# GEOLOGY AND MASSIVE SULPHIDES OF THE BATHURST CAMP, NEW BRUNSWICK

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Field Trip B7

22–25 May 1997

Geological Association of Canada, Mineralogical Association of Canada
Joint Annual Meeting, 1997, Ottawa, Ontario, Canada

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*Recommended citation:*

McCutchean, S.R. (Compiler). 1997. Geology and massive sulphides of the Bathurst Camp, New Brunswick. Geological Association of Canada – Mineralogical Association of Canada, Joint Annual Meeting, Ottawa '97, Field Trip B7, Guidebook, 85 p.

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## INTRODUCTION: STRATIGRAPHIC AND STRUCTURAL FRAMEWORK OF THE BATHURST CAMP

*(S.R. McCutcheon, L.R. Fyffe, S.J. Gower, J.P. Langton, and R.A. Wilson)*

The following description provides a synopsis of the stratigraphic and structural relationships of rock units in the Bathurst Camp (Fig. 1), with an overview of the settings 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is extracted from published papers and other field guidebooks (see references), but some of it is based on previously unpublished data.

### Stratigraphy

The rocks in the Bathurst Camp, part of the northern Miramichi Highlands, have been separated into three groups, 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 below in detail.

The Cambrian(?) to Lower Ordovician Miramichi Group comprises a monotonous sequence of quartz wacke and slate of unknown thickness, which probably represents a flysch 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) than in the lower part (Chain of Rocks Formation). Near the top of the Miramichi Group, the slate may contain abundant interbeds of volcaniclastic wacke with clear quartz and plagioclase phenoclasts (Patrick Brook Formation). Originally these rocks were assigned to the Tetagouche Group (van Staal and Fyffe 1991) but they are now known to be part of the Miramichi Group (Fyffe *et al.* 1996). 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 basalt and minor gabbro. The basalt is mainly primitive tholeiite with MORB-like compositions but there are also compositions intermediate between MORB and oceanic-island basalt, reflecting the back-arc oceanic depositional setting (van Staal *et al.* 1992). The conformably overlying Millstream Formation consists of lithic and feldspathic wacke 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 (Fig. 1) 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, in general, consists of a felsic volcanic pile that is overlain by a mafic volcanic pile. Sedimentary rocks are intercalated with the volcanic rocks and there is a distinctive post-volcanic sedimentary succession that is currently included in the Group. The felsic volcanic pile ranges in composition from dacite to rhyolite, whereas the mafic volcanic pile mostly comprises alkalic to tholeiitic basalt (Whitehead and Goodfellow, 1978; van Staal 1987; van Staal *et al.* 1991; Rogers 1995). The first formal subdivision of the Group was made by van Staal and Fyffe (1991), but additional formal units have been defined because the stratigraphic succession varies both within and between major thrust sheets or nappes, at least four of which contain Tetagouche rocks. These nappes are separated from one another by $D_2$ or younger faults. The formal subdivisions of the Group, as currently understood, are shown in Figure 2; each formation is briefly described below, starting with the units in the structurally lowest nappe. Unless otherwise noted, the formation names are from van Staal and Fyffe (1991).

*Nappe 1* is characterized by abundant sedimentary rocks of the Miramichi Group, part of which may be autochthonous because it hosts Ordovician granite that is probably comagmatic with parts of the Tetagouche Group (Whalen 1993). This nappe, or nappe basement, is exposed around the perimeter of the Bathurst Camp, in the eastern, southern and western parts (Fig. 1). In each of these parts, the Tetagouche Group comprises two or more formations that conformably to disconformably overlie the Miramichi Group. In the east (1a and 1b in Fig. 1 and 2), the Tetagouche Group comprises the Vallée Lourdes, Nepisiguit Falls, Flat Landing Brook and Boucher Brook formations in ascending stratigraphic order; in the south (1c in Fig. 1 and 2), the Clearwater Stream, Sevogle River and Boucher Brook formations; in the west (1d in Fig. 1 and 2), the Nepisiguit Falls and Flat Landing Brook formations and in the northwest (1e in Fig. 1 and 2), the Mount Brittain and Boucher Brook formations.

In the east, in the Little Falls area (Fig. 1 and 2), a thin unit of nodular to siliciclastic limestone (calcarenite of Rice and van Staal 1992), calcareous sandstone and siltstone disconformably overlies the Miramichi Group and underlies the Nepisiguit Falls Formation. This unit is considered to be an additional reference section for the type Vallée Lourdes (VL) Formation, located about 10 km farther east-northeast along Tetagouche River, in Nappe 2. Brachiopods (Fyffe 1976; Neuman 1984) and conodonts (Nowlan 1981) from this unit indicate a middle Arenigian to early Llanvirnian age and confirm that the overlying felsic volcanic pile is mainly Llanvirnian, as elsewhere deduced from U-Pb geochronology (Sullivan and van Staal 1996). However, no fossils have been found at the type locality of the VL Formation so correlation between the two sections is not confirmed.

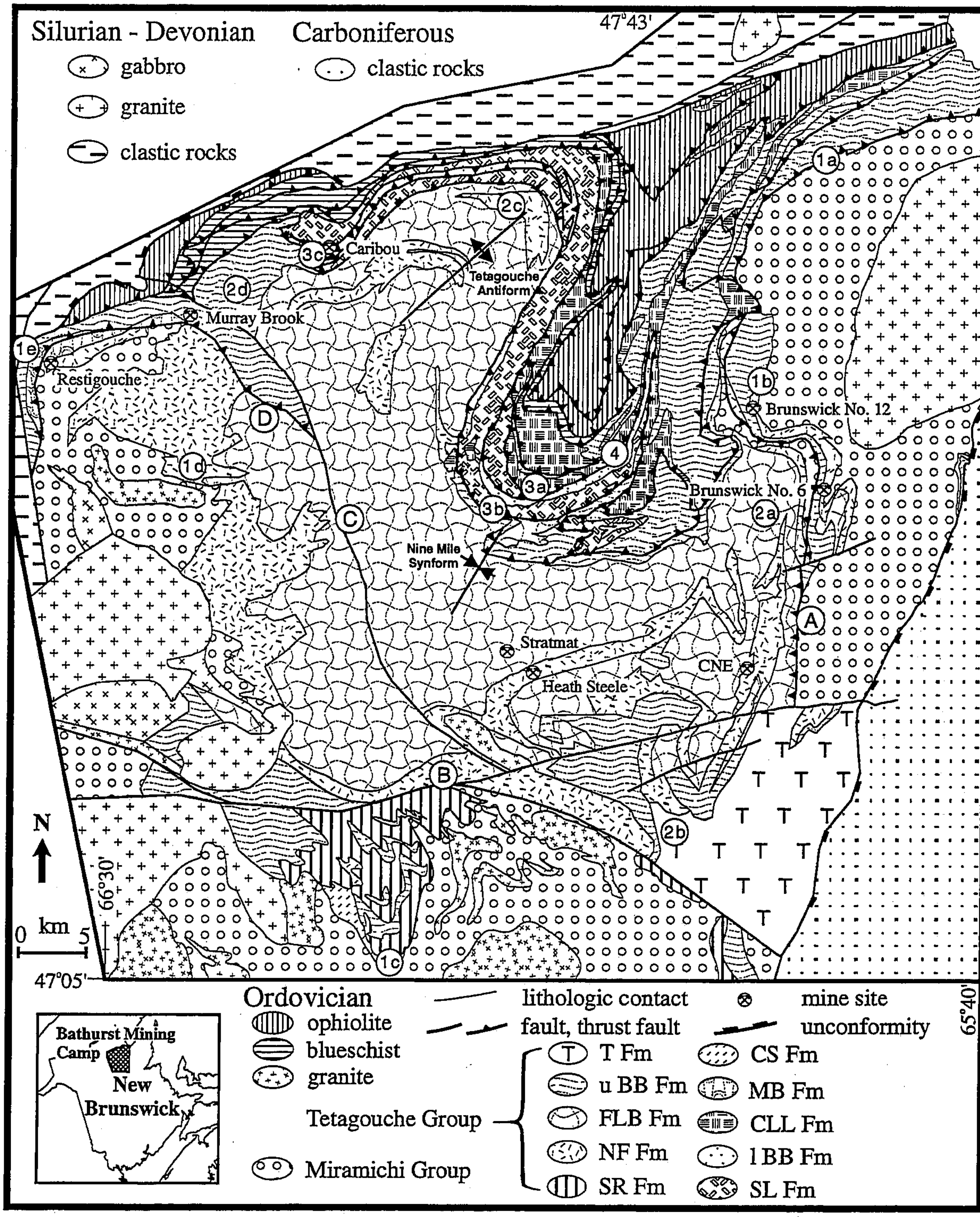



*Figure 1. Simplified geological map of the Bathurst Camp (modified from Rogers and van Staal 1996) showing the major nappes and locations of stratigraphic columns (1a to 4) shown in Figure 2. Legend as in Figure 2 except for the following: A = Pabineau Fault, B = Mountain Brook-Moose Brook Fault, C = Upsalquitch Fault and D = Forty-Mile Brook Fault.*

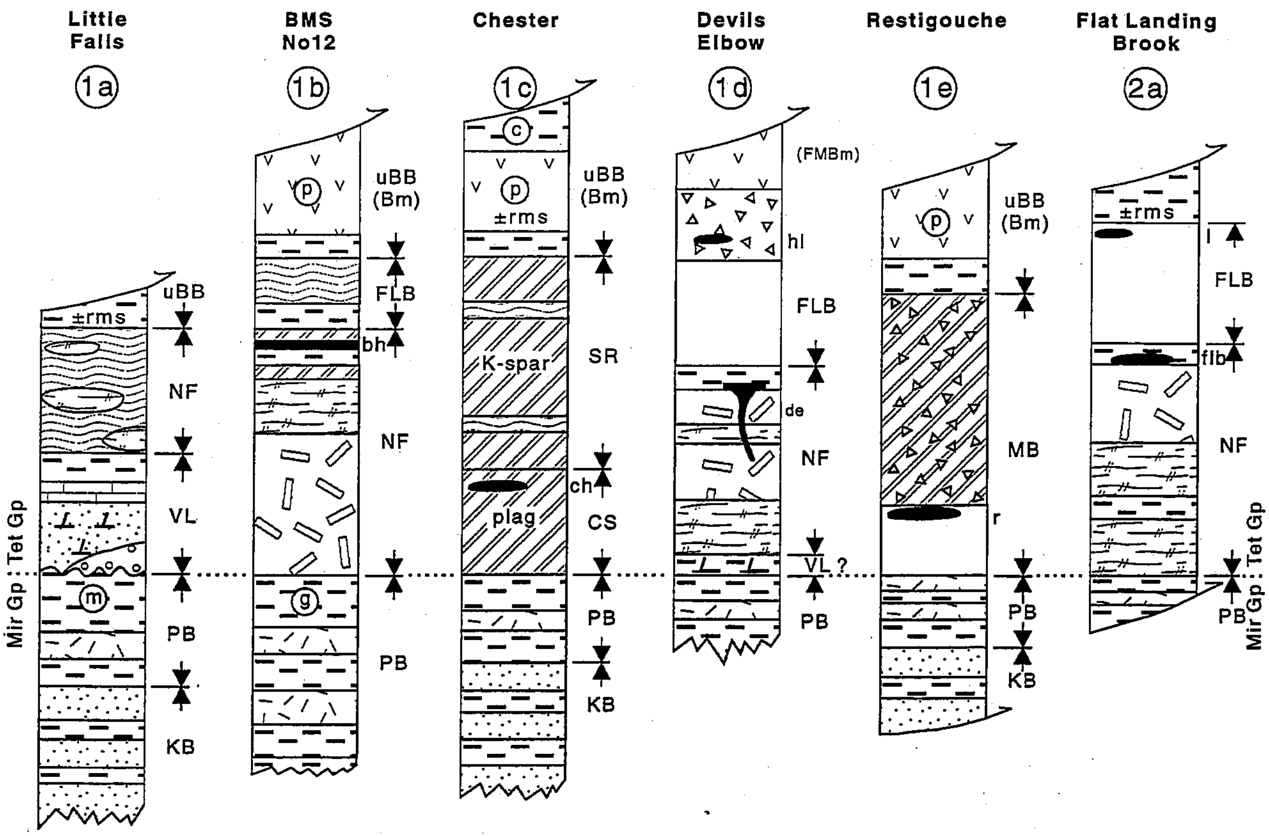
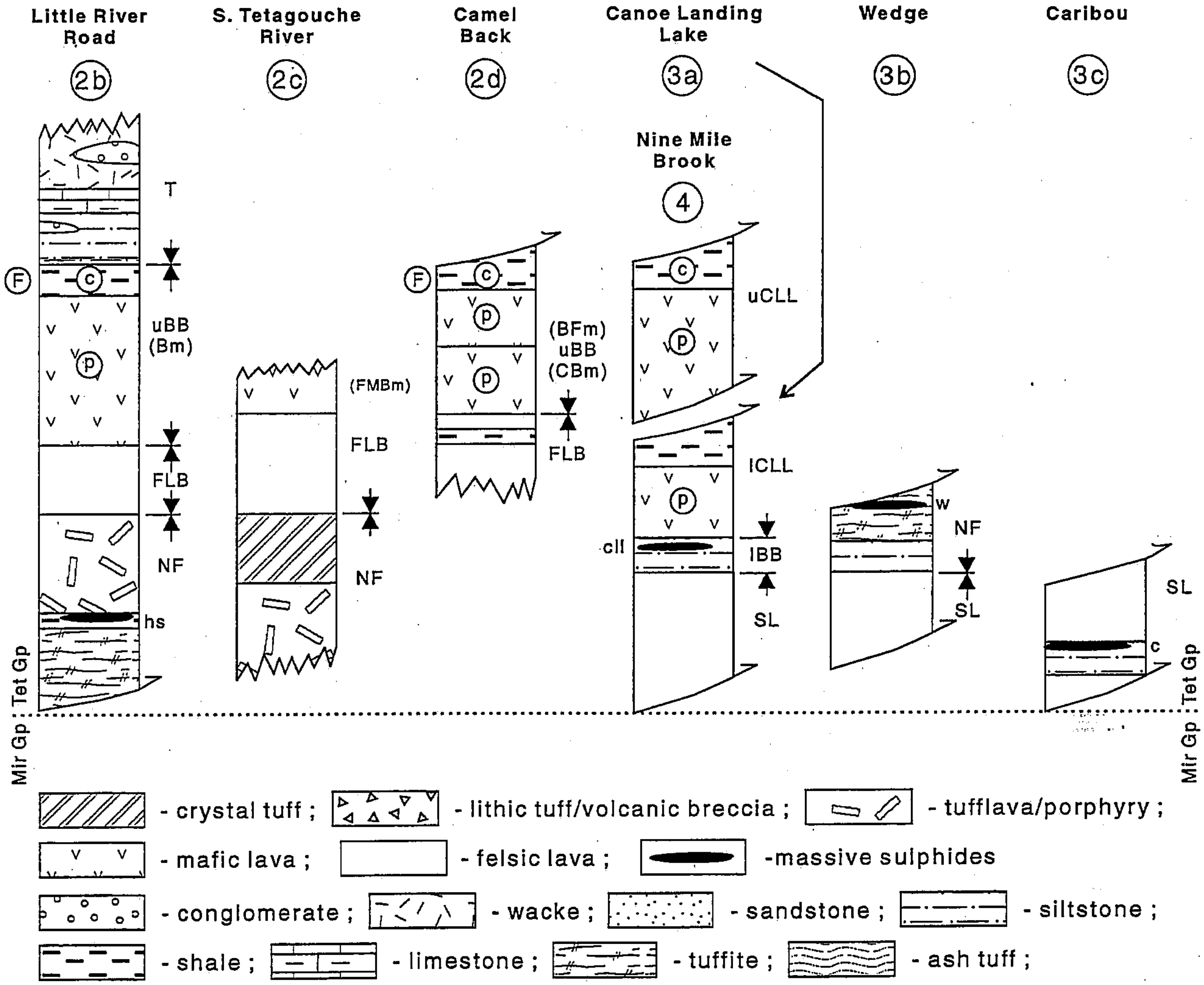



*Figure 2. Representative stratigraphic columns from various parts of the Bathurst Camp; circled number-letter combinations designate the nappe and location in Figure 1. Abbreviated formation names are as follows: BB - Boucher Brook Formation (l = lower, u = upper, Bm = Brunswick Member, CBm = Camel Back Member, BFm = Beresford Member), CLL - Canoe Landing Lake Formation, CS - Clearwater Stream Formation, FLB - Flat Landing Brook Formation (FMBm = Forty Mile Brook Member), KB - Knights Brook Formation, MB - Mount Brittain Formation, NF - Nepisiguit Falls Formation, PB - Patrick Brook Formation, (cont$^{d}$.-)*

The type section of the Nepisiguit Falls (NF) Formation, consists of a 200-metre-thick, massive, quartz-feldspar porphyritic (2-15 mm) tufflava or subvolcanic sill that is overlain by medium- to coarse-grained, granular, quartz-feldspar-rich volcaniclastic rocks containing minor ash tuff. These volcaniclastic rocks become finer grained near the top and are interlayered with light to dark greenish grey, chloritic mudstone that is locally iron rich ("chloritic iron formation") and




*(Figure 2, cont[d].) SL - Spruce Lake Formation, SR - Sevogle River Formation, T - Tomogonops Formation and VL - Vallée Lourdes Formation. Deposit abbreviations are as follows: bh = Brunswick, c = Caribou, ch = Chester, cll = Canoe Landing Lake, de = Devils Elbow, flb = Flat Landing Brook, hl = Hartts Lake, hs = Heath Steele, l = Louvicourt, r = Restigouche and w = Wedge. Other abbreviations, including circled letters, are: c = chert, F = fossil locality, g = graphitic, k-spar = potash feldspar phenocrysts, m = melange, p = pillows, plag = plagioclase feldspar phenocrysts, rms = red manganiferous slate and / = calcareous.*

constitutes the "Brunswick Horizon". The basal contact of the NF Formation is concordant with the underlying Knights Brook Formation.

Elsewhere, the proportions of massive porphyritic and granular volcaniclastic rocks in the NF Formation vary; consequently, Langton and McCutcheon (1993) defined proximal (Grand Falls Member) and distal (Little Falls Member) facies in this formation. The Grand Falls Member consists of interbedded medium- to coarse-grained, quartz-feldspar-phyric volcaniclastic rocks and tufflava/porphyry with some associated greenish grey sedimentary rocks, whereas the Little Falls Member consists of greenish grey ash tuff and fine- to medium-grained, quartz-feldspar-phyric volcaniclastic rocks interbedded with dark greenish grey to black slate; tufflava/porphyry is absent. The section at the type locality is a good example of the proximal facies, whereas the Little Falls section is representative of the distal facies (Fig. 2). The transition from one facies to the other can occur within a few hundreds of metres, *e.g.* from one limb to the other of major folds. A U-Pb zircon age of 469±2 Ma was obtained from rocks of the Grand Falls Member and an age of 471±3 Ma was obtained from the Little Falls Member (Sullivan and van Staal 1996).

The type Flat Landing Brook (FLB) Formation is in Nappe 2, rather than Nappe 1 (Fig. 1). It comprises aphyric to feldspar-phyric (±quartz) rhyolitic flows, hyaloclastite, crackle breccia and minor sedimentary rocks including some iron formation. In the past, most of these rocks were interpreted as pyroclastic deposits, but now many are considered to be the products of lava flows (van Staal 1987; Langton and McCutcheon 1990; Wilson 1993). Feldspar±quartz phenocrysts are small (1–3 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.

In Nappe 1, FLB rocks are generally similar to those in the type area and a recent U-Pb zircon age of 466±2 Ma (Rogers *et al.* in press) from rhyolite near Brunswick No. 6 supports the stratigraphic evidence that the FLB Formation is younger than the NF Formation. However, in the west-central part of the Camp (1d in Fig. 1 and 2), the FLB Formation also contains fragmental rocks of pyroclastic origin, which are at or near the top of this formation. Many of these fragmental rocks have polymictic felsic clasts in a greenish grey to greenish black matrix of intermediate to mafic composition. These fragmental rocks appear to grade upward into mafic lavas of tholeiitic composition, which constitute part of the "Otter Brook tholeiite" of van Staal *et al.* (1991) and the "Moody Brook andesite" of Wilson (1993). They occupy the same stratigraphic position as the Brunswick Member of the Boucher Brook Formation (see below).

At its type section, which is in Nappe 3 rather than Nappe 1, the Boucher Brook (BB) Formation conformably overlies the Spruce Lake Formation (31 in Fig. 1 and 2). Though not originally recognized, the type BB is divisible into lower and upper parts that are separated by a high strain zone. The non-volcanic lower part of the BB Formation mainly consists of thinly bedded, bluish grey siltstone and greenish black slate with minor amounts of fine- to medium-grained quartz wacke. Near the contact with the Spruce Lake Formation, the wacke appears to be feldspathic but the "feldspar" actually comprises small fragments of white-weathering rhyolite. Radiometric ages from the conformably underlying Spruce Lake rhyolite (Walker and McCutcheon 1996; Rogers *et al.* in press) indicate an Arenigian to Llanvirnian age, suggesting that the base of the lower BB Formation is earliest Middle Ordovician. The upper part of the BB Formation, on the other hand, mainly consists of alkali basalt with interbedded greenish grey to black slate, siltstone and sandstone with minor conglomerate and limestone, containing poorly preserved conodonts that could be as young as Caradocian (Nowlan 1987).

In Nappe 1, mafic volcanic and associated sedimentary rocks have been correlated with the upper part of the BB Formation; they either conformably and/or structurally overlie the Flat Landing Brook Formation in the east, the Sevogle River Formation in the south and the Mount Brittain Formation in the northwest (1b, 1c and 1e, respectively, in Fig. 2). The mafic lavas have been included in the Brunswick alkali basalt suite (van Staal *et al.* 1991) of the BB Formation, which comprises "all basalts with Nb/Y ratios ranging between 0.65 and 1.0, with Cr not exceeding 200 ppm.." Since this geochemical subdivision is not a formal lithostratigraphic unit and since the type BB Formation clearly needs revision, we propose the name Brunswick Member be used for both the basalt and associated sedimentary rocks. At the reference locality, *i.e.* the back-fill quarry at Brunswick No. 12, this unit consists of massive to pillowed basalt, breccia and hyaloclastite, with interflow sedimentary rocks including chert and red metalliferous slate. Most of the interlayered fine-grained sedimentary rocks are of turbiditic origin.

The type Clearwater Stream Formation (Fyffe 1994*a*) is in Nappe 1 (southern part) and consists of medium to dark greenish grey, plagioclase-phyric (30–50%) felsic to intermediate volcanic rocks that overlie the Patrick Brook Formation. Intense deformation and biotite-grade metamorphism have generally destroyed primary textures but broken crystals and rare bedding features suggest a pyroclastic origin. Carbonate porphyroblasts (up to 3.5 mm) are a characteristic feature (Fyffe 1995).

The type Sevogle River Formation (Wilson and Fyffe 1996) is also in the southern part of Nappe 1; it conformably overlies the Clearwater Stream Formation and comprises schistose to massive felsic lavas containing up to 15% alkali feldspar phenocrysts ranging in size from 0.2 to 2.0 mm. The contact with the overlying Boucher Brook Formation (Brunswick Member) is locally marked by a layer of cherty ironstone.

The type Mount Brittain Formation (Gower 1996), previously considered part of the Flat Landing Brook Formation, is in the northwestern part of Nappe 1 and mainly consists of feldspar crystal-lithic felsic tuff that overlies less abundant, aphyric to sparsely feldspar phyric dacitic lava. Quartz microphenocrysts (0.3–0.4 mm) are visible in thin sections but are not obvious in the field. The Mount Brittain Formation conformably overlies rocks of the Patrick Brook Formation and is overlain by sedimentary and mafic volcanic rocks that are assigned to the upper Boucher Brook Formation.

*Nappe 2*, characterized by the virtual absence of Miramichi rocks and stratigraphy similar to Nappe 1, is bound by the Pabineau, Mountain Brook-Moose Brook, Upsalquitch and Forty-Four Mile Brook faults (Fig. 1). The Tetagouche Group in this nappe is divisible into four formations, namely Nepisiguit Falls, Flat Landing Brook, Boucher Brook (upper part) and Tomogonops. Nepisiguit Falls rocks are generally similar to those in Nappe 1, except in parts of the Tetagouche antiform (Fig.1), where lapilli tuff and interbedded ash tuff are present. As in Nappe 1, the upper part of the Flat Landing Brook Formation contains fragmental rocks of intermediate to mafic composition in the central part of the Camp, which are not present in the type area. These fragmental rocks occupy the same stratigraphic position as mafic lavas south of Heath Steele and east of Murray Brook, which have been assigned to the Boucher Brook Formation.

Within the confines of our Nappe 2, van Staal *et al.* (1991) distinguished four alkali basalt suites in the Boucher Brook Formation. They are the Eighteen Mile Brook, Camelback (*sic*), Beresford and Robertville suites. They considered the first two suites to be part of their Brunswick alkali basalt and to be older than the other two, which are shown collectively on later maps, *e.g.* van Staal (1995), as Beresford alkali basalt. Since the Camel Back basalt contains significant amounts of interlayered trachyandesite and comendite, and is not in the same thrust sheet as the Brunswick basalt, we advocate using Camel Back Member rather than Brunswick Member for the lower basalt and associated volcanic and sedimentary rocks in Nappe 2, and Beresford Member for the upper basalt and associated sedimentary rocks. The Beresford Member contains early to middle Caradocian fossils in the Camel Back Mountain area (Nowlan 1981) and yielded a U-Pb zircon age of 457±1 Ma (Sullivan and van Staal 1996) from trachyandesite west of Beresford.

The type Tomogonops Formation (Langton 1994) is in Nappe 2 and comprises a post-volcanic, coarsening-upward sedimentary sequence that historically has been assigned to the Tetagouche Group. Light to dark grey, thinly bedded, commonly highly calcareous siltstone (± limestone) and fine-grained sandstone predominate near the base but thickly bedded, non-calcareous, coarse-grained wacke and conglomerate, containing mafic and felsic volcanic clasts up to 15 cm in size, are abundant toward the apparent top. The Tomogonops Formation appears to conformably overlie early Caradocian graphitic slate and pelagic chert (Langton 1995), which commonly mark the end of Ordovician volcanism.

*Nappe 3* contains no rocks of the Miramichi Group, *i.e.* it is entirely allochthonous, and is lithologically different from Nappes 1 and 2. The Tetagouche Group is divisible into three formations, namely Spruce Lake, Boucher Brook and Canoe Landing Lake (lower part) in ascending stratigraphic order. The Spruce Lake Formation has only recently been distinguished from the Flat Landing Brook Formation (Rogers and van Staal 1996).

The type Spruce Lake (SL) Formation, formerly "Caribou Mine Formation" of Rogers (1995), is mainly composed of feldspar-phyric felsic lavas, autobrecciated lavas and pyroclastic rocks, including polymictic fragmental rocks and crystal tuff, with minor mafic volcanic rocks (part of the Forty Mile Brook tholeiite of van Staal *et al.* 1991). In the Caribou Mine area (3c in Fig. 1 and 2) sedimentary rocks that host the massive sulphide deposit are provisionally assigned to the SL Formation because they underlie and/or are intercalated with feldspar-phyric lavas. This formation is exposed only in the Tetagouche antiform and Nine Mile synform (Fig. 1). The characteristic K-feldspar phenocrysts, up to 1 cm in size, constitute up to 20% of many rocks but they are virtually absent in some. Two U-Pb zircon ages, 471±2 Ma (Walker and McCutcheon 1996) and 471+5/-3 Ma (Rogers *et al.* in press), from different parts of this formation show that it is approximately coeval with, or slightly older than, the Nepisiguit Falls Formation. The apparent basal contact of the SL Formation is tectonic and the upper contact is conformable with the lower (sedimentary) part of the Boucher Brook Formation.

In Nappe 3, the lower part of the Boucher Brook Formation (see description of the type section above) is well represented in the Tetagouche antiform, but no mafic volcanic rocks are present. The reason for this is that the upper part of the Boucher Brook Formation at its type section actually belongs with Nappe 4 rather than Nappe 3, as shown by new airborne electomagnetic and magnetic maps (GSC 1996*a*, 1996*b*). Clearly, revision of this formation is required and we recommend that the name be used only for the lower sedimentary part of the original type section. The lower Boucher Brook sedimentary rocks have a geochemical signature similar to sedimentary rocks of the Miramichi Group, *i.e.* a continental affinity, unlike those associated with the basalt, which have an oceanic affinity (*cf.* Walker and McDonald 1995; Lentz *et al.* 1996; Langton, in preparation). Near Canoe Landing Lake, in the core of the Nine Mile synform, Walker and McDonald (1995) have shown that the Canoe Landing Lake alkali basalt of van Staal *et al.* (1991) conformably overlies these Boucher Brook sedimentary rocks and hence is part of Nappe 3. A K-feldspar-phyric tuff near the base of the alkali basalt unit, which lithologically resembles rocks in the Spruce Lake Formation, yielded a U-Pb age from zircon and monazite of 470+4/-2 Ma (Sullivan and van Staal 1993), whereas the conformably underlying Spruce Lake rhyolite yielded a U-Pb zircon age of 471±2 Ma (Walker and McCutcheon 1996). These data indicate that the Spruce Lake rhyolite, Boucher Brook sedimentary rocks and Canoe Landing Lake alkali basalt represent one younging-upward succession that was deposited in late Arenigian to early Llanvirnian time (31 in Fig. 2).

The Canoe Landing Lake (CLL) Formation, as originally defined, comprises two basalt suites. The structurally lower Canoe Landing Lake suite consists of high-chromium alkali basalt with intercalated red slate, chert and rare felsic volcanic rocks, whereas the structurally higher Nine Mile Brook suite is composed of tholeiitic pillow basalt with intercalated alkali basalt, red slate and chert (van Staal *et al.* 1991). As noted above, the alkali basalt is not in the same nappe as the tholeiitic basalt and therefore, should not be included in the same formation. We propose that the name Canoe Landing Lake Formation be restricted to the structurally lower suite and that the name Nine Mile Brook Formation be used for the upper suite. Recent drilling to the north of Canoe Landing Lake (Brown 1996) has revealed that the contact between the two suites is marked by a broad zone of melange.

*Nappe 4* is characterized by the virtual absence of felsic rocks. The Tetagouche Group has been divided into two formations, namely Canoe Landing Lake and Boucher Brook. However, we prefer to assign all the rocks in this nappe to the Nine Mile Brook Formation for reasons discussed above. In other words, the formation consists of a lower member dominated by tholeiitic basalt and an upper member dominated by fine-grained sedimentary rocks of oceanic affinity.

## Chemostratigraphy

A comprehensive review of the lithogeochemistry of the Bathurst Camp (*cf.* Lentz 1996*a*) is beyond the scope of this guidebook. However, some generalizations about the use of lithogeochemistry for differentiating rock units within the Camp are given below; for details, the reader is directed to the cited references.

Formal subdivision of volcanic rocks in the Bathurst Camp has been greatly enhanced by the use of lithogeochemistry. Different alkalic and tholeiitic basalt units were distinguished and mapped by van Staal *et al.* (1991), as noted in the preceding section; however, they did not attempt to subdivide the felsic rocks to any extent. Langton (1991) was the first to report chemical differences between felsic rocks in the Nepisiguit Falls (NF) and Flat Landing Brook (FLB) formations and Lentz and Goodfellow (1992*a*) suggested that these differences are probably related to a two-stage partial melting of a single lower-crustal source area. The major-element contents of the two formations are similar but the FLB has slightly higher amounts of heavy-rare-earth elements, Zr, Nb, Y and Th (Lentz 1996*b*). In particular, Th/Yb versus Ta/Yb ratios are lower in the FLB Formation than in the NF Formation (Langton 1991; Langton and McCutcheon 1993; Wilson 1993). Subsequently, the Mount Brittain, Clearwater Stream, Sevogle River and Spruce Lake formations have been defined, based on textural and geochemical differences from the NF and FLB formations (*cf.* Gower 1996; Fyffe 1995; Rogers and van Staal 1996; Wilson and Fyffe 1996). For example, the Spruce Lake Formation generally has a higher Y/Zr ratio than other felsic volcanic units in the Tetagouche Group (Rogers and van Staal 1996).

Lithogeochemistry has also been used to help differentiate among various sedimentary rock units in the Bathurst Camp. The first regional-scale lithogeochemical study of sedimentary rocks in the Camp was done by Connell and Hattie (1990), prior to formal subdivision of the Miramichi and Tetagouche groups. Subsequently, their data have been interpreted by Lentz *et al.* (1995) in a stratigraphic context and other work has been done by Fyffe (1994*b*), Lentz *et al.* (1996) and Langton (1997).

## 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 complex geometry (van Staal and Williams 1984; van Staal *et al.* 1988; de Roo *et al.* 1990, 1991; de Roo and van Staal 1991, 1994).

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 ($S_1$), and generally a stretching lineation ($L_1$). The $D_1$ fabric elements are interpreted to have formed in the Late Ordovician to Early Silurian (van Staal *et al.* 1992) as a result of imbrication in a northwest-dipping subduction complex (see Fig. 3d). They are typically concentrated in narrow ductile 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 1994) that formed in the subduction zone.

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 were interpreted to have formed in the Late Silurian (de Roo and van Staal 1994) but are now considered to be Early Silurian or older (Gower and McCutcheon in press). 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 $S_2$ cleavage 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 generally the dominant fabric elements throughout the area. In the latter stages of $D_2$, which is associated with obduction of the accretionary wedge onto the basin margin, out-of-sequence thrusts formed. These $D_2$ thrusts, which locally cut off $F_2$ folds, are commonly marked by melange zones and they bound the major nappes.

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 1994), which occurred in the Late Silurian (Gower and McCutcheon in press). Where $D_3$ was intense, $S_1$ and $S_2$ are 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 ages (Sullivan and van Staal 1996) 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 3.

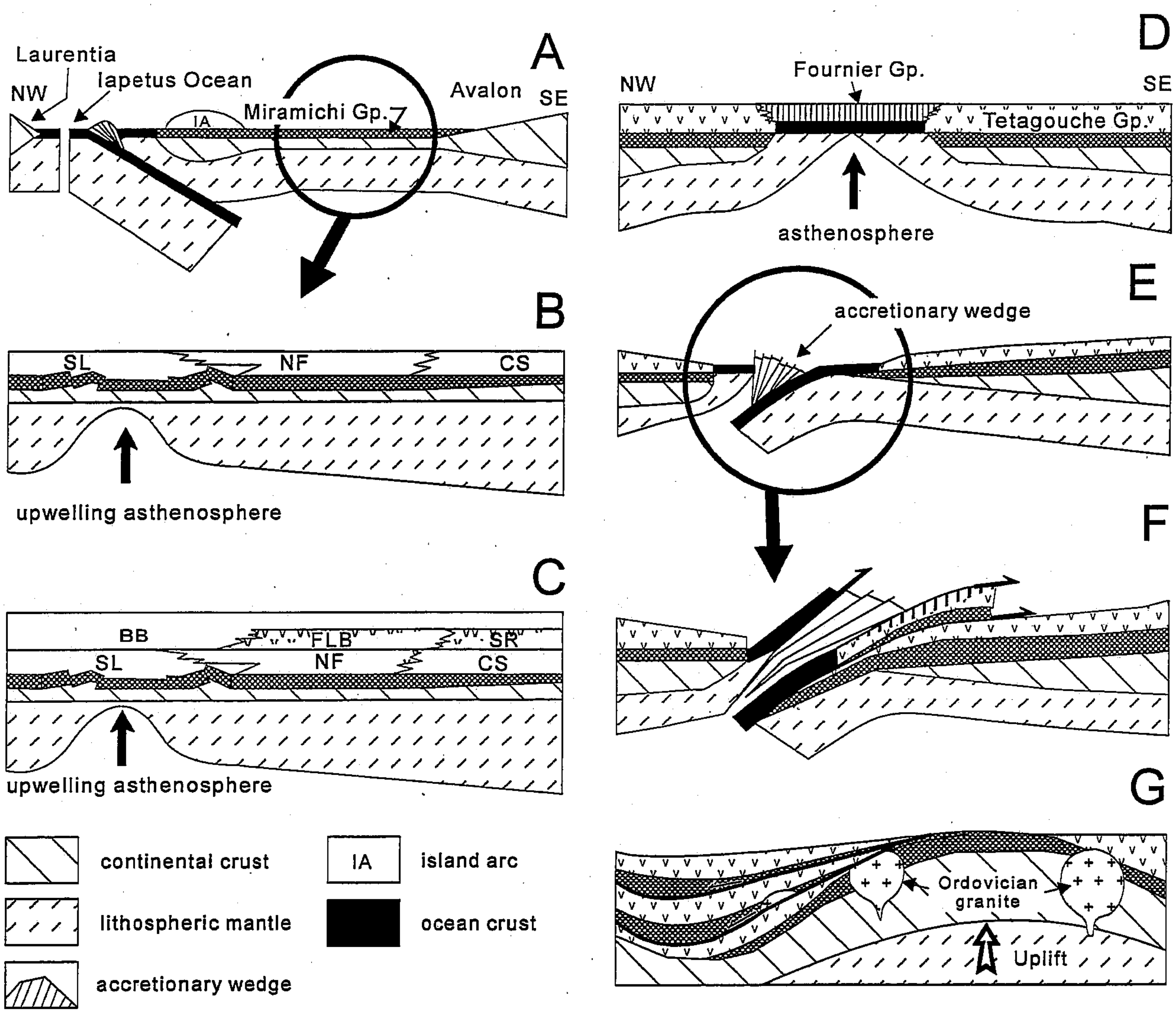



*Figure 3. Schematic tectonic model of the Bathurst Camp. A) Initial stage in the development of a back-arc basin behind an ensialic arc on the Avalon margin of Iapetus (circa 480 Ma). B) Slab roll-back causes mantle upwelling and generates widespread felsic volcanism (circa 470 Ma), e.g. Spruce Lake (SL), Clearwater Stream (CS) and Nepisiguit Falls (NF) formations. C) Further crustal melting and thinning produces a second stage of felsic volcanism and widespread mafic volcanism (circa 465 Ma), e.g. Flat Landing Brook ( FLB), Sevogle River (SR) and upper Boucher*

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; van Staal 1994*a*). The rocks of the northern Miramichi Highlands are thought to have been assembled in the subduction complex, *i.e.* Tetagouche 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 the Fournier Group yielded ages ranging from 453±6 Ma to 416±6 Ma, with the most precise age of blueschist metamorphism being 447±6 Ma (van Staal *et al.* 1990); (2) the youngest rocks of the Tetagouche Group involved in thrusting are late Caradocian (van Staal 1994*a*); (3) the Fournier Group is unconformably overlain by Lower Silurian (Llandovery) conglomerates of the Chaleur Group. Within this tectonic scenario, $D_1$ is subduction-related and occurred in the accretionary wedge prior to closure of the oceanic basin, whereas $D_2$ is obduction-related and occurred when the accretionary wedge was thrust over the basin margin (Fig. 3e). Post-$D_2$ deformation resulted from the subsequent oblique, more or less continuous collision between Laurentia and Avalonia, which ended in the Early 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, and Heath Steele deposits, whereas Brunswick No. 6, Caribou, CNE, Stratmat and Wedge are past producers; Chester and Key Anacon reached the bulk-sampling stage of development (Fig. 4). Mining will commence soon at the Restigouche deposit in conjunction with the re-opening of the Caribou Mine. 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 hangingwall of the Austin Brook massive-sulphide deposit was mined for iron.

Massive-sulphide deposits occur in several stratigraphic positions within the Tetagouche Group but the major ones occur in, or with, felsic volcanic rocks in the lower part of the Group. Many are closely associated with felsic volcaniclastic rocks of the Nepisiguit Falls Formation; a few are in the Clearwater Stream, Mount

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*Brook (BB) formations. D) Crustal separation results in the formation of oceanic crust and pelagic sedimentation (circa 460 Ma), e.g. Fournier Group and post-volcanic slates and cherts of the Tetagouche Group. E) Subduction ($D_1$) produces an intraoceanic accretionary wedge containing underplated blueschist. F) The deformed accretionary wedge and trailing ophiolite are obducted (D2) onto the continental margin (circa 430 Ma). G) Continental collision causes uplift, gravity sliding and refolding of earlier fabrics (420–390 Ma).*

Brittain and Spruce Lake formations; others are in the lower sedimentary part of the Boucher Brook Formation and some are within the Flat Landing Brook Formation. Previously, three groups of deposits were recognized (van Staal and Williams 1984; van Staal 1986) but more recent work indicates that this is an over-simplification.

Within the Nepisiguit Falls Formation, stratiform deposits are associated with fine-grained rocks, generally near the contact with the underlying Patrick Brook Formation (Miramichi Group) or the overlying Flat Landing Brook Formation. The Heath Steele (this volume) and Halfmile Lake (Adair 1992) deposits are examples of the former, and the Brunswick deposits (this volume) and Key Anacon (Lentz and Langton 1993; Lentz 1995) are examples of the latter. Typically, the host rocks are greenish grey to dark grey mudstones that are interbedded with fine- to medium-grained volcaniclastic rocks, in which feldspar has been destroyed by hydrothermal alteration (Lentz and Goodfellow 1993*a*). Algoma-type iron formation commonly caps and/or is laterally equivalent to the massive sulphides (Peter and Goodfellow 1996). There are also some deposits that crosscut Nepisiguit Falls rocks, *e.g.* Devils Elbow (Walker in prep.), and presumably represent feeder zones to stratiform mineralization higher in the volcanic pile.

The overlying Flat Landing Brook Formation contains both stratiform and stratabound deposits. Examples of stratiform deposits include Headway and Stratmat, whereas Taylor Brook and Hartts Lake are examples of stratabound deposits (Fig. 4). The stratiform deposits are hosted by ash tuff and/or fine-grained sedimentary rocks but the stratabound deposits are within hyaloclastite and fragmental rocks; the former deposits may contain iron formation, particularily those near the base of the formation, but the latter never do.

Deposits in the Clearwater Stream, Mount Brittain and Spruce Lake formations are all contained in volcanic rocks, and none has an associated iron formation. Examples include Chester, Restigouche and Armstrong B (Fig. 4), respectively.

A number of stratiform massive-sulphide deposits occur in the lower Boucher Brook, hosted entirely within sedimentary rocks that overlie the Spruce Lake Formation; however none has an associated iron formation. Examples include Canoe Landing Lake and Orvan Brook. The Caribou deposit occurs in similar sedimentary rocks that appear to underlie the Spruce Lake Formation, based upon metal zoning (Cavalero 1993). However, it seems more likey that these sedimentary rocks are intercalated with the Spruce Lake felsic volcanic pile.

**Field trip summary**

During the next three days (Fig. 4), seven deposits will be visited, namely: Heath Steele, Wedge (Day 1), Brunswick No. 6, Brunswick No. 12, Austin Brook (Day 2), Restigouche and Murray Brook (Day 3). All are within Nappe 1 except Heath Steele (Nappe 2), Wedge (Nappe 3) and Murray Brook (Nappe 2).

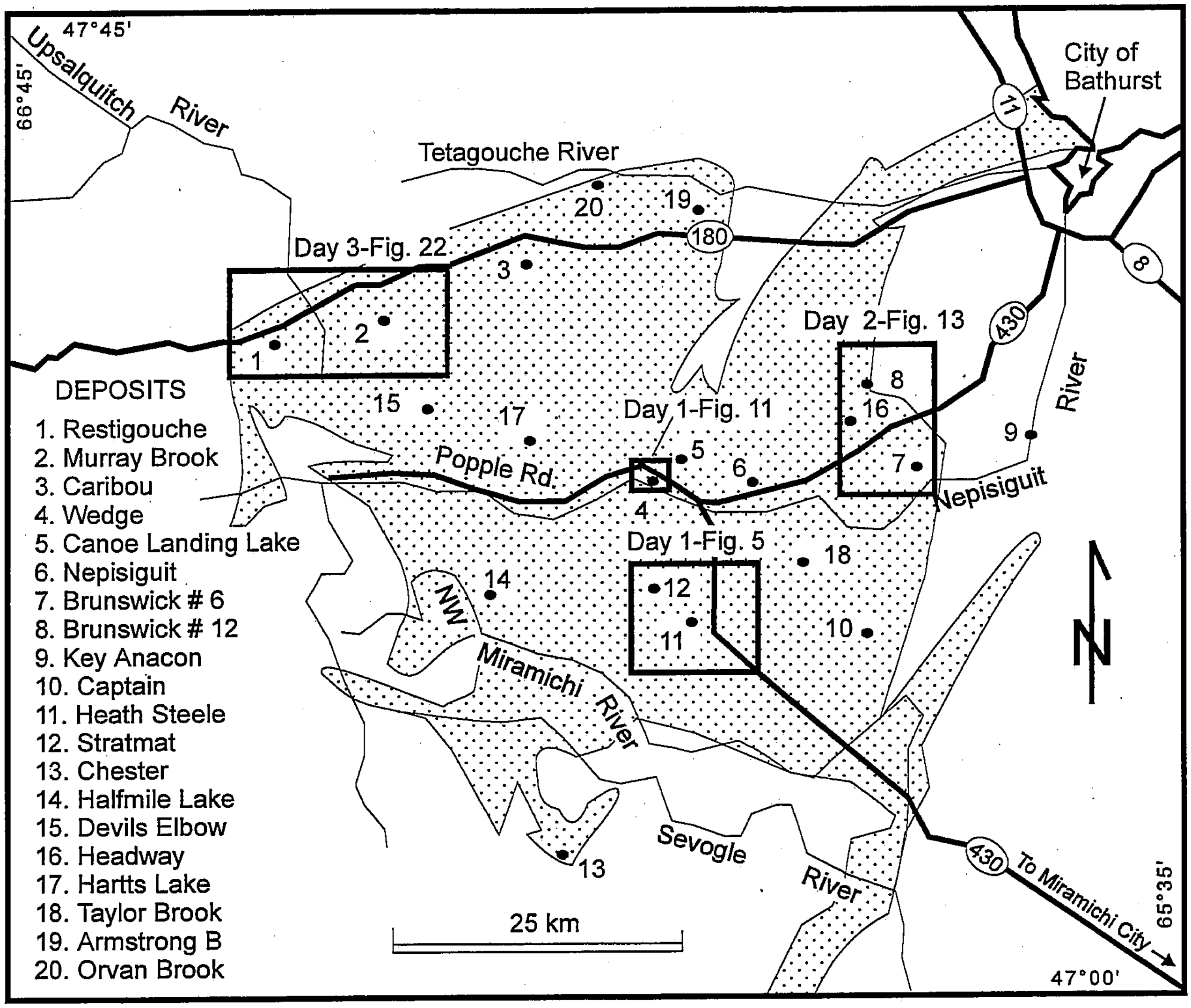



*Figure 4. Location map showing the areas to be visited and locations of massive sulphide deposits mentioned in the text. Stippled area represents the approximate distribution of the Tetagouche Group.*

<u>Day 1: Heath Steele and Wedge deposits</u>

| | |
|---|---|
| Stop C-1 | Underground tour, C Zone, Heath Steele Mine |
| Stops HS-1 – HS-3 | Surface exposures, Heath Steele Mine |
| Stops W-1 – W-10 | Surface exposures, Wedge deposit |

<u>Day 2: Brunswick No. 12 and No. 6, and Austin Brook deposits</u>

| | |
|---|---|
| Stops 12-1 – 12-13 | Underground tour, 850 m level, Brunswick No. 12 Mine |
| Stops NF-1 – NF-7 | Nepisiguit Falls Formation stratotype |
| Stops A-1 – A-3 | Quarry, Austin Brook deposit |
| Stops 6-1 – 6-9 | Surface exposures, Brunswick No. 6 deposit |

<u>Day 3: Restigouche and Murray Brook deposits</u>

| | |
|---|---|
| Stops R-1 – R-3 | Quarry and surface exposures, Restigouche deposit |
| Stops R-4 – R-12 | Surface exposures, Murray Brook deposit |

## DAY 1. THE HEATH STEELE AND WEDGE DEPOSITS

### Part I. The Heath Steele deposits *(A. Hamilton and R.A. Wilson)*

Introduction and history

The Heath Steele property is approximately 65 km southwest of Bathurst and 50 km northwest of Newcastle, between the Northwest Miramichi and Nepisiguit rivers in northern New Brunswick (Fig. 4). Discovery of massive sulphides at Heath Steele followed shortly after the 1952 discoveries of the Brunswick No. 6 and No. 12 deposits. In 1953, the International Nickel Company (INCO) and AMAX (formerly American Metals) carried out an airborne electromagnetic survey over the Heath Steele area. Numerous anomalies were detected, and the follow-up ground-EM and soil-geochemical surveys highlighted targets that were diamond-drilled in 1954. This drilling led to the discovery of the A, B, C, D and E zones (Fig. 5). 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. Of the five major mineralized zones, the largest is the B Zone (Table 1).

Mining began in 1957 but ceased in 1958 because of metallurgical problems and low metal prices. Mining operations resumed in 1962 and lasted until 1983 when low metal prices prompted another shutdown. Production during this period included 508 000 t from the A Zone, 150 000 t from D Zone and 15 794 000 t 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 t of gold-bearing gossan ore were processed with an average grade of 4.8 g/t Au and 175.5 g/t Ag. 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, 4 km northwest of Heath Steele (Fig. 5), was acquired from Cominco; when the mill was put back into production in 1989, ore was mined from the Boundary Zone and B Zone (the Boundary Zone straddles the boundary of the Stratmat property and the Heath Steele lease). In 1990, it was 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; however, mining and milling operations were suspended from mid-1993 to mid-1994 because of depressed metal prices. Production from 1989 to August 31, 1996 included 1 137 600 t from the Boundary and

*Table 1. Cumulative production statistics 1957 – August 31, 1996*

| Zone | Tonnes | Pb(%) | Zn(%) | Cu(%) | Ag(g/t) |
|---|---|---|---|---|---|
| ACD Zone | 1 548 000 | 2.17 | 7.81 | 0.61 | 84 |
| B Zone | 19 649 600 | 1.75 | 4.76 | 0.98 | 65 |
| Stratmat | 1 137 600 | 2.98 | 8.11 | 0.35 | 44 |

nearby N-5 zones, 3 489 800 t from the B Zone and 884 000 t from the ACD Zone with an average grade of 2.24% Pb, 6.67% Zn, 0.63% Cu and 66 g/t Ag. Ore reserves at September 1, 1996 totalled 3 526 000 t grading 1.72% Pb, 6.46% Zn, 0.87% Cu and 72 g/t Ag. The B Zone is currently being mined along with parts of the ACD Zone (the three zones are generally considered together).

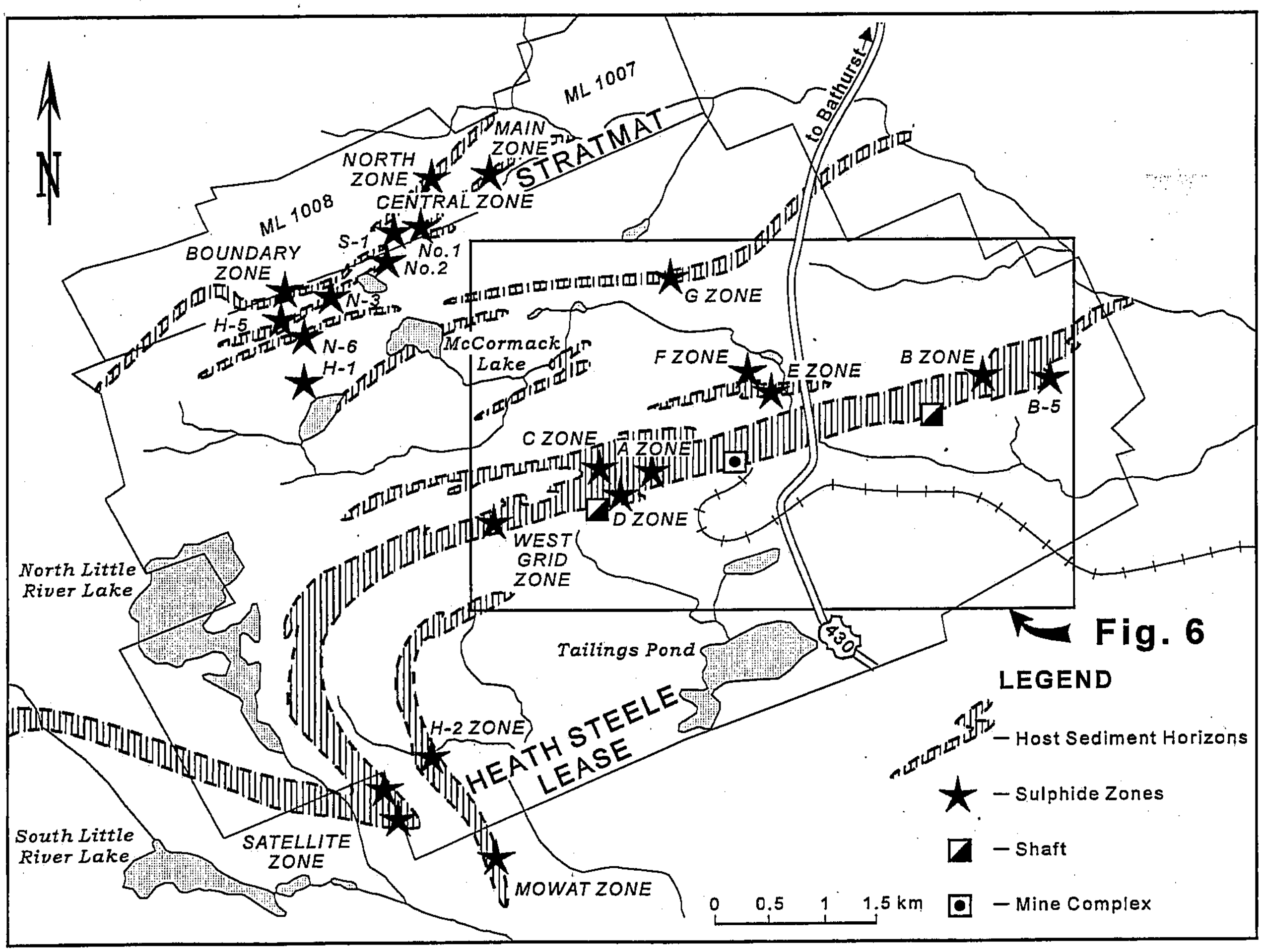



*Figure 5. Map showing the boundaries of the Heath Steele lease and the Stratmat property (modified from Hamilton 1992). See Figure 4 for approximate location of this map.*

## Stratigraphy

All of the massive-sulphide deposits at the B, ACD and E zones are hosted by and concordant with tuffaceous sedimentary and crystal-rich volcanic/volcaniclastic rocks (Fig. 6) of the Nepisiguit Falls Formation (van Staal and Fyffe 1991), which is part of the Tetagouche Group (Skinner 1974). At the Brunswick No. 6 and No. 12 deposits, mineralization is concentrated at or near the contact between footwall quartz-feldspar crystal tuff/tuffite and hangingwall rhyolite of the Flat Landing Brook Formation. In contrast, at Heath Steele the footwall consists mainly of fine- to medium-grained siltstone and quartz wacke with local interbeds of crystal tuff/tuffite, whereas the hangingwall comprises massive quartz-feldspar crystal tufflava/porphyry that is overlain by Flat Landing Brook rhyolite. Thus, if the Brunswick footwall and Heath Steele hangingwall crystal-rich volcanic rocks are assumed to be coeval, the Heath Steele deposits are older than those at Brunswick. South of the mine a zone of high strain (Heath Steele Fault of de Roo *et al.* 1991) juxtaposes Flat Landing Brook rhyolite against Nepisiguit Falls rocks (Fig. 6). The Heath Steele stratigraphy can be followed to the west and southwest, around the nose of a regional-scale $F_2$ fold structure (North Little River Lake fold of de Roo *et*

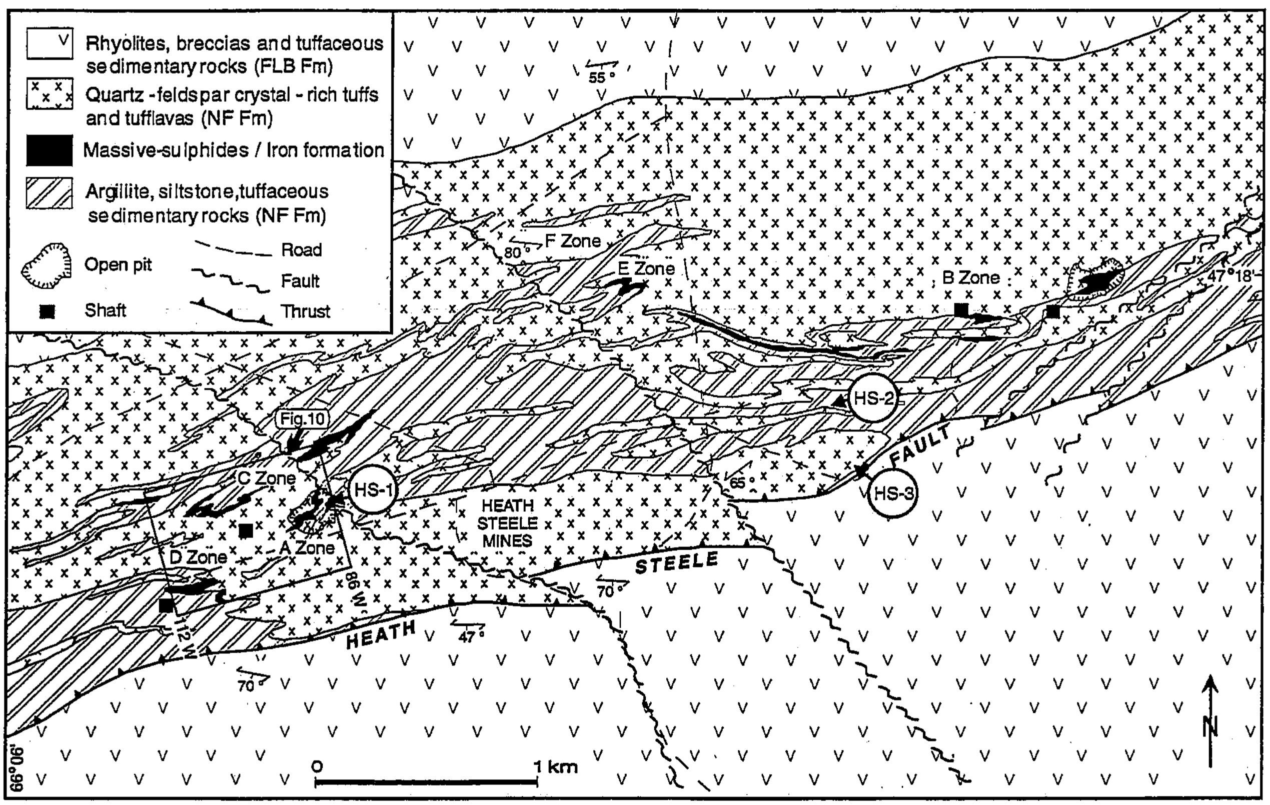



*Figure 6. Geological map of Heath Steele Mines area, showing locations of field trip stops (modified from Wilson 1993). NFFm = Nepisiguit Falls Formation; FLBFm = Flat Landing Brook Formation. Arrow shows perspective for Figure 10. See Figure 5 for location of this map.*

*al.* 1990), where the subeconomic Mowat and Satellite base-metal deposits occupy the same stratigraphic horizon (Fig. 5). 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.

The stratigraphic succession at Heath Steele consists of an alternating sequence of sedimentary and quartz-feldspar-phyric volcanic rocks. Interpretations differ (Fig. 7) as to whether crystal tuff intersected in the structural footwall represent fold repetitions of the hangingwall tuff (*e.g.* Moreton 1994; de Roo *et al.* 1991), or are distinct, stratigraphically lower (older) pyroclastic rocks (McBride 1976; Owsiacki 1980; Wilson 1993). Recent chemostratigraphic studies (Lentz and Wilson in press; Lentz *et al.*, in press) indicate that the footwall and hangingwall crystal tuff at the B Zone have distinct chemical signatures and, therefore, support the latter interpretation (Fig. 7). The main body of crystal tuff at Heath Steele, *i.e.* the hangingwall crystal tuff, typically resembles a lava flow because of its glassy microfelsitic groundmass and large euhedral to subhedral phenocrysts of alkali feldspar. Local intercalation of volcaniclastic rocks indicate reworking of the parent tuff/tufflava. Evidence for a pyroclastic origin includes large lateral extent but limited thickness of units, local (large-scale) internal bedding structures, gradational contacts

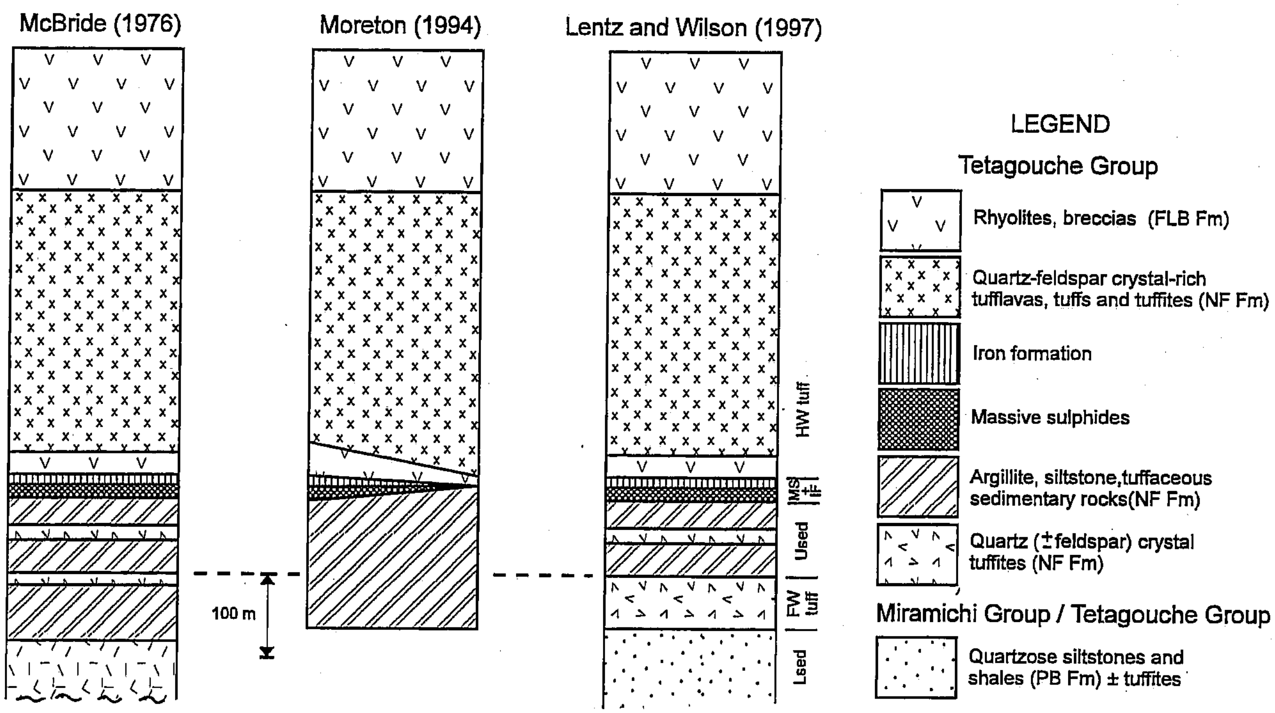



*Figure 7. Schematic stratigraphic columns comparing previous (McBride 1976; Moreton 1994) and current (Lentz and Wilson 1997) interpretations of the Heath Steele mine stratigraphy. Lsed = lower footwall sedimentary rocks; FW tuff = footwall crystal tuffite; Used = upper footwall sedimentary rocks; HW tuff = hangingwall crystal tuff/tufflava; NFFm = Nepisiguit Falls Formation; FLBFm = Flat Landing Brook Formation; PBFm = Patrick Brook Formation.*

with tuffaceous (epiclastic) sedimentary rocks, and, in places, broken quartz-phenocrysts (Wilson 1993). However, bubble-wall shards and pumice fiammé are rare to absent, which 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, or more likely, rapid exsolution of volatiles was inhibited by the confining pressure of the overlying water column, thus reducing explosivity (*cf.* Cas 1992). Interbeds of crystal tuff or tuffite in the footwall of the deposit more commonly exhibit primary features typical of a pyroclastic origin.

Sedimentary rocks of the Nepisiguit Falls Formation include quartzose siltstone and sandstone, shale, feldspathic wacke, and local massive sulphides and ironstone. The clastic rocks are typically medium to dark green, locally sericitic and commonly moderately to highly chloritic; maximum chloritization occurs in proximity to massive-sulphide bodies, where local usage describes the rocks as "chloritic tuffs". In the chemostratigraphic studies referred to above (*e.g.* Lentz and Wilson in press), lithological and chemical differences between lower and upper sequences of sedimentary rock at the B Zone suggest that the lower footwall sedimentary rocks (dark grey, locally graphitic shale, siltstone, and sandstone) are more typical of the Patrick Brook Formation (Miramichi Group), whereas the upper footwall sequence (green shale and siltstone intercalated with volcaniclastic beds) chemically resembles the Nepisiguit Falls Formation. Chemostratigraphic studies are continuing in the ACD zone to the west; however, at this writing it appears that the Patrick Brook-like rocks may pinch out west of the B Zone, and that all sedimentary rocks at the ACD zone (and in the southwestern part of the belt) belong to the Nepisiguit Falls Formation. This is supported by the presence of crystal tuff or tuffite interbeds in sedimentary rocks in this area.

The Flat Landing Brook Formation consists primarily of aphyric or feldspar-phyric rhyolite flows and domes, plus minor felsic hyaloclastite, sedimentary rocks, and local alkalic or tholeiitic, subvolcanic mafic intrusions. Spherulitic and perlitic textures, indicating an originally glassy state, are common in the rhyolite, and pseudo-fragmental (lapilli-like) textures are locally produced by devitrification and alteration of glassy rhyolite (*cf.* Allen 1988). In high-strain zones, false ignimbritic textures may be created by extreme attenuation of pseudo-fragments, spherulites and/or phenocrysts (Wilson 1992). However, deformation of the Tetagouche Group is markedly heterogenous (*cf.* van Staal 1987; van Staal and Langton 1990), and primary textures and structures are locally well preserved in the rhyolite. Felsic hyaloclastite 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), and are relatively abundant in the vicinity of the Stratmat deposit.

Structure

In general, the rocks of the mine sequence strike east-west and dip steeply north, although steep southerly dips are encountered at depth (900 m). Because the mine sequence is flanked to the north and south by younger rocks of the Flat Landing Brook Formation, the gross structure defines a large-scale antiform, first recognized by Dechow (1960), whose simplistic structural model has since been elaborated and refined by numerous workers, *e.g.* McMillan (1969), Whitehead (1973), McBride (1976), Owsiacki (1980), de Roo *et al.* (1990, 1991), Moreton (1994) and Park (in prep.). For example, although Dechow (1960) interpreted the mine sequence in the B Zone as a south-younging succession, all subsequent interpretations confirm that the sequence is north-younging. Detailed structural analyses in the Heath Steele area by McBride (1976), de Roo *et al.* (1990, 1991) and Moreton (1994) indicate at least five sets of fabric elements that accompanied five deformational events; these are described briefly below.

*First deformation ($D_1$).* The earliest deformation is characterized by tight to isoclinal recumbent sheath folds indicative of high strain (Moreton 1994). $F_1$ folds have been documented at both outcrop- and mine-scale, and have been invoked to account for younging reversals and local repetition of hangingwall units in the structural footwall (Moreton 1994). Using the relationship of cleavage ($S_1$) to bedding ($S_0$) in a limited number of exposures in the B Zone, McBride (1976) concluded that the first deformation was characterized by north-northwest facing recumbent folds ($F_1$). In contrast, Moreton (1994) suggested that the vergence of $F_1$ is towards the southeast; this is consistent with recent paleotectonic models that invoke southeast-directed tectonic transport (obduction) in this part of the Appalachian Orogen during the Late Ordovician (van Staal 1987). In the ACD Zone, Owsiacki and McAllister (1979) documented only the four youngest deformations, probably because of the obliteration of $D_1$ features by later events.

*Second deformation ($D_2$).* In the vicinity of the B Zone, the second deformation ($D_2$) is characterized by northerly-overturned, open to tight folds of earlier layering (Fig. 8 and 9). In general, the $F_2$ folds have a moderate westerly plunge and a moderately south-southwest-dipping axial-planar foliation (Moreton 1994). The intensity of $S_2$ is such that it generally obliterates $S_1$ by transposition, producing a composite $S_{1-2}$ schistosity. As the dip of this foliation is opposite that of the orebody as a whole, Moreton and Williams (1986) and de Roo *et al.* (1991) have interpreted the ore slabs as marking the enveloping surface of $F_2$ folds. In contrast to the B Zone, $F_2$ folds at the A and C zones are sheath folds with strongly curvilinear hinge lines, whose long axes plunge generally southwest (Park, in prep.). The strike of $S_2$ varies from 050° to 120°, mainly because of the effects of the younger deformations.

*Third, fourth and fifth deformations ($D_{3-5}$).* The younger deformation events are characterized by open folds of the main $S_{1-2}$ composite foliation. The third generation of folds ($F_3$, or $F_H$ of de Roo *et al.* 1990, 1991) features flat to shallowly

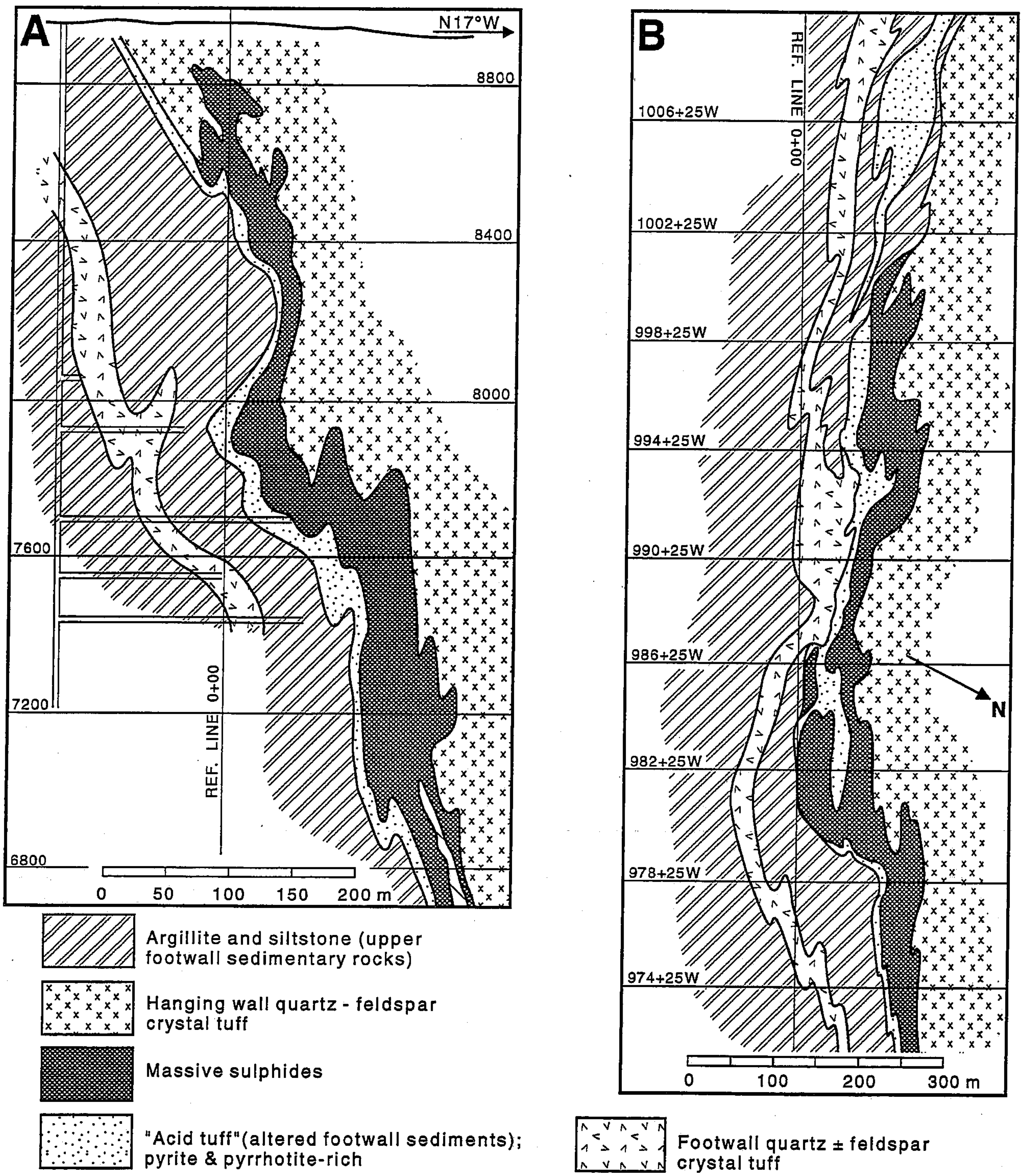
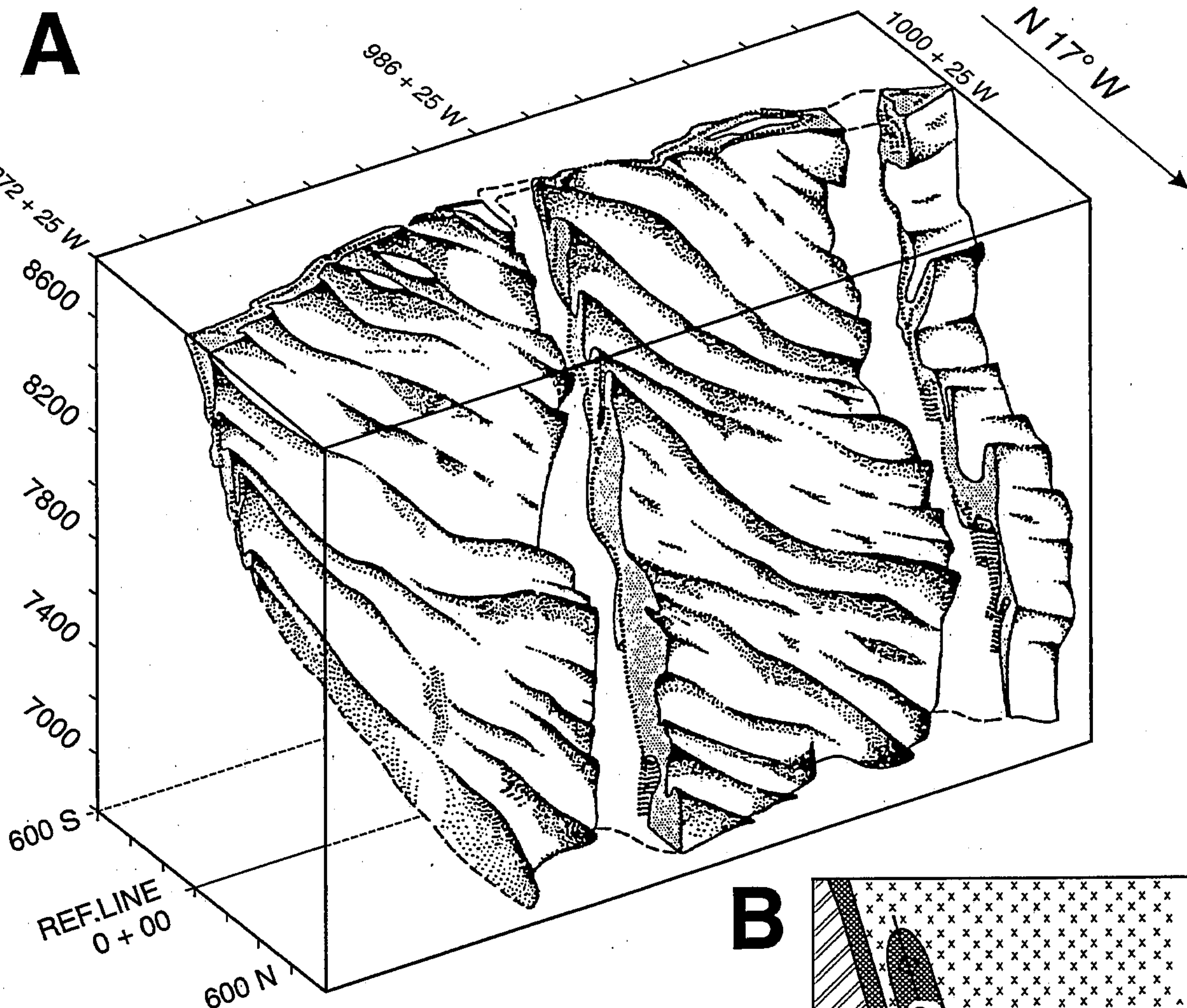



*Figure 8. A) Geological cross section of B Zone at 980+25W. B) geological plan of the 7800 level at B-Zone. Modified from McDonald (1983) (in Davies et al. 1983).*



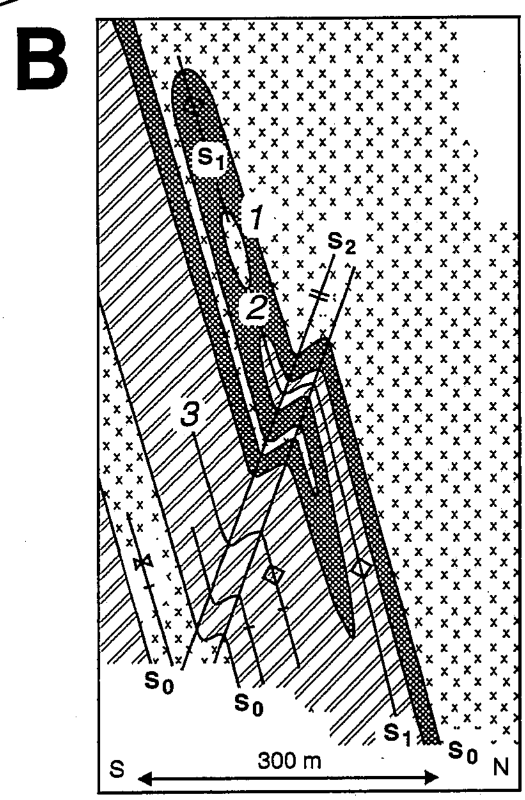




*Figure 9. A) Block diagram of the Heath Steele B Zone showing the geometry of the massive-sulphide body and orientation of $F_2$ folds. The co-ordinate system is the same as in Figure 8. Diagram from McDonald (1983) (in Davies et al. 1983). B) Schematic structural-stratigraphic section of B Zone, illustrating geometry of $F_1$ and $F_2$ folds. The $F_1$ sheath fold (1) is related to the $F_1$ antiform (2), which is parasitic to the larger scale $F_1$ antiform (3) (modified from de Roo et al. 1991). Legend as in Figure 8.*

dipping axial surfaces; these folds account for much of the variability in the strike and dip of $S_2$. The fourth and fifth deformations have subvertical axial surfaces, and (respectively) northwest- and northeast-plunging fold axes. These two generations of folds can be considered to define a conjugate pair at the B Zone, whereas at the C Zone a clear $F_4$-$F_5$ interference pattern is seen (Park, in prep.). In most cases, the axial-plane foliation is a fracture cleavage that may contain remobilized quartz and base metals.

Massive sulphides

Considerable evidence has been accumulated (*e.g.* base-metal zoning within the deposits, the oxide-facies iron formation overlying the deposits, and the presence of abundant feeder-zone type stockworks) to suggest that the deposits are syngenetic, and accumulated from exhalative solutions in subaqueous basins (Lusk 1969, 1992; Whitehead 1973; Wahl 1978). This model contrasts with the earlier suggestion by Dechow (1960) that the deposits are epigenetic; more recently, de Roo *et al.* (1991, 1992) cite some evidence for an epigenetic origin (*e.g.* local concentration of sulphide lenses parallel to $S_1$ in $F_1$ closures) but point out that conclusive evidence for either model has been obliterated by deformation and mass transfer. De Roo *et al.* (1992) argue that their complex interpretation of the geometry of $S_0$ does not support the simple model of base-metal zonation presented by Lusk (1969). However, some of this apparent stratigraphic complexity (*e.g.* repetition of hangingwall tuff in the structural footwall) is simplified if the crystal tuff in the structural footwall is a distinct stratigraphic unit, as proposed by Lentz *et al.* (in press) and Lentz and Wilson (in press); in this way the two conflicting interpretations may, at least in part, be reconciled.

*B Zone.* The B Zone forms a continuous to locally discontinuous tabular body, up to 60 m thick, that has been traced over a strike length of 1500 m and a depth of 800 m. The stratabound orebody strikes east-west, dips steeply to the north, and is deformed into westerly-plunging, northerly-overturned mesoscopic $F_2$ folds (Fig. 8, 9). Three distinct sulphide zones can be recognized: massive pyrite, banded pyrite-sphalerite-galena and pyrrhotite-chalcopyrite fragmental ore. The 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. It occurs mainly along the footwall of the massive sulphides, although in some areas it both overlies and underlies the orebody, and locally appears to display a cross-cutting relationship, especially where the sulphide bodies are affected by $F_2$ folds. Owsiacki and McAllister (1979) suggested that the fragmentation was volcanic-related, *i.e.* formed by soft-sediment slumping of the sulphides. McDonald (1983) and Moreton (1994), on the other hand, suggest that $D_1$ thrusting was responsible for creating the breccia because it locally transects the massive sulphides, 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 all been recognized at the B Zone. Intercalated layers of chert are a common feature in the various types. Thinly layered iron formation may be superposed on, marginal to, or intercalated with massive sulphides, although the latter case probably reflects $F_1$ and $F_2$ folding. McMillan (1969) recognized metamorphic biotite, chlorite and/or stilpnomelane in the iron formation, and identified the most common silicate as chamosite, although McBride (1976) used X-ray diffraction to conclude that it is in fact the chlorite group mineral diabantite. Fine-grained, concentrically zoned siderite in the carbonate-facies iron formation was interpreted to be of oolitic origin by both McMillan (1969) and McBride (1976). If this interpretation is correct, it may indicate a shallow water environment for the formation of the sulphide deposits, although this remains to be investigated. Mn/Fe ratios in iron formation have been used to document a change from a reducing depositional environment (low Mn/Fe) in the vicinity of the massive sulphides, to an oxidizing environment (high Mn/Fe) more distal from the deposits (Wahl 1978; Whitehead 1973).

Mineralogically, the B Zone ore is composed dominantly of pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, arsenopyrite, tetrahedrite and Ag-bearing Pb-Bi-Sb sulfosalts. A chemical analysis (1977) of average mill feed yielded the following: 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 and <1.1 ppm Au (Chen and Petruk 1980). Proven and probable ore reserves for the B Zone at September 1, 1996 were 1 688 000 t of 2.02% Pb, 5.54% Zn, 1.00% Cu and 75 g/t Ag.

*ACD Zone*. This zone comprises the A, C and D deposits which, though separate, probably lie along a single contiguous horizon (Fig. 10). For example, the A and C (sub)zones define a semi-continuous massive-sulphide body that can be followed for a strike length of approximately two kilometres, and can be traced in the subsurface to depths of more than 400 m. Massive sulphides typically occur along the contact between quartz-feldspar crystal tuff/tufflava and chloritic sedimentary rocks (argillite and siltstone); however, in places the massive sulphides are bounded by sedimentary rocks, probably as a result of transposition related to $D_1$ or $D_2$ tectonism. Like the B Zone, the ACD Zone is structurally complex; isoclinal $F_1$ sheath folds that are refolded by $F_2$ folds account for much of this complexity (de Roo *et al.* 1991).

According to de Roo *et al.* (1991), the A Zone and the nearby C-1 Zone occupy the noses of an $F_1$ antiform and an attenuated $F_1$ synform, respectively (section 90W, Fig. 10). Similarly, to the west (*i.e.* sections 98W to 112W, Fig. 10), the C-4 Zone and D Zone occur within an isoclinal $F_1$ antiform and synform, respectively. These $F_1$ structures were described as elongate sheath folds with southwest-plunging axes, that have been modified by $F_2$ folds with south-dipping axial surfaces and westerly plunges of 10° to 45° (de Roo *et al.* 1990, 1991). In contrast, Park (in press) identifies the southwest-plunging sheath folds as $F_2$ structures, and states that the large-scale antiform in the A Zone pit is an $F_5$ fold. In any case, the dominant fabric is an $S_{1-2}$ composite (transposition) foliation, defined by a pervasive mineral (stretching)

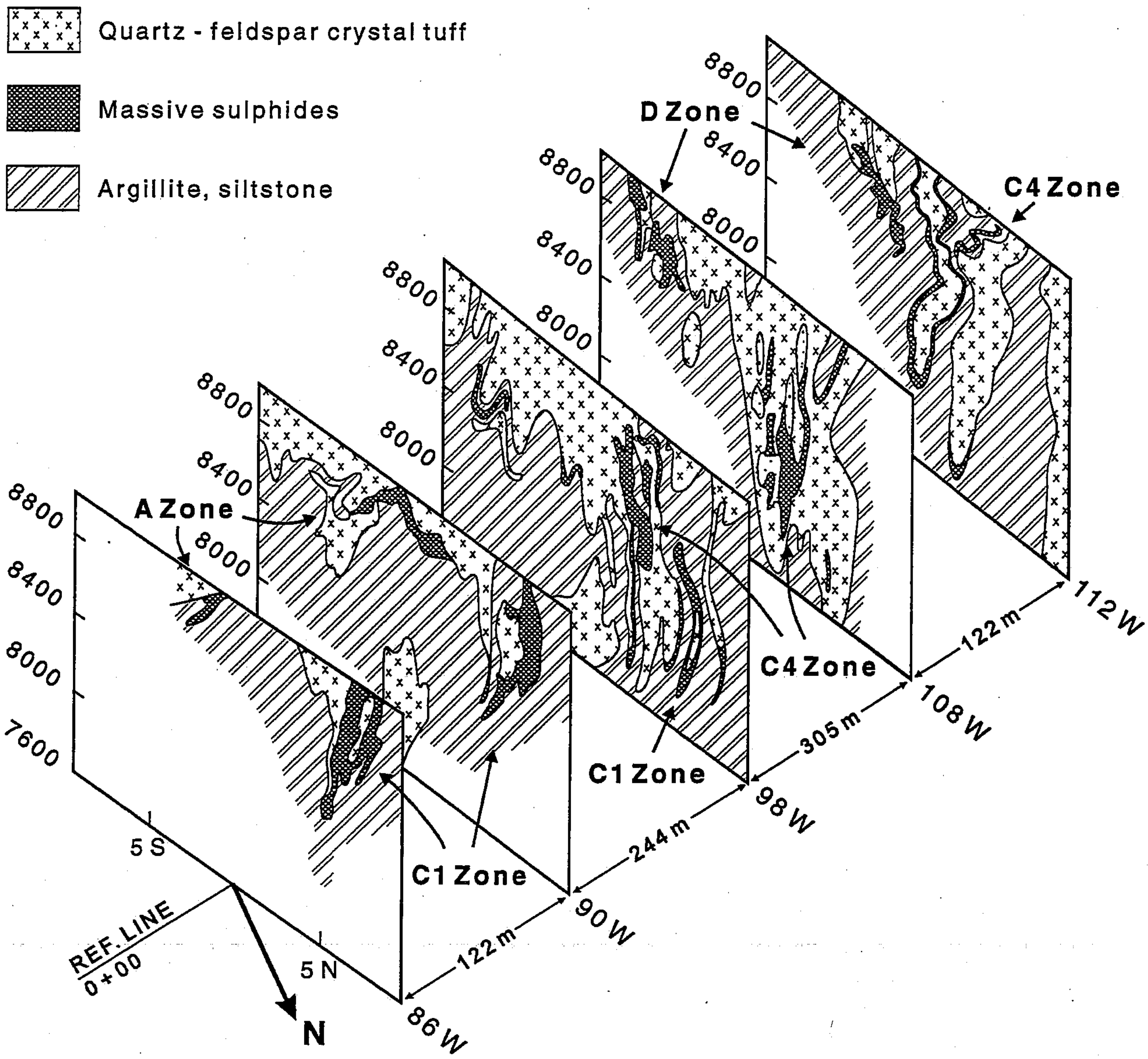



*Figure 10. Cross sections through the A, C and D zones, looking southwest (from de Roo et al. 1991). Vertical and N-S scales are 1 cm = 100 m. See Figure 6 for location of sections.*

lineation ($L^m{}_2$) that plunges consistently to the southwest. Variations in strike and dip of the $S_{1\text{-}2}$ schistosity is attributed to post-$F_2$ deformation, particularly $F_5$ folding.

Within the footwall sedimentary sequence, discontinuous lenses of quartz and quartz-feldspar crystal tuff/tufflava have been interpreted as structural repetitions of the hangingwall (de Roo *et al.* 1991). Immediately below the sulphide body is a thin, intermittent layer of felsic tuff containing bands of pyrite and pyrrhotite. Lateral base-metal zoning is evident in the C Zone; for example, the north limb of the enclosing ($F_1$?) fold is a copper-rich fragmental ore, whereas massive pyrite and banded pyrite-sphalerite-galena ores occur in the centre of the ore lens or in the hinge areas of parasitic 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 September 1, 1996, were 1 838 000 t of 1.45% Pb, 7.31% Zn, 0.76% Cu and 69 g/t Ag.

*E Zone.* The E Zone, located midway between the B and ACD zones (Fig. 5 and 6), was thought to lie along a common stratigraphic horizon; however, detailed mapping and trenching in recent years by Moreton (1994) 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 (near surface) 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 is concordant with the enclosing rocks, and 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.

## Alteration

Quartz-feldspar crystal tuff/tufflava and sedimentary rocks in the structural footwall of the Heath Steele massive-sulphide deposits are hydrothermally 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). Where intense footwall alteration leads to the destruction of feldspar, crystal tuff/tufflava is commonly referred to as "quartz porphyry" or "quartz-eye schist". Some of the most intense alteration in the area (*e.g.* abundant "quartz porphyries") is associated with the C Zone orebodies, both in the hangingwall and the footwall (Wahl 1978). Under most of the deposits, there is a relatively thin unit of variably pyritic, sericitic schist/phyllite which, though termed "acid tuff" in mine usage, probably represents altered footwall sedimentary rocks (Wahl 1978).

Using discriminant analyses, Whitehead and Govett (1974) found that Pb content is higher in the hangingwall rocks above the ore zones, whereas there is no apparent distinction between the hangingwall and footwall Pb content away from the ore zone. Low Mn/Fe ratios (more reducing) are associated with proximal settings with respect to the sulphide bodies, and in general are characteristic of the footwall, whereas high ratios typify the iron formation (and other hangingwall rocks) and areas distal from the deposits (Whitehead 1973). Such geochemical data have been used to support a north-younging direction in the B Zone (Whitehead 1973; Whitehead and Govett 1974). 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 background values. In addition to the major elements, Cu, Pb, Zn, Co, Ag, Cr and P contents also increase during alteration.

**Part II. The Wedge deposit** *(J.A. Walker and S.R. McCutcheon)*

Introduction and history

The Wedge deposit is located on the north bank of the Nepisiguit River, 40 km southwest of the city of Bathurst and 12.5 km north-northwest of the Heath Steele Mine (Fig. 4). The deposit was discovered in the mid 1950s just after the initial rush in the Bathurst Mining Camp. Following the identification of a gossan outcrop, a wedge shaped parcel of unstaked ground (from which the deposit got its name), was claimed in 1956. Detection and subsequent drilling (total 20 000 feet) of an EM anomaly in 1957-1958 by Cominco resulted in the discovery of the deposit.

In 1959 the decision was made to go underground with a three compartment shaft (sunk to 1150 feet) with levels at 150-foot intervals. Production of 750 tons/day began in 1962 and ended in May 1968. The ore was milled at the Heath Steele mine site and total production from the deposit, at the mill head, was 1 503 500 t grading 0.65% Pb, 1.61% Zn, 2.88% Cu, and 20.6 g/t Ag, (Luff 1995).

Stratigraphy

The Nepisiguit Falls Formation, which hosts the Wedge deposit, structurally overlies rocks assigned to the upper Boucher Brook Formation and is stratigraphically underlain by rocks assigned to the Spruce Lake Formation (Fig. 11). The Wedge mine site is the only known area where the stratigraphic relationship between the Spruce Lake and Nepisiguit Falls formations can be inferred. The rock types within each of these three formations, as they are manifested in the vicinity of the deposit, are briefly described below. A more detailed description, complete with lithogeochemical data, can be found in Walker and McCutcheon (1996).

The Spruce Lake Formation is represented by massive, aphyric to feldspar phyric rhyolite that is north and east of the mine site. This rhyolite was formerly assigned to the Flat Landing Brook Formation by Wilson (1993) and van Staal (1994*b*) but recently has been reassigned to the Spruce Lake Formation by Rogers and van Staal (1996). Typical Spruce Lake rocks, which are light green and potassium-feldspar phyric, occur east of the thrust that parallels Forty Mile Brook, whereas non-typical, aphyric to sparsely quartz-phyric rhyolite occurs immediately north of the deposit. The aphyric rhyolite is geochemically similar to typical Spruce Lake rocks and hence is included in this formation (Walker and McCutcheon 1996); in contrast the fine-grained quartz-phyric rhyolite near the upper contact of this unit has chemical similarities to the overlying Nepisiguit Falls Formation.

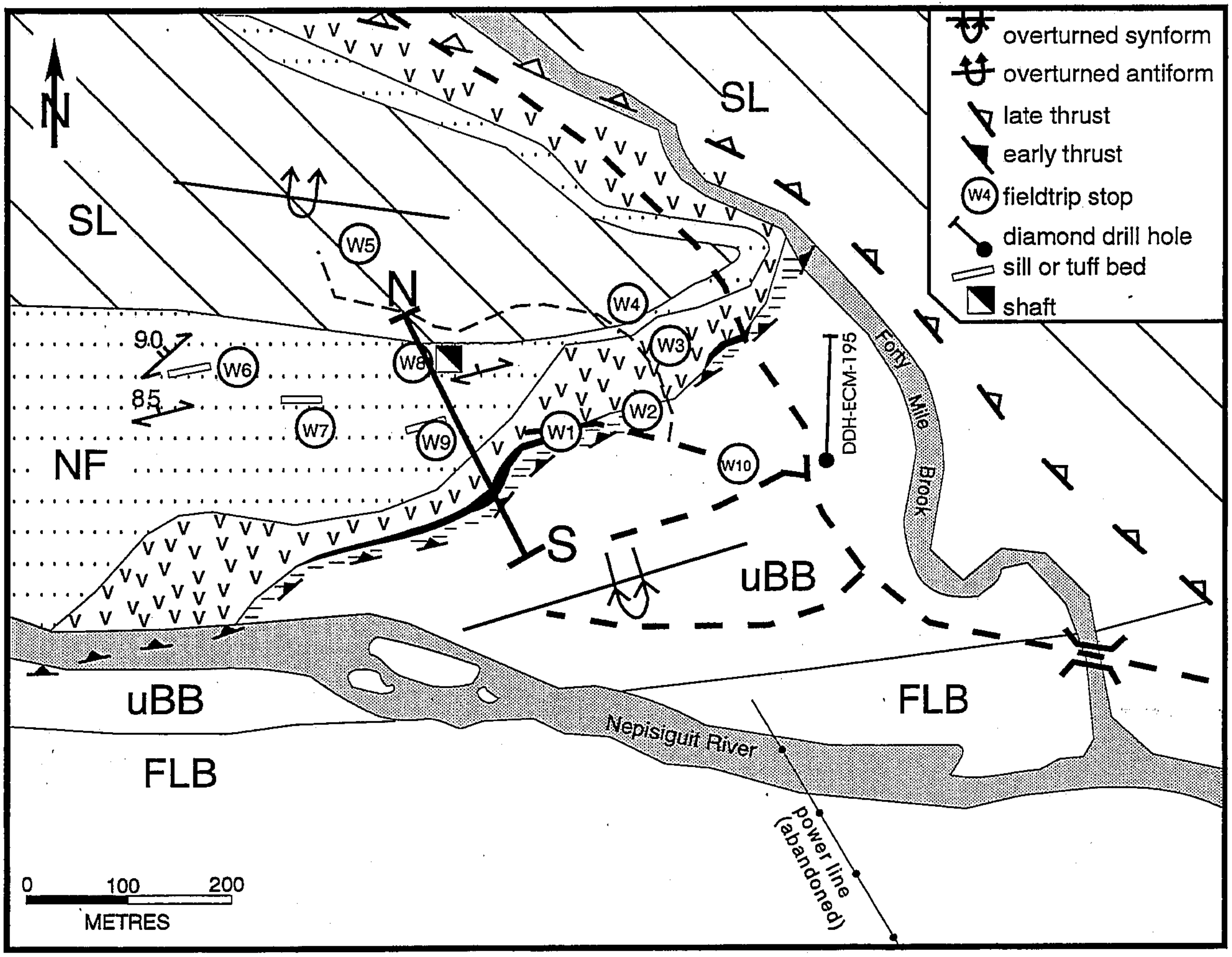



*Figure 11. Geological map of the Wedge mine area (modified from an unpublished map by B. Mitton) showing field trip stops. Unit abbreviations are as follows: uBB = upper Boucher Brook Formation, FLB = Flat Landing Brook Formation, NF = Nepisiguit Falls Formation (V-pattern = quartz-feldspar phyric volcaniclastic rocks, stipple = sedimentary rocks), SL = Spruce Lake Formation, black = massive sulphides. See Figure 4 for the location of the Wedge Mine site.*

Walker and McCutcheon (1996) also included rhyolite south of Nepisiguit River (Fig. 11) in the Spruce Lake Formation, but new geophysical data (GSC 1996*c*) are not consistent with this interpretation. Therefore, this rhyolite is reassigned to the Flat Landing Brook Formation, as previously done by Wilson (1993) and van Staal (1994*b*).

The Nepisiguit Falls Formation is divisible into lower and upper parts. The lower part consists of thin- to medium-bedded (1–30 cm), fine- to medium-grained sedimentary rocks containing subvolcanic sills and/or tuff layers that are geochemically similar to the Spruce Lake rocks. This strongly suggests that the contact with the underlying Spruce Lake Formation is gradational and conformable. The upper part comprises quartz-feldspar-phyric volcaniclastic rocks that are lithologically similar to the distal facies of the Nepisiguit Falls Formation in the type area. The Wedge massive sulphide deposit is in the upper part.

The Boucher Brook Formation is also subdivided into two parts in the mine area, namely a lower unit comprising tectonic melange and broken formation, and an upper unit comprising wacke, slate and minor mafic volcanic rocks (Fig. 11 and 12). The melange, *sensu stricto,* is not part of the Boucher Brook Formation because it postdates this formation; however, it is largely composed of rocks derived from the Boucher Brook, so is described here.

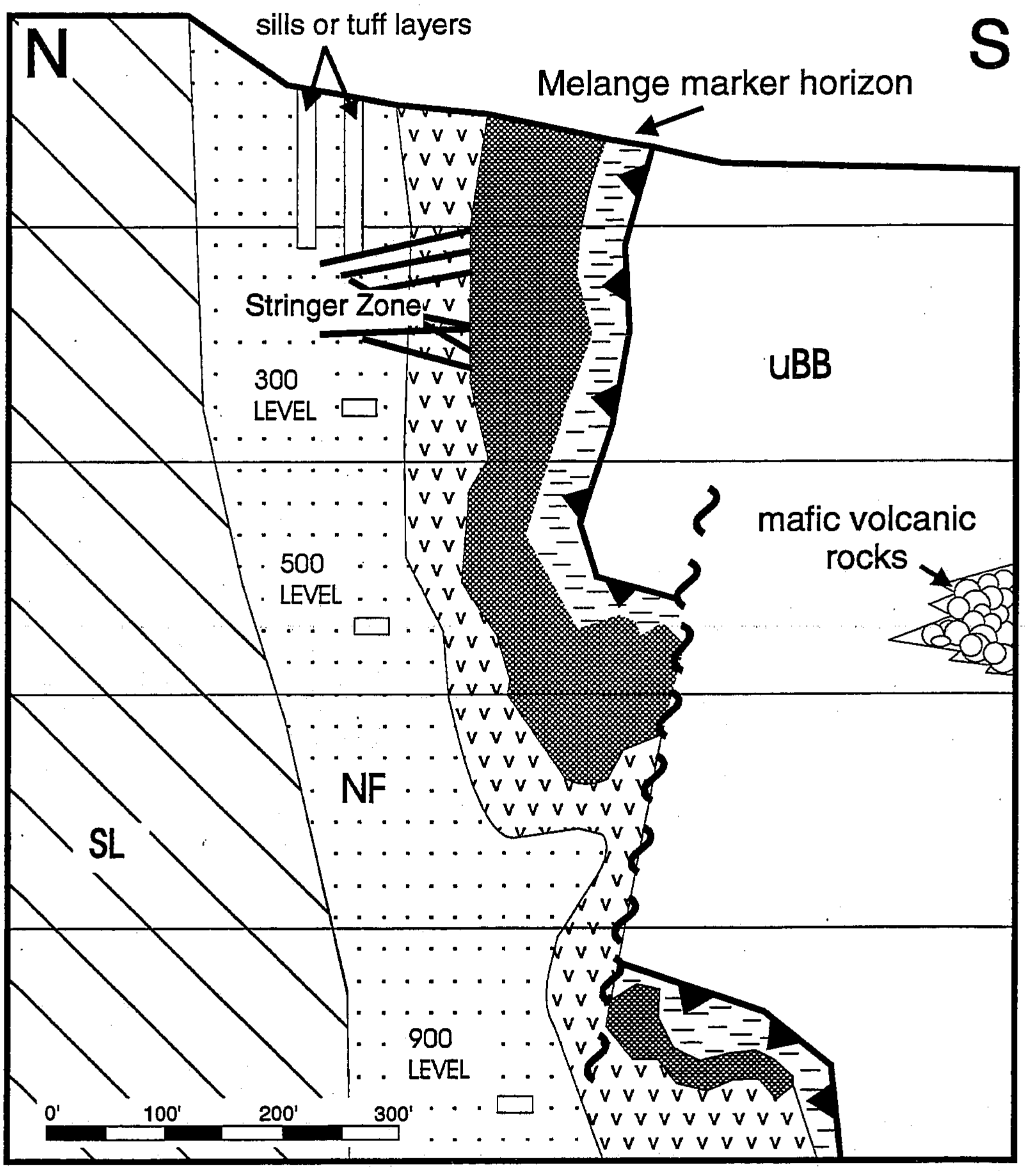



*Figure 12. Cross section through the Wedge Mine (modified from Douglas 1965). Line of section is approximately located on Figure 11. Symbols as in Figure 11.*

The mine geologists considered the tectonic melange to be a fragmental "Marker-Horizon" that capped the orebody. According to Miller (1980), this marker unit is traceable from surface to the 900-foot level, is laterally continuous along strike, and is variable in thickness. It has several facies including: 1) dark grey massive argillite, 2) volcanic breccia, and 3) a mixture of poorly sorted sedimentary and volcanic (rhyolitic) fragments in an argillaceous matrix. At surface, these fragmental rocks are not exposed but there is black (commonly graphitic) slate that has been intensely deformed with quartz veining at the millimetre scale.

Gradationally overlying the melange "marker" is a less deformed sequence comprising grey, fine- to medium-grained, thin- to medium-bedded lithic wacke and dark grey siltstone. Slate rip-ups are common in the wacke beds. On Forty Mile Brook some wacke beds reach 1 m in thickness. The upper unit also contains mafic volcanic rocks that do not crop out at surface but were intersected in drilling. These comprise green to grey, massive to amygdaloidal basalt flows, tuff, minor green and red chert and related epiclastic rocks.

## Structure

Even though only two penetrative fabrics have been recognized in the vicinity of the Wedge deposit, there is little doubt that the first one ($S_{Main}$) is a composite $S_1$-$S_2$ cleavage. This fabric trends between 060° and 075°, dips steeply north or south and is axial planar to the major fold axes, which are interpreted as $F_2$ structures. Locally this fabric is folded about tight to isoclinal upright folds, interpreted as $F_5$ structures, which have a well developed fabric only in the more micaceous layers. This second sub-vertical fabric trends 060° and is co-planar with the axis of the Nine Mile synform.

The $F_2$ antiform north of the Wedge deposit and $F_2$ synform south of the deposit are considered to be upward-facing but overturned slightly to the south. These interpretations are based upon younging directions indicated by metal zoning (see below) in the antiform and from grading in drill core (hole ECM-195, Fig. 11) in the synform. Consequently, the Nepisiguit Falls and Spruce Lake rocks in the antiform structurally overlie the upper Boucher Brook rocks in the synform. The fault that separates them, which is marked by the melange that caps the Wedge deposit, is interpreted as a $D_1$ or early $D_2$ thrust. In drill hole ECM-195, a wide zone of variably deformed slates and felsic and mafic volcanic rocks was intersected immediately above and below the projected extension of the ore horizon (Taylor 1995). This suggests that the ore horizon itself tectonically pinches out toward the north, in the vicinity of Forty Mile Brook, where the fault appears to be cut off (or merge with) a younger thrust that truncates the $F_2$ fold axes. Therefore, the latter fault is considered to be a late $D_2$ or younger structure.

## Massive sulphides

Generally, the sulphide body, which is 3-45 m thick, 360 m long, and 150 m deep, strikes 075° and (at surface) dips steeply to the north. At depth (300-foot level in the mine), it flattens out and then reverses dip (065° south), resulting in a fish-hook shaped geometry in cross-section (Fig. 12). According to Douglas (1965), the sulphide mineralogy of the ore zone is pyrite >> chalcopyrite > sphalerite > galena ± tennantite. Metal zonation is indicated by concentration of chalcopyrite and coarse-grained pyrite in the thicker parts of the deposit to the west and along the footwall contact, whereas fine-grained pyrite and narrow bands of sphalerite and galena are associated with the hangingwall side, adjacent to the fragmental unit and in the eastern end of the deposit (Douglas 1965). The presence of disseminated chalcopyrite and discordant stringer zone mineralization immediately below (north of) the massive sulphide body corroborates Jambor's (1979) interpretation of a proximal-autochthonous setting for this deposit, and supports the southward younging direction of the sulphide body, as inferred from local stratigraphy.

Both the volcaniclastic and sedimentary rocks of the Nepisiguit Falls Formation contain sulphide stringers and are variably altered to chlorite. Chloritization is intense and stringer pyrite veins abundant in the sedimentary rocks immediately southwest of the shaft (Fig. 11).

Unlike many of the other deposits in the Bathurst Camp, a laterally continuous, sulphide-capping, Fe-rich exhalite (iron formation in camp terminology) is not present at the Wedge deposit. Two hypotheses explain this observation: (1) Fe-rich sediment was never precipitated, or (2) it was subsequently cut out during thrusting. The later hypothesis implies that if the deposit had a Pb-Zn-rich cap, then it too may have been tectonically cut out, and potential reserves could exist along strike or down dip of the thrust.

## DAY 1. ROAD LOG AND STOP DESCRIPTIONS

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

| *cum. km* | |
|---|---|
| *0.0* | *Proceed south on Route 430 from overpass at Route 11.* |
| *22.75* | *Road forks (to BM&S); continue south on Route 430 .* |
| *23.3* | *Route 430 turns west (right) on gravel road.* |
| *45.25* | *Intersection with Popple Road; turn south (left).* |
| *55.95* | *Heath Steele B Zone haulage road.* |
| *57.05* | *Heath Steele main security: stop to register. Proceed through gate.* |
| *57.95* | *Entrance to office/mill complex; turn right.* |
| *58.1* | *Proceed to Visitors Parking in front of office; meet the mine geologists and get ready to go underground.* |

### Stop C-1. **Underground tour of the C Zone**

A description of the underground tour will be provided by the mine geologists. Stop C-1 is reached via a ramp that decends from Stop HS-1.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *58.1* | *Proceed west to the road.* |
| *0.15* | *58.25* | *At the road, turn right.* |
| *0.25* | *58.35* | *Main haulage way; turn west (left).* |
| *0.8* | *58.9* | *Turn right into A Zone pit.* |
| *1.0* | *59.1* | *Park off haulage way at east wall of pit.* |

### Stop HS-1. **East side of A Zone open pit, and outcrops at top of north wall** (Fig. 6).

The east side of the A Zone open pit provides a section through part of a major $F_2$ fold re-oriented by an $F_5$ structure (Park, in prep.), as well as typical hangingwall–ore horizon–footwall stratigraphy within the Nepisiguit Falls Formation. Quartz-feldspar porphyry/tufflava that forms the hangingwall to the A and C zone ores, is exposed at the southern part of the pit wall. It is weakly foliated and consists of alkali feldspar and quartz phenocrysts in a fine-grained matrix dominated by quartz and sericite. Toward its contact with footwall metasedimentary rocks, this porphyry/tufflava becomes more strongly foliated ($S_2$), and the phenoclasts have quartz beards defining the $L^m{}_2$ mineral stretching lineation.

Underlying the porphyry/tufflava is ten metres of "chaotic" chlorite schist (deformed tectonic melange). Deformation in this unit is extremely heterogeneous, varying from schistose with a weak lineation to a rodded, quartz-rich, chloritic L-tectonite. A diverse assemblage of rocks is present, dominated by coarse chlorite or chlorite-quartz schist, and material that looks like extremely schistose porphyry/tufflava. The entire assemblage is cut by veins of pyrrhotite-chalcopyrite, barren quartz and 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. Local polydeformed breccias discordant to $S_2$ contain clasts of chlorite ± sericite schist, vein quartz and sulphides, in a matrix of coarse-grained quartz, commonly with chalcopyrite. This appears to represent localized brittle fracturing during the ductile $D_2$ event. High fluid-pressures seem to have existed at this time, with mass transfer an important process.

Underlying the "chaotic" chlorite-schist zone, the ore-host assemblage consists of a pure chlorite rock, a black, sulphide-rich slate, and coarse-grained phyllite with abundant quartz layers and variable amounts of pyrite. However, no *in situ* ore is now visible in the pit wall.

Throughout this section, composite $S_{1-2}$ is the dominant fabric (defined by sericite- and chlorite-rich seams), although locally $S_1$ and/or lithological layering are preserved. The geometry of the ore-bodies and their host rocks is a complex interference pattern of tight to isoclinal, upward-closing $F_2$ sheath folds with steeply southwest-plunging long axes, refolded by southwest-plunging (40°), more open $F_5$ folds ($F_4$ folds of Park, in prep.). Near the C Zone portal, a vertical crenulation cleavage ($S_5$) is axial planar to the $F_5$ antiform seen over the portal itself. Locally, a nearly horizontal cleavage ($S_3$) is axial planar to open recumbent folds.

The rocks at the top of the A pit north wall are footwall chloritic (meta)-argillite and siltstone, interpreted as fine-grained turbidite. Bedding is preserved as quartz-rich layers (siltstone), and graded bedding is evident locally at the contacts between siltstone and (meta)argillite. In siltstone beds, $S_2$ can be distinguished by dark phyllosilicate segregations (differentiated layering), whereas in the argillite only an $S_{1-2}$ composite foliation can be seen.

The glaciated surface is at a high angle to the stretching lineation, but $F_2$ and $F_5$ folds can be seen along the western edge of the outcrop. $F_5$ folds are open structures plunging towards the west-southwest, with a nearly vertical axial-planar cleavage; they are responsible for some of the variation in strike of the bedding and foliation. On surfaces parallel to $S_2$ the intersection lineation $L^2{}_5$ lies very close to the mineral lineation ($L^m{}_2$).

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *59.1* | *Return to Route 430 via haulage road (east).* |
| *1.90* | *61.0* | *Route 430; turn right, and take an immediate left toward elevated pipeline.* |
| *2.1* | *61.2* | *Keep left at fork in road, proceed parallel to elevated pipeline.* |
| *2.5* | *61.6* | *Turn right, pass under powerline.* |
| *2.6* | *61.7* | *Park.* |

Stop HS-2. **Pavement outcrops under powerline** (Fig. 6)

The rocks exposed at this location consist of footwall crystal tuff/tuffite and lower footwall sedimentary rocks (Nepisiguit Falls Formation). The latter consist of dark green, highly deformed chloritic argillites, and comparatively massive, lighter green siltstone and feldspathic wacke. Apparent bedding laminations in both siltstone and argillite are, in many cases, an $S_1$ metamorphic differentiated layering. Quartz-feldspar crystal tuff/tuffite are medium- to coarse-grained, with local crude bedding defined by variation in phenoclast size and abundance. Local cherty fragments (mostly lenticular, rarely angular) appear rhyolitic, though some may represent silicified pumice. The absence of sedimentary clasts and apparent finer-grained texture in the tuff/tuffite near its contact with the sedimentary rocks (grading?), suggests that the former underlie the latter.

Both $S_1$ and $S_2$ are differentiated fabrics, particularly in the sedimentary rocks. $S_0$ is transposed into $S_1$, which strikes east-west, dips steeply to the north or south, and is characterized by abundant parallel quartz veins, typically <2 cm but locally thickening to large pods or lenses. $S_{0\text{-}1}$ is partially transposed into $S_2$, which strikes northwest-southeast and dips 60–70° southwest. In one exposure, an $F_1$ minor fold closure (rarely preserved in the Bathurst Camp) with $S_1$ axial-planar foliation is present; this fold is deformed by smaller-scale $F_2$ minor folds. Local steeply-plunging $F_5$ minor folds with northeast-trending axial surfaces re-orient earlier structures.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *61.7* | *Continue east on gravel road.* |
| *0.45* | *62.15* | *Turn right at intersection.* |
| *0.95* | *62.65* | *Park at backfill quarry.* |

Stop HS-3. **Backfill quarry** (Fig. 6).

The rocks exposed in the backfill quarry comprise volcanic and sedimentary rocks of the Nepisiguit Falls Formation and felsic volcanic rocks of the Flat Landing Brook Formation. In the former, dark green, chloritic, locally sericitized, silicified or pyritiferous siltstone, argillites and mudstones are interpreted as part of the lower footwall sedimentary sequence, whereas coarse-grained, massive and homogenous quartz-feldspar tufflava/porphyry is typical of hangingwall crystal-rich tufflavas. If this interpretation is correct, then the footwall crystal tuff and upper footwall sedimentary rocks are absent on the south limb of the Heath Steele antiform. The tufflavas do not display the primary features (typical of a pyroclastic origin) seen in the tuff/tuffite at Stop HS-2. The Flat Landing Brook Formation consists of green, typically massive, sparsely feldspar-phyric, slightly amygdaloidal rhyodacites, with local fine-grained fragmental or tuffaceous rocks (probably hyalobreccias or hyalotuff).

Sedimentary rocks dominate the north wall of the quarry, but only 5 m of sedimentary rock exists between the tufflava/porphyry that occupies the central part of the quarry, and Flat Landing Brook rhyodacites on the east side. This "cutting-out" of the sedimentary rocks coincides with a zone of very high strain that is characterized by quartz veining, local mylonitic fabrics, and fragmental textures (tectonic breccia?) in the tufflava; it is therefore interpreted as a tectonic contact along which Nepisiguit Falls rocks were thrust over the Flat Landing Brook rhyodacites. The dominant fabric in the high-strain zone trends 160-040°/60° west, which, by comparison with overprinting relationships preserved in sedimentary rocks near the north wall, is $S_1$. Thus, the thrust is interpreted as a $D_1$ event, and the tufflava appears to occupy the core of an $F_1$ synform with a truncated sedimentary sequence on its south limb. The variation in orientation of $S_1$ is likely related to $F_2$ folds ($S_2$ trends more or less uniformly northwest-southeast, and dips southwest), though $F_4$ folds could have a similar effect. $F_3$ recumbent folds with axial-planar cleavage trending 170°/25° east are locally observed in sedimentary rocks in the high-strain zone.

Locally, $S_1$ is weak and $S_2$ intense, whereas elsewhere the reverse is true. $S_1$ may be weaker near the west end of the quarry because most $D_1$ strain may have been taken up by the sedimentary rocks along the thrust contact to the east. The heterogeneity in the intensity of $S_1$ and $S_2$ is typical throughout the Bathurst Camp and contributes to the complexity of structural mapping in this polydeformed terrain.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *62.65* | *Proceed west to return to Route 430.* |
| *0.85* | *63.5* | *At Route 430, turn right (north).* |
| *11.55* | *74.2* | *Intersection with Popple Depot road; turn left (west).* |
| *15.75* | *78.4* | *Bridge over Forty Mile Brook.* |
| *16.05* | *78.7* | *Continue to the top of the hill and turn left (west).* |
| *16.35* | *79.0* | *Take the right hand fork and continue for 300 m to the boulders at the foot of the slope. Park.* |

For stops W-1 to W-10 at the Wedge deposit, see Figure 11.

Stop W-1. **Overview of the Wedge mine site**

To the south, the Nepisiguit River flows west to east. You are standing in the footwall of the Wedge deposit immediately north of the surface projection of the sulphide lens. Approximately 30 m to the south, is a sequence of slate and wacke with intercalated mafic volcanic rocks that is assigned to the upper Boucher Brook Formation.

*Walk back (east) along the road approximately 70 m to the junction with the trail going up the hill to the north.*

Stop W-2. **Highly deformed graphitic slate, upper Boucher Brook Formation**

Low-relief outcrops of highly deformed black graphitic slate (melange) mark the tectonic contact between the upper Boucher Brook Formation and the Nepisiguit Falls Formation. These rocks lie within a major $D_1$ thrust zone that, in part, cuts out the sulphide lens to the east.

*Turn up the hill along the trail to the north; walk approximately 50 m.*

Stop W-3. **Quartz-feldspar-phyric tuffite, Nepisiguit Falls Formation**

In the roadbed, there are several outcrops of quartz-feldspar-phyric rocks that are assigned to the Nepisiguit Falls Formation because of lithological and geochemical similarities to rocks in the type area. The variation in grain size and in phenoclast abundance between outcrops indicate that these rocks are volcaniclastic, *i.e.* tuffite.

*Continue walking up the road approximately 100 m to the bend.*

Stop W-4. **Sparsely quartz-phyric rhyolite of the Spruce Lake Formation**

A low-relief outcrop of sparsely quartz-phyric rhyolite occurs on the north side of the road. Note the two fabrics in this outcrop. This rhyolite is strongly depleted in HREE compared to felsic volcanic rocks elsewhere on the property but it has a Zr/Y ratio (>4.3) typical of the Spruce Lake Formation.

*Continue walking along road for approximately 300 m to the crest of the hill; turn right into the bush and proceed over the crest to the outcrop about 50 m beyond.*

Stop W-5. **Sparsely feldspar-phyric rhyolite of the Spruce Lake Formation**

This sparsely feldspar-phyric rhyolite looks very similar to the last outcrop but has a Zr/Y ratio that is typical of the Spruce Lake Formation. Therefore, it is assigned to the Spruce Lake, even though large potassium-feldspar phenocrysts, which typify this formation, are absent.

*Retrace steps for 100 m; turn right (down bank) into the cleared area and walk about 100 m to the long east-west-trending outcrop immediately north of the very large boulder (>4 m).*

Stop W-6. **Interlayered Nepisiguit Falls and Spruce Lake rocks**

The micaceous layers are fine-grained tuffite that are chemically similar to the coarser grained tuffite at Stop W3, whereas the massive siliceous layer is a tuff or sill that is chemically similar to the rhyolite at Stop W5. Two penetrative fabrics are visible in the outcrop. The dominant east-west fabric ($S_{Main}$) is parallel to the compositional layering and is best developed in the micaceous layers, whereas the second fabric ($S_2$ locally but $S_5$ regionally) trends northeasterly, parallel to the Nine Mile synform, and cuts across the compositional layering. At first glance it appears that the east-west fabric postdates the northeast fabric but this is because $S_5$ actually diffracts across the early $S_{Main}$ fabric. At Stop W-7, this relationship is clear. Note the effects of intense hydrothermal alteration.

*Walk along slope about 50 m.*

Stop W-7. **$F_5$ minor folds**

Small outcrops containing fine-grained sandstone (Nepisiguit Falls Formation) occur in this area. One of them contains a good example of an $F_5$ minor fold that shows $S_{Main}$ is the earlier fabric.

*Walk about 100 m northeast to the area between the concrete footings, which were the foundations for the hoist house and shaft.*

Stop W-8. **Fine-grained sandstone**

This fine-grained sandstone is situated between the tuffite at Stops W-3 and W-6 (Fig. 11) and is considered to be part of the Nepisiguit Falls Formation. It is within the lower, predominantly sedimentary, unit that lies between Spruce Lake rhyolite and typical Nepisiguit Falls volcaniclastic rocks. This unit thins dramatically to the northeast.

*Walk south approximately 100 m.*

Stop W-9. **Altered tuffite**

Hydrothermally altered Nepisiguit Falls tuffite with folded stringers of pyrite.

*Return to vehicles and drive east about 300 m; stop just before the junction of the two bush roads at the rubbly outcrop on the right side of the road.*

Stop W-10. **Lithic wacke of the upper Boucher Brook Formation**

Coarse-grained lithic wacke of the upper Boucher Brook Formation.

*End of Day 1; return to Bathurst.*

# DAY 2. THE BRUNSWICK No. 12, BRUNSWICK No. 6 AND AUSTIN BROOK DEPOSITS

*(W. M. Luff, D.R. Lentz and S.R. McCutcheon)*

## Introduction

The Brunswick No. 12 and 6 massive-sulphide deposits are approximately 25 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. 13). The massive-sulphide deposits and associated iron formation known as the "Brunswick horizon" occur at the top of the Nepisiguit Falls Formation of the Tetagouche Group.

Since formal subdivision of the Tetagouche Group is a relatively recent phenomenon (*cf.* van Staal and Fyffe 1991), formation names are generally not used by the mine geologists; instead, the long-established mine nomenclature continues to be applied to the rock units. Consequently, both the mine terminology and the formal nomenclature are used in the 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 164 000 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 "No. 3 body" (Young 1911) or "Zone III" (Lindeman 1913) of the Austin Brook iron deposit forms the hangingwall to the Brunswick No. 6 massive-sulphide deposit, and was intersected by a few diamond-drill holes in 1907. 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 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*a*). At the same time, a vertical-loop electromagnetic (EM) survey was initiated at the recommendation of Mr. Robert J. Issacs, chief mining engineer for M.J. Boylen. Subsequent

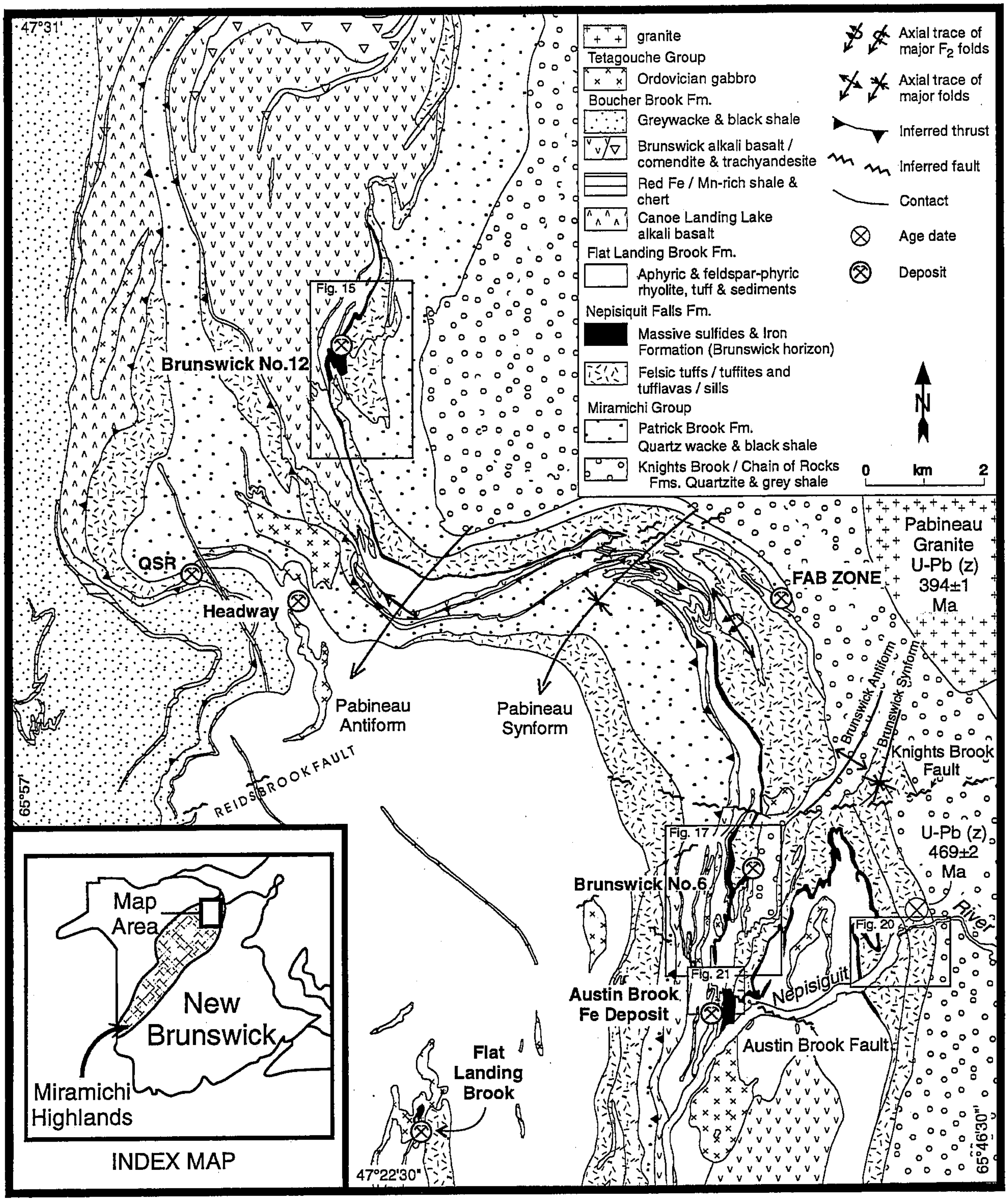



*Figure 13. Simplified geological map of the Brunswick Mines area (modified from Luff et al. 1993) showing the locations of Figures 15, 17, 20 and 21. See Figure 4 for location.*

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).

**Stratigraphy**

Both the formal nomenclature of van Staal and Fyffe (1991) and the informal mine terminology are shown in Figure 14. The formally defined units, in ascending stratigraphic order, comprise the Knights Brook/Patrick Brook, Nepisiguit Falls, Flat Landing Brook and Boucher Brook formations (van Staal 1994*c*). The informal mine units are older metasediments, quartz-eye schist (including quartz-feldspar porphyry), metasediments, crystal tuff, footwall metasediments, massive sulphides, iron formation, "hanging-wall" metasediments and acid tuff, basic volcanic rocks and quartz-feldspar porphyry dyke (Luff 1977; Luff *et al.* 1992).

The oldest rocks in the Brunswick mine sequence, "older metasediments" (OM), belong to the Patrick Brook Formation at Brunswick No. 12 and the Knights Brook Formation at Brunswick No. 6. Both formations are part of the Miramichi Group and locally contain dark grey, in places graphitic, slate.

The "quartz-eye schist" (QES) of Luff *et al.* (1992), which constitutes the base of the Nepisiguit Falls Formation, structurally overlies the older metasediments at Brunswick No. 12 but conformably overlies them at Brunswick No. 6 and is divisible into massive and granular "quartz-feldspar-augen schist" (QFAS) as well as "quartz-augen schist" (QAS). At the Brunswick No. 12 deposit, most of the QFAS is massive and relatively homogeneous with a cryptocrystalline groundmass (Lentz and Goodfellow 1992*b*; 1993*a*). In general, quartz and feldspar are coarse grained (3-10 mm) and constitute 20 to 40 vol.% of the rock. At Brunswick No. 6 massive QFAS generally constitutes the lower part of the section and is overlain by granular or volcaniclastic QFAS. The granular QFAS contains a high percentage of rounded crystals, and locally contains interbeds of fine-grained crystal tuff (CT). In many places, it is difficult to distinguish massive from granular QFAS because alteration and deformation have obliterated primary textures. 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 vol.% quartz crystals ranging from 1 to 5 mm in size. The QAS probably was not deposited as such but was originally massive and/or granular QFAS. The fact that massive QFAS is converted to QAS in the hydrothermal alteration zone beneath the

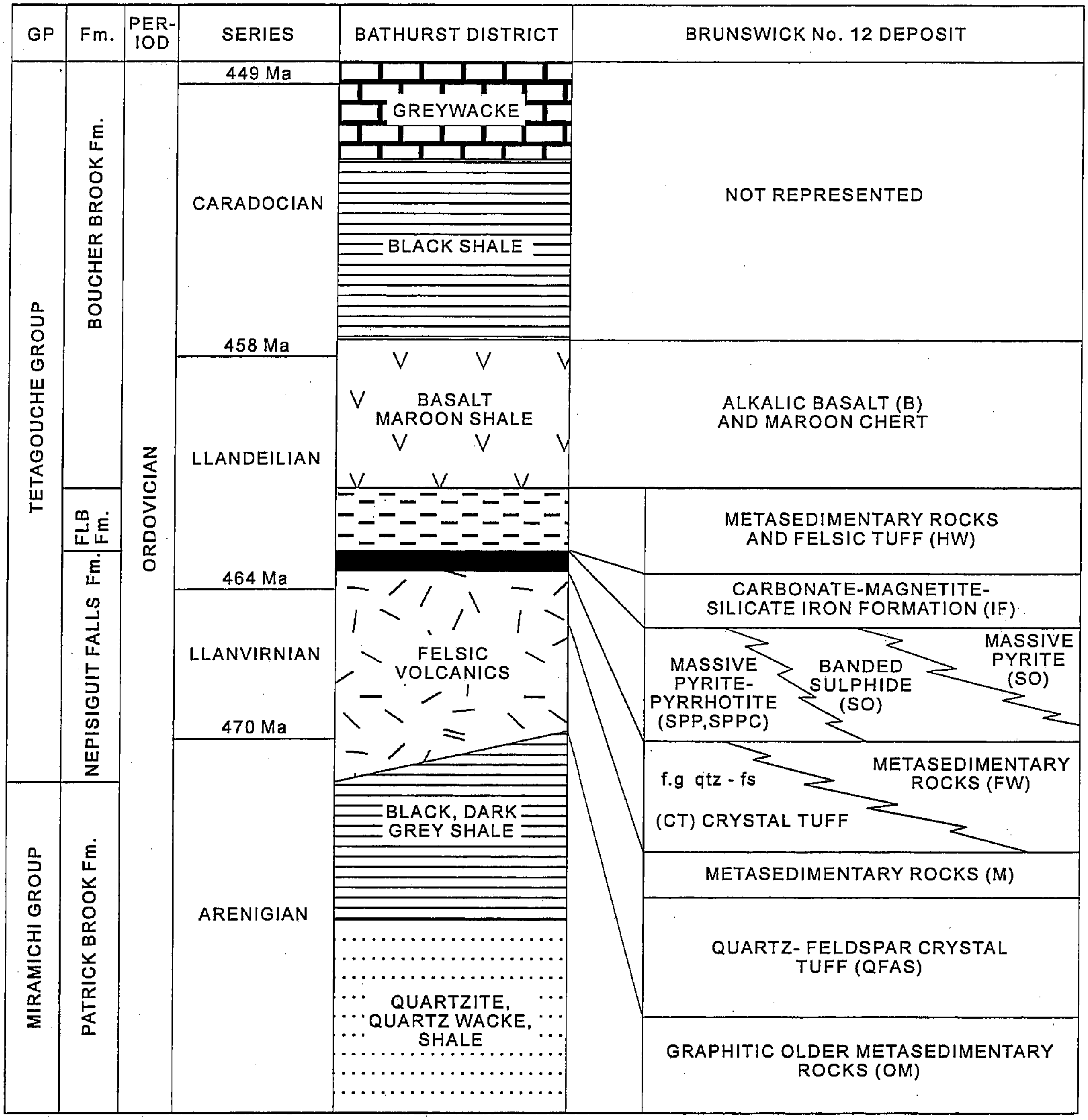



*Figure 14. Schematic columns showing the correlation between mine terminology and formal terminology of rock units (modified from Lentz and Goodfellow 1992c).*

Brunswick No. 12 deposit (Juras 1981; Luff *et al.* 1992; Lentz and Goodfellow 1992*a*, 1993*a*, 1994*a*) strongly suggests that most QAS is the result of seawater- and/or vent-related alteration of existing QFAS.

A laterally-continuous, fine-grained 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 both the No. 6 and No. 12 deposits. The footwall sedimentary rocks appear to be laterally equivalent to the 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 Fig. 15 and 16), commonly referred to as the "Brunswick Horizon", overlie the "footwall metasediments" (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

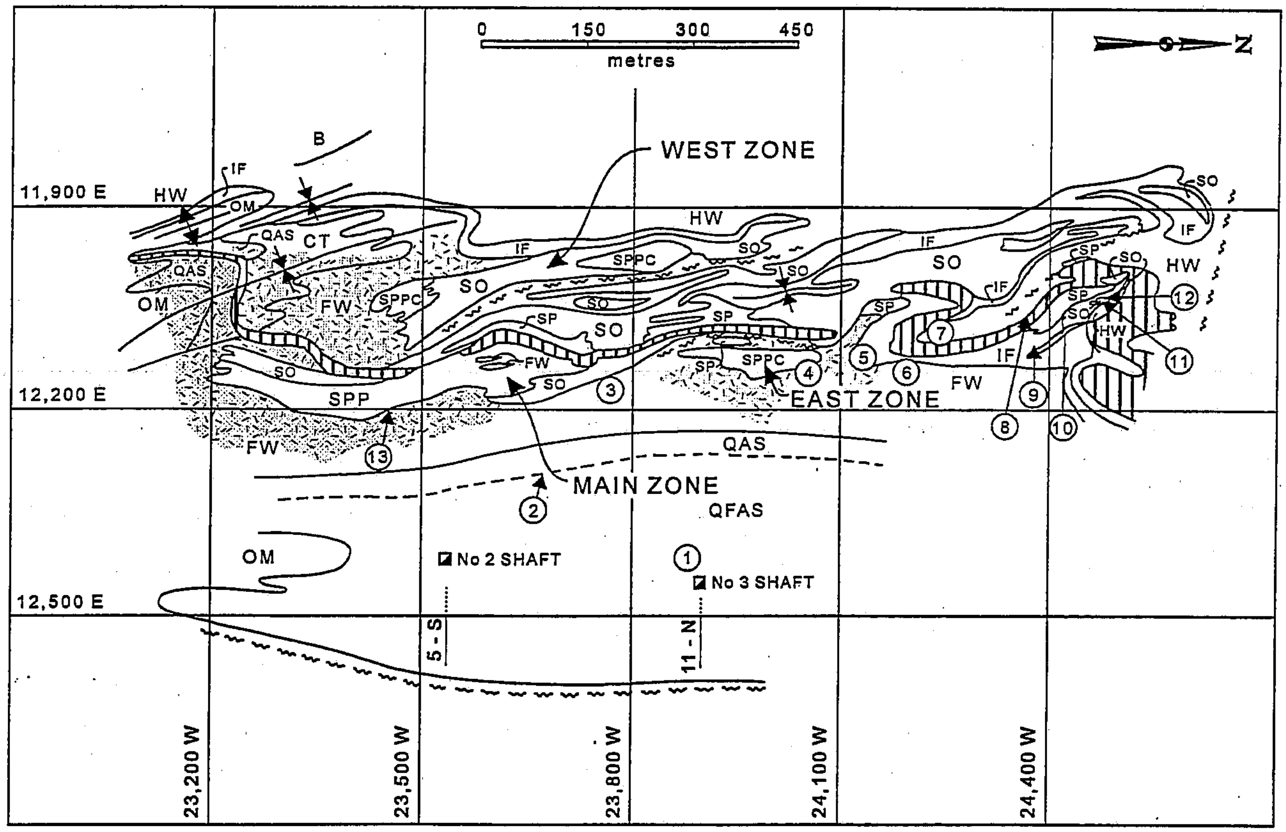



*Figure 15. Geological plan of the 850 m level at Brunswick No. 12 showing the approximate stop locations. Mine terminology is used (see Fig. 14 for abbreviations) with the following additions: QAS = quartz-augen schist, dash pattern = stringer mineralization and line pattern = porphyry dyke. See Figure 13 for location of this map with respect to the surface geology.*

the iron formation along the Brunswick Belt (van Staal 1994*c*) because it marks 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, silicate, and chert (pyrite) facies are most closely associated with the massive sulphides at the Brunswick No. 12 deposit, whereas the oxide facies is most prevalent at the Austin Brook and No. 6 deposits. 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

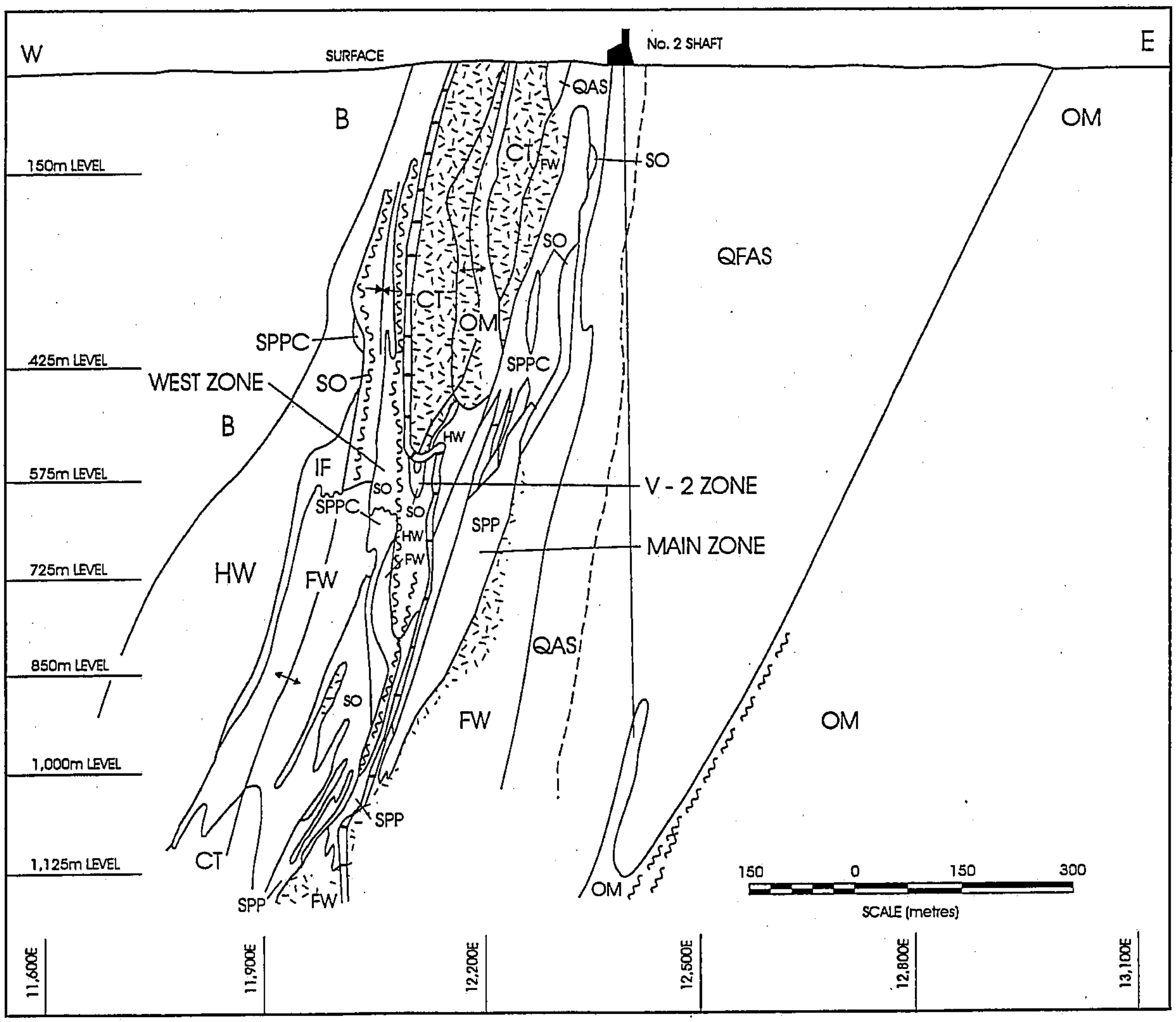



*Figure 16. East-west cross section 5-S (looking north) through the No. 2 shaft at the Brunswick No. 12 mine (modified from Luff et al. 1992). See Figure 14 and Figure 15 for abbreviations and location.*

1970; Davies 1972; Saif 1980; Saif 1983; Peter and Goodfellow 1993, 1996). 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 "hanging-wall metasediments and acid tuffs" (HW) at Brunswick No. 12 belong to the Flat Landing Brook (FLB) Formation; at Brunswick No. 6 the FLB Formation has a different character (McCutcheon 1990, 1992). At Brunswick No. 12, the FLB Formation consists of light to dark grey, fine-grained sedimentary rocks and interbedded felsic 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.

At both No. 6 and 12, "basic volcanics" (B) overlie the "hanging-wall" felsic rocks and consist of massive to pillowed alkali basalt (Brunswick member), pillow breccia and hyaloclastite (van Staal 1987, van Staal *et al.* 1991) with minor interbedded sedimentary rocks that include dark grey siltstone and 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 at the base of the basalt pile; however, RMS also occurs intermittently throughout the pile in association with altered magnetic basalt. 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 and has been dated by U/Pb zircon method at 459+2/-1 Ma (Sullivan and van Staal 1996). 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 than 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 rhyolite (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 the intense footwall alteration was pre-metamorphic and of syngenetic hydrothermal origin, rather than resulting from deformation processes (Lentz and van Staal 1995).

The "hanging-wall" rocks of the No. 6 mine (Fig. 17) are intruded by a southwesterly plunging body of tholeiitic gabbro (Group "C" gabbro of van Staal 1987), which cannot be the intrusive equivalent of the overlying Brunswick alkali basalt (upper Boucher Brook Formation). 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); however, it is alkalic and compositionally indistinguishable

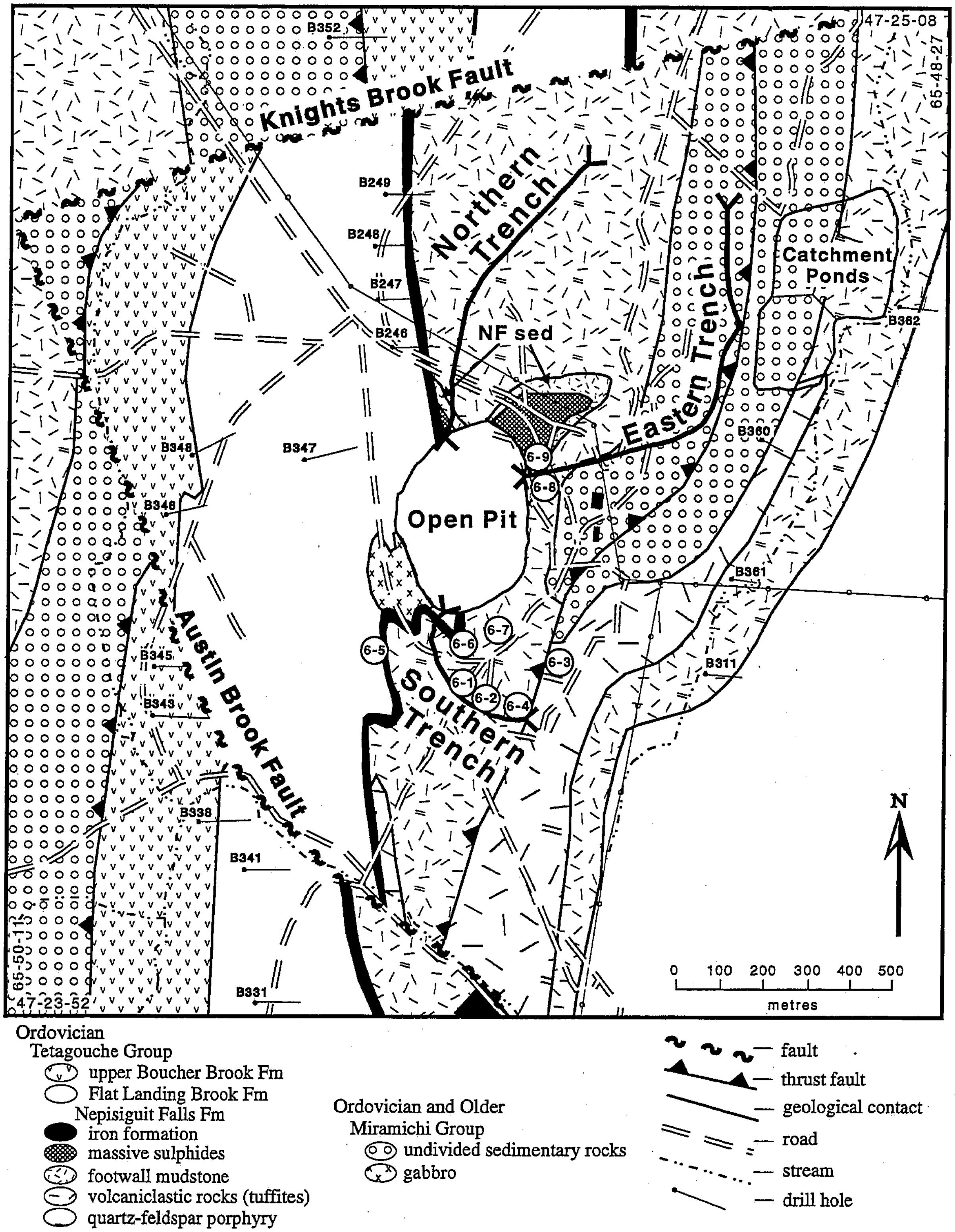



*Figure 17. Simplified geological map of the area around the Brunswick No. 6 open pit (modified from van Staal 1994c). See figure 13 for location of this map.*

from the overlying basalt (Lentz and Moore 1995). 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 1994*b*).

### 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 variation in plunge resulting from the influence of the earlier ($F_1$) fold closures. Cross-sections parallel to the $F_2$ axial surfaces show that the metal zoning in both the No. 12 (Fig. 18) and No. 6 (Fig. 19) 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.

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 12 197 000 t of ore grading 5.43% Zn, 2.16% Pb, 0.39% Cu and 67.0 g/t Ag. Mining began at the No. 12 deposit in 1964 and by the end of 1996 had produced 82 277 000 t of ore grading 8.82% Zn, 3.51% Pb, 0.33% Cu and 99.0 g/t Ag with proven ore reserves of 55 035 000 t grading 9.11% Zn, 3.64% Pb, 0.32% Cu, and 103.5 g/t Ag.

The No. 12 deposit comprises four zones (West, Main, East and V2) that merge at depth (Fig. 15 and 16). 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

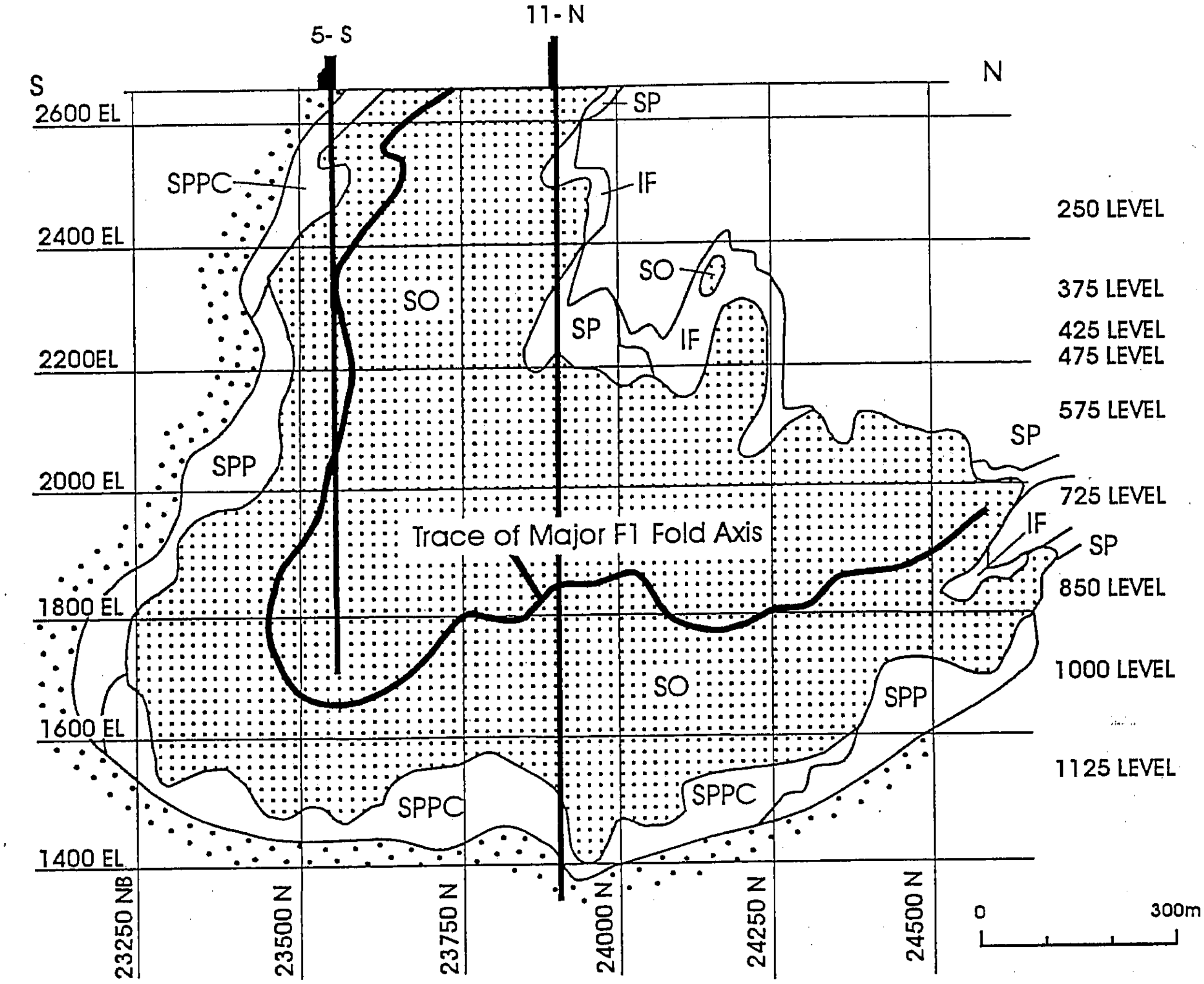



*Figure 18. North-south longitudinal section of the Brunswick No. 12 mine (from Luff et al. 1992) drawn through the No. 2 and No. 3 shafts (see Fig. 15). Abbreviations as in Figure 14.*

pyrite containing minor amounts of sphalerite and galena, and minor to significant amounts of chalcopyrite, pyrrhotite, and magnetite (SPP or SPPC); 2) banded 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).

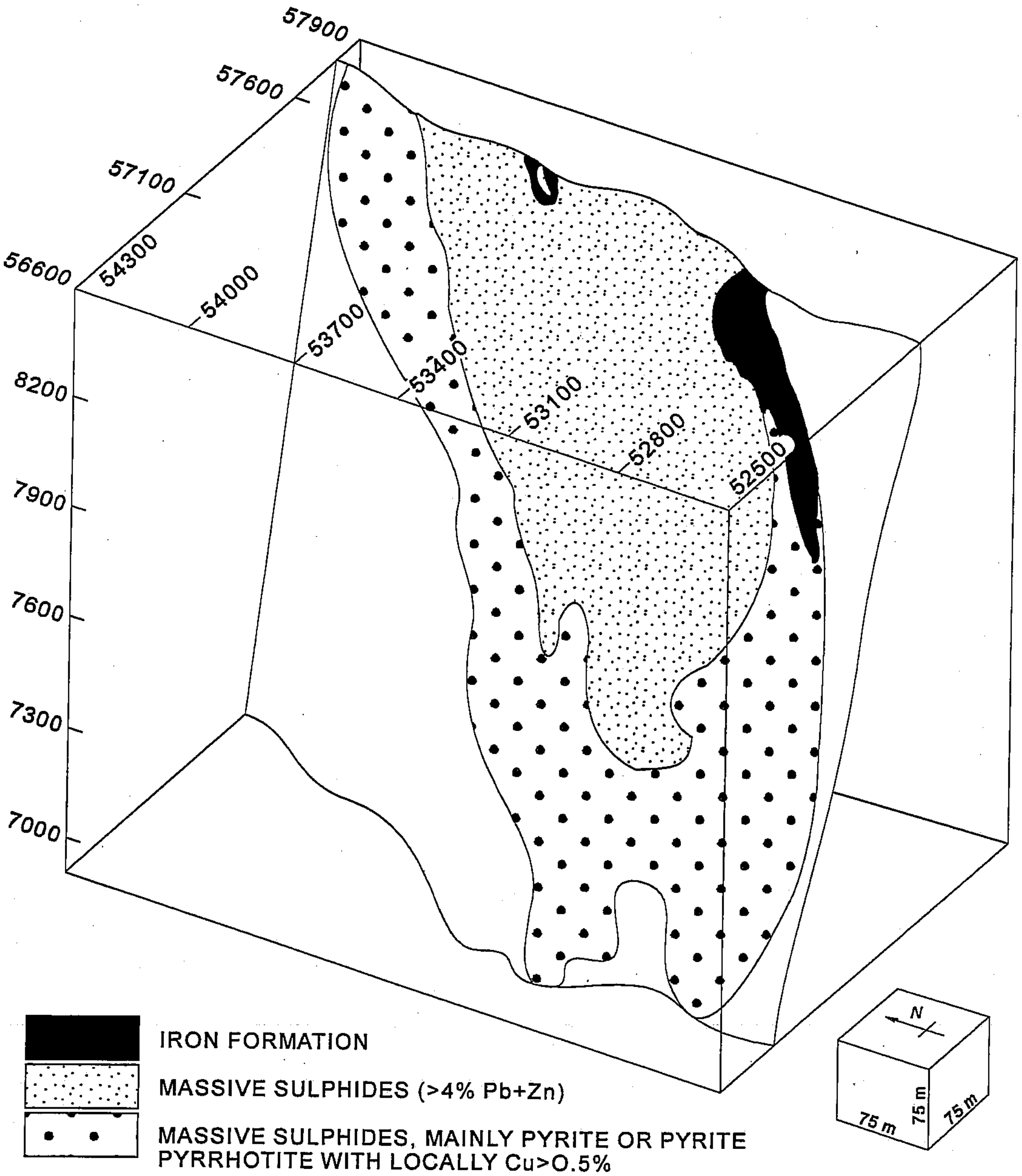



*Figure 19. North-south longitudinal section of the Brunswick No. 6 mine, parallel to the $F_2$ axial surface (from van Staal and Williams 1984).*

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, 1975; Fuller 1968; Sutherland and Halls 1969; Owens 1980; Laflamme and Cabri 1986*a*, 1986*b*; 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 1975*a*, 1975*b*; Juras 1981; Nelson 1983; Luff *et al.* 1992; Lentz and Goodfellow 1992*a*, 1993*a*, 1994*a*, 1996). 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 (1994*a*) 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 (proximal), 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 (Lentz and Goodfellow 1996). In the Discovery Hole (A1), which intersects the zone of most intense stringer mineralization, Lentz and Goodfellow (1993*b*) 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 1993*c*). 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). This altertion zone has a radiometric expression (Lentz 1994); it forms a much broader alteration halo than the stringer sulphide zone (Lentz and Goodfellow 1992*a*, 1993*a*) 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.

## DAY 2. ROAD LOG AND STOP DESCRIPTIONS

*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.*

| *cum. km* | |
|---|---|
| *0.0* | *Drive south on Route 430.* |
| *4.5* | *Junction with road to Pabineau Falls; bear right on Route 430.* |
| *15.6* | *Junction with Route 360 to Allardville; continue straight on Route 430.* |
| *22.1* | *Junction with road to Brunswick No. 12 Mine; bear right on paved road to Brunswick No. 12.* |
| *29.5* | *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 1 through 13 (Fig. 15).* |

### Stop 12-1. **Quartz-feldspar-augen schist**

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 12-2. Contact zone between quartz-augen schist and quartz-feldspar-augen schist**

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 12-3. Altered footwall sedimentary rocks**

Weak to moderately altered footwall sedimentary rocks (FW) with the $S_1S_2$ composite foliation that is orthogonally cut by a weak $S_5$ cleavage.

**Stop 12-4. Contact between footwall sedimentary rocks and massive pyrite**

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

**Stop 12-5. Siliceous-sulphide stringer veins**

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 12-6. Tectonically thinned section of footwall sedimentary rocks, massive pyrite and iron formation**

Tectonically thinned section comprising footwall sedimentary rocks and massive pyrite grading up into thin-layered pyrite-magnetite-chlorite iron formation (IF).

**Stop 12-7. Contact between porphyry dike and iron formation**

Contact between porphyry dike and iron formation (IF). This dyke also cuts the siliceous and sericitic "hanging-wall" sedimentary rocks.

**Stop 12-8. $F_2$ folds in the iron formation at the porphyry dike contact**

**Stop 12-9. IF with southerly plunging $F_2$ folds**

**Stop 12-10 Semi-massive pyrite zone hosted in iron formation**

Stop 12-11. **Barite associated with iron formation**

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

Stop 12-12. **High-grade Pb-Zn ore lens**

High-grade Pb-Zn ore lens near the core of a large-scale $F_2$ fold. 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 12-13. **Footwall sedimentary rocks with stringer sulphides in contact with Cu-rich po-py mineralization**

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.*

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *29.5* | *Return to the parking lot.* |
| *7.4* | *36.9* | *Drive back the Brunswick No. 12 road to the junction with Route 430. Turn right (west) on Route 430.* |
| *8.1* | *37.6* | *Junction between Route 430 and chip-sealed road to Bathurst Mines (Nepisiguit Falls); continue straight.* |
| *9.1* | *38.6* | *Junction with dirt road to Brunswick No. 6 Mine; turn left.* |
| *10.7* | *40.2* | *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.* |
| *12.6* | *42.1* | *The stop sign at the forks in the road overlooks the Nepisiguit Falls dam and power generating station that was built in 1921.* |
| *12.8* | *42.3* | *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 east (down river) along this roadbed about 700 m, to the point where the road widens. Follow the beaten path up over the bank on the right and down to the river (Fig. 20).* |

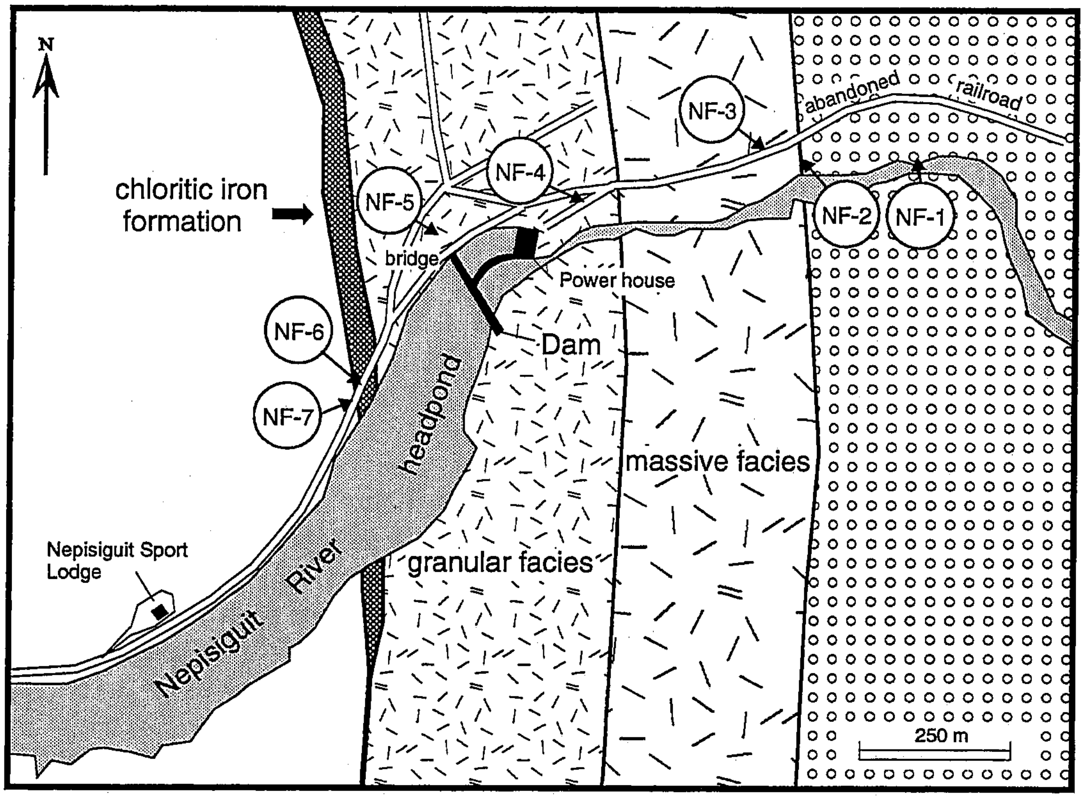



*Figure 20. Simplified geological map of the Nepisiguit Falls area showing stop locations (from McCutcheon et al. 1993b). Legend as in Figure 17 and map location shown in Figure 13.*

## Stop NF-1. **Quartz wacke and grey slate of the Knights Brook Formation**

Rusty-weathering quartz wacke and grey slate of the Knights Brook (KB) 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 roadway and walk back towards the dam about 300 m. At the gully containing the old car, turn left along its west bank toward the river and follow the path about 50 m.*

## Stop NF-2. **Basal contact of the type Nepisiguit Falls Formation**

The basal contact of the Nepisiguit Falls 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-metre-thick chloritic quartz-augen schist (QAS) layer. The QAS is overlain by a

45-centimetre-thick quartz wacke bed; this bed is overlain by more QAS that grades upward away from the contact into quartz-feldspar-augen schist (QFAS).The QAS is interpreted as QFAS from which the K-feldspar phenocrysts have been lost because of alteration.

*Return to the old railway roadbed and walk back towards the dam about 50 m.*

Stop NF-3. **Massive tufflava/porphyry (QFAS) of the type Nepisiguit Falls Formation**

The roadcut on the right 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 texture of a typical intrusive porphyry, *i.e.* the groundmass was originally glass, and has phenocryst textures typical of a lava flow rather than a pyroclastic rock. However, characteristic flow facies, *e.g.* carapace breccias, are absent. Therefore, it is interpreted as a sub-volcanic sill or very unusual flow (tufflava). Such rock constitutes the lower half of the Nepisiguit Falls section in this area.

*Continue west along the railroad bed about 250 m. The contact between massive QFAS and granular QFAS occurs towards the west end of this interval but is not exposed. Turn left onto the trail that leads down to the foot of the power station.*

Stop NF-4. **Granular tuff/tuffite and ash tuff of the type Nepisiguit Falls Formation**

In the first part of the rock-cut on the right, a thin layer of ash tuff caps fining-upward, granular QFAS. This ash tuff represents the fine-grained fraction (glass particles) that separated from a crystal-rich, subaqueous, pyroclastic eruption when it was emplaced as a cold debris flow. These ash tuff beds are rare in the proximal facies of the NF Formation but predominate in the distal facies. The granular (volcaniclastic) QFAS in the upper part of the NF Formation is interpreted as a series of cold debris flows of juvenile pyroclastic material, rather than a number of hot pyroclastic deposits. In the outcrop that overlooks the river, lenses of coarse-grained, granular QFAS with quartz crystals up to 5 mm can be seen in finer grained, granular QFAS.

*Return to the railroad bed and proceed west (upriver) past the vehicles about 200 m to the point where the bridge crosses to the dam. Turn right along the path that goes up the hill and proceed to the small outcrop in the path.*

Stop NF-5. **Granular tuff/tuffite with accidental fragments in type Nepisiguit Falls Formation**

Granular texture is apparent in this outcrop of QFAS, which predominantly consists of juvenile volcaniclastic material with a few accidental lithic fragments. 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.

*Return to the old railroad bed and continue west about 300 m, through the trees and up the bank onto the gravel road.*

Stop NF-6. **Upper contact of the type Nepisiguit Falls Formation**

The outcrop in the ditch 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 (QAS) indicating that they are the product of hydrothermal alteration.

*Continue west along the road about 50 m.*

Stop NF-7. **Massive, aphyric rhyolite of the Flat Landing Brook Formation**

Outcrops of massive, aphyric rhyolite occur along the hillside northwest of the roadway. All these rocks are part of the Flat Landing Brook Formation.

| km | cum. km | |
|---|---|---|
| 0.0 | 42.3 | *Return to the vehicles in the parking lot at the power station.* |
| 0.2 | 42.5 | *Drive up the hill to the intersection. At the stop sign overlooking the power generating station, bear left (southwest) and follow the gravel road up river.* |
| 1.2 | 435 | *The Nepisiguit Sport Lodge is on the right above the road; just past the lodge there is a large roadcut containing rhyolitic hyaloclastite and minor sedimentary rocks. Cleavage is much better developed in these rocks than in the preceding outcrop (Stop NF-7) of massive aphyric rhyolite.* |
| 2.8 | 45.1 | *At this point Austin Brook crosses the road.* |
| 2.9 | 45.2 | *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 (Fig. 21).* |

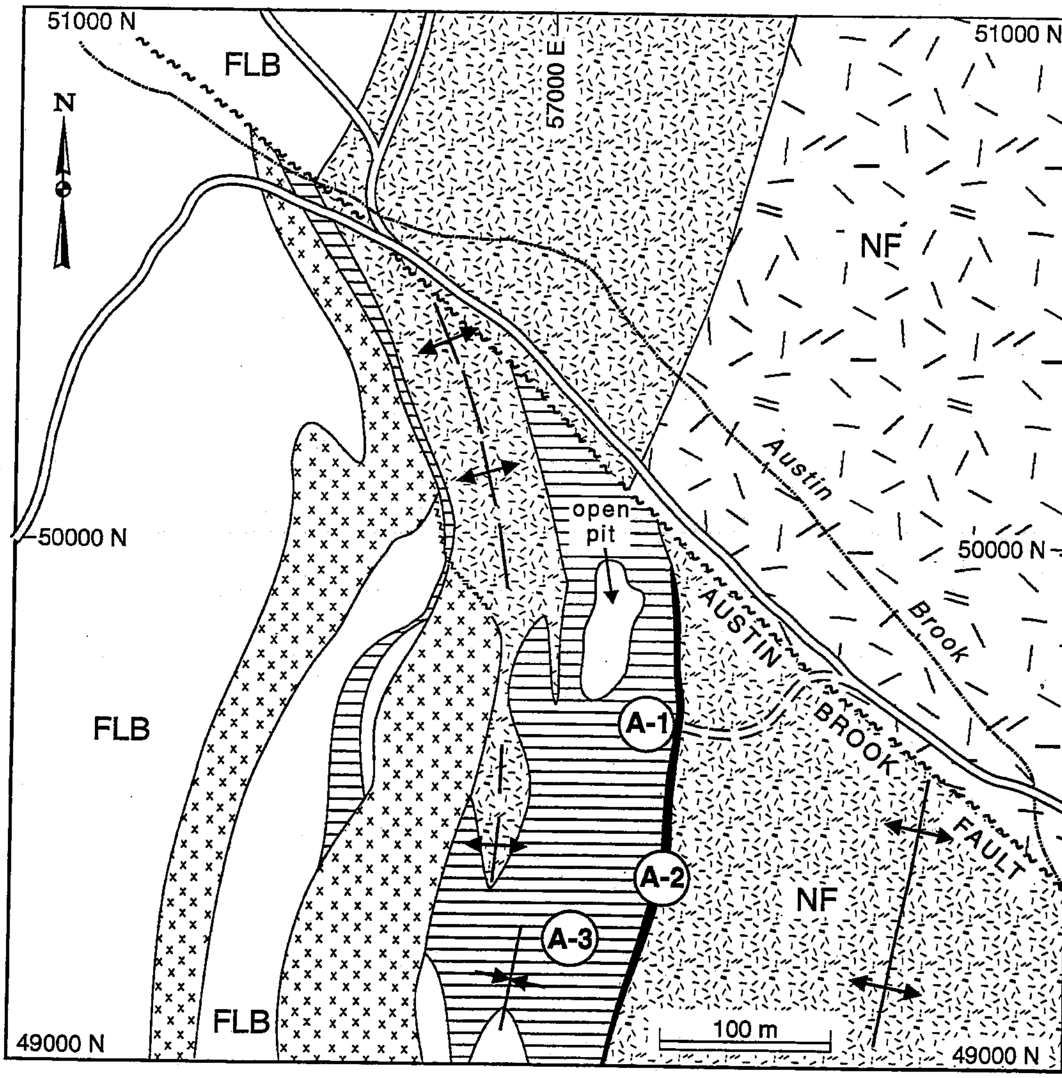



*Figure 21. Simplified geological map (modified from Boyle and Davies 1964) of the area around the Austin Brook quarry showing stop locations. Legend as in Figure 17 except that horizontal-line pattern is iron formation and black is massive sulphides. See Figure 13 for location of this map.*

### Stop A-1. **Austin Brook quarry: footwall pyritic-sericitic sedimentary rocks**

The Austin Brook 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. 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. **Austin Brook quarry: massive-sulphide layer with minor sphalerite**

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. **Austin Brook quarry: hematite-magnetite iron formation**

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 jasper. 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 phenomenon may be related to the well developed compositional layering that is defined by alternating competent (jasper and magnetite) and incompetent (hematite) lamina.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *45.2* | *Return to the vehicles.* |
| *0.5* | *45.7* | *Continue west along the gravel road and bear right (north) at the forks.* |
| *0.4* | *46.1* | *At the earthern and rock barrier, stop and park.* ***[NOTE: If you have not obtained permission to enter the Brunswick No. 6 property from the Mine Geologist (W. Luff) at Brunswick Mining and Smelting, do not pass this barrier.]*** |

*Climb over the barrier and proceed along the road, about 100 m, to the large trench that crosses the road. This trench exposes the entire upper part of the Nepisiguit Falls Formation, i.e. the granular (volcaniclastic) rocks, which occurs from its contact with massive QFAS in the east to iron formation in the west, near the perimeter of the open pit. Surface exposures will be examined first before coming back to this trench. The first stop is about 15 m past the trench and 10 m east of the road (Fig. 17).*

## Stop 6-1. **Ash tuff and very fine-grained tuffite with two cleavages.**

The pavement outcrop consists of ash tuff and very fine-grained tuffite (QAS) with two cleavages. Dissolution has occurred along both the $S_1$ and $S_2$ planes resulting in development of losenge-shaped microlithons between the intersecting cleavages in the ash tuff. The $S_1$ fabric is represented by thin recessive-weathering phyllosilicate layers; this cleavage is refolded by $F_2$ folds with a penetrative axial-planar $S_2$ foliation. 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 compositionally different phyllosilicate layers. This situation is analogous to cleavage refraction in a sandstone-slate sequence. The relationship between the differentiated $S_1$ foliation and the refracted $S_2$ cleavage is obvious in the $F_2$ minor folds.

## Stop 6-2. **Lenses of coarse-grained, granular tuff/tuffite (QAS).**

Lenses of coarse-grained, granular tuff/tuffite (QAS) with quartz crystals up to 5 mm can be seen in finer grained, granular QAS. The rocks are weakly chloritic and very similar to rocks by the power dam (Stop NF-4) except that feldspar is absent. Other outcrops between this one and the next stop consist of medium- to coarse-grained, granular QAS, locally with finer grained interbeds. All QAS in this area is interpreted to be the product of feldspar-destructive alteration of originally quartz-feldspar-rich volcaniclastic rocks in the upper part of the Nepisiguit Falls Formation.

*Walk northeast about 140 m, across the road and along the west side of the drained tailings pond to the road that crosses the north end of this former pond. Follow this road about 50 m to the outcrop on the opposite side of the former pond and on the south side of the road.*

Stop 6-3. **Massive tufflava/porphyry (QFAS) with very large feldspar.**

In this outcrop, massive tufflava/porphyry (QFAS) can be seen with very large feldspar (up to 1.5 cm) and quartz crystals, some of which are tectonically broken. Both $S_1$ and $S_2$ fabrics are moderately well developed in this outcrop and quartz veins occur along the west side of it. The adjacent outcrops a few metres to the west, *i.e.* in the former tailings pond, consist of granular QFAS with smaller crystals and well developed fabrics. The short concealed interval between the two rock types may conceal a fault that separates the east and west limbs of the Brunswick No. 6 antiform. To the east, all the contiguous outcrops consist of massive QFAS with a cryptocrystalline (originally glassy) matrix and little or no alteration. The beta-quartz phenocrysts exhibit well preserved growth textures, something that is characteristic of lava flows rather than pyroclastic eruptions, and the feldspars have microperthitic lamellae. However, about 100 m to the north there is a QFAS outcrop in which feldspar exhibits intermediate stages of alteration to mica. All of the QFAS in this area was originally tufflava or subvolcanic porphyry.

*Continue walking south about 50 m along the east side of the former tailings pond to the point opposite the drainage trench. Note the quartz veins and strong fabric along the west edge of the semi-continuous outcrop. Cross over to this trench and proceed along it.* ***[NOTE: Do not enter this trench without a hardhat.]***

Stop 6-4. **Trench containing altered Nepisiguit Falls volcaniclastic rocks and sulphide veins.**

At the beginning of the trench, poorly developed layering exists in very fine to coarse grained, granular (volcaniclastic) QFAS. These greenish grey to dark greenish grey rocks contain abundant vitreous volcanic quartz and milky quartz ± mica that represents replaced feldspar phenoclasts. However, there is also some feldspar preserved in these rocks. About 50 m into the trench, these rocks pass abruptly into dark greenish grey to greenish black, chloritic QAS that locally contains veins/stringers of coarse-grained pyrite. Kink bands are well developed in these chloritic rocks, which continue for about 50 m to the contact with greenish grey to dark greenish grey ash tuff and very fine-grained QAS, which were seen on surface at Stop 6-1. On the other side of the road, the trench contains greenish grey to dark greenish grey, very fine-grained QAS interlayered with medium- to coarse-grained QAS for about 20 m, but farther along towards the pit-perimeter road, the very fine-grained rocks are absent. In general, the rocks between the two roads are less altered than those east of Stop 6-1, even though they are spatially and stratigraphically closer to the No. 6 deposit, which is represented by iron formation rubble in the trench just north of the pit-perimeter road.

*From the intersection of the trench and the pit-perimeter road, walk southwest approximately 150 m to some low-relief, glacially polished outcrops in the bushes.*

Stop 6-5. **Massive to fragmental rhyolite of the Flat Landing Brook Formation.**

The rocks in this area consist of massive to fragmental, aphyric to feldspar-phyric rhyolite of the Flat Landing Brook Formation. They constitute the "hanging-wall" rocks to the Brunswick No. 6 deposit, which is represented by iron formation that lies along the east side of some of the outcrops.

*Return to the intersection of the trench and pit-perimeter road. Proceed north along the east side of the trench and around the screen of trees, approximately 70 m, to the first outcrop overlooking the open pit.*

Stop 6-6. **Thin-layered, magnetite-rich iron formation, Nepisiguit Falls Formation.**

Thin-layered, magnetite-rich iron formation with chlorite, chert and siderite in contact with very fine grained volcaniclastic rocks. From this point, looking northeast, various rock units are visible in the pit wall including grey massive sulphides, yellowish green footwall-sedimentary rocks and blocky-jointed QAS. About 20 m to the south, there is granular fine-grained QAS that underlies the iron formation. The $S_1S_2$ fabric is moderately developed.

*Proceed to the next outcrop about 50 m to the east.*

Stop 6-7. **Sericitic ash tuff layers in granular tuff/tuffite (QAS), Nepisiguit Falls Formation.**

Very fine-grained sericitic layers in this granular tuff/tuffite (QAS) outcrop represent ash tuff that was winnowed from the crystal-rich, volcaniclastic debris flows. All the feldspar has been replaced by milky quartz ± mica. The spaced (solution) cleavage in this outcrop is $S_1$, not $S_2$ as it appears.

*Proceed east approximately 100 m to the roadway; then walk north about 300 m to the ramp leading down into the pit.*

Stop 6-8. **Pyritiferous, chlorite-sericite-rich, footwall mudstones, Nepisiguit Falls Formation.**

Pyritiferous, chlorite-sericite-rich, footwall mudstones 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.

*Walk down the ramp about 50 m to the drainage trench. **[NOTE: Do not enter this trench]**.*

Stop 6-9. **Trench cutting altered footwall rocks, Nepisiguit Falls and Knights Brook formations, beneath the Brunswick No. 6 deposit.**

From the ramp looking east along the trench for about 140 m, there are fine- to coarse-grained, granular (volcaniclastic) rocks of the Nepisiguit Falls Formation, which show increasing alteration toward the massive sulphide contact. Immediately below the contact, which is close to the trench-ramp intersection, and extending about 40 m east, the rocks are dark greenish grey, chloritic, strongly silicified and contain numerous veins/stringers of very fine- to coarse-grained sulphides. Farther east and extending about 60 m, the rocks are greenish black to dark greenish grey, strongly chloritic and have few sulphide veins/stringers. In the remaining 40 m to the contact with the underlying Knights Brook Formation, the rocks are greenish grey to dark greenish grey and sericitic; feldspar is partly preserved, particularily toward the base, in contrast to the rest of the section where it is totally obliterated. Bleaching is apparent in the underlying Knights Brook rocks, particularily in the sandstone. The contact between the two formations is conformable and apparently depositional.

*Return to the top of the ramp and walk south along the pit-perimeter road back to the vehicles. End of Day 2; return to Bathurst.*

# DAY 3: THE RESTIGOUCHE AND MURRAY BROOK DEPOSITS

*(S.J. Gower and S.R. McCutcheon)*

## Introduction

The Restigouche (Zn-Pb rich) and Murray Brook (Cu-rich) massive sulphide deposits are located on the northern limb of the Upsalquitch Lake anticlinorium (Fig. 22) in the northwestern corner of the Bathurst Mining Camp, approximately 70 km and 65 km west of the City of Bathurst, respectively. In this area, the Tetagouche Group conformably overlies the Patrick Brook Formation of the Miramichi Group and comprises feldspar-crystal lithic tuff with minor amounts of aphyric to sparsely feldspar phyric felsic volcanic flows of the Mount Brittain Formation, and slates, cherts and alkali mafic volcanic rocks of the upper Boucher Brook Formation. The Restigouche deposit is hosted by felsic volcanic rocks of the Mount Brittain Formation, and appears to be localized between feldspar-crystal-rich and feldspar-crystal-poor sequences. In contrast, the Murray Brook deposit is hosted by sedimentary rocks that either overlie or underlie the Mount Brittain Formation.

The Restigouche deposit was discovered in 1958 when New Jersey Zinc drilled a strong soil geochemical anomaly and has recently been acquired by Breakwater Resources Ltd., who have announced plans to mine the deposit in conjunction with the Caribou orebody. The deposit has drill-proven reserves of 1.59 million tonnes grading 6.81% Zn, 5.38% Pb, 108 g/t Ag and 1.1 g/t Au (Breakwater Resources Ltd., September 5, 1995, press release).

The Murray Brook 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). The deposit was discovered in 1956 but not developed until NovaGold Resources Inc. commenced open-pit mining of the precious-metal-rich gossan in 1989 (Rennick and Burton 1992). The gossan was exhausted in 1992 with total production of 1.41 million grams (45 434 oz.) Au and 10.78 million grams (346 457 oz.) Ag (Burton 1993). The second phase of open-pit mining is proposed to exploit a near surface copper zone with mineable reserves of 436 455 tonnes averaging 2.83% Cu and 40 gpt Ag (Giancola 1996).

The geology of the deposits is discussed using the regional stratigraphic terminology that has been developed for the camp (van Staal and Fyffe 1991; van Staal *et al.* 1992) and recently modified in this area by Gower (1996). Most drill logs and geological maps prepared by the private sector in this area pre-date van Staal's work and therefore are based on descriptive terminology rather than the formal stratigraphic nomenclature.

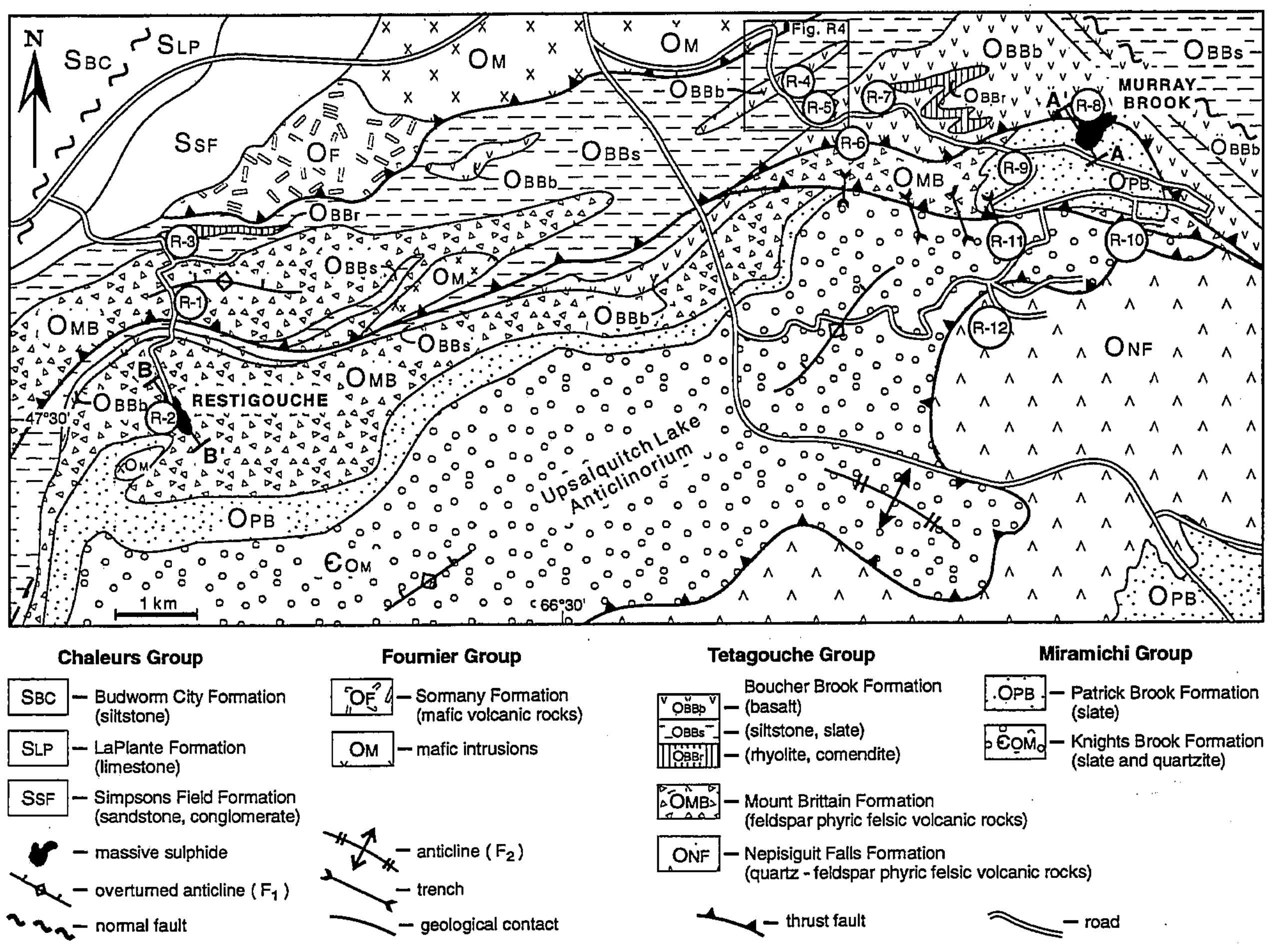



*Figure 22. Simplified geological map of the area around the Restigouche and Murray Brook deposits showing stop locations. See Figure 4 for location of this map.*

## Exploration history

*Restigouche.* The Restigouche property was initially staked by Selco in 1954 because of strong base-metal anomalies in streams in the area. In 1957, the property was optioned to New Jersey Zinc Company who discovered the deposit by drilling a significant soil geochemical anomaly. The property has since been optioned by Teck, Gowganda Silver Mines, Placer Development, Billiton Canada Ltd., Lincoln Resources, Southwind Resources and Marshall Minerals Corporation. After acquiring the mineral rights to the property in 1988, Marshall Minerals embarked on an extensive drilling program to further define reserves and to conduct metallurgical studies. Results proved favorable and the company obtained Environmental Impact Assessment (EIA) approval to proceed with development of the project. They did not advance any further, however, because of several factors, including the suspension of operations at the Caribou Mine in 1990. The deposit was recently sold to Breakwater Resources Limited, who have announced plans to mine the deposit as an open-pit, in conjunction with reopening underground operations at the Caribou Mine. The company is currently (October 1996) carrying out stripping operations at the Restigouche site.

*Murray Brook.* The Murray Brook claim group was originally staked by Kennco Exploration in 1955 on the basis of an airborne electromagnetic survey. Ground follow up and drilling of EM anomalies failed to uncover mineralization. Stream-sediment geochemistry, initiated after finding mineralized float, ultimately led to the discovery of the deposit in 1956 (Perusse 1958; Fleming 1961). By 1958, Kennco had calculated reserves of 21.5 million tonnes of 2.81% combined Pb-Zn.

The property was subsequently optioned to a number of companies including Cominco Ltd., Gowganda Silver Mines Ltd., Canex Placer, and Northumberland Mines Ltd. Northumberland Mines Ltd. systematically tested the economic potential of precious metals in the gossan zone and in 1986 received approval from the provincial government to proceed with the initial stages of mine development. In 1988, Northumberland Mines Limited and the Murray Brook deposit were acquired by NovaGold Resources Inc.

Production began in September 1989, using an indoor cyanide vat leaching process for the first time in Canada. Mining of the gossan was completed in mid-1992. During the 3 yr. life of the mine about 1.41 million grams (45 434 oz.) Au and 10.78 million grams (346 457 oz.) Ag were produced (Burton 1993).

NovaGold Resources Inc. embarked on an exploratory drilling program in 1988-89 to test the copper zone beneath the gossan. The mine facility was converted to a bio-heap leach operation in 1992 and the company began mining the copper portion of the deposit (Burton 1993). In the fall of 1992, approximately 50 000 t of massive sulphides were mined, crushed and delivered to leach pads constructed above the open pit. These sulphides constituted a mixture of low-grade primary and secondary copper ore and high-grade primary copper ore, averaging 2.50% Cu (Burton 1993). However, 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 (about 15 km east of Murray Brook). Definition drilling had established a mineable reserve of 386 455 t at a grade of 2.98% Cu, which is amenable to flotation at the Caribou mill (Burton 1993). However, the agreement between NovaGold and Arimetco International expired with neither company exercising it's options. In 1995, Nova Gold Resources Inc. signed a joint venture agreement with Sheridan Platinum Group Ltd. to advance the project to production. Sheridan will become the operator.

## Geology

*Restigouche.* The Restigouche deposit occurs on the northern limb of a major overturned $F_1$ anticlinorium (Fig. 22) referred to as the Upsalquitch Lake anticlinorium (Helmstaedt 1971). Miramichi Group sedimentary rocks found in the core of this structure are in thrust contact with quartz-feldspar phyric volcanic rocks of the Nepisiguit Falls Formation to the south. In contrast, on the northwestern limb of the anticlinorium, the Tetagouche Group conformably overlies the Patrick Brook Formation (Miramichi Group) and comprises the Mount Brittain and

Boucher Brook formations. The Restigouche massive sulphide deposit occurs within the Mount Brittain Formation and appears to be localized between feldspar-crystal-rich and feldspar-crystal-poor sequences (Fig. 23).

The Mount Brittain Formation consists mainly of feldspar-crystal, lithic tuff. Typically, these volcanic rocks contain 10–25% alkali feldspars (1–3 mm in size) and lesser amounts of plagioclase. Lithic clasts are mainly aphyric rhyolite and locally range up to 15 cm in size. However, rare mafic volcanic clasts are present locally. Although not readily identified in outcrop, thin sections indicate that small (0.3–0.4 mm) euhedral quartz crystals are generally present. Minor aphyric to sparsely feldspar-phyric flows and pyroclastic rocks occur near the base of the felsic volcanic section. The stratigraphic position (*i.e.* conformably overlying the Patrick Brook Formation) and a preliminary U-Pb age (468±2 Ma, V. McNicoll, pers. comm.) indicate that the Mount Brittain Formation is about the same age as the Nepisiguit Falls Formation. At the Restigouche deposit the hangingwall comprises amygdaloidal, feldspar-crystal lithic tuff interlayered with thin "rhyolite tuff" marker horizons (Fig. 23). Relict bubble wall shard textures are preserved in the hangingwall. Chert-like pods and lenses that occur in the immediate hangingwall (Rankin 1982) may represent a disrupted exhalite horizon. Footwall rocks comprise silicified, chloritized, aphyric to sparsely feldspar phyric rhyolite.

*Murray Brook.* The Murray Brook deposit occurs in the core of a sheath-like, synclinal structure (Fig. 24) reflecting the interference of southeasterly overturned $F_1$ and southwesterly overturned $F_2$ folds (Rennick and Burton 1992). The footwall comprises dark grey slate, quartzose siltstone and quartz wacke, and is overthrust by mafic and sedimentary rocks of the Camel Back Member (Camelback (*sic*) suite of

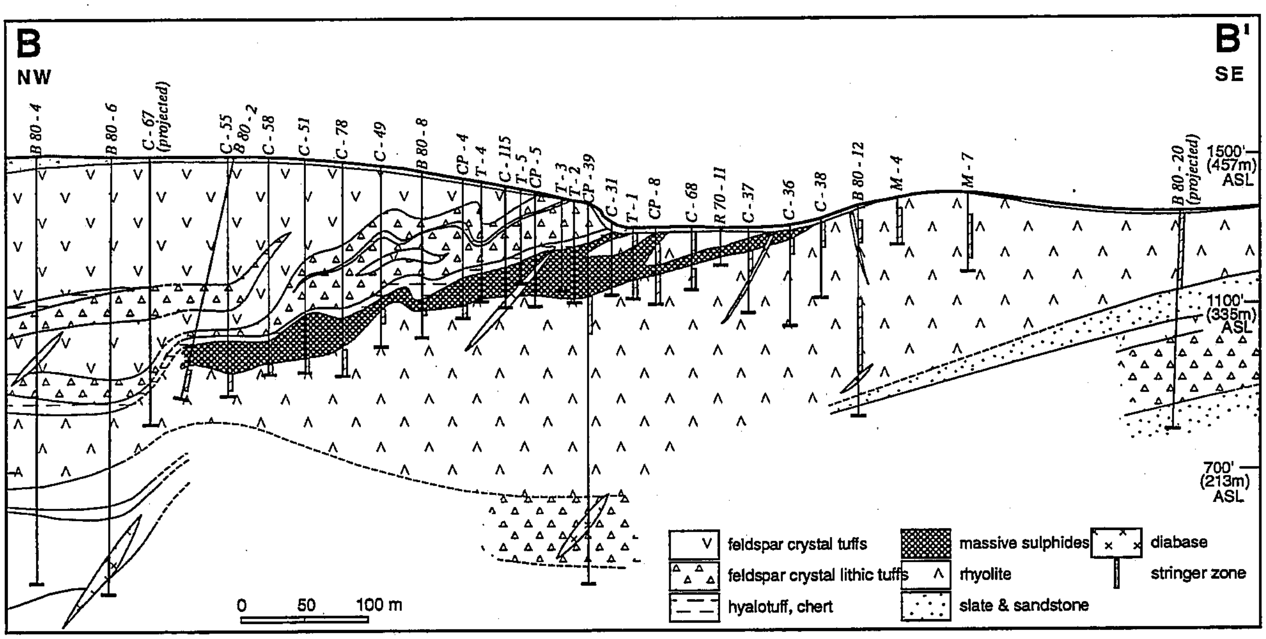



*Figure 23. Northwest-southeast longitudinal section B-B' (see Fig. 22) of the Restigouche Deposit (from Barrie 1982).*

van Staal *et al.* 1991) of the Boucher Brook Formation. Because the deposit occurs in the core of a synform, the stratigraphic hangingwall is not known *i.e.* it has been removed by erosion. This has made the stratigraphic position of the Murray Brook deposit problematic. Rennick and Burton (1992) and van Staal (1994*d*) assigned the footwall sedimentary rocks at the Murray Brook deposit to the Patrick Brook Formation, largely because these rocks occur at the northeastern end of the Upsalquitch Lake Anticlinorium. The sulphides lie close to the contact with felsic volcanic rocks (Fig. 22) that were assigned to the Nepisiguit Falls Formation by Rennick and Burton (1992) but to the Flat Landing Brook Formation by van Staal (1994*d*).

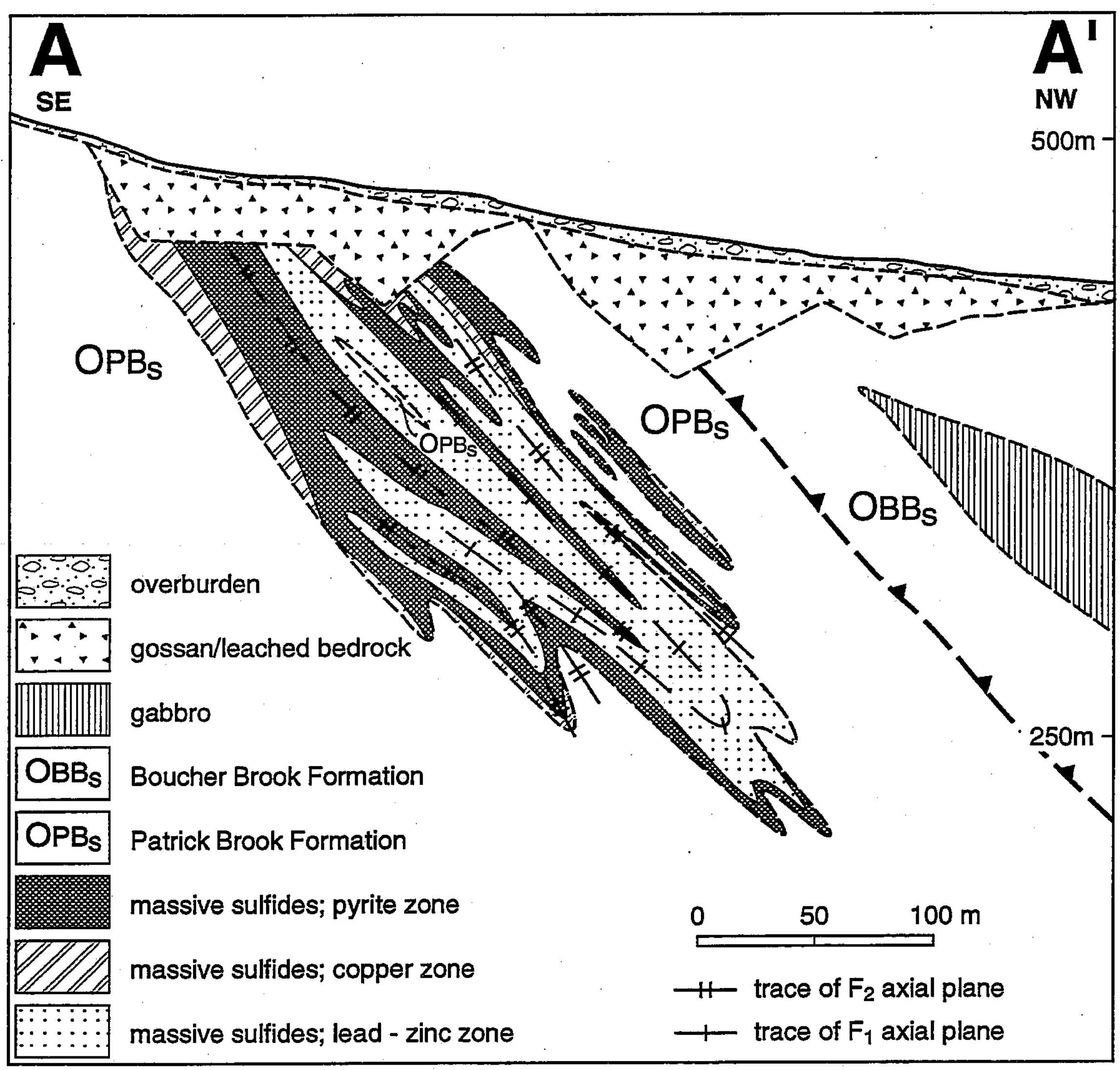



*Figure 24. Northwest-southeast cross section A-A' (see Fig. 22), showing the geology, structure and metal zoning of the Murray Brook deposit (from Rennick and Burton 1992).*

Recent mapping, however, indicates that the stratigraphy on the northern limb of the Upsalquitch Lake Anticlinorium is significantly different than that on the southern limb because of major thrust faults. On the southern limb, quartz-feldspar phyric volcanic rocks of the Nepisiquit Falls Formation are stratigraphically overlain by aphyric to sparsely feldspar phyric rhyolite, lithic tuff and breccias of mafic to intermediate composition and tholeiitic basalt of the Flat Landing Brook Formation. On the northern limb, feldspar-phyric lithic tuff and flows of the Mount Brittain Formation are stratigraphically and/or structurally overlain by sedimentary and mafic volcanic rocks of the upper Boucher Brook Formation. The Murray Brook deposit is within sedimentary rocks that appear to overlie the Mount Brittain Formation, *i.e.* on the northern limb, but these rocks occur within a separate thrust sheet that cuts off the northeastern end of the Upsalquitch Lake Anticlinorium (Fig. 22). Preliminary geochemical results indicate the sedimentary rocks that host the Murray Brook deposit have lower Cr, Ni, V and higher high field strength elements compared to sedimentary rocks of the upper Boucher Brook Formation (*cf.* Lentz *et al.* 1996; J. Langton, pers. comm.). Therefore, they are chemically more akin to the Patrick Brook Formation of the Miramichi Group, although the metal zoning in the deposit and field relationships suggest that these rocks occupy the core of a synform overlying the Mount Brittain volcanic rocks.

Two strong fabrics are evident in the rocks: $S_2$ strikes NNW and dips to the northeast and is axial planar to very tight $F_2$ folds; $S_1$ has an east to southeast trend and shallow to moderate northerly dips. The thrust contact between the sedimentary rocks that host the Murray Brook deposit and upper Boucher Brook alkalic basalt is parallel to the intense $S_2$ cleavage and has been interpreted as a $D_2$ thrust (Rennick and Burton 1992). Recent trenching (Miller 1994) west of the Murray Brook deposit indicates that the Mount Brittain Formation is in structural contact with Miramichi Group sedimentary rocks along an east-west trending, shallowly north-dipping fault zone (Fig. 22). This fault, described as a 50–100-m-wide zone of sericite-talc schist, is also interpreted to be an $D_2$ thrust. The northwest trending $D_2$ thrusts appear to truncate the major northeast trending $D_1$ thrust along the southern limb of the Upsalquitch Lake Anticlinorium.

A third phase of deformation is represented by north-trending axial-planar crenulations and north-plunging open and upright folds. A fourth phase is manifested by an east trending fracture cleavage. The geology is further complicated by a series of north- to northwest-trending normal faults with minor displacement. Numerous undeformed diabase dikes, that generally strike ENE and dip steeply, are interpreted to be Silurian in age.

**Massive sulphides**

*Restigouche.* The Restigouche massive sulphide deposit has drill-proven reserves of 1.59 million tonnes of 6.81% Zn, 5.38% Pb, 108 g/t Ag and 1.1 g/t Au (Breakwater Resources Ltd., September 5, 1995 press release). The orebody is elongate in form and plunges to the north-northwest at 15°–20°, oblique to the northeast regional trend of the geology (Fig. 23). The zone is 490 m long and averages 90 m wide and 30 m thick and has been traced to a vertical depth of 183 m to the north (Carroll 1995).

The deposit comprises at least two separate lenses of massive sulfide, which coalesce in the central part of the orebody, and is underlain by a chlorite-pyrite stringer zone. The top of each lens is markedly rich in silver (Westoll 1989). The massive sulphides, in order of abundance, are pyrite, sphalerite, galena and chalcopyrite. Unlike the Brunswick-type deposits, there are no sedimentary rocks or iron formation associated with this deposit. Two northwest-trending diabase dikes transect the Restigouche deposit and are parallel to faults exhibiting minor offsets.

*Murray Brook.* The Murray Brook deposit has total sulphide reserves of 21.5 million tonnes at a grade of 0.48% Cu, 0.66% Pb, 1.95% Zn (Perusse 1958). The deposit is dominantly pyritic with lesser amounts of sphalerite, galena, chalcopyrite, arsenopyrite, magnetite, pyrrhotite, marcasite, and tetrahedrite (Rankin 1982). Although common as inclusions in pyrite, pyrrhotite accounts for less than 1% of the sulphides. The deposit dips moderately to the north and plunges gently to the east (Fig. 24). As noted by Rankin (1982) and Rennick and Burton (1992), three sulphide zones can be distinguished, namely an outer Cu zone, an intermediate massive pyrite zone, and in the core, a layered Pb-Zn zone. A 1-3-m-wide zone of chloritized sedimentary rocks containing disseminated pyrite surrounds the deposit. The high abundance of quartz and Fe-rich chlorite in the structural footwall of the deposit compared to the structural hangingwall and the presence of carbonate in the hangingwall sedimentary rocks (Rankin 1982), suggest that the most proximal part of the deposit is in the structural footwall. Furthermore, the highest Cu abundance is also in the structural footwall of this sheath-like fold (Burton 1993).

**Gossan**

The Murray Brook gossan developed under a temperate climate, in a pre-glacial period about two to three million years ago (Pliocene), as a result of a prolonged period of oxidation and weathering of the underlying massive sulphide deposit (Boyle 1995). To date, it is the largest gossan found in the Bathurst Camp. The gossan was about 45 m thick prior to mining and has been subdivided into six distinct units: altered massive sulphides; pyrite-quartz sand, massive sulphide gossan, disseminated sulfide gossan, ferruginized wallrock and leached bedrock (Boyle 1995). The massive sulphide gossan constitutes the main body of economic mineralization and consists of goethite, primary quartz, secondary amorphous silica, K-Fe-Pb-As-Sb-Ag hydrated sulfate and oxide minerals (beudantite, plumbojarosite, jarosite, bindheimite, scorodite), trace cinnabar and cassiterite of primary origin (Boyle 1995). 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).

## DAY 3. ROAD LOG AND STOP DESCRIPTIONS

The road log begins at the junction of Route 180 and the access road to the Restigouche deposit. This junction is 70.4 km west of the overpass above Highway 11 (Exit 310) on Route 180, or 5.8 km from the turn off to the Murray Brook Mine (TV Tower Road). The turn-off to the Caribou Mine is located 43.8 km west of Exit 310.

| *cum. km* | |
|---|---|
| *0.0* | *Turn left (south) from Route 180. Travel southeast on the main road.* |
| *1.2* | *At the crest keep right (south).* |
| *1.5* | *Turn right at the junction. We will return to this junction and turn east for Stop 3.* |
| *1.6* | *Keep left (south) at the fork.* |
| *1.95* | *Stop at the outcrop at the crest of the hill.* |

### Stop R-1. Feldspar-crystal, lithic tuff, Mount Brittain Formation

This outcrop occurs on the southern limb of a southerly overturned east-northeast plunging anticline. There are two well developed foliations: one has a north-westerly trend and dips to the east (140°/50°) whereas the other strikes north-south and dips steeply west (015°/75°) and is axial planar to the regional $F_4$ fold in the area. A thrust contact with rocks of the Camel Back Member is located approximately 200 m to the south.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *1.95* | *Return to vehicles and continue south. Mafic volcanic rocks of the Camel Back Member subcrop about 250 m farther along on the left (east) side of the road.* |
| *0.35* | *2.3* | *Turn right (west).* |
| *0.55* | *2.5* | *Turn south at the junction.* |
| *0.79* | *2.74* | *Keep left at the fork.* |
| *1.25* | *3.2* | *Stop at the top of the bank overlooking the stream valley.* |

### Stop R-2. Restigouche Deposit (access depending on mining operations)

The outcrops north of the stream valley represent the hangingwall of the Restigouche deposit, which plunges shallowly to the northwest and dips to the west. The hangingwall comprises amydaloidal, feldspar-crystal lithic tuff. Note the cherty lenses and veins. A thin unit of "rhyolite tuff" (exhalite?) immediately overlies the deposit. Footwall rocks (silicified, chloritized rhyolite) are exposed across the stream, in the pit. The main cleavage strikes northwest to northeast and generally dips moderately west. A second cleavage that is axial planar to recumbent folds strikes northeast and dips shallowly to the west. A third cleavage strikes north-northwest and is parallel to the axis of a large regional $F_4$ fold. The cleavages are not uniformly well developed throughout the outcrops.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *3.2* | *Turn around and proceed back toward Route 180.* |
| *1.7* | *4.9* | *At the fork keep right.* |
| *1.95* | *5.15* | *Stop and walk north into the woods about 50 m.* |

## Stop R-3. **Mount Brittain Formation**

Light greenish grey, feldspar-phyric felsic volcanic rocks of the Mount Brittain Formation crop out at this location. Note the rhyolite fragments. The contact of the Mount Brittain Formation with sedimentary rocks of the upper Boucher Brook Formation is located farther along the road, about 500 m to the east.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *5.15* | *Return to Route 180.* |
| *1.75* | *6.9* | *At Route 180 bear right (east).* |
| *7.55* | *12.7* | *Turn south from Route 180 onto the TV Tower road (there is a sign saying Murray Brook Mine).* |
| *8.55* | *13.7* | *Turn left (east) at the fork and continue on the main road.* |
| *10.4* | *15.55* | *Bear south at the fork in the road and up the hill.10.4* |
| *10.65* | *15.8* | *Beginning of outcrop.* |
| *10.95* | *16.1* | *Stop and look at the outcrop exposed along the east side of the road, north of the burrow pit.* |

## Stop R-4. **Beresford Member of the Boucher Brook Formation**

At this stop (Fig. 25), we are looking at the upper part of the Boucher Brook Formation. Grey, greenish grey to reddish grey, thinly-bedded (1–3 cm) chert and siltstone are interlayered with greenish grey, foliated mafic volcanic rocks. Bedding strikes northwest (300°) and dips moderately to the north and the rocks are not highly strained.

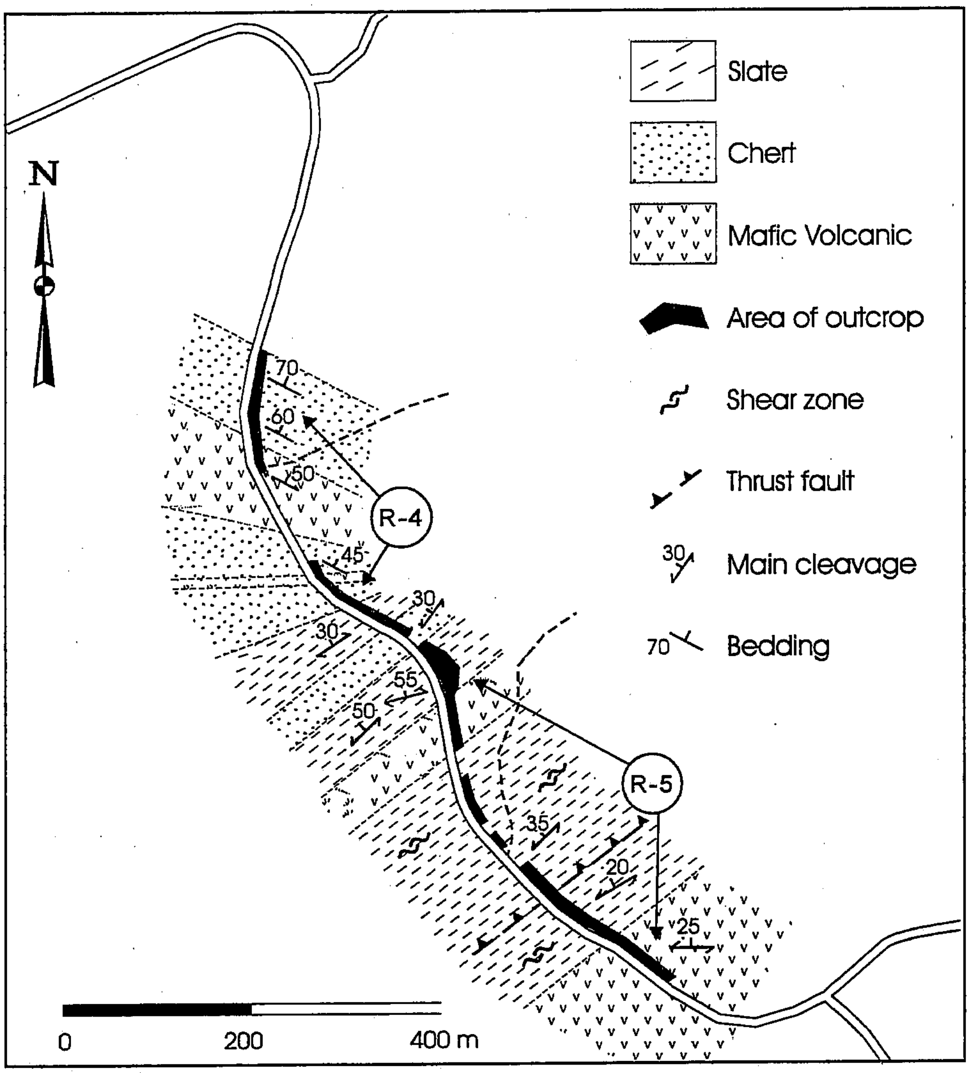



*Figure 25. Reference section for the upper part of the Boucher Brook Formation in the northwestern part of the Bathurst Camp. See Figure 22 for the location of this map.*

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *16.1* | *Continue south.* |
| *0.1* | *16.2* | *Mafic volcanic rocks are exposed just south of the pit.* |
| *0.4* | *16.5* | *Stop and look at the deformed sedimentary rocks exposed along the road; walk south to the basalt contact.* |

## Stop R-5. **Camel Back Member of the Boucher Brook Formation**

Here, the rocks are highly strained, in contrast to the last stop. Deformation progressively increases to the south, toward an interpreted thrust contact with felsic volcanic rocks of the Mount Brittain Formation. Zones of intense deformation and quartz veining probably represent localized thrust movement within the section. Near the base of the section, grey shale conformably overlies amydaloidal mafic volcanic rocks. Note the highly strained pillows in the basalt.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *16.5* | *Continue south, turning east around a sharp turn.* |
| *0.35* | *16.85* | *Park at the entrance to the side road on the right (south). Walk about 400 m south along this side road, keeping right at the fork 130 m in, to a small outcrop on the left.* |

Stop R-6. **Mount Brittain Formation, Murray Brook area**

This outcrop comprises feldspar-phyric, felsic volcanic rocks of the Mount Brittain Formation that structurally underlie mafic volcanic rocks of the Camel Back Member of the upper Boucher Brook Formation. A trench, located 200 m to the south, exposed feldspar-phyric and aphyric tuff in fault contact with siltstone and shale. The faulted, felsic volcanic-sedimentary rock contact was exposed in four trenches excavated by Teck Exploration Limited in 1994 and is interpreted to be a $D_2$ thrust fault.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *16.85* | *Return to the vehicles. Continue east (right) on the main access road. Mafic volcanic rocks are exposed intermittently along the road.* |
| *0.65* | *17.5* | *Stop and look at the outcrop on the south side of the road.* |

Stop R-7. **Camel Back Member: fragmental mafic volcanic rocks**

Greenish grey, mafic pyroclastic rocks near the base of the Camel Back Member are exposed along the south side of the road. This fragmental unit occurs in the immediate structural hangingwall at the Murray Brook Mine. Two cleavages are evident: both have a northwesterly trend and dip steeply to the northeast ($S_1$ = 150°/75° and $S_2$ = 140°/80°). A massive, dark grey diabase dike also crops out at this location; similar dikes are common in the Murray Brook-Restigouche area and generally strike westerly and dip steeply. These dikes are undeformed and are probably Silurian in age.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *17.5* | *Continue east toward the mine.* |
| *1.05* | *18.55* | *Keep left on the main road. We will be returning later to the road to the southeast.* |
| *1.25* | *18.75* | *Gate to the Murray Brook Mine.* |

### Stop R-8. **Murray Brook Mine Site**

Participants will view plans and sections and examine representative drill cores through the deposit.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *18.75* | *Return to the gate and proceed west.* |
| *0.25* | *19.0* | *Turn left and drive southeast.* |
| *0.47* | *19.22* | *Outcrop of Mount Brittain felsic volcanic rock on the south side of the road. Continue southeast.* |
| *0.32* | *19.55* | *Walk south, uphill along an old trench for 150 m and bear SE 100 m through the woods to an outcrop exposed along an old road.* |

### Stop R-9. **Patrick Brook Formation (?)**

This outcrop consists of fine-grained, quartz lithic wacke and siltstone that hosts the Murray Brook deposit and is considered by most workers (van Staal 1994, Rennick and Burton 1992) to represent the Patrick Brook Formation. Alternatively, these rocks may be correlative with the type-(lower) Boucher Brook Formation if the Mount Brittain and Spruce Lake formations are time equivalent. The outcrop has two well developed foliations; $S_2$ is a spaced cleavage that strikes northwest and dips to the east (140°/45°) and $S_1$ trends NNE (015°/45°).

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *19.55* | *Return to vehicles and continue southeast. There is an outcrop of rusty sedimentary rock about 300 m farther along the road.* |
| *0.55* | *20.1* | *View of the Murray Brook Mine.* |
| *1.65* | *21.2* | *Keep right at the Y-intersection.* |
| *1.95* | *21.5* | *Turn right and drive south.* |
| *2.0* | *21.55* | *At the T-junction keep right (northwest). Rusty altered sedimentary rock is exposed about 100 metres farther along the road.* |
| *2.75* | *22.3* | *Park at the junction and walk south, 150 m, to the T-junction.* |

### Stop R-10. **Mount Brittain–Patrick Brook contact (Murray Brook horizon)**

The outcrop near the junction consists of fine-grained, feldspar phyric, volcaniclastic rocks that are interpreted to be part of the Mount Brittain Formation. About 200 m to the south, the structural contact with quartzite of the Knights Brook Formation is exposed. Dark grey shale, siltstone and quartzose sandstone of the Patrick Brook Formation (?) are exposed along the road east of the felsic volcanic rocks.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *22.3* | *Return to vehicles and continue west.* |
| *0.9* | *23.2* | *Turn left (south).* |
| *1.3* | *23.6* | *Turn right (west).* |
| *1.6* | *23.9* | *Stop and look at the outcrop on the left (SE side of the road.* |

Stop R-11. **Knights Brook Formation**

This outcrop consists of siltstone and shale, interlayered with thin- to medium-bedded quartzite typical of the Knights Brook Formation. The NNW (135°/40°) $S_2$ crenulation cleavage is well developed.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *23.9* | *Continue southwest.* |
| *0.3* | *24.2* | *Turn right (west) at the quadruple junction.* |
| *0.4* | *24.3* | *Stop at the intersection and walk south. There is an outcrop of Nepisiguit Falls Formation volcanic rock about 100 m along the road on the left side.* |

Stop R-12. **Nepisiguit Falls Formation**

Felsic volcanic rocks of the Nepisiguit Falls Formation, on the southern limb of the Upsalquitch Lake Anticlinorium, differ from those of the Mount Brittain Formation in that quartz eyes are readily visible. A strong crenulation cleavage, which is an $S_2$ or younger feature, strikes NW-SE (115°) and dips shallowly to the northeast.

| *km* | *cum. km* | |
|---|---|---|
| *0.0* | *24.3* | *Return to vehicles and continue west. The Knights Brook Formation is exposed along the road. There is a view of Upsalquitch Lake 700 m farther along the road.* |
| *0.97* | *25.27* | *Bear right at the T-intersection.* |
| *1.6* | *25.9* | *Keep left at the junction.* |
| *2.2* | *26.5* | *Keep right (west).* |
| *2.5* | *26.8* | *Turn left at the junction and then sharp right at 50 m farther along.* |
| *2.9* | *27.2* | *Keep right at the clearing.* |
| *3.05* | *27.35* | *Turn north (right) at the junction with the TV Tower road.* |
| *5.5* | *29.8* | *Junction with the access road to the Murray Brook Mine, continue north.* |
| *6.5* | *30.8* | *Route 180, turn right.* |

*End of Day 3, return to Bathurst.*

## ACKNOWLEDGEMENTS

We thank Brunswick Mining and Smelting, Heath Steele Mines and East-West Caribou Mining for giving us and the trip participants access to their respective mine sites. We also thank Phillip Evans and Terry Leonard for preparation of the figures. Lastly, we appreciate the editorial comments that Tony Davidson gave us on an earlier version of this guidebook; this version is improved because of them.

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