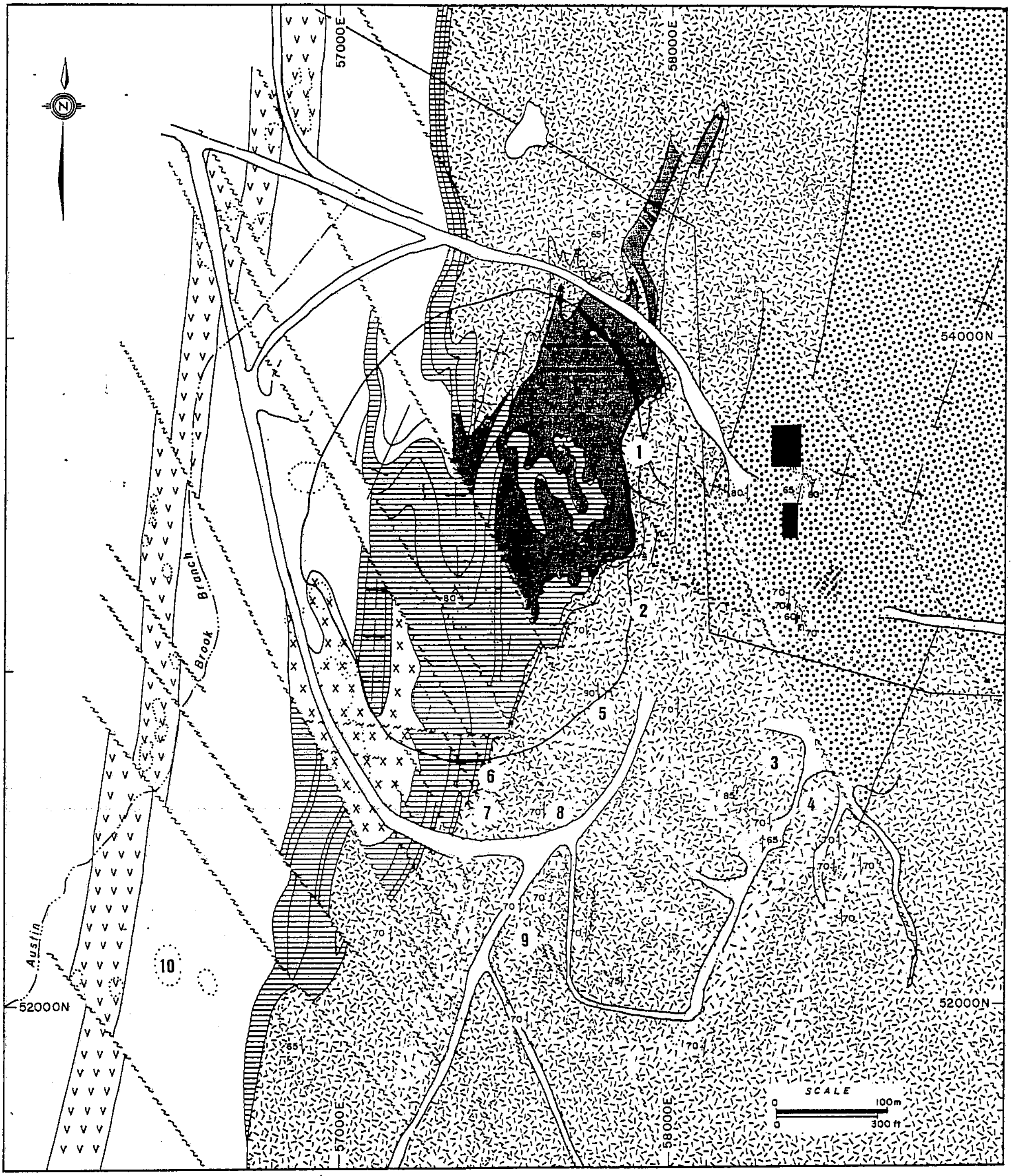

Figure BM2. Detailed geology of the Brunswick No.6 massive sulphide deposit (after Boyle and Davies 1964) with present pit perimeter shown. The locations of the roads are approximate having been drawn from an air photograph. Patterns as follows: open dots = Miramichi Group rocks, stiple = Nepisiguit Falls volcanic and volcaniclastic rocks, dark grey = massive sulphides, horizontal hatching = iron formation, blank = Flat Landing Brook rhyoltes, V-pattern = Boucher Brook basalts, X-pattern = gabbro, black = buildings.

Continue walking southeast to the low-relief glaciated outcrops.

STOP 6-4: All the outcrops in this area consist of massive quartz-feldspar-phyric (crystals up to 1.5 cm) tufflava with a cryptocrystalline (originally glassy) matrix. The beta-quartz phenocrysts exhibit well preserved growth textures, something that is characteristic of lava flows rather than pyroclastic eruptions. Feldspars have microperthitic lamella and locally are tectonically broken. However, most of the strain is taken up in the matrix, which has two strong fabrics.

Return to the pit perimeter, approximately 100 m south of STOP 2.

STOP 6-5: Sericitic and moderately chloritic, coarse-grained quartz-augen schist (QAS). Other outcrops between this one and the next stop consist of medium- to coarse-grained QAS, locally with fine-grained interbeds. All QAS in this area is interpreted as an alteration product of original quartz-feldspar-rich volcaniclastic rocks (tuffites).

Continue southwestward along the pit perimeter for another 100 m.

STOP 6-6: Thin-layered, magnetite-rich iron formation with chlorite, chert and siderite in contact with fine-grained volcaniclastic rocks. From this point, looking northeast toward STOP 1, various rock units are visible in the pit wall including grey massive sulphides, yellowish green footwall-sedimentary rocks and blocky-jointed quartz-augen schist.

Proceed to the next outcrop 20 m to the south.

STOP 6-7: Granular fine-grained crystal-rich tuffite underlying the iron formation. The S_1S_2 fabric is moderately developed.

Walk around the screen of trees via the roadway to the next outcrop about 70 m to the east.

STOP 6-8: Very fine-grained sericitic layers in this outcrop probably represent hyalotuff that was winnowed from the crystal-rich, volcaniclastic debris flows (tuffites). The spaced (solution) cleavage in this outcrop is S_1, not S_2 as it appears; the relative ages of the cleavages can be clearly demonstrated at the next stop.

Walk along the southwesterly-trending roadway approximately 100 m; then step off the roadway to the left (southeast) through the screen of bushes to the low-relief outcrops behind.

STOP 6-9: The outcrop knob closest to the road contains the F_2 fold that is shown in Figure BM3. Dissolution has occurred along both the S_1 and S_2 cleavage planes resulting in the development of losenge-shaped microlithons between the intersecting cleavages in the sericitic hyalotuff (or mudstone ?). The original rock composition prior to deformation is represented by the microlithons. About 10 m farther east, there is a pseudo-fragmental outcrop containing large (over 1 cm) tectonic microlithons exhibiting compositional zonation. The microlithons are very siliceous indicating that the rock was originally silicified as well as highly sericitic. The relationship between the differentiated S_1 foliation and the

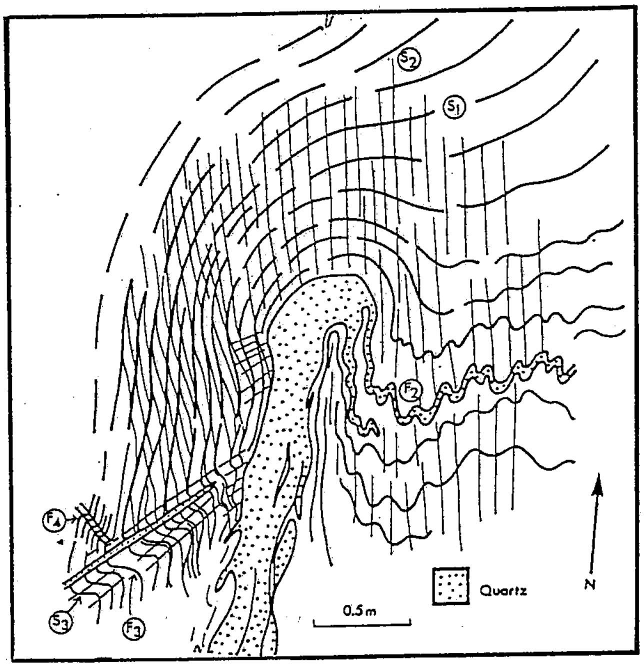

Figure BM3. Sketch of structural overprinting relationships in phyllitic sedimentary rocks exposed to the southeast of the open pit (from van Staal and Williams 1984).

refracted S_2 cleavage is obvious in this area. A few meters farther east there is a change in slope, which marks the contact between the altered hyalotuff and the coarse-grained QAS.

Return to the roadway and walk west about 250 m into the cleared area, the reclaimed site of a waste-rock pile. In this area there are scattered outcrops among the small bushes.

STOP 6-10:

The rocks in this area consist of massive to fragmental, aphyric to feldspar-phyric rhyolites of the Flat Landing Brook Formation. They constitute the hanging-wall rocks to the Brunswick No. 6 deposit.

Return to the vehicles and drive back to the junction with the road to Bathurst Mines (Nepisiguit Falls). Reset the road log.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Turn right (east) on road to Bathurst Mines.

Distance (in km)	Cumulative Distance	Description
3.5	3.5	Stop Sign overlooking the Nepisiguit Falls dam and power generating station, which was constructed in 1921. Turn right (southwest).
1.0	4.5	The Nepisiguit Sport Lodge is on the right above the road; just past the lodge is a large roadcut through Flat Landing Brook rhyolitic rocks.
2.6	7.1	At this point Austin Brook crosses the road; part of the bridge is missing so be carefull driving across.
0.1	7.2	The trail to the old Austin Brook Mine is on the left. Park and walk up the trail about 100 m to the forks; bear right and proceed another 50 m to the entrance into the quarry.

STOP A-1:

The quarry contains a thick body of oxide iron-formation that is folded into an isoclinal, moderately to shallowly south-plunging, S-shaped F_2 fold (Fig.BM4). At the entrance to the quarry, very fine-grained, pyritic and sericitic, sedimentary rocks of the Nepisiguit Falls Formation constitute the footwall to this deposit. The amounts of chlorite (?) and disseminated sulphides increase towards the iron formation. This type of alteration also underlies the massive sulphides at the next stop.

Turn left (south) and follow the open cut to the end where the path on the left leads to the top of the outcrop ridge. Proceed over the top to the sulphide outcrop on the back side of this ridge.

STOP A-2:

The coarse-grained, pyrite-rich, massive-sulphide layer with minor sphalerite is located above altered, footwall sedimentary rocks and beneath iron formation. The sericitic-chloritic phyllites in the footwall contain anomalous amounts of apatite and Fe-rich chlorite.

Continue along the outcrop ridge to the south past the area of broken rock.

STOP A-3:

Complexly folded, thinly layered, hematite-magnetite iron formation is exposed in the glacially polished outcrop. Besides magnetite, this iron formation also contains chlorite, chert, siderite, specularite and jaspar. The fold sketches shown in Figure BM5 are based upon observations made here. These complex folds are interpreted to be post-lithification structures based on the following arguments: 1) the folds are coplanar to F_1 and F_2 folds developed in the surrounding volcanic rocks and also have the same style and plunge directions; 2) quartz in jasper layers and intrafolial folded quartz veins shows evidence of intracrystalline deformation and grain boundary adjustment and has a c-axis fabric related to the folding; 3) hematite is strongly foliated, kinked or bent in the hinges of the F_1 and F_2 folds, indicating intracrystalline deformation. Why tectonic folds are so well developed in the iron formation, compared to the surrounding rocks, is not clear. However, this phenomon may be related to the well developed compositional layering that is defined by alternating competent (jasper and magnetite) and incompetent (hematite) lamina.

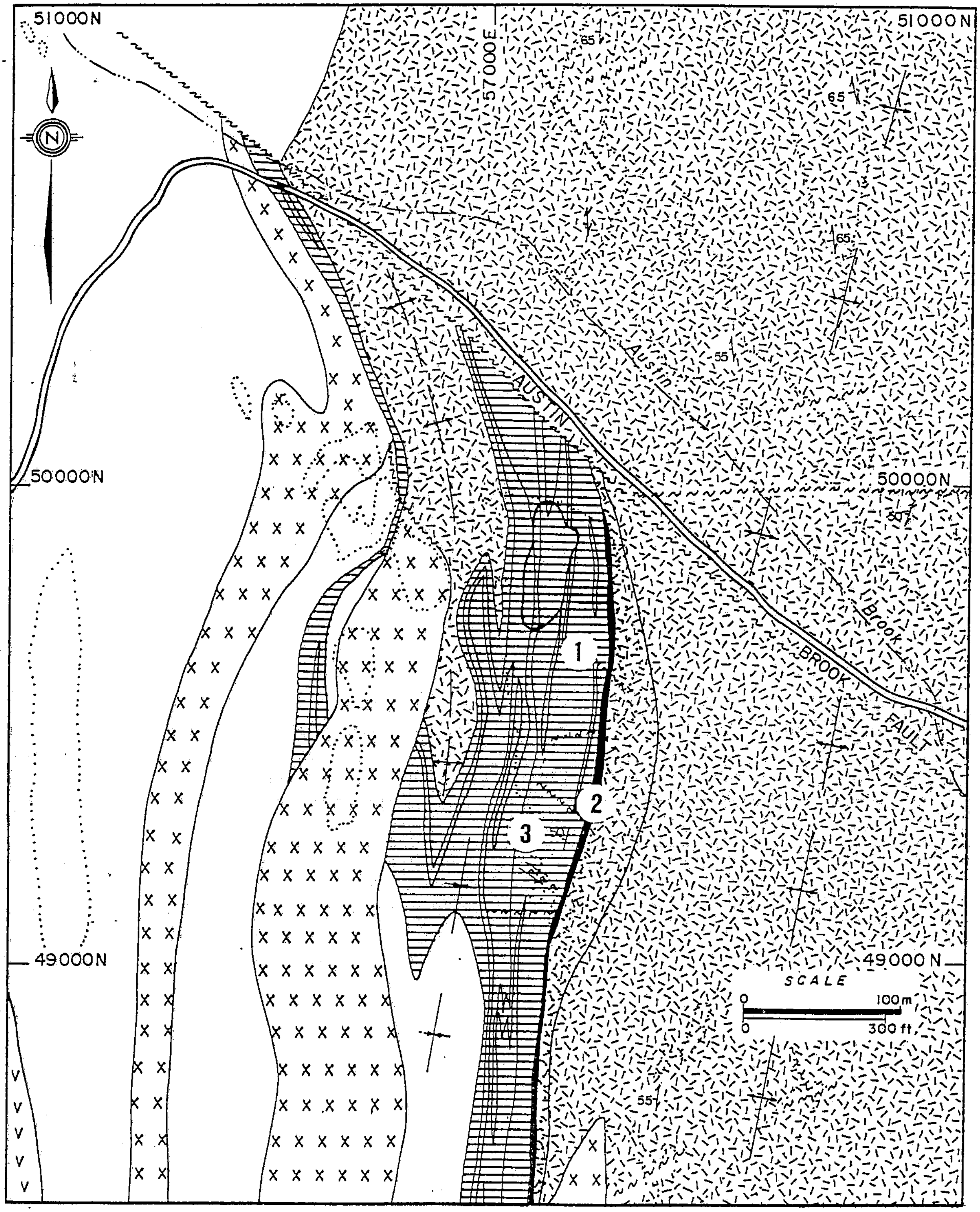

Figure BM4. Detailed geology of the Austin Brook Iron deposit (after Boyle and Davies 1964) with present pit outline. Map patterns as in Figure BM2.

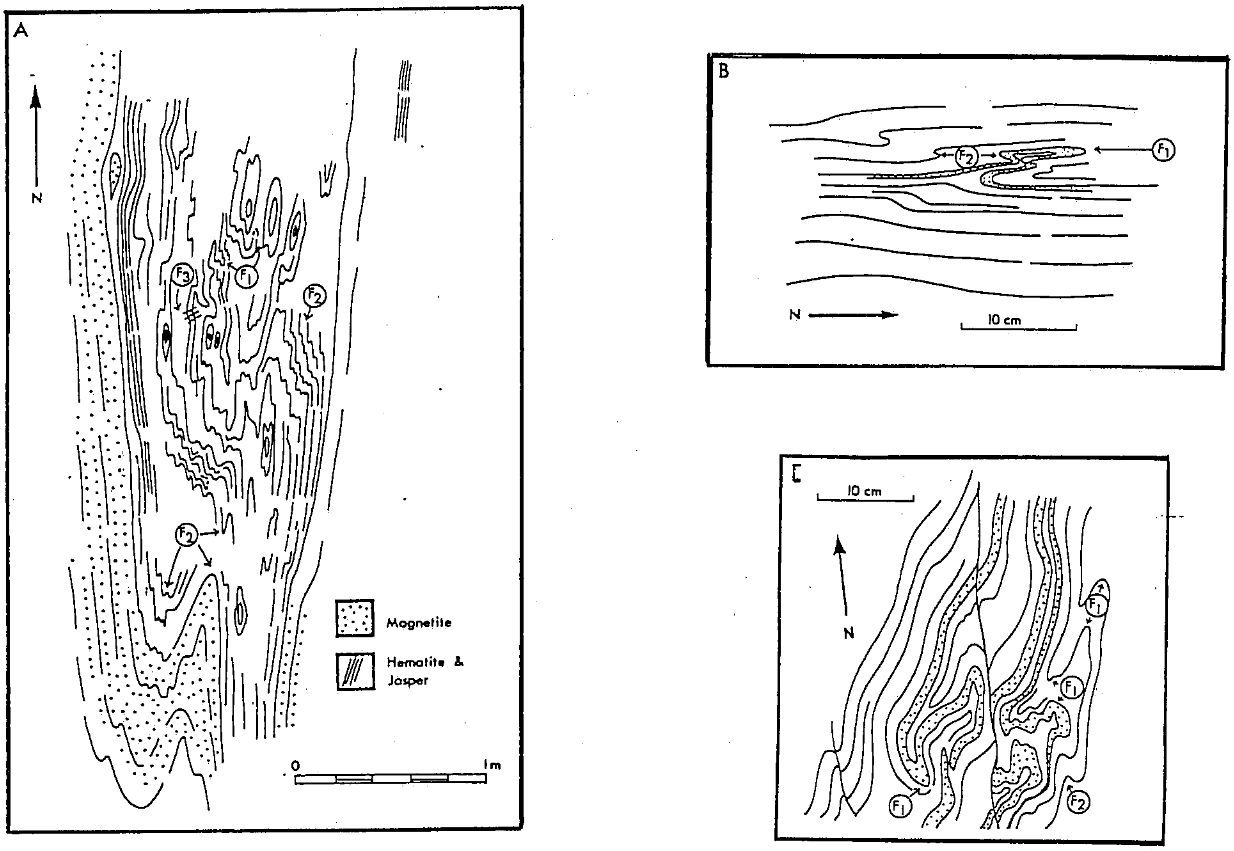

Figure BM5. A) Sketch of structural overprinting relationships in thinly layered iron formation at Austin Brook. B) Detail of an F_1/F_2 closure from the same outcrop. C) Detail of an F_1/F_2 interference pattern cut by a D_2 shear. All sketches are taken from van Staal and Williams (1984).

THE KEY ANACON MASSIVE-SULFIDE DEPOSIT

D.R. Lentz[1] and J.P. Langton[2]

INTRODUCTION

The Key Anacon deposit is 20 km south of Bathurst, New Brunswick (see Fig.2 of McCutcheon *et al.*, this volume; Fig.1) on the east side of the Nepisiguit River about 500 m north of Gordon Meadow Brook. This deposit is within the Tetagouche Group on the eastern side of the Chain of Rocks antiform and west of the Carboniferous cover rocks.

HISTORY

Although Cu mineralization was first recognized in 1930 at Middle Landing, just south of the Allardville Road (now Route 360), the area was not drilled until 1947, after having been staked by Mr. P. Leger. In 1952, New Larder "U" acquired the property to examine the aeromagnetic anomaly located southeast of the Cu showing. The deposit was discovered in 1953 during follow-up drilling of this electromagnetic anomaly. A total of 110 holes were drilled before the.company was acquired by Anacon Lead Mines Ltd. in 1954. Subsequently, a 457 metre shaft was sunk and 9 levels were developed prior to shut-down in 1957. In 1964, Anacon Lead Mines Ltd. joined with Keymet Mines Ltd. to form Key Anacon Mines Ltd. and briefly re-opened the mine. Underground exploration was conducted between 1970 and 1973; 7 additional holes were drilled from surface in 1981. Rio Algom Exploration Incorporated now has an option on this property and is actively exploring the depth and lateral extent of the mineralization. A Northern Miner press release (Nov.17/92) reported assays from two sulphide intersections, one from DDH 92-10, which cut 7.2 m of 4.49% Pb, 6.22% Zn, and 253.7 g/t Ag approximately 260 m beneath the old exploration workings, and the other from DDH 92-17, which intersected 14.3 m of 4.62% Pb, 12.18% Zn, and 123 g/t Ag about 450 m below surface on a new zone, east of the main deposit. A more recent Northern Miner press release (Aug.16/93) reported an 83 m intersection of massive sulphides, within which there is a 19.9 m interval grading 0.33% Cu, 3.58% Pb, 7.86% Zn, and 78.08 g/t Ag.

STRATIGRAPHY

As the stratigraphy in the Key Anacon area (Fig.2) is very similar to that in the Bathurst Camp, and particularly to the Brunswick mine stratigraphy, established formation names (cf. van Staal and Fyffe 1991) are used to describe the rocks.

The lowermost unit in the mine area is the Patrick Brook Formation (van Staal and Fyffe 1991), which comprises graphitic slate, siltstone, and quartz wacke with vitreous volcanic quartz. The coarse-grained quartz wacke units are locally graded and crossbedded providing reliable younging directions, both in outcrop and drill core. The Patrick Brook Formation represents a period of transition between the deposition of the underlying Miramichi Group and the overlying Tetagouche Group rocks.

To the south, Skinner (1974) recognized fine-grained, grey limestone that straddles the contact between the Patrick Brook and Nepisiguit Falls formations. This limestone, which is correlated with the Vallée Lourdes Formation, is interlayered with the overlying crystal-rich tuffites of the Nepisiguit Falls Formation.

At Key Anacon, the Nepisiguit Falls Formation is represented by fine-grained, quartz- and K-feldspar-rich volcaniclastic rocks, the distal facies (Little Falls Member) of Langton and McCutcheon (1993). These volcaniclastics can be considered as reworked pyroclastic rocks or tuffites. The contact with the underlying Patrick

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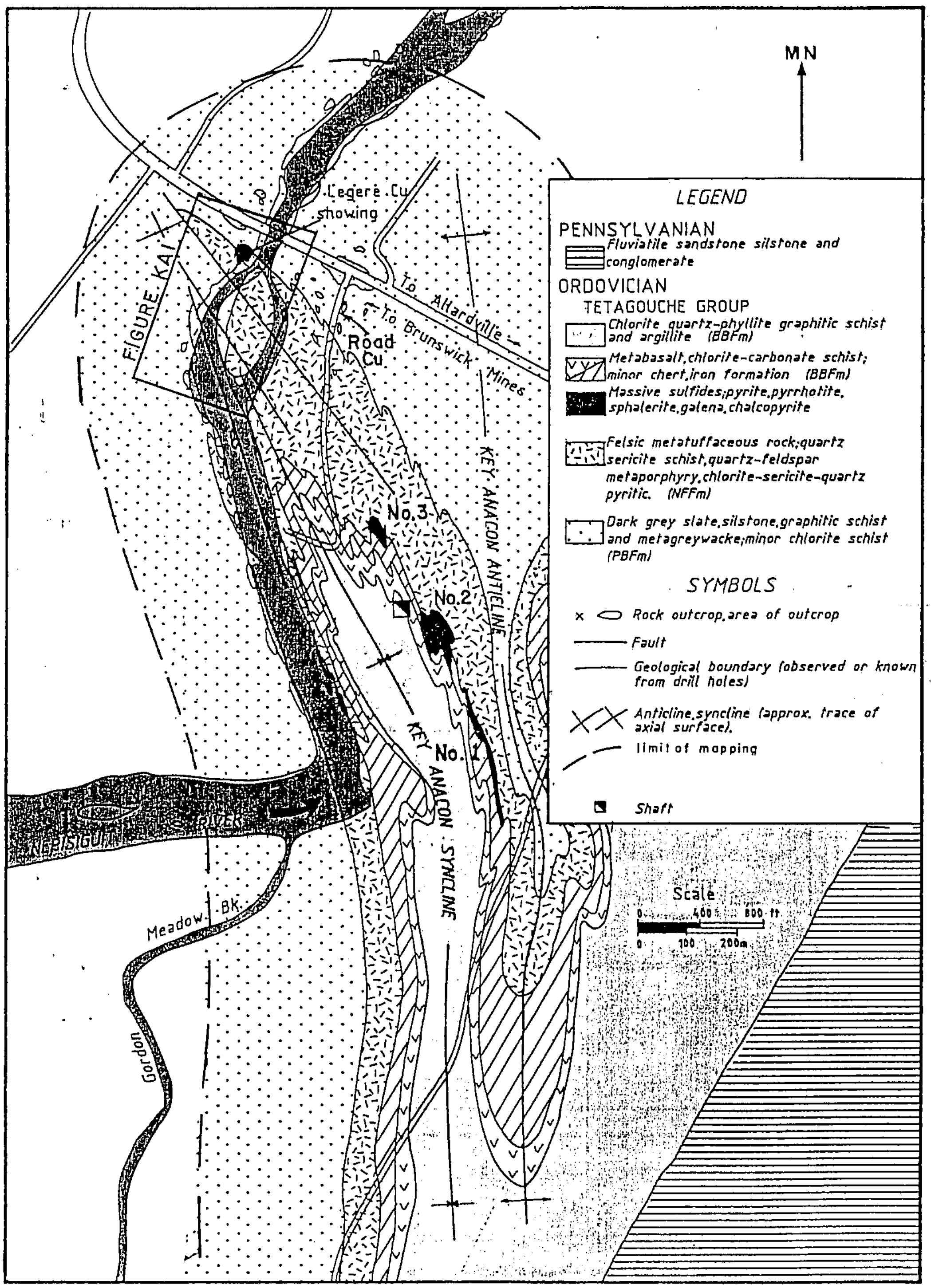

Figure 1. Geological map of the Key Anacon area (modified after Saif *et al.* 1978).

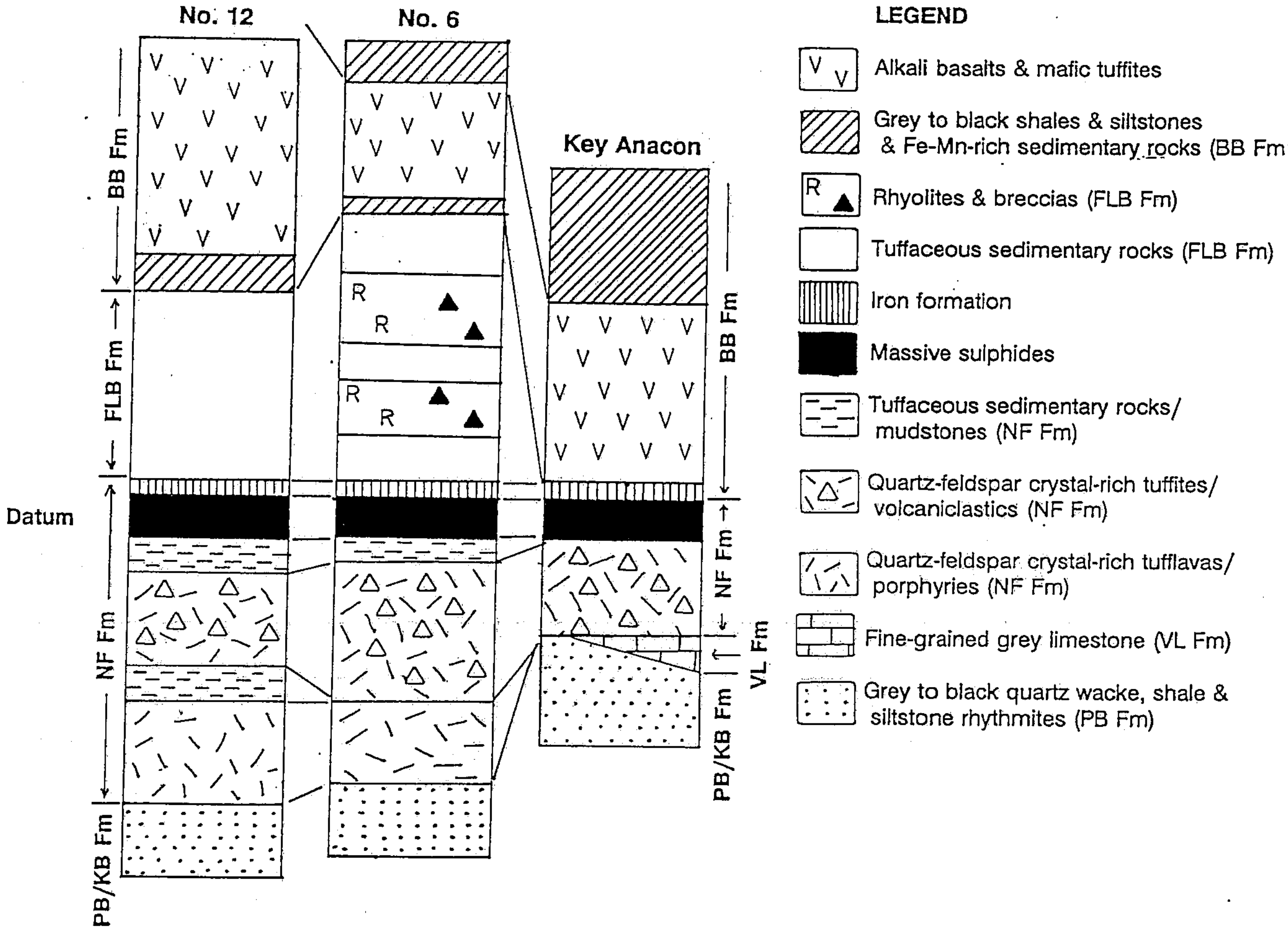

Figure 2. Stratigraphic sections for the Brunswick No. 12, Brunswick No. 6 and Key Anacon areas. The sections compare equivalent units and have no time implications. The unit thicknesses are not exaggerated. KB Fm - Knights Brook Formation, PB Fm - Patrick Brook Formation, Vallée Lourdes Formation, NF Fm - Nepisiguit Falls Formation, FLB Fm - Flat Landing Brook Formation, BB Fm - Boucher Brook Formation.

Brook Formation is sharp, indicating that relatively little mixing took place during deposition. The relatively unaltered rocks around the deposit are recognizable as Tetagouche Group because they contain greater than 10% K-feldspar, though this is not obvious within the footwall alteration zone (see below). For the most part, the Key Anacon massive sulphides occur at or near the top of this volcaniclastic unit (Irrinki 1992). Saif (1977) first suggested that these rocks represent distal equivalents to the crystal-rich tuffs that are present near Brunswick No.6; Saif *et al.* (1978) further suggested that the exhalative unit encompassing both the sulphide bodies and associated iron formation be called the Austin Brook Formation because of its lateral continuity and apparent time-stratigraphic significance. However, this nomenclature has not been adopted because exhalative units occur at other stratigraphic positions within the Nepisiguit Falls Formation, as well as in younger formations.

Highly altered alkali-basalts and related sedimentary rocks of the Boucher Brook Formation directly overlie rocks of the Nepisiguit Falls Formation in much of the mine area, i.e. the Flat Landing Brook Formation is absent. The mafic volcanic rocks have a pronounced magnetic signature, which prompted the original interest in this property. Interestingly, these rocks have been described as iron formation and equated with the iron formation at Austin Brook and elsewhere along the Brunswick horizon. However, based on the geochemical data presented by Saif (1980), it is more likely that alteration of the mafic rocks has produced a banded magnetite-carbonate-epidote-chlorite rock that has been mistakenly identified as iron formation. The basalt in the upper part of the formation is more pristine, consistent with the hypothesis that this alteration is somehow related to the sulphide-generating hydrothermal system. As the banded magnetite-carbonate-epidote-chlorite rock at the mine was thought to have some metallogenic significance it was mapped as a separate unit (Saif *et al.* 1978; Fig.1). Interbedded with the alkali-basalts are dark grey to green slates and phyllites that are commonly magnetic and locally contain garnetiferous zones, indicating probable manganese enrichment. Although some magnetite may be primary, most of the magnetite is secondary and was probably released during breakdown of ferromagnesian silicates.

The stratigraphy at Key Anacon differs from that of the Brunswick Belt (cf. Luff *et al.* this volume) in three ways. Firstly, fine-grained siliciclastic limestone of the Vallée Lourdes Formation locally occurs at the contact between the Patrick Brook and Nepisiguit Falls formations at Key Anacon. Secondly, the juvenile volcaniclastic material that represents the Nepisiguit Falls Formation at Key Anacon is relatively fine-grained with an absence of tufflavas (cf. McCutcheon *et al.* this volume) or porphyries. Thirdly, rhyolites and related leucocratic metasedimentary rocks of the Flat Landing Brook Formation are absent between the Nepisiguit Falls and Boucher Brook formations at the Key Anacon deposit, but occur in the hanging wall of both the Brunswick No. 6 and 12 deposits.

STRUCTURE AND METAMORPHISM

The Key Anacon syncline is a tight, steeply southward-plunging F_2 fold with a well-developed axial-planar cleavage (S_2). Macroscopic to microscopic parasitic F_2 folds are developed around this major structure (Fig.1). The Nepisiguit Falls and Boucher Brook formations are slightly thicker in the hinge of this fold, suggesting that some structural thickening has occurred. The S_2 fabric trends south to south-southeast and is subvertical to steeply westward-dipping, with a steeply plunging stretching lineation related to F_2 folding. Although the F_2 fold axis is southward-plunging at surface, at depth the F_2 folds plunge steeply towards the north. This plunge-reversal is thought to reflect the influence of F_1 folds, and as the Brunswick No.6, Brunswick No.12, Heath Steele, and Stratmat deposits are all associated with F_1/F_2 fold closures, the possible presence of a similar structure at Key Anacon is being tested. The change in plunge of F_2 is reflected by the geometry of the ore deposits (Saif *et al.* 1978; Irrinki 1992). A spaced, northeast-trending, subvertical cleavage (S_5) is developed throughout most of the area, and is approximately axial-planar to open folds (F_5) that affect the earlier fabric elements. This S_5 fabric is believed to be contemporaneous with the deformation event that produced the Pabineau Antiform/Synform pair, which caused the S-shaped surface-distribution of rock units between the Brunswick No. 12 and No. 6 mines. Several post-F_5, south- to southeast-trending and steeply to vertically dipping normal faults disrupt the fold pattern northeast of the deposit (Figs.1 and 2). These have had little effect on the geometric distribution of the massive sulphides at Key Anacon.

The rocks around Key Anacon have attained upper greenschist-grade, indicated by the appearance of metamorphic biotite and spessartine in compositionally favourable units. The deposit is possibly within the thermal aureole of the Pabineau Granite, located to the north, which may account for the presence of biotite and garnet locally (Saif 1977). Saif *et al.* (1978) indicated that peak metamorphism was post-S_2 and was possibly associated with what was then interpreted as D_3, but which we now consider as D_4. However, elsewhere in the camp peak regional-metamorphism was pre-D_2 (van Staal 1985); therefore, the metamorphic overprint at Key Anacon may be more of a contact-metamorphic than a regional-metamorphic effect.

MINERALIZATION AND ALTERATION

According to Irrinki (1992), there are two zones of massive-sulphide mineralization (No.1 and No.2) and two zones of stockwork-style mineralization (No.3 and Road Cu zones). The No.1 zone (490 m length x 180 m depth x 2 m width) is located farthest to the south and has estimated probable reserves of 337 000 t grading 1.05 % Pb, 3.86 % Zn, and 42.9 g/t Ag (Carroll 1988). The No.2 zone is the most extensively explored zone in the area, boasting a shaft, nine underground levels, and detailed underground drilling. This zone has proven reserves of 1.11 Mt with an average grade of 0.22% Cu, 8.41% Zn, 3.47% Pb and 96 g/t Ag (Carroll 1988; Irrinki 1992). The No.3 zone (located to the north of the No.2 zone (490 m length x 180 m depth x 2.5 m width) with estimated probable reserves of 79 000 t of 1.69 % Pb, 7.4)% Zn, and 50.4 g/t Ag. The Road Cu zone is approximately 60 m long x 3.1 m wide and extends to a depth of 150 m with very low-grade Cu. However, sections from 0.3 to 1 m wide, grading between 2 and 10 % Cu (NBIC 88-1), have been intersected. The chalcopyrite mineralization is disseminated within altered rocks of the Patrick Brook Formation, and may represent part of a stockwork hydrothermal system.

The No.1 and 2 zones occur at the contact between altered tuffite and altered alkali-basalt and possibly iron formation. The mineralization is concentrated in the hinges of parasitic F_2 folds that seem to have attenuated limbs (Saif 1977; Irrinki 1992). The trough-shape of the eastern-most lens (see Irrinki 1992) may result from an F_1/F_2 fold interference pattern similar to that recognized at Brunswick No.6 and No.12 (see Luff *et al.* this volume), suggesting that the F_2 hinge, which "hosts" the deposit, may flatten at depth due to the influence of F_1 folding.

The hydrothermal alteration around the deposit is concentrated along the eastern limb and to a lesser extent in the nose of the Key Anacon syncline. At surface, sericitization and minor chloritization are associated with disseminated sulphides (mainly pyrite and pyrrhotite). Chloritic alteration seems to be much more pervasive in the mine area, but no published work exists on the distribution of alteration around this deposit. Stringer-sulphide veins are concentrated in the Road Cu zone but its relation to the No.1, 2, and 3 zones is not well-understood. Wahl's (1977) lithogeochemical analyses indicates that the alteration is most intense along the eastern limb of the syncline, beneath the deposits. The lithogeochemical features are virtually identical to those identified around the Brunswick and Heath Steele deposits (Wahl 1977).

As mentioned previously, the strong magnetic anomaly in the hanging-wall mafic rocks that overlie the Nepisiguit Falls Formation has been described as "basic iron-formation" (Austin Brook Formation) by Saif (1977), Saif *et al.* (1978) and Saif (1980). From the average compositional data presented by Saif (1980), this unit is compositionally similar to the mafic rocks that overlie it. The compositional range of iron and manganese in the basic iron-formation is within the range for alkali basalts (see McCutcheon *et al.* this volume). There are two reasonable hypotheses for the origin of these rocks: 1) mixing of mafic sedimentary components with components of hydrothermal discharge and 2) hydrothermal alteration of the alkali basalt. The intense deformation in these rocks has obliterated most primary textures, so the carbonate-silicate interlayering is probably tectonic banding rather than bedding. The lateral continuity of the "basic iron-formation" suggests a mixing origin but this has yet to be tested.

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ROAD LOG FOR EXCURSION TO THE KEY ANACON AREA

The starting point for the road log is at the junction of Route 430 and Route 360.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Turn east on Route 360 toward Allardville.
5.1	5.1	Turn left before the Middle Landing bridge over Nepisiguit River and park in clearing. Proceed on foot across the road and up the west side of the river to the first stop (Fig.KA1).
STOP K-1:		Dark grey to black mudstone with interlayered light to dark grey, fine-grained quartz wacke containing minor feldspar (plagioclase?) is assigned to the Patrick Brook Formation. Steeply dipping S_2, S_5, and gently dipping S_3 cleavages are well-developed in the outcrop adjacent to the river.
		Continue upriver along the bank to the sulphide-showing at the pit.
STOP K-2:		The Legere Cu showing, or the Discovery zone, occurs in the faulted contact between the Patrick Brook rocks and altered, fine-grained volcaniclastic rocks (distal facies) of the Nepisiguit Falls Formation. Adjacent to this S_2-parallel fault bedding and cleavage are at a high angle to one another indicating proximity to a fold closure. This also shows that remobilization of copper has taken place during deformation. The sericitic alteration is more pronounced in the rocks on the promintory about 10 m farther along. On the other side of the promintory, there are more Patrick Brook rocks, indicating that the altered volcaniclastic rocks occupy the core of a macroscopic, southerly-plunging F_2 syncline, albeit with faulted limbs.
		Continue upriver approximately 100 m.
STOP K-3:		Another parasitic, synclinal keel of Nepisiguit Falls volcaniclastic rocks occurs in this area. A few hundred metres farther upriver, Vallée Lourdes limestone is interlayered with similar rocks just above the depositional contact with the Patrick Brook Formation.
		Return to the bridge and cross to the other side of the river. Make your way down to the outcrop on the upriver (south) side of the bridge.
STOP K-4:		Cross-bedding and grading in the coarse-grained wacke units is evident, indicating that these Patrick Brook rocks young south into the fine-grained volcaniclastic rocks of the Nepisiguit Falls Formation. However, downriver below the bridge, by the old abutment, grading indicates the opposite younging direction. Therefore, there must be a southerly-plunging F_2 anticline between these two localities.
		Return to the road and walk east about 100 m to the entrance to the Key Anacon property on the right (south). This locality is not shown on Figure KA1.

STOP K-5:

By the gate, intensely altered quartz wacke and interbedded slate (phyllite) of the Patrick Brook Formation are recognizable. The Road Cu zone is just to the east and extends from 20 to 200 m depth. Strain in the rocks is heterogeneous, with the S_1 and S_2 fabric elements best-developed in the slates and highly-altered units. The quartz wackes behave more competently during deformation and are boudinaged. A prominent northeast-trending spaced cleavage (S_5), axial-planar to open folds, transects the map-scale Key Anacon Syncline.

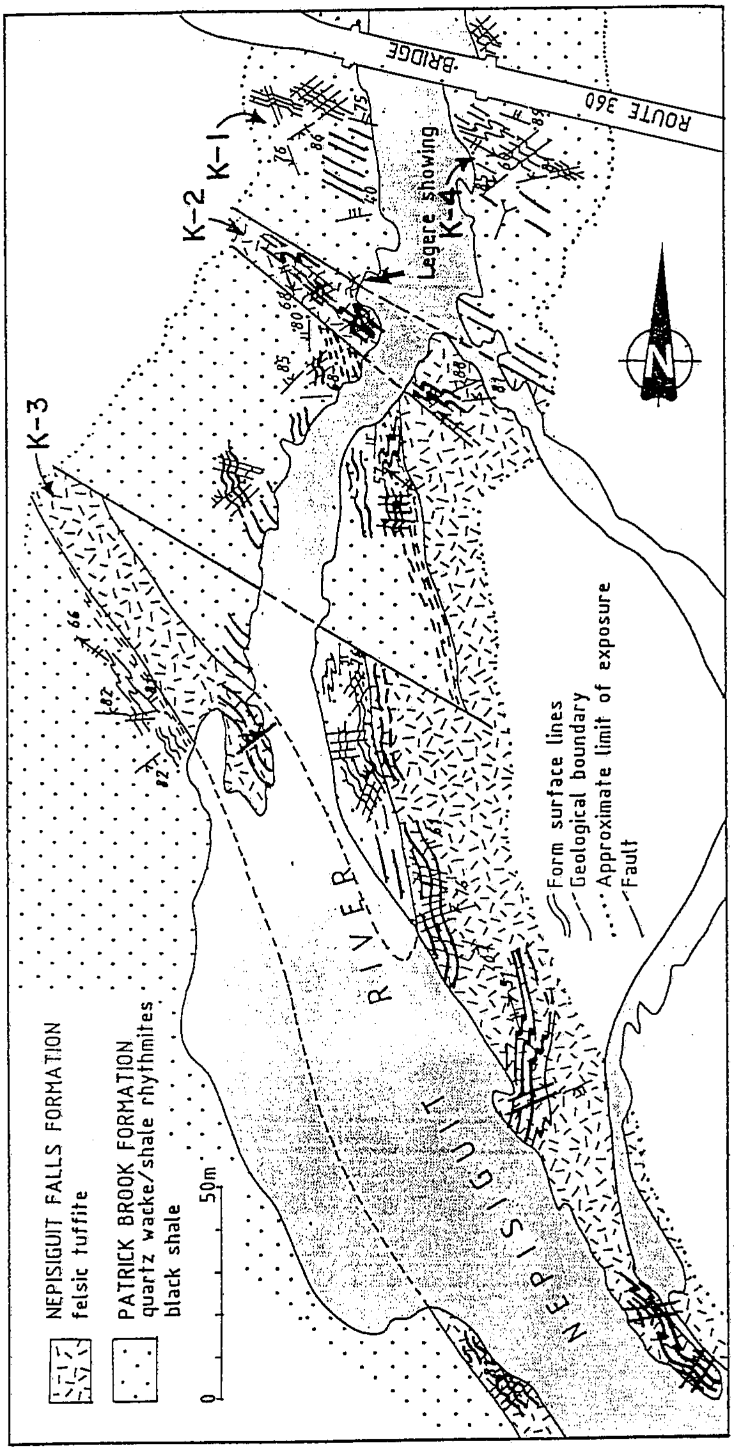

Figure KA1. Geology and form-surface map of the Middle Landing area on the Nepisiguit River (modified from van Staal and Langton 1990).

THE CARIBOU MASSIVE-SULPHIDE DEPOSIT, BATHURST CAMP, NEW BRUNSWICK

R.A. Cavelero[1]

INTRODUCTION

The Caribou Zn-Pb-Cu deposit is located 50 km west of Bathurst, New Brunswick in the north-central part of the Bathurst Mining Camp (see Fig.2 of McCutcheon *et al.* this volume). The total massive-sulphide resource, to a depth of 1200 m, is estimated at 70 million tonnes of 1.6% Pb, 4.3% Zn, 0.5% Cu, 51 g/t Ag, and 1.7 g/t Au. The deposit remains open at depth to the north. Current ore reserves at a 10% Pb + Zn cut-off and 3.5 m minimum mining width, to a depth of 1000 m, are 13 million tonnes of 3.52% Pb, 8.18% Zn, 0.38% Cu, 102 g/t Ag, and 1.4 g/t Au.

Past production includes: 1) 337,400 tonnes of 3.66% Cu from a supergene blanket, mined by open pit in 1970 - 1974; 2) 61,500 tonnes of gossan, mined in 1970 but heap-leached in 1982 - 1983, which yielded 110,000 oz. Ag and 8,300 oz. Au; 3) 728,400 tonnes of 3.54% Pb and 7.17% Zn mined from underground during 1988 - 1990. The orebody has been developed to a depth of 287 m by ramp and sublevels and a production shaft has been partially completed to a depth of 140 m. The property is currently in a standby and maintenance mode.

HISTORY

The Caribou deposit was discovered by the Anaconda Company (Canada) Limited in 1955. Following the discovery of the Brunswick and Heath Steele deposits and the recognition of their association with felsic volcanic rocks, Anaconda conducted an airborne EM survey in December 1954 over the northwestern part of the Bathurst Camp. During the following summer, geological reconnaissance mapping and evaluation of anomalies from the EM survey led to four massive-sulphide discoveries east of Caribou, namely Armstrong A and B, Rocky Turn and McMaster. The airborne anomaly at the Caribou site was tested by ground EM methods because of the structurally complex host rocks, which were considered favourable for the localization of massive sulphides, based on the Brunswick example. The resulting EM anomaly defined an open "U"-shaped fold, subsequently to be called the Caribou Synform (cf. Roscoe 1971). Furthermore, stream silt and water samples from Forty Mile Brook, which transects both limbs of the Caribou Synform, and seep samples collected from the hill above the deposit, yielded anomalous base-metal values.

The first hole was drilled in December on the east limb of the Caribou Synform and intersected over 15 m of massive pyrite containing interesting values in lead, zinc, silver and copper (Cheriton 1958). By 1965, a total of 59 holes had been drilled from surface. An exploration adit, begun in 1959 to collect a bulk sample of the ore, was resumed in 1965 and drifted the full length of the deposit. By 1967, a ramp and an exploration level, 100 m below the adit, had been completed. Ventilation raises driven to the surface in 1966 led to the discovery of the supergene-copper blanket and gossan cap above the primary ore. Open-pit mining of this supergene zone began in 1970; the copper ore extracted from the open pit, which was largely composed of covellite and chalcocite, proved virtually untreatable by the conventional flotation processes used at the time. This led to the popular misconception that the Caribou massive sulphides are more difficult metallurgically than other deposits in the Bathurst Camp. However, the most recent production run (1988 -1990) on the primary lead/zinc ore indicates this is not the case.

Exploration drilling in 1966 discovered a zone of high-grade massive sulphide just below the surface, 450 m north of the adit along the Caribou horizon, but no follow-up drilling was ever conducted. A deep-drilling program in 1980-1981 traced the Caribou deposit to a depth of 1088 m on the west limb of the synform. The deposit remains

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open at depth to the north under the mineralization discovered in 1966. Furthermore, geophysical surveys conducted over the years, including two recent airborne surveys, show that there is approximately 12 km of potential sulphide-bearing horizon yet to be tested on the property.

In December 1986, Caribou was purchased from the Anaconda Company by East West Minerals, N.L. of Sidney Australia. A new base-metal concentrator was built in 1988 on the site of the old Anaconda copper mill and underground production was carried out until July 1989. Breakwater Resources, the current Tucson-based owner, acquired Caribou in February 1990 and resumed production until October 1990 when operations were suspended.

REGIONAL SETTING

Since its discovery, geologists have agreed that the Caribou deposit is within Tetagouche Group rocks, but there is still debate about the subdivision of this group in the Caribou area. Consequently, the stratigraphic position of the deposit within the Tetagouche Group, as well as the younging direction of the mine sequence, are not firmly established. This is largely because there is disagreement about the number and timing of deformational events (cf. Roscoe 1971; Davis 1972, 1973; Helmstaedt 1973), especially since the recognition of ductile, high-strain zones in the Bathurst Camp (van Staal 1986).

More specifically, recent mapping by van Staal (1991) places the footwall phyllite and underlying basic volcanic rocks at Caribou in the Boucher Brook Formation, the youngest unit in the Tetagouche Group (cf. Fig.3 of McCutcheon *et al.* this volume). Felsic volcanic rocks both underlying the footwall sequence and overlying the massive sulphide are assigned to the older Flat Landing Brook Formation, but a high-strain zone is inferred between the sulphides and the hanging-wall rocks. Accordingly, the Caribou deposit is interpreted to occur above the Flat Landing Brook Formation and at the base of the Boucher Brook Formation (van Staal *et al.* 1992). However, base-metal zoning at Caribou indicates younging to the north into the structural hanging wall (Roscoe 1971).

Informal mine terminology is used in the following description, since correlations based on current stratigraphic subdivisions of the Tetagouche Group are ambiguous at Caribou. The mine stratigraphy is based on two premises: 1) there are no major structural discontinuities, i.e. ductile thrusts, which repeat stratigraphy, and 2) the section consistently youngs to the north in the vicinity of the deposit.

CARIBOU STRATIGRAPHY

Based on detailed mapping of surface outcrop, underground workings, and drill core, the mine stratigraphy, as defined to date, amounts to approximately 3000 m of section; 2400 m into the footwall and 600 m into the hanging wall from the massive-sulphide horizon. The section represents a continuous depositional sequence facing generally northward as it wraps around the Caribou Synform (Fig.CM1). The stratigraphic section in the vicinity of the Caribou Mine is herein divided into three parts, called the *lower-footwall sequence*, the *mine sequence* and the *hanging-wall sequence*. Each one is described below. All of the rocks in the Caribou area are metamorphosed, but most of them are only lower greenschist grade. Therefore, the prefix "meta" is omitted from the rock names in the following description.

Lower-Footwall Sequence: There are significant differences in the *lower-footwall sequence* from the west limb to the east limb of the Caribou Synform. Consequently, each limb is described separately.

The **west limb** of the Caribou Synform consists of a thick sedimentary unit overlain by a volcanic sequence dominated by mafic rocks with interlayered felsic tuffs. The <u>sedimentary unit</u> is a dark grey to black, graphitic phyllite with local interbeds of light grey siltstone and coarse-grained greywacke.

The <u>mafic volcanic rocks</u> are predominantly dark green to greyish green, fine grained and moderately schistose containing chlorite + epidote + albite ± calcite ± quartz. They are typically massive, though locally amygdaloidal

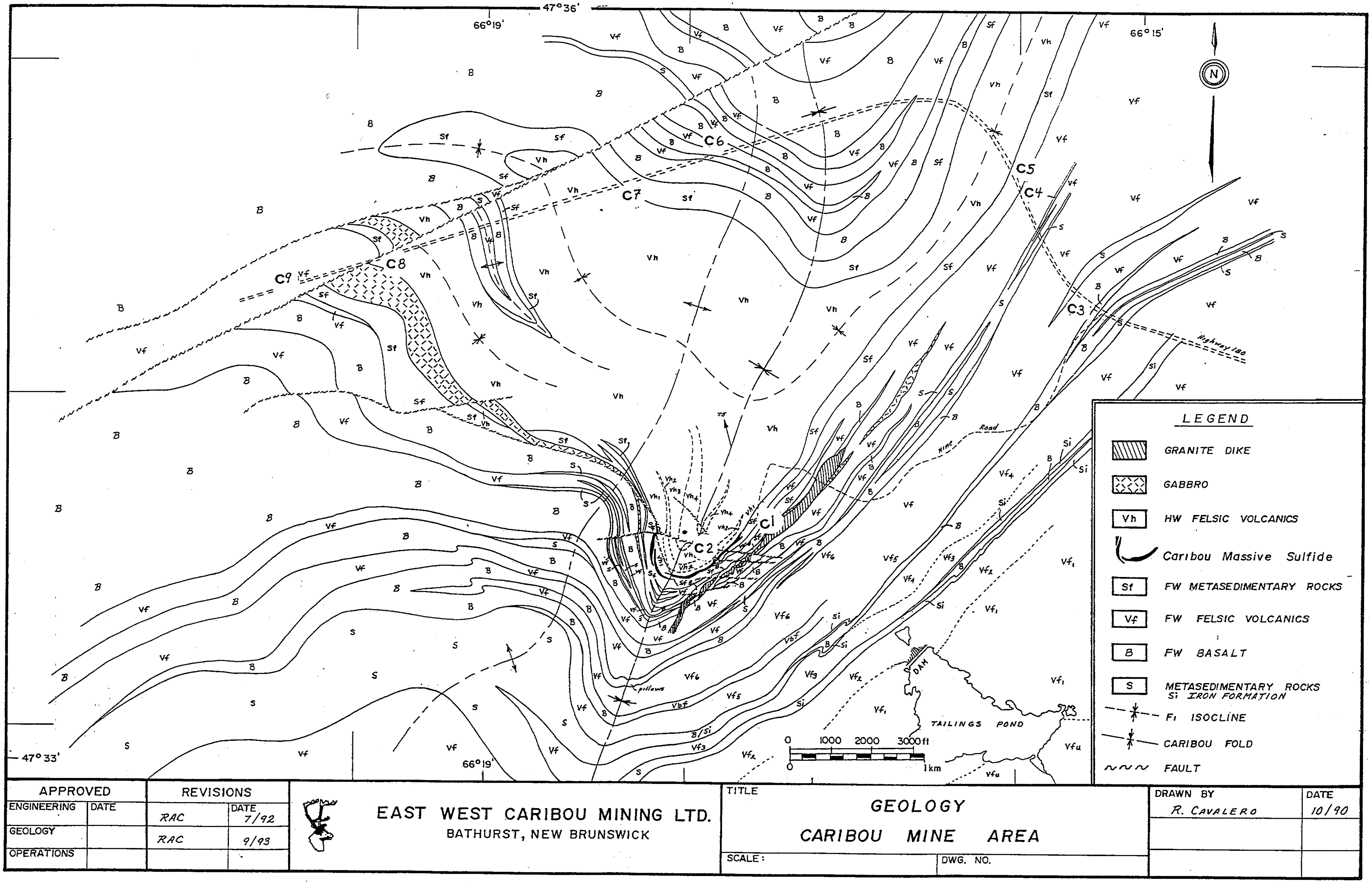

Figure CM1. Simplified geological map of the area around the Caribou Mine.

toward the base, and grade upward toward the Caribou horizon, where they become more schistose and tuffaceous in appearance. Individual flow units are commonly separated by thin, red and green phyllitic intervals. Pillows were seen in only one basalt unit near the hinge of the Caribou Synform. Calcite as amygdules, veins, and fracture fillings, is a common constituent. Magnetite is also common but is rarely visible even though it causes a relatively strong magnetic response in the rocks. Associated rocks include feldspar porphyry, diabase, laminated tuff, and coarse-grained fragmental rocks.

The interlayered felsic volcanic rocks are generally similar to others in the Caribou area, consisting predominantly of quartz-sericite-orthoclase schist. Colors and textures are highly variable ranging from shades of greenish grey to pale yellowish grey. Most varieties are silicic with the micas confined to thin partings in a fine-grained, foliated quartzose matrix. Nearly all are porphyritic to varying degrees, with subhedral orthoclase dominant and small, ovoid quartz phenocrysts occurring locally with the feldspar. Other variations include nearly massive, commonly banded porphyry and non-porphyritic, fissile micaceous, phyllite. Phyllitic sedimentary interbeds typically mark lithologic changes within the section and generally occur near the contacts with basalt. The amount of interlayered phyllite increases toward the Caribou deposit. All contacts, observed in outcrop and in drill core, between the major lithologies are sharp and conformable. The felsic units are interpreted as thinly layered sequences of tuff, tuffite, and volcaniclastic sediment with minor, thin rhyolite flows and/or welded tuff.

The *lower-footwall sequence* of the **east limb** of the Caribou Synform is different than the west limb; the east limb is dominated by felsic, rather than mafic, volcanic rocks. The sedimentary unit of the west limb is represented by two thin bands of red, hematitic iron formation (Unit Si in Fig.CM1) associated with mafic tuff. The basalt units also continue into the east limb, but are much thinner and subordinate to the felsic volcanic rocks. The felsic rocks have been divided into six textural varieties or units, labelled Vf_1 to Vf_6, going from the tailings pond northwestward (Fig.CM1).

Unit Vf_1 is typically a dark greenish grey (white to buff weathered), siliceous, porphyritic, quartz-muscovite schist with characteristic compositional banding parallel to the pervasive schistosity. The banding results from dark green, strongly orthoclase-porphyritic, muscovitic layers that alternate with white weathered, fine-grained siliceous layers. The siliceous layers may or may not be orthoclase porphyritic. The muscovitic layers are generally 1-4 cm wide, discontinuous and lenticular. Transposition parallel to the pervasive schistosity is evident and rare isoclinal folds, plunging 65° to the southwest, have been observed. The siliceous layers range from nearly massive, through weakly schistose bands with micaceous portions to highly foliated layers with pronounced lamination. Although a pervasive white to buff weathering is characteristic of the outcrops, fresh surfaces are generally dark grey, although there are local pink rhyolitic bands with anastomosing muscovite folia.

Small, ovoid to elongated rhyolitic fragments are scattered throughout unit Vf_1 and fragmental horizons occur locally. These are well-banded consisting of siliceous, orthoclase-porphyritic schist interlayered with fissile, micaceous schist. Abundant elongated and flattened (both parallel to schistosity and down dip) pale green, white and pink fragments of rhyolite and quartz-feldspar porphyry occur in the siliceous bands. This unit also contains nearly massive rhyolite layers, locally up to 25 m thick. These are moderately porphyritic, weakly micaceous and may represent interlayered, thin tufflavas.

The upper contact with unit Vf_2 is sharp and conformable, but at a slight angle to schistosity west of the tailings dam. A thin, massive white rhyolite occurs along the contact east of the dam. The basal contact of unit Vf_1 is exposed near the southeast corner of the tailings pond, where it trends nearly east-west, i.e. at a high angle to the regional trend of the units.

Unit Vf_2 is a light olive green to yellowish grey-green porphyritic quartz-muscovite-sericite-feldspar schist with a medium-grained granular texture. Pale yellow-green sericite and darker green muscovite occur in about equal proportions and impart a pervasive schistosity throughout the unit. Micaceous layers are fissile, locally very sericitic, and sparsely porphyritic. Siliceous layers are slightly less schistose and highly porphyritic. The dominant feldspar is subhedral orthoclase with subordinate euhedral albite. Small quartz phenocrysts and larger quartzo-feldspathic augen are abundant locally. The augen result from strong, quartz-pressure-shadow development around tectonically shattered feldspar crystals. Weathered outcrops display pronounced color and textural banding parallel to schistosity, which is produced by variations in mica species, quartz and phenocryst content. Fresh outcrops appear more homogeneous, but display a subtle banding that is enhanced by the surface weathering. Thin cherty interbeds and lenses occur locally (1-25 cm thick). Rare silicic (cherty to rhyolitic) fragments are scattered throughout.

The lower iron formation (unit Si in Fig.CM1) averages 50 m in width and has been traced for 2600 m along strike to the northeast. It is a thinly bedded to laminated chemical sedimentary rock with pronounced slaty cleavage (S_{Main}) that is parallel to bedding. The unit is in sharp, conformable contact with underlying unit Vf_2 along its extent. To the northeast, the iron formation is overlain by a thin basalt that pinches out to the southwest. The basalt is overlain by another band of iron formation, which also pinches out to the southwest and thickens to the northeast. All contacts with the basalt are extremely sharp and conformable. The base of the iron formation is a massive, brick red, hematitic chert that grades upward into thinly bedded, purplish red, hematitic phyllite. Toward the top, near the basalt contact, the iron formation contains interlayered grey and greenish grey siliceous lamina and white, lenticular quartz lamina. The iron formation overlying the basalt displays a similar gradation upward, but the contact with the overlying felsic volcanic schists is not exposed. The basalt is a green, fine- to medium-grained, chloritic rock that is strongly schistose, especially adjacent to the iron formation. It appears to be a mafic tuff rather than one of the massive flows. To the west, the iron formation becomes less homogeneous. Red cherty phyllite is interlayered with dark purple, manganiferous phyllite that locally contains white cherty lenses. The latter become dominant to the west along the basal half of the unit. Local interbeds of light green and dark grey siltstone and rare chloritic tuff suggest that the iron formation has a more clastic nature to the west than to the east.

The felsic volcanic schist that overlies the lower iron formation is divided into two units (Vf_3 and Vf_4 in Fig.CM1). Unit Vf_3 is a relatively homogeneous, thinly layered tuff sequence dominated by orthoclase porphyritic quartz-sericite schist. The unit is generally light green to grey-green, moderately silicic, and uniformly schistose. Locally there is a banded silicic tuff, comprising highly porphyritic and rarely, red cherty lenses in a fine-grained, non-porphyritic matrix. Unit Vf_4 only occurs in the northeastern part of the area, where it is separated from unit Vf_3 by a thin, pinkish-white, massive, weakly porphyritic chloritic horizon. Unit Vf_4 is a highly silicic, uniformly banded, orthoclase-porphyritic, quartz-sericite schist. The banding, produced by alternating silicic, porphyritic light grey and pinkish layers, is enhanced by an evenly spaced, micaceous foliation (S_{Main}). Red cherty lamina occur locally and commonly exhibit isoclinal folding with an S_{Main} axial planar schistosity.

The upper iron formation (also labelled Si in Fig.CM1), which overlies unit Vf_3 to the southwest and unit Vf_4 to the northeast, is more mafic than sedimentary in nature. Northwest of the tailings pond, an isoclinally folded segment of this iron formation consists of brick red to purplish, hematitic chert that lies along the contacts of a core zone of massive, dark green, finely granular basalt. To the northeast, this basalt overlies unit Vf_4 and is overlain by iron formation that is brick red and cherty at the base but grades upward into deep purple phyllite. The contact with the overlying felsic schist is defined by an interval of thinly interlayered, purple phyllite and pale green, fine-grained, non-porphyritic, laminated tuff. The basal contact between the basalt and unit Vf_4 is very sharp and locally isoclinally folded. The underlying felsic schist is characterized by alternating light grey porphyritic schist and yellow-green to white cherty bands with rare, red cherty lamina. The basalt is well foliated, but coarsely granular at the base grading upward into a bright green, banded, and well-foliated chlorite-epidote-quartz schist with red and white cherty interbeds. To the southwest, the basalt becomes a bright green chloritic tuff with abundant white, altered feldspars and contains thin interbeds of red, hematitic, cherty phyllite with minor red chert lenses. The lower contact with unit Vf_3 is sharp and conformable. The upper contact is gradational consisting of interlayered chloritic tuff, red cherty phyllite and porphyritic felsic schist.

Unit Vf_5 is a banded, silicic, orthoclase-porphyritic, quartz-sericite schist that overlies the upper iron formation and its associated basalt. The rocks are similar in many respaects to those of unit Vf_4. However, unit Vf_5 is less homogeneous, slightly less silicic and more sericitic and is more variably porphyritic than unit Vf_4. Furthermore, it lacks the distinctive pink bands and lenses of Vf_4.

Unit Vbf consists of a thinly interlayered, heterogeneous sequence of mafic and felsic volcaniclastic rocks, which only occurs northwest of the tailings pond (Fig.CM1). To the east, fissile, non-porphyritic felsic tuffite is interlayered with fissile, brown-weathered chloritic tuffite and minor sedimentary phyllite. To the west, more typical silicic, orthoclase-porphyritic quartz-sericite-(muscovite) schist is bounded by weakly foliated mafic tuff to the south and fissile, bright green chloritic tuff to the north. In the hinge zone of the Caribou Synform, this unit consists of weakly foliated basalt that is correlated with the lowest basalt unit of the west limb sequence. All contacts with the underlying and overlying felsic schists are sharp.

Unit Vf_6 is a distinctive felsic volcanic schist that is typically grey and coarsely porphyritic with a quartz-sericite-groundmass. Abundant, large (up to 1cm) orthoclase phenocrysts occur in a granular, silicic groundmass transected by evenly spaced, thin micaceous partings. Small felsic fragments occur locally. The upper part of the unit is a pale greenish-grey, fine-grained, fissile quartz-sericite schist that is non-porphyritic and less silicic than the lower part.

Overlying Vf_6 is a complexly interlayered sequence of felsic and mafic volcanic rocks with some sedimentary rocks, which represents the condensed continuation of the west-limb units of the Caribou Synform. The basalt layers at the apparent base of this condensed package are predominantly fissile, chloritic and tuffaceous, commonly with thin, red hematitic, cherty to phyllitic interbeds. Weakly foliated, blocky, massive basalt is most common, generally occurring at the base of the units, but pillows are evident near the contact with unit Vf_6, in the hinge zone of the Caribou Synform. The pillowed horizon is overlain by porphyritic basalt that is characterized by large elongated, white feldspar phenocrysts and tiny, epidote-lined vesicular cavities in a massive chlorite-albite-epidote groundmass. This particular flow unit can be traced eastward along the base of the section. The basalt layers higher in the sequence are typically massive but can be locally amygdaloidal and/or porphyritic. The felsic volcanic rocks interlayered with the basalts are highly variable in color and texture. Most are quartz-sericite schists that are moderately to highly silicic and variably orthoclase porphyritic. Dark-colored schists (grey, grey-green) are typically porphyritic, whereas light-colored schists (pale green, yellow-green, pale yellow) are sericitic, less silicic, and weakly to non-porphyritic. Gradations from medium-grained, silicic, porphyritic schist to fine-grained, fissile, micaceous, aphyric schist, upward toward the massive-sulphide horizon, are common. Sedimentary interbeds occur throughout the condensed package and include red chert and cherty phyllite, red and green phyllite, and grey, quartz-sericite phyllite. The red chert and phyllite generally occur within the mafic tuffs and along the basalt/felsic schist contacts, but they also occur, together with red and green laminated phyllite, within the felsic schist in the upper part of the section. The grey, argillaceous phyllite occurs locally along the basalt/felsic schist contacts, but is more commonly interlayered within the felsic schist units often alternating with or grading into volcaniclastic phyllite and tuffite.

Mine Sequence: The *mine sequence* includes sedimentary and felsic volcanic rocks, in addition to massive sulphides. The sedimentary rocks occur in the footwall and are divisible into two units. Felsic volcanic rocks underlie, are interlayered with and overlie massive sulphides. The massive sulphides comprise six discrete lenses that have an en echelon distribution about the Caribou Synform. They are numbered 1 through 6, from the north on the west limb, to the south and east around the fold axis, onto the east limb where Lens 6 occurs. The massive sulphides are described in detail in a later section entitled: Massive Sulphides.

A fine-grained footwall-sedimentary unit overlies the rocks of the *lower-footwall sequence*, on both the east and west limbs of the Caribou Synform. These rocks are divisible into two units in the mine area. The lower one is referred to as graphite schist and the upper one is called the footwall phyllite in mine terminology.

The graphite schist is dark grey to black with abundant white, metamorphic quartz veinlets and lenses oriented subparallel to schistosity and is barren of sulphides. Interbeds of light grey greywacke commonly occur throughout the unit. Graphite content is variable ranging from a few percent to over 30 percent and greatly affects the competency of this unit. Even though the contacts with the adjacent units are sharp and conformable, the graphite schist has undergone a high degree of internal deformation. The greywacke interbeds, quartz veins, and S_{Main} schistosity are contorted and exhibit disharmonic folds, suggesting that this unit took up a large amount of the strain during deformation. The graphite schist attains a thickness of 70 m on the west limb of the Caribou Synform below lenses 1-3 and overlies the upper basalt unit of the footwall sequence. To the north of the deposit and east from the hinge area of the fold, the graphite schist diminishes in thickness interfingering with or grading laterally to barren quartz-sericite phyllite. Only minor, thin graphitic horizons occur beyond the deposit.

The footwall phyllite, which ranges from 3-25 m in thickness, but averages about 15 m, is grey to dark grey with abundant quartz veinlets and lenses oriented subparallel to the S_{Main} schistosity. Bedding is generally not well-developed, but locally, there is a well-defined lamination that is best seen in drill core. The lamination is generally parallel to the S_{Main} schistosity, but locally schistosity intersects contacts between light and dark phyllite at moderate to high angles. Disseminated pyrite, as well as thin lenses and seams of pyrite occur in a zone 3-10 m thick, adjacent to the massive-sulphide contact. Pyrite may exceed 10 percent near this upper contact but it gradually diminishes to zero at the base of the phyllite. With few exceptions, the phyllite directly underlies the massive sulphide lenses.

Two of these exceptions are worth describing. The first occurs below Lens 2, where there is a dark green chlorite-stilpnomelane-pyrite schist. The schist is lenticular in shape, up to 8 m thick adjacent to the central part of Lens 2, and pinches out against the sulphide to the north, but extends beyond Lens 2 to the south, interfingering with and pinching out in the phyllite. Pyrite as bands, lenses, and disseminations, constitutes up to 25 percent of this schist. Adjacent to the massive-sulphide contact, there are concentrations of chalcopyrite as bands, seams and irregular blebs. Bedding is absent and the sulphides are generally subparallel to the well-developed S_{Main} schistosity. Contacts with both the massive sulphide and phyllite are sharp and conformable.

The second occurs in the upper levels of the deposit, adjacent to Lens 3, where a chlorite schist extends from the surface to a depth of 100 m before it pinches out against massive sulphides. This chlorite schist is similar to the one by Lens 2 in composition and shape, but the south half of this schist, adjacent to Lens 3, contains a 2 m thick zone with massive chalcopyrite bands up to 30 cm thick. These bands are oriented parallel to the schistosity and sulphide contact. As with Lens 2, the schist is in sharp contact with the underlying phyllite and interlayered with it as the schist pinches out to the south.

The felsic volcanic rocks that occur beneath massive sulphides are mainly confined to the northern and eastern extremities of the deposit, i.e. they are rare in the central part. Below Lens 1, a distinctive quartz-ribbed felsic tuff (quartz-sericite schist) interfingers with footwall phyllite and can be traced south nearly to the end of the sulphide lens before it pinches out. The massive sulphide that was discovered in 1966, north of Caribou, occurs both on the footwall and on the hanging wall of this schist, along the contact with footwall phyllite. Thin lenses of pale green, non-porphyritic quartz-sericite schist are present in the central part of the deposit. At the east end of the deposit, a thick, pale yellow-green, silicic, weakly porphyritic, quartz-sericite schist occurs within the footwall phyllite. Below Lens 4, at the base of the graphitic schist but above the uppermost basalt unit, there is a thick, lens of grey-green, orthoclase-porphyritic, quartz-sericite schist that pinches out in footwall phyllite to the east and intertongues with footwall phyllite in the vicinity of the fold hinge.

Hanging-Wall Sequence: The *hanging-wall sequence* is a complex accumulation of felsic volcanic rocks that are mineralogically simple but are highly variable in color and texture. Individual units range from a few metres to tens of metres in thickness and are generally lenticular with limited strike extent. The result is a complex intertonguing sequence in which units often terminate abruptly along strike and down dip. In general, the hanging wall rocks are porphyritic quartz-sericite-orthoclase schists. Orthoclase is the dominant phenocryst in all of the schists, but some units contain small albite and quartz phenocrysts as well. Disseminated pyrite is extremely rare and chlorite is virtually absent. The hanging-wall schists are divided into four units, labelled Vh1 through Vh4 inclusive, but these units are too small to show in Figure CM1.

Unit Vh_1 consists of at least 10 subunits that directly overlie the deposit; most of them occur on the west limb, where they pinch out into the footwall phyllite below Lens 4 or into the schist above Lens 4. Three of the subunits are distinctive, lenticular bodies that separate lenses 1, 2, and 3 from one another and pinch out into the footwall phyllite. Footwall phyllite interlayered with tuff in the transition zone between lenses 3 and 4, commonly displays a sharp basal contact and gradational upper contact with the adjacent tuff. The only known fragmental rocks occur in Unit Vh1, where this subunit overlies Lens 1 and contains abundant pale yellow (sericitic), discoidal fragments up to 30 cm in diameter. In addition, this subunit is unique because it contains rounded, massive sulphide and basalt fragments. Unit Vh_1 has a minimum thickness of 5 m above Lens 6; a thickness of 40 m above Lens 3, but exceeds 40 m thickness beyond Lens 1, on the west limb of the Caribou Synform.

Unit Vh_2 is dominated by highly silicic, weakly foliated to nearly massive porphyritic rhyolitic schist. On the west limb, Unit Vh_2 consists of a cream-colored, extremely silicic quartz-orthoclase-sericite schist that is characterized by thin anastomosing, green mica folia in a siliceous, aphanitic groundmass. The schist is highly porphyritic with abundant subhedral orthoclase phenocrysts and minor small quartz phenocrysts. This type of schist grades upward into a more micaceous and schistose rock that is grey-green and porphyritic. Orthoclase is the dominant phenocryst, but small, ovoid-quartz phenocrysts are also common. This schist, in turn, grades upward into bright yellow-green, highly schistose, non-porphyritic quartz-sericite-muscovite-orthoclase schist. This gradational sequence is repeated at least four times in the hinge area of the synform, between the adit and second level.

Unit Vh_2 overlies four different Vh_1 subunits on the west limb of the Caribou Synform, but on the east limb, it overlies a distinctive, very dark grey, quartz-sericite schist with orthoclase and albite phenocrysts. This dark grey schist lies above Unit Vh_1 and is separated from Unit Vh_2 by a thin sedimentary horizon that locally contains thin beds and lenses of high-grade massive sulphides; these sulphides are 20 m above the main ore horizon. The dark grey schist intertongues with Unit Vh_2 in the hinge zone of the synform but pinches out into Unit Vh_2 on the west limb, where it is bounded by thin sedimentary phyllite beds. To the east, Unit Vh_2 and the underlying dark grey schist pinch out above the distal edge of the massive sulphides.

Unit Vh_3 conformably overlies Unit Vh_2 and contains a variety of predominantly porphyritic quartz-sericite schist subunits that are similar to those in Unit Vh_1. To the east, Unit Vh_3 directly overlies Unit Vh_1 and together tthese two units form the hanging wall to the Caribou horizon, beyond the point where the sulphide mineralization ends.

Unit Vh_4 is a relatively homogeneous, highly silicic, weakly foliated, pink to cream colored porphyritic rhyolitic schist that is virtually identical to the more massive parts of Unit Vh_2. This unit conformably overlies the upper Vh_3 subunits in the centre of the Caribou Synform. Unit Vh_4 pinches out to the east, but continues well beyond the limit of known mineralization to the west.

Intrusive rocks: Intrusive rocks do not cut the Caribou deposit but there are at least two mappable intrusive bodies in the mine area. One is a microgranite dyke, varying from a few metres to 80 m in thickness, which lies immediately below the footwall-sedimentary unit (Unit Sf in Fig.CM1) and trends sub-parallel to layering. In detail, it intrudes both the uppermost basalt and underlying rhyolitic tuff of the *lower-footwall sequence*. It also intrudes a coarse-grained, schistose gabbro and appears to have followed the same pathway as the gabbro. The microgranite is non-schistose but its age with respect to the Caribou Synform is not known, because it only occurs on the east limb of this fold. The dyke is, however, older than the faults that postdate the fold.

To the west, multiple gabbro dykes cut across the footwall-sedimentary unit (Unit Sf) and coalesce into a large intrusive body that follows the upper contact of this unit and the hanging-wall felsic schists (Unit Vh in Fig.CM1). Thin gabbro dykes (not shown in Fig.CM1) can be traced around the Caribou Synform; they occur within the *lower-footwall sequence.*

STRUCTURE

Analysis of secondary structures and textures indicate that at least three and perhaps four major phases of deformation have affected the Caribou rocks (Davis 1972; Helmstaedt 1973). The first and second were the most pervasive giving rise to a penetrative schistosity (S_{Main}) and isoclinal folds. The formation of the massive sulphide bodies preceded the earliest deformation as indicated by textures in the sulphide minerals (Davis 1972; Helmstaedt 1973).

The dominant structural element is a strong, penetrative schistosity (S_{Main}) that pervades all of the rock units around Caribou, with the exception of the microgranite dyke. Ranging from a slaty cleavage in the sedimentary units to a spaced cleavage in the felsic volcanic rocks, this schistosity is remarkably uniform, dipping subvertically and oriented subparallel to lithologic contacts. In detail, however, bedding commonly strikes at low angles to the schistosity producing a steep, intersection lineation.

Ample evidence exists in the area to show that the schistosity is axial planar to isoclinal folds. Mesoscopic isoclinal folds, intrafolial folds and transposed bedding are evident in thinly bedded rocks and sulphide lenses within the footwall phyllite. Folds in the volcanic rocks are not abundant, but are commonly found where bedding is locally preserved, and they are particularly well-defined by thin, red cherty beds that occur in some of the units. Quartz-orthoclase veins also commonly display isoclinal folds, but the best evidence of isoclinal folding is seen in the iron formations of the *lower-footwall sequence*. Small isoclinal folds with amplitudes ranging up to 60 cm are locally abundant. These folds plunge moderately south at 30° to 65° and are minor structures on what is interpreted to be the south limb of a major regional isocline that includes the Caribou deposit. This interpretation, which is based on reconnaissance mapping and geophysical data, is shown in Figure CM1.

Kink folds postdate the main schistosity; there are two sets that predate the Caribou Synform and one set that is coeval with it. In the *lower-footwall sequence* the dominant set is oriented at 50° to 60° to S^{Main}, whereas the second set is oriented perpendicular (± 10°) to S^{Main}. Individual kinks of both sets have subvertical axial planes and steep plunges. However, the first set has a sinistral sense of asymmetry, whereas the second set has a dextral sense. Conjugate sets occur locally. In the *mine sequence* and the *hanging-wall sequence*, the dextral set predominates. Where these kinks are closely spaced, e.g. in some of the quartz-sericite schists, a crenulation cleavage is produced. A third set of kink folds overprints the other two sets and is best developed in the hinge area of the Caribou Synform.

The Caribou Synform has a vertical west limb and an 80°-85° northwest-dipping east limb (Figs.CM1 and CM2). The axial plane strikes N 25°E and dips 75°-80° west; the plunge is N 15°W at approximately 75°. There is no axial-plane cleavage associated with this synform although the third set of small-scale kink folds mimic the large fold in orientation. The Caribou Synform predates the major brittle faults in the mine area but postdates all of the other structural elements, which are re-oriented around this fold axis (Davis 1972). This synform is considered to have formed as a large-scale dextral kink on the north limb of the Tetagouche Antiform. According to Davis (1972), the Caribou Synform is a D_4 structure post-dating the Tetagouche Antiform, a structure that Helmstaedt (1970) considered to be an F_3 fold.

North-northwest and westerly trending brittle faults are the youngest structures in the mine area. The earliest set trends northwest and dips 60°-70 east (Figs. CM2 and CM3). One of these truncates Lens 2 on the surface and Lens 1 on the adit level. The fault passes from hanging wall to footwall in the mine and becomes a major structure to the northwest, where it forms the contact between the footwall-metasedimentary unit and underlying basalt. To the south this fault is offset by a westerly trending one, but continues south and cuts the massive sulphides with minimal offset. Fault movement is reverse with approximately 40 m of left-lateral displacement but the dip-slip component is unknown. A parallel, companion fault occurs in the hanging wall to the east and dips 50°-75° west.

The youngest fault-set trends westerly. One of these faults affects lenses 1 and 2 (Fig. CM2) and continues across the Caribou Synform, through the distal end of the massive sulphides on the east limb into the footwall rocks. Where this fault cuts the sulphides on the west limb, it bifurcates into a complex fault zone bounded by the main westerly trending fault to the south and a northwesterly trending fault to the north. The westerly trending fault is vertical at surface, dips 80° south at the adit level, flattens to 60° south on Level 2 (100 m below), and continues

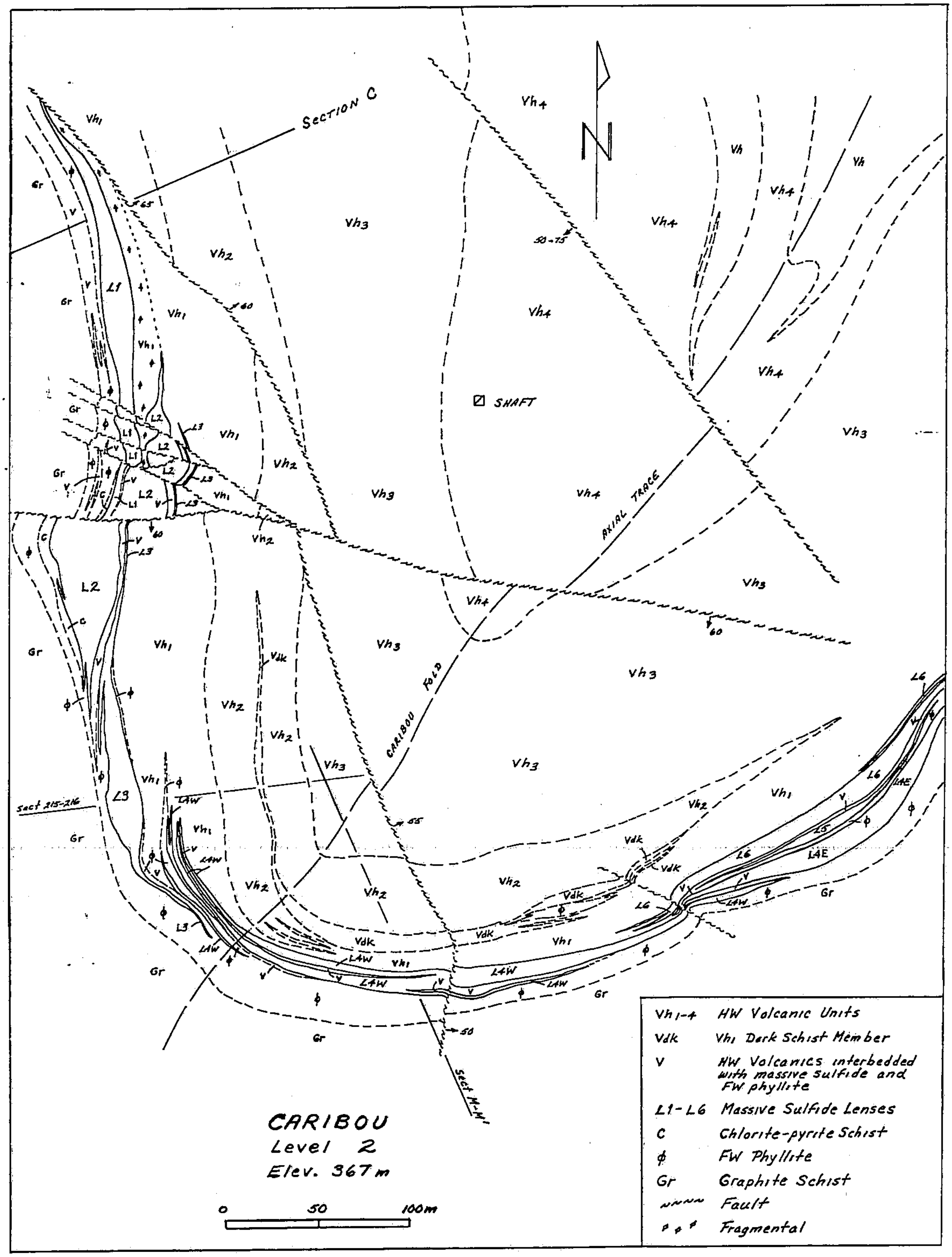

Figure CM2. Geological plan of Level 2 showing the distribution of the sulphide bodies around the Caribou Synform. Geology by Cavellero (1990). Lens 1, Lens 2, Lens 3 and Lens 4 correspond to the Northwest, North, South and East sulphide bodies of Jambor and LaFlamme (1978). See Figure CM1 for location of this plan.

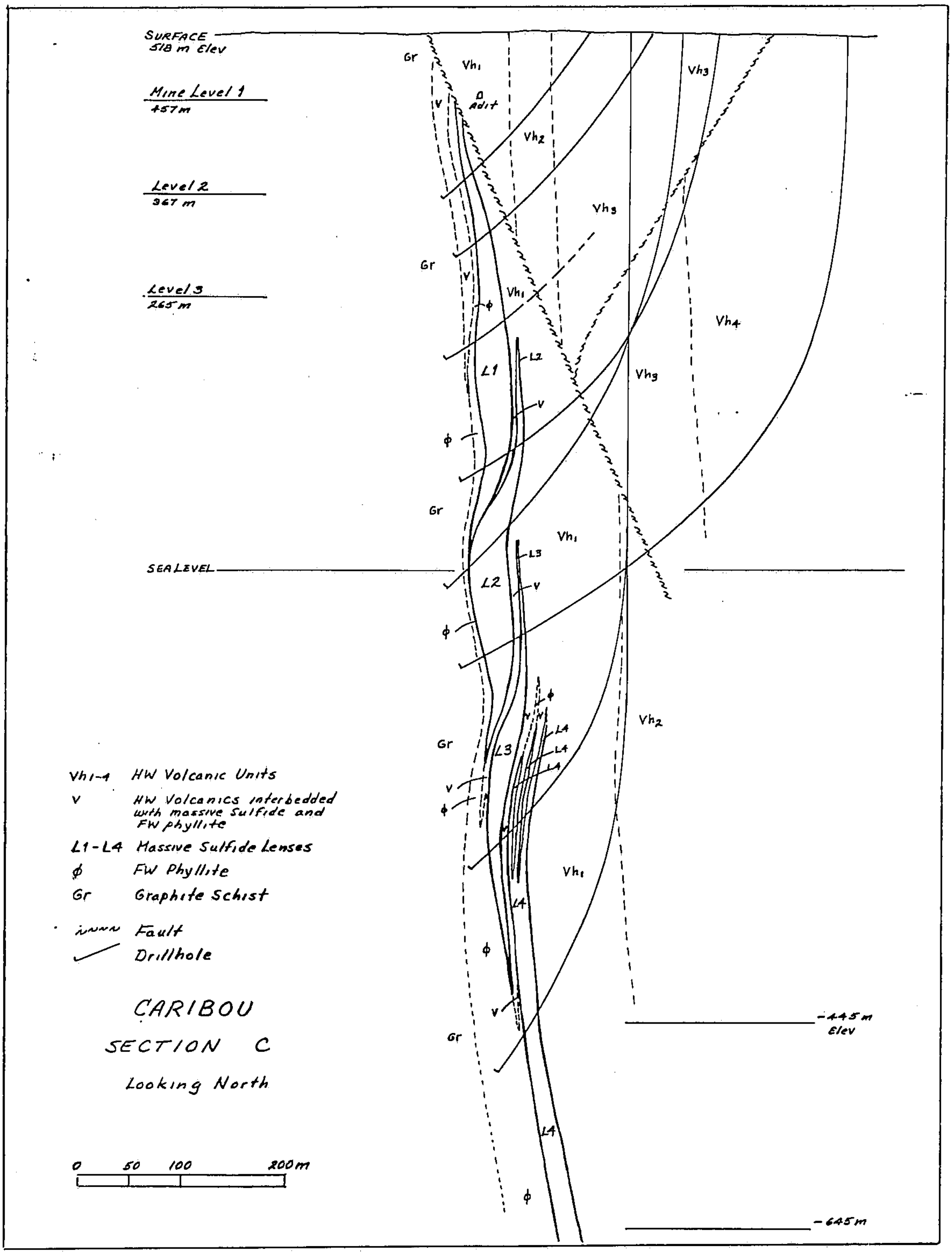

Figure CM3. Cross section "C" through the west limb of the Caribou Synform. The location of this section is shown in Figure CM2.

to flatten at depth. The northwesterly trending fault is vertical and merges with the westerly-trending fault in the hanging wall east of the massive sulphides. Movement on both faults is normal resulting in a horst block containing the south end of Lens 1 and the north end of Lens 2. This horst block has 25 m of right-lateral displacement, as well as 25 m of up-dip movement.

A myriad of minor faults and joints occur throughout the underground workings. These are generally tight, structures that have little effect on the overall continuity of the rock units, but in the sulphide lenses, these structures are comonly mineralized by quartz, siderite, ankerite, dolomite, gypsum, and chlorite. Rarely, sphalerite and galena have been remobilized and precipitated in open-space fractures adjacent to the major faults. Similarly, silver has been reprecipitated as pyrargyrite, proustite and xanthoconite in shatter zones adjacent to the major faults.

MASSIVE SULPHIDES

As noted above, the Caribou massive-sulphide deposit consists of six en echelon lenses that are folded around the Caribou Synform. From north to south on the west limb and northeasterly on the east limb, they are designated lenses 1 through 6 (Fig.CM2). The length of individual lenses ranges up to 305 m and the total length of the deposit is 1524 m. The sulphide lenses are known to extend to a vertical depth of 1200 m. Lenses 1, 2, 3 and 4 correspond to the Northeast, North, South and East Sulfide bodies described in detail by Jambor and LaFlamme (1978). For simplicity, lenses 1 to 3 will be referred to as the west-limb lenses, whereas lenses 4 to 6 will be called the east-limb lenses.

Significantly, the lenses have a pronounced rake from northeast to southwest around the fold hinge, so that at a depth of approximately 600 m below surface, the entire deposit lies along the west limb of the Caribou Synform. Within 150 m of the surface, the sulphide lenses rake at approximately 75°; below this the rake gradually flattens to about 45°. As a result of this, the deepest drill intercept in Lens 2 (1000 m below surface) lies 500 m north of its most northern surface extent in the west limb of the Caribou Synform.

Mineralogy: Even though the lenses differ in detail, certain characteristics apply to the deposit as a whole. The deposit contains approximately 90 percent metallic minerals consisting predominantly of pyrite with a significant amount of magnetite. The ore minerals, in the order of their abundance, are sphalerite, galena and chalcopyrite. Tetrahedrite, marcasite, and arsenopyrite are widespread, but minor constituents. Pyrrhotite, common in many of the deposits in the Camp, is rare. Several other minerals are present in trace amounts, with the most important being electrum and bournonite. The sulphides are very fine grained, seldom exceeding 50 microns, and can range down to microcrysts less than 1 micron across. Non-sulphide gangue minerals consist predominantly of siderite, stilphnomelane, quartz, and iron-rich chlorite with lesser amounts of dolomite, talc, minnesotaite, greenalite and chamosite. Other minerals occurring in trace amounts are described by Jambor (1981).

Texture: Banding, parallel to the lenses and wallrock contacts, is a prominent feature of the deposit and occurs in both mineralogical and textural varieties. Mineralogical banding, characteristic of the high-grade zones, consists of alternating pyritic and sphalerite/galena-rich layers. In places, there are also numerous lamina and crudely banded, ovoid to irregular clots of fine-grained, euhedral magnetite. Less commonly, chalcopyrite may alternate with pyritic layers. Textural banding is commonly developed in the low-grade pyritic zones as clusters of colloform and framboidal pyrite and as aggregates of coarse-grained, euhedral pyrite. In addition to the colloform and framboidal textures, relict fine-grained sulphide microcrysts, and microscopic inclusions of one sulphide species in another, indicate a syngenetic origin for the sulphides and probably precipitation from a colloidal sulphide gel (Chen 1978). Allogenic pyrite, locally occurring near the base of each lens and abundant in the footwall phyllite, exhibits microscopic dropstone textures that are also evidence of a sedimentary origin (Jambor 1981). The presence of fine-grained primary marcasite suggests a low temperature of formation, less than 250° C and probably around 150° C (Jambor 1981).

Zoning: Zoning is a prominent feature of the Caribou deposit; not only is a well-developed base-metal zoning pattern evident for each lens, but a progressive change in mineralogy occurs from lens to lens. Base-metal zoning is defined by assay values, with "high grade" referring to Zn + Pb content exceeding 10% combined and "low grade" referring to pyritic zones containing less than 10% Zn + Pb. Zn/Pb ratios are given for the high-grade zones only, since the low-grade zones in each lens give erratic ratios.

The **west-limb lenses** (1 to 3, Figs.CM2 and CM3) generally bear similar characteristics. Both across-layer and lateral zoning are well-defined. Across-layer zoning is manifested by high-grade Zn + Pb along the hanging wall, a pyritic zone in the center, and a copper zone along the footwall. Mineralogical banding is characteristic of the high-grade zone and the contact with low-grade pyritic zone is generally sharp, but may be gradational, locally.

Copper values are uniformly low in the high-grade zone, averaging 0.4%, but they increase to 0.6% in the pyritic zone. The footwall copper zone is best developed in the thick, central keel of lenses 1 and 2, where Cu values range from 0.7% to over 2.0%. In the upper levels of the deposit, Lens 1 has the highest overall copper content, including a zone of plus 4% in the south-central part of the lens. In the lower levels, high copper values are restricted to the footwall in the central keel of Lens 1. The central keel of Lens 2 also has a well-defined copper zone along its depth extent. Copper content diminishes in Lens 3 with no well-defined footwall copper zone, although the pyritic zone contains elevated copper values as in the other two lenses.

Lateral zoning is manifested by thickening of each high-grade Zn + Pb zone to the north in the direction of Lens 1. In this direction, very high grade tails continue beyond where the lenses pinch out. To the south, in the direction of Lens 3, the high-grade zones become thinner. As the lenses pinch out to the south, they become increasingly lower in grade and become extensions of the pyritic zone of each lens.

Zinc to lead ratios average approximately 2.7:1 for the high-grade zones of the west-limb lenses. Lens 1 has the highest ratio at 3.4:1 and Lens 2 the lowest at 2.2:1. Zn values are similar for these lenses and the change in ratios reflects a higher Pb content for Lens 2. Lens 3 has a ratios of 2.5:1 with the highest Zn and Pb content of the three.

Silver values vary proportionally with the lead content. An estimated 75% of the silver occurs in solid solution with galena (Jambor and LaFlamme 1978). The remainder occurs with gold in electrum and to a minor extent in tetrahedrite-tennantite.

Gold generally co-varies with silver and is highest in the high-grade Zn-Pb zones, where it ranges from 1.8 g/t in Lens 2 to 2.2 g/t in Lens 3. Most of the gold occurs in electrum. In the pyritic zones of the west-limb lenses, gold averages 0.8 g/t in Lens 2, 1.0 g/t in Lens 3, and 2.0 g/t in Lens 1, which is higher than the 1.9 g/t in the high-grade zone of Lens 1. The high gold content of the pyrite zones is attributed to extremely fine-grained, free gold that occurs interstitial to, and as inclusions in, arsenian pyrite and minor arsenopyrite.

In addition to the high gold content of the Lens 1 pyritic zone, a separate discreet gold zone extends from surface to a depth of 200 m. The zone rakes parallel to Lens 1, is up to 12m in width and averages 4.1 g/t. The gold zone, associated with arsenian pyrite, occurs above and north of the parallel raking high-grade copper zone of Lens 1. Locally, this gold zone overlaps the copper zone and the high grade Zn-Pb zone at its distal ends.

Magnetite is a major constituent of the west-limb lenses and is confined to discreet zones with well-defined boundaries that parallel layering. Within the zones, magnetite can occurs in bands, as large ovoid clots, irregular masses and scattered grains ("buckshot texture"). Although the magnetite zones generally lie along the footwall parts of the lenses, parallel lenticular zones are common and where the lenses thin toward their distal ends, they may extend from hanging wall to footwall. Of the three lenses, Lens 1 contains the most magnetite, both in terms of thickness of the zones and their depth extent. Magnetite in Lens 2 is confined to the upper levels of the deposit, i.e. it is absent at depth. Magnetite in Lens 3 is most abundant in the upper levels, locally overlapping the high-grade Zn + Pb zone, but in the thick pyritic zones, and the pyritic tails to the south at depth, it is confined to lenticular bodies. Magnetite is absent in the wallrocks.

Interstitial, non-metallic gangue minerals in the west-limb lenses are predominatly iron carbonates and silicates, which never exceed 10%, and typically constitute 1-5% of the lenses. In lenses 1 and 2, siderite is the dominant carbonate with subordinate dolomite and rare calcite. The dominant silicate is stilpnomelane with subordinate iron-rich chlorite and minor, widespread minnesotaite and greenalite. Talc occurs locally in Lens 1. The dominant assemblage in Lens 3 is siderite and stilpnomelane (Jambor 1981). In all three lenses, iron-rich chlorite increases toward the footwall and within a metre of the contact, it is relatively abundant (10-20%). A thin selvage of Mg-chlorite occurs in the wallrocks adjacent to both the footwall and hanging-wall contacts. This selvage apparently represents a post-depositional (metamorphic?) reaction rim.

The **east-limb lenses** (4 to 6, Figs.CM2 and CM4) exhibit significant changes in their zoning characteristics compared to the west-limb lenses. Discrete copper zones are absent; values seldom exceed 0.5% Cu and average 0.35% Cu in both the high- and low-grade Zn + Pb zones.

Across-layer, base-metal zoning is absent in the western half of Lens 4 (Lens 4 West). High-grade Zn + Pb extends from hanging wall to footwall and grades laterally to low-grade pyritic sulphide in the east as the lens thin down. Midway through the east limb Lens 4 thickens (Lens 4 East) and displays a typical across-layer zoning pattern with high-grade Zn + Pb concentrated toward the hanging wall in multiple, parallel zones alternating with low-grade pyritic sulphide. Farther east, the high-grade bands terminate by grading laterally into pyritic sulphide at the end of the lens. At depth, in the eastern part of Lens 4 East, high-grade Zn + Pb occurs along the footwall. The extent of this unusual pattern has not been tested by deep drilling. Significant differences between the western and eastern parts of Lens 4 may indicate that these two are actually separate lenses, but this cannot be proven because of the lack of good underground exposure in the critical area.

Lens 5 is a small lens between Lens 4 East and Lens 6 and terminates within 200 m of the surface. The lens is generally low grade throughout with local high-grade Zn + Pb zones in the distal tail and in the hanging wall of the western part of the lens.

Lens 6 is typically zoned with a high zone Zn + Pb tail to the west and a well-developed hanging-wall zone that extends to the east above a low-grade pyritic footwall zone. The high-grade hanging wall passes laterally into low-grade pyritic sulphide farther east at the distal end of the lens.

In the east-limb lenses, the Zn/Pb ratios average 2:1 for the high-grade zones of the east limb and range from 1.9:1 in Lens 4 West, to 2.1:1 in Lens 6. The hanging-wall zone in Lens 4 East is more typical of the west-limb lenses at 2.8:1. The overall lower Zn/Pb ratio of the east limb compared to the west-limb lenses is the result of a higher Pb content because the combined Zn + Pb grade is similar to that of the west limb.

Some fluctuations in silver content are related to argentiferous galena rather than argentiferous tetrahedrite-tennantite. In the low-grade pyritic zone along the footwall in the eastern part of Lens 4, silver values drop abruptly at the transition from high-grade to low grade Zn + Pb and remain low. Local fluctuations correlate with lead grade and indicate either that tetrahedrite-tennantite is not argentiferous or is absent. Data are lacking for Lens 5 and most of Lens 6.

Gold values in the high-grade Zn + Pb zones of the east-limb lenses show no relationship to Zn, Pb, and Ag grade and range from 0.3g/t to 1.0 g/t in a given interval. The average grade for Lens 4 West is 0.9 g/t and for Lens 6 is 0.8 g/t. The low-grade pyritic zones of the east-limb lenses are consistently low, averaging approximately 0.25 g/t. It is likely that most of the gold occurs in electrum, but Jambor (1981) reported 2-3% arsenopyrite in Lens 4 West so there may be a gold/arsenopyrite association. No assays are available for Lens 4 East.

The east-limb lenses contain considerably less magnetite than the west-limb lenses. Lenticular zones of magnetite occur locally toward the footwall of the pyritic zone of Lens 4 West. The mineral is absent in Lens 5 and only occurs locally in the pyritic footwall of Lens 6. Magnetite is most abundant in Lens 4 East, where it forms irregular

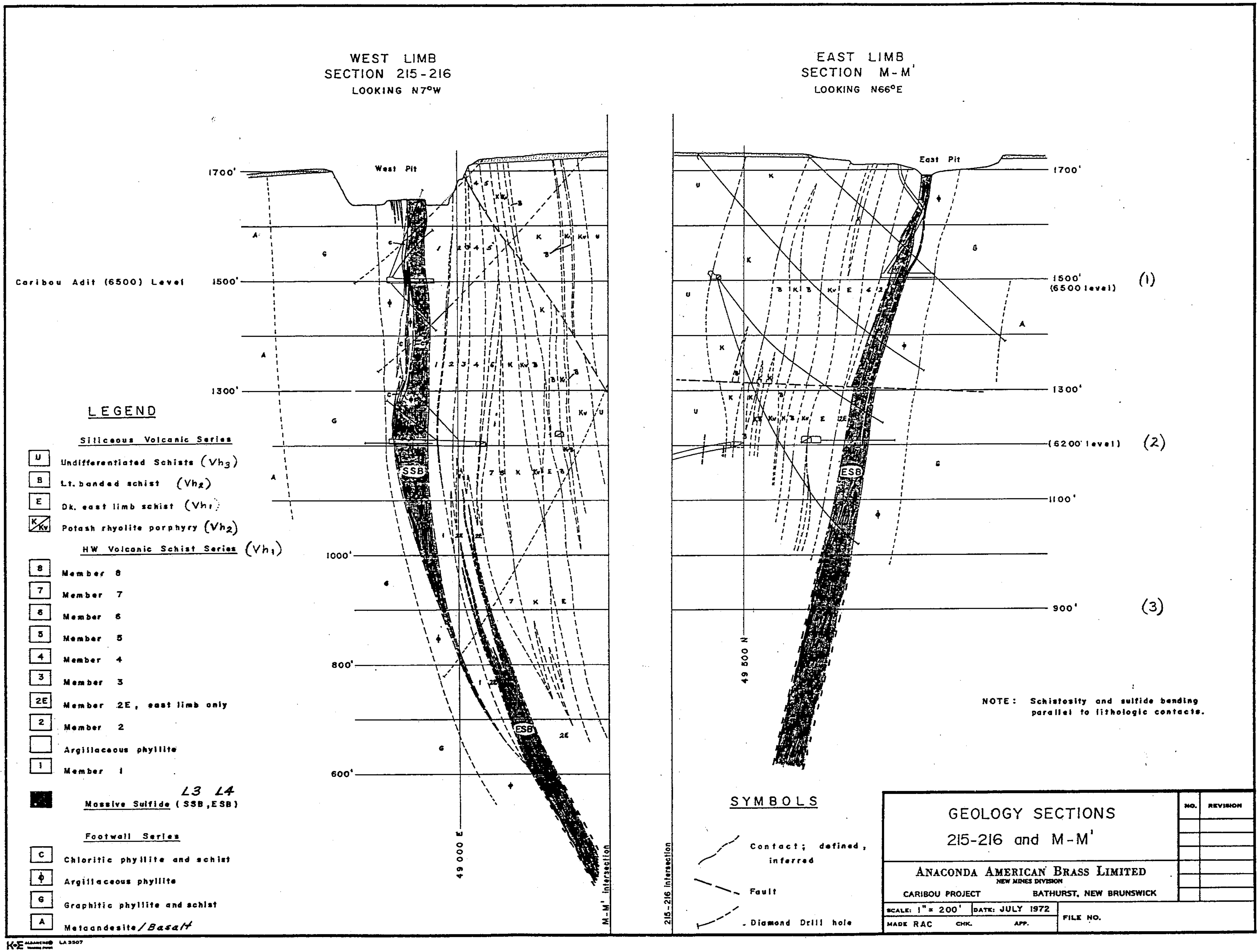

Figure CM4. Cross sections 215 - 216 and M -M' through the Southern (SSB) and Eastern (ESB) sulphide bodies, lenses 3 and 4 respectively, near the axis of the Caribou Synform. The locations of these sections are shown in Figure CM2.

bands and disseminations within parallel zones along the footwall part of the lens, i.e generally in low-grade massivesulphide but locally in the atypical high-grade zone on the footwall of this lens.

The gangue mineralogy within the high-grade Zn + Pb zones of Lens 4 West and Lens 6, in contrast to the west-limb lenses, is dominated by two forms of quartz. The first type is cryptocrystalline silica that occurs as small lenses and patches within individual sulphide laminae and it constitutes 5-15% of the massive sulphide. The second type forms separate quartz lamina (recrystallized chert) that are interlayered with massive sulphide. These interlaminated horizons vary from a few centimetres to over a metre in thickness and can be traced for more than 100 m along strike. Semi-massive sulphide layers result where the quartz lamina exceed 50% of the interval. Locally, the laminated quartz (chert) grades into quartz-sericite phyllite interbeds within the massive sulphide. Near the hanging-wall contact of Lens 4 West, between finely laminated-massive sulphide layers, is a metre-wide zone of interlayered sulphide and quartoze phyllite, which has been traced for more than 150 metres along strike and down dip.

The massive, low-grade pyritic zones of the east-limb lenses are characterized by an interstitial gangue assemblage of stilpnomelane, siderite, chlorite and minor quartz. The quartz is most abundant toward the hanging wall, whereas chlorite increases toward the footwall. Semi-massive layers of interlaminated phyllite and sulphide commonly occur within the massive sulphide and, locally, along the footwall, but to a much lesser extent than in the high-grade zones of Lens 4 West and Lens 6. Stilpnomelane-chlorite phyllite predominates, but quartz phyllite occurs locally.

ALTERATION AND METAMORPHISM

The footwall phyllite shows a noticeable increase in chlorite and disseminated pyrite towards the massive sulphides. Graphite is conspicuously absent in the footwall phyllite directly beneath the deposit and chlorite is rare, except near lenses 2 and 3 as described previously. The chlorite is Fe-rich and most abundant near Lens 2, called the North Sulphide Body by Jambor (1981), which coincidently is also a Cu-rich part of the deposit. These chloritic rocks are interpreted to have been formed by alteration of the footwall sediments from above, rather than by alteration from below because there is no stringer sulphide zone beneath these chloritic rocks (Jambor 1979, 1981). The altered footwall rocks generally have higher Fe, Mn, Co, and Ni but lower K and Ca contents than the rocks of the *hanging-wall sequence* (Gandhi 1977).

The *hanging-wall sequence* close to the massive sulphides is rich in white micas and contains minor Mg-Fe chlorite (Gandhi 1977; Jambor 1981) although some K-feldspar phenocrysts are still preserved. Anomalous Cu, Pb, Zn, Co, Ni, Mg, Fe, Mn, and Hg are most closely associated with the mineralization and form a halo 600 m long and 200 m wide (Gandhi 1977); K and F decrease with proximity to the massive sulphides.

The effects of metamorphism on the sulphides are evidenced by a general recrystallization to a fine-grained granoblastic texture with authigenic overgrowths and development of coarse-grained, euhedral aggregates from the colloform and framboidal pyrite in the low grade pyritic zones. Irregular fine-grained intergrowths of the ore minerals with pyrite and granoblastic texture in the pyrite layers are typical of the high-grade zones (Chen 1978). Despite the pervasive schistosity in the wallrocks, the foliation in the sulphides is only apparent microscopically and is defined by: (1) elongated sutured pyrite aggregates, (2) oriented fragments of broken pyrite, (3) oblate pyrite framboids, (4) laminae of sphalerite, chalcopyrite, and galena, (5) lens-shaped sphalerite grains, (6) microlaminae of aligned platy pyrite crystals, and (7) sulphide pressure shadows (Davis 1972).

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ROAD LOG FOR EXCURSION TO THE CARIBOU MINE

Depart from Keddys Hotel and proceed via St. Peter Avenue and Vanier Blvd. to the overpass above Highway 11 (Exit 310). At this point Vanier Blvd. becomes Route 180, also called the Road to Resources. This is the starting point of the road log.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Proceed westward on Route 180.
9.6	9.6	The turn-off into the Tetagouche Falls provincial picnic site is on the right (north) side of the road. Continue west on Route 180.
12.7	22.3	Cross-roads; the Arsenault road is on the left (south) and the road to Elmtree Resources' limestone quarry is on the right. Continue west on Route 180.
22.0	44.3	Turn left (southwest) off Route 180 onto the road leading to the Caribou Mine.
1.0	45.3	Junction (Caribou Depot) with the old Caribou road is on the left (south); bear right.
2.9	48.2	Front gate and parking lot of the Caribou Mine; park and proceed to the mine office.
STOP C-1:		Plans, sections and diamond drill cores from the deposit will be on display.
STOP C-2:		Massive sulphides and hanging-wall schists can be seen in the Caribou open pit.
0.0	0.0	Return to the vehicles and drive back to Route 180. Reset the road log to zero.
0.1	0.1	Turn left (northwest) onto Route 180.
STOP C-3:		The outcrop on the left (southwest) side of the road consists of highly deformed, sparsely porphyritic felsic volcanic rocks, which are along strike from Unit Vf_5 of the *lower-footwall sequence* (Fig.CM1). These rocks were assigned to the Flat Landing Brook Formation by van Staal (Fig.CM5).
1.8	1.9	Continue northwest on Route 180.
STOP C-4:		The outcrop on the right (northeast) side of the road comprises schistose and sericitic, orthoclase-porphyritic rhyolite that is along strike from Unit Vf_6 of the *lower-footwall sequence.*
0.3	2.2	Continue northwest on Route 180.
STOP C-5:		The outcrop on the right (northeast) side of the road consists entirely of grey phyllites of the footwall-sedimentary unit. The Caribou Horizon should be just northwest of this outcrop.

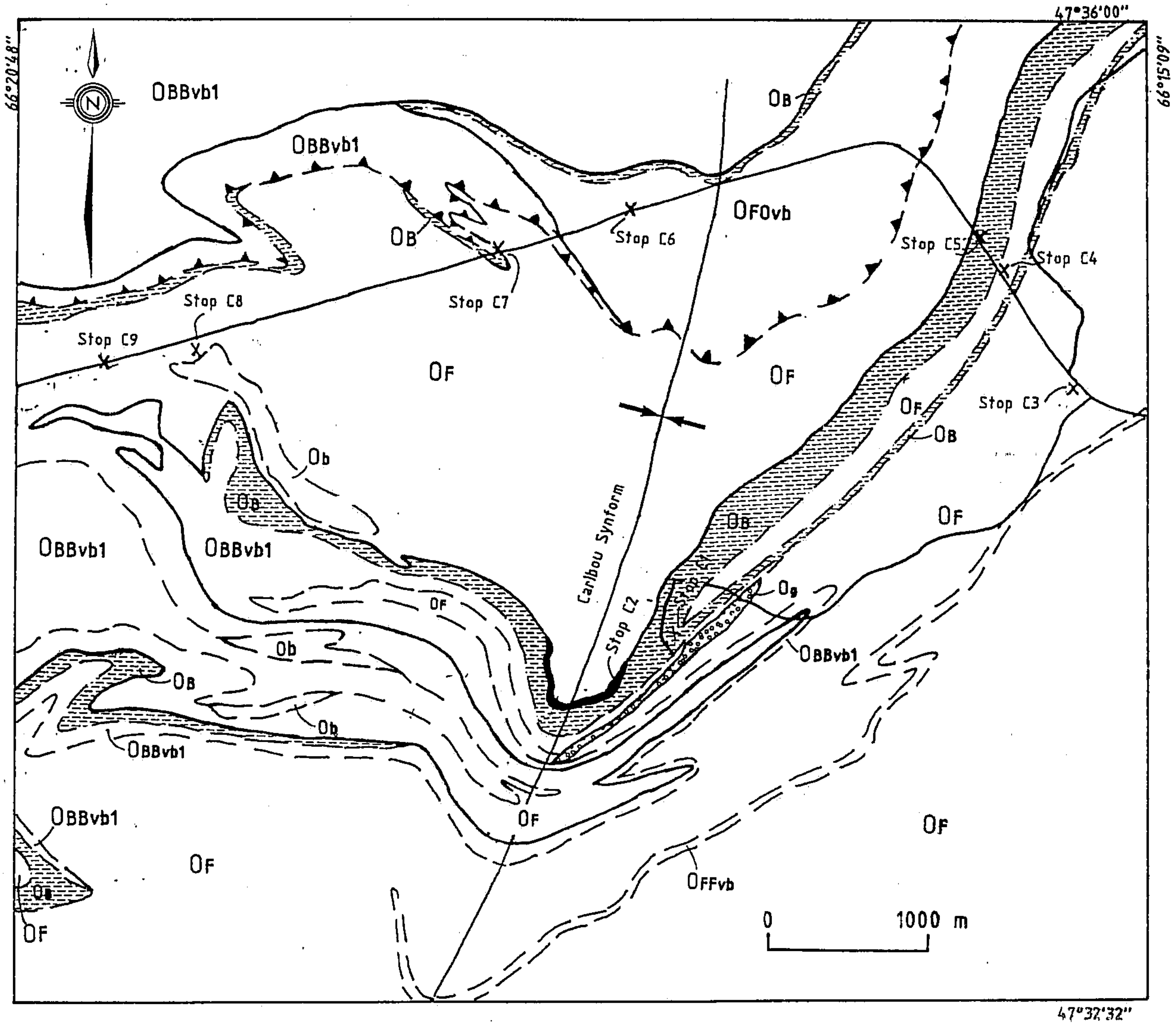

Figure CM5. Simplified geological map of the Caribou Mine area showing stop locations. Modified from van Staal (1991). Unit designations as follows: OF = Flat Landing Brook felsic volcanic rocks; OFFvb = Flat Landing Brook tholeiitic basalt (Forty Mile Brook type); OFOvb = Flat Landing Brook tholeiitic basalt (Otter Brook type); OBBvb1 = Boucher Brook alkali basalt (Brunswick type); OB = Boucher Brook sedimentary rocks (dashed pattern); Ob = gabbro; Og = granite (circle pattern); black = massive sulphides.

Distance (in km)	Cumulative Distance	Description
0.9	3.1	The side-road on the right goes past the outcrop where blueschist was first discovered in the Bathurst Camp. At this point Route 180 has a west-southwest, rather than northwest, orientation.
1.6	4.7	Continue westward on Route 180.
STOP C-6:		The roadcut on the right (north) consists of highly deformed basalts (blueschists) of the Fournier Group. The rocks have a distinctive bluish coloration.
1.0	5.7	Continue westward on Route 180.
STOP C-7:		The roadcut on the left (south) behind the bushes shows the tectonic contact (Fig.CM5) between schistose rhyolite and maroon shale with some mafic phyllonite. The mafic phyllonite can be walked out into blueschists. The schistose rhyolite can be walked out into the feldspar-phyric rhyolite that is in the next roadcut, 150 m farther west. The sedimentary rocks are part of the footwall-sedimentary unit, whereas the rhyolite is part of the *hanging-wall sequence* (Fig.CM1).
1.8	7.5	Continue westward on Route 180.
STOP C-8:		The outcrop on the left (south) comprises highly deformed, orthoclase-porphyritic rhyolite of the *hanging-wall sequence.*
0.5	8.0	Continue westward on Route 180.
STOP C-9:		The rusty rocks in the roadcut on either side of the highway consist of massive, orthoclase-porphyritic rhyolite containing abundant quartz veinlets and pyrite, both disseminated and in stringer veinlets. Deformation is very mild in contrast to the previous stop, probably because the rocks were silicified prior to deformation. The euhedral feldspar phenocrysts are up to 5 mm long, show baveno as well as carlsbad twins, and are, in part, altered to chess-board albite. This rhyolite body forms the hanging wall to the Caribou massive-sulfide deposit.
13.9	21.9	Continue westward on Route 180 to the turn-off to the Murray Brook deposit.

THE MURRAY BROOK (Cu-RICH) MASSIVE-SULPHIDE DEPOSIT, BATHURST CAMP, NEW BRUNSWICK

D.M. Burton[1]

INTRODUCTION

The Murray Brook Cu-Zn-Pb deposit is located in Restigouche County, approximately 60 km west of the city of Bathurst. This deposit is one of the largest massive sulphide deposits in the Bathurst Mining Camp with total sulphide reserves of 21.5 million tonnes at a grade of 0.48% Cu, 0.66% Pb, 1.95% Zn and 31.4 g/t Ag (Perusse 1958). This deposit was discovered in 1956 but not developed until Murray Brook Resources commenced open-pit mining of the precious-metal-rich gossan (1.9 million tonnes grading 1.52 g/t Au and 65.86 g/t Ag) in 1989. The gossan was exhausted in 1992 with total production of 1.413 million grams (45 434 ozs.) Au and 10.78 million grams (346 457 ozs.) Ag. The second phase of mine development is centred on exploitation of a near surface copper zone by open-pit mining.

EXPLORATION HISTORY

The Murray Brook claim group was originally staked by Kennco Exploration in 1955 on the basis of an airborne electromagnetic (EM) survey. Ground follow up and drilling of these EM anomalies failed to uncover mineralization. Stream-sediment geochemistry that was initiated after finding mineralized float was ultimately responsible for the discovery of the deposit in 1956 (Perusse 1958; Fleming 1961). This makes the Murray Brook deposit one of the first geochemically discovered deposits in the Bathurst Camp (Rennick and Burton 1992). By 1958, Kennco had calculated reserves of 21.5 million t of 2.81% combined Pb-Zn.

LOCAL GEOLOGY

The Murray Brook massive-sulphide appears to sit stratigraphically near the contact between two major rock units. The older one comprises dark grey slate and quartz ± feldspar wacke, which occupy the core of a northeasterly to northerly trending, F_1 anticline (Fig.MB1). These rocks were assigned to the Knights Brook Formation by vzn Staal (1991) but to the Patrick Brook Formation by Rennick and Burton (1992). The younger unit consists of quartz-feldspar phyric volcanic and volcaniclastic rocks that conformably (and gradationally ?) overlie the older one. The younger rocks were assigned to the Flat Landing Brook Formation by van Staal (1991) but to the Nepisiguit Falls Formation by Rennick and Burton (1992). Although it appears likely that Murray Brook is comparable to Heath Steele, i.e. at or near the Patrick Brook-Nepisiguit Falls contact, this cannot be demonstrated unequivocally because, at the deposit, the Patrick Brook is overthrust by mafic volcanic and sedimentary rocks of the Boucher Brook Formation. This thrust contact can be observed in drill core.

The deposit sits in a northerly-trending, parasitic F_1 synform that is overprinted by northwesterly trending F_2 folds. Two strong fabrics are evident in the rocks. However, S_2 dips about 40° N and is axial planar to the very tight F_2 fold that gives the sheath-like form to the deposit (Rennick and Burton, 1992). This form results from the interference between southeasterly overturned F_1 folds and southwesterly overturned F_2 folds. The high abundance of quartz and Fe-rich chlorite in the structural footwall of the deposit compared to the structural hanging-wall and the presence of carbonate in the hanging-wall sedimentary rocks, features noted by Rankin (1982), suggest that the most proximal part of the deposit is in the structural footwall. Furthermore, the highest Cu abundances are also in the structural footwall of this sheath-like fold.

MASSIVE SULPHIDES

The entire deposit has total sulphide reserves of 21.5 million tonnes at a grade of 0.48% Cu, 0.66% Pb, 1.95% Zn

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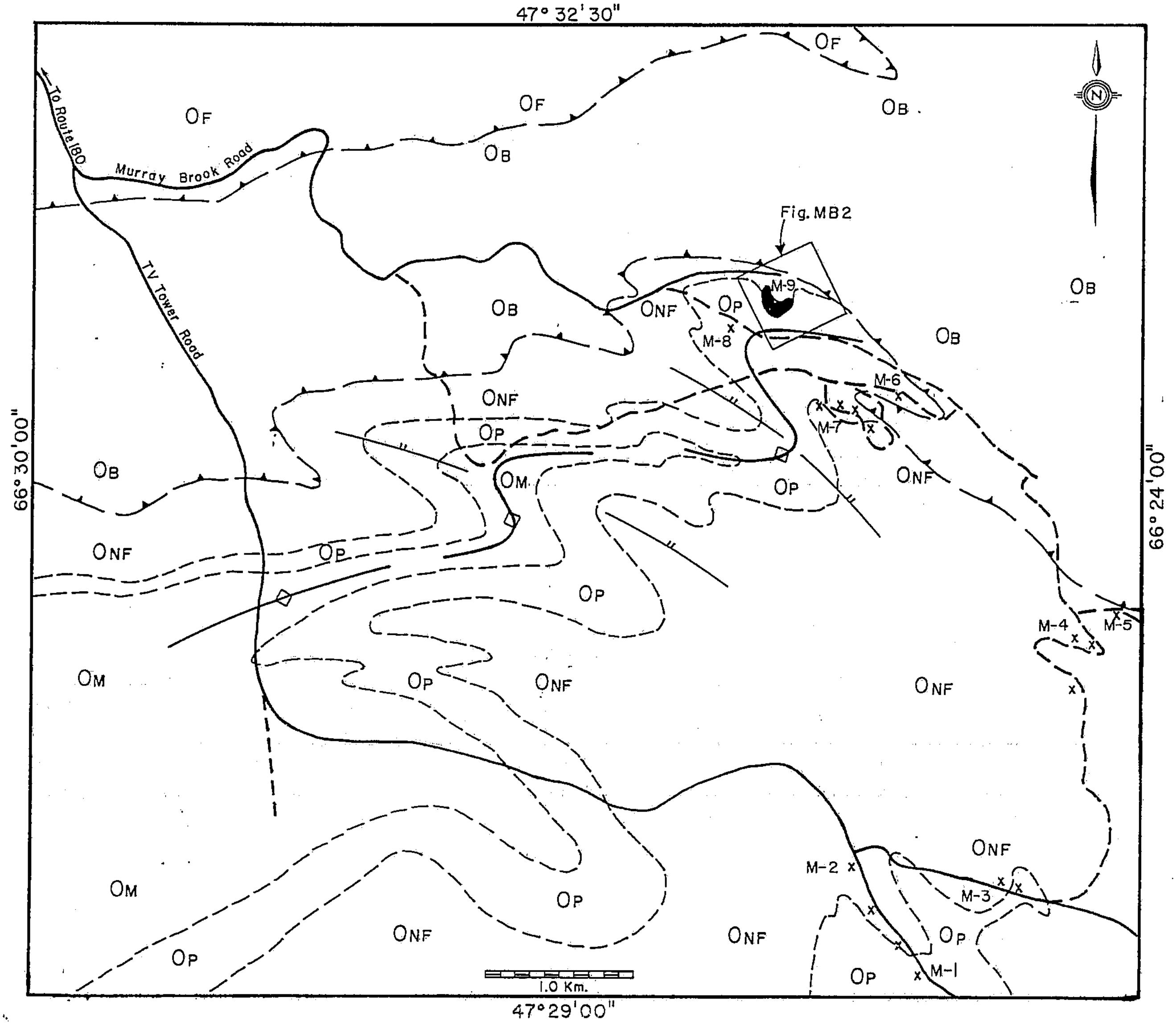

Figure MB1. Simplified geology map of the area around the Murray Brook deposit (modified from van Staal 1991). OM - Miramichi Group; OP - Patrick Brook Formation, ON - Nepisiguit Falls Formation; OB - Boucher Brook Formation; OF - Fournier Group. Symbols as follows: dashed line = approximate geological contact; dashed line with teeth = thrust contact; heavy line with diamond = F_1 anticlinal axis; dashed line with double tick = trend of S_2 foliation.

and 31.4 g/t Ag (Perusse 1958). The deposit is dominantly pyritic with lesser proportions of sphalerite, galena, chalcopyrite, arsenopyrite, magnetite, pyrrhotite, marcasite, and tetrahedrite (Rankin 1982). Pyrite occurs as framboidal, botryoidal, colloform, and sieve textures, euhedral to subhedral grains and subgrains and as euhedral. porphyroblasts (Rankin 1982). Although common as inclusions in pyrite, pyrrhotite accounts for less than 1% of the sulphides present. As noted by Rankin (1982) and Rennick and Burton (1992), three types of sulphide zones can be distinguished, namely massive pyrite zones, layered Pb-Zn zones and Cu zones. The Cu zones have subsequently been divided into low-grade and high-grade zones for mining purposes. Only the copper zones are described below.

COPPER ZONES

Previous drilling by Kennco, Canex Placer and Northumberland Mines had intersected high-grade, primary copper zones within the Murray Brook massive sulphide deposit. Assessments of the copper zones assumed a lateral distribution of copper based upon vertical drill intercepts to a depth of 200 metres. Structural analysis of the Murray Brook deposit has largely reflected interpretations of metal zonation (Pitman 1984; Rennick and Burton 1992). These interpretations suffered from poor stratigraphic control because both the hanging-wall and footwall sedimentary sequences comprise monotonous quartzose and schistose rocks lacking any definitive marker horizons. Evaluation of the zones in this manner established geologic reserves of 2,860,000 tonnes of 2.12% Cu (Pitman 1984) and more recently 2,331,000 tonnes of 2.04% Cu (Rennick and Burton 1992).

Following removal of the auriferous gossan, NovaGold Resources undertook an evaluation of the high-grade copper zone immediately underlying the gossan that was believed to be related entirely to supergene enrichment. Structural contouring of the footwall contact based on drilling prior to 1989 defined a north-plunging synform, the east limb of which coincides with the known high-grade copper mineralization (Figs.MB2 and MB3). Detailed drilling by NovaGold in the immediate open pit permitted detailed definition of the massive sulphide/footwall sediment contact. Drilling employed a series of east-directed, inclined holes to test for a steeply dipping primary copper zone paralleling the sulphide/footwall contact.

Drilling defined a primary copper zone comprising some 75,576 tonnes (80,000 tons) at a grade of 7.4% Cu. The narrow dimensions and steeply dipping attitude of the zone, and its proximity to the gossan/sulphide interface, account for the difficulty in recognizing the primary nature of the zone prior to the inclined drilling program (Fig.MB3). Future drilling will address the possibility of delineating mineable reserves of high grade copper zones for an underground operation. Economic grades over mineable widths are known from Kennco and Canex Placer drill holes to a vertical depth of 200 meters (Fig.MB2). Close-spaced drilling is required to determine the continuity and nature of these intersections. Hole CP-30 may have intersected a stringer copper zone in the immediate footwall (6.56% Cu/19.8 meters) based on descriptions from the drill logs. No core was preserved from the Kennco or Canex Placer programs.

In the fall of 1992, approximately 50,000 tonnes of massive sulphides were mined, crushed and delivered to leach pads constructed above the open pit. This ore comprised a mixture of low-grade primary and secondary copper ore and high-grade primary copper ore averaging 2.50% Cu. Attempts to start the outdoor bio-assisted, sulphuric acid leach process in November of 1992 were unsuccessful because of cold temperatures. NovaGold Resources Inc. entered into a joint venture agreement with Arimetco International/Breakwater Resources to evaluate the feasibility of processing the bulk of the open pit copper reserves at the Caribou mill (11 km east of Murray Brook), in conjunction with a summer leaching operation. Metallurgical testing by Arimetco International has determined that both primary and secondary copper ores at Murray Brook are amenable to floatation providing that zinc concentrations are below 0.5%. Definition drilling by the joint venture established a mineable reserve of 386,455 tonnes at a grade of 2.98% Cu that is amenable to floatation at the Caribou mill. Zinc-rich copper ores would be selectively mined and delivered to the leach pads for processing. The bio-leach process will produce a copper cement.

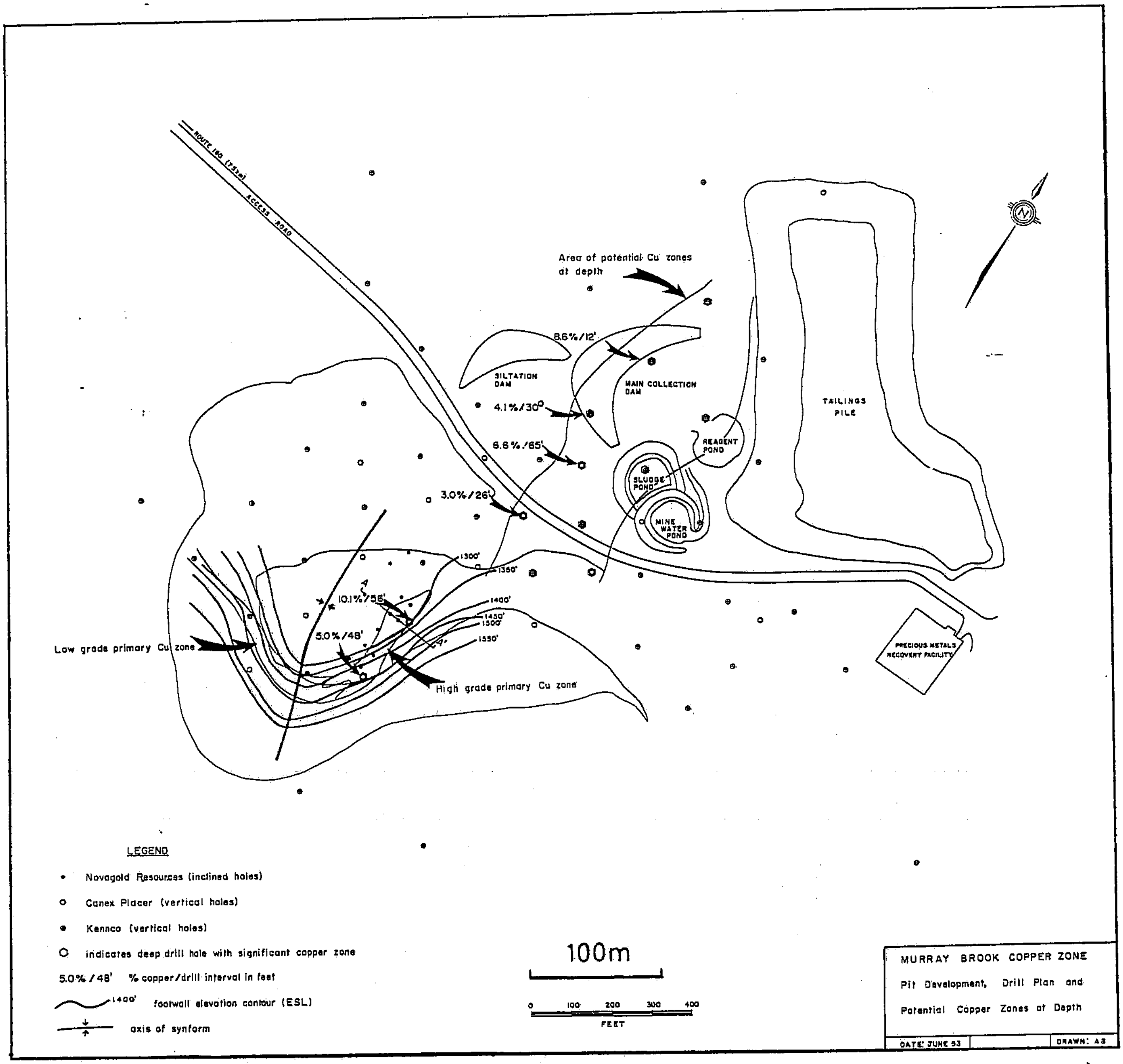

Figure MB2. Plan view of the Murray Brook mine area (see Fig.MB1 for location). The primary copper zone in the open pit parallels the footwall contact. Wide-spaced vertical drilling has intersected high grade (3-8%) Cu within a broad zone of significant (1-3%) Cu mineralization.

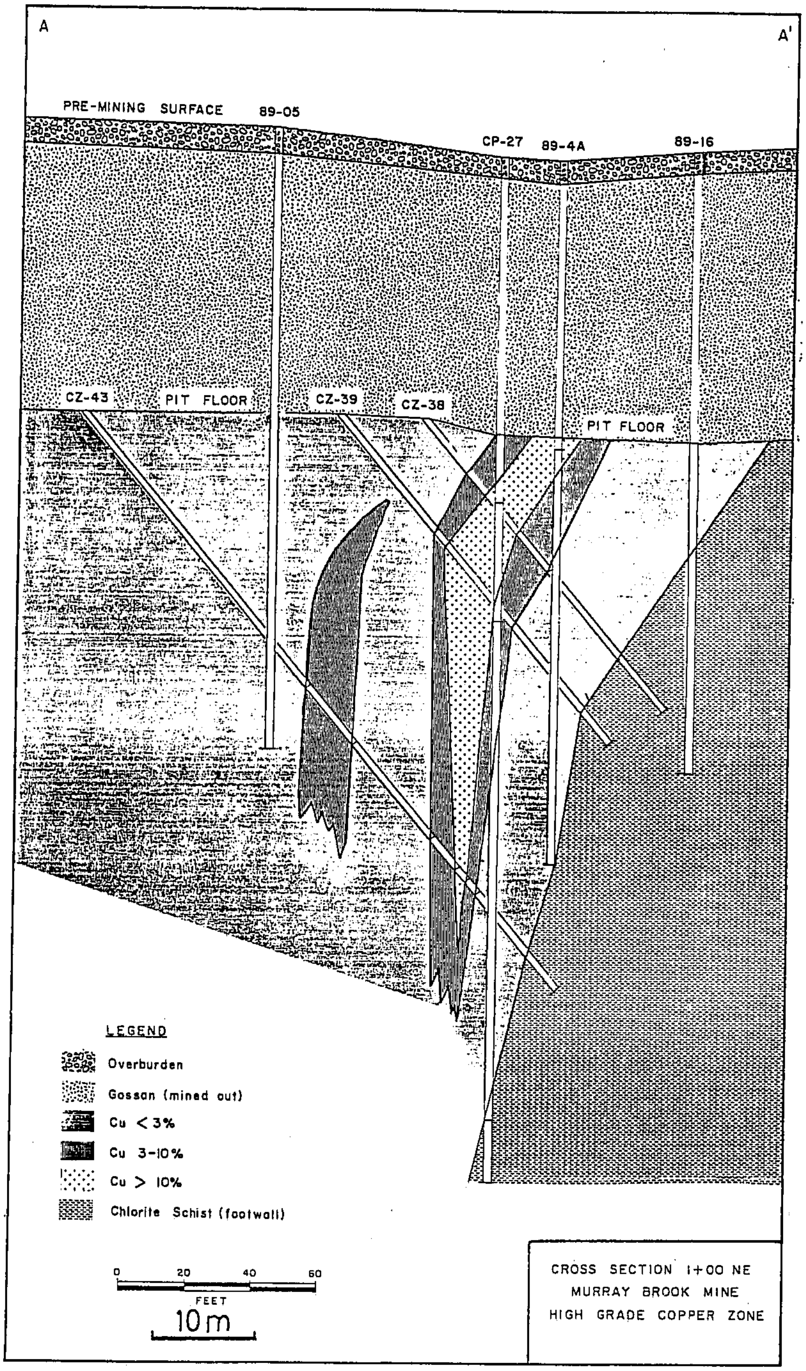

Figure MB3. Geologic cross section through a high-grade primary copper zone. Note the steeply dipping attitude of the zone that parallels the footwall contact. These lenses can be easily missed by wide-spaced vertical drilling (see Fig.MB2 for location of section A-A').

GOSSANS

The Murray Brook gossan developed as a result of a prolonged period of oxidationand weathering of the underlying massive sulphide deposit. To date, it has been the largest gossan found in the Bathurst Camp. Prior to mining the gossan was up to 70 m thick in areas and subdivided into barren gossan, fertile gossan, gossanous breccia, quartz sand, pyrite sand, and altered massive sulphide (Boyle and Burton 1990). The gossan consisted of two textural units (cellular and pseudomorphic replacement) composed of goethite, primary and secondary quartz, plumbojarosite, jarosite, beudanite, and cassiterite. The gossanous breccia represents replacements along late faults crosscutting the sulphides. The altered massive sulphide consists of chalcopyrite that has been converted to covellite and bornite (Boyle and Burton 1990).

Continuous year-round processing of gossan from the Murray Brook deposit from September 1989 to February 1992 yielded 1.41 million grams (45 434 ozs.) Au and 10.78 million grams (346 457 ozs.) Ag from 1,013,867 tonnes (1,117,597 short tons) of ore with an average head grade of 1.79 g/t (0.052 oz/t) Au and 61.38 g/t (1.78 oz/t) Ag). Modifications to the indoor vat leach facility during production increased gold recovery to 85% during the last 18 months of operation. An additional 28,708 g (923 ozs.) Au and 945,763 g (30,407 ozs.) Ag were recovered during re-processing and clean-up operations prior to final shut-down in August 1992.

ACKNOWLEDGEMENTS

Reviews of earlier versions of this manuscript by Dave Lentz and Steve McCutcheon improved this final product. I also wish to thank Steve McCutcheon and Alain Caron for providing the road log.

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ROAD LOG FOR EXCURSION TO THE MURRAY BROOK MINE

The road log for this segment of the trip begins at the junction of Route 180 and the TV-Tower road. This junction is 66.2 km west of Exit 310 (at Hwy.11) on the outskirts of Bathurst, or 21.9 km from the turn-off to the Caribou Mine.

Distance (in km)	Cumulative Distance	Description
0.0	0.0	Turn left (south) from Route 180 onto the TV-Tower road.
1.0	1.0	The junction with the road to the Murray Brook Mine is on the left (east). At the end of the excursion you will be returning to this point via the Murray Brook road. Continue straight on the TV-Tower road.
3.9	4.9	At the forks in the road, bear left (southeast).
4.6	9.5	The road on the left (east) leads to STOP M-3; continue straight on the TV-Tower road.
1.0	10.5	Stop at the large outcrop on the right (west) side of the road (Fig.MB1).
STOP M-1:		The outcrop consists of dark grey slates interbedded with fine grained quartz wackes of the Patrick Brook (or Knights Brook ?) Formation. A complex fold-interference pattern is visible on the easterly dipping face. The upright folds that plunge about 30° to the north-northwest overprint northeasterly trending, minor folds that are overturned to the southeast. On the same side of the road but about 100 m to the northwest, there are rusty boulders (subcrop) of fine-grained volcaniclastic rocks; 250 m farther along there is an outcrop of quartz-feldspar porphyry (tufflava) of the Nepisiguit Falls Formation. The rusty boulders are at, or near, the contact between the two formations, i.e. they represent the Murray Brook Horizon.
0.9	11.4	Turn around and drive back to the outcrop on the left (west) side of the road, which is approximately 100 m from the junction described before STOP M-1.
STOP M-2:		This outcrop consists of quartz-feldspar porphyritic tufflava (porphyry) with two well-developed folaitions. Both have a northerly trending strike but one dips steeply west (170/75°) and the other dips shallowly east (350/35°). The shallowly dipping cleavage is at least S_2, if not S_3.
0.1	11.5	Continue north to the junction and turn right (east) onto the side-road.
0.8	12.3	Proceed east to the small outcrop on the left (north) side of the road.
STOP M-3:		In this outcrop, the Nepisiguit Falls tufflava exhibits a southerly overturned mesocopic fold with an axial-plane cleavage that dips moderately to the north (275/50°). This is at least an F_2 fold, if not an F_3. About 100 m farther along there is a small outcrop of fine-grained volcaniclastic rocks in the roadbed. These rocks mark the transitional contact with the underlying Patrick Brook Formation.

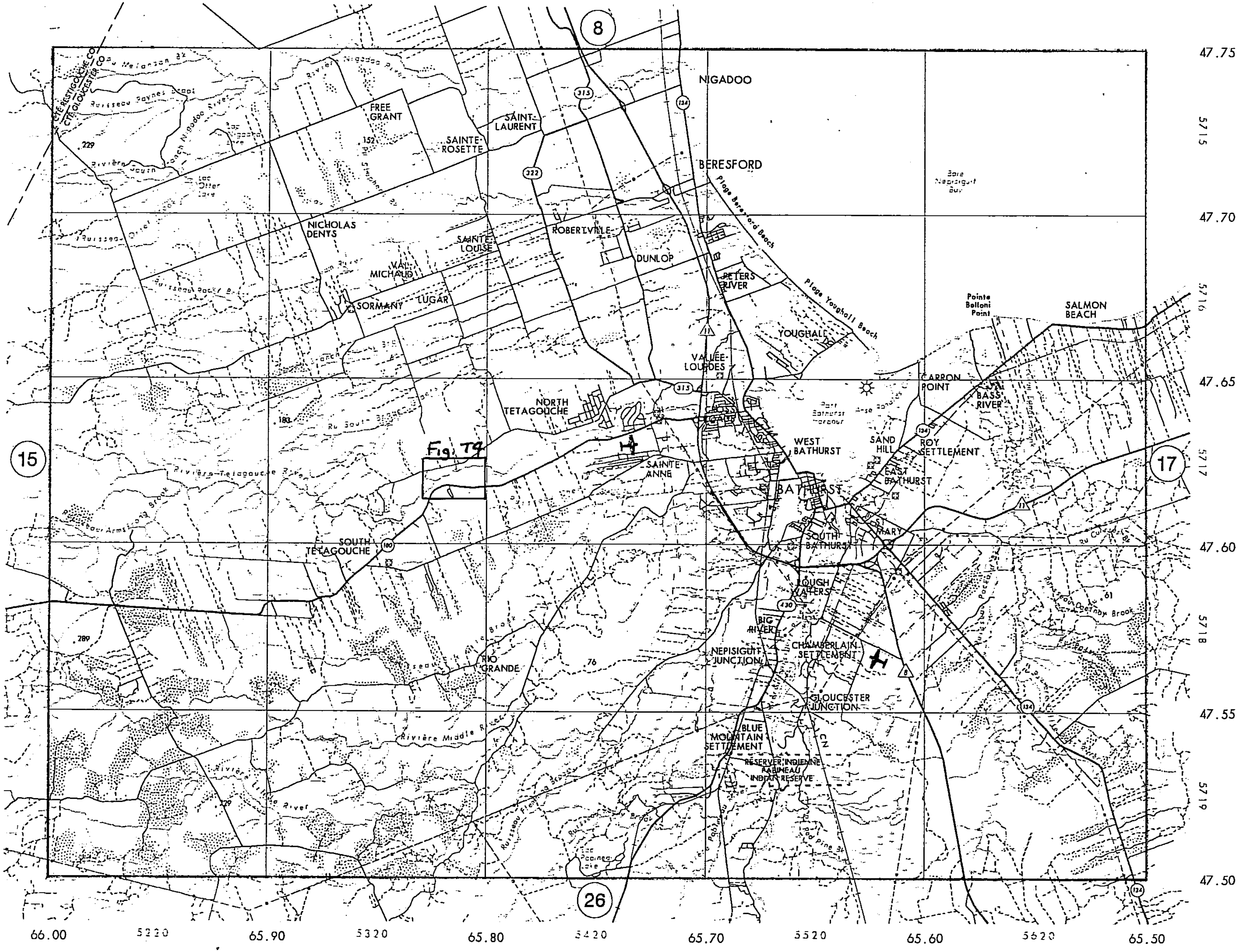
Distance (in km)	Cumulative Distance	Description
0.7	13.0	Continue eastward and at the forks in the road bear left (north).
0.9	13.9	The outcrop on the left (west) side of the road is Nepisiguit Falls tufflava.
0.7	14.6	Another outcrop of tufflava occurs beside the road in the edge of the spruce plantation.
0.6	15.2	Park at the wide spot on the left (north) side of the road.
STOP M-4:		There is a small outcrop in the edge of the trees to the north. This outcrop consists of quartz-feldspar porphyritic tufflava similar to that seen in the previous stops. Two cleavages are evident: one strikes easterly and dips south (096/67°), whereas the other strikes northwesterly and dips steeply east (288/73°). The strike of the latter cleavage is more or less parallel to the thrust contact with rocks of the Boucher Brook Formation, which is about 400 m to the northeast. The northwesterly trending cleavage is at least S_2.
0.4	15.6	Continue eastward around the hairpin turn [WATCH FOR LOGGING TRUCKS]. There is another outcrop of tufflava on the left.
0.3	15.9	The road swings sharply right (east) at this point; the less travelled side-road on the left, into the jackpine plantation, leads to the Murray Brook Mine. Bear right.
0.3	16.2	At the forks in the road park and walk to the nearby outcrops.
STOP M-5:		The outcrops near the forks are Nepisiguit Falls tufflavas. About 200 m farther along the left-hand fork, there are outcrops of Boucher Brook basalts. The thrust contact between the two units is in the concealed interval between the two groups of outcrops.
0.3	16.5	Turn around and proceed back to the junction by the jackpine plantation.
0.5	17.0	Turn right and proceed north to the forks in the road. Through the trees to the right a ridge of outcrop is visible; this outcrop is of Boucher Brook basalt.
0.4	17.4	At the forks, bear right and continue to the clearing. Bear right in the clearing; 100 m farther along the road swings sharply left. Continue northwesterly.
1.1	18.5	At the junction with the side-road, turn left (southeast).
0.2	18.7	Proceed up the hill to the right and stop at the first outcrop along the left side of road.
STOP M-6:		Rusty, pyritic Patrick Brook rocks crop out intermittently for about 100 m along the road. There are at least two foliations with the second one striking northwesterly (325/60°).

Distance (in km)	Cumulative Distance	Description
0.5	19.2	Continue westerly, past the first side-road to the second one; turn left.
0.2	19.4	Drive south to the T-junction and park.Proceed on foot from here.
STOP M-7:		The outcrop near the junction consists of fine-grained volcaniclastic rocks that mark the transition between the Patrick Brook and Nepisiguit Falls formations. To the east, along the road for about 200 m, there are low-relief outcrops of dark grey slate and quartz wacke. Another 100 m farther, there is another small outcrop of volcaniclastic rocks along the left side of the road.
0.9	20.3	Return to the vehicles and drive to the junction preceding STOP M-6 (at 18.5 km).
1.4	21.7	Turn left (northwest) at the junction and proceed to the point overlooking the Murray Brook Mine site.
STOP M-8:		Photo opportunity. See Figure MB2 for the site plan. About 100 m farther along the road there is a small outcrop of Patrick Brook rocks on the left.
1.0	22.7	Continue northwest to the junction with the Murray Brook road. Turn right (east) toward the mine site.
0.9	23.6	Murray Brook Mine.
STOP M-9:		Participants will view plans and sections, examine representative drill cores through the deposit, and tour the processing facilities.

APPENDIX I

Road Maps of Tetagouche Lakes (21O/9), Bathurst (21P/12), California Lake (21O/8) and Nepisiguit Falls (21P/5) map-areas[1]

[1] *These maps are extracted from "New Brunswick Maps", the map-book that was published by the New Brunswick Geographic Information Corporation in 1993.*



BATHURST 21P/12

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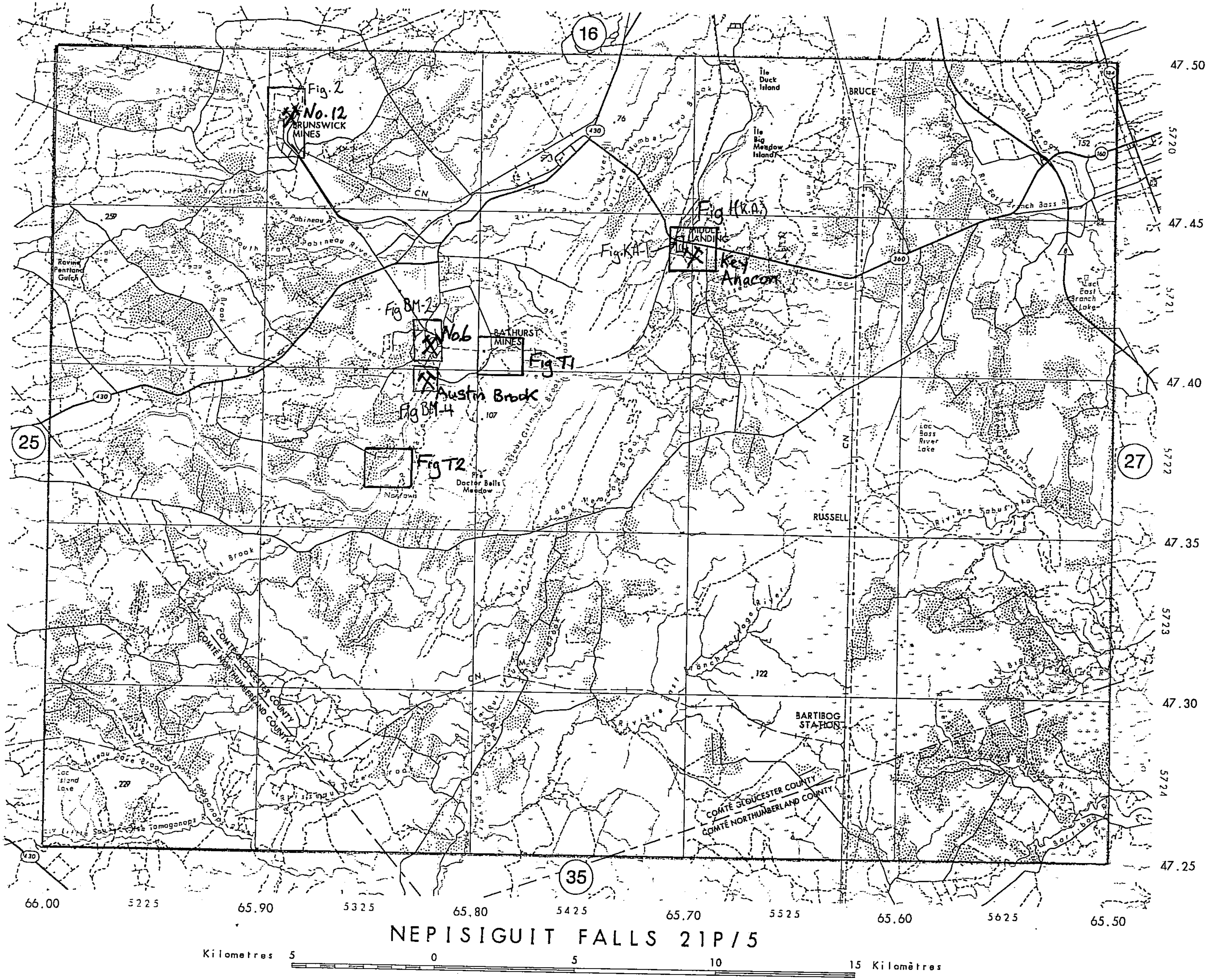

Fig. 2
No. 12
BRUNSWICK MINES
Fig 1(KA)
Fig KA-1
MIDDLE LANDING
Key Anacon
Fig BM-2
No.6
BATHURST MINES
Fig T1
Austin Brook
Fig BM-4
Fig T2
Doctor Bells Meadow
Narrows
Île Duck Island
Île Big Meadow Island
BRUCE
RUSSELL
BARTIBOG STATION
Lac East Branch Lake
Lac Bass River Lake
Ravine Pentland Gulch
Lac Island Lake
COMTÉ GLOUCESTER COUNTY
COMTÉ NORTHUMBERLAND COUNTY
CN
16
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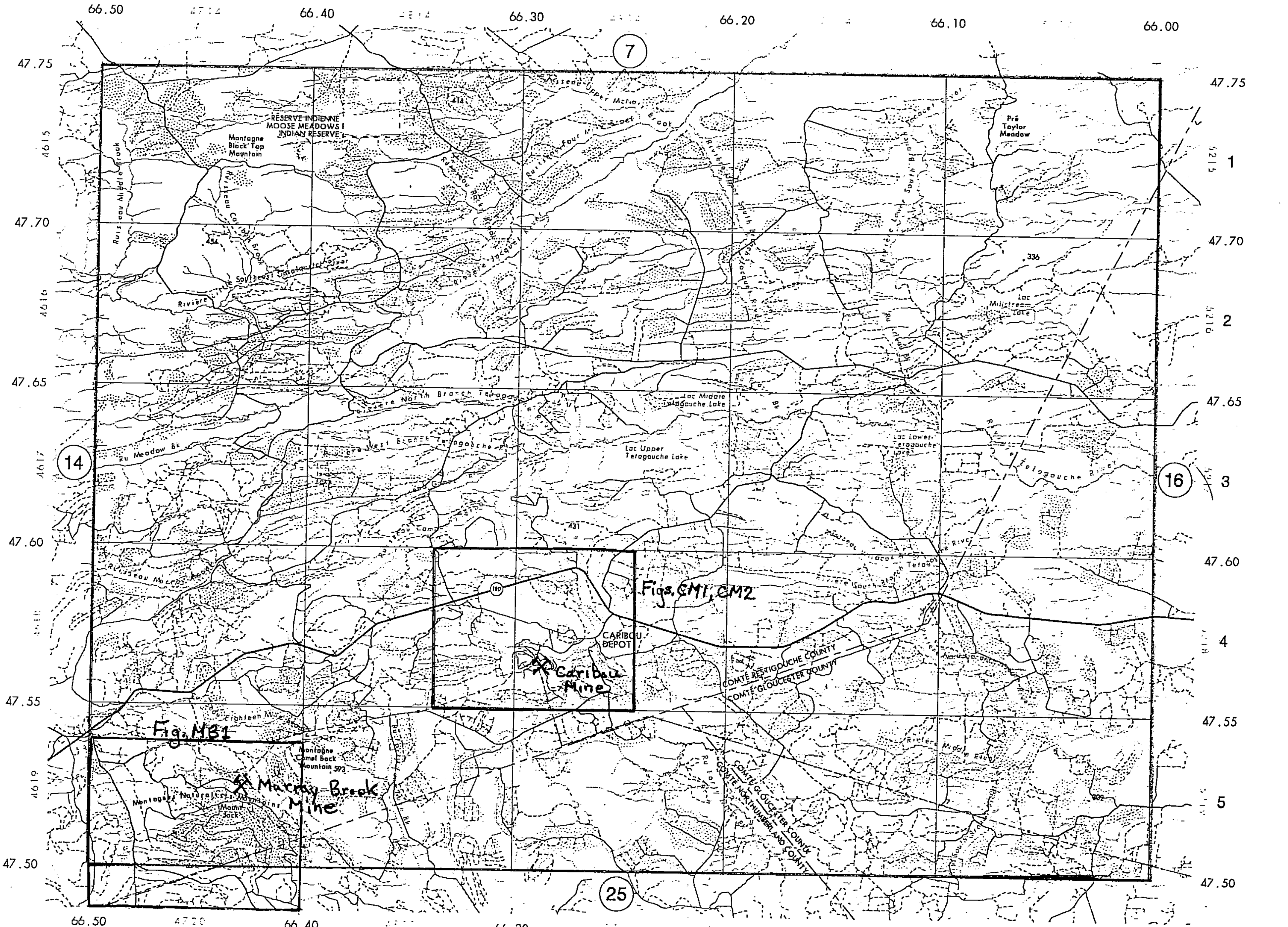
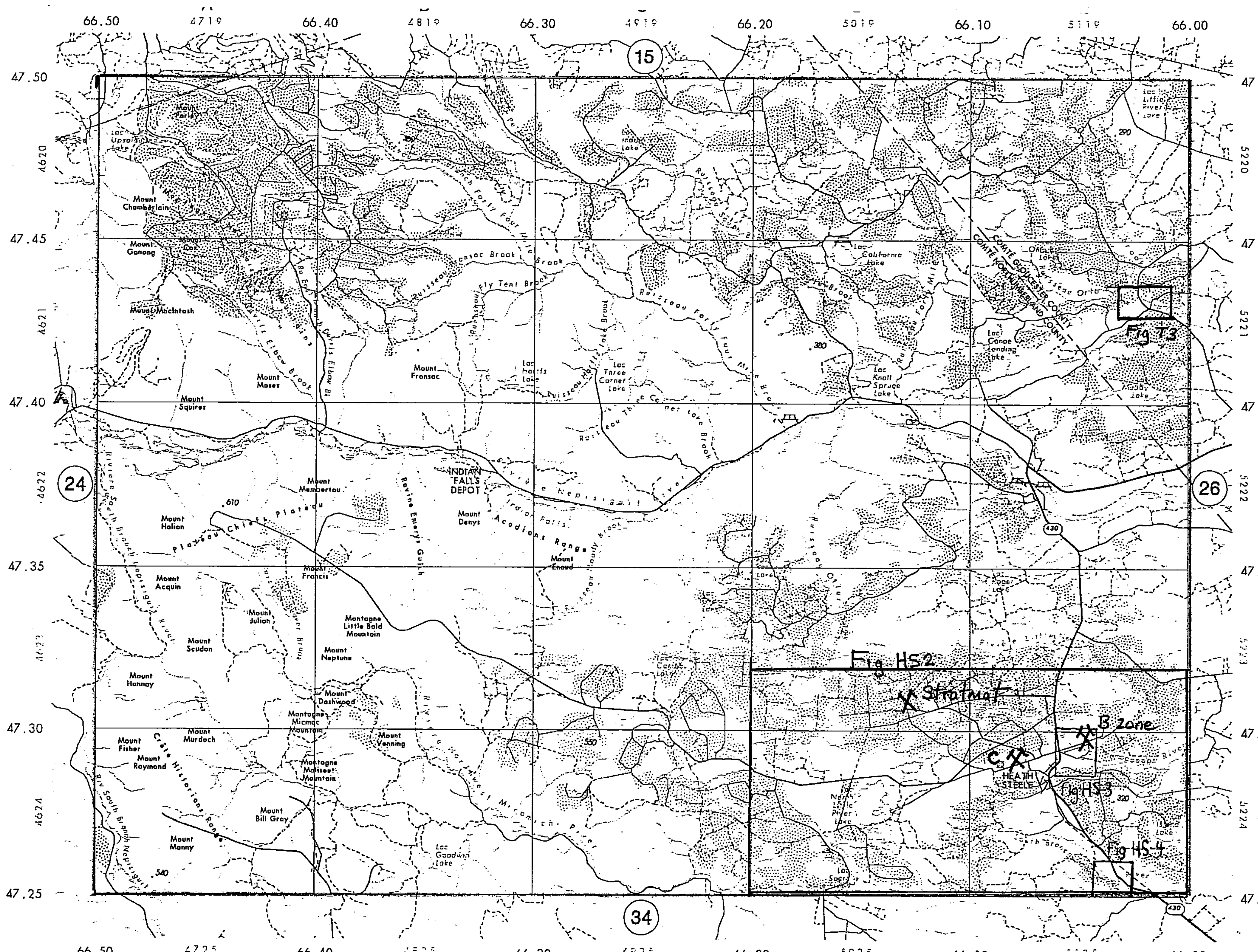


TETAGOUCHE LAKES 210/9

Kilometres 5 0 5 10 15 Kilomètres



CALIFORNIA LAKE 210/08

Kilometres 5 0 5 10 15 Kilomètres

APPENDIX II

Lexicon-Style Descriptions of Formations in the Bathurst Camp

CHAIN OF ROCKS FORMATION (Miramichi Group) **Cambro-Ordovician**

Author: van Staal and Fyffe (1991).

Type Locality: Chain of Rocks Rapids, Nepisiguit River (NTS 21 P/5E).

Lithology: Fine to coarse grained, light greenish-grey (pale-grey weathering) quartz-rich sandstone with some interbedded light to dark greenish-grey slate. Tabular sandstone beds range in thickness from several centimetres to over one metre, whereas slate forms centimetre to decimeter thick lenses. Locally the sandstone contains a minor amount of clear volcanic quartz.

Contact Relationships: The base of this formation is not exposed, i.e. the underlying rocks are unknown. The upper contact with the Knights Brook Formation is covered but is in an interval of discontinuous outcrop in which the number and thickness of slate beds increases at the expense of sandstone, i.e. it appears gradational and is drawn at the base of the first black slate (Rice and van Staal 1992).

Distribution and Thickness: The Chain of Rocks Formation outcrops intermittently in a belt that extends from the upper reaches of Portage River in the south to Tetagouche River in the north. Lithologically similar rocks are also present in the northwestern part of the Bathurst Camp eg. Unit 1 of Helmstaedt (1971). The total thickness of this formation is unknown but is at least 500m (Helmstaedt 1971).

Age Justification: The age is based upon stratigraphic position with respect to the Knights Brook Formation.

History: The literature prior to van Staal and Langton (1990a, 1990b) and van Staal and Fyffe (1991) reported that these rocks constituted part of the lower Tetagouche Group (eg. Skinner 1974); even van Staal *et al.* (1988), assigned them to the Tetagouche Group and referred to them informally as the "Nepisiquit (sic) formation". Rocks of this unit were included in Unit Os_2 of Davies (1979). Rice and van Staal (1992) briefly described the sedimentology of the Chain of Rocks Formation.

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KNIGHTS BROOK FORMATION (Miramichi Group) **Early Ordovician**

Author: van Staal and Fyffe (1991).

Type Locality: Nepisiguit River near the vicinity of the mouth of Knights Brook, upstream to the gorge at Nepisiguit Falls (21 P/5W).

Lithology: Dark grey to black slate with interbedded fine-grained greenish grey to dark grey sandstone (thin to medium beds). The slates are commonly pyritic, in places graphitic, and have well developed cleavage.

Contact Relationships: On Nepisiguit River the lower contact of the Knights Brook is placed where dark grey to black slates disappear from the section. The upper contact is abrupt rather than gradational and drawn at the base of the first massive quartz-feldspar-augen schist (tufflava) layer of the Nepisiguit Falls Formation. This contact can be seen in the Nepisiguit Falls gorge between the river and the old railroad bed. Both contacts are thought to be conformable. On Tetagouche River, Knights Brook rocks are disconformably overlain by the Vallée Lourdes Formation.

Distribution and Thickness: Knights Brook rocks are exposed intermittently from Portage River in the south to Tetagouche Falls in the north. A narrow inlier of these rocks lies along the Pabineau Fault between Brunswick No. 6 and Brunswick No. 12. Knights Brook-type rocks also have been mapped in the northwestern part of the Bathurst Camp, eg. Unit 2 of Helmstaedt (1971). Structural thickness based on the map pattern, is approximately 500 meters.

Age Justification: No fossils have been found in the Knights Brook but correlative rocks in the Woodstock area, the Bright Eye Brook Formation, have yielded Tremadocian to middle/late Arenigian graptolites (van Staal and Fyffe 1991).

History: The literature prior to van Staal and Langton (1990a and 1990b) and van Staal and Fyffe (1991) reported that these rocks constituted part of the lower Tetagouche Group (cf. Skinner 1974; Fyffe 1982). At Brunswick No. 6 these rocks were referred to informally as "older metasediments" (Luff 1977) and they were included in Unit Os_2 of Davies (1979). Rice and van Staal (1992) briefly described the sedimentology of this formation.

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PATRICK BROOK FORMATION (Tetagouche Group) **Early to Middle Ordovician**

Author: van Staal *et al.* (1992).

Type Locality: Tetagouche River near the mouth of Patrick Brook, but the best reference section is on Middle River downstream from the Rio Road for about 2 km. (NTS 21 P/12W)

Lithology: Dark grey, thinly to thickly bedded, commonly graded, sandstones interlayered with dark grey to black slates. The sandstones are characterized by abundant (commonly >5%) phenoclasts of millimetre-sized volcanic quartz (+/- feldspar).

Contact Relationships: The lower contact is not exposed at the type locality but at Little Falls, farther down river, black slates (Patrick Brook ?) overlie the Vallée Lourdes Formation and are intercalated with the Nepisiguit Falls Formation. The upper contact at the type locality, with calcareous fossiliferous, greenish-grey siltstones of the Vallée Lourdes Formation, is also concealed. On Middle River, the lower contact with the Knights Brook Formation is probably gradational, though concealed; the upper contact with the Flat Landing Brook (or Nepisiguit Falls?) Formation is abrupt but conformable.

Age Justification: The Vallée Lourdes Formation near the mouth of Patrick Brook and at Little Falls yielded middle to late Arenigian brachiopods (Fyffe 1976; Newman 1984) and Arenigian to Lanvirnian conodonts (Nowlan 1981), respectively.

Distribution and Thickness: Patrick Brook rocks occur in at least three belts. One extends from Pabineau River in the south to Tetagouche River in the north and is folded around the Six Mile Brook Anticline. A second belt, which is west of the Pabineau Fault, extends from the Narrows in the south to Tetagouche River and beyond in the north. The third belt is in the Nine Mile Brook area and is folded around the Lovalls Lake Synform and Lovalls Lake Antiform. Thin, fault-bound slivers of Patrick Brook Formation also occur in the Canoe Landing Lake-California Lake area. Furthermore, there are Patrick Brook rocks in the western part of the Bathurst Camp, eg. the Halfmile Lake area (de Roo and van Staal 1991). The thickness of this formation appears to vary from one to several hundred meters.

History: The name, Patrick Brook Formation, first appeared in the literature last year (de Roo and van Staal (1991) but was not defined until this year (van Staal *et al.* 1992). Previously some of these rocks were included in Unit Os_2 of Davies (1979) whereas others were included in Unit Os_3. The "older metasediments" at Brunswick No. 12 (cf. Luff 1977) are part of this formation but those at Brunswick No. 6 belong to the Knights Brook Formation. Rice and van Staal (1992) briefly described the sedimentology of the Patrick Brook Formation.

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VALLEE LOURDES FORMATION (Tetagouche Group) **Early to Middle Ordovician**

Author: van Staal *et al.* (1988).

Type Locality: Tetagouche River about 800m upstream from the railway bridge near Vallée Lourdes with an additional reference section at Little Falls, about 11 km farther upriver (21 P/12E).

Lithology: Greenish grey siltstone interbedded with calcareous sandstone and/or siliclastic limestone (calcarenite to calcrudite); minor polymictic conglomerate. Sandstone and limestone beds are 2-20 cm in thickness, commonly fine upward and exhibit ripple cross-lamination.

Contact Relationships: The lower contact in the type section is in a covered interval between outcrops of greenish grey Vallée Lourdes rocks and dark grey Patrick Brook rocks; the upper contact is concealed by a dyke. At Little Falls the Vallée Lourdes overlies the Knights Brook Formation and underlies the Patrick Brook Formation. The basal contact is marked by conglomerate that contains clasts of Miramichi Group rocks (Rice and van Staal 1992).

Age Justification: Middle Arenigian to earliest Llanvirnian conodonts and brachiopods were recovered from the Vallée Lourdes Formation (Fyffe 1976; Nowlan 1981; Newman 1984).

Distribution and Thickness: The Vallée Lourdes Formation occurs intermittently as lenses at the base of the Tetagouche Group in the eastern part of the Bathurst Camp. It can be seen at 3 localities on the Tetagouche River, on Middle River about 800m upstream from Rio Road, and has been reported by Skinner (1974) on Nepisiguit River about 200m downstream from the mouth of Gordon Meadow Brook. Also, one occurrence of Vallée Lourdes rocks has been reported (D. Hattie, pers. comm; 1991) from the western part of the Bathurst Camp, east of Clearwater Lake near Big Sevogle River. The Vallée Lourdes Formation has a maximum thickness of 25m at Little Falls (Rice and van Staal 1992).

History: The limestone at Vallée Lourdes was first described by Young (1911, p.30), but not given formation status until van Staal *et al.* (1988). The Vallée Lourdes Formation was briefly described by van Staal and Fyffe (1991) and the sedimentology of this unit was described by Rice and van Staal (1992).

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NEPISIGUIT FALLS FORMATION (Tetagouche Group) **Middle Ordovician**

Author: Saif (1977).

Type Locality: Nepisiguit Falls on Nepisiguit River (NTS 21 P/5W).

Lithology: Thick to medium bedded, medium to coarse grained, commonly sericitic, volcaniclastic or tuffaceous sandstones (also called reworked pyroclastics, epiclastics, tuffites, crystal tuffs, quartz-augen schists and quartz-feldspar-augen schists) interlayered with quartz-feldspar porphyritic (2-15 mm) tufflavas or subvolcanic sills; light to dark greenish grey, commonly chloritic, mudstone and iron formation (including massive sulphides) generally occur at the top of the formation, i.e. the : "Brunswick Horizon".

Contact Relationships: The upper and lower contacts on Nepisiguit River are abrupt but appear to be depositional; this is confirmed by diamond drill cores from just south of the river (Assessment File 470337). The upper contact is placed at the base of a massive aphyric rhyolite that overlies chloritic iron-rich rocks near the river but fine-grained volcaniclastic sandstone in the drill core; the lower contact is drawn at the base of the lowest quartz ± feldspar porphyritic tufflava or subvolcanic sill. To the north, Nepisiguit Falls volcaniclastic rocks overlie and/or interfinger with volcaniclastic rocks of the Patrick Brook Formation. However, the Nepisiguit Falls is distinguished from the Patrick Brook Formation by the absence of carbonaceous black shales and by a the presence of K-feldspar.

Age Justification: A U-Pb zircon age of 469 ± 2 Ma was obtained from crystal tuff (tuffaceous sandstone) at Nepisiguit Falls (van Staal and Fyffe 1991). Also a U-Pb zircon age of 471 ± 3Ma was obtained from a coarse tuffaceous sandstone at Tetagouche Falls. These ages indicate a dominantly Llanvirnian age for this formation.

Distribution and Thickness: Nepisiguit Falls rocks underlie much of the eastern part of the Bathurst Camp, from Sevogle River in the south to Tetagouche River in the north. They also occur in the northwestern part of the camp (cf. Helmstaedt 1971). The thickness of this formation is variable ranging from a few meters at Tetagouche River to about 250m at Nepisiguit Falls.

History: The name, Nepisiguit Falls Formation, was introduced by Saif (1977) but was not generally used until van Staal and Fyffe (1991) adopted it. Rocks of this formation were previously mapped as "rhyolitic volcanic rocks" (subunit 3b) by Helmstaedt (1971), as "rhyolitic crystal tuffs" (unit 3b) by Skinner (1974). At Brunswick No. 12 Nepisiguit Falls rocks include the quartz eye schist (QES) metasediment (M), crystal tuff (CT) and footwall metasediment (FW) units as well as massive sulphides and iron formation (Luff 1977). The best descriptions of the Nepisiguit Falls Formation that have been published to date are in van Staal *et al.* (1992), Langton (1992), and Lentz and Goodfellow (1992b).

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FLAT LANDING BROOK FORMATION (Tetagouche Group) **Middle Ordovician**

Author: van Staal and Fyffe (1991).

Type Locality: The type-area is between Route #430 and the headwaters of Flat Landing Brook. Good exposures occur along this highway on either side of the junction with the Nine Mile East road and on adjacent bush roads (21 P/5W).

Lithology: Aphyric to sparsely feldspar (+/- quartz) phyric rhyolite flows, crackle breccias and hyaloclastites; tholeiitic basalts (Otter Brook and Forty Mile Brook tholeiites) and minor pyroclastic rocks occur locally.

Contact Relationships: The lower contact of the Flat Landing Brook Formation with Nepisiguit Falls rocks is exposed at the Narrows on Nepisiguit River and along the road 250 m upriver from the Nepisiguit Falls power dam; the upper contact with the Boucher Brook Formation is exposed on Nine Mile Brook about 300m downstream from the mouth of Boucher Brook. Both contacts are abrupt but depositional.

Age Justification: U-Pb zircon ages of 465 $\pm$ 2 Ma and 466 $\pm$ 5 Ma were obtained from aphyric rhyolite near the top of the Flat Landing Brook Formation, south of Canoe Landing Lake and in the upper reaches of the Pabineau River, respectively (van Staal and Sullivan 1992; Sullivan and van Staal 1990). These dates indicate a Llanvirnian to Llandeilan age for this unit.

Distribution and Thickness: Flat Landing Brook rocks are voluminous and underlie large areas in the central part of the Bathurst Camp. The thickness of this formation is unknown.

History: The name, Flat Landing Brook Formation, first appeared in Sullivan and van Staal (1990) but had been previously defined in a manuscript that was not published until a year later (van Staal and Fyffe 1991). Rocks of this formation were previously mapped as "rhyolitic volcanic rocks" (subunit 3a) by Helmstaedt (1971), as "rhyolite tuff" (unit 3a) by Skinner (1974) and were encompassed in Unit Ofv_1 of Davies (1979). The "acidic tuff" (hyaloclastite and associated volcaniclastic sediments) in the hanging wall at Brunswick No. 12 is part of the Flat Landing Brook Formation. A more complete description of the Flat Landing Brook Formation is found in van Staal *et al.* (1992) then in van Staal and Fyffe (1991).

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BOUCHER BROOK FORMATION (Tetagouche Group) **Middle to Late Ordovician**

Author: van Staal and Fyffe (1991).

Type Locality: Nine Mile Brook, from a point about 300m downstream from the mouth of Boucher Brook, upstream to a point about 700m above the mouth of Boucher Brook (NTS 21 0/8E). Additional reference sections are along Nine Mile Brook south of the Mud Lake Antiform (NTS 21 0/8E) and along Middle River approximately 1.5 kilometers up- and downstream from the bridge on Arseneault Road (NTS 21 P/12W).

Lithology: Thinly bedded, dark grey to black, lithic wacke/siltstone rhythmites that grade upward into homogeneous black slate. Both the rhythmites and black slate contain lenses of alkalic volcanic rocks, locally with associated chert, multicolored metalliferous slate or limestone.

Contact Relationships: The lower contact with the Flat Landing Brook Formation is an abrupt depositional contact that is exposed on Nine Mile Brook about 300m downstream from the mouth of Boucher Brook. The upper contact with Canoe Landing Lake basalts is tectonic and marked by a high-strain zone. However, there are also sedimentary rocks that overlie the Canoe Landing Lake basalts, which are assigned to the Boucher Brook Formation.

Age Justification: The underlying Flat Landing Brook Formation yielded U-Pb zircon ages of 466 ± 5 Ma and 465 ± 2 Ma (Sullivan and van Staal 1990; van Staal and Sullivan 1992), whereas black slate in the upper part of the Boucher Brook Formation yielded Llandeilian to late Caradocian graptolites from three localities near Bathurst (van Staal, *et al.* 1988). Furthermore, early Caradocian conodonts were recovered from Boucher Brook limestone at Camel Back Mountain (Kennedy *et al.* 1979; Nowlan 1981).

Distribution and Thickness: The Boucher Brook Formation underlies a large area on the east side of the Nine Mile Synform from the Wedge Mine on Nepisiguit River to Tetagouche River and beyond in the north. Boucher Brook rocks are less extensive on the west limb of the Nine Mile Synform, but can be traced north around the Tetagouche Antiform and west to Camel Back Mountain and beyond. The thickness of the Boucher Brook is unknown.

History: The name, Boucher Brook Formation, first appeared in the literature in 1990 (cf Sullivan and van Staal 1990; van Staal and Langton 1990a and 1990b) but was already defined in a manuscript (van Staal and Fyffe 1991) that did not get published until a year later. Boucher Brook rocks were previously mapped as Unit 4 by Helmstaedt (1971); constituted part of the "sedimentary unit" (Unit 1) of Skinner (1974) and part of Unit Os_3 of Davies (1979). At Brunswick No. 12, the upper part of the unit, called "hanging wall metasediments and acidic tuff" (Luff 1977), belongs to the Boucher Brook Formation. Also, Caribou-type massive sulphide deposits are hosted in the basal part of the Boucher Brook Formation (van Staal *et al.* 1992).

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CANOE LANDING LAKE FORMATION (Tetagouche Group) — Late Ordovician

Author: van Staal and Fyffe (1991).

Type Locality: The type area is around Canoe Landing Lake but the best reference section is on Nine Mile Brook starting about 400m downstream from the bridge on Nine Mile West Road.

Lithology: Primitive alkali basalt with intercalated red shale, chert comendite and rhyolite (Canoe Landing Lake suite), which are structurally overlain by tholeiitic pillow basalt with intercalated alkalic basalt, red shale and chert (Nine Mile Brook Suite).

Contact Relationships: The basal contact of the Canoe Landing Lake suite with Boucher Brook rocks is tectonic; the upper contact with sedimentary rocks, which are also assigned to the Boucher Brook Formation, is depositional. Similarly, the basal contact of the Nine Mile Brook suite is tectonic and the upper contact is depositional, both contacts being with sedimentary rocks of Boucher Brook type.

Age Justification: Comendite from the Canoe Landing Lake suite just south of Canoe Landing Lake yielded U-Pb zircon and monazite ages of 472 ± 4 Ma (van Staal *et al.* 1991). This is a Llanvirnian age.

Distribution & Thickness: The Canoe Landing Lake Formation is restricted to the northeastern part of the Bathurst Camp and is mostly in the Nine Mile Synform and adjacent Mud Lake Antiform - Synform pair. There is also a northerly to northeasterly trending belt that starts west to Brunswick No. 12 and extends to the coast at Beresford. The thickness of this formation is unknown.

History: The name, Canoe Landing Lake Formation, first appeared in the literature in 1990 (cf. van Staal and Langton 1990a, 1990b; van Staal *et al.* 1990) but was already defined in a manuscript (van Staal and Fyffe 1991) that did not get published until a year later. Canoe Landing Lake rocks constitute part of the "metabasalt unit" (Unit 2) of Skinner (1974) and part of Unit Omv_2 of Davies (1979). The geochemistry of the Canoe Landing Lake basalts is described in van Staal *et al.* (1991).

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SORMANY FORMATION (Fournier Group) **Middle Ordovician**

Author: van Staal and Fyffe (1991); van Staal *et al.* (1991).

Type Locality: The type area is in the headwaters of Armstrong Brook and adjacent lumber roads near the boundary between the Bathurst and Tetagouche Lakes map-areas (NTS 21 P/12W & 21 O/9E).

Lithology: The Sormany Formation is divided into three members namely the Murray Brook, Armstrong Brook and Lincour basalts, in ascending structural order. The Murray Brook Member consists of primitive alkalic basalt that occurs almost exclusively within a blueschist belt. The Armstrong Brook Member comprises primitive high - Cr pillow basalts and hyaloclastites of tholeiitic composition (MORB). The Lincour Member basalts are also tholeiitic, but are lower in Cr than the Armstrong Brook basalts.

Contact Relationships: The Sormany Formation is in tectonic contact with the Boucher Brook Formation and is conformably overlain by, and in part interbedded with, lithic wackes and arkoses of the Millstream Formation.

Distribution and Thickness: The Sormany Formation mainly occurs in the Nine Mile Synform from the vicinity of Orlo Brook Lakes north and northeast to the coast at Beresford. Sormany rocks also outcrop in a narrow band along the northern margin of the Bathurst Camp from the Restigouche Deposit east to Upper Tetagouche Lake.

Age Justification: Correlation with the Devereaux Formation, from which a U-Pb zircon age of 464 $\pm$ 1 Ma has been obtained (Sullivan *et al.* 1990).

History: The name, Sormany Formation, first appeared in the literature in 1990 (van Staal and Langton 1990 a, 1990 b; van Staal *et al.* 1990) but was already defined in a manuscript (van Staal & Fyffe 1991) that did not get published until a year later. Sormany rocks constitute part of the "metabasalt unit" (unit 2) of Skinner (1974) and part of Unit Omv_2 of Davies (1979). The lithogeochemistry of the Sormany Formation is described in van Staal *et al.* (1991).

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MILLSTREAM FORMATION (Fournier Group) — Middle to Late Ordovician

Author: van Staal *et al.* (1988).

Type Locality: Millstream River from the railway bridge upstream and west to a point about 800 m above the bridge on the Dunlop road (Route #315).

Lithology: Very fine to coarse-grained, thickly bedded, greenish grey, quartzo-feldspathic sandstones, and locally lithic wackes, interbedded with grey to black slates; minor pebble conglomerate and felsic peperite. Sandstone beds generally lack sedimentary structures and commonly contain intraformational shale clasts.

Contact Relationships: Neither the lower or upper contact of the Millstream Formation is exposed in the type section. However, Millstream rocks conformably overlie, and locally are interstratified with basalts of the Sormany Formation (van Staal and Fyffe 1991). The upper contact with the Silurian Chaleur Group is probably a disconformity (cf. Walker *et al.* 1991).

Age Justification: Correlation with the Llandeilian to Caradocian Pointe Verte Formation in the Belledune Inlier.

Distribution and Thickness: The Millstream Formation is restricted to the northeastern part of the Bathurst Camp and is mostly north of Route #180. The thickness is unknown.

History: Rocks of the Millstream Formation were previously included in the "sedimentary unit" (Unit 1) of Skinner (1974) and Unit Os_3 of Davies (1979). Rice and van Staal (1992) briefly described the sedimentology of this unit.

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