FIELD GUIDE TO MASSIVE SULPHIDE DEPOSITS IN NORTHERN NEW BRUNSWICK

Edited by

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June, 1990

This report should be referenced in the following manner:

FYFFE, L.R. (editor) 1990. Field guide to massive sulphide deposits in northern New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, 162 p.

FOREWORD

The mineral industry of New Brunswick is now a very important factor in the economy of the province. The value of mineral production in New Brunswick in 1989 was approximately $911 million. Nearly 70% of this amount is derived from the zinc-lead-silver-copper ores of the Bathurst-Newcastle district. To ensure the health of the industry, new ore reserves must be found to replace those that have been mined over the past 30 years.

One of the prime responsibilities of the Geological Surveys Branch (GSB) of the New Brunswick Department of Natural Resources and Energy (DNRE) is to encourage exploration for additional ore reserves by providing geoscience data, thus reducing the risk factor involved. In keeping with this role, the GSB asked the New Brunswick Prospectors and Developers Association (NBPDA) and the Geology Division of the Canadian Institute of Mining and Metallurgy (CIM) to co-sponsor a base metal symposium in Bathurst, June 10 to 13, 1990. The purpose of the symposium was to highlight the geology of Appalachian stratabound massive sulphide deposits, and to emphasize the exploration potential of the Bathurst-Newcastle area.

The geology of northern New Brunswick, despite poor bedrock exposure, is fairly well understood, thanks to the efforts of the Provincial GSB and the Geological Survey of Canada (GSC), as well as the significant contribution of numerous industry and university geoscientists. Since 1970, funding of government geological mapping has been primarily via Federal-Provincial mineral development agreements.

This guide was prepared for field excursions in the Bathurst-Newcastle district held in conjunction with the base metals symposium. The guide reviews the tectonic setting of the massive sulphide deposit in the northeastern Appalachians; the volcanic stratigraphy of the northern Miramichi Highlands; and the present genetic models applicable to the Bathurst-Newcastle sulphide deposits. The final sections outline the exploration history, geology, and mining technidqes used in developing deposits in the region. A road log is also included which describes locations of regional geologic interest.

I congratulate L.R. Fyffe for his efforts in putting this guidebook together, and to the geoscientists and other individuals who have contributed in one way or another to the final product. The guidebook was typed by Diane Blair. Technical editing was completed by Barbara Carroll. Drafting services were provided by Gerry Johnston, Terry Leonard, and Kevin Smith, and photographic services by George Tims and his staff.

I also acknowledge the assistance and cooperation of Brunswick Mining and Smelting Corporation, Heath Steele Mines Limited, NovaGold Resources, Marshall Minerals, and East West Minerals (Breakwater Resources Ltd.).

J.L. Davies
Director, Geological Surveys Branch

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LATE PRECAMBRIAN-EARLY PALEOZOIC VOLCANIC REGIMES AND ASSOCIATED MASSIVE SULPHIDE DEPOSITS IN THE NORTHEASTERN MAINLAND APPALACHIANS

L.R. Fyffe, C.R. van Staal, and J.A. Winchester

INTRODUCTION

A symposium on base metal deposits was held in Bathurst from June 10-13, 1990, sponsored jointly by the Geological Surveys Branch of the New Brunswick Department of Natural Resources and Energy, the New Brunswick Prospectors and Developers Association, and the Geology Division of the Canadian Institute of Mining and Metallurgy. Papers prepared for the symposium are being published as a series of articles in the CIM Bulletin. This first paper in the series presents an overview of the tectonic setting of massive sulphide deposits in the northeastern Appalachians with emphasis on volcanic geochemistry.

The stratiform volcanogenic nature of the massive sulphide deposits in the Appalachian Orogen was recognized shortly after the discovery of several large orebodies in the Bathurst-Newcastle area of New Brunswick (Stanton 1959; McAllister 1960). With the development of plate tectonic theory, it became apparent that the origin of these deposits was related to the extension and contraction of oceanic basins (Wilson 1966; Hutchinson 1973; Strong 1974), bordered by Grenvillian continental crust in the northwest and, at least by the Late Paleozoic, by Avalonian crust in the southeast (Williams 1964). In recent years, detailed geological investigations in the Canadian Appalachians have established that sulphide deposition occurred in at least three distinct tectono-volcanic environments, i.e., ocean-floor, island-arc, and back-arc settings (Stephens et al. 1984).

A sizeable literature is now available documenting the geochemistry of volcanic rocks in the Appalachian system. This paper reviews the data from the Early Paleozoic of New Brunswick, Maine, and Eastern Townships of Quebec, and from the Precambrian of southern New Brunswick, and groups the volcanics according to tectonic setting. The reader is referred to Strong (1977) and Swinden et al. (1989) for a similar treatment of the Newfoundland Appalachians.

The six volcanic regimes recognized on the Canadian mainland and in adjacent Maine are systematically distributed with respect to the ancient continental margin of North America (Fig. 1). From the northwest to southeast, these include: (1) continental rift volcanics; (2) fore-arc ophiolites; (3) intra-oceanic island-arc volcanics; (4) back-arc ophiolites; (5) back-arc ensialic volcanics; and (6) magmatic-arc volcanics. The relationship of the Paleozoic volcanic rocks (regimes 1 to 5) to the Appalachian orogenic cycle is fairly well understood, but the relevance of the Precambrian Avalonian volcanics

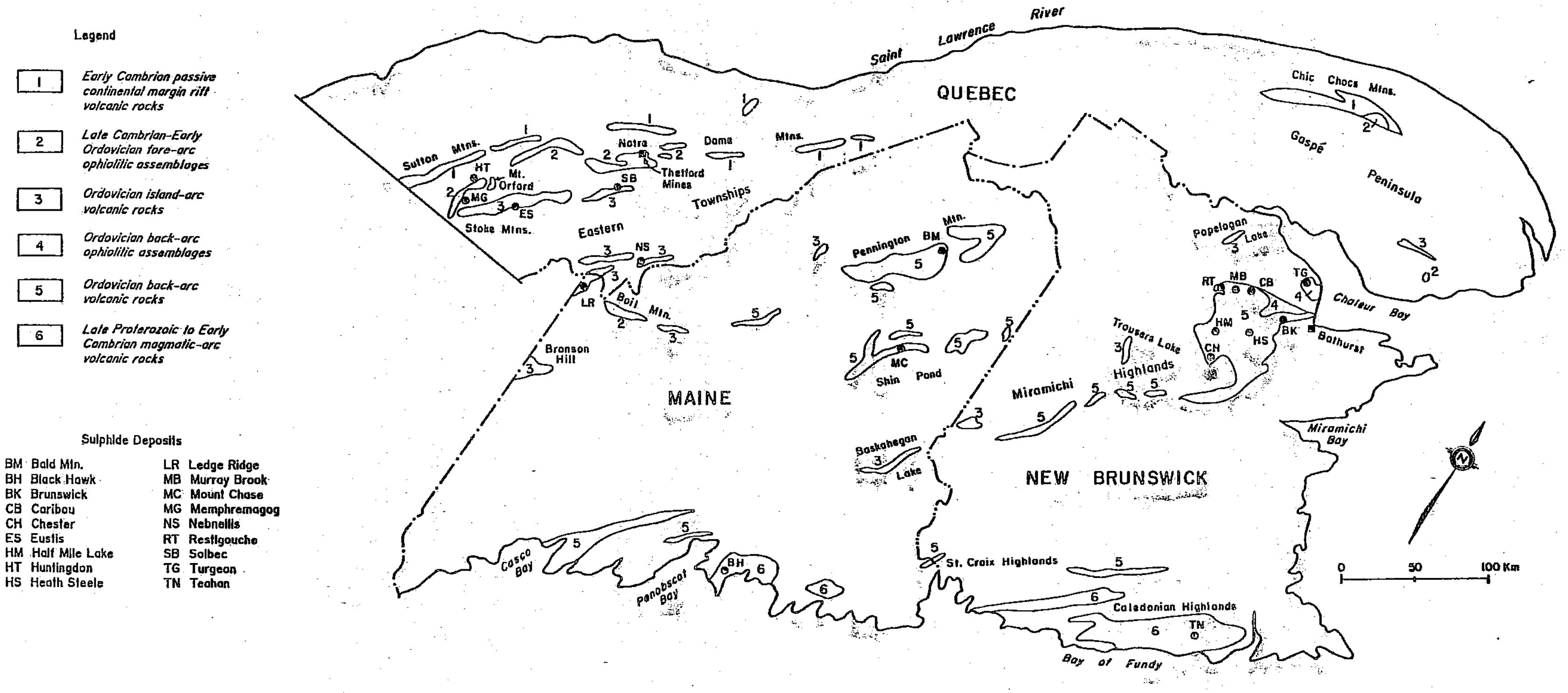

FIGURE 1. Distribution of Late Proterozoic to Early Paleozoic volcanic rocks and associated sulphide deposits in New Brunswick, Quebec, and Maine. The volcanic rocks are divided into six tectonic regimes on the basis of regional stratigraphic relationships and geochemisty.

(regime 6) to this cycle is less clear.

The geochemical characteristics of each volcanic regime, together with brief descriptions of representative sulphide deposits are given below.

CONTINENTAL-RIFT VOLCANICS

Crustal extension along the northwestern margin of the Appalachian Orogen is evident in the Late Proterozoic (615 Ma, U-Pb) - the emplacement age of the Long Range dyke swarm into Grenville gneisses on the southeastern coast of Labrador (Kamo et al. 1989). The Early Cambrian (554 Ma, U-Pb) age of the Tibbit Hill Formation (Kumarepali et al. 1988), underlying the Sutton Mountains in the Eastern Townships of Quebec (Fig. 1), indicates that rifting of the Laurentian craton occurred over a period of 60 Ma. High-field-strength-element (HFSE) ratios (Fig. 2a) and rare-earth-element (REE) profiles (chrondrite-normalized $La_N/Yb_N = 5$) from mafic flows of the Tibbit Hill Formation indicate that they are transitional to alkalic basalts. These basalts and associated peralkaline rhyolites are typical of within-plate, rift lavas (Pintson et al. 1985; Kumarapeli et al. 1988).

The Sutton Mountains are part of a thrust duplex emplaced to the northwest over Ordovician shelf carbonates of the North American foreland. However, to the southwest in the Green Mountains of Vermont, volcanic rocks of the Tibbits Hill Formation rest directly on Grenvillian basement, confirming theircontinental setting (St-Julien and Hubert 1975).

FORE-ARC OPHIOLITES

Ultramafic-mafic complexes of the Eastern Townships occur as a northeast-trending series of thrust slices overlying miogeoclinal clastic rocks of the Notre Dame Mountains (Fig. 1). Many of these Cambrian complexes are dismembered, but those at Mount Orford and Thetford Mines contain a nearly complete ophiolitic assemblage varying from peridotite at the base (lacking at Mount Orford), to dunite and pyroxenite through to gabbro, sheeted diabase (lacking at Thetford Mines), and pillow lavas (Laurent 1975).

The volcanic rocks of the Mount Orford complex comprise a lower unit of massive and pillowed lavas that is separated from an upper unit of amygdaloidal pillow lavas and tuff by a thin argillite layer. The flows of both units are evolved, high titanium-low magnesium tholeiitic basalts. However, those of the lower unit are light rare-earth-element (LREE)-depleted ($La_N/Yb_N = 0.6$) and resemble mid-oceanic-ridge basalts, whereas the upper unit is LREE-enriched ($La_N/Yb_N = 1.6$) and contains a high absolute REE abundance and HFSE ratios (Fig. 2b) similar to island-arc basalts (Harnois 1989).

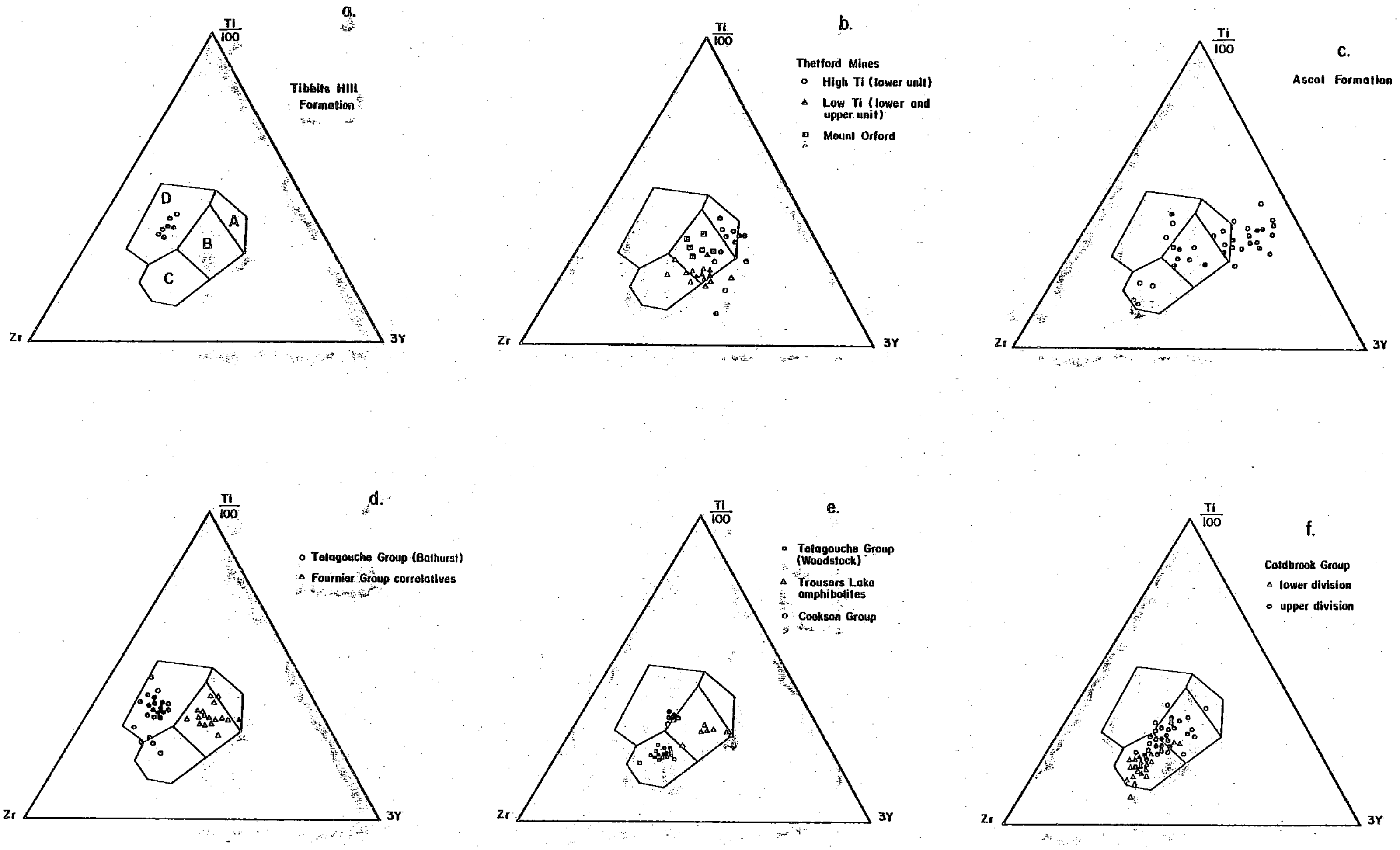

FIGURE 2. Ti-Y-Zr discrimination diagrams for some of the volcanic rocks shown in Figure 1. Geographic locations and sources of the plotted data are given in the text. Island-arc tholeiites in fields A and B, ocean floor tholeiites in field B, calc-alkaline basalts in field C and B, within-plate alkali basalts in field D, and within-plate tholeiites in fields D and B (after Pearce and Cann 1973).

The mafic lavas of the Thetford Mines complex are separated into an upper and lower unit by a 50 m thick layer of cherty argillite. The lower unit contains an abundance of high titanium-low magnesium basalts (Fig. 2b) with flat REE profiles ($La_N/Yb_N = 0.8$) similar to primitive island-arc tholeiites. In contrast, the upper unit is low in titanium, high in magnesium, and possesses concave REE profiles ($La_N/Yb_N = 1.4$) resembling present-day boninites (basaltic andesites) from the Mariana fore-arc basin (Fig. 2b). It has, therefore, been suggested that the Quebec ophiolites were formed at a fore-arc spreading-centre above a southeast-dipping subduction zone (Pearce et al. 1984; Church 1987; Oshin and Crocket 1986, Crocket and Oshin 1987; Laurent and Hébert 1989).

The fore-arc oceanic crust of the Quebec Appalachians was obducted onto the eastern edge of the Laurentian craton during the Taconian Orogeny (Laurent 1975; St-Julien and Hubert 1975; Williams and St-Julien 1982). An age of 491 Ma (Ar-Ar) on hornblende from the metamorphic sole of the Thetford Mines ophiolite suggests that it became detached from the mantle in the Tremadoc (Early Ordovician; Clague et al. 1981). Sedimentological and paleontological evidence indicate that the ophiolite complexes were emplaced on the continental margin by mid-Ordovician time (St-Julien and Hubert 1975). This obduction process was a consequence of collision between the passive Laurentian margin and an island arc (Bird and Dewey 1970).

The largest Cyprus-type deposit in the Quebec Appalachians is located at Huntingdon to the southwest of Mount Orford (Fig. 1). The deposit is contained within a slice of basalt, tectonically interleaved with serpentinite, wacke, and slate, in a highly strained zone marking the leading edge of the allochthonous ophiolite belt. The host pillow basalt possesses a boninitic affinity according to its high MgO, Ni, and Cr contents and REE profile. The pyrrhotite and chalcopyrite mineralization occurs in a series anastomizing quartz stringers and as a small lens of massive sulphides. The orebody contained 1.9 million tonnes grading 0.9% Cu (Trottier et al. 1987).

ISLAND-ARC VOLCANICS

The Late Cambrian(?) to Early Ordovician(?) volcanics, wackes, and slates of the Ascot Formation, which underlie the Stoke Mountains (Fig. 1), occupy a higher thrust slice to the southeast of the ophiolitic rocks (Labbé and St-Julien 1989). The volcanics are predominantly basaltic flows with rarely preserved pillows, and felsic pyroclastic rocks; porphyritic andesites are a minor portion of the sequence. Pervasive alteration has caused considerable scatter in the HFSE ratios of the mafic volcanics (Fig. 2c; Hynes 1980); however, REE profiles are similar to island-arc tholeiites and boninites (Tremblay and Bergeron 1988; Tremblay et al. 1989).

It is uncertain whether the allochthonous island-arc volcanics of the Stoke Mountains were built on an oceanic or continental foundation. However, the geochemistry of the basalts and their close spatial association with ophiolites support an intra-oceanic setting. Recent geological and seismic investigations are consistent with formation as a fringing arc off the northwestern margin of the Chain Lakes massif - a fragment of non-Grenvillian continental crust (Spencer et al. 1989). The Ordovician Bronson Hill volcanics and Late Cambrian Boil Mountain ophiolite presumably represent a continuation of the fore-arc basin-volcanic-arc complex in New England and may have formed, as least in part, on continental crust (Leo 1985; Coish and Rogers 1987; Schumacher 1988; Boone and Boudette 1989). Andesitic rocks in the Popelogan Lake inlier of north-central New Brunswick (Philpott 1988) are interpreted as the northeastern extension of this same arc into the Canadian Maritime Provinces.

In the southwestern Miramichi Highlands (Fig. 1), mafic volcanic rocks included in the Tetagouche Group, near Woodstock to the west of Fredericton, possess a chemistry distinct from that of the Bathurst area. Their range of SiO_2 content (46 to 55%), high Al_2O_3 (avg. 17.6%), low TiO_2 (avg. 0.53%), low Fe to Mg ratios, HFSE ratios (Fig. 2e), and LREE-enrichment (La_N/Yb_N = 5.4) are all consistent with a calc-alkaline affinity. Clinopyroxenes are low-Al and low-Ti augites typical of arc-related magmatism (Dostal 1989). Graptolites from associated feldspathic wackes suggest a Llandeilian age for the mafic sequence (Fyffe et al. 1983). Similar volcanic rocks occur in the Baskahegan Lake area of adjacent Maine.

Amphibolite-facies mafic rocks interlayered with psammites and pelites in the Trousers Lake area of the central Miramichi Highlands (Fig. 1) contain a suite of HFSE-depleted amphibolites resembling island-arc tholeiites. These volcanic rocks are no younger than Caradocian as determined by the 451 Ma (U-Pb) age of cross-cutting granite, but their maximum age is unconstrained (Fyffe et al. 1988a). Based on the above geochemistry, it is possible that the Trousers Lake tholeiites and calc-alkaline volcanics of the southwestern Miramichi Highlands (Fig. 2e) represent remnants that became separated from the volcanic arc to the northwest during Ordovician back-arc rifting.

The Ascot Formation of the Eastern Townships hosts several volcanogenic massive sulphide deposits; the larger orebodies, containing more than one million tonnes, include the Solbec, Cupra, and Weedon mines in the northeast, and the Eustis mine in the southwest (Fig. 1). The deposits appear to be restricted to a single stratigraphic horizon folded about an axial surface dipping moderately to the southeast. Individual sulphide lenses range from 55 to 350 m in strike-length, extend down-dip for up to 2000 m, and vary in thickness from 30 cm to 6 m. The typical lithologic sequence in the vicinity of a deposit, as determined by increasing Zn:Cu ratios toward the stratigraphic top, comprises from oldest to youngest (thickness in brackets):

(1) felsic volcanic schists; (2) chlorite schist with 5 to 30% disseminated pyrite; (3) massive pyrite (20 cm) grading to banded pyrite, chalcopyrite, sphalerite, and minor galena (30 cm to 6 m); (4) jasper lenses (1-2 m); and (5) mafic volcanic schists. The tonnage and grade of the orebodies are as follow: Solbec - 1.9 million tonnes of 1.6% Cu, 4.6% Zn, and 0.7% Pb; Cupra - 2.5 million tonnes of 2.8% Cu, 3.3% Zn, and 0.5% Pb; Weedon - 1.7 million tonnes of 2.5% Cu; and Eustis - 1.6 million tonnes of 2.7% Cu (Sauvé et al. 1972).

Stratiform sulphides of the Ledge Ridge deposit were discovered in western Maine in 1973 (Fig. 1). The steep, northwest-dipping sulphide horizon has been traced continuously along strike for 975 m and averages 2 m in thickness. Mafic tuff with fine bands of hematitic chert forms the footwall and a grey laminated siliceous sedimentary unit, containing up to 20% pyrite, forms the hanging wall. Pillow basalts structurally underlie the mafic tuffs; graphitic slate and felsic volcanic rocks overlie the siliceous sedimentary unit. Based on comparison with similar deposits in Quebec (see above) and Maine, it is probable that the stratigraphic section is overturned, i.e., the sequence youngs to the southeast. The deposit contains 3.3 million tonnes of probable reserves grading 0.95% Cu, 2.3% Zn, and 0.85% Pb (Cummings 1988).

BACK-ARC OPHIOLITES

A fragment of oceanic crust occurs within the Ordovician Elmtree-Belledune inlier, which is unconformably overlain by Early Silurian conglomerate along Chaleur Bay in northern New Brunswick (Pajari et al. 1977; Rast and Stringer 1980) (Fig. 1). Mafic rocks of the Fournier Group within this inlier are part of two south-directed thrust sheets that are separated from underlying mid-Ordovician quartz wacke and slate of the Elmtree Formation by a tectonic mélange. The upper thrust sheet contains gabbros, mylonitic amphibolites, plagiogranites, diabase dykes, and pillow lavas of the Devereaux Formation. These are separated by a high strain zone from feldspathic and lithic wacke, red siltstone, grey slate, alkaline pillow lavas, chert, and minor felsic volcanic rocks comprising the Pointe-Verte Formation of the lower sheet. Only the Devereaux Formation has the characteristic rock assemblage of an ophiolite (Langton and van Staal 1989). A radiometric date of 461 Ma (U-Pb) indicates that the coarse-grained gabbro and plagiogranite of the Devereaux Formation are Llandeilian (van Staal et al. 1988a; Flagler 1989; Flagler et al. 1989; Spray et al. 1990).

Volcanic rocks in the Devereaux Formation include both tholeiites chemically akin to mid-ocean-ridge tholeiites with flat REE profiles ($La_N/Yb_N = 0.9$), and HFSE-depleted basalts with sloping REE profiles ($La_N/Yb_N = 2.8$) that are chemically intermediate between mid-ocean-ridge and island-arc tholeiites. Such compositions are typical of back-arc oceanic settings (Saunders and Tarney 1984).

By contrast, the pillow lavas of the Pointe Verte Formation are highly-evolved alkaline basalts and trachyandesites ($La_N/Yb_N = 6.7$) associated with minor trachyte flows (Pajari et al. 1977; Winchester and van Staal 1988; Flagler 1989), which may have been generated above a deep-seated mantle plume within the back-arc basin. Graptolites from black slate and conodonts from limestone pods within pillow lavas of the Pointe Verte Formation are late Llandeilian to early Caradocian in age (Fyffe 1986).

Geochemically similar rocks occur at the highest structural levels preserved in the northernmost part of the Miramichi Highlands of New Brunswick (Figs. 1, 3). These rocks include an upper suite of HFSE-depleted basalts with gently sloping REE profiles ($La_N/Yb_N = 1.9$) and a lower suite of mid-ocean-ridge-like tholeiites with flatter REE profiles ($La_N/Yb_N = 1.3$). They are underlain in the west by a suite of highly-evolved alkaline basalts. Each of these suites resembles basalts from the Elmtree-Belledune inlier, and are therefore assigned to the Fournier Group. Together they form the most easterly exposures in mainland Canada of mid-Ordovician back-arc basin ocean crust.

The Turgeon deposit, a Cyprus-type deposit in the Elmtree-Belledune inlier (Fig. 1), is described in a later section of this guidebook.

BACK-ARC ENSIALIC VOLCANICS

The Miramichi Highlands of New Brunswick are underlain by Lower to Middle Ordovician, bimodal volcanic suite, extending from Chaleur Bay in the northeast nearly to the Maine border in the southwest (Fig. 1). These volcanic rocks, together with associated feldspathic wackes and varicoloured slates, constitute the Tetagouche Group. Underlying quartz wackes and slates of the Miramichi Group (Potter 1969; van Staal and Fyffe, in press) have been interpreted as part of a clastic turbidite wedge deposited off the margin of Avalon (Schenk 1971; Helmstaedt 1971; Rast and Stringer 1974). Brachiopods in a thin unit of limestone at the top of the Miramichi Group are Arenigian (Early Ordovician) in age (Neuman 1984). Volcanic rocks of similar chemistry occur in the Pennington Mountain and Shin Pond belts of northern Maine (Hynes 1976). Sedimentary rocks equivalent to the Miramichi Group in Maine are known as the Grand Pitch Formation (Neuman 1984).

The lower portion of the felsic volcanic sequence in the Bathurst area of New Brunswick (Fig. 3) is dominated by greenschist-facies porphyritic flows containing abundant, large quartz and feldspar phenocrysts. A thin unit of chlorite schist and iron formation separates the coarsely porphyritic rocks from fine-grained, sparsely feldspar-phyric and aphyric felsic flows,

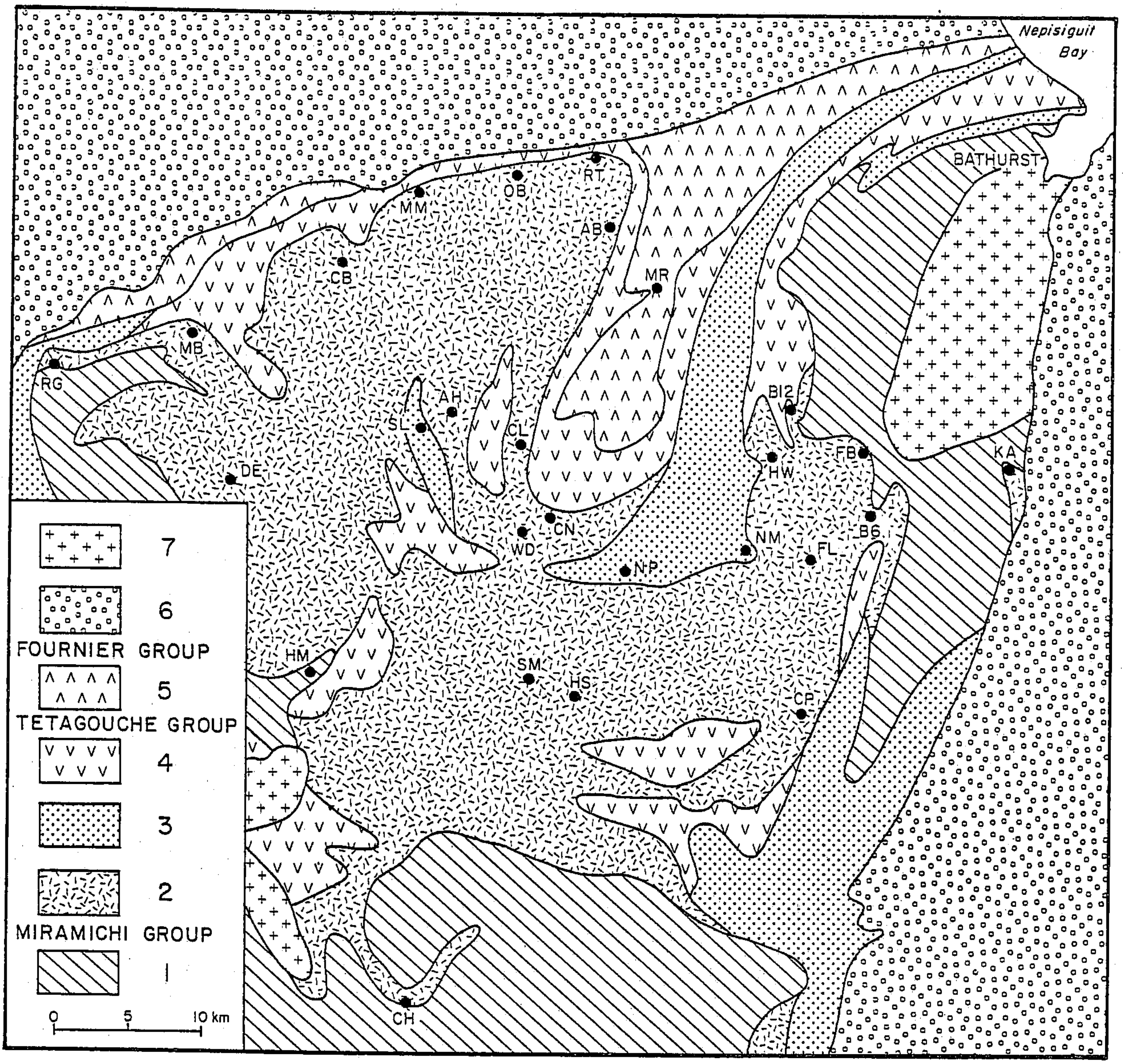

FIGURE 3. Geology of the Bathurst area showing location of massive sulphide deposits for which estimated reserves are available.

Map units: 1 = Cambro-Ordovician quartz wacke and slate; 2 = Ordovician porphyritic and aphyric felsic flows, pyroclastic and epiclastic rocks; 3 = Ordovician feldspathic wacke and varicoloured slates; 4 = Ordovician tholeiitic and alkalic basalts; 5 = Ordovician tholeiitic basalts, lithic wacke, limestone and slate - includes some alkali basalts in the west; 6 = Siluro-Devonian volcanic and sedimentary rocks in the north, Carboniferous sedimentary rocks in the east; 7 = Devonian granite. Sulphide deposits: AB = Armstrong Brook; AH = Ahearn Brook; B6 = Brunswick #6; B12 = Brunswick #12; CB = Caribou; CH = Chester; CN = Canoe Landing Lake; CP = Captain; DE = Devils Elbow; FB = Fab Metal Mines; FL = Flat Landing Brook; HS = Heath Steele; HM = Halfmile Lake; HW = Headway; KA = Key Anacon; MB = Murray Brook; MM = McMaster; MR = Middle River; NM = Nine Mile Brook; NP = Nepisiguit; OB = Orvan Brook; RG = Restigouche; RT = Rocky Turn; SL = Strachens Lake; SM = Stratmat; WD = Wedge.

and minor mafic volcanic rocks that form the upper part of the pile (Smith and Skinner 1958; Boyle and Davies 1964; Helmstaedt 1971; Skinner 1974). The felsic pile was extruded between the early Llanvirnian and early Llandeilian (472-466 Ma, U-Pb; van Staal and Fyffe, in press).

The felsic volcanic rocks of the Bathurst area range in composition from dacite to rhyolite with rhyolite being the most voluminous; andesites typical of volcanic-arc suites are virtually absent (Whitehead and Goodfellow 1978). The coarsely porphyritic felsic flows are highly LREE-enriched with a distinct negative Eu-anomaly (McCutcheon et al. 1989). Associated mafic volcanic rocks possess LREE-enriched profiles ($La_N/Yb_N = 3.5$) similar to continental tholeiites (Winchester and van Staal 1988).

A thick sequence of pillow lavas structurally overlies the felsic volcanic pile in the Bathurst area. This mafic sequence is divisible on the basis of HFSE ratios into a tholeiitic suite and an alkaline suite (Fig. 2d) (Whitehead and Goodfellow 1978; Winchester and van Staal 1988). The tholeiitic suite has chemical similarities with minor mafic volcanics associated with the underlying felsic pile, except that it is characterized by lower Zr/Y ratios and displays a less steeply sloping REE profile ($La_N/Yb_N = 2.3$). The alkaline suite is dominated by evolved alkali basalts, characterized by typically steeply sloping REE profiles ($La_N/Yb_N = 6.3$), with subordinate trachyandesites, trachytes, and comenditic lavas. This sequence is directly overlain by a blueschist-bearing high strain zone that separates the Tetagouche Group from previously described basalts of the Fournier Group (Fig. 3). Fossils from crystalline limestone and black slate together with a 457 Ma (U-Pb) date on associated trachyte indicate a Caradocian age for the alkaline suite (Skinner 1974; Kennedy et al. 1979; Riva and Malo 1988; van Staal and Fyffe, in press). The tholeiitic suite immediately underlies the alkaline suite and may be late Llandeilian in age.

The felsic volcanic rocks and structurally overlying basalts of the Tetagouche Group are interpreted as the volcanic products of rift-related magmatism generated along a continental margin during opening of a back-arc basin in the Ordovician, as both possess chemical compositional ranges consistent with such a model. The contemporary basaltic rocks of the Fournier Group in the thrust sheet overlying the blueschist-bearing zone are interpreted as a fragment of back-arc ocean floor that was transported southward over the continental rift-sequence during closure of this basin (van Staal 1987; Winchester and van Staal 1988).

Numerous massive sulphide deposits are present in the Tetagouche Group of the Bathurst area (Fig. 3). The geology of some of these are described later in this guidebook.

Middle Ordovician mafic and subordinate felsic volcanic rocks underlie the Pennington Mountain and Shin Pond areas of northeastern Maine (Fig. 1). Whole-rock and pyroxene analyses demonstrate that the mafic volcanics of the Winterville and Bluffer Pond formations in the Pennington Mountain belt possess an affinity to intraplate alkaline oceanic islands, whereas those of the Shin Pond Formation are tholeiitic (Hynes 1976). Unfortunately, the lack of trace-element data precludes assignment of these suites to a specific tectonic environment on geochemical criteria alone. Given the presence of island-arc volcanics to the west in the Stoke Mountain belt, to the southwest in the Bronson Hill belt, and to the southeast in New Brunswick (see above), it is tentatively concluded that the volcanic rocks of northeastern Maine were generated in an extensional environment associated with back-arc rifting.

A belt of Ordovician sedimentary and volcanic rocks, referred to as the Cookson Group, underlies the St. Croix Highlands in southwestern New Brunswick. The relationships of the Cookson Group to the Cambro-Ordovician succession in the Miramichi Highlands to the northwest and to Precambrian Avalonian rocks to the southeast are obscured by intervening Silurian rocks. Pillow lavas interbedded with Tremadocian black shales at the base of the Cookson Group are evolved, mildly LREE-enriched, within-plate tholeiitic basalts (La_N/Yb_N = 1.3) that may have formed by rifting of continental crust in the Early Ordovician (Fig. 2e) (Fyffe et al. 1988b; Thomas and Willis 1989; Whalen et al. 1989). No geochemical data are available from mid-Ordovician mafic tuffs in the upper part of the Cookson Group - these tuffs locally host narrow stratiform lenses that assay 2 to 7% Cu (Ruitenberg 1970).

A large volcanogenic sulphide deposit was discovered in the Pennington Mountain belt of Maine in 1977. At Bald Mountain (Fig. 1), the Winterville Formation contains a northeast-trending, ovoid-shaped sulphide body that is separated into a main zone and much smaller western zone by a north-northwest-trending fault. In surface plan, the long and short dimensions of the main zone are approximately 350 and 250 m, respectively. The massive sulphides bottom out at a depth of 250 m and are underlain by a chloritic stringer zone containing veins of chalcopyrite and pyrite. Fragmental felsic volcanic rocks immediately underlie the stringer zone, and a locally preserved hematitic chert caps the massive sulphides to the southwest. Extensive thicknesses of mafic volcanic rocks both underlie and overlie the local deposit sequence (Josey 1981; Cummings 1988).

The main massive sulphide body is divisible into a lower dominately pyrrhotite-chalcopyrite zone and an upper dominately pyrite-sphalerite zone. In plan view, this mineral zoning is reflected in Cu/Zn ratios that can be used to outline tight, southwest-plunging folds in the massive sulphides (Cummings 1988). The deposit is estimated to contain 32 million tonnes of 1.5% Cu and 2.5% Zn (Josey 1981).

A massive sulphide deposit was discovered within volcanic rocks of the Shin Pond Formation of Maine in 1979. The southeast-facing sulphide-bearing sequence at Mount Chase (Fig. 1) comprises from oldest to youngest: (1) quartz-feldspar crystal tuff; (2) flow-banded rhyolite; (3) lapilli tuff and tuffaceous breccia; (4) stratiform massive sulphides in two laterally-adjacent lenses; (5) crystal-lithic tuff; (6) mafic volcanic flows; (7) purple and green slate; and (8) black and grey slate. The sulphide horizon is up to 15 m thick and contains a high grade, banded sphalerite-galena-chalcopyrite zone in the lower part, and a low grade, massive pyrite zone in the upper part. Local disruption of the banding suggests that some slumping took place during sulphide deposition. The high grade zone is estimated to contain three million tonnes of 10.2% Zn, 4.5% Pb, and 1.3% Cu. Disseminated and stringer mineralization with up to 30% pyrite and chalcopyrite is associated with a narrow chloritic and broader sericitic alteration zone beneath the massive sulphides (Scully 1988).

AVALONIAN MAGMATIC-ARC VOLCANICS

Late Precambrian volcanic and associated plutonic rocks, extending along the eastern seaboard of North America from the Avalon Peninsula in Newfoundland to Florida, define the southeastern margin of the Appalachian oceanic tract (Rast et al. 1976; Rast and Skehan 1983; O'Brien et al. 1983). Avalonian volcanic rocks underlying the Caledonian Highlands along the Fundy coast of New Brunswick (Fig. 1), traditionally included in the Coldbrook Group (Matthew 1863), have recently been separated into two broad divisions (Giles and Ruitenberg 1977; Currie 1986, 1988; McLeod 1986; Barr and White 1988). The lower division contains felsic, intermediate and mafic tuffs, pillow lavas, laminated green siltstone, and arkosic sandstone and conglomerate. The upper division comprises rhyolite porphyry flows, welded tuffs, vesicular basalts, and red siltstone and tuffaceous sandstone. The volcanic and plutonic rocks range in age from Late Proterozoic to Early Cambrian (625-548 Ma U-Pb) (Watters 1987; Currie 1988; Bevier 1988; 1989) and are, therefore, in part contemporaneous with the rift-related volcanics of the Tibbit Hill Formation on the Laurentian craton.

Basalts of the lower division are LREE-enriched (La_N/Yb_N = 5.8), and calc-alkaline on the basis of their iron to magnesium, and HFSE ratios (Fig. 2f). Basalts of the upper division are tholeiitic and transitional in character between subduction- and rift-related volcanics (Strong et al. 1979; Dostal and Strong 1983; McLeod 1986; Currie 1988; Barr and White 1988).

The stratiform Teahan deposit in the northeastern Caledonian Highlands is hosted by intermediate tuffs of the Coldbrook Group (Fig. 1). The sulphide-bearing zone varies from 2 to 10 m thick, dips about 50° to the northwest, and has been traced along strike for about 650 m. The mineralization consists of brecciated pyrite, chalcopyrite, sphalerite, and minor galena in a carbonate-quartz-talc gangue. Assays yield about one percent combined zinc and copper (Ruitenberg et al. 1979).

CONCLUSIONS

The temporal and spatial variations in volcanic geochemistry summarized in the previous sections provide vital information on the plate tectonic processes that controlled the tectonic evolution of the mainland Canadian Appalachians. The calc-alkaline volcanics of the Caledonian Highlands, primitive oceanic-arc volcanics of the Eastern Townships, and within-plate volcanics of the Miramichi Highlands can be related to a progressive change in mode of subduction from compressional Andean-type in the Late Proterozoic to extensional Western Pacific-type in the Early Paleozoic (cf. Dewey 1980). A proposed model to explain this change in plate configuration is illustrated in Figure 4. This model follows Williams (1964) in that it places Laurentia and Avalon on opposing margins of a Late Precambrian ocean. An alternative model by Murphy and Nance (1989) emplaces Avalon opposite Laurentia by transcurrent motion in the Paleozoic. Both models are consistent with the change from compressional to extensional plate convergence.

An extensive ocean is assumed to have existed in the Late Proterozoic (Fig. 4a) to account for the development of distinctive Cambrian fauna on the Laurentian and Avalon continental margins (Wilson 1966). Isotopic evidences indicate the presence of a separate continental block, referred to as Miramichia (after Rodgers 1971) within this ocean (Whalen et al. 1989). By the Cambrian, subduction of oceanic crust had shifted from a continental margin to intra-oceanic setting following collision of Miramichia with Avalon (Fig. 4b). Early Ordovician obduction of fore-arc oceanic crust was caused by collision of the Laurentian craton and intra-oceanic island arc. Following this obduction event, back-arc oceanic crust and associated volcanic rocks were generated within Miramichia (Fig. 4c).

The development of marginal oceanic basins in the Paleozoic would have created a more favourable environment for volcanogenic sulphide deposition, particularly in back-arc areas (cf. Uyeda 1983). This influence of tectonic setting is reflected in the regional distribution, size, and metal ratios of stratiform sulphide deposits (Fig. 1). Deposits hosted by the Cambrian to Early Ordovician island-arc volcanics in the Eastern Townships typically contain about two million tonnes averaging 2.2% Cu, 4.0% Zn, and 0.6% Pb (Sauvé et al. 1972), whereas the more numerous deposits hosted by the Early to Middle Ordovician back-arc volcanics of the Bathurst area average nine million tonnes grading 0.6% Cu, 5.4% Zn, and 2.2% Pb (Lydon 1984).

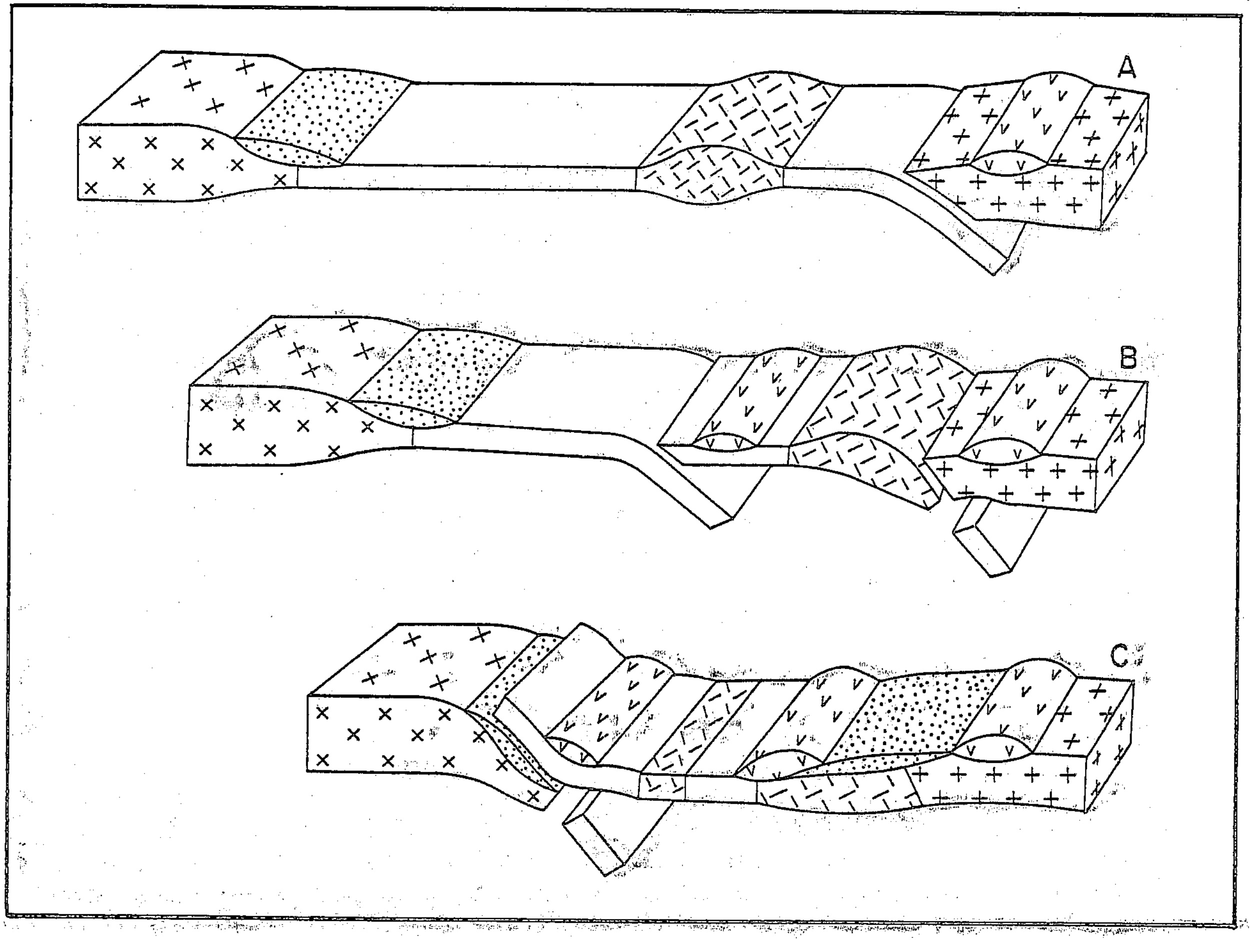

FIGURE 4. Schematic diagram illustrating proposed plate tectonic model for area shown in Figure 1. Transcurrent displacement of unknown extent presumably accompanied the collisional events.

Legend: crosses = Laurentia, pluses = Avalon, dashes = Miramichia, chevrons = volcanic arcs, dots = clastic sedimentary wedges, plain = oceanic crust. See text for explanation.

GEOLOGY OF ORDOVICIAN MASSIVE SULPHIDE DEPOSITS AND THEIR HOST ROCKS IN NORTHERN NEW BRUNSWICK

C.R. van Staal and J.P. Langton

GEOLOGICAL SETTING OF NORTHERN NEW BRUNSWICK

New Brunswick forms part of the northern Appalachians (Fig. 1) and comprises three of the five tectonostratigraphic zones recognized in this part of the orogen (Williams 1979). These are, from south to north respectively, the Avalon, Gander, and Dunnage zones, which are mainly defined on their pre-Silurian geology. The Gander and Dunnage zones are commonly combined into the Central Mobile Belt and are generally thought to represent respectively the vestiges of a Lower Paleozoic west facing, passive margin and an oceanic (Iapetus 1) or back-arc basin (Iapetus 2) (Williams 1979; van Staal 1987).

ORDOVICIAN TECTONOSTRATIGRAPHIC FRAMEWORK OF NORTHERN NEW BRUNSWICK

The Miramichi Highlands and the Elmtree-Belledune Inlier (Fig. 5) are the principal areas where Cambro-Ordovician rocks of the Gander and Dunnage zones are exposed in northern New Brunswick.

The Cambro-Ordovician rocks in these areas have been separated into four groups: (1) the Miramichi Group; (2) the Tetagouche Group; (3) the Fournier Group; and (4) the Balmoral Group. The Balmoral Group, which consists of Middle Ordovician andesitic and picritic volcanics and Caradocian black shale occurs in the Popelogan Inlier to the northwest of the Miramichi Highlands (Philpott 1988) and is not treated here. The Miramichi Group (Fig. 5) comprises a monotonous sequence of quartz wacke and pelite of unknown thickness. Pelite becomes more abundant and graphitic towards the stratigraphic top, which is defined by the contact with the disconformably overlying volcanic and sedimentary rocks of the Tetagouche Group. The Miramichi Group is Arenigian and older (Fyffe et al. 1983) and defines the Gander Zone in northern New Brunswick.

The Tetagouche Group mainly consists of a voluminous bimodal suite of Middle Ordovician mafic and felsic volcanic rocks (Fig. 5). Felsic volcanic rocks dominate and have compositions that range from dacite to rhyolite (Whitehead and Goodfellow 1978; Winchester and van Staal 1988). The felsic volcanic rocks comprise a heterogeneous mixture of flows, shallow intrusions (e.g., porphyries), pyroclastic, and proximal epiclastic deposits (van Staal 1987). For mapping purposes, these rocks are generally divided into aphyric or feldspar-phyric rhyolite of the Flat Landing Brook Formation, and quartz- and feldspar-phyric flows, pyroclastic and proximal epiclastic rocks of the Nepisiguit Falls Formation (cf., Skinner 1974). Field,

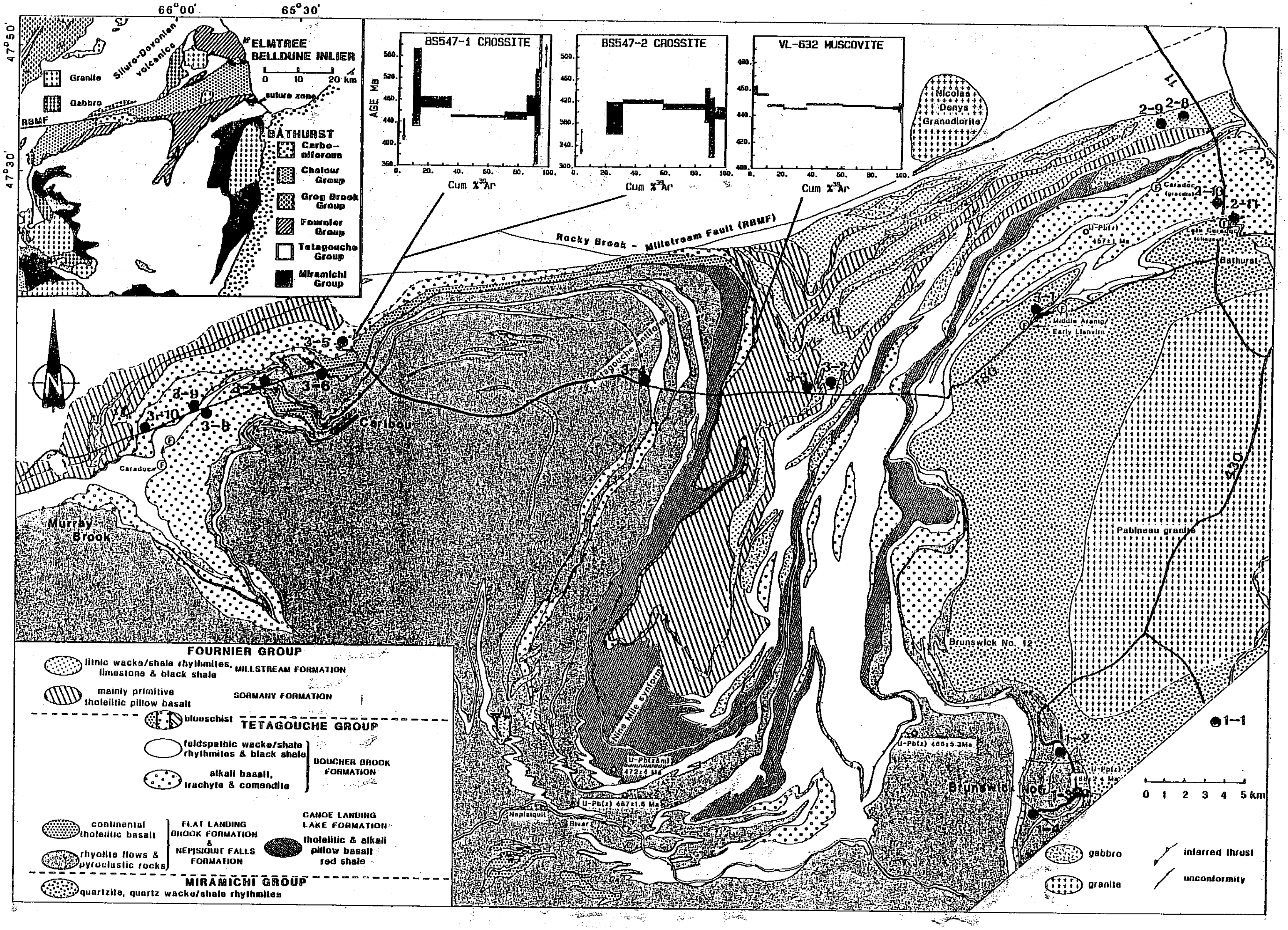

FIGURE 5. Simplified geology of the northern Miramichi Highlands with road tours.

geochemical, and petrographic studies have indicated that a large part of the felsic volcanics previously interpreted as ash flows represent rhyolite flows (van Staal 1987; McCutcheon et al. 1989). The large areal extent of the rhyolite flows indicates that the felsic magma was relatively fluid, probably because it was dry and hot.

The felsic volcanic rocks are locally interbedded with thin, but generally laterally extensive bodies of iron formation, jasper, and a multicoloured (red, purple, green, and black) Fe-Mn-rich phyllite. These metalliferous sediments are closely associated with most of the major base metal Zn-Pb-Cu-Ag massive sulphide deposits in northern New Brunswick. Locally, the felsic volcanics are also interbedded with minor bodies of tholeiitic basalt that are enriched in light rare-earth-elements indicative of a continental within-plate setting. These basalt bodies mainly represent massive flows, sills and pyroclastic tuffs, breccias and agglomerates. Pillows common in all other basalt suites in the northern Miramichi Highlands are rare or absent, suggesting a subaerial environment of deposition for at least part of these rocks. However, a shallow water environment of deposition is indicated by fossils and sedimentary structures for most of the associated iron formation and epiclastic, tuffaceous sediments. These include stromatolites and ooids in carbonate facies iron formation (McMillan 1969; van Staal 1987) and brachiopods and pelecypods in shaly sediments (Bolton 1968; Fyffe 1976; Gummer et al. 1978; Neuman 1984). Probably part of the volcanic complex was emerged or experienced differential uplift during a part of the volcanic history. Of interest are the rare pelecypods that have been found only in tuffaceous and/or epiclastic sediments that host the Devils Elbow (Bolton 1968) and Taylor Brook (Gummer et al. 1978) massive sulphide deposits. Analogous to the faunas found around hydrothermal vents on the seafloor, these pelecypods may represent fossilized Ordovician vent faunas.

U-Pb zircon ages of the felsic volcanics range from 472 to 466 Ma (Sullivan and van Staal 1989), but cluster around 468 Ma. In the northeastern part of the northern Miramichi Highlands, the felsic volcanic rocks are conformably underlain by a thin unit of shallow-water sandy or conglomeratic limestone and/or a calcareous phyllite (Fyffe 1976, 1981) referred to as the Vallée Lourdes Formation (van Staal et al. 1988b). Brachiopods and conodonts indicate a middle Arenigian to early Llanvirnian age for this formation. These ages suggest that the formations containing the felsic volcanic and minor interbedded sedimentary rocks are mainly Llanvirnian in age. The Vallée Lourdes Formation defines the base of the Tetagouche Group and can be seen to lie disconformably on top of the Miramichi Group during low water levels in the Tetagouche River, east of Tetagouche Falls, 12 km west of the city of Bathurst. The disconformity is marked by a thin bed of conglomerate, which contains quartzite and shale pebbles of the underlying Miramichi Group. This conglomerate is interpreted to mark a bulging disconformity that formed as a result of back-arc rifting during the middle to late Arenigian.

The Flat Landing Brook and Nepisiguit Falls formations are conformably overlain by the Boucher Brook Formation (Fig. 5), which comprises thin-bedded feldspathic wacke/shale rhythmites, black shale and a chemically distinct (low-Cr) alkali basalt with minor trachyandesite, trachyte, and comendite. The Boucher Brook Formation ranges in age from the Llandeilian to latest Caradocian on the basis of several fossil localities and U-Pb zircon ages of the volcanics (Nowlan 1981; Riva and Malo 1988; van Staal et al. 1988a; Sullivan and van Staal 1989). The Elmtree Formation in the Elmtree-Belledune Inlier contains lithologically and chemically similar rocks as the Boucher Brook Formation (Fig. 6).

The Flat Landing Brook-Boucher Brook package is structurally overlain by another volcanic unit-Boucher Brook package (Fig. 5). The volcanic unit mainly consists of tholeiitic and minor alkali pillow basalts of the Canoe Landing Lake Formation, which are also Llanvirnian in age (van Staal and Sullivan, unpublished report). The presence of interbedded red Fe-Mn-rich phyllites supports the age dating. Since old overlies young, the contact between these two packages is interpreted as a major thrust, marked by the presence of a narrow zone of phyllonite (van Staal 1986). Each of these two tectonostratigraphic packages is internally imbricated (Fig. 5) and the thrust zones are marked by cut-offs and, where exposed, by zones of phyllonite or mylonite.

The Tetagouche Group is structurally overlain by the Fournier Group, which consists of the Sormany and Millstream formations in the northern Miramichi Highlands (Fig. 5). The Sormany Formation consists of pillow basalts and minor gabbro. The basalts are mainly primitive tholeiites with MORB-like compositions, but also show compositions intermediate between MORB and IAT. These basalts are chemically and lithologically equivalent to part of the ophiolitic Devereaux Formation (Pajari et al. 1977) in the Elmtree-Belledune Inlier. Therefore, this part of the Sormany Formation is also interpreted as a fragment of back-arc oceanic crust. A U-Pb zircon age of 463±1 Ma for a pegmatitic gabbro pod in the gabbroic part of the Devereaux Formation (Sullivan et al. 1989) indicates that formation of oceanic crust was slightly later than eruption of the majority of the rift volcanics and supports the back-arc setting proposed by van Staal (1987). The Millstream Formation consists of lithic wacke/shale rhythmites, minor conglomerate, arkose or feldspathic wacke, limestone, high-Cr alkali basalt, and black shale. Lithologically equivalent rocks are present in the Pointe Verte Formation of the Elmtree-Belledune Inlier, which ranges in age from middle/late Arenigian to early Caradocian (Nowlan 1983, 1988a; Riva in Fyffe 1986).

The Devereaux and Pointe Verte formations define the

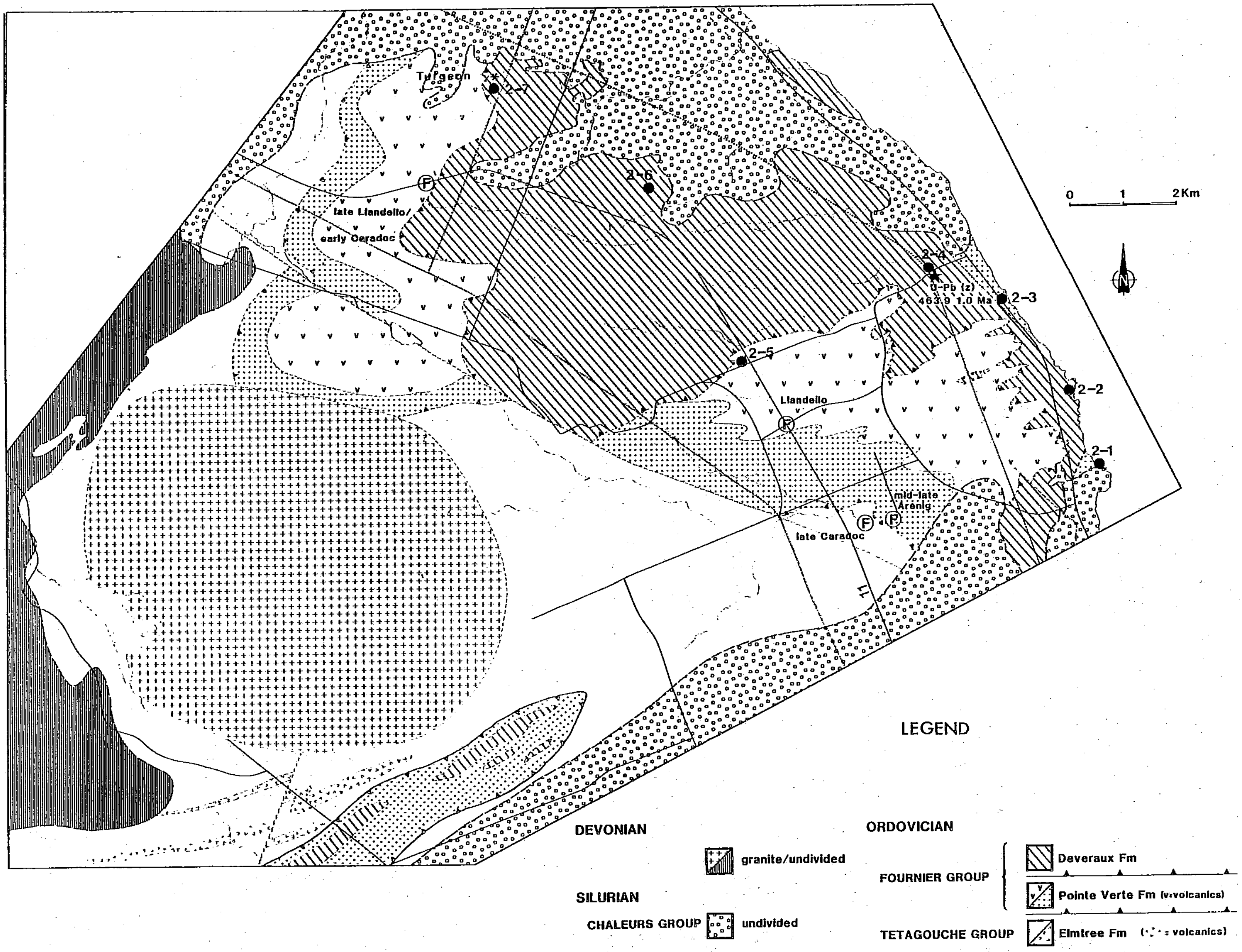

FIGURE 6. Geology of the Elmtree-Belledune Inlier.

Fournier Group in the Elmtree-Belledune Inlier (Fig. 6). The contact between these two rock formations is a thrust since the Devereaux Formation is older than the underlying, early Caradocian part of the Pointe Verte Formation. A narrow zone of amphibole-chlorite phyllonite marks the thrust in the field. The contact between the Pointe Verte Formation and the structurally underlying Elmtree Formation of the Tetagouche Group in the Elmtree-Belledune Inlier is also interpreted as a thrust. The contact between these two units is marked by a narrow zone of phyllonite and mélange exposed in the Elmtree River where it separates late Caradocian black shales of the Elmtree Formation (Dean 1975) from structurally overlying middle to late Arenigian limestone (Nowlan 1988a) of the Pointe Verte Formation.

The contact between the Fournier and Tetagouche groups is a major thrust zone along its entire length (Figs. 5, 6) and can be traced from the Miramichi Highlands into the Elmtree-Belledune Inlier with an apparent dextral offset along the Rocky Brook-Millstream Fault (RBMF). Noteworthy is an extensive belt of sodic amphibole-bearing blueschists, unparalleled in the Appalachian/Caledonian orogen, that defines this contact for at least 70 km in the northern Miramichi Highlands, which suggests that this contact marks a suture.

STRUCTURE AND TECTONICS

The Ordovician rocks in northern New Brunswick experienced a complex polyphase folding and faulting history (van Staal and Williams 1984; van Staal 1987). At least five generations of folds have been demonstrated on the basis of overprinting relationships. The earliest structures comprise a strong layering parallel foliation (S_1), asymmetrical intrafolial folds (F_1), and a stretching lineation (L_1). The D_1 structures are typically concentrated in narrow zones of high strain, which commonly coincide with repetitions in stratigraphy. The D_1 structures are interpreted as a result of a progressive deformation associated with thrusting. The D_1 deformation is markedly heterogeneous on all scales and consequently the amount of strain recorded in the rocks as well as the spectrum of structures present varies from place to place. The narrow zones of rocks affected by D_1 are strongly altered and transformed into phyllonites or mylonites. This reaction and fabric softening of the rocks localizes the subsequent increments of the polyphase deformation history and enhances the heterogeneous distribution of the strain.

The D_1 structures are refolded by F_2 into tight to isoclinal folds (van Staal and Williams 1984) that define flat and steep belts (van Staal 1987). The coherency of the D_1 tectonostratigraphy was retained after F_2 folding in the northernmost part of the Miramichi Highlands (Fig. 5) suggesting that the F_2 enveloping surface makes a small angle with the orientation of S_1 in this part of the area. This feature and several other criteria suggest that this part of the Miramichi Highlands lies on the northern limb of a regional scale F_2 antiform cored by the felsic volcanics. The F_2 structures are refolded by open recumbent F_3 folds, which tend to be symmetrical and restricted to outcrop scale (de Roo et al. 1990) indicating a small degree of vertical shortening. The D_1, F_2, and F_3 structures are overprinted and refolded by F_4 and F_5 folds and kinks which range in size from millimetre to kilometre scale. The Pabineau structures (van Staal and Williams 1984) are F_4 folds, whereas the Nine Mile synform and Tetagouche antiform (Fig. 5) are F_5 structures (van Staal 1986, 1987). The steep northerly plunge (60-70°) of these structures created a large amount of structural relief in the core of the Nine Mile synform. Based on a lack of overprinting relationships, F_3 was previously thought to represent F_5 (van Staal and Williams 1984). As a consequence of recent work (de Roo et al. 1990), the nomenclature has changed and F_3 and F_4 have become F_4 and F_5, respectively. F_4 and F_5 are interpreted as a result of dextral transpression that culminated in a large dextral offset along the Rocky Brook-Millstream Fault (van Staal and Langton 1988). A minimum displacement of 20 km is indicated by the offset of Siluro-Devonian gabbros and a displacement of approximately 50 km, is suggested by the offset of the Fournier/Tetagouche Group suture.

Early plate tectonic models suggested that the Tetagouche rocks represented the remnants of the Taconic arc formed above an eastward-dipping subduction zone (e.g., Pajari et al. 1977). Chemical compositions of volcanic rocks of the Tetagouche Group (see above) do not correspond with a magmatic arc setting, but instead closely resemble volcanics found in an ensialic rifting environment (van Staal 1987; Winchester and van Staal 1988). Van Staal (1987), therefore, proposed that the bulk of the volcanic rocks of the Tetagouche Group formed in a Taconic back-arc basin that started to open in middle to late Arenigian times. The Devereaux and Sormany formations of the Fournier Group represent back-arc basin oceanic crust. This hypotheses was tested by age dating, which showed that the oceanic crust is slightly younger than the rifting suite of the Tetagouche Group (see above), and thus is consistent with the back-arc basin model. Restoration of seismically defined lower crustal blocks to a precollisional configuration also supports the presence of a wide back-arc basin (Stockmal et al. 1990).

The back-arc basin (Iapetus 2; van der Pluijm and van Staal 1988) started to close in Late Ordovician times by northward-directed subduction (van Staal 1987), which lasted at least until Late Silurian times. This time period is constrained by (1) Ar^{39}/Ar^{40} age dating of crossite and phengite from the blueschist belt (Fig. 5), which yielded ages ranging from 450 to 410 Ma (Ravenhurst et al. 1990); (2) the youngest rocks of the Tetagouche Group involved in the D_1 thrusting are late Caradocian in age (Riva and Malo 1988); and (3) the blueschist belt is unconformably overlain by Late Silurian (Ludlovian) conglomerates of the Chaleurs Group (Helmstaedt 1971). Within this tectonic scenario, D_1 and M_1 are seen as the products of the subduction-related deformation and metamorphism. Post-D_1 ductile deformation resulted mainly from the oblique collision between North America (with the accreted Taconic arc) and Avalonia.

MASSIVE SULPHIDE DEPOSITS

The Tetagouche Group in the northern Miramichi Highlands is characterized by an anomalous abundance of base metal-rich massive sulphide deposits. Over 30 mineral deposits are known (Davies 1979). At present, ore is produce from the Brunswick No. 12 and Heath Steele mines. The Brunswick No. 6, Wedge, and Caribou deposits have been mined in the past for base metals. Economical gold and silver concentrations in the gossans overlying the massive sulphides have been mined in the Caribou and Heath Steele mines and are at present extracted from the voluminous gossan of the Murray Brook deposit (Fig. 5). The large iron formation in the hanging wall of the Austin Brook deposit (Fig. 7) was mined for iron in the beginning of this century (Boyle and Davies 1964).

The massive sulphide deposits of the Tetagouche Group are invariably closely associated with the felsic volcanic and epiclastic rocks of the Nepisiguit Falls and Flat Landing Brook formations. At least two, and possibly three sets of deposits can be recognized (van Staal and Williams 1984; van Staal 1986). The first set of deposits, what is referred to as the Brunswick-type, forms an integral part of a laterally extensive Algoma-type iron formation (McAllister 1960; Gross 1967; Davies 1972). Included in this set are the Brunswick No. 12 (Luff 1975), No. 6 (Boyle and Davies 1964), Austin Brook (Boyle and Davies 1964; Davies 1972), Flat Landing Brook (Troop 1984), Key Anacon (Saif et al. 1978), and Heath Steele deposits. The Brunswick-type generally occurs along or close to the contact between the Miramichi Group and the Nepisiguit Falls Formation of the Tetagouche Group. Since rocks of the latter formation have a U-Pb age of 468 Ma, these deposits formed in Llanvirnian times, during the earliest stages of felsic volcanism.

The second set of massive sulphide deposits, the Caribou-type, is generally hosted by feldspathic wackes and phyllites of the Boucher Brook Formation or occurs at the contact with the underlying felsic volcanics of the Flat Landing Brook or Nepisiguit Falls Formation (McAllister 1960; Helmstaedt 1973; van Staal 1986). The Caribou-type thus seems to occur at a higher stratigraphic level than the Brunswick-type near the end stages of felsic volcanism. This set includes the Nepisiguit A, B, C, Nine Mile Brook, Canoe Landing Lake, Orvan Brook, Murray Brook, and the Caribou deposits (Fig. 5). The Caribou-type does not contain a laterally extensive Algoma-type iron formation, although it is generally associated with a red, relatively Fe-Mn-rich shaly and cherty phyllite that approximately occupies

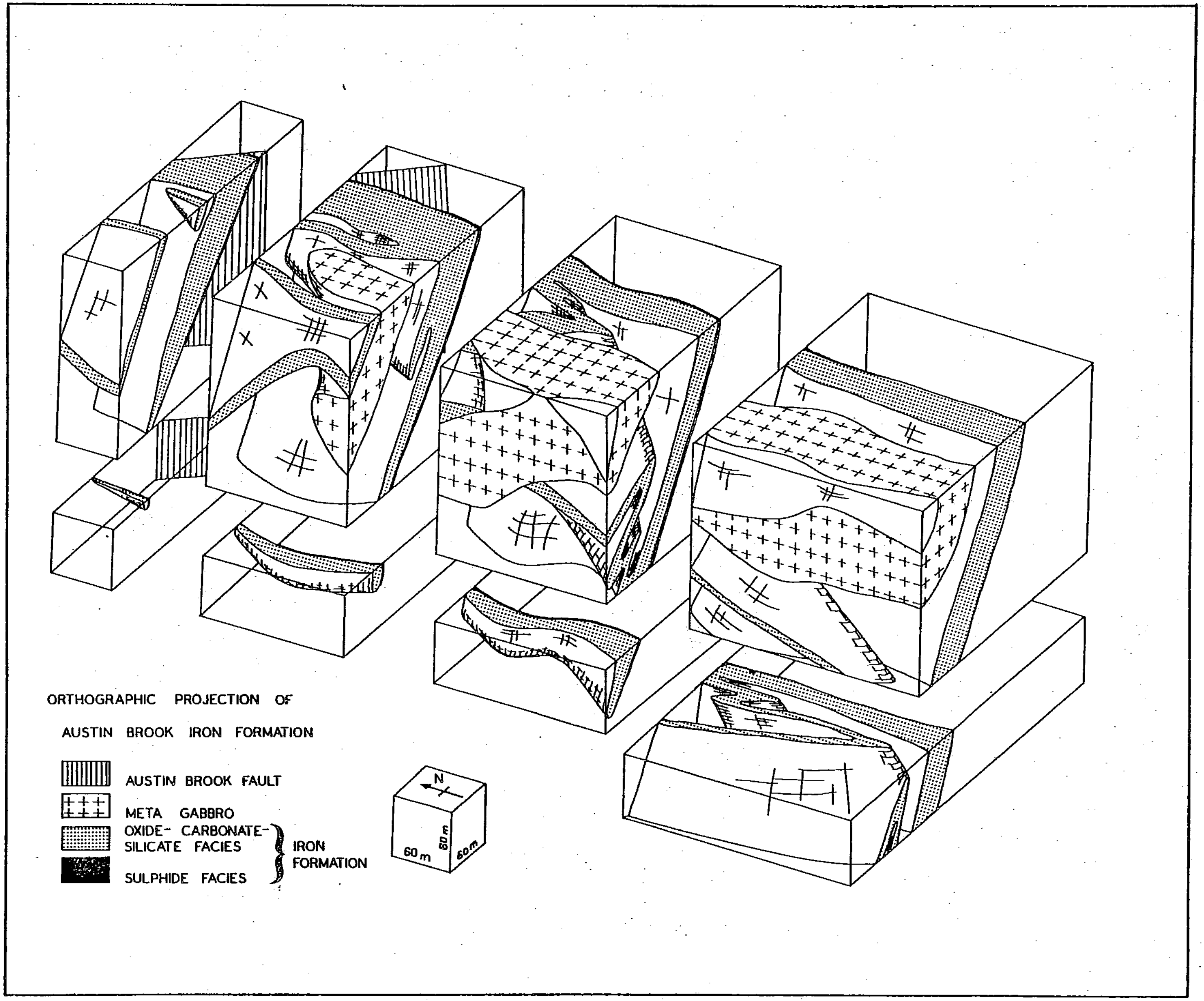

FIGURE 7. Block diagram of the Austin Brook iron formation body.

the same stratigraphic position as the sulphides distal from the massive sulphide deposits (van Staal 1986). However, the sulphides and the red phyllite have not been found in contact or in close proximity with one another.

This twofold division is supported by as yet unpublished (but referred to in Swinden and Thorpe 1984) lead isotope data, which show that the Brunswick-type galenas have slightly lower $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios than the galenas of the Caribou-type. This division is also consistent with sulphur isotope patterns (Lusk 1972).

A tentative third set of massive sulphide deposits, the Halfmile Lake-type, is hosted by silty and shaly phyllites occurring at the contact between the Miramichi Group and the overlying Tetagouche Group. This set includes small deposits such as the Halfmile Lake, Chester (Harley 1979; Jambor 1979), and the FAB (van Staal and Williams 1984). Their overall stratigraphic position thus appears to be slightly lower than the Brunswick-type, although locally the latter is also in contact with the Miramichi Group. However, the Halfmile Lake-type deposits have no associated iron formation-like metalliferous sediments and we, therefore, tentatively treat them as a separate type.

The three types of deposits range in size from small showings to supergiants, such as the Brunswick No. 12 deposit (Whiteway 1989), and consist of concordant massive and disseminated bodies of pyrite, sphalerite, galena, chalcopyrite, magnetite, and, in places, pyrrhotite. Several other sulphides, particularly arsenopyrite, sulphosalts, and oxides occur in minor amounts.

The sulphide deposits generally display a large scale mineralogical and chemical zonation, as well as a small scale compositional layering or banding (Boyle and Davies 1964; Rutledge 1972; Luff 1977; Jambor 1979). The zonation is best developed in the Brunswick-type, which exhibits variation perpendicular and parallel to strike. The lateral zonation in the Brunswick-type is defined by a gradual change from massive sulphide into iron formation (Boyle and Davies 1964; Luff 1975; Troop 1984; van Staal 1985), such that there is locally a mixed sulphide-iron formation body. In the Caribou deposit (Fig. 5) lateral zoning is illustrated by a decrease in magnetite, chalcopyrite, and Zn, Pb, Ag from the west limb of the Caribou fold, around the nose to the east limb (Jambor 1979). The vertical zonation in the Brunswick-type sulphide deposits is ideally made up of four zones (Rutledge 1972; Luff 1977; van Staal and Williams 1984). These are: (1) a massive or crudely layered pyrite body with variable amounts of pyrrhotite, magnetite, and chalcopyrite at the footwall; (2) a zone of well layered (centimetre-millimetre scale) pyrite, sphalerite, and galena with minor chalcopyrite and pyrrhotite; (3) a massive pyrite body with thin discontinuous layers or lenses of sphalerite and galena; and (4) iron formation. Thus, there is a decrease in the Cu-content between zone 1 and 3 and an apparent enrichment of Zn and Pb in zones 2 and 3. This zonation is best developed in the Brunswick No. 6 and No. 12 and parts of the Heath Steele orebodies. The principles of this zonation are also present in the Austin Brook deposit (Fig. 7), although the sulphide section is condensed here (van Staal 1985). A decrease in Cu-Pb+Zn from stratigraphic footwall to hanging wall has also been observed in the Caribou and Halfmile Lake deposit (Jambor 1979).

Although the sulphide zonation is not always continuous, due to primary lateral impersistence of the zones and complications induced during deformation, it is interpreted as a pre-deformational feature (van Staal and Williams 1984) that can be used as a younging indicator (cf., Large 1977). For example, the metal zonation in the Halfmile Lake deposit indicates that the orebody is tectonically inverted. Another type of zonation is displayed by the Brunswick-type iron formation on a regional scale. For instance, the part of the iron formation that is continuous between the Austin Brook deposit and the Brunswick No. 12 mine changes respectively from an oxide iron formation consisting dominantly of banded hematite, magnetite, and jasper to a carbonate and/or silicate iron formation.

A chlorite phyllite with variable amounts of disseminated pyrite-pyrrhotite-chalcopyrite (>0.5% Cu) typifies the footwall of the Halfmile Lake-type, whereas the footwall of the Brunswick-type deposits generally comprise chlorite and/or sericite-chlorite schists, which locally contain relict quartz phenocrysts. The chlorite in the footwall of the Brunswick-type is typically iron-rich (Davies 1972; Juras 1981; van Staal 1985), while pyrite, pyrrhotite, magnetite, and apatite are locally important accessory minerals. These rocks represent, at least in part, altered and metamorphosed tuffites, but probably also contain a chemical component, sometimes referred to as the footwall iron formation (Jambor 1979; van Staal and Williams 1984). However, both the Brunswick No. 6 and No. 12, as well as the Heath Steele deposits, are locally in direct contact with phyllites of the Miramichi Group (Luff 1977; van Staal 1985; Moreton and Williams 1986), suggesting that these sulphide bodies form an integral part of the Nepisiguit Falls Formation. They appear to be conformably overlain by aphyric or feldspar phyric rhyolite and rhyolite lapilli or ash tuffs of the Flat Landing Brook Formation, although a very Mg-rich chlorite phyllite layer overlies the iron formation in the hanging wall of the Brunswick No. 12 deposit (van Staal 1985). Preserved fine-scale bedding or laminations, but no other sedimentary structures, in low strain zones and some quartz phenoclasts suggest that the protolith of this phyllite was deposited under relatively quiescent conditions, probably having a tuffaceous or epiclastic component. Mg-rich chlorites were also observed in the hanging wall rather than the footwall of the Caribou deposit by Jambor (1979).

The Cu-pyrite Turgeon deposit is the only known sulphide body of significance in the Fournier Group of the Elmtree-Belledune Inlier. A small Cu-pyrite occurrence (Middle River) in the northern Miramichi Highlands also occurs in the Fournier Group. The Turgeon deposit, located near Belledune approximately 30 km northwest of Bathurst (Fig. 6), is hosted by massive to pillowed tholeiitic basalt flows that are interbedded with jasper and wacke/shale rhythmites (Fig. 8). Close to the sulphide mineralization, the mafic volcanic rocks are silicified, chloritized, and locally brecciated (Kettles 1987). Most of the sulphide mineralization (pyrite, pyrrhotite, chalcopyrite, and sphalerite) occurs in stringer-type or disseminated bodies. Massive Zn-Pb-Cu pyrite lenses or pods comprise a smaller fraction of the sulphide mineralization (Fyffe et al. 1990). The sulphide zones plunge steeply to the southeast and crosscut the relatively shallow, east-dipping volcanic sequence that hosts the sulphide mineralization (Fig. 9). These crosscutting zones possibly represent old fractures that channelized metal-bearing fluids during ocean floor-related hydrothermal activity.

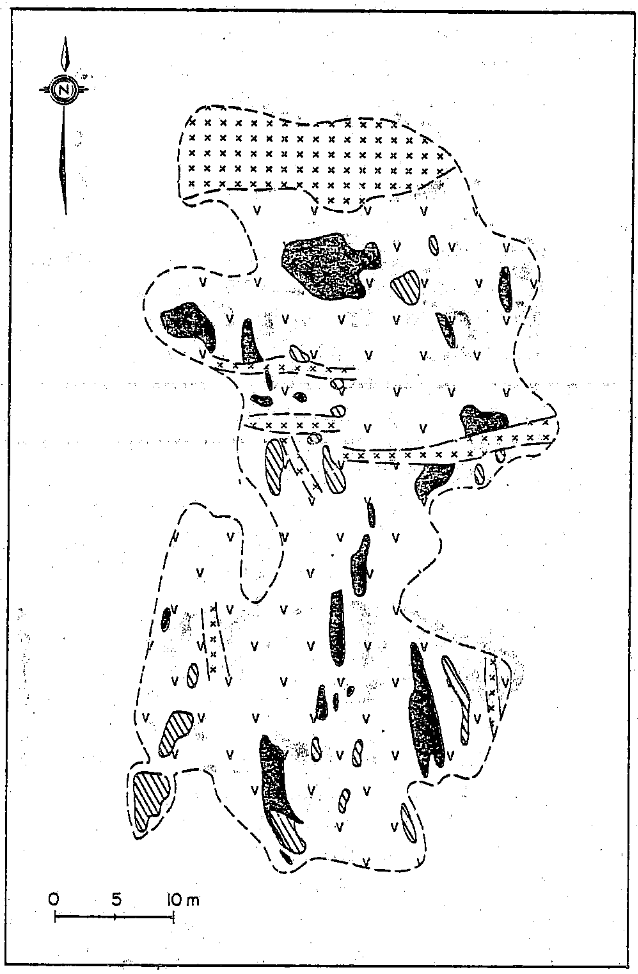

FIGURE 8. Geology at northern end of Turgeon deposit. Dotted pattern outlines limit of overburden stripping (after Kettles 1987). See Figure 9 for legend.

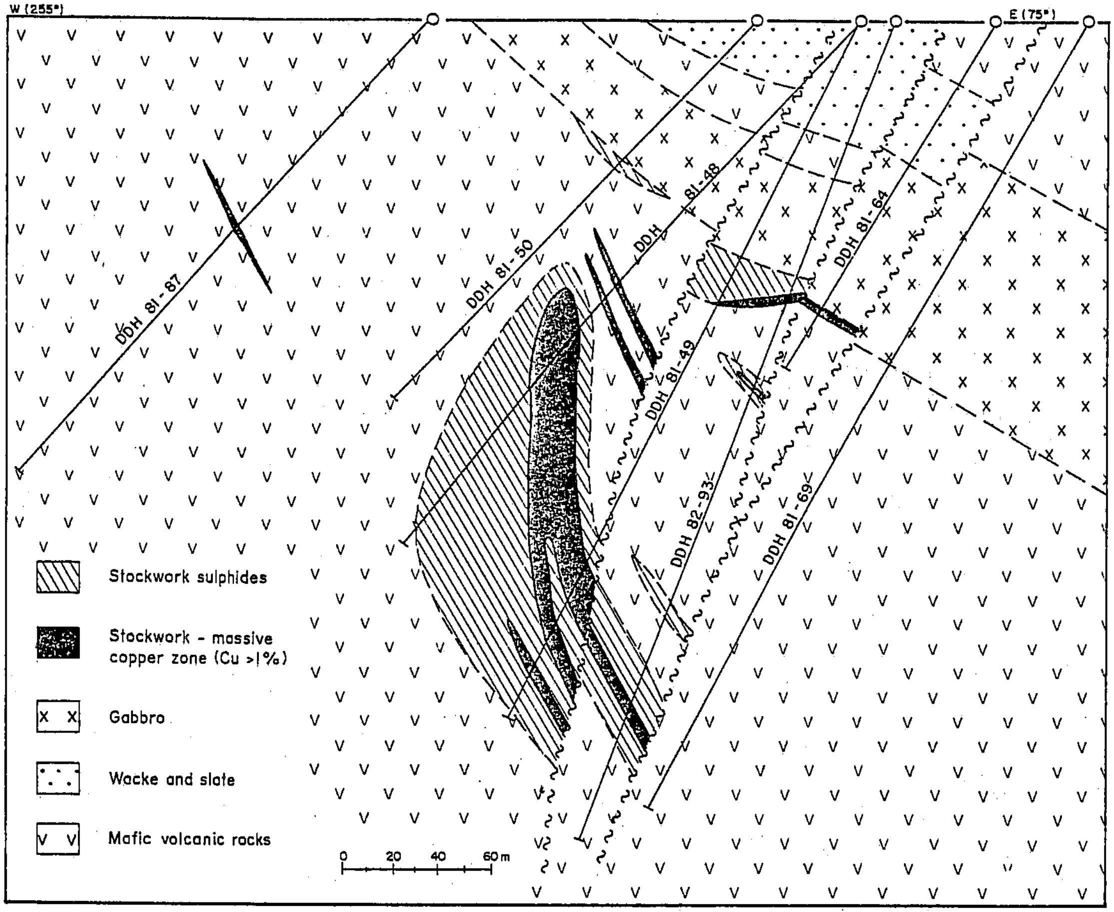

FIGURE 9. East-west cross-section of Turgeon deposit. Section is located just south of trench shown in Figure 8.

ROAD LOG FOR EXCURSION TO MIRAMICHI AND TETAGOUCHE GROUPS

0 km - Junction of Vanier Boulevard with Bathurst by-pass (Highway No. 11, Exit 310). Proceed south on Route 11.

6.2 km - Take Exit 304 and proceed southward on Route 430.

22.6 km - Turn east on Route 360 toward Allardville (Fig. 5).

27.7 km - **STOP #1-1: Nepisiguit River Bridge at Key Anacon Deposit**

Quartz wacke (locally feldspathic)/shale rhythmites of the Miramichi Group are in contact with rusty sericitic phyllites of the Nepisiguit Falls Formation of the Tetagouche Group (Fig. 10). The sericitic phyllites either represent highly strained and altered felsic tuffs or epiclastic rocks derived from a felsic volcanic protolith. Cross-bedding and grading in the wacke beds are best preserved on the eastern side of the river and indicate that the Miramichi Group is older than the Tetagouche Group.

Strain is mainly concentrated in the shale beds with the competent wacke beds behaving as relatively rigid bodies that are, in part, boudinaged. This partitioning of the deformation is responsible for the preservation of the sedimentary structures in the thick, competent wacke beds. Close to the contact with the sericitic phyllites, the wacke/shale rhythmites grade into a thin layer of black, graphitic shale. Black shale is commonly found near the top of the Miramichi Group. The vergence of the F_2 folds changes across the outcrop and suggests the presence of a large steeply plunging F_2 fold, the hinge of which is obscured by faulting (Fig. 10). This structure was outlined by Saif et al. (1978) on the basis of their mapping and drillhole interpretation.

The F_2 structures fold a well developed differentiated layering (S_1), but are themselves overprinted by northeast-trending F_4 and north-northwest- to west-trending F_5 folds and kinks. Recumbent kinks or open folds may represent F_3 structures, although overprinting relationships with F_4 and F_5 to prove this tentative grouping on the basis of style and orientation have not been observed.

An important massive sulphide deposit, the Key Anacon deposit (Saif et al. 1978), is located on the eastern side of the river and is stratigraphically underlain by the sericitic phyllites and overlain by alkali basalts and sediments of the Boucher Brook Formation. These alkali basalts are chemically similar to those overlying the Brunswick No. 12 deposit and contain appreciable amounts of magnetite, which makes them a good magnetic marker. Where these basalts are strongly deformed into phyllonites, they can be mistaken for silicate iron formation (Saif 1980).

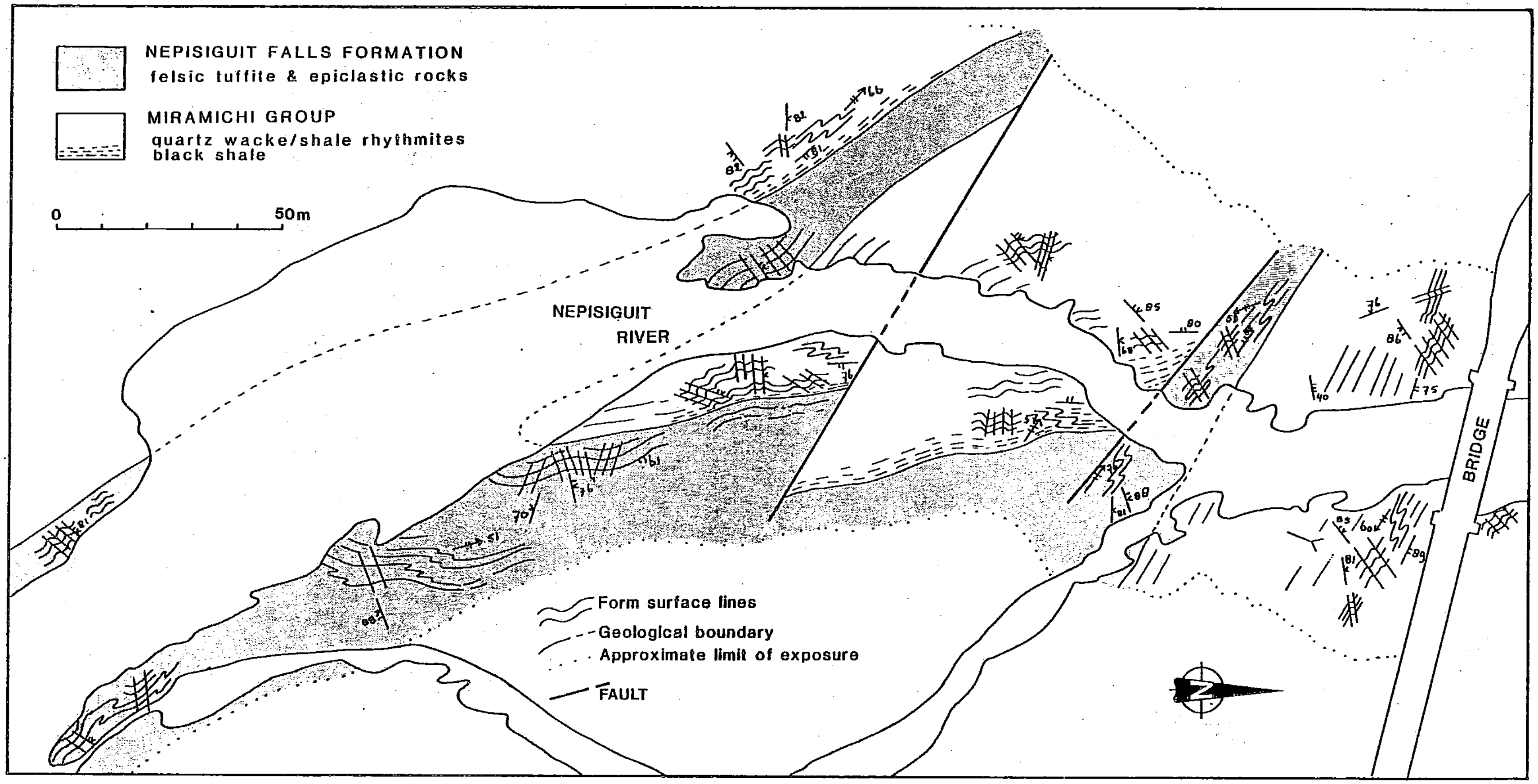

FIGURE 10. Geology and form surface map of the Key Anacon mine area.

0 km - Return westward to Route 430 and turn left.

6.7 km - Turn left off the paved highway onto gravel road and proceed southward to intersection with the road to Nepisiguit Falls on the left.

8.5 km - Turn left on Nepisiguit Falls road.

10.5 km - <u>STOP #1-2</u>: Knights Brook

Quartz wacke/shale rhythmites of the Miramichi Group are exposed to the right on Knight Brook. The rocks are strongly folded by F_2, which are accompanied locally by slides parallel to bedding. The F_2 structures are overprinted by the S_4 (trending N50°E) and S_5 (trending N120°E) cleavages.

12.1 km - <u>STOP #1-3</u>: Nepisiguit Power Dam

Cross the dam and descend to the rocks exposed on the eastern side of the dam. Exposures show very clean and polished rocks of the Nepisiguit Falls Formation that form the footwall to the Brunswick No. 12 and No. 6 deposits. These rocks comprise the quartz augen schist (QAS), quartz feldspar augen schist (QFAS), and sericitic phyllites, previously interpreted as felsic pyroclastic rocks. The QFAS form massive, homogeneous bodies of quartz- and feldspar-phyric rhyolite, locally containing lithic clasts. The feldspar phenocrysts are very large (up to 1-2 cm), but not broken suggesting a lava flow or sill rather than a pyroclastic flow. The QFAS are surrounded by well layered and graded QFAS that do not contain feldspar phenocrysts. The quartz augen are subrounded and embayed, which together with the sedimentary structures, clearly indicate that these rocks are sediments (McCutcheon <u>et al</u>. 1989), either proximal epiclastic deposits or a mixture of pyroclastic and epiclastic material. Igneous zircons in the QAS yielded similar ages as the zircons in the volcanics with which they are interbedded and favour the latter interpretation.

2.5 km - <u>STOP #1-4</u>: Austin Brook Quarry

Proceed westward from dam to Austin Brook Quarry on the left side of the road. The quarry mainly consists of a thick body of oxide iron formation that is folded into an isoclinal, moderately to shallowly, south-plunging S-shaped F_2 fold (Fig. 7). The iron formation is stratigraphically underlain by a lenticular massive sulphide body up to several metres thick. The sulphide body has a massive pyrite base followed, in turn, by a Zn/Pb-rich (up to 17% combined) zone and a cherty pyrite layer, respectively. The sulphides are, in turn, underlain by a thin layer (0-2 m) of chloritic phyllites containing anomalous amounts of apatite; the chlorite is characteristically iron-rich. The footwall of the metalliferous horizon comprises altered and highly strained pyrite-bearing sericitic phyllites of the Nepisiguit Falls Formation. Except for the anomalously thick oxide iron formation, the Austin Brook deposit is identical in make-up to the Brunswick-type deposits with which it is connected by a layer of metalliferous sediment (iron formation).

The iron formation shows abundant minor folding, comprising both F_1 and F_2 folds. These folds are interpreted to be post-lithification structures on the basis of 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 bend in the hinges of the F_1 and F_2 folds, indicating intracrystalline deformation. The great abundance of small scale folds in the iron formation with respect to the surrounding volcanic rocks is probably caused by the presence of a well developed compositional layering defined by alternating competent (jasper and magnetite) and incompetent (hematite) beds.

ROAD LOG FOR EXCURSION TO FOURNIER GROUP AND PARTS OF THE TETAGOUCHE GROUP IN THE BELLEDUNE-ELMTREE INLIER AND NORTHERNMOST PART OF MIRAMICHI HIGHLANDS

0 km - Exit 310 on Bathurst by-pass (Route 11). Turn north onto by-pass.

16.3 km - Turn right at Exit 326 onto Rue LaPlante to Petit Rocher.

0 km - Restart road log. Turn left at intersection with Rue Principale (Route 134).

4 km - Turn right onto Doucet Road to the coast (Fig. 6).

- **STOP #2-1: Limestone Point**

Middle Ordovician feldspathic (pinkish albitized plagioclase fragments) to lithic wackes are rhythmically interbedded with shale. The wacke beds are relatively thick and commonly graded. Note interbedded, pinkish coloured, aphyric felsic beds (trachytic?) with micro-laminations, which are strongly folded. Going southward, the wackes are gradually replaced by reddish coloured siltstones, which are tightly folded by shallowly to steeply, eastward-plunging folds. The reddish siltstones are bounded to the south with a sharp nearly vertical contact by late Llandoverian limestone of the Armstrong Brook Formation (Nowlan 1988b). Five metres south of this contact, a small channel of reddish conglomerate is interleaved with the limestone (Fig. 11). The erosional base of the channel appears to have acted as an inhomogeneity during deformation and localized the formation of asymmetrical folds. Basalt and gabbro pebbles, presumably derived from the ophiolitic Devereaux Formation, indicate that the accretionary complex in which the ophiolitic fragment was incorporated was locally exposed and

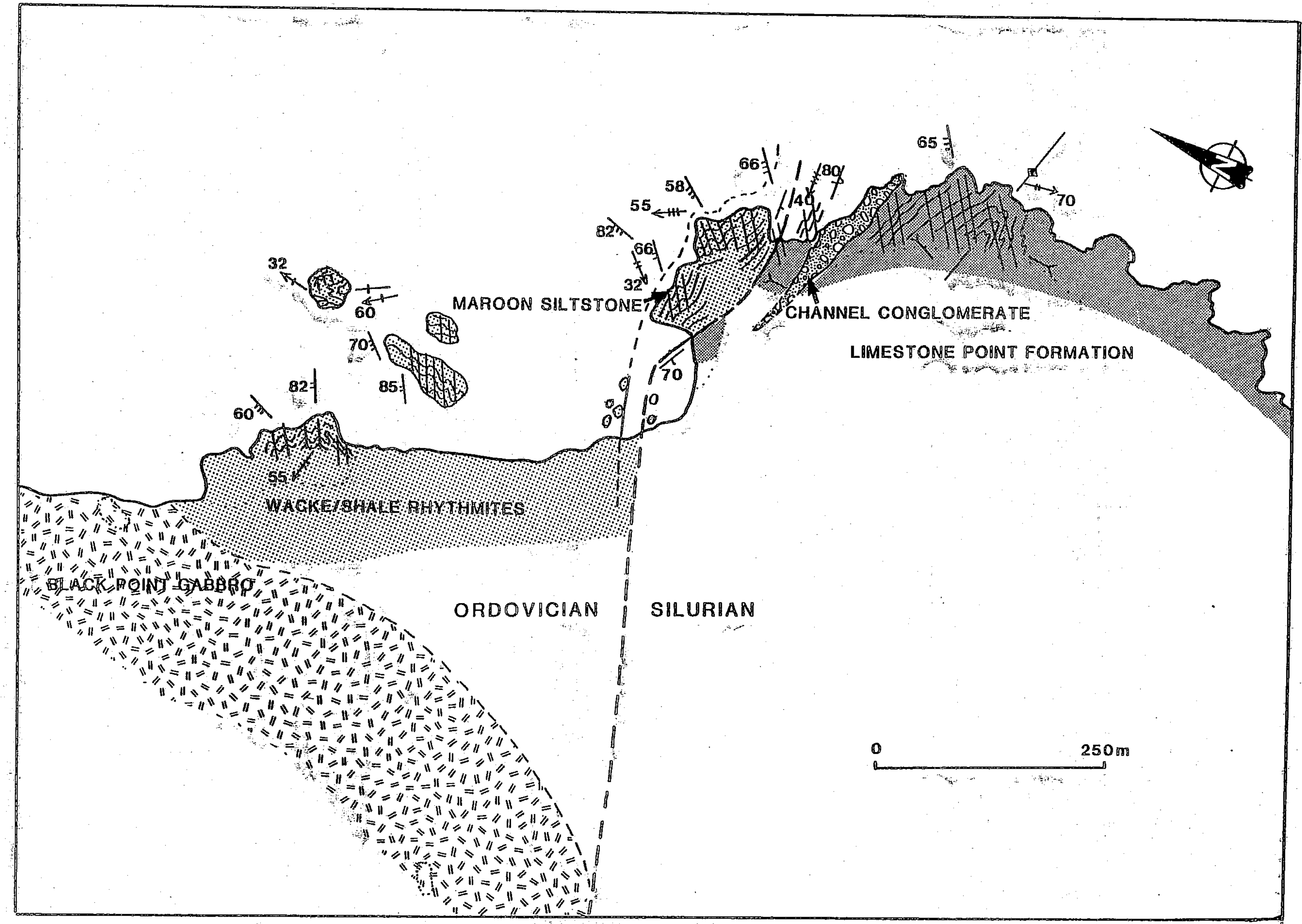

FIGURE 11. Geology and form surface map of the Limestone Point area.

subject to erosion in Early Silurian times. The regional cleavage in the Silurian rocks transects the upright folds in an anticlockwise fashion (Stringer 1975), indicating dextral transpression. This Silurian cleavage corresponds with the axial plane cleavage of asymmetrical, Z-shaped F_3 folds in the Ordovician rocks. The presence of polyphase folds and cleavages locally in the Silurian rocks indicate that the Silurian regional cleavage is also a third generation structure. The apparent hiatus between the Silurian and Ordovician rocks, combined with the sharp, conformably contact suggest the presence of a fault or a major disconformity.

0 km - Restart road log. Return to Route 134, turn right.

1.6 km - Turn right, park car, and walk to the coast.

- STOP #2-2: Black Point

Outcrop close to the structural base of the Devereaux ophiolitic fragment shows an example of highly strained gabbroic gneisses, which have been folded into shallowly east-plunging F_2 folds. The shear zones in the gneisses formed under amphibolite facies conditions, conditions which are not found in any other Ordovician rock type in the Elmtree-Belledune Inlier. These presently, shallowly dipping shear zones can be traced northward into stratigraphically higher parts of the gabbro where they have steep dips instead. This change in dip is attributed to non-coaxial strain associated with the final emplacement of the ophiolitic fragment. The steeply dipping shear zones are thought to have formed during transform faulting.

3.1 km - Turn right onto Rue de la Bateau and walk along the beach southward to first outcrop.

- STOP #2-3: Point Verte Mélange

A sequence of wacke/shale rhythmites, similar to those of Stop #2-1; black shale, chert, and alkali pillow basalt of the Pointe Verte Formation are strongly deformed during F_1 (Fig. 12). The F_1-related deformation caused intense transposition and locally mixing of the various rock types, giving rise for instance to large rafts of chert in a shale matrix. Hence, its interpretation as a mélange by Rast and Stringer (1980). The F_1 folds typically have no associated axial plane cleavage and are recumbent in the hinges of large shallowly, eastward-plunging F_2 folds. F_2 refolding of the overturned limbs of F_1 folds produce downwards facing structures. The F_2 structures are overprinted by the northeast-trending F_3 folds and cleavages.

Proceed northward for approximately 1.7 km and turn left onto Rue de la Gare (log 4.8).

5.6 km - **STOP #2-4: Green Point Station**

Turn left just before the railway crossing and park car.

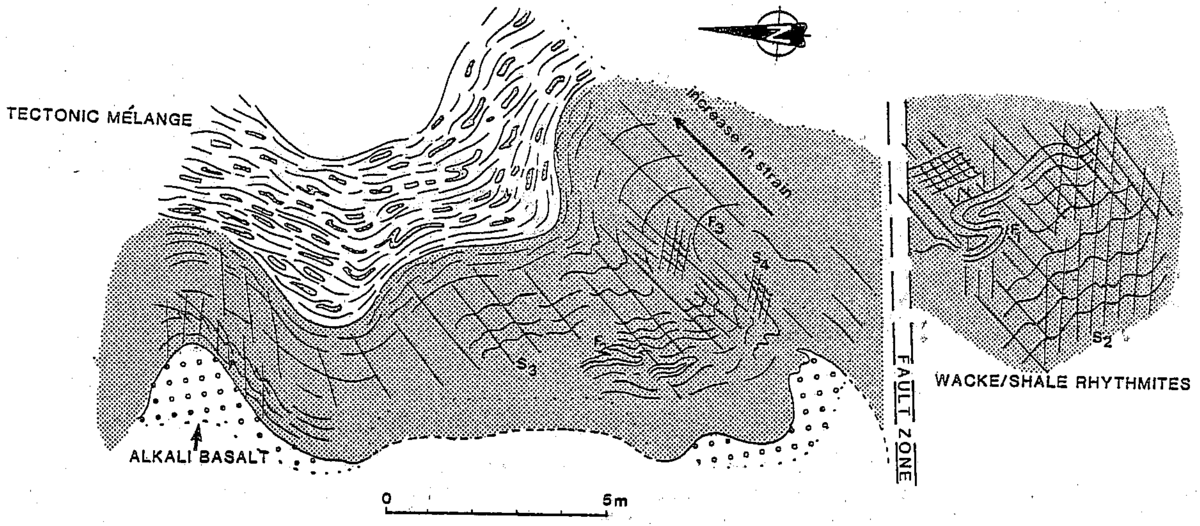

FIGURE 12. Sketch of small scale structures in the Pointe Verte Formation on approaching the mélange in Pointe Verte.

Walk south to large outcrop along the railway.

Strongly shared gabbroic gneisses (like in Stop #2-2) of the Devereaux ophiolitic fragment are intruded by diabase and plagiogranite dykes. Zircons extracted from a low strain pegmatitic gabbro pod yielded a concordant U-Pb zircon age of 463.9±1.0 M (Sullivan _et al._ 1989). The sheared gabbro is cut by plagiogranite dykes, which are also strained by these steeply dipping high grade shear zones, albeit weaker. The plagiogranite dyke has a concordant U-Pb zircon age of 459.6±1.0 Ma (Sullivan _et al._ 1989) and probably intruded off-axis in a transform fault setting.

10.5 km - _STOP #2-5_: Exit 333 Overpass on Route 11

This roadcut shows the gradual contact between the pillowed alkali basalt and pyroclastic rocks of the Madran Member with the wackes and shales of the Quitard Brook Member. Together these two members define the Pointe Verte Formation. The pillows in the northern part of the roadcut face upwards instead of sideways and suggest that the Madran Member has a relatively shallow dip in this part of the area. The alkali basalt has a relatively high chromium content (>200 ppm) which makes it distinct from any of the other alkali basalt suites in the area. Interpillow limestone yielded a conodont fauna indicative of the _P. anserinus_ zone, which corresponds with a late Llandeilian age (Nowlan 1983). Higher up in the section these alkali basalts are interbedded with black shale, which yielded graptolites of the lower Caradocian N. gracilis zone (Riva in Fyffe 1986).

0 km - Restart road log. Proceed northward on Route 11.

7.0 km - Approximately 550 m before the railway crossing, turn right on a small road, which should be followed for approximately 2 km. Then turn right at the first bifurcation in the road and proceed southward upon reaching a rock quarry filled with bulrush.

- STOP #2-6: Bulrush Quarry

The quarry consists of a gabbro sill in basalt that is interbedded with wackes and red-green shales of the Devereaux Formation. These basalts have compositions intermediate between MORB and IAT, i.e., they are depleted in high-field-strength elements with respect to N-MORB. Such basalts are typical of back-arc basins (Saunders and Tarney 1984).

Return to Route 11 and proceed northward for approximately 350 m and turn left onto a small sandy road. Proceed for approximately 1.6 km and park car at a small clearing. Walk the rest of the road, the last part parallel to the power line, to a big clearing.

- STOP #2-7: Turgeon Deposit

The Turgeon deposit is a small pyritic Zn-Cu deposit, comprising several massive lenses, pods, veins, and disseminated sulphide bodies. They are hosted by tholeiitic basaltic rocks interbedded with jasper of the Devereaux Formation. Alteration is locally intense and includes silicification of the basalts (Figs. 6, 8, 9).

Return to Route 11 and proceed southward.

20.5 km - Exit to Beresford and proceed 300 m westward, turn left and follow road approximately 1 km to the bridge.

- STOP #2-8: Millstream River bridge in Beresford

Thick-bedded, lithic and feldspathic wackes of the Middle Ordovician Millstream Formation are rhythmically interbedded with greyish green shales. Grading, cross-bedding, rip-up clasts, and lamination can be seen in sandy layers in clean washed outcrops during low water levels, which suggest that these rocks represent turbidite deposits. The Millstream Formation is lithologically very similar to the Pointe Verte Formation in the Elmtree-Belledune Inlier i.e., the sediments that overlie the Devereaux Formation.

Return to main road and proceed approximately 1 km westward to the intersection with Route 315. Turn left and cross the bridge over the Millstream River in Robertville. Park car in cul-de-sac on right side of road. Walk down to the river at the location of the falls behind second house from the road (Please ask permission).

- **STOP #2-9: Millstream River bridge in Robertville**

Small body of tholeiitic basalt of the Sormany Formation intercalated with the wackes of the Millstream Formation. The basalt is generally aphyric and mainly consists of a fine groundmass of fans of diverging plagioclase (albite) needles. Some vague indications of pillow structures are locally preserved. A narrow fault zone with unknown sense of displacement seems to be located in the river. Despite the presence of a potential fault zone, the isolated nature of this basalt body suggests that the Llandeilian basalts of the Sormany Formation are interlayered with the wackes of the Millstream Formation. The Millstream wackes are also, at least in part, Middle Ordovician in age.

0 km - Restart road log. Return to Route 11 and head south.

4.5 km - **STOP #2-10: Rock cut on Bathurst by-pass and adjacent quarry**

Rock cut and quarry contain pillow basalt, which is interbedded with red shale and chert, pyroclastic breccias, and a few diabase sills in the rock cut along the by-pass. Basalts and sills are locally vesicular or amygdular.

These basalts, which are strongly alkaline and chemically very distinctive, are referred to as the Beresford alkali basalt suite. The suite contains trachyandesite, trachyte, and commendite and is interbedded with the sediments of the Boucher Brook Formation. An interbedded trachyte yielded a U-Pb zircon date of 457±1 Ma. Overlying black shale contains an early Caradocian graptolite fauna, probably of the _N. gracilis_ zone (Riva, personal communication). Both ages suggest that the Beresford alkali basalt suite is late Llandeilian or early Caradocian in age. The pillows in the rock quarry young toward the north, but the sedimentary structures indicate that the rocks have a dominantly southward facing direction in the rock cut along the by-pass (Fig. 13). This change in facing direction confirms the presence of an anticline (_cf._, Skinner 1956), but is contrary to the interpretations of Rast and Stringer (1980). Younging indicators are best preserved at the northern end of the outcrop. These include large flames of red mud or silt in the pillow basalt and grading and channelling in the interlayered red shales and silts. As a consequence, the late Caradocian (_D. clingani_) black shale (Riva and Malo 1988) that bound these basalts to the south must be in tectonic contact with the latter. Van Staal _et al_. (1988b) interpreted this fault as a thrust (Fig. 14), which is located in the narrow zone occupied by the strongly deformed black shale (Stop #2-11).

Proceed southward.

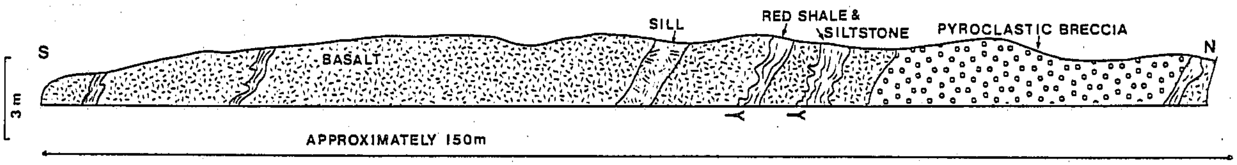

FIGURE 13. Sketch of the geological relationships in the roadcut on Route 11 just north of Peters River north of Bathurst.

2.0 km - Park car on right side of road next to a sand pit. Walk through sand pit along the east-trending path to the Tetagouche River. Walk northward along river for approximately 300 m to the bend in the river.

- **STOP #2-11: Tetagouche River railway bridge**

Black shale of the Boucher Brook Formation is well exposed along the banks of the Tetagouche River for a length of approximately 400 m going upstream from the railway bridge. The outcrop pattern of the black shale and basalt suggests the presence of a tight Z-shaped fold (Fig. 14). The black shale yielded abundant graptolites at two localities (van Staal *et al*. 1988b), which indicate a late Caradocian age (*D. clingani* zone; Riva and Malo 1988). The basal contact of the black shale with a polymictic conglomerate is highly sheared and is probably faulted. The upper contact with red shale is sharp and devoid of any brittle deformation features. However, these rocks contain a very well developed bedding parallel cleavage, which is thought to have formed by bedding-parallel shear (see above). This boundary between the black and red shales is, therefore, probably the site of the thrust contact. The strong deformation concentrated along the basal contact of the black shale unit may be due to footwall collapse. If correct, the black shale unit is a tectonic horse. The black shale layer is bounded to the south, respectively, by a conglomeratic to sandy limestone unit, and a sequence of thin-bedded calcareous siltstones, mudstones, and cross-bedded limestone. Together these calcareous rocks are combined into the Vallée Lourdes Formation (van Staal *et al*. 1988b). Large granitoid pebbles in the limestone yielded Grenvillian age U-Pb zircon ages (R. Sullivan, personal communication) and suggest that Grenvillian age basement was exposed in close proximity during their time of deposition or the pebbles are basement fragments brought up during explosive volcanic eruptions. However, the Vallée Lourdes Formation contains middle/late Arenigian Celtic brachiopod faunas (Neuman 1984) and Arenigian to early Llanvirnian North Atlantic conodont faunas (Nowlan 1981)

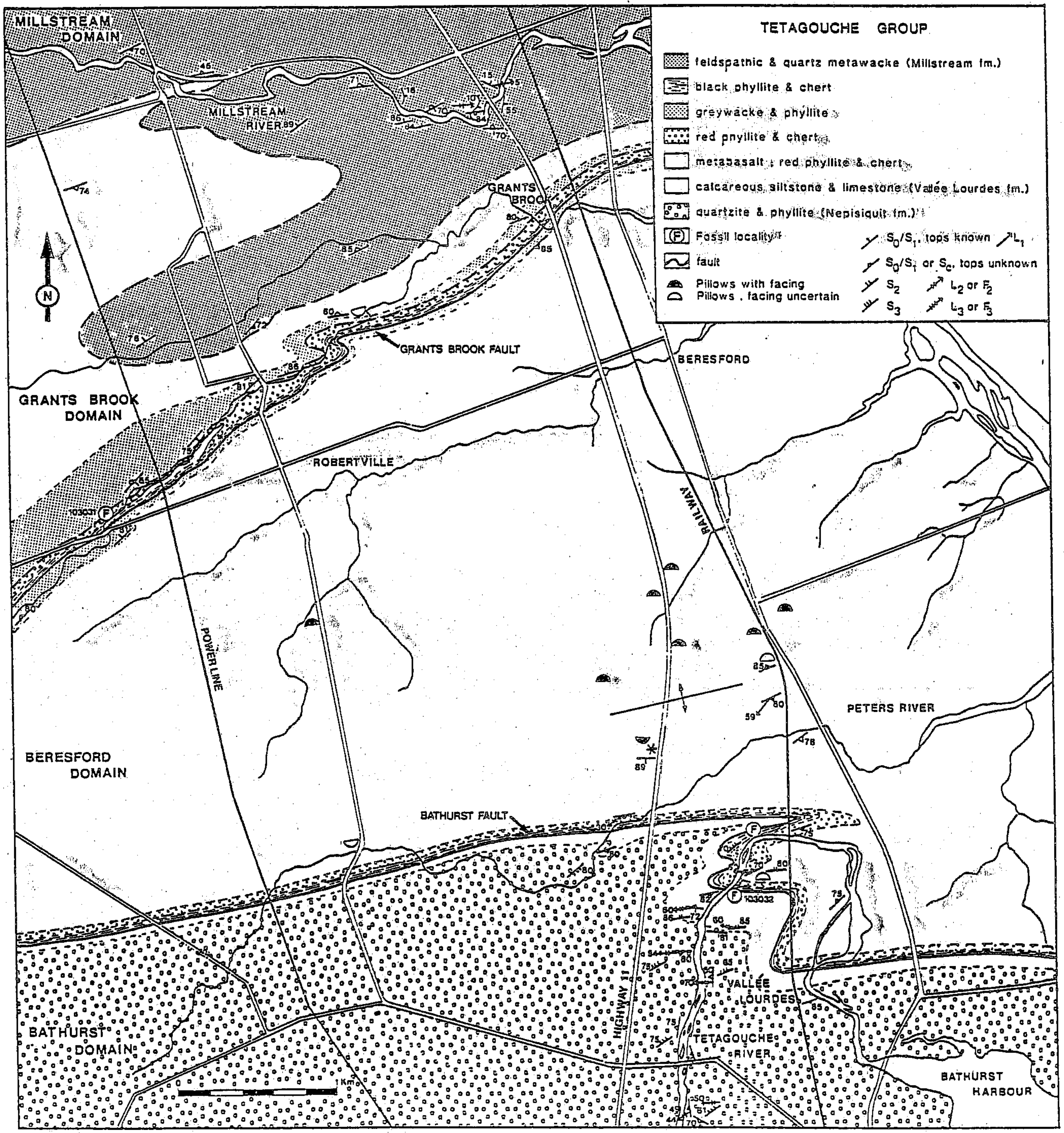

FIGURE 14. Geology in the vicinity of the city of Bathurst.

indicating significant separation from the North American continent.

The Vallée Lourdes Formation is underlain quartzite and quartz wacke/shale rhythmites of the Miramichi Group. The contact between the Vallée Lourdes Formation and the Miramichi Group is not exposed in the Tetagouche River in Bathurst, but 10 km westward along strike at Little Falls. This contact can be shown here to be a disconformity (Fyffe and Noble 1985).

ROAD LOG FOR EAST-WEST TRANSECT THROUGH THE TETAGOUCHE GROUP AND PARTS OF THE FOURNIER GROUP IN THE NORTHERN MIRAMICHI HIGHLANDS

0 km - Exit 310 on Bathurst by-pass. Proceed westward on Vanier Boulevard pass the Bathurst airport where it turns into the Road to Resources (Route 180).

9.8 km - Turn right into the Tetagouche Falls provincial picnic site.

- **<u>STOP #3-1</u>:**

The viewing area is underlain by pyroclastic and tuffites/proximal epiclastic rocks of the Nepisiguit Falls Formation, the principal unit underlying most of the Brunswick-type massive sulphide deposits. The rocks here are closely associated, and partly interbedded, with a multicoloured (red, green, and black) manganiferous shale, which seems to occupy the same stratigraphic position as the Brunswick iron formation unit. The rocks are folded into a large Z-shaped, steeply plunging F_2 fold with its axial plane trending approximately parallel to the river (Fig. 5).

24.3 km - Intersection with the Arsenault road toward the south and limestone quarry road to the north. Turn right on quarry road and immediately turn right again onto narrow gravel road. Proceed on this road for 500 m.

- **<u>STOP #3-2</u>:**

Exposures show tholeiitic, pillowed oceanic floor basalts of the Fournier Group. Progressive flattening of the pillows shows that the lavas become progressively more strained in a southward direction toward the basal thrust contact with the Tetagouche Group, which is not exposed here.

Return to Road to Resources and continue westward.

26.4 km - **<u>STOP #3-3</u>:**

Roadcut shows mildly strained pillowed ocean floor basalts of the Fournier Group. Note epidotized pillow selvages and contrast in strain with respect to the previous stop.

37 km - **STOP #3-4**:

Roadcut with small quarry showing contact of highly strained phyllonitic mafic rocks with quartz and feldspar phyric rhyolite.

50.0 km - Turn right onto narrow gravel road and proceed northwestward.

51.3 km - **STOP #3-5**:

Exposure shows highly strained blueschists with a millimetre scale S_1 differentiated layering consisting of epidote- and sodic amphibole- (glaucophane/crossite) rich layers. Note the complex deformation that superceded S_1, comprising F_2, F_4, and F_5 folds.

Return to Route 180, restart road log and continue westward.

1.8 km - **STOP #3-6**:

Roadcut showing the tectonic contact between rhyolite and maroon shale and some mafic phyllonite. The mafic phyllonite can be walked out into blueschists. The rhyolite is transformed into a sericitic phyllonite by the high deformation, but can be walked out into a feldspar-phyric rhyolite.

4.2 km - **STOP #3-7**:

Alkali feldspar-phyric rhyolite. Deformation is very mild and highlights the strain contrast with the previous stop. Greenish coloured phyllosilicates are light greenish muscovite (probably phengitic). Alkali feldspar phenocrysts are generally idiomorphic and show baveno as well as carlsbad twins. They are, in part, altered to chess-board albite.

This rhyolite body forms the hanging wall to the Caribou massive sulphide deposit with which it is interpreted to be in tectonic contact.

7.0 km - **STOP #3-8**:

Caradocian black shale of the Boucher Brook Formation, which represents the youngest rock type known in the Tetagouche Group. South of the road, close to the Camel Back Mountain, these sediments overlie or are interbedded with lower to middle Caradocian limestone lenses (Nowlan 1981).

8.0 km - **STOP #3-9**:

Roadcut on right side of the road is close to the tectonic contact between the shales of the Boucher Brook Formation and the structurally overlying Camel Back alkali basalt suite. The latter is older than the middle Caradocian limestone; hence old overlies young. The structural contact is marked by maroon and red shaly phyllonites. These alkali basalts generally contain sodic amphiboles, whereas chemically identical basalts south of this contact contain typical greenschist-facies assemblages.

This indicates that this tectonic contact also marks a sudden jump in metamorphic grade with high pressure rocks overlying lower pressure rocks.

9.3 km - STOP #3-10:

Roadcut in phyllonitic basalts containing, at least locally, sodic blue amphibole. These rocks mark the tectonic contact between two chemically different alkali basalt bodies, each incorporated into the blueschist belt. These bodies consist of chromium-poor (Cr <30 ppm) Camel Back alkali basalts to the southeast and the Eighteen Mile Brook alkali basalts, characterized by intermediate chromium values (30-200 ppm) to the northwest.

Continue from here to the Murray Brook deposit.

BASE METAL DEPOSITS OF THE BATHURST-NEWCASTLE DISTRICT

S. R. McCutcheon

INTRODUCTION

The base metal deposits of the Bathurst-Newcastle district occupy a subcircular area, approximately 50 km in diameter, at the northeastern end of the Miramichi Highlands of New Brunswick (Fig. 15). The deposits are in the Middle Ordovician Tetagouche Group, a bimodal volcanic and sedimentary sequence that probably formed along a continental margin in a back-arc rift environment (van Staal, 1987). The district contains about 100 known base-metal occurrences, including 35 deposits with defined tonnage (New Brunswick Mineral Occurrence File). With one exception all these occurrences/deposits can be classified as the Zn-Pb-Cu type (cf. Solomon 1976; Franklin et al. 1981; Lydon 1984).

Most of the known occurrences/deposits were discovered prior to 1970 with the most prolific period of discovery between 1952 and 1960 (MacKenzie 1958; Davies and Smith 1966). All are at, or near, the surface and were mainly found by geochemical and geophysical methods. The lack of recent discoveries largely reflects the limitations of these techniques in detecting deeply buried deposits. Reported exploration drilling up to 1986 (Mines Division Assessment Files) illustrates how little deep exploration has been done in the Bathurst-Newcastle district. Of 5169 holes, only 326 exceed 300 m and only 1434 exceed 150 m.

If significant new discoveries are to be made in the district, then the stratigraphy, structure and depositional setting of the deposits must be known in enough detail to guide exploration in the third dimension. Proof that geology-oriented, exploration works in finding deeply buried deposits is shown by the recent discovery of Brunswick Mining & Smelting (Northern Miner, Dec. 4, 1989) near the No. 12 mine. Brunswick made this discovery because the geology in the vicinity of the No. 12 deposit is well known; in fact much better known than in most of the district. Also, van Staal and his co-workers have advanced our knowledge considerably with respect to the structural complexity of the district. What remains to be determined is the internal stratigraphy of the felsic volcanic pile with which the deposits are spatially associated.

The purpose of this paper is to summarize some of the characteristic features of the known deposits, and to critically examine the depositional setting of the Brunswick No. 6 and No. 12 deposits. The classic Kuroko model does not apply to Brunswick (van Staal and Williams 1984) and may not be applicable to many of the deposits in the Bathurst-Newcastle district, if volcanological and stratigraphic constraints imposed by the felsic volcanic pile in the vicinity of the Brunswick deposits can be extrapolated to the rest of the camp.

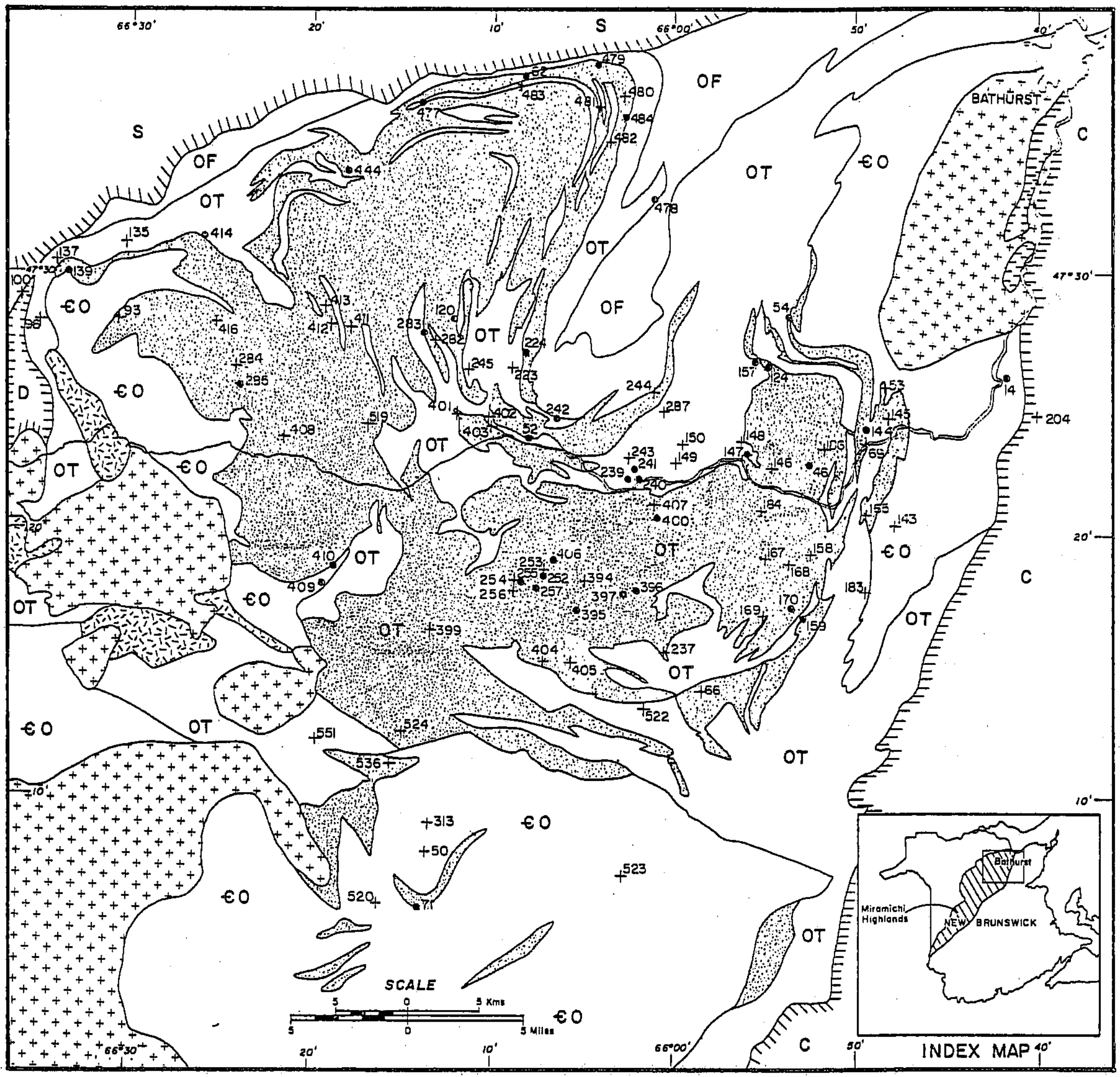

FIGURE 15. Simplified geologic map of northern New Brunswick showing the distribution of known mineral occurrences/deposits. Geology modified after Davies (1979).

Legend: C = Carboniferous sedimentary rocks; crosses = Devonian felsic intrusions; dashes = Devonian mafic intrusions; D = Devonian volcanic + sedimentary rocks; S = Silurian sedimentary rocks; OF = Middle Ordovician Fournier Group (ocean-floor basalts); OT = Middle Ordovician Tetagouche Group (stippled = felsic volcanic rocks; unstippled = sedimentary and/or mafic volcanic rocks); ЄO = Cambro-Ordovician sedimentary rocks (Miramichi).

DEPOSIT CHARACTERISTICS

The characteristics of many of the base-metal deposits in the Bathurst-Newcastle district were summarized by Jambor (1979), who attempted to classify them into proximal and distal types using the criteria of Large (1977). Some of the general features noted by him are as follow: (1) The massive-sulphide deposits are fine-grained, layered stratiform lenses that are pyrite-rich, barite-poor and texturally complex; (2) Pyrite, sphalerite, galena, chalcopyrite and pyrrhotite constitute more than 95% of the lenses with minor arsenopyrite, marcastie, tetrahedrite and bournonite; (3) Layering results from variations in mineral abundances and/or variations in grain size and is best developed in zinc-lead-rich parts of the lenses; (4) Disseminated mineralization, mainly pyrite, underlies most of the lenses but is generally absent in the hanging-wall rocks; (5) Many of the stratiform sulphide deposits are overlain by, and/or have a laterally equivalent, oxide (±carbonate and silicate) iron-formation; (6) A few of the stratiform deposits are apparently underlain by discordant stockwork zones containing pyrrhotite, pyrite and chalcopyrite.

Specific features for 94 deposits/occurrences are listed in Tables 1, 2 and 3. These data are mainly from the New Brunswick Mineral Occurrence File that was compiled largely from information in assessment reports. Consequently, more is known about some deposits/occurrences than others. The locations of these deposits/occurrences are indicated in Figure 15.

The 94 deposits/occurrences are grouped according to the 1:50 000 map area (NTS) in which they are located (Table 1). The majority are in 21 O/8E and 21 P/5W. Only 21 of them have been discovered since 1970, a pitifully small number considering the advances that have been made in exploration technology during the past twenty years. Of the 94 deposits/occurrences, 31 are classified as massive with another 25 that are in part massive (Table 2). Nineteen (19) contain only disseminated mineralization with another 31 that have some disseminated mineralization. There are only 7 occurrences that are wholly composed of stringer-type mineralization, with another 17 that have a stringer-type component.

Although there is considerable variation in rock terminology (Table 2), most of the host rocks are fine-grained clastics, felsic tuffs or their metamorphosed equivalents (schists). In fact, many deposits/occurrences are reported to be at the contact between tuffaceous and sedimentary rocks. If a lot of the tuffaceous rocks are actually sedimentary rather than pyroclastic (see next section), then most of the deposits/occurrences are sediment-hosted. Notably, Smith and Skinner (1958) made this observaton over thirty years ago. Only 8 occurrences are in rhyolite or metarhyolite with another 4 in unspecified felsic volcanics.

TABLE 1. BASE-METAL OCCURRENCES/DEPOSITS IN THE BATHURST - NEWCASTLE DISTRICT

URN	NAME	NTS	LAT	LONG	DISCOVERED
050	BELLECHASSE	21 O 01 E	47 08 16	66 13 35	1952-GEOCHEM
071	CHESTER	21 O 01 E	47 05 57	66 13 44	1955-AIRBOURNE EM SURVEY
313	LEAD POND	21 O 01 E	47 09 20	66 13 27	1982-GEOCHEM/GEOPHYS-BRUNSWICK
523	NORTH SEVOGLE RIVER	21 O 01 E	47 07 25	66 02 42	1955-GEOPHYS-ARJON GOLD MINES
522	SOUTH TOMOGONOPS	21 O 01 E	47 13 43	66 01 30	1966-GEOPHYS-CONSLD RED POPLAR
551	BEAR LAKE (CANOE LAKE)	21 O 01 W	47 12 27	66 19 34	PRE-1953- AEROMAG
536	CLEARWATER LAKE	21 O 01 W	47 11 38	66 15 31	1977- GEOPHYS- SEREM
520	SOUTH SEVOGLE RIVER	21 O 01 W	47 06 22	66 16 10	1966- SULLICO MINES
096	PORTAGE BROOK	21 O 07 E	47 28 15	66 35 00	1977- CANEX PLACER
100	PORTAGE LAKES	21 O 07 E	47 29 11	66 35 52	C.1957- NEW JERSEY ZINC?
093	UPSALQUITCH LAKE	21 O 07 E	47 28 30	66 30 40	C.1958- LEITCH GOLD MINES LTD.
120	A'HEARN BROOK	21 O 08 E	47 28 17	66 11 58	1968-FINDATHORAN SYNDICATE
244	BOUCHER BROOK	21 O 08 E	47 25 41	66 01 02	1950
224	CALIFORNIA LAKE - 32S ZONE	21 O 08 E	47 27 07	66 08 22	1956-AMERICAN METAL CO
223	CALIFORNIA LAKE - 68S ZONE	21 O 08 E	47 26 37	66 08 48	1975-BOLIDEN-PREUSSAG
242	CANOE LANDING LAKE	21 O 08 E	47 24 39	66 06 24	1960-BAIE HOLDINGS LTD.
400	CONSOLIDATED MORRISON	21 O 08 E	47 20 43	66 00 35	1977-AEM-CONSOLIDATED MORRISON
399	FORTY-TWO MILE BROOK	21 O 08 E	47 16 34	66 13 22	1978- PREUSSAG CANADA
395	HEATH STEELE A,C & D ZONES	21 O 08 E	47 17 28	66 05 13	1954-AEM- AMERICAN METAL CO.
396	HEATH STEELE B-ZONE	21 O 08 E	47 17 58	66 02 39	1954-AEM- AMERICAN METAL CO.
397	HEATH STEELE E-ZONE	21 O 08 E	47 17 56	66 03 59	1954-AEM- AMERICAN METAL CO.
394	HEATH STEELE G-ZONE	21 O 08 E	47 18 33	66 04 50	PRE-1955- AEM- HEATH STEELE
257	HEATH STEELE NORTH ZONE(N5)	21 O 08 E	47 18 17	66 08 10	EARLY 1960'S-HEATH STEELE
237	ISLAND LAKE	21 O 08 E	47 15 37	66 00 25	1954-EM ANOM-O'LEARY MALARTIC
405	LITTLE RIVER LAKE (MOWAT)	21 O 08 E	47 15 23	66 05 41	1958- GEOPHYS- JR MOWAT
404	LITTLE RIVER LAKE (SATELLITE)	21 O 08 E	47 15 30	66 07 10	1955- UNITED MONTAUBAN MINES
401	LOWER 44 MILE BROOK	21 O 08 E	47 24 42	66 11 50	1978- ESSEX MINERALS
241	NEPISIGUIT "A"	21 O 08 E	47 22 46	66 01 50	1955-56-GEOPHYS/DRILL-KENNCO
240	NEPISIGUIT "B"	21 O 08 E	47 22 30	66 01 36	1956-GEOPHYS/DRILLING-KENNCO
239	NEPISIGUIT "C"	21 O 08 E	47 22 23	66 02 30	1956-GEOPHYS/DRILLING-KENNCO
245	SOUTH FORTY MILE BROOK	21 O 08 E	47 26 28	66 11 04	EARLY 1960'S
282	STRACHENS BROOK EAST	21 O 08 E	47 27 40	66 13 24	1982-GEOCHEM/GEOPHYS-BM&S
283	STRACHENS LAKE BROOK	21 O 08 E	47 27 40	66 13 52	C.1970-FINDATHORAN SYNDICATE
252	STRATMAT CENTRAL	21 O 08 E	47 18 42	66 07 07	1972-COMINCO
406	STRATMAT MAIN	21 O 08 E	47 19 11	66 06 31	1956-GEOPHYS- STRATEGIC METALS
253	STRATMAT NORTH	21 O 08 E	47 18 55	66 07 10	1979- GEOPHYS/GEOCHEM-COMINCO
254	STRATMAT WEST B-ZONE	21 O 08 E	47 18 30	66 08 27	1961- GEOPHYSICS-COMINCO
256	STRATMAT WEST STRINGER ZONE	21 O 08 E	47 18 20	66 08 25	1972- GEOPHYS- COMINCO
255	STRATMAT/HEATH BOUNDARY (WEST A)	21 O 08 E	47 18 28	66 08 03	1961- GEOPHYS -COMINCO
407	TAYLOR BROOK	21 O 08 E	47 21 28	66 01 10	1967- MINING CORP OF CANADA
052	WEDGE	21 O 08 E	47 23 46	66 07 58	1956-EM-COMINCO
402	WEST WEDGE	21 O 08 E	47 24 43	66 10 03	1983- GEOCHEM- BP MINERALS
403	WESTED (TRIBAG)	21 O 08 E	47 24 23	66 10 00	1953- STREAM GEOCHEM- SELCO
287	WILLETT	21 O 08 E	47 24 52	66 00 20	1975-PROSPECTING-CA WILLETT
285	DEVIL'S ELBOW	21 O 08 W	47 25 49	66 24 01	1957-AIRBORNE EM-AMER METAL CO
411	FORTY-FOUR MILE BROOK- NO 1	21 O 08 W	47 28 10	66 17 57	1970- DRILLING- ANACONDA
412	FORTY-FOUR MILE BROOK- NO 2	21 O 08 W	47 28 10	66 18 50	1972-DRILLING-NORANDA
410	HALFMILE LAKE NORTH(MAIN)	21 O 08 W	47 18 23	66 19 06	1955- EM- TEXAS GULF
409	HALFMILE LAKE (AB & C ZONES)	21 O 08 W	47 18 23	66 19 06	1955- EM- SWEET GRASS OILS
408	MT. FRONSAC	21 O 08 W	47 23 45	66 21 15	1956- TEXAS GULF

(Table 1 concluded)

URN	NAME	NTS	LAT	LONG	DISCOVERED
416	UPSALQUITCH (DUNGANNON)	21 O 08 W	47 28 20	66 25 07	C.1976-AIRBORNE EM-DUNGANNON
284	WEST 44 MILE BROOK	21 O 08 W	47 27 26	66 24 05	1961-GEOPHYS- NEW JERSEY ZINC
484	ARMSTRONG A	21 O 09 E	47 36 06	66 02 33	1956- ANACONDA
482	ARMSTRONG B	21 O 09 E	47 35 09	66 03 27	C.1956?-IP ANOMALY?-ANACONDA
481	ARMSTRONG C	21 O 09 E	47 36 25	66 04 03	PRE-1971- ANACONDA
480	ARMSTRONG D	21 O 09 E	47 36 47	66 02 35	C.1957-EM ANOMALY-ANACONDA
477	MCMASTER	21 O 09 E	47 36 26	66 13 59	1957-GROUND EM-ANACONDA
478	MIDDLE RIVER WEST *	21 O 09 E	47 33 01	66 01 10	1968-PROSPECTING-A & F SMITH
062	ORVAN BROOK	21 O 09 E	47 37 37	66 08 07	1938-EXPOSURE IN BROOK
483	ORVAN BROOK SOUTH	21 O 09 E	47 37 15	66 08 25	C.1959-EM-ANACONDA
479	ROCKY TURN	21 O 09 E	47 38 00	66 04 11	C.1957-ANACONDA
444	CARIBOU	21 O 09 W	47 33 39	66 17 38	1955- MAPPING/GEOPHYS-ANACONDA
414	MURRAY BROOK	21 O 09 W	47 31 31	66 25 51	1956- GEOCHEM- KENNCO EXPL.
139	RESTIGOUCHE	21 O 10 E	47 30 20	66 33 50	1958- NEW JERSEY ZINC
137	RESTIGOUCHE N-C4 & C5 ZONES	21 O 10 E	47 30 24	66 34 03	C.1954- STREAM GEOCHEM- SELCO
135	SE UPSALQUITCH RIVER- WEST	21 O 10 E	47 31 19	66 30 14	C.1960- NEW JERSEY ZINC
060	LITTLE SEVOGLE RIVER NO.1	21 P 04 W	47 00 03	65 59 23	PRE-1957
066	ROCHE LONG LAC	21 P 04 W	47 14 15	65 58 22	1955-ROCHE LONG LAC MINES LTD.
014	KEY ANACON	21 P 05 E	47 26 06	65 41 54	1953-EM ANOMALY
149	ASTRABRUN NORTH & SOUTH	21 P 05 W	47 23 03	65 59 35	PRE-1955
069	AUSTIN BROOK	21 P 05 W	47 23 48	65 49 21	1897-PROSPECTING
054	BRUNSWICK NO. 12	21 P 05 W	47 28 24	65 53 31	1953-EM ANOMALY
144	BRUNSWICK NO.6	21 P 05 W	47 24 26	65 49 25	1952-EM & DRILLING
159	CAPTAIN	21 P 05 W	47 17 03	65 52 58	1956-GEOPHYS-CAPTAIN MINES
170	CAPTAIN NORTH EXTENSION	21 P 05 W	47 17 40	65 53 10	1978-GEOCHEM-SABINA INDUSTRIES
169	CAPTAIN WEST	21 P 05 W	47 17 10	65 54 53	1979-GEOPHYS;DRILLING-SABINA
146	COULEE	21 P 05 W	47 22 51	65 54 20	1966-DRILLING SP ANOM-COULEE
122	FAB MAIN ZONE	21 P 05 W	47 26 45	65 49 00	1950
046	FLAT LANDING BROOK	21 P 05 W	47 22 55	65 52 35	1975-GEOL &GEOPHYS-SABINA IND.
186	FLAT LANDING BROOK EAST	21 P 05 W	47 23 30	65 51 30	1976
143	GILMOUR BROOK-BEEHLER	21 P 05 W	47 20 40	65 47 50	1953-EM-NEW JERSEY ZINC
167	GORDON MEADOW BROOK	21 P 05 W	47 19 20	65 50 40	1954-GEOL/GEOPHY-BRUNSWICK M&S
124	HEADWAY	21 P 05 W	47 26 48	65 54 01	1957-PROSPECTING-HEADWAY
053	KNIGHT BROOK	21 P 05 W	47 25 45	65 48 11	EARLY 1950'S-PROSPECTING
147	LOUVICOURT DEPOSIT	21 P 05 W	47 23 25	65 55 59	1964-ROAD CONSTRUCTION-C.SMYTH
148	LOUVICOURT NORTH	21 P 05 W	47 23 48	65 56 09	1957-GEOPHYS-DRILLING
158	MCDONOUGH TREND B	21 P 05 W	47 19 25	65 52 20	1953-AREA FIRST STAKED
168	MCDONOUGH WEST (TREND A)	21 P 05 W	47 19 15	65 53 30	1953
184	NEPISIGUIT BROOK NORTH	21 P 05 W	47 21 10	65 55 00	1954-GEOPHYS/DRILLING-STRATMAT
145	NEW HIGHRIDGE	21 P 05 W	47 24 40	65 48 10	1953- GEOPHYS & DRILLING
157	PABINEAU	21 P 05 W	47 26 58	65 55 07	1953
183	PORTAGE RIVER- UDD	21 P 05 W	47 18 10	65 49 25	1954-EM/DRILLING-STRATMAT
165	TAYLOR BROOK ROAD	21 P 05 W	47 20 55	65 49 28	1978-GEOCHEM/GEOPHY-KEY ANACON

Note: URN is the Unique Record Number of each occurrence/deposit in the New Brunswick Mineral Occurrence File.

TABLE 2. GEOLOGICAL CHARACTERISTICS OF BASE-METAL OCCURRENCES/DEPOSITS IN THE BATHURST - NEWCASTLE DISTRICT.

URN	NAME	FORM*	HOST ROCKS	ASSOCIATED ROCKS	CHLORITE ZONE	OXIDE FE-FORM	CU ZONE
484	ARMSTRONG A	m	augen schist	----	yes	--	--
482	ARMSTRONG B	d+m	augen schist	----	yes	--	yes
481	ARMSTRONG C	m+d	phyllite	mafic volcanics	--	--	yes
480	ARMSTRONG D	m+d	augen schist	----	--	--	--
149	ASTRABRUN N.& S.	d	slate	----	--	--	--
069	AUSTIN BROOK	m	felsic volcanics	augen schist	--	yes	--
120	A'HEARN BROOK	m	felsic tuff	metasediments	--	--	--
551	BEAR(CANOE) LAKE	d	brecciated graphitic seds	mafic lavas	--	yes	--
050	BELLECHASSE	d	graphitic seds	felsic tuff	--	--	--
244	BOUCHER BROOK	d	felsic tuff	graphitic slate	--	--	--
054	BRUNSWICK NO. 12	m+d	metasediments	augen schist + fel tuff	+stilp	yes	yes
144	BRUNSWICK NO.6	m	metasediments	augen schist + fel tuff	+talc?	yes	--
224	CALIFORNIA L.- 32S	m+d+s	graphitic slate	porphyritic rhyolite	--	--	--
223	CALIFORNIA L.- 68S	m	felsic tuff	sed rocks	yes	--	yes
242	CANOE LANDING L.	m	argillaceous seds	mafic volcanics	--	--	--
159	CAPTAIN	m+s+d	augen schist	metasediments	yes	--	yes
170	CAPTAIN NORTH EXT.	m+s	chert + qtz-ser schist	slate + augen schist	--	--	yes
169	CAPTAIN WEST	s	felsic tuff	graphitic schist	--	--	--
444	CARIBOU	m	chlorite schist +phyllite	acid metavolcanics	+stilp+talc	yes?	yes
071	CHESTER	m	qtz-sericite schist	felsic volcanics	+talc	--	yes
536	CLEARWATER LAKE	d+s	graphitic schist	qtz-sericite schist	--	--	--
400	CONSOLIDATED MOR.	m+d	felsic tuff	qtz-fspar porphyry	yes	--	--
146	COULEE	d	felsic tuff	----	--	yes	--
285	DEVIL'S ELBOW	d+m	felsic tuff	qtz-eye schist	yes	--	yes
122	FAB MAIN ZONE	d+m	sericite schist	augen schist	--	--	--
186	FLAT LANDING BK E.	d+m	felsic volcanics	breccia	yes	yes	--
046	FLAT LANDING BROOK	m+d	felsic tuff	qtz-augen tuff	--	yes	--
399	42 MILE BROOK	d	brecciated chert	tuff + greywacke	--	--	--
411	44 MILE BK- NO 1	d	brecciated rhyolite	ser + graphitic schists	--	--	--
412	44 MILE BK- NO 2	d	brecciated rhyolite	ser + graphitic schists	--	--	--
143	GILMOUR BK(BEEHLER)	s	sericite schist	----	yes	yes	--
167	GORDON MEADOW BK	s	augen schist	graphitic schist	--	yes?	--
409	HALFMILE AB &C ZONES	m	argillaceous seds	felsic pyroclastics	yes	--	yes
410	HALFMILE NORTH(MAIN)	m	argillaceous seds	felsic pyroclastics	yes	--	yes
124	HEADWAY	m+d	qtz-sericite schist	mafic volcanics	yes	--	--
395	HEATH STEELE ACD	m	metasediments	crystal tuff	--	yes?	yes
396	HEATH STEELE B-ZONE	m	metasediments	crystal tuff	--	yes?	yes
397	HEATH STEELE E-ZONE	m	metasediments	crystal tuff	--	yes?	--
394	HEATH STEELE G-ZONE	s	felsic tuff	fragmental felsic	yes	--	--
257	HEATH STEELE N-5	m	metasediments	crystal tuff	yes	--	--
237	ISLAND LAKE	d	fragmental rhyolite	mafic volcanics	--	--	--
014	KEY ANACON	m	metasediments	felsic tuff + mafic volc	--	--	yes
053	KNIGHT BROOK	d+s+m	sericite schist	augen schist	--	--	--
405	L RIVER LAKE(MOWAT)	m	metasediments	crystal tuff	yes	yes	--
404	L RIVER LAKE(SAT.)	d+s	felsic tuff	chlorite schist	yes	yes?	--
060	L SEVOGLE RIV #1	d	chlorite schist	----	--	--	--
313	LEAD POND	d+s	felsic tuffs	agglomerate + rhyolite	--	--	yes

* m=massive, d=disseminated, s=stringer

(Table 2 concluded)

URN	NAME	FORM*	HOST ROCKS	ASSOCIATED ROCKS	CHLORITE ZONE	OXIDE FE-FORM	CU ZONE
147	LOUVICOURT	m	brecciated rhyolite	metased + basalt	--	yes	--
148	LOUVICOURT NORTH	d	metarhyolite	metasediments	--	--	--
401	LOWER 44 MILE BK	m	graphitic seds	felsic tuff	--	--	--
158	MCDONOUGH TREND B	s+d+m	felsic tuffs	----	yes	--	--
168	MCDONOUGH W(TR-A)	d+s	felsic tuffs	----	yes	--	--
477	MCMASTER	m+s+d	chlorite schist	graphitic schist	yes	--	yes
478	MIDDLE RIV. W	d+m	chlorite schist	mafic volcanics	yes	--	yes
408	MT. FRONSAC	m+d	metasediments	qtz-fspar augen schist	yes	--	--
414	MURRAY BROOK	m	metasediments	----	yes	--	yes
184	NEPISIGUIT BK N	m?	felsic tuffs	----	--	--	--
241	NEPISIGUIT "A"	m	graphitic slate	felsic tuff	--	--	--
240	NEPISIGUIT "B"	m	slate	felsic volcanics	--	--	--
239	NEPISIGUIT "C"	m	slate	felsic volcanics	--	--	--
145	NEW HIGHRIDGE	d+s+m	metasediments	felsic tuff	yes	--	--
523	NORTH SEVOGLE RIV.	d	graphitic schist	----	--	--	--
062	ORVAN BROOK	m	sericite schist	graphitic schist	--	--	--
483	ORVAN BROOK SOUTH	d	phyllite	augen schist	--	--	--
157	PABINEAU	d	metarhyolite	augen schist	--	--	--
096	PORTAGE BROOK	d+s	lapilli tuff	mafic volc + graph schist	yes	--	--
100	PORTAGE LAKES	s	brecciated rhyolite	----	--	--	yes
183	PORTAGE RIVER- UDD	s	felsic tuff	slate	--	--	yes
139	RESTIGOUCHE	m+d	felsic tuff	brecciated rhyolite	--	--	yes
137	RESTIGOUCHE C4 & C5	d+s	felsic volcanics	graphitic schist	yes	--	yes
066	ROCHE LONG LAC	d+s	felsic tuff	graphitic argillite	yes	--	--
479	ROCKY TURN	m+d	qtz-sericite schist	----	--	--	--
135	SE UPSALQUITCH RIV.	d+m	metasediments	mafic volcanics	--	--	--
245	SOUTH 40 MILE BK	d	augen schist	----	--	--	--
520	SOUTH SEVOGLE RIV.	d	phyllite	----	yes	--	yes
522	SOUTH TOMOGONOPS	d+s	graphitic schist	volcanics	--	--	--
282	STRACHENS BK EAST	d+s	felsic tuff	----	yes	--	--
283	STRACHENS LAKE BK	d+m	cherty argillite	felsic tuff	yes	--	--
252	STRATMAT CENTRAL	m	felsic tuff	----	--	--	--
406	STRATMAT MAIN	d+m	felsic tuff	mafic volcanics	yes	--	yes
253	STRATMAT NORTH	m	sericite schist + chert	felsic volcanics	--	--	--
254	STRATMAT W. B-ZONE	m	metasediments	felsic tuff	yes	--	--
256	STRATMAT W. S-ZONE	s	metasediments	felsic tuff	--	--	yes
255	STRAT/HEATH BOUNDARY	m	metasediments	chlorite tuff	+talc	--	--
407	TAYLOR BROOK	d	felsic volcanics	----	--	--	yes
165	TAYLOR BROOK ROAD	m	felsic tuff	tuffaceous seds	yes	yes	--
416	UPSALQUITCH	d	qtz-sericite schist	qtz-fspar porphyry	yes	--	--
093	UPSALQUITCH LAKE	d	argillaceous seds	felsic volcanics	yes	--	yes
052	WEDGE	m	graphitic slate	felsic tuff	--	--	yes
284	WEST 44 MILE BK	m	qtz-sericite schist	----	--	--	--
402	WEST WEDGE	m+s	metasediments	crystal tuff	yes	--	--
287	WILLETT	m	slate	felsic volcanics	--	--	yes

* m=massive, d=disseminated, s=stringer

TABLE 3. DEFINED TONNAGES FOR BASE-METAL DEPOSITS IN THE BATHURST - NEWCASTLE DISTRICT.

URN	NAME	TONNES	TYPE			GRADE				UPDATE	SOURCE
		(x1000)		Cu%	Pb%	Zn%	Zn/Pb	Au g/t	Ag g/t	YEAR	
484	ARMSTRONG A	3100.0	COMB	0.29	0.42	2.29	5.5	0.68	2.40	1974	D.WILLIAMS, 1974 DNR MIN OCCURRENCE COMPILATION
069	AUSTIN BROOK	907.2	POSS	0.00	1.86	2.93	1.6	0.00	34.29	1974	D.WILLIAMS, 1974 DNR PROPERTY COMPILATION
054	BRUNSWICK NO. 12	59222.0	PPRO	0.32	3.65	8.99	2.5	0.00	99.00	1989	NORTHERN MINER MAG; APRIL,1989.
054	BRUNSWICK NO. 12	97000.0	PROV	0.32	3.65	8.99	2.5	0.00	99.00	1989	NORTHERN MINER MAG; APRIL,1989.
144	BRUNSWICK NO.6	12125.0	PPRO	0.39	2.16	5.43	2.5	0.00	67.00	1983	DAVIES ET AL, 1985, GAC EXCURSION 2, REFNO:3
242	CANOE LANDING L.	20380.0	DRIL	0.56	0.64	1.82	2.8	1.07	29.50	1985	DNR INFO CIRC 86-1, P.56
159	CAPTAIN	311.2	DRIL	1.99	0.00	0.00		0.58	9.60	1983	DNR INFO CIRC 83-2, P.44
170	CAPTAIN NORTH EXT.	210.0	DRIL	0.00	2.98	7.60	2.6	0.00	100.11	1990	NORTHERN MINER; JANUARY 29, 1990.
444	CARIBOU	825.6	PPRO	3.40	0.00	0.00		0.00	0.00	1974	DNR INFO CIRC 84-1, P.46
444	CARIBOU	63.5	PPRO	0.00	0.00	0.00		1.40	26.58	1983	DNR INFO CIRC 85-2, P.76
444	CARIBOU	5500.0	POSS	0.00	3.59	8.37	2.3	1.78	101.76	1989	NORTHERN MINER MAG; JANUARY,1989
444	CARIBOU	5428.0	COMB	0.00	3.91	8.77	2.2	1.66	113.25	1989	NORTHERN MINER MAG; JANUARY,1989
444	CARIBOU	290.3	PPRO	0.35	3.34	7.24	2.2	1.37	102.85	1990	R. CAVELLERO, CARIBOU MINES
071	CHESTER	1451.5	PROB	0.63	0.83	2.12	2.6	0.00	0.00	1983	DNR INFO CIRCULAR 83-2
071	CHESTER	11793.0	PROB	0.77	0.00	0.00		0.00	0.00	1983	DNR INFO CIRCULAR 83-2
122	FAB MAIN ZONE	16330.0	POSS	0.30	0.00	0.60		0.00	10.29	1979	H.E.MACLELLAN/D.W.HATTIE; NB MIN OCCURR FILE
046	FLAT LANDING BROOK	1751.0	PROB	0.03	0.94	4.90	5.2	0.00	19.50	1979	DNR OPEN FILE REPT 82-31, P 96
409	HALFMILE C-ZONE	800.0	DRIL	0.08	3.63	10.06	2.8	0.00	52.00	1989	DNR INFO CIRC 89-1
410	HALFMILE NORTH(MAIN)	1088.6	DRIL	0.46	0.87	4.63	5.3	0.00	8.90	1989	DNR INFO CIRC 83-2 P.80
409	HALFMILE (LOWER AB)	7900.0	DRIL	0.10	2.43	7.45	3.1	0.00	22.00	1989	DNR INFO CIRC 89-1
409	HALFMILE (UPPER AB)	2100.0	DRIL	0.45	2.26	6.55	2.9	0.00	37.00	1989	DNR INFO CIRC 83-2 P.80
124	HEADWAY	263.1	POSS	1.43	2.10	6.20	3.0	0.00	20.91	1966	DNR ASSESSMENT FILE #472314
395	HEATH STEELE ACD	663.9	PPRO	0.47	2.03	7.25	3.6	0.00	67.20	1983	D.ARCHIBALD, HEATH STEELE MINES
395	HEATH STEELE ACD	4700.0	DRIL	1.00	1.31	5.34	4.1	0.00	48.40	1985	DAVIES ET AL, 1985, GEOL ASSOC CAN EXCURSION 2
396	HEATH STEELE B-ZONE	15793.9	PPRO	1.01	1.65	4.48	2.7	0.00	62.06	1983	D.ARCHIBALD, HEATH STEELE MINES
396	HEATH STEELE B-ZONE	2280.0	PROV	0.74	2.28	6.05	2.7	0.00	69.71	1990	NORTHERN MINER MAG; JANUARY, 1990.
397	HEATH STEELE E-ZONE	699.0	PROV	1.18	2.48	5.29	2.1	0.00	93.19	1990	NORTHERN MINER MAG; JANUARY, 1990.
257	HEATH STEELE N-5	204.0	PROV	0.35	3.18	6.84	2.2	0.00	26.88	1990	NORTHERN MINER MAG; JANUARY, 1990.
014	KEY ANACON	1686.0	DRIL	0.20	3.03	7.43	2.5	0.00	91.54	1985	CANADIAN MINES HANDBOOK 1985-86
147	LOUVICOURT	136.1	PROV	0.42	1.23	1.00	0.8	0.96	90.86	1976	DNR ASSESSMENT FILE # 471255
477	MCMASTER	180.0	DRIL	0.60	0.00	0.00		0.00	0.00	1964	D.WILLIAMS,1974/ DNR MIN OCCURR COMPILATION
414	MURRAY BROOK	1724.0	PROV	0.00	0.00	0.00		1.21	41.37	1989	NORTHERN MINER MAG, JANUARY, 1989
414	MURRAY BROOK	298.5	PROV	4.68	0.00	0.00		0.00	0.00	1989	NORTHERN MINER, APRIL 17, 1989
414	MURRAY BROOK	2721.6	PROB	0.00	1.60	4.90	3.1	0.00	54.85	1989	NORTHERN MINER, APRIL 17, 1989
241	NEPISIGUIT "A"	1542.2	DRIL	0.40	0.60	2.80	4.7	0.00	10.29	1976	D. WILLIAMS, 1976 DNR MIN OCCURR COMPILATION
240	NEPISIGUIT "B"	1360.8	DRIL	0.10	0.40	1.90	4.8	0.00	10.29	1976	D. WILLIAMS, 1976 DNR COMPILATION
239	NEPISIGUIT "C"	635.0	DRIL	0.40	0.70	2.10	3.0	0.00	20.57	1976	D. WILLIAMS, 1976 DNR PROPERTY COMPILATION
062	ORVAN BROOK	136.1	DRIL	0.20	3.27	7.13	2.2	0.58	86.40	1974	D. WILLIAMS, 1974 DNR PROPERTY COMPILATION
157	PABINEAU	136.1	POSS	0.00	0.87	2.65	3.0	0.00	0.00	1980	DNR ASSESSMENT FILE # 472530
139	RESTIGOUCHE	1569.4	PROV	0.35	5.36	6.94	1.3	1.20	112.11	1989	NORTHERN MINER, MAY 1, 1989
139	RESTIGOUCHE	1043.1	PROV	0.38	5.96	7.71	1.3	1.37	124.11	1989	NORTHERN MINER, MAY 1, 1989
479	ROCKY TURN	180.0	POSS	0.30	1.50	7.00	4.7	0.00	78.86	1974	D.WILLIAMS,1974/DNR MIN OCCURR COMPILATION
283	STRACHENS LAKE BK	500.0	POSS	0.70	0.60	2.60	4.3	0.00	0.00	1984	HE MACLELLAN, DNR MIN OCCURR FILE, SUSSEX
252	STRATMAT CENTRAL	181.4	DRIL	0.50	4.30	8.00	1.9	0.00	0.00	1983	DNR INFO CIRC 83-2 P.81-82
406	STRATMAT MAIN	453.6	DRIL	1.90	0.00	0.00		0.00	0.00	1982	DNR OPEN FILE REPORT 82-31 P.101
406	STRATMAT MAIN	635.0	DRIL	0.30	1.80	5.20	2.9	0.00	65.14	1982	DNR OPEN FILE REPORT 82-31 P.101
256	STRATMAT W. S-ZONE	181.4	DRIL	2.00	0.00	0.00		0.00	0.00	1982	DNR OPEN FILE REPORT 82-31 P.101
255	STRAT/HEATH BOUNDARY	443.0	PROV	0.27	2.84	7.30	2.6	0.00	44.57	1990	NORTHERN MINER; JANUARY,1990.
255	STRAT/HEATH BOUNDARY	238.0	PROV	0.32	4.38	9.67	2.2	0.00	59.97	1990	NORTHERN MINER; JANUARY, 1990.
052	WEDGE	1503.8	PPRO	2.17	0.24	0.46	1.9	0.03	9.60	1962	D. WILLIAMS, 1976 DNR PROPERTY COMPILATION

TABLE 4. ASSAY VALUES FOR BASE-METAL DEPOSITS IN THE BATHURST - NEWCASTLE DISTRICT.

URN	NAME	SAMPLE	CORE		ASSAY					UPDATE	SOURCE
		TYPE	LENGTH meters	Cu%	Pb%	Zn%	Zn/Pb	Au g/t	Ag g/t	YEAR	
482	ARMSTRONG B	CORE	2.1	0.57	2.07	8.72	4.2	0.00	5.27	1971	DNR ASSESSMENT FILE # 471705
481	ARMSTRONG C	CORE	0.5	0.34	0.00	1.25		0.00	0.00	1971	DNR ASSESSMENT FILE # 471705
480	ARMSTRONG D	CORE	1.5	0.60	1.32	2.20	1.7	0.00	21.60	1971	DNR ASSESSMENT FILE # 471704
149	ASTRABRUN N.& S.	CORE	1.5	0.00	0.18	0.44	2.4	0.00	0.00	1955	DNR ASSESSMENT FILE # 471094
120	A'HEARN BROOK	CORE	1.5	0.19	3.44	1.95	0.6	0.00	14.74	1983	DNR ASSESSMENT FILE # 472948
120	A'HEARN BROOK	CORE	6.9	2.26	16.60	29.10	1.8	0.00	209.14	1983	DNR ASSESSMENT FILE # 472948
551	BEAR(CANOE) LAKE	CORE	13.7	0.00	1.10	0.30	0.3	0.00	3.09	1955	DNR ASSESSMENT FILE # 470755
050	BELLECHASSE	CORE	27.4	0.38	1.93	4.82	2.5	0.00	24.83	1955	DNR ASSESSMENT FILE # 470682
244	BOUCHER BROOK	CORE	2.8	0.00	0.25	2.42	9.7	0.00	0.00	1959	DNR ASSESSMENT FILE # 470982
224	CALIFORNIA L.- 32S	CORE	6.1	0.51	2.56	7.86	3.1	1.71	83.66	1956	DNR ASSESSMENT FILE # 470921
223	CALIFORNIA L.- 68S	CORE	6.2	0.07	0.67	2.00	3.0	0.34	12.00	1976	DNR ASSESSMENT FILE # 470953
169	CAPTAIN WEST	CORE	6.0	0.01	0.21	0.39	1.9	0.00	8.80	1979	DNR ASSESSMENT FILE # 472488
536	CLEARWATER LAKE	CORE	0.9	0.00	1.20	0.04		0.00	81.26	1977	DNR ASSESSMENT FILE # 470475
400	CONSOLIDATED MOR.	CORE	3.7	0.00	0.55	1.53	2.8	0.14	17.49	1986	DNR ASSESSMENT FILE # 473316
146	COULEE	CORE	0.6	0.00	0.07	1.17	16.7	0.00	0.00	1966	DNR ASSESSMENT FILE # 471144
285	DEVIL'S ELBOW	CORE	0.3	0.05	0.90	1.34	1.5	0.00	564.34	1981	DNR ASSESSMENT FILE # 472686
186	FLAT LANDING BK E.	CORE	3.4	0.06	0.38	0.99	2.6	0.00	7.54	1982	DNR ASSESSMENT FILE # 472549
399	42 MILE BROOK	CHIP		0.00	0.17	0.25	1.5	0.00	0.00	1978	DNR ASSESSMENT FILE # 472335
411	44 MILE BK- NO 1	CORE	4.6	0.00	0.15	0.35	2.3	0.00	6.86	1970	DNR ASSESSMENT FILE # 471535
412	44 MILE BK- NO 2	CORE	0.2	0.00	0.00	1.00		0.00	0.00	1972	DNR ASSESSMENT FILE # 471637
143	GILMOUR BK(BEEHLER)	CORE	0.9	0.00	0.00	0.78		0.17	0.00	1954	DNR ASSESSMENT FILE # 471227
167	GORDON MEADOW BK	CORE	15.2	0.01	0.06	0.23	3.8	0.00	0.00	1956	DNR ASSESSMENT FILE # 472305
394	HEATH STEELE G-ZONE	CORE	2.0	1.74	0.13	0.22	1.7	0.00	22.30	1955	D.BOURNE, 1964
237	ISLAND LAKE	CORE	1.2	0.00	0.70	1.80	2.6	0.00	6.17	1954	DNR ASSESSMENT FILE # 471478
053	KNIGHT BROOK	CORE	6.4	0.15	0.05	1.02	20.4	0.00	0.34	1977	DNR ASSESSMENT FILE # 472142
405	L RIVER LAKE(MOWAT)	CORE	6.6	0.02	1.42	2.63	1.9	0.00	29.14	1985	DNR ASSESSMENT FILE # 473283
404	L RIVER LAKE(SAT.)	CORE	0.6	0.08	1.15	1.94	1.7	0.00	17.14	1985	DNR ASSESSMENT FILE # 473283
060	L SEVOGLE RIV #1	GRAB		0.11	0.00	0.10		3.42	0.00	1957	DNR ASSESSMENT FILE # 470315
313	LEAD POND	CORE	0.3	0.01	0.09	0.92	10.2	0.00	6.86	1983	DNR ASSESSMENT FILE # 472925
148	LOUVICOURT NORTH	CORE	4.5	0.10	0.20	1.30	6.5	0.00	3.43	1957	DNR PROPERTY COMPILATION, D.WILLIAMS, 1974

(Table 4 concluded)

URN	NAME	SAMPLE TYPE	CORE LENGTH meters	ASSAY Cu%	Pb%	Zn%	Zn/Pb	Au g/t	Ag g/t	UPDATE YEAR	SOURCE
401	LOWER 44 MILE BK	CORE	1.6	0.09	0.70	2.46	3.5	0.41	18.86	1979	DNR ASSESSMENT FILE # 472511
158	MCDONOUGH TREND B	CORE	7.2	1.17	0.02	0.02	1.0	0.00	5.49	1973	DNR ASSESSMENT FILE # 471211
168	MCDONOUGH W(TR-A)	GRAB		0.02	1.22	0.17	0.1	0.69	16.11	1975	DNR ASSESSMENT FILE # 472413
478	MIDDLE RIV. W	CORE	1.2	1.53	0.02	0.19	9.5	3.43	9.60	1975	DNR ASSESSMENT FILE # 471795
408	MT. FRONSAC	CORE	2.1	0.00	2.59	2.57	1.0	0.00	60.34	1979	DNR OPEN FILE REPORT 81-25 P.70
184	NEPISIGUIT BK N	CORE	1.0	0.30	0.15	0.00		0.00	5.49	1954	DNR ASSESSMENT FILE # 471264
145	NEW HIGHRIDGE	CORE	1.2	0.14	0.89	1.64	1.8	0.00	17.14	1965	DNR ASSESSMENT FILE # 471129
523	NORTH SEVOGLE RIV.	CORE	1.5	0.00	0.15	0.30	2.0	0.00	0.00	1955	DNR ASSESSMENT FILE # 470676
483	ORVAN BROOK SOUTH	CORE	0.2	0.28	1.12	3.50	3.1	0.38	34.56	1970	DNR ASSESSMENT FILE # 471700
096	PORTAGE BROOK	CORE	46.9	0.21	0.36	2.30	6.4	0.00	0.00	1978	DNR ASSESSMENT FILE # 472813
100	PORTAGE LAKES	CORE	1.5	0.22	0.00	0.00		0.00	0.00	1961	DNR ASSESSMENT FILE # 470867
183	PORTAGE RIVER- UDD	CORE	0.9	0.11	0.00	0.49		0.00	0.00	1954	DNR ASSESSMENT FILE # 471269
137	RESTIGOUCHE C4 & C5	CORE	3.1	0.30	0.10	0.70	7.0	0.00	0.00	1958	DNR ASSESS FILE #'S 471881 AND 471882
066	ROCHE LONG LAC	CORE	1.5	0.60	1.41	2.13	1.5	0.00	17.73	1955	D.HATTIE / NB MINERAL OCCURRENCE FILE
135	SE UPSALQUITCH RIV.	CORE	0.3	0.00	0.87	2.36	2.7	0.00	0.00	1962	DNR ASSESSMENT FILE # 471884
245	SOUTH 40 MILE BK	GRAB		0.02	0.07	0.00		0.00	0.00	1963	C.S.CLEMENTS, 125TH ANNUAL REPORT, DNR, 1963
520	SOUTH SEVOGLE RIV.	CORE	0.7	0.50	0.00	0.00		0.00	0.00	1966	D.WILLIAMS, 1974 NB MINERAL OCCURRENCE FILE
522	SOUTH TOMOGONOPS	CORE	0.5	0.00	0.08	0.54	6.8	0.00	0.00	1966	DNR ASSESSMENT FILE # 470698
282	STRACHENS BK EAST	CORE	1.0	0.03	0.22	1.05	4.8	0.00	1.92	1983	DNR ASSESSMENT FILE # 472962
253	STRATMAT NORTH	CORE	9.0	0.35	0.62	2.03	3.3	0.00	8.57	1981	DNR ASSESSMENT FILE # 472679
254	STRATMAT W. B-ZONE	CORE	1.3	0.40	6.46	13.96	2.2	0.00	75.77	1976	D.WILLIAMS, 1976 MIN OCCURR COMPILATION
407	TAYLOR BROOK	CORE	1.0	0.58	0.00	0.00		0.00	0.00	1967	DNR ASSESSMENT FILE # 471681
165	TAYLOR BROOK ROAD	CORE	0.2	0.11	13.60	13.23	1.0	0.00	37.37	1980	DNR ASSESSMENT FILE # 472516
416	UPSALQUITCH	CORE	0.6	0.12	1.20	2.25	1.9	1.03	31.54	1978	DNR ASSESSMENT FILE # 472451
093	UPSALQUITCH LAKE	GRAB		0.05	0.42	1.18	2.8	0.00	1.37	1983	DNR ASSESSMENT FILE # 472947
284	WEST 44 MILE BK	CORE	0.4	0.01	0.00	5.15		0.17	0.00	1962	DNR ASSESSMENT FILE # 471626
402	WEST WEDGE	CORE	3.8	0.78	5.35	12.84	2.4	1.30	70.60	1984	DNR INFO CIRC 86-1: NB MINERAL INDUSTRY-1985
287	WILLETT	CORE	0.9	3.17	12.83	9.78	0.8	0.00	473.83	1976	D.WILLIAMS, 1976 NB MIN OCCURR COMPILATION

Chlorite is common in the footwall of some deposits but its lateral distribution is not well-established. Compositional data are limited to four deposits (Chester, Austin Brook, Brunswick No. 12 and Caribou); the chlorites associated with them are all high in Fe (Petruk 1959; Sutherland 1967; Davies 1972; Juras 1981; van Staal 1985). Chlorites associated with Kuroko-type deposits typically have high-Mg contents, rather than high Fe (Shirozu 1974; Urabe et al. 1983), and according to Franklin (1986, pp. 62-63) the Mg is derived from downward-circulating seawater that becomes entrained in the metal-bearing fluids. The only Mg-rich mineral in the Bathurst-Newcastle deposits is talc, which is a minor constituent in at least four deposits.

An Algoma-type iron-formation (Davies 1972), composed of banded magnetite+hematite+quartz, is associated with some deposits. It overlies the sulphide bodies and commonly extends laterally beyond them. A few have silicate (chlorite)-facies and carbonate (siderite)-facies iron-formatons as well, e.g., Brunswick No. 12, (Luff 1975, 1977), but the spatial and genetic relationships among the three types are not well documented.

Several deposits have distinct Cu-zones and at least one is a Cu-only deposit (Middle River West). A few Cu-zones have been interpreted as stockwork, feeder-pipes (cf. Jambor 1979), but van Staal and Williams (1984) questioned this interpretation, at least for the Brunswick deposits. If the Cu-zones are related to "feeder-pipes", there is little or no evidence of hydrothermal brecciation, implying that the metal-bearing fluids were of relatively low temperature and devoid of a gas-phase, i.e., probably non-magmatic. The Middle River West deposit is within the pillow lava sequence that structurally overlies the felsic volcanic pile (cf. van Staal and Langton, this volume). Other Cu-only deposits should be present in these mafic volcanics.

Table 3 shows tonnage and grade figures for 35 deposits and Table 4 shows assay results from 59 occurrences. A striking feature of the deposits is that they have very similar Zn/Pb ratios. Most fall in the range 1.5 to 3.5. Only eight (Armstrong A, Flat Landing Brook, Halfmile Lake North, Heath Steele A, C, D, Nepisiguit A & B, Rocky Turn and Strachens Lake Brook) are greater than 3.5 and two (Louvicourt and Restigouche) are less than 1.5. Most of the 59 occurrences also fall in the same range with twelve greater than 3.5 and five less than 1.5.

STRATIGRAPHY OF THE BRUNSWICK DEPOSITS

The Brunswick No. 6 and No. 12 deposits (144 and 54, respectively in Fig. 15) are spatially associated with a "felsic volcanic pile". These felsic rocks are underlain by a quartzite/phyllite unit commonly referred to as "older sediments," (Miramichi Group of van Staal and Fyffe, in press) and are overlain by a mafic volcanic unit and/or a greywacke/slate unit generally called "younger sediments," (Boucher Brook Formation of van Staal and Fyffe. In the past, these volcanics were divided into two lithologic units (cf. Davies 1979); namely a schistose to massive rhyolite unit (Ofv1) and a quartz and/or feldpsar-porphyritic unit (Ofv2), informally referred to as Bathurst porphyry or augen schist. The former unit was thought to be a mixture of tuff, breccia and flow-banded lava, whereas the latter unit was considered to be a submarine ash-flow tuff (Davies and McAllister 1980; Davies et al. 1983, 1985). These units comprise the Flat Landing Brook and Nepisiguit Falls formations, respectively, of van Staal and Fyffe (in press).

In general, the rocks in the felsic volcanic pile at the No. 6 deposit are very similar to those at No. 12 (cf. Rutledge 1972), although there is an important difference in the hanging-wall stratigraphy of the two deposits as indicated below. The footwall sequence at both deposits comprises three rock units in ascending stratigraphic order (Fig. 16). They are quartz-feldspar-augen schist (QFAS), quartz-augen schist (QAS) and chlorite schist (GGS).

The QFAS contains 5-10% quartz (up to 5 mm) and 10-20% feldspar (up to 15 mm). Primary layering is absent. Thin sections of less deformed rocks show that the quartz has volcanic features, i.e., crystals are euhedral to rounded with numerous embayments and some contain devitrified glass inclusions. These features are not compatible with a porphyroblastic origin for this quartz as suggested by Hopwood (1976). The absence of angular quartz-fragments, excluding tectonically broken crystals, shows that the QFAS is a lava or hypabyssal intrusion rather than a pyroclastic unit. The feldspar in the QFAS is subhedral to euhedral and locally exhibits twinning. Originally, it was probably sanidine but it is now microperthite, a common mineral in devitrified rhyolites.

Quartz-augen schist overlies and is in apparent depositional contact with the QFAS. The QAS contains 10-20% quartz (1-5 mm) and little or no feldspar. Primary layering is present but difficult to see except in large polished outcrops. Layers range in thickness from 30 cm to more than 1 m. Poorly developed, normal grading occurs in some layers and overall the unit fines upward, although there are exceptions as indicated by the lower unit of fine-grained siltstone in the stratigraphic column for No. 12. Thin sections show that quartz grains in the QAS are subangular to subrounded and that feldspars, or pseudomorphs after feldspar, are generally absent. The absence of feldspar is difficult to explain if the QAS is an ash-flow tuff, as generally reported in the literature, but can be attributed to pre-depositional weathering if the QAS is of sedimentary origin.

Chlorite schist, also called "footwall metasediments" (Luff 1975), gradationally overlies fine-grained QAS and directly underlies massive sulphides. The chlorite schist is a dark greenish grey siltstone (GGS) that typically contains disseminated pyrite. Primary layering is generally obscured by

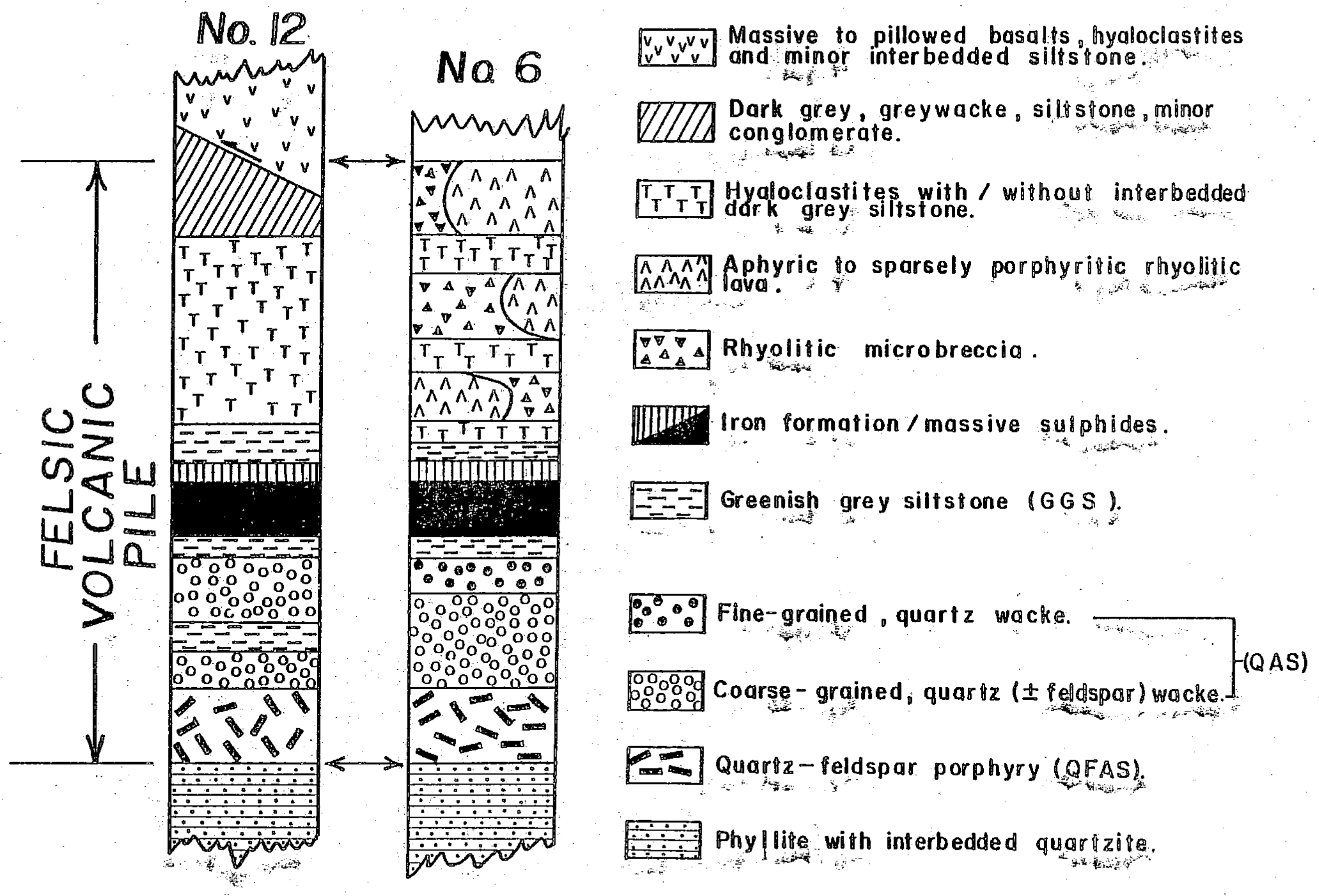

FIGURE 16. Diagrammatic stratigraphic columns of the Brunswick No. 6 and No. 12 deposits.

deformation, but where visible is very thin. Lithologically similar rocks overlie the iron formation but are light greenish grey in color, i.e., non-chloritic and devoid of pyrite.

The hanging-wall stratigraphy at No. 12 differs from that at No. 6. At No. 12 the rocks include siltstone, re-sedimented(?) hyaloclastite, greywacke and minor conglomerate that, in at least one locality, contains massive sulphide clasts. Massive rhyolite and pyroclastic rocks are absent at No. 12. At No. 6, felsic volcanic rocks are common in the post-ore sequence and are mainly aphyric or feldspar-porphyritic rhyolites and their autobrecciated equivalents (including hyaloclastites).

GEOCHEMISTRY

Lithogeochemistry (Tables 5, 6, Fig. 17) shows that the QFAS is compositionally uniform and comparable to average rhyolites in SiO_2, Al_2O_3, CaO, and K_2O. Total iron (as Fe_2O_3), TiO_2, and MgO are high, whereas Na_2O is low by an order of magnitude. The low Na_2O must be an alteration effect but the high TiO_2 (and Fe_2O_3) is probably a primary feature that may have metallogenic significance. The QAS and GGS are compositionally variable but are similar to sandstones and mudstones, respectively, particularly in their SiO_2, Al_2O_3, and K_2O contents (Fig. 17). The hanging-wall rhyolites (HWR) have higher Th and Y contents than the QFAS but lower La/Yb ratios (Figs. 18, 19). However, both the HWR and QFAS are distinct from QAS and GGS in a total alkalies versus SiO_2/Al_2O_3 diagram (Fig. 20). Also, the iron to iron-plus-magnesium ratio (F/F+M) is generally higher in the QAS and GGS than in the QFAS or HWR, whereas Sr is lower (Fig. 18).

There are similarities and differences in the rare-earth-element (REE) profiles from the four rock types. Profiles from the QFAS are all very similar and exhibit light-REE enrichment relative to heavy-REE's with a moderate, negative-Eu anomaly (Fig. 21a). Profiles from the QAS are similar in form to the QFAS but display a greater range in REE values (Fig. 21b). Profiles from the HWR differ from those in the QFAS in that they are more enriched in heavy REE's and have a more pronounced negative-Eu anomaly (Fig. 21b). Those in the GGS are also enriched in heavy-REE's but they have an insignificant Eu anomaly (Fig. 21b).

DISCUSSION

The "felsic volcanic pile" in the vicinity of the No. 6 and No. 12 deposits contains a significant sedimentary component. It is divisible into a lower sequence that is characterized by megacrystic rhyolite or porphyry (QFAS) and coarse to fine-grained quartz (±feldspar) wackes (QAS), and an upper sequence that is characterized by aphyric to sparsely porphyritic rhyolite (HWR), microbreccias and hyaloclastites with interbedded dark grey sedimentary rocks. True pyroclastic rocks appear to be absent. A greenish grey silstone (GGS) unit, which

TABLE 5. COMPOSITIONAL RANGES OF THE BRUNSWICK NO. 6 AND 12 MINE SEQUENCE.

	"GGS" (n= 5)	"QAS" (n=16)	"QFAS" (n=6)	"HWR" (n=7)
SiO_2	51.5 - 66.5	60.7 - 74.5	71.2 - 72.0	69.2 - 77.1
TiO_2	0.54 - 1.09	0.38 - 0.88	0.5 - 0.54	0.18 - 0.68
Al_2O_3	11.0 - 19.5	10.8 - 15.3	12.9 - 13.5	11.6 - 14.4
Fe_2O_{3T}	9.0 - 18.0	6.2 - 14.2	3.16 - 3.56	1.54 - 4.31
MgO	1.29 - 4.67	0.85 - 3.31	1.25 - 1.87	0.44 - 1.45
CaO	0.05 - 0.35	0.04 - 0.24	0.35 - 0.44	0.10 - 2.3
Na_2O	0.04 - 0.06	0.02 - 0.16	2.05 - 2.87	1.56 - 5.77
K_2O	1.09 - 5.17	0.71 - 2.74	3.93 4.3	0.36 - 6.63

	Mudrocks (n=894)	Sandstones (n=208)	Rhyolites (n=343)
SiO_2	3.4 - 60.2	66.1 - 77.1	71.1 - 75.9
TiO_2	0.5 - 0.8	NO DATA	0.14 - 0.40
Al_2O_3	3.8 - 17.3	8.1 - 15.1	13.1 - 15.1
Fe_2O_{3T}	5.7 - 7.9	2.3 - 6.6	1.3 - 2.5
MgO	2.1 - 2.7	0.5 - 2.4	0.2 - 0.6
CaO	1.4 - 6.0	0.6 - 6.2	0.7 - 2.0
Na_2O	1.0 - 1.8	0.9 - 3.1	3.6 - 3.8
K_2O	2.6 - 3.7	1.3 - 2.9	4.3 - 4.9

<u>NOTE</u>: Mudrock and sandstone data from Blatt, Middleton, and Murray (1971); and rhyolite data from Ewart (1979) are provided for comparison.

GGS	greyish green siltstone
QAS	quartz augen schist
QFAS	quartz-feldspar augen schist
HWR	hanging wall rhyolites

TABLE 6. CHEMICAL ANALYSIS OF THE BRUNSWICK NO. 6 AND 12 MINE SEQUENCE.

SAMPLE	OP-6A	OP-7A	OP-8	OP-22	OP-24	OP-11	OP-3B	OP-10	OP-4A	OP-21	OP-3A	OP-19
GROUP	1	1	1	1	1	2	2	2	2	2	2	2
SiO_2	51.50	65.90	66.50	64.10	64.20	64.90	67.80	74.50	63.50	63.70	67.40	60.70
TiO_2	1.09	0.77	0.74	0.65	0.54	0.83	0.48	0.38	0.66	0.74	0.73	0.77
Al_2O_3	19.50	12.90	12.90	14.20	11.00	15.20	16.80	11.50	12.40	13.30	13.10	13.40
Fe_2O_3	4.61	3.45	3.43	1.52	10.55	1.95	1.18	1.53	8.30	1.99	2.52	0.86
FeO	6.20	5.80	5.00	8.80	6.70	7.60	2.20	5.00	5.40	10.00	7.90	12.00
MnO	0.21	0.21	0.16	0.08	0.06	0.06	0.08	0.03	0.16	0.06	0.08	0.08
MgO	4.67	2.76	2.55	2.13	1.29	1.96	2.27	1.18	1.50	2.51	1.33	3.31
CaO	0.35	0.32	0.30	0.13	0.05	0.19	0.31	0.17	0.04	0.13	0.24	0.16
Na_2O	0.17	0.10	0.11	0.14	0.13	0.16	3.16	0.13	0.06	0.10	0.11	0.08
K_2O	5.17	3.58	3.70	2.47	1.09	2.74	3.37	2.30	2.22	1.94	2.43	1.59
P_2O_5	0.30	0.23	0.23	0.12	0.18	0.18	0.21	0.16	0.16	0.15	0.16	0.15
H_2O+	3.80	3.00	2.80	3.30	3.60	3.20	2.20	2.30	4.70	4.00	4.20	4.50
Total	97.57	99.02	98.42	97.64	99.39	98.97	100.06	99.18	99.10	98.62	100.20	97.60
Li	58	30	26	30	18	22	26	32	12	28	18	32
Be	7	6	5	3	4	6	4	3	7	4	6	4
Sc	24	15	13	9	8	7	7	3	10	14	9	11
V	68	56	56	120	58	80	42	16	100	94	72	88
Cr	1	2	2	46	16	24	20	1	44	1	20	14
Co	14	13	14	9	73	11	7	7	3	12	6	17
Ni	5	3	3	37	15	12	19	3	4	12	6	16
Cu	4	10	10	6	1100	1	2	2	61	14	2	0
Zn	540	460	390	57	1200	28	82	38	60	58	47	29
Ga	32.5	16.9	18.1	21.9	15.4	22.3	26.3	16.8	19.1	20.2	18.4	21.4
As	7	3	4	12	230	10	4	11	20	11	23	7
Rb	211	72	80	134	59	138	140	125	124	116	132	88
Sr	25	16	16	9	32	8	77	10	531	7	10	4
Y	32	18	18	7	6	11	59	14	8	10	11	13
Zr	565	390	373	97	114	341	204	174	97	318	295	300
Nb	18	14	14	7	6	5	19	6	17	8	39	4
Sn	3	2	6	5	2	5	4	9	7	5	9	5
Sb	1.4	1.2	1.6	1.2	7.6	0.8	1.0	0.6	1.4	1.2	2.2	0.6
Ba	2140	794	795	738	920	407	648	312	378	516	415	314
La	63.1	40.4	36.2	31.4	21.0	61.2	89.0	21.1	32.2	44.4	48.7	52.5
Yb	4.9	2.9	2.7	1.1	1.3	1.0	3.0	1.7	1.3	1.0	1.3	1.0
Tl	3.1	1.0	1.2	1.4	3.3	0.9	0.9	0.8	0.5	0.8	0.5	0.5
Pb	1	12	44	1	300	12	142	1	4	1	12	1
Th	19.1	11.9	11.9	9.9	6.8	19.3	17.0	11.1	11.2	16.8	17.0	18.1
U	5.4	3.4	3.2	3.9	1.9	2.3	5.9	4.3	2.6	1.6	2.1	1.8

(Table 6 continued)

SAMPLE	OP-9	OP-17	OP-12	OP-16	OP-14	OP-18	OP-15	OP-20	OP-13	OP-32	OP-6B	OP-34
GROUP	2	2	2	2	2	2	2	2	2	4	4	4
SiO_2	73.60	67.90	69.50	72.30	74.10	73.80	73.20	63.50	63.60	71.60	71.10	72.00
TiO_2	0.39	0.75	0.70	0.46	0.38	0.58	0.46	0.76	0.88	0.50	0.53	0.51
Al_2O_3	8.74	13.30	13.20	10.80	11.60	11.20	11.40	14.20	15.30	13.50	14.10	13.30
Fe_2O_3	1.46	1.48	1.42	1.48	1.07	0.81	1.34	1.15	1.93	0.99	1.03	1.27
FeO	10.20	7.00	7.10	6.90	4.60	5.70	5.80	9.40	8.70	2.20	2.30	1.70
MnO	0.06	0.05	0.05	0.08	0.03	0.04	0.02	0.05	0.05	0.06	0.05	0.06
MgO	1.09	1.66	1.88	1.61	0.85	0.94	0.98	2.35	2.17	1.38	1.47	1.25
CaO	0.21	0.13	0.17	0.18	0.23	0.21	0.21	0.14	0.17	0.34	0.82	0.41
Na_2O	0.02	0.13	0.12	0.10	0.11	0.14	0.13	0.15	0.13	2.38	2.95	2.87
K_2O	0.71	2.46	2.28	1.86	2.61	2.25	2.20	2.38	2.59	4.34	4.02	3.93
P_2O_5	0.18	0.15	0.15	0.15	0.18	0.16	0.18	0.15	0.18	0.16	0.18	0.17
H_2O^+	2.80	3.20	2.90	2.80	2.20	2.10	2.50	3.60	3.60	1.40	1.40	1.50
Total	99.46	98.21	99.47	98.72	97.96	97.93	98.42	97.83	99.30	98.85	99.95	98.97
Li	18	20	26	22	16	16	22	36	28	38	32	32
Be	3	4	4	3	2	2	2	3	5	2	4	2
Sc	4	5	7	3	4	5	5	10	9	4	8	5
V	24	52	58	32	32	40	40	68	80	44	62	40
Cr	6	18	10	8	6	14	1	20	1	16	18	16
Co	21	9	10	9	6	7	7	12	12	6	6	6
Ni	7	10	12	8	4	8	4	12	10	12	12	11
Cu	13	6	1	1	2	2	0	6	3	13	10	14
Zn	260	43	26	25	16	44	13	65	19	76	57	62
Ga	14.7	19.3	18.9	17.9	16.2	17.0	16.6	20.8	21.0	18.1	16.7	16.4
As	490	6	4	1	8	4	9	9	4	110	11	10
Rb	58	125	125	114	161	126	121	122	135	153	160	135
Sr	19	6	7	6	6	16	7	7	7	73	104	67
Y	9	10	10	12	12	10	9	12	10	14	14	15
Zr	173	321	311	185	158	242	176	335	356	171	186	208
Nb	4	8	5	8	6	8	7	8	8	11	23	12
Sn	4	4	9	9	6	5	5	5	4	2	3	5
Sb	3.0	0.4	0.6	0.6	0.8	0.8	0.4	0.6	0.6	0.6	0.2	0.2
Ba	123	464	347	378	340	403	356	521	409	866	733	789
La	31.6	44.6	51.2	33.1	24.4	36.1	31.9	51.9	56.3	35.6	34.9	36.1
Yb	0.8	0.9	0.9	1.7	1.6	1.0	1.1	0.8	0.9	1.6	1.5	1.7
Tl	0.3	0.7	0.7	1.1	0.9	0.7	0.7	0.8	0.8	0.8	0.6	0.6
Pb	8	12	1	12	8	1	1	12	1	36	16	24
Th	9.9	15.8	16.3	11.6	10.1	14.3	11.9	17.6	20.7	14.5	13.5	13.4
U	2.2	1.8	1.9	3.2	3.9	2.7	3.2	1.8	1.9	3.6	3.6	3.5

(Table 6 concluded)

SAMPLE	OP-36	OP-35	OP-33	KB-6	OP-5A	OP-7B	OP-4B	OP-6C	OP-5B	KB-5
GROUP	4	4	4	5	5	5	5	5	5	5
SiO2	71.60	71.70	71.20	73.50	72.00	77.10	75.20	73.80	69.20	76.30
TiO2	0.50	0.54	0.52	0.20	0.68	0.18	0.50	0.50	0.53	0.22
Al2O3	12.90	13.50	13.50	13.00	13.30	11.60	12.30	12.40	14.40	12.10
Fe2O3	1.25	1.34	0.95	0.89	1.71	0.54	0.61	1.15	1.27	0.80
FeO	1.90	2.00	2.40	1.40	2.34	0.90	2.00	2.60	2.20	0.90
MnO	0.05	0.06	0.05	0.03	0.14	0.03	0.09	0.12	0.10	0.03
MgO	4.08	1.28	1.42	0.60	1.45	0.44	0.91	1.36	1.20	1.09
CaO	0.35	0.36	0.44	0.10	0.25	0.21	1.06	0.91	2.39	0.10
Na2O	2.05	2.73	2.68	2.67	3.53	2.89	5.77	4.07	3.40	1.56
K2O	4.08	4.17	4.12	6.63	2.18	4.90	0.36	1.63	2.31	5.36
P2O5	0.16	0.17	0.17	0.06	0.15	0.03	0.14	0.14	0.15	0.05
H2O+	1.40	1.40	1.30	0.80	2.30	0.50	0.90	1.30	1.60	1.20
Total	100.32	99.25	98.75	99.88	100.03	99.32	99.84	99.98	98.75	99.71
Li	44	38	34	10	24	10	11	18	17	13
Be	3	2	3	4	5	5	3	4	4	6
Sc	6	7	5	10	9	6	10	10	10	11
V	46	36	38	8	66	6	20	20	26	12
Cr	14	18	14	6	24	15	16	15	12	6
Co	6	7	7	0	8	3	5	8	8	0
Ni	10	11	10	2	10	23	3	11	10	3
Cu	13	14	17	4	13	6	4	4	8	8
Zn	58	78	77	83	130	83	65	89	82	83
Ga	17.4	18.8	18.1	21.5	17.1	20.5	15.2	17.9	23.0	22.6
As	5	7	7	2	21	8	16	1	4	3
Rb	157	136	131	229	107	106	17	84	127	224
Sr	51	60	67	32	61	91	155	148	283	50
Y	19	16	15	27	13	94	70	66	58	53
Zr	212	216	226	247	259	312	356	373	384	265
Nb	11	13	11	40	19	28	20	21	22	34
Sn	1	3	2	2	3	10	22	6	11	3
Sb	0.4	0.2	0.4	0.2	0.6	1.1	1.7	0.8	2.0	0.1
Ba	780	827	851	1830	705	1110	211	363	417	1610
La	43.8	38.3	39.1	31.8	42.3	60.0	47.0	43.0	52.0	67.6
Yb	2.0	1.5	1.5	6.0	1.3	6.2	4.0	4.1	4.7	6.9
Tl	0.9	0.8	0.8	1.3	0.3	0.6	0.1	0.6	0.7	0.9
Pb	36	24	28	12	36	16	8	14	17	30
Th	14.3	15.2	14.3	20.8	16.0	22.0	19.0	19.0	21.0	19.9
U	3.2	3.9	3.8	4.7	2.2	4.5	5.3	5.5	5.8	4.6

NOTE:

GROUP 1 = GGS
GROUP 2 = QAS
GROUP 4 = QFAS
GROUP 5 = HWR

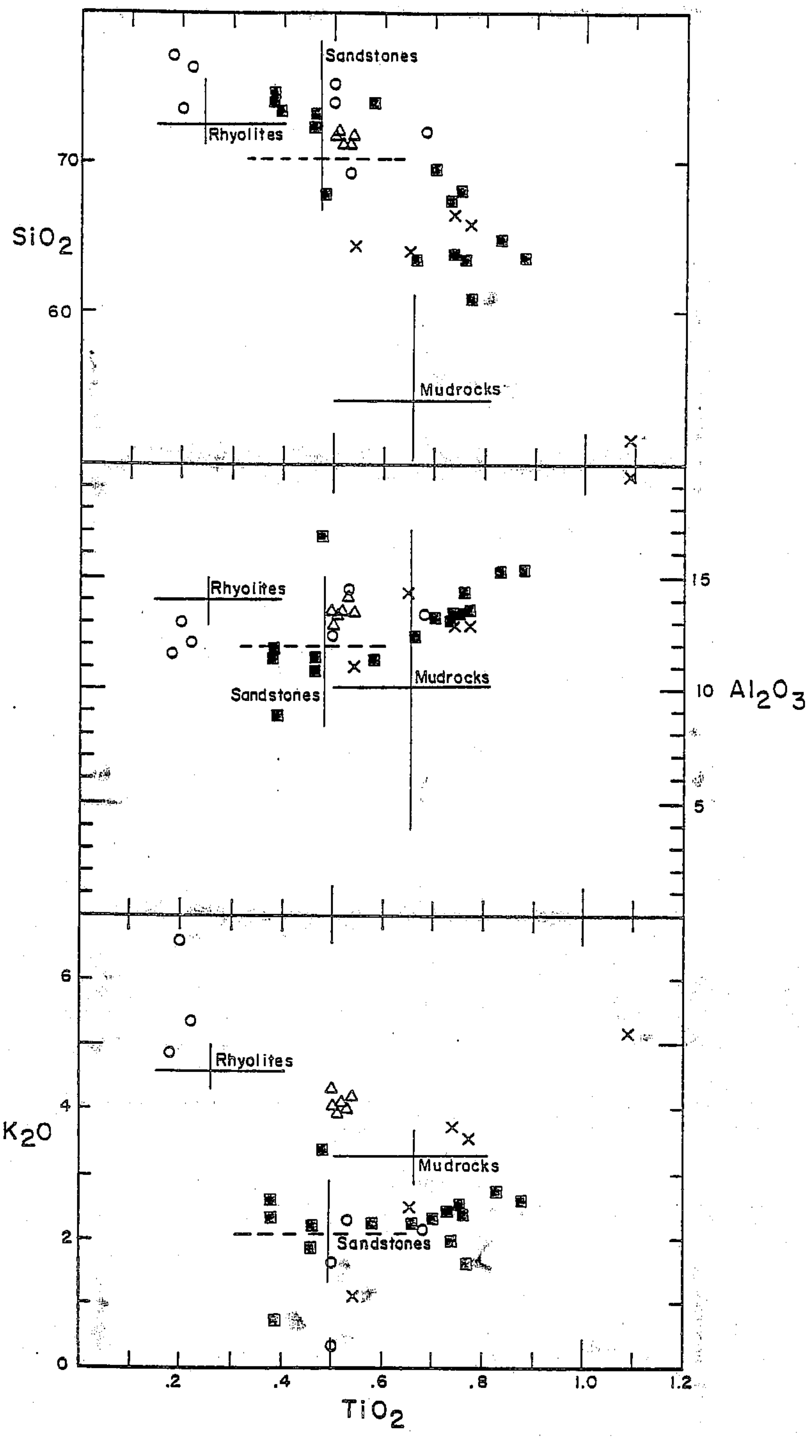

FIGURE 17. Two-element variation diagrams showing SiO_2, Al_2O_3 and K_2O plotted against TiO_2. The compositional ranges of rhyolites, sandstones and mudstones from Table 5 are also shown.

Legend: cross = chlorite schist, open box = fine-grained quartz-augen schist, solid box = coarse-grained quartz-augen schist, triangle = quartz-feldspar-augen schist.

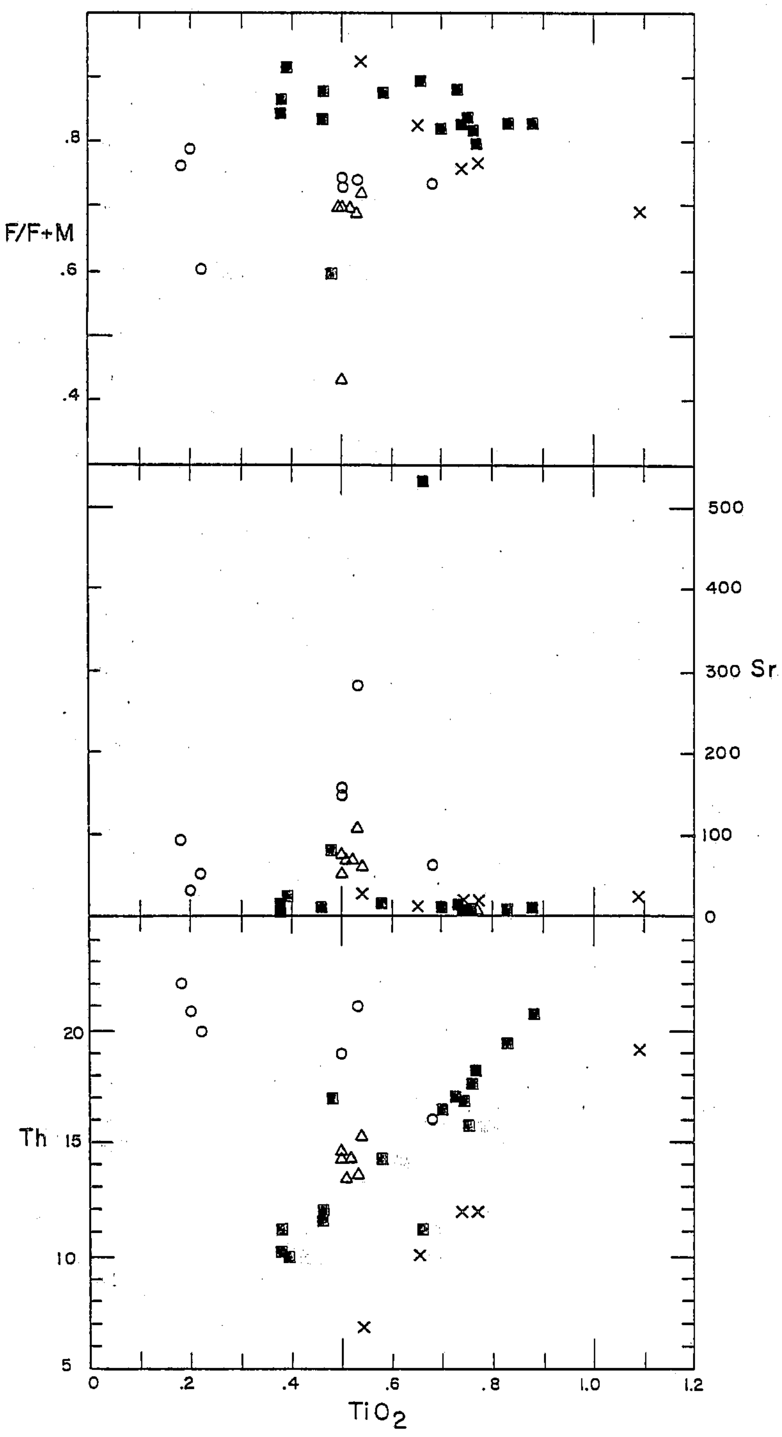

FIGURE 18. Two-element variation diagrams showing F/(F+M), Sr, and Th plotted against TiO_2. Symbols as in Figure 17.

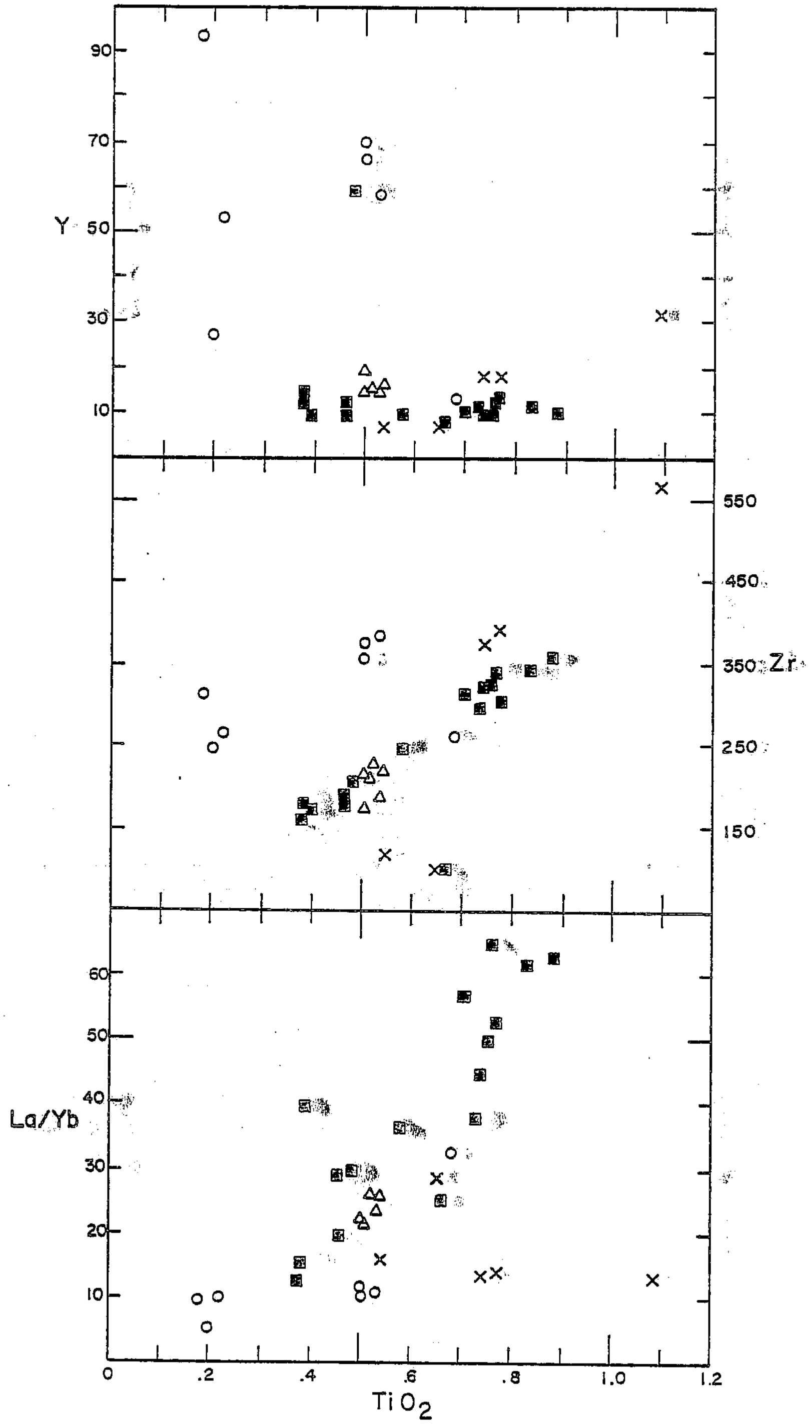

FIGURE 19. Two-element variation diagrams showing Y, Zr, and La/Yb plotted against TiO_2. Symbols as in Figure 17.

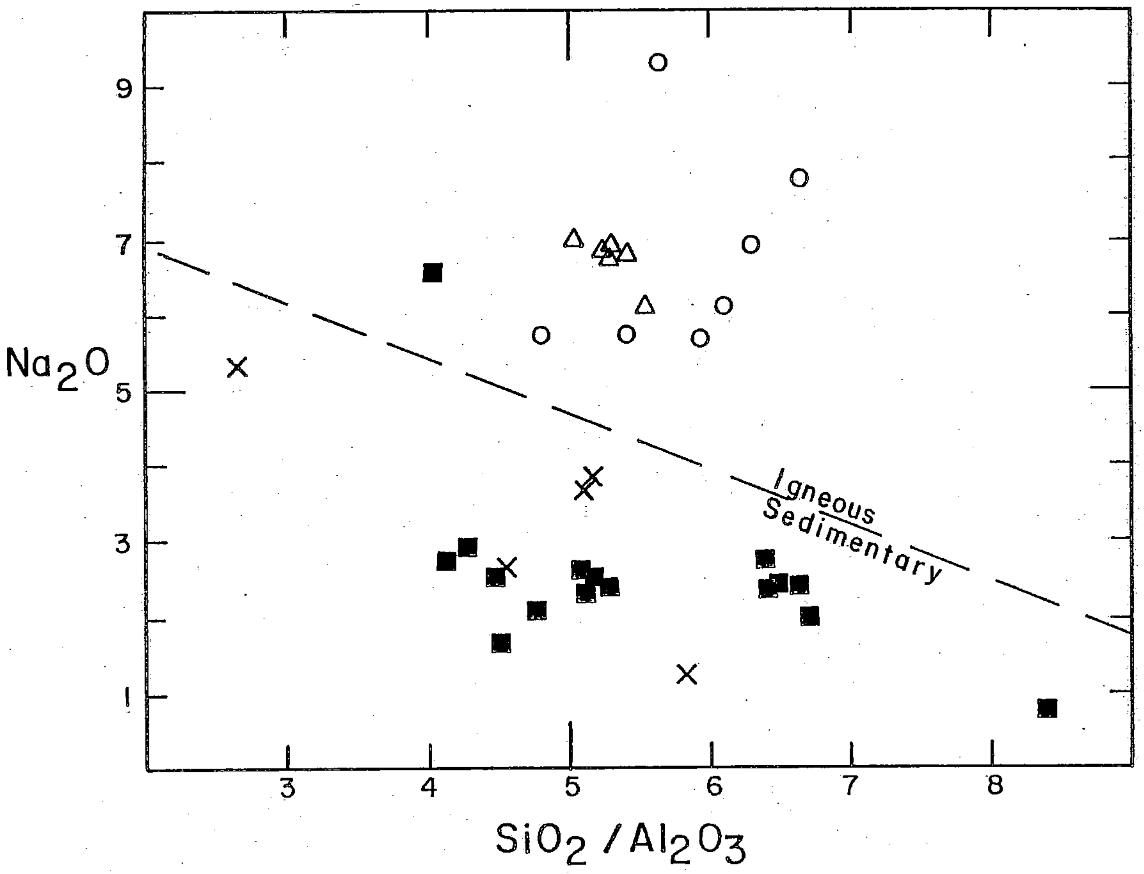

FIGURE 20. Total alkalies versus SiO_2/Al_2O_3. The dashed line separates the igneous samples (above) from the sedimentary samples (below). Symbols as in Figure 17.

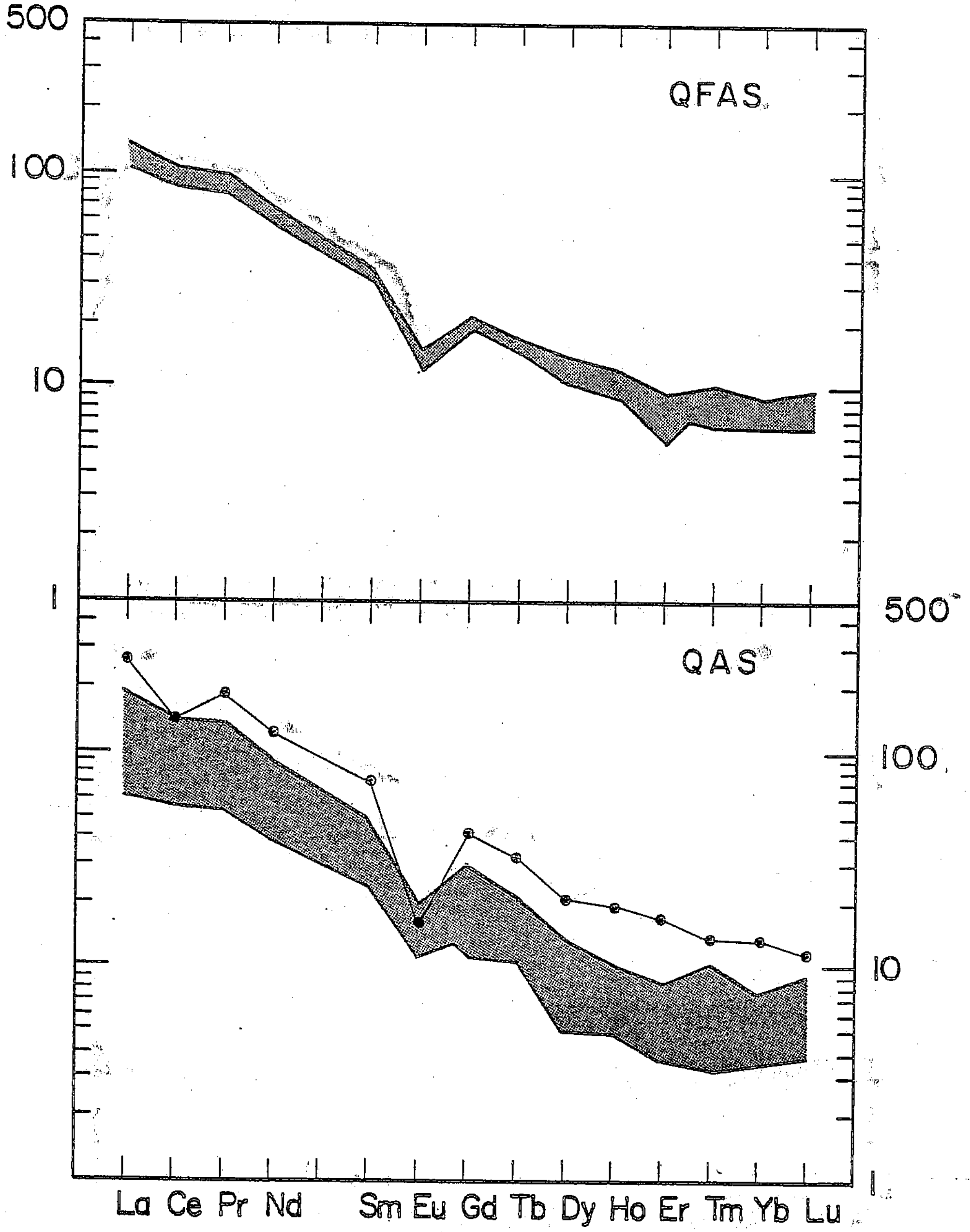

Figure 21a. REE profiles (shading indicates range) for QFAS (n=6) and QAS (n=16). Sample of QAS with large europium anomaly is plotted separately. REE normalization factors are from Nakamura (1974).

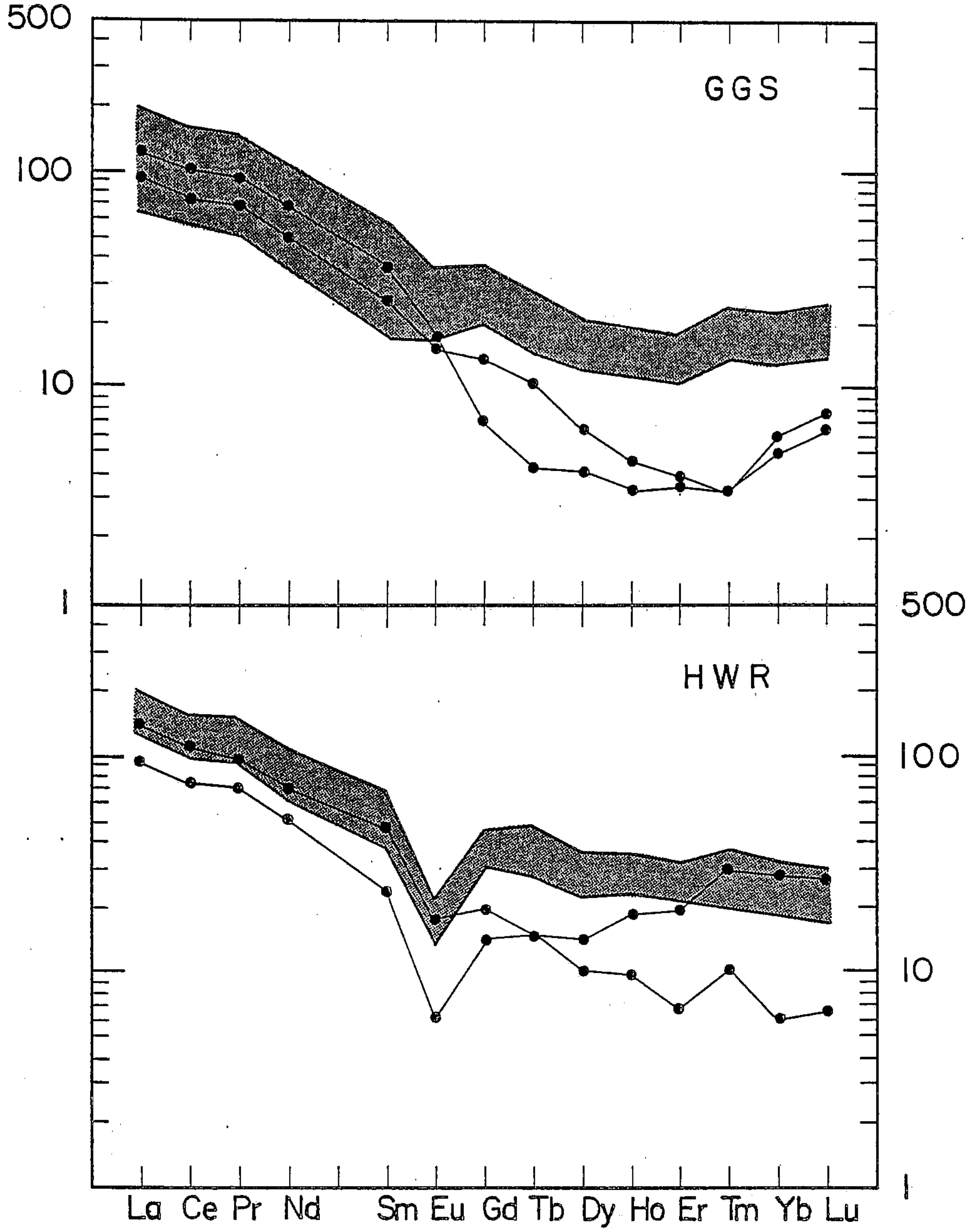

FIGURE 21b. REE profiles (shading indicates range) for GGS (n=5) and HWR (n=7). Two altered chlorite-rich samples of GGS are plotted separately, as are two samples of HWR that fall outside the normal range. REE normalization factors are from Nakamura (1974).

hosts the sulphide deposits, separates the two sequences.

A sedimentary origin for the QAS has several important implications: (1) Rocks similar to the QFAS, or an unidentified coarse-grained granite, were subaerially exposed in order to provide a source of quartz grains (up to 5 mm in diameter) for the QAS; (2) The QAS should be laterally persistent, with a much greater areal extent than the QFAS, and its distribution should be more predictable than that of the volcanic rocks; (3) The QAS was probably deposited in fairly shallow water, at least initially; (4) The overall decrease in grain size of the QAS going toward the GGS either indicates that the water depth became progressively deeper or that the sediment supply was reduced.

The difference in post-ore stratigraphy from No. 6 to No. 12 can be explained in terms of depositional facies associated with a subaqueous rhyolite dome. A subaqueous rhyolite (cf. Pichler 1965; de Rosen-Spence et al. 1980) consists of a core of massive, commonly flow-banded, lava flanked by autobrecciated rhyolite containing massive lobes, flanked by unlayered to layered microbreccias and bedded (in part reworked) hyaloclastites (Fig. 22). The depositonal facies are comparable to those in subaqueous basalts (cf. Dimroth et al. 1978) except that a pillowed-facies is absent. The post-ore rocks at No. 12 are clearly more distal from the eruptive center than those at No. 6 according to this model.

A subaqueous-rhyolite model adequately explains the post-ore stratigraphy, but it does not apply to the pre-ore stratigraphy because there are no breccia and hyaloclastite facies associated with the QFAS. This either indicates that the QFAS represents (a) megacrystic rhyolites deposited in a subaerial environment or (b) extremely high-level sills emplaced beneath the sediment-water interface. The latter interpretation is the most likely.

If pyroclastic rocks are as rare throughout the Bathurst-Newcastle district as they are in the Brunswick stratigraphy, then it would be unlikely that a caldera complex exists in the area as suggested by Harley (1979). A caldera 50 km in diameter, as he postulated, should have pyroclastic eruption products proportional to its area, i.e., about 2000 km^3 (cf. Smith 1979). However, rhyolites rather than pyroclastic rocks predominate in the district and their eruption volumes are too small to effect catastrophic subsidence, i.e., caldera collapse.

If the stratigraphic relationships in the vicinity of the Brunswick deposits can be extrapolated to the rest of the district, then a diagrammatic stratigraphic model can be constructed for the camp (Fig. 23). In this model, a felsic volcanic pile interfingers with coeval sedimentary rocks. The lower part of the pile consists of quartz (±feldspar) wackes, erosional detritus derived from igneous rocks containing quartz up to 5 mm in diameter, and quartz-feldspar porphyritic

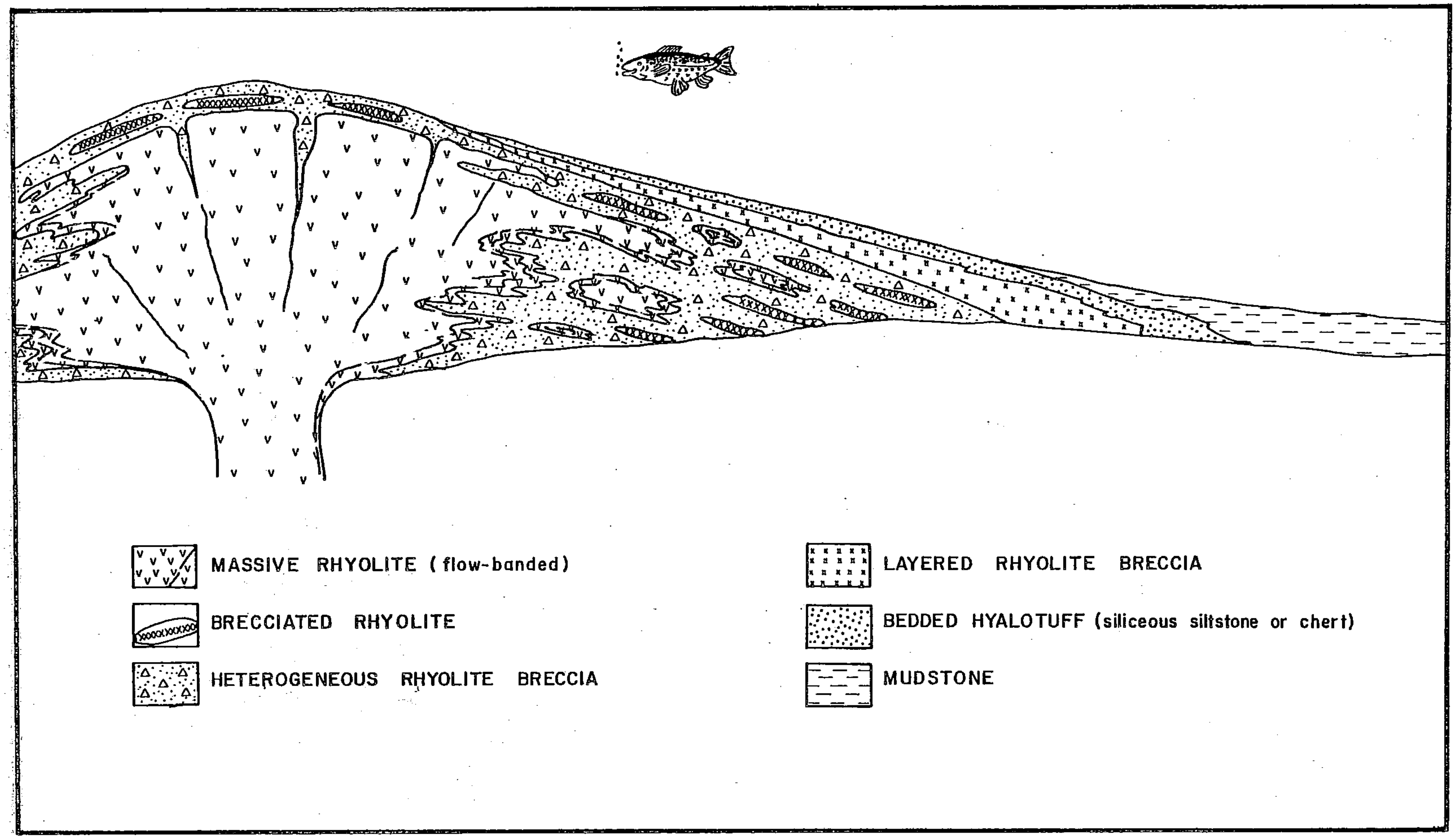

FIGURE 22. Diagrammatic depositional facies of a subaqueous rhyolite flow. Modified after Pichler (1965) and de Rosen-Spence _et_ _al_. (1980).

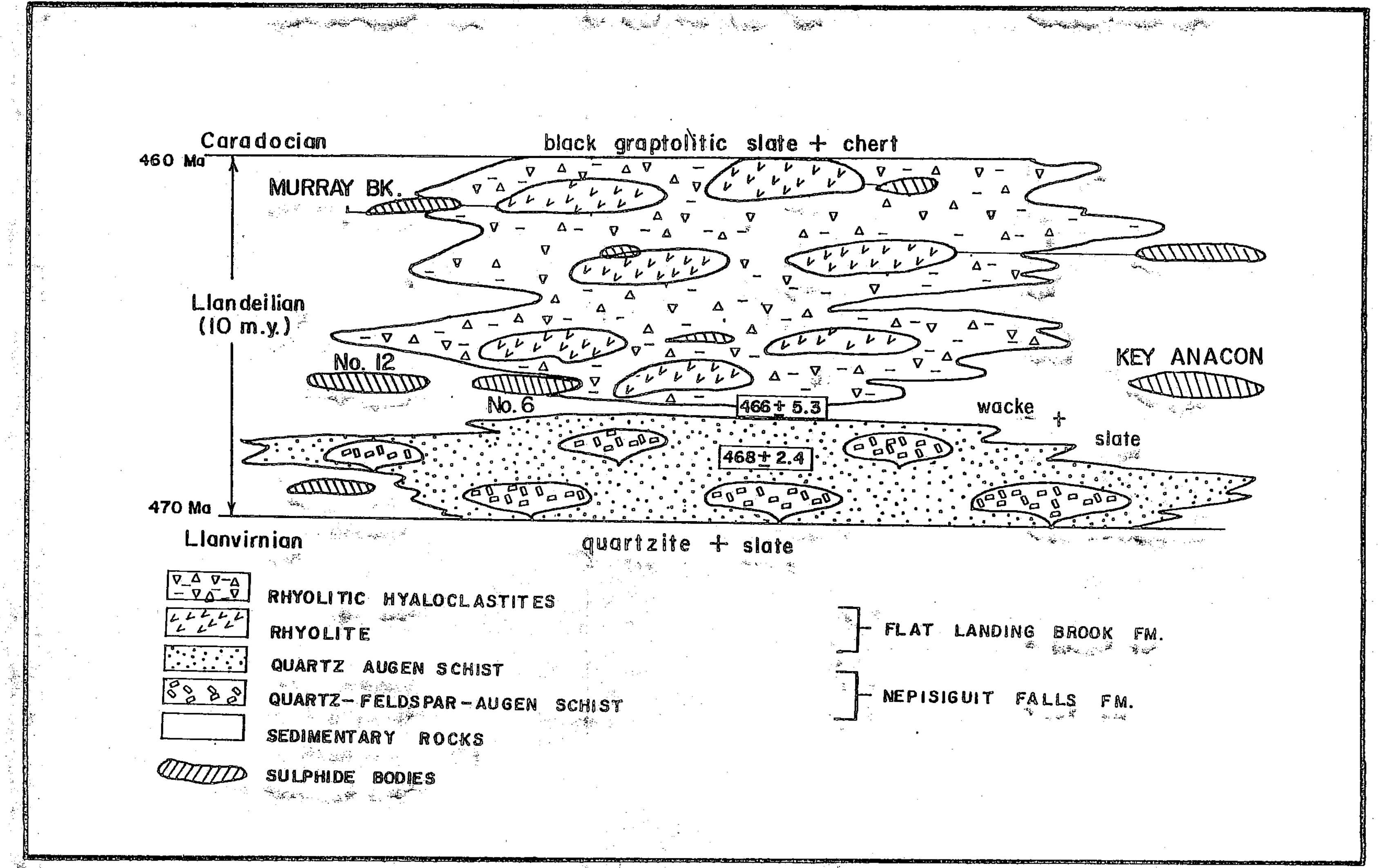

FIGURE 23. Diagrammatic representation of the stratigraphy of the felsic volcanic pile. Formation names and isotopic ages are from van Staal and Fyffe (in press).

(2-15 mm) sills. The upper part consists of aphyric or sparsely feldspar-porphyritic (generally less than 3 mm) lavas and their associated hyaloclastites. The longevity of the igneous activity is uncertain, but is restricted to a 10 m.y. interval (Llandeilian or late Middle Ordovician) based upon fossils and radiometric ages (van Staal and Fyffe, in press).

The relative stratigraphic position(s) of the sulphide deposits in the volcanic pile is (are) not clear as pointed out by Davies et al. (1985, p. 13). However, many geologists consider that there are two sulphide-bearing intervals in the district: a lower one represented by the Brunswick deposits, the so-called "Brunswick horizon"; and an upper one, of which the Canoe Landing Lake, Caribou, and Murray Brook deposits are examples. Recently van Staal and Fyffe (in press) have suggested that massive sulphides occur in three stratigraphic positions. Whether there are two, three, or several productive horizons depends upon the relationships between volcanism, and the source of the sulphide-bearing fluids. At present this is not known but clues may be obtained from other base-metal camps.

In general, there are two major hypotheses regarding the source of metal-bearing fluids that produce volcanogenic massive-sulphide deposits (Franklin 1986). One states that the fluid is mainly deep-circulating seawater that is modified by metamorphic processes and brought back to surface by convective upwelling associated with volcanic centers. The other states that the fluid is produced by de-watering and that this water accumulates in an acquifer until the time the acquifer is ruptured and the fluid escapes to surface. The latter hypothesis is probably the only way to account for very large sulphide deposits because of thermal-energy and fluid-volume constraints (Franklin 1986; Lydon 1988).

Since the Bathurst deposits have been compared to the Kuroko deposits of Japan, it is worthwhile reviewing some of the features of the latter. Among the characteristics summarized by Ohmoto and Skinner (1983) are the following: (1) Kuroko deposits occur in clusters measuring 1.5 x 3 km; clusters are 5-10 km apart; (2) Deposits in a cluster are coeval but there are age differences of 2-3 million years between clusters; (3) Basement fractures and irregular sea-floor topography (depressions) are important in the formation and localization of the deposits; (4) Deposits are spatially associated with felsic igneous rocks ("white rhyolites") of different ages that were derived from centers 5-10 km apart; these centers are aligned subparallel to basement fracture systems; (5) The massive sulphides were deposited prior to and during emplacement of "white rhyolite domes"; (6) Parts of some massive-sulphide deposits were formed within unconsolidated, porous sediments; (7) Most deposits exhibit clastic textures indicative of mechanical transportation of ore fragments, which may have been caused by emplacement of the rhyolite domes; (8) Massive sulphide deposition was a two-stage process involving precipitation (at less than 300°C) of fine-grained black ore composed mostly of sphalerite, galena, pyrite, and barite, followed by sequential metasomatic transformations (by later fluids greater than 300°C) to coarse-grained black ore, to chalcopyrite-rich yellow ore and finally to pyrite-rich ore; (9) Alteration halos exist in the footwall rocks with distal asssemblages that contain zeolites and proximal assemblages that contain sericite and chlorite; (10) Within the alteration halos, Na, Ca, Sr and Cl decrease toward the ore zones wheras K, Mg and S increase. Also, the Mg/(Mg+Fe) ratio in chlorites increases toward the ore, i.e., the chlorites are Mg-rich; (11) Sulphur-, oxygen-, strontium-, and lead-isotope halos extend more than 3 km from the ore zones whereas Na and Sr halos are confined to within 500 m; (12) Kuroko deposits are generally capped by a chert-hematite layer (tetsusekiei) and are commonly flanked by gypsum and/or anydrite that formed by mixing of mineralizing fluids with cold seawater.

Jambor (1979) pointed out two major differences between Kuroko and Bathurst deposits, and there are at least three others. They are as follow: (1) Pyrrhotite and magnetite are common in Bathurst ores but are absent from Kuroko ores; (2) Barite and anhydrite are absent or rare in Bathurst deposits but are abundant in Kuroko deposits; (3) An Algoma-type iron formation overlies many of the Bathurst deposits, whereas others have no iron formation at all; Kuroko deposits are capped by a chert-hematite layer; (4) Chlorites in the Bathurst deposits have low Mg/(Fe+Mg) ratios, whereas those in Kuroko deposits typically have high Mg/(Fe+Mg) ratios; (5) Clastic textures are rarely observed in Bathurst ores but are a common feature of Kuroko ores; (6) Most Bathurst deposits are hosted by fine-grained sedimentary rocks (mudstones), whereas Kuroko deposits are intimately associated with rhyolites.

Based upon the above discussion and the characteristics described previously, the following inferences can be made concerning the genesis of the Bathurst deposits: (1) They were not formed in a caldera complex but are spatially associated with a number of hypabyssal porphyry intrusions and rhyolite domes that were probably emplaced along basement fracture zones. (2) Most deposits do not show a close spatial association with rhyolites but rather are stratiform bodies (lacking clastic textures) within fine-grained sedimentary rocks. This requires that they are distal deposits if the sulphide-bearing fluids were derived from volcanic centers on that the fluids came from fracture zones remote from volcanic centers. (3) The scarcity of barite and other sulphates in the deposits suggest that there was very little mixing between the metal-bearing brines and cold seawater. Also, the low Mg/(Fe+Mg) ratios in the chlorites suggest that the brines did not contain a significant seawater component. (4) The large sulphide deposits like Brunswick No. 12 almost certainly formed from pore-water brines. The quartz (± feldspar) wacke sequence in the lower part of the pile is the most likely source-acquifer and it was probably magmatically heated. (5) One way to explain the presence or absence of a capping iron-formation in the deposits is by ponding of the metal-bearing brine (Fig. 24). Without ponding an iron-formation is absent but with ponding, an Algoma-type iron-formation is developed. (6) Some deposits are in greenish grey sedimentary rocks, whereas others are in dark grey sedimentary rocks. This color contrast probably has stratigraphic significance.

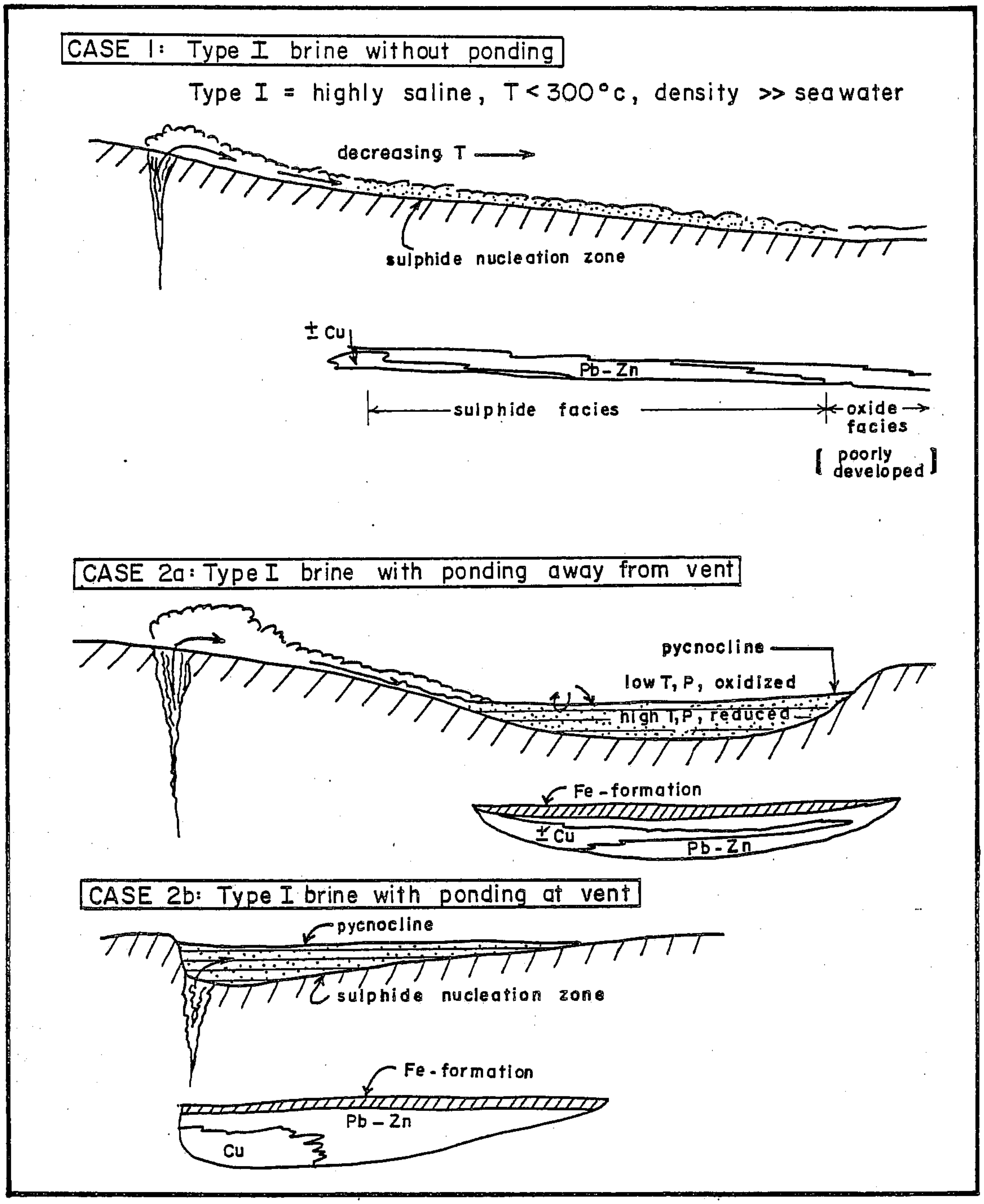

FIGURE 24. Hypothetical models showing three scenarios of sulphide deposition from a high-density, sea-floor brine (modified after Lydon 1988).

THE BRUNSWICK NO. 12 AND NO. 6 MINES, BRUNSWICK MINING AND SMELTING CORPORATION LIMITED

C. van Staal and W.M. Luff

INTRODUCTION

The Brunswick No. 12 and No. 6 mines are 10 km apart and 27 km southwest of the City of Bathurst, N.B. They occur at or near the same stratigraphic horizon and are part of the complexly deformed rocks of the Tetagouche Group (Fig. 5).

A few diamond-drill holes were put down in Brunswick No. 6 deposit in 1907 during an investigation of the associated iron ore similar to that mined in the past at the Austin Brook mine, 0.8 km to the south. The No. 6 sulphide deposit was not recognized as such until late in 1952. At this time, interest in the sulphur content of the Austin Brook deposit led to renewed exploration of the area, including a vertical loop electromagnetic survey. Subsequent drilling of strong anomalies revealed the No. 6 sulphide body, although the first eleven holes of the 1952 drilling campaign were put down in the Austin Brook deposit. Geological Survey of Canada airborne magnetic maps indicated the regional lithological trends, and resulted in extensive staking of magnetic anomalies in 1952-53. The Brunswick No. 12 deposit was discovered early in 1953 by drilling a strong electromagnetic anomaly (MacKenzie 1958; Davies and Smith 1966).

Production of ore began from the No. 12 deposit in 1964, followed by No. 6 in 1966. The No. 12 mine has lead-zinc ore reserves of 97 million tonnes grading 8.99% zinc, 3.65% lead, 0.32% copper and 9.68 g/t silver; 60 million tonnes of similar grade have been mined. Separate copper reserves are 12,786,000 tonnes grading 1.27% zinc, 0.45% lead, 1.11% copper and 35.3 g/t silver. The No. 6 mine ceased operations in 1983 after producing 12,125,000 tonnes of ore grading 5.43% zinc, 2.16% lead, 0.39% copper and 66.5 g/t silver.

STRATIGRAPHY

The rocks underlying the Brunswick No. 6 - No. 12 mine area have been subdivided as shown in Figures 25 and 26 (Rutledge 1972; Luff 1975, 1977). The following descriptions refer specifically to the No. 12 mine; however, the lithologies and sequence are essentially the same at the No. 6 mine.

The oldest rocks in the mine sequence comprise grey quartz phyllites and metaquartzites (OM) that are assigned to the upper part of the Miramichi Group (van Staal and Langton, this volume). Close to the contact with the overlying volcanic rocks of the Tetagouche Group, phyllites become more abundant and more chloritic and graphitic. Small amounts of disseminated pyrite and pyrrhotite are common and small massive sulphide

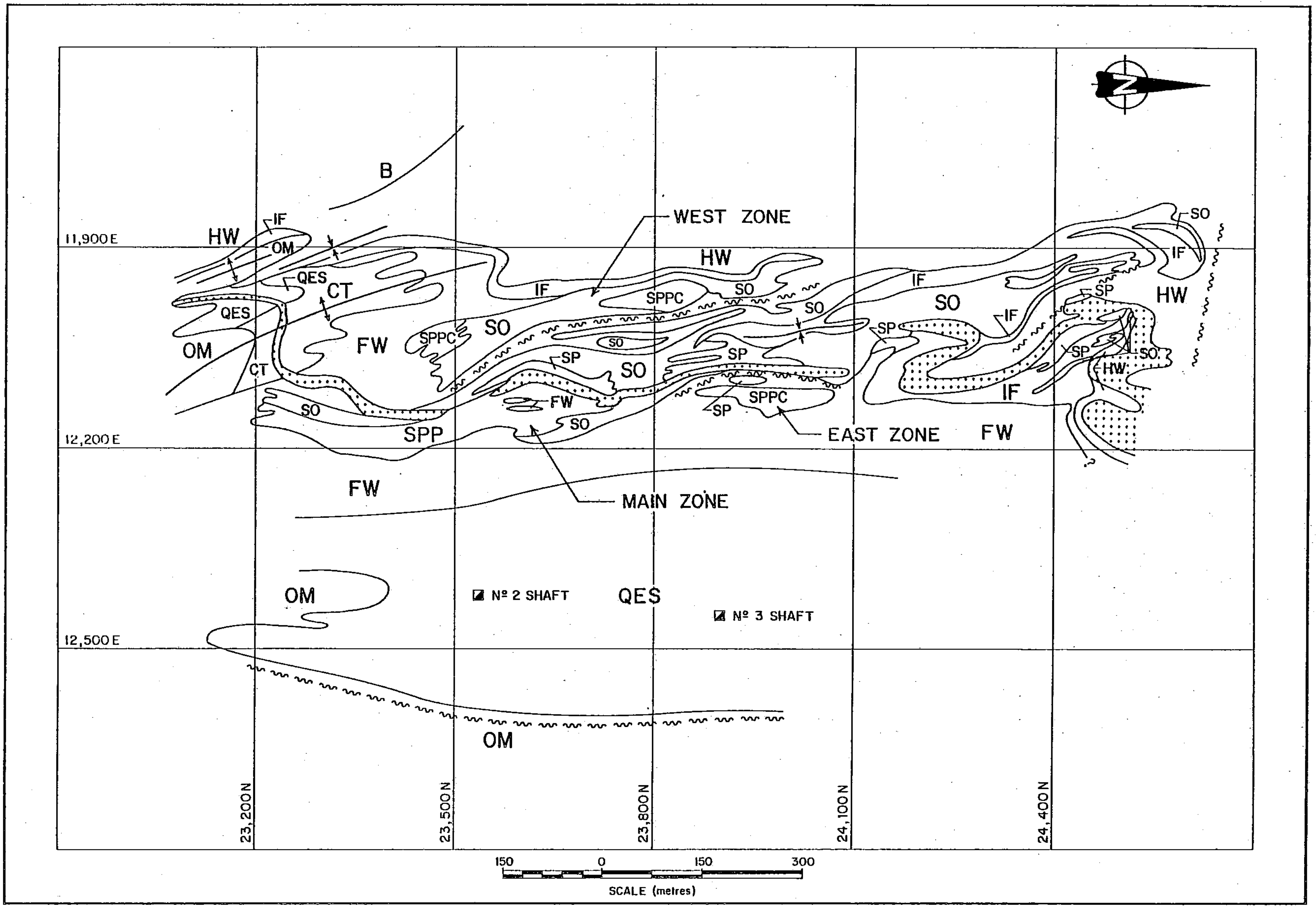

Figure 25. Geological map of the 850 m level of the Brunswick No. 12 orebody.

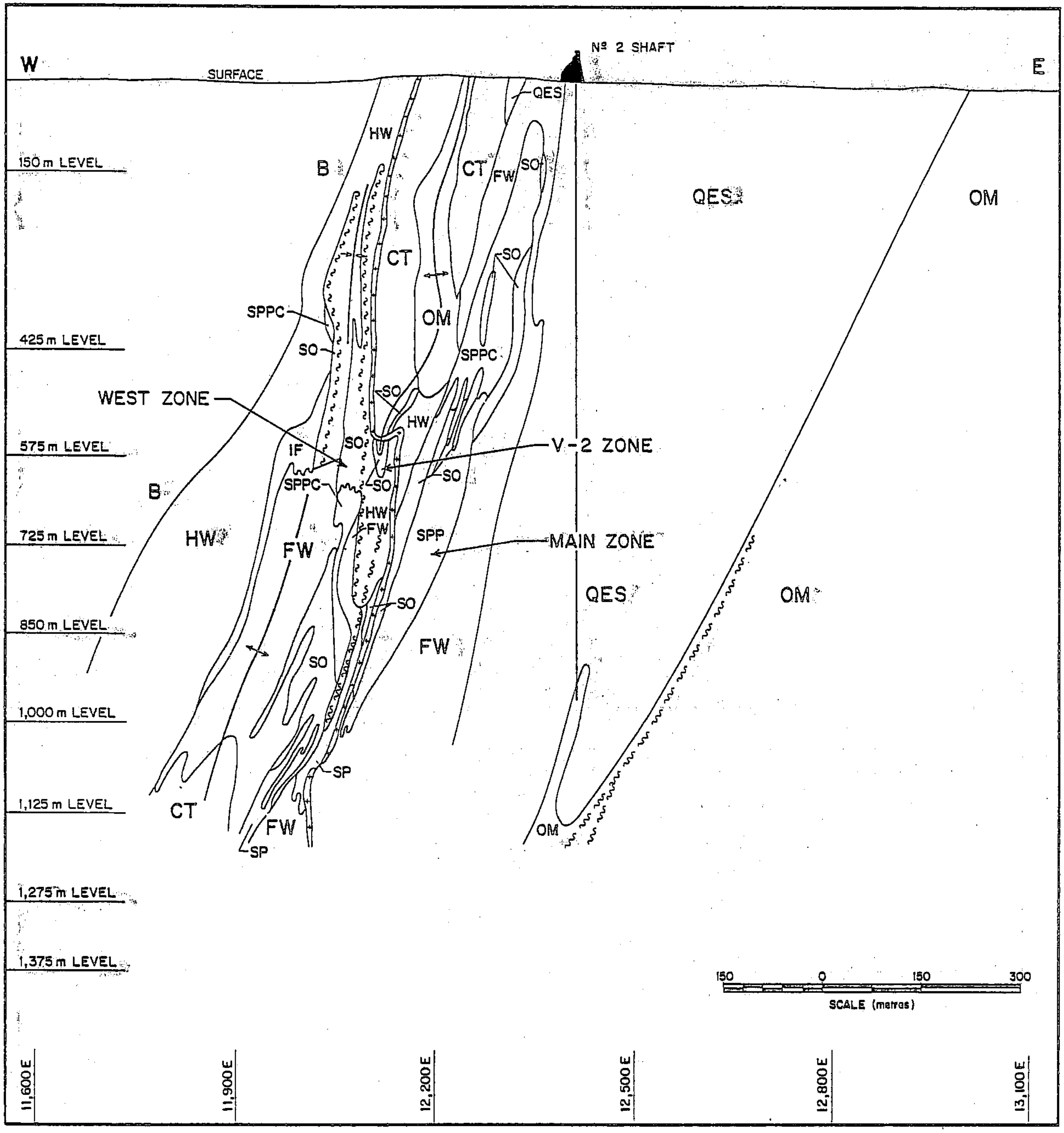

Figure 26. Cross-section through the Brunswick No. 12 orebody.

bodies occur locally. The phyllites are overlain by felsic volcanic rocks referred to by mine geologists as quartz-eye schist (QES) and crystal tuff (CT) of the Nepisiguit Falls Formation.

The immediate footwall rocks (FW) to the massive sulphides comprise green, chloritic phyllites with thin interbeds of wacke, chert, and pyrite. Goodfellow (1975) and Juras (1981) interpret some of these rocks to be the product of pre-metamorphism alteration related to formation of the massive sulphides. The chlorite compositions in these rocks, however, are similar to those of the chloritic facies of the iron formation, i.e., they are iron-rich suggesting a primary compositional feature.

The massive sulphide body is divisible into three zones from the footwall to hanging wall: (1) a massive pyrite zone, containing minor to large amounts of chalcopyrite and pyrrhotite, and minor amounts of sphalerite and galena (SPP or SPPC); (2) massive banded pyrite-sphalerite-galena with minor chalcopyrite and pyrrhotite (SO); the latter two minerals become more abundant below the 850 m level in the No. 12 deposit; (3) massive pyrite, comprising very fine-grained pyrite, with minor sphalerite, galena and chalcopyrite (SP).

Iron formation (IF) overlying the massive sulphides, consists of an oxide, chlorite (silicate) and carbonate facies. Contacts with massive sulphides are gradational, and it is generally accepted that the sulphides represent a facies of the iron formation (e.g., Davies 1972). The immediate hanging wall rocks (HW) consist of grey chloritic and sericitic phyllites that grade upward into aphyric and feldspar-phyric rhyolite and lapilli tuff of the Flat Landing Brook Formation. A red hematitic phyllite separates the felsic sequence from overlying pillowed, alkali basalts (B) of the Boucher Brook Formation.

The Miramichi Group in the Brunswick No. 12 - No. 6 area is intruded by the Papineau Falls granite to the northeast (Fig. 5). Growth of large biotites in the rocks hosting the No. 6 deposit is probably related to metamorphism associated with this intrusion. A northerly trending felsic porphyry dyke (crosses on Figs. 25, 26) is the only intrusive rock in the Brunswick No. 12 area. It is composed of phenocrysts of quartz, K-feldspar, and albite set in a weakly schistose fine-grained matrix of quartz, sericite and chlorite.

In the Brunswick No. 6 area, the hanging wall rocks are intruded by a southwesterly plunging body of tholeiitic gabbro. The mesostructures and greenschist facies mineral assemblages indicate the intrusion predates or is coeval with the earliest deformation. Folded diabase and gabbro dykes are also prominent rocks in the Austin Brook area (Boyle and Davies 1964; Davies 1972).

STRUCTURE AND DISTRIBUTION OF THE MASSIVE SULPHIDES

Structural analysis of the Brunswick No. 12 and No. 6 mines and surroundings demonstrates that the structural history and the geometries of the two orebodies are essentially the same as shown in the simplified diagrams in Figures 27, 28, 29, and 30. Both deposits occur in large asymmetrical F_2 folds, which show a marked variation in plunge but a constant axial plane orientation. On the basis of regional stratigraphy, metal zoning and the stratigraphic position of the iron formation with respect to the sulphides, the F_2 folds can be divided into upward and downward facing structures. For instance, the large, steeply south-plunging Z-shaped fold in the Brunswick No. 12 mine is downward facing. At depth this fold changes plunge by more than 90° passing through the vertical and then into the horizontal to finally plunge shallowly towards the south such that it becomes upward facing (Figs. 27, 31). The trace of the F_2 fold plunge, drawn in a section parallel to the axial plane of the F_2 fold, therefore defines a large overturned F_1 fold (Fig. 31). The large scale geometries of both deposits, which define overturned, asymmetrical basins, are therefore interpreted as interference structures between F_1 and F_2 folds.

Massive sulphides in the Brunswick No. 12 mine occur in four major zones, the Main Zone, the East Zone, the West Zone, and the V-2 Zone (Figs. 25, 26). These zones all join below the 850 m level, where the F_2 folds are formed close to a F_1 fold hinge, and where the metalliferous rocks can be expected to be thick. The separation of the sulphides on the shallower levels is, therefore, better explained as a result of the attentuation and faulting that is generally found along the short limbs of the F_2 folds rather than interpreting them as separate bodies deposited in second-order basins. The attentuation of alternate limbs of almost isoclinal folds resulted in an en echelon pattern of tabular sulphide bodies that correspond to the hinges and long limbs of F_2 folds. Numerous intrafolial, isoclinal F_1 and F_2 folds in the sulphide bodies attest to the intense transposition that these rocks experienced. The marked boudinage of the porphyry dyke in the massive sulphide body (Fig. 25) is another indication of the high strain experienced by the sulphide bodies.

ORIGIN OF THE SULPHIDES

Sections parallel to the F_2 axial surfaces (Fig. 31, 32) show that the metal zoning is folded by F_1 and probably predates the earliest deformation. All other structural data also indicate that the mineralization, with the exception of some remobilized material, has been affected aby the earliest deformation recorded in the country rocks. The structural evidence is thus compatible with a volcanogenic-exhalative origin of the ores. However, proximal features such as a feeder pipe-stringer zone and syngenetic alteration are either

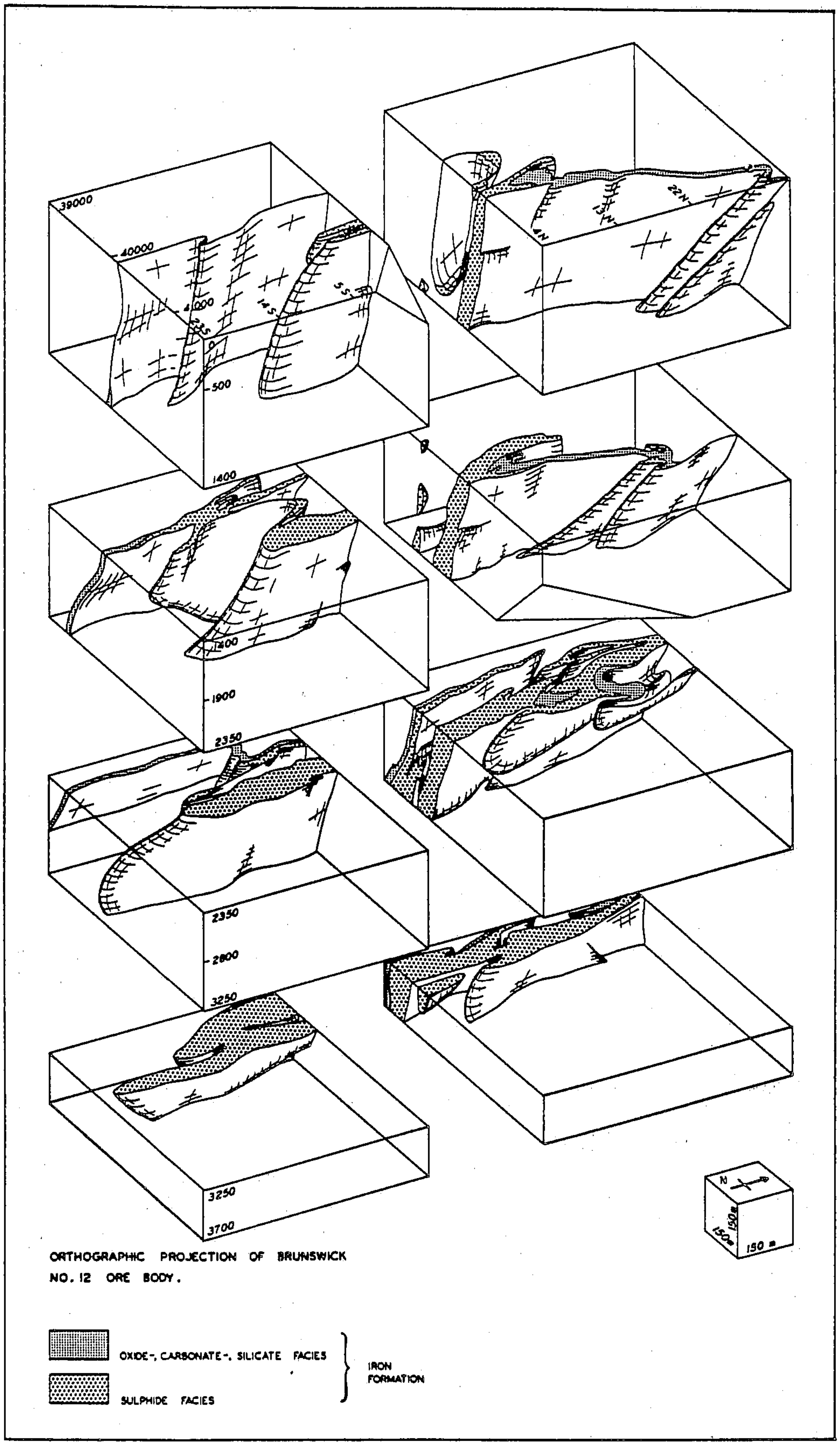

Figure 27. Block diagram of the Brunswick No. 12 orebody.

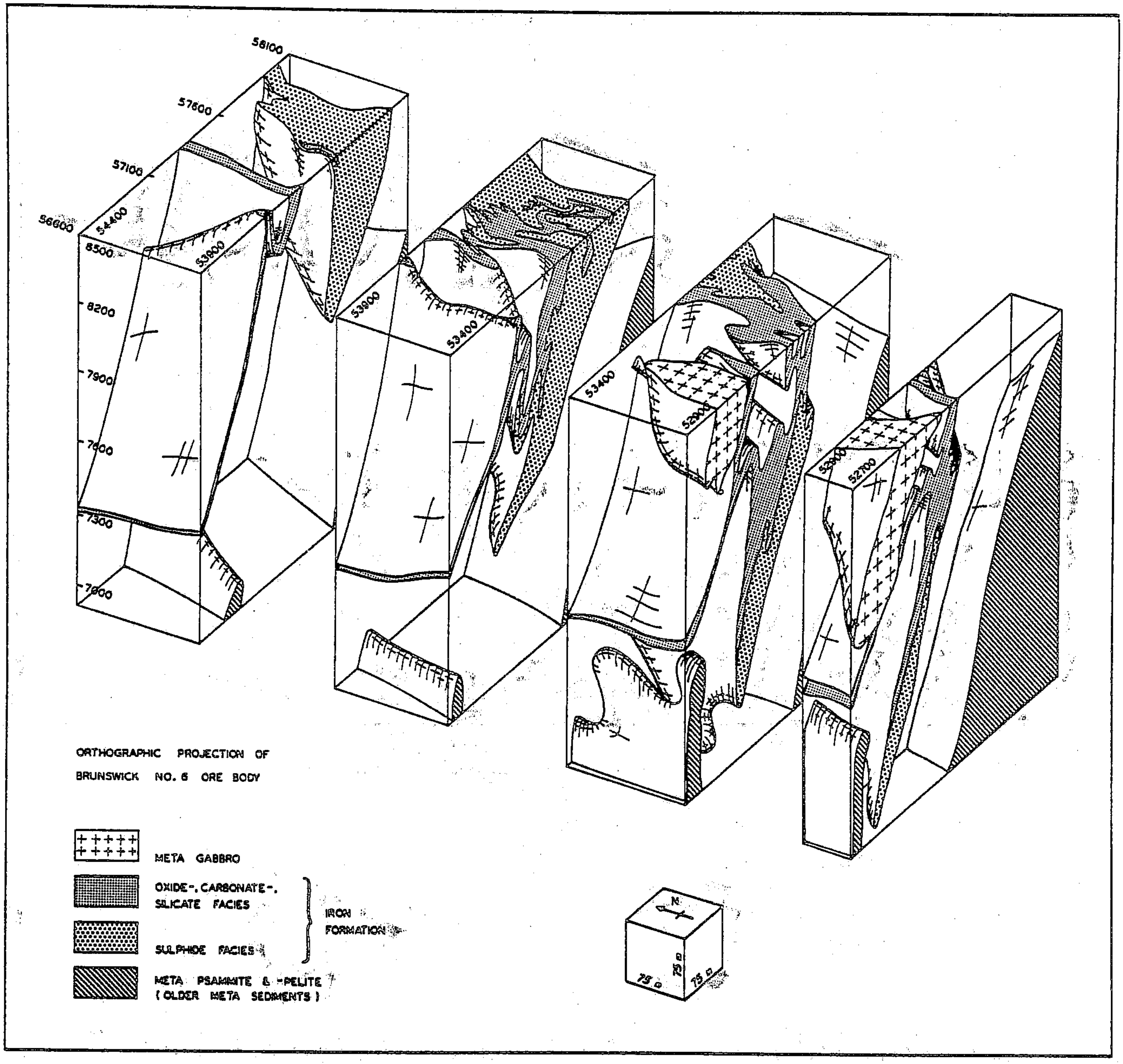

Figure 28. Block diagram of the Brunswick No. 6 orebody.

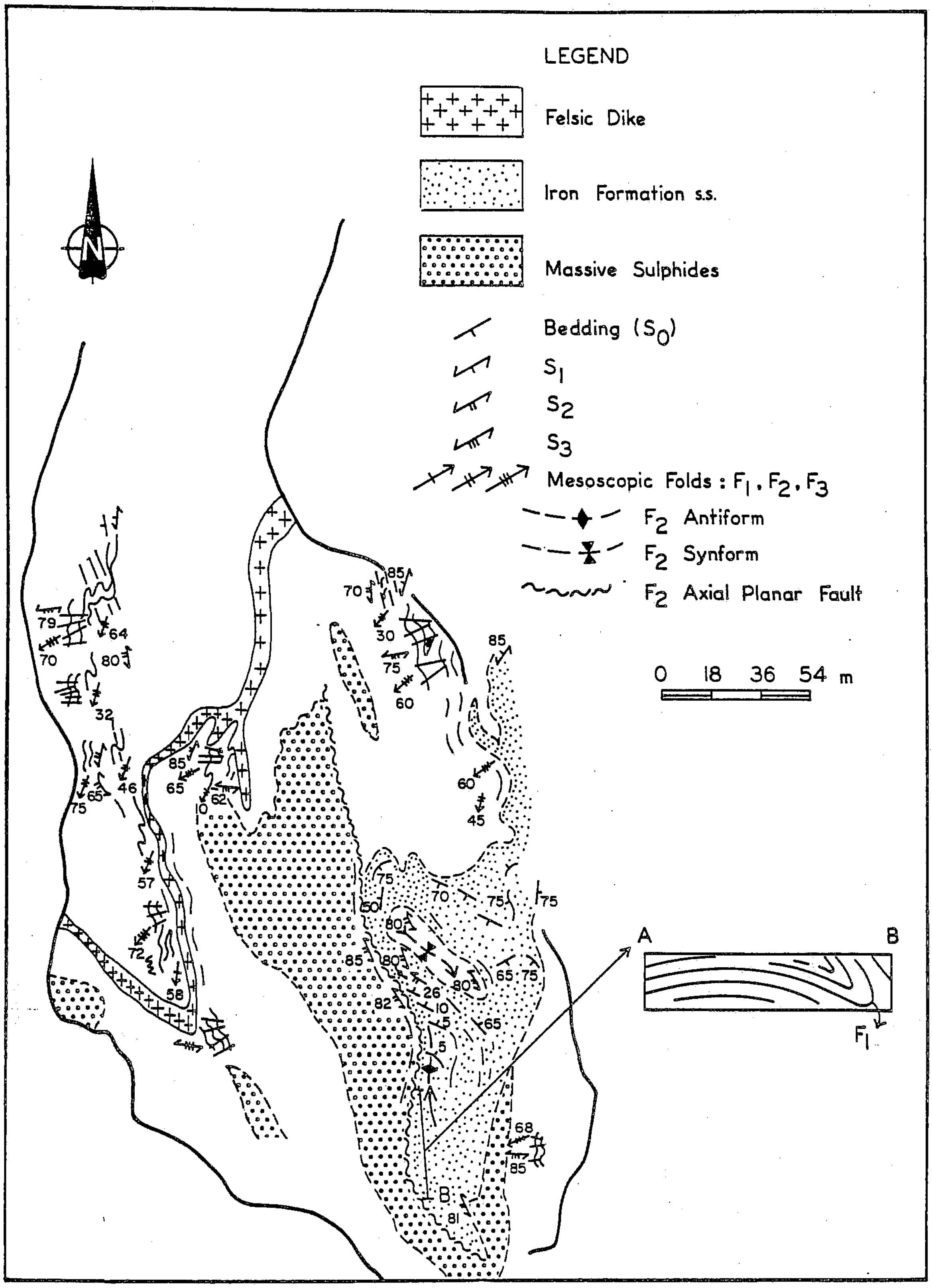

Figure 29. Surface geology of the Brunswick No.12 open pit.

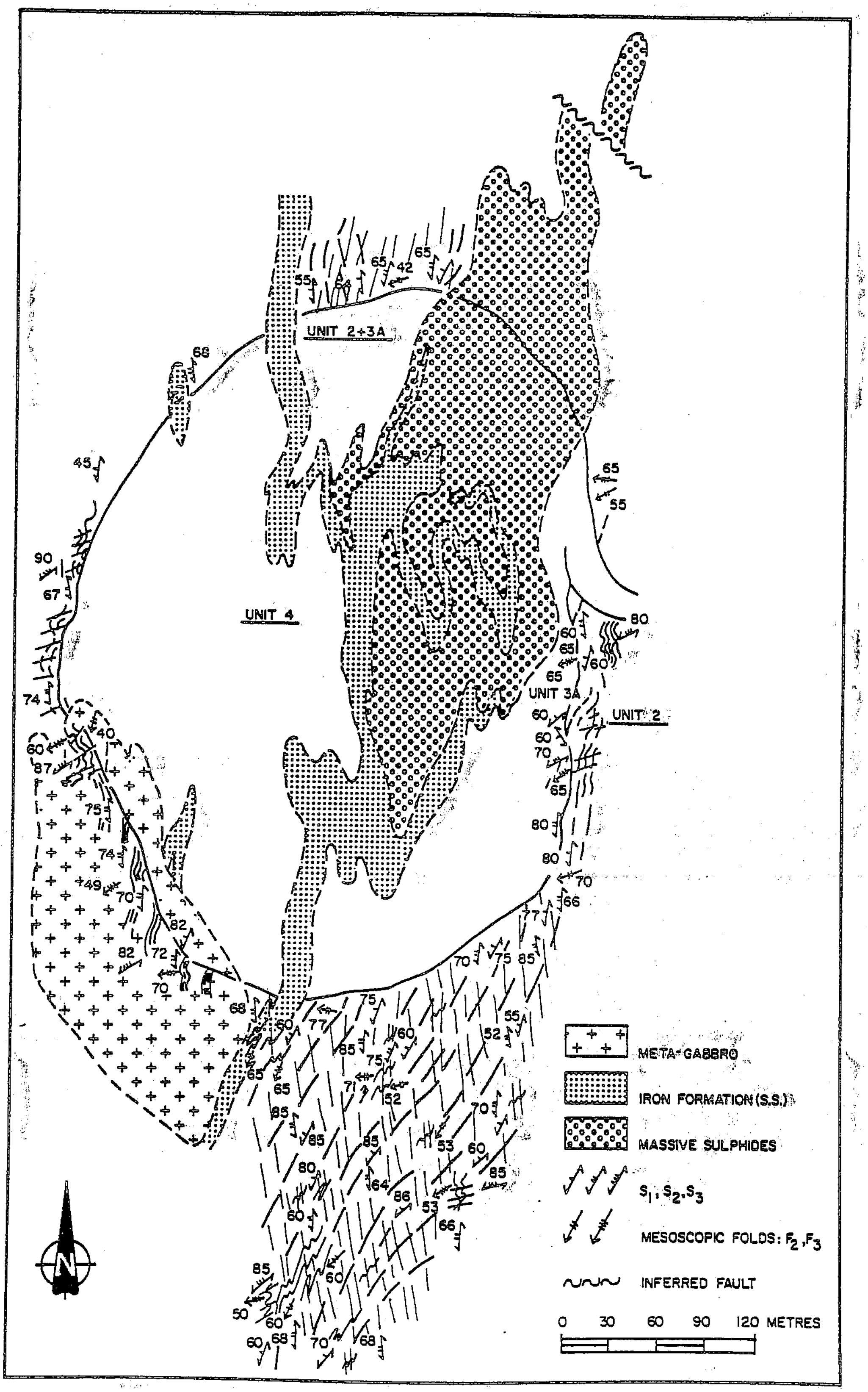

Figure 30. Surface geology with form surface map of the Brunswick No. 6 orebody before open pit mining.

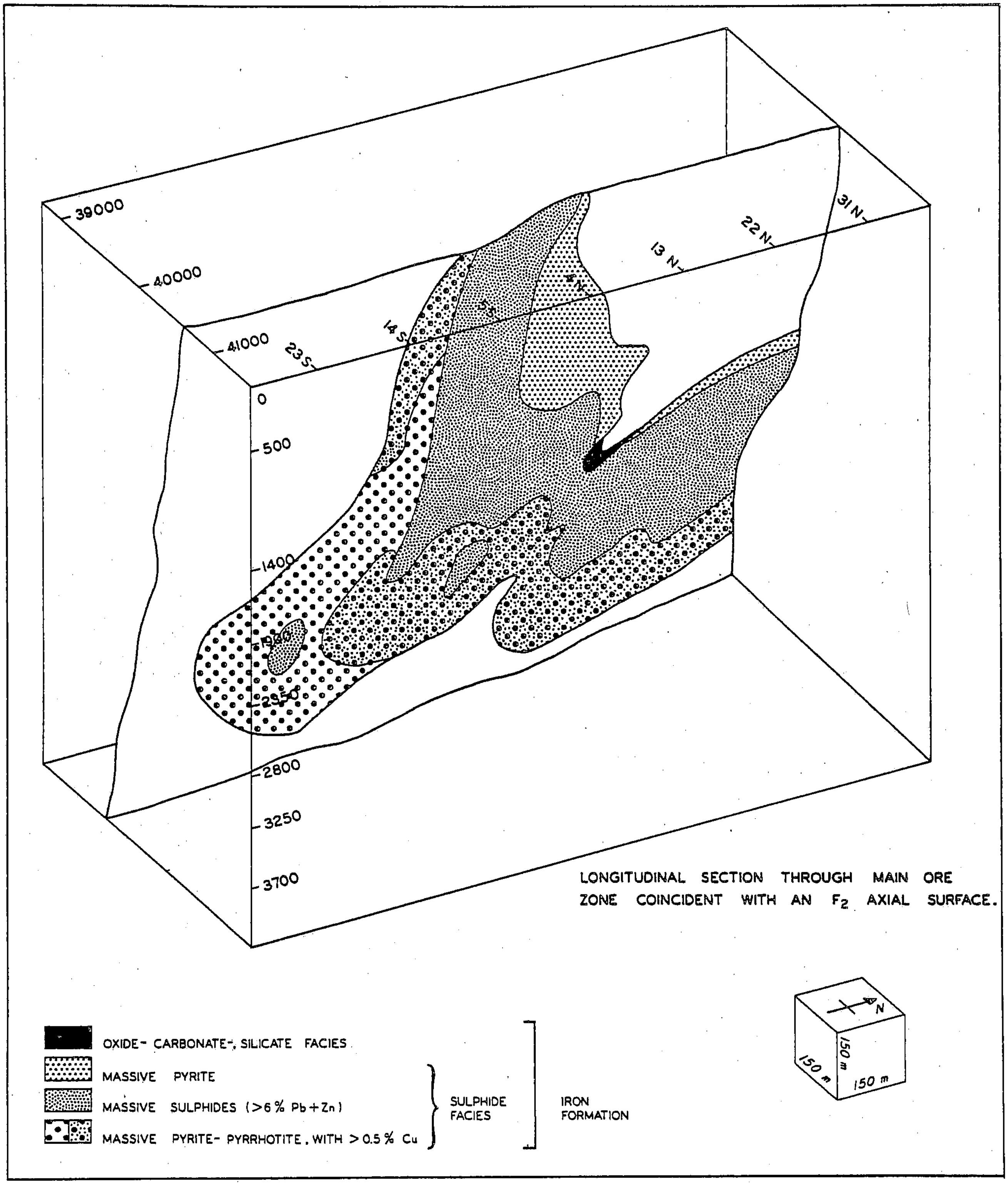

Figure 31. Longitudinal section, Main Zone, Brunswick No. 12 orebody parallel to an axial plane of second folds.

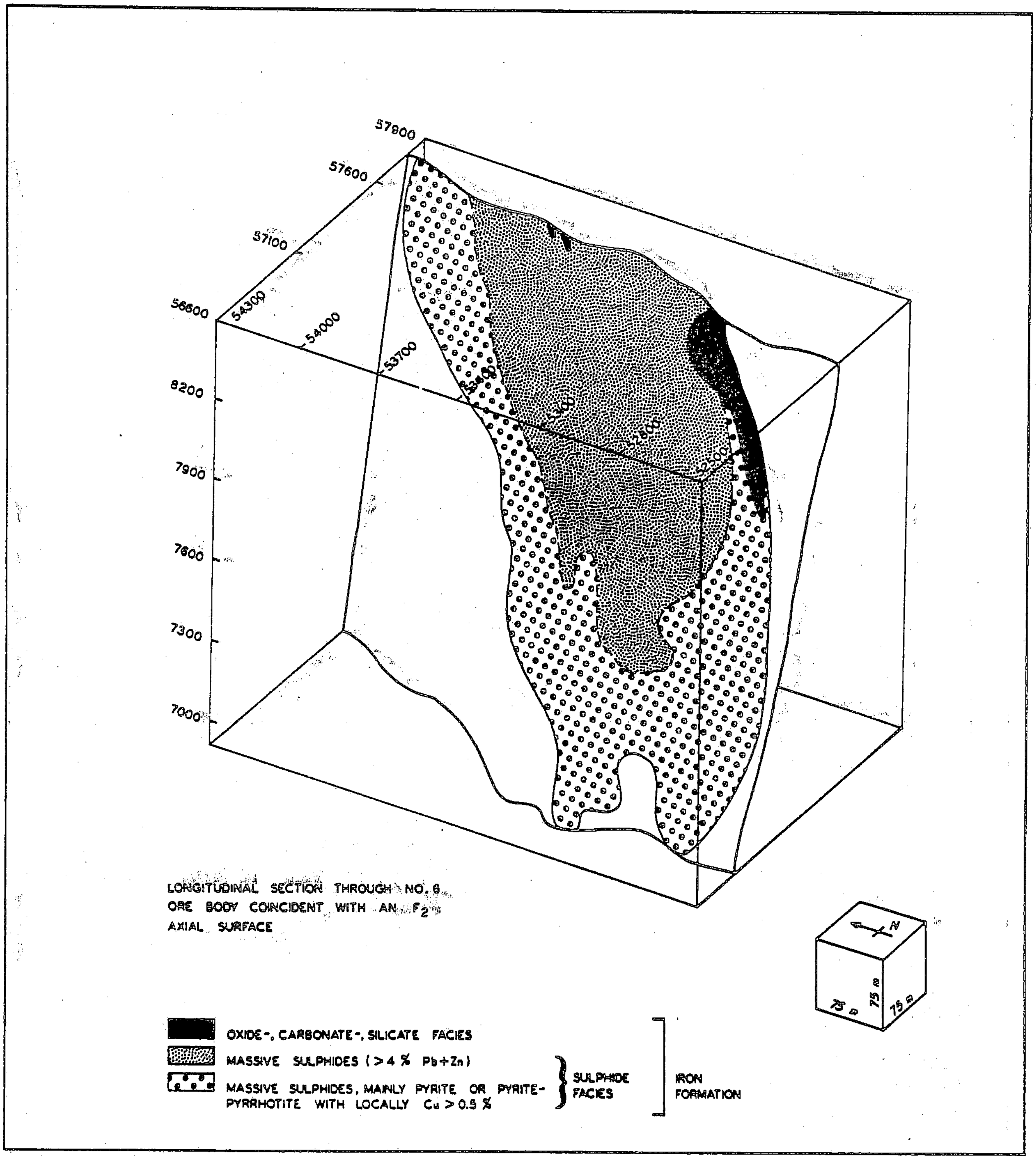

Figure 32. Longitudinal section of the Brunswick No. 6 orebody parallel to an axial plane of second folds.

missing or obscured by deformation and later alteration. At least part of the cross-cutting sulphide stringers are parallel to the axial surfaces of F_1 and F_2 folds (van Staal and Williams 1984) and, therefore, cannot be primary. The origin of the folded sulphide stringers, which are generally parallel to layering in the phyllites is hard to determine, since most if not all of the primary relationships between the stringers and the footwall sediments have been obscured by the strong deformation concentrated in the incompetent phyllites. It is possible that part of the stringers are related to the ore forming event, but this cannot be proven with the presently available data set.

STRUCTURE OF THE HEATH STEELE SULPHIDE DEPOSITS

J.A. de Roo, C. Moreton, and P.F. Williams

INTRODUCTION

At Heath Steele Mines, base metals are concentrated in five major deposits, known as the A, B, C, D, and E zones. The deposits are located below surface and are variably capped by gossans. Only the B zone is presently accessible underground, and its gossan is exposed in an open pit. With the exception of the E zone, the deposits have all been partially mined. The E and B deposits together have estimated reserves of 25.6 million tonnes of Ag-Pb-Zn-Cu ore (Davies et al. 1983); total reserves of the other sulphide bodies were of lower tonnage and/or higher grade. Profitable sulphide deposits that occur in the nearby "Stratmat" zone are considered in the following section.

The Heath Steele deposits are spatially associated with horizons of Lower Paleozoic sedimentary rocks that are situated in an igneous rock complex comprising acid and basic volcanics, volcaniclastics, and high-level intrusions. The complex has been subjected to low-grade metamorphism and five generations of deformation (D_1-D_5). The first two generations produced tight to isoclinal, conical, folds. These were overprinted by two generations of upright, open folds and one of recumbent folds. Regionally, first generation sheath folds have been associated with D_1 thrusting along the earliest recognized layering (S_0).

Overall, the deposits occur along the contact (S_0) between metasedimentary rocks and augen schists, but massive sulphides are concentrated in pods and slabs that are arranged along the S_1 cleavage in D_1 fold hinges. This concentration likely reflects syn-D_1 remoblization of syngenetic sulphides associated with iron formation.

LITHOSTRATIGRAPHY

In the Heath Steele area, the distinction of a lithostratigraphy has been complicated by a paucity of primary (depositional) features and poor outcrop. The various rock types in the area are grouped into five lithological associations (Fig. 33), classified as tectonic units since they are probably in fault contact with one another.

Clastics: Grey, mica-rich, pelites, blue-grey or green semi-pelites, and grey felsitic rocks with a mesoscopic, compositional layering form a lithological association, marked by its rusty weathering and the abundance of veins. The unit comprises rocks that have been described as metasedimentary (McMillan 1969; McBride 1976), and chloritic phyllites. A volcaniclastic derivation may be applicable to some of the layered felsitic rocks, but is generally hard to demonstrate

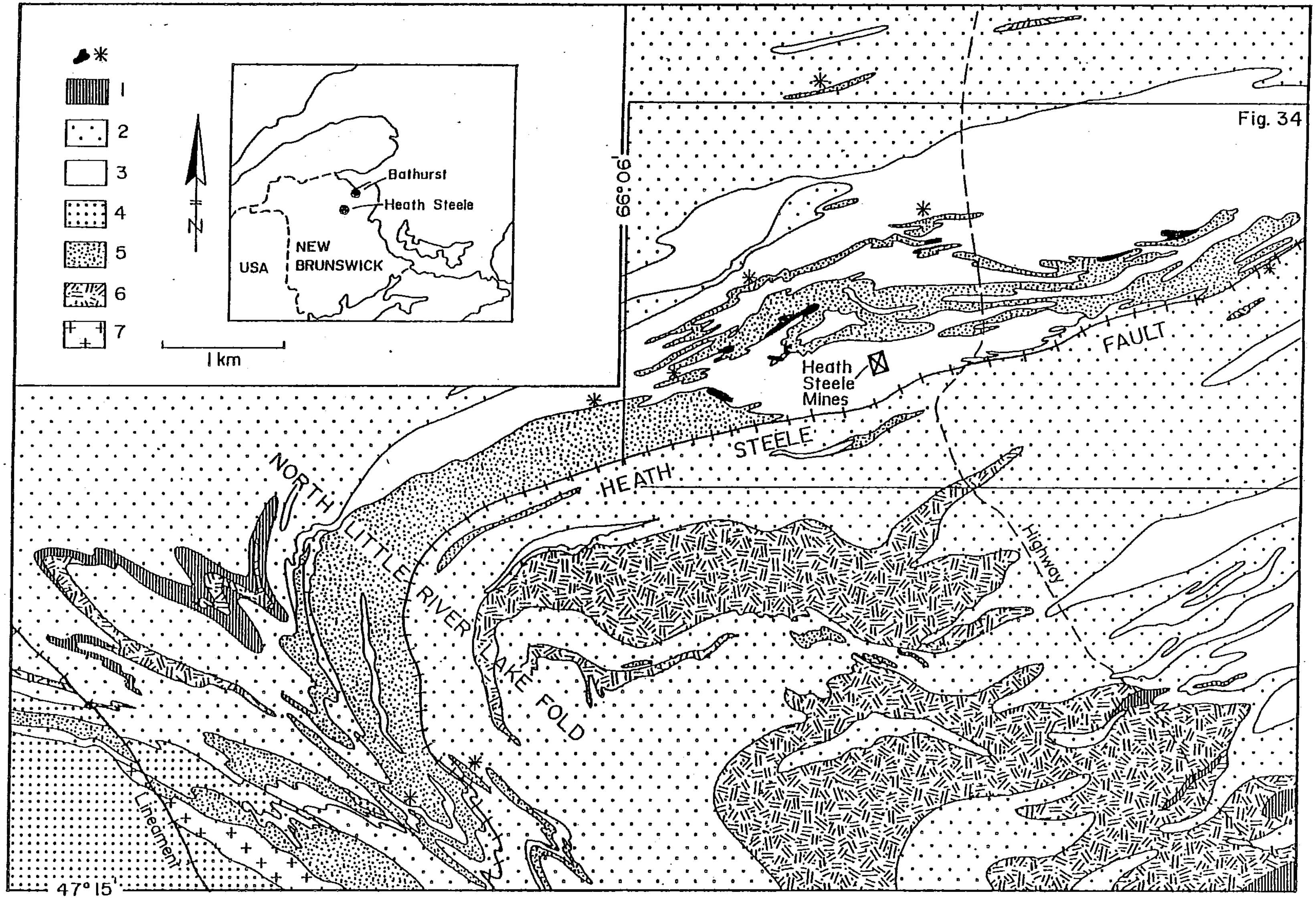

Figure 33. Geological setting of the sulphide deposits at Heath Steele Mines. Black = massive sulphides; * = prospects; 1 = greenschist; 2 = felsic phyllite and metarhyolite; 3 = augen schist; 4 = metaporphyry; 5 = metasedimentary rocks; 6 = metadolerite; 7 = metagranitoid.

(Moreton and Williams 1986).

Augen Schists: Locally, the metasedimentary rocks are juxtaposed to, or intercalated with, augen schists. On the basis of augen composition, the schists can be subdivided into two lithotypes: quartz augen schist and quartz-feldspar augen schist. Although most augen are quartz and feldspar porphyroclasts, lithic augen are also present. The augen are set in a felsic matrix that is mostly fine-grained and schistose, but locally consists almost entirely of unoriented sericite and chlorite. Locally, there is a laterally discontinuous, crude layering that is defined by variations in matrix phyllosilicate content and/or augen size and abundance. Augen schists with intercalations of pelite, varying in amount from isolated layers up to 50% of the rock volume, were interpreted by Davies et al. (1983) as water-lain felsic tuffs. There is a lack of sorting of augen on the basis of size or abundance in some areas, suggesting an ignimbritic origin.

A mostly structureless metaporphyry, consisting of quartz crystals in a matrix of massive, fine-grained felsite, occupies the southwestern part of the study area. The metaporphyry is considered to be a less deformed equivalent of the quartz augen schists, and the two were therefore mapped as one lithostratigraphic unit.

Felsic Phyllites and Metarhyolite: A major part of the region is occupied by dark blue-grey, fine-grained and featureless felsic phyllites. Massive metarhyolite with spherulitic or amygdaloidal textures, and, rarely, banded cherts have been preserved among the less deformed phyllites. Due to chloritization, the felsic phyllites may resemble rocks of the clastic unit. Others contain augen, but are distinguished from rocks of the augen schist unit by the small size and dispersed nature of the porphyroclasts and lithic augen. This distinction may partly reflect strain variation. Alternatively, felsic phyllites with fragments and/or relict, devitrified shards may have formed as pyroclastic flows (Skinner 1974; Irrinki 1986; van Staal 1987). Horizons of meta-agglomerate abound in this unit.

Greenschists, Metadolerite, and Blue Phyllites: The three lithotypes that define this unit can be mapped separately, and their association is not always primary. Greenschists (1) mainly occur in the southeastern part of the region. Some greenschists are basic metavolcanics with relict pillows, or with structures that possibly represent pillow breccia. Other greenschists contain highly attenuated felsic fragments, or grade into dykes and massive pods of metadolerite (2) with relict ophitic textures. Blue phyllite (3), iron-rich and typically strongly manganese stained, forms narrow horizons in, and near, the metadolerite. These horizons have a cherty lamination, but otherwise are hard to distinguish from deformed metadolerite.

Metagranitoid: The northern part of the main body of metaporphyry in Figure grades laterally into rocks with a coarse crystalline, semi-porphyritic texture. This section of the metaporphyry has been described as part of a suite of pre-Silurian granites, radiometrically dated by Rb/Sr at about 480 Ma (Fyffe et al. 1977, 1981; van Staal 1987).

Dykes with feldspar phenocrysts are present east of the metagranitoid. The dykes are up to 2 m wide and follow the strike of the main foliation. Unlike the metagranitoid, they are undeformed, overprint the youngest crenulations and folds in the area, and contain fragments of the schistose wall rock. These relationships argue for a post-tectonic age for the dykes.

REGIONAL DEFORMATION

The rocks of the area have been subjected to locally intense, polyphase deformation. Generations of structures were distinguished in key outcrops on the basis of micro- and mesoscopic overprinting relationships. Structures were then correlated between outcrops by their orientation, style and/or age, relative to other sets present. Five regional generations of deformation (D_1-D_5) were established by this procedure.

The earliest deformation (D_1) is marked by F_1 folds of a compositional layering (S_0) that may be bedding, but could equally be of tectonic origin (Moreton and Williams 1986). The axial planar foliation (S_1) generally dips steeply to the south (Fig. 34). S_1 is differentiated and locally parallel to a layering, containing rootless, isoclinal F_1 folds of S_0. These folds indicate that locally S_1 is a transposition foliation. A steeply plunging extension lineation in S_1 is defined by a phyllosilicate preferred orientation and by microboudinaged porphyroclasts of feldspar and quartz. S_1 is overprinted by F_2 folds, the axial planes of which vary in orientation between flat-lying and sub-vertical, striking west-northwest-east-southeast (S_2; Fig. 34). S_2 is a crenulation cleavage that is locally differentiated, and some F_2 folds of S_1 are intrafolial in S_2, indicating local D_2 transposition of S_1.

S_2 is folded by two generations of folds, one (F_v) with a northwest-southeast striking, vertical axial plane cleavage (S_v) and gently plunging fold axes, and the other (F_h) with a horizontal axial plane cleavage (S_h). Inconclusive overprinting relationships between D_v and D_h structures preclude dating of the two deformations relative to one another, but they are either third or fourth generations (D_3, D_4). S_2 is also warped into folds with a vertical northeast-southwest striking axial plane cleavage (S_5). The open, kink-like, F_5 folds occur in localized domains, one of which intersects the A zone sulphide deposit (Fig. 34). The giant Nine Mile Synform, which dominates the structure of the eastern Bathurst Camp, also developed during this deformation (van Staal 1987).

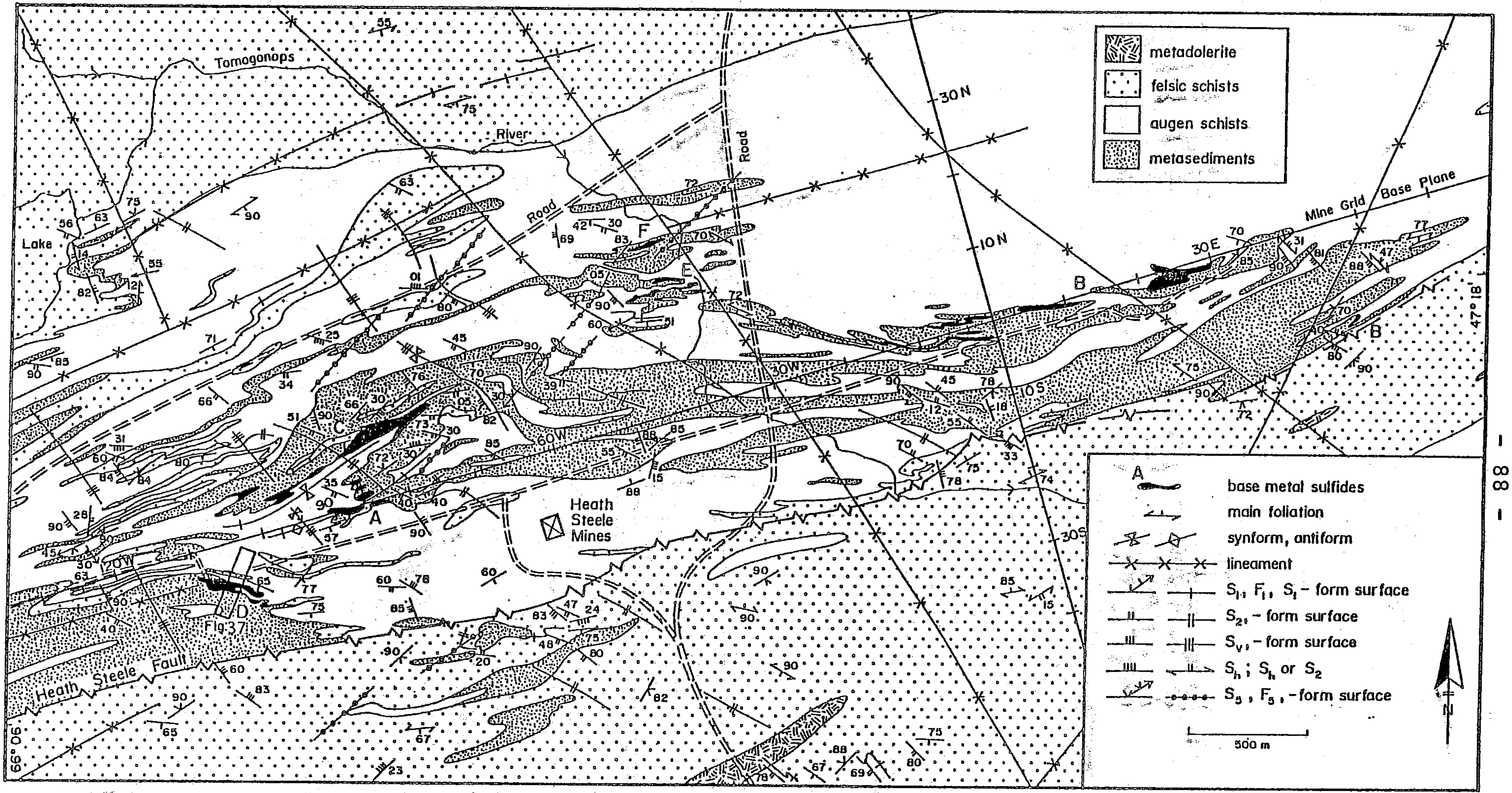

Figure 34. Structural setting of the Heath Steele A, B, C, D, E, and F sulphide zones (for location, see Fig. 33). The deposits occur near lineaments, most of which correspond to cleavage form surfaces. The mine reference grid is represented by its base plane and the plane of zero departure (0W; e.g., the A zone is at 90W, 0N).

SULPHIDE DEPOSITS

The five major sulphide deposits at Heath Steele Mines are pods or slabs that mainly consist of stratabound accumulations of pyrite, galena, sphalerite, chalcopyrite, and pyrrhotite. Within the deposits, three lithotypes can be distinguished: massive pyrite, banded sulphide, and fragmental sulphide (Davies et al. 1983). The banded-type comprises pyrite layers alternating with layers of sphalerite and galena, and aggregates of chlorite, quartz and host, interlayered with massive sulphides or disseminations of granoblastic pyrite.

The A, C, and D Zone Deposits: The A, C, and D zones form a spatially distinct group of sulphide deposits (Fig. 34). Geological compilations of drill core data from these zones illustrate the intense upright folding in the area (Figs. 35, 36). The two easternmost mine sections show massive sulphides of the A zone in an open antiform, which is located south of an attenuated synform that also contains a sulphide deposit (the C_1 zone). The massive sulphides occur along the contact between augen schists and metasedimentary rocks in the hinges and southward dipping limbs of these folds, as shown by Owsiacki and McAllister (1979) and Owsiacki (1980). Comparison of the three easternmost sections reveals that the two folds plunge west, and that toward the west (i.e., in section 98W), an attenuated, antiformal structure has emerged between both folds. This new structure hosts a sulphide deposit, referred to as the C_4 zone. Further west (section 108W), the A zone antiform has all but disappeared, whereas the C_1 zone synform has opened up. The C_4 zone antiform separating them has been transformed into a group of tight, sulphide-rich folds, but is a single, mineralized antiform once more in section 112W. Note the reduction of the sulphide abundance westward from sections 108W to 112W, coincidental with the reconstruction of this antiform. The A zone antiform has re-emerged in section 112W as an attenuated antiform that separates the C_4 zone fold from tight synforms to the south. These synforms are host to the massive sulphides of the D zone.

The upper part of the D zone sulphide deposit is a slab with a steep north-northeasterly dip, and is thus oriented at an angle to the sections of Figure 35. A section normal to the strike of the slab (Fig. 37; section D 54) shows the D zone as being situated across a fold complex, consisting of an attenuated antiform, wedged between two tight synforms. In section D 50, the fold complex has been attenuated even more, and now forms a narrow band between two new synforms.

The main foliation in trenches across the A and C_1 zone folds is a transposition cleavage (S_1) that is parallel to the axial plane of both folds. S_1 is overprinted by an inclined S_2 crenulation cleavage (Fig. 35). The F_2 crenulation asymmetry is constant across the macroscopic folds, which therefore are F_1 structures.

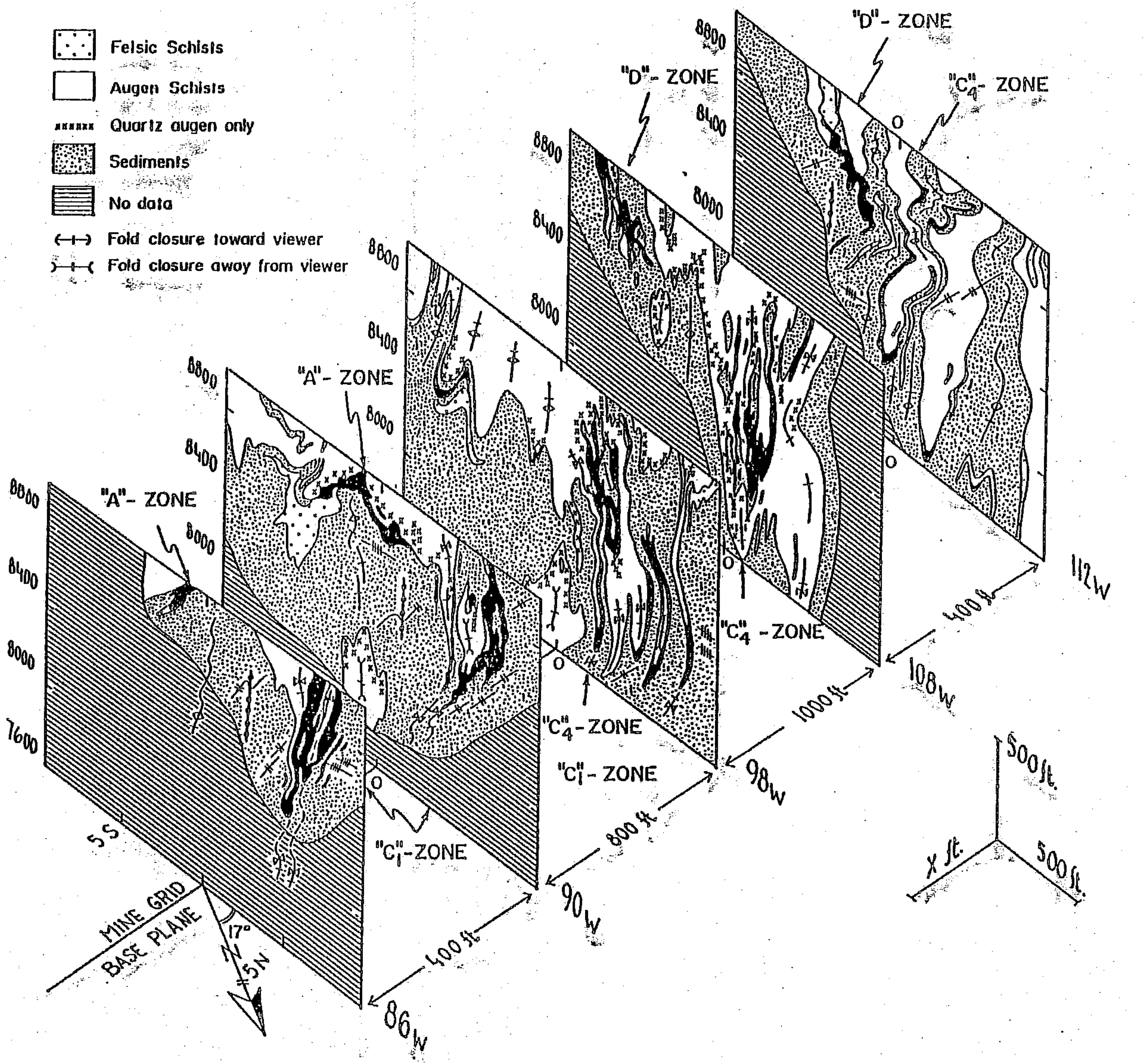

Figure 35. The structure of the Heath Steele A, C, and D sulphide deposits, as seen looking to the southwest at five sections (constructed in perspective view; surface is at about 9,000 mining level). Section numbers (86W, etc.) refer to their location on the mine grid in Figure 34. Structural symbols, other than explained in the Figure also relate to Figure 34.

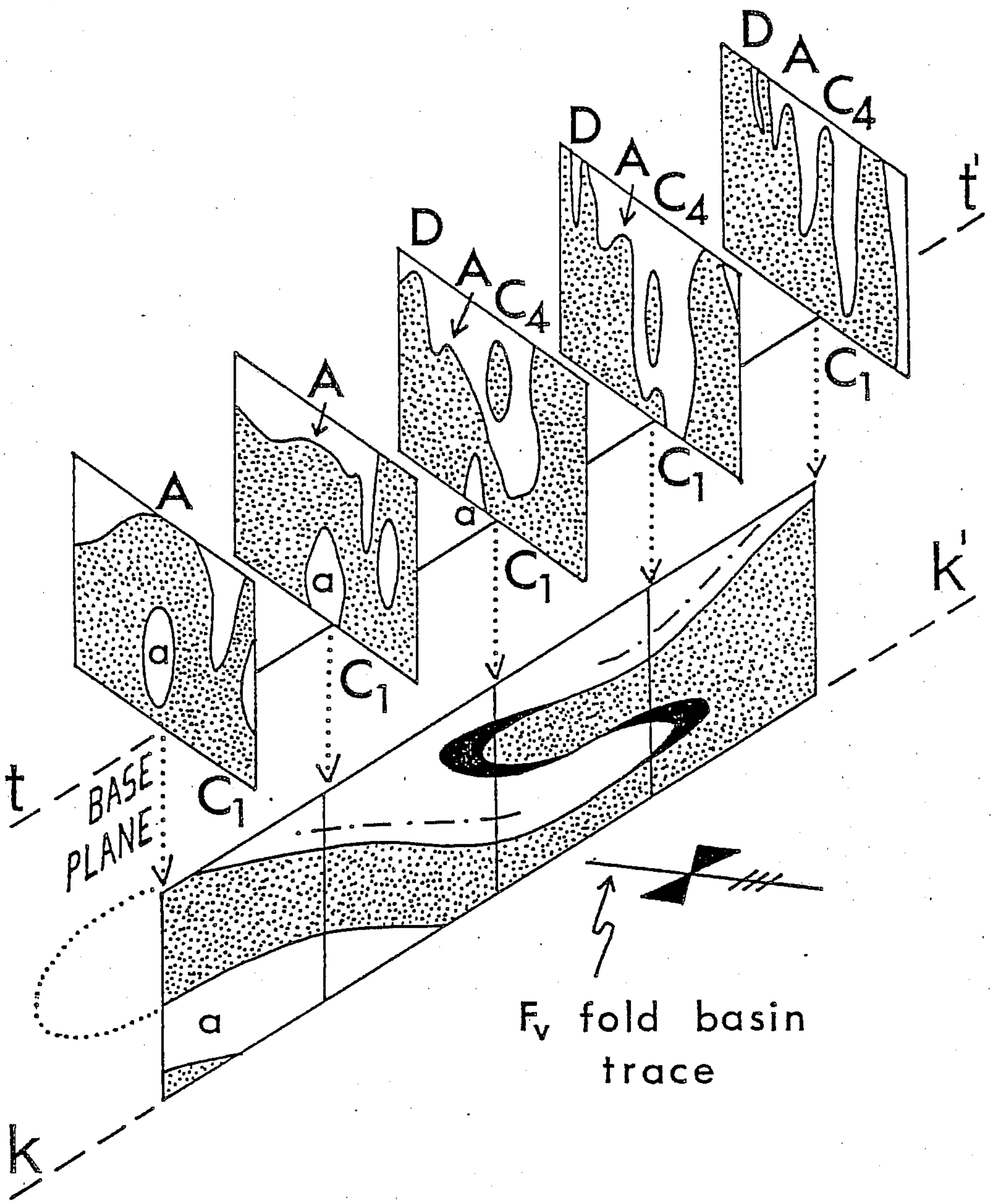

Figure 36. Conceptual simplification of Figure 35, illustrating the lateral change in shape of F_1 folds labelled a, A, C_1, C_4, and D. Although strikes of the fold axial planes vary, the section in the base plane of the mine gride adequately illustrates one interpretaion of the shape of the F_1 folds (below: kk^1-tt^1). In this model, the F_1 folds are overturned, sheath-like, domes and basins, and idealized orebodies (black) occur in the fold closures. The superposed trace of S_2 (dash-dots) outlines an F_V basin.

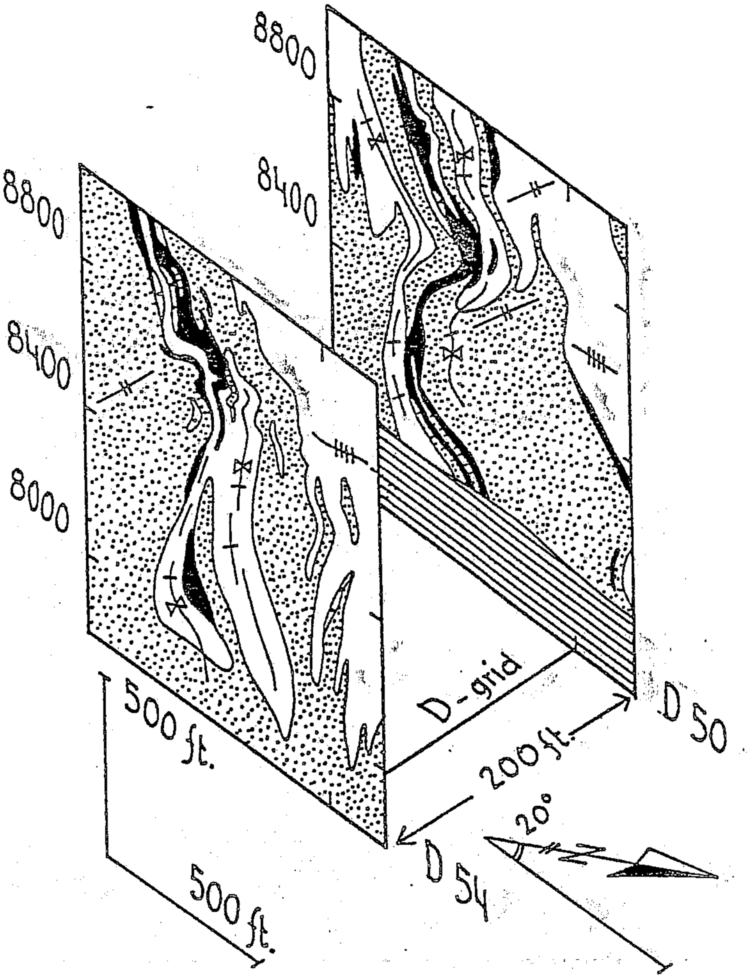

Figure 37. The structure of the Heath Steele D zone, constructed in the same way as Figure 35 (same symbols), both sections are oriented in a separate grid. The location of the block is shown in Figure 34.

On the surface in the A and C zones, S_2 generally dips to the southwest, despite F_5 refolding (Fig. 34). West of the D zone, S_2 dips to the east, and the asymmetry of small-scale F_V folds of S_2 is reversed relative to the asymmetry in most of the area. These relationships indicate the presence of an open F_V synform in S_2 with a southeasterly plunge, bisecting the A, C, and D zone area. Thus, the A, C, and D zone deposits delineate the fringe of a tectonic basin, created by a combination of F_1 fold plunge variation and D_V refolding (Figs. 34, 36).

When compared in detail, adjacent sections of the F_1 folds in Figure 35 do not match up. This is partly due to the post-D_1 folding, but individual folds also change shape rapidly along strike; e.g., the C_4 zone (compare sections 90W, 98W). The discontinuous structures could be described as doubly plunging, upright F_1 folds, but recumbent fold closures also occur in S_1, as shown by the semi-ellipsoidal pod of augen schist in the C_1 zone of sections 90W and 98W (Fig. 35). Both sections show another pod of augen schist underneath the A zone horizon. This pod was not drilled in section 86W, but trenching revealed that further east it emerges on surface, indicating a westerly plunge for the top of the pod. Quartz augen schist in the pod overlies quartz-feldspar augen schist. This sequence is reversed above the A zone, suggesting that the augen schists above and below the sulphides are the same stratigraphic unit, repeated vertically by the overturning of a fold basin (Fig. 36, pod a). The basin axis plunges westward in this scenario. The geometry of sections 90W and 98W could also be explained by stratigraphic or tectonic repetition of the augen schist protolith normal to S_0, before the upright folding.

Drill core compilations show the major sulphide masses as stratabound deposits on, or near, contacts between augen schists and metasedimentary rocks. Detailed core studies show that the sulphides crosscut the lithocontacts and form lobes along the fold axial plane cleavage. This was also noted by Owsiacki (1980), and is illustrated by the sulphide pattern in the C_4 zone in sections 98W and 108W.

The B Zone Deposit: The B zone is the largest massive sulphide deposit at Heath Steele Mines. It is roughly tabular in shape and dips steeply north, with metasedimentary rocks predominating in the footwall, and augen schists in the hanging wall (Figs. 38, 39). Within the orebody, a foliation (S_1) is present that is defined by stratiform sulphides, sulphide banding, and a compositional layering (S_0) in the host rocks. Intrafolial folds in S_1 are exposed underground. They deform an earlier layering and are presumably tectonic in origin. The intrafolial folds have been deformed into open to isoclinal F_2 folds, in the axial plane of which a new layering (S_2) has locally developed. S_2 is parallel to the axial planes of macroscopic folds of the ore/host contact (McBride 1976). These folds plunge steeply to the west, whereas S_2 dips to the south-southwest (Fig. 39d). In outcrop, this dip direction corresponds to that of S_1, but is opposite to that of the orebody as a whole (slab S in Fig. 39e). The latter has been interpreted as the enveloping surface to mesoscopic F_2 folds of the main foliation S_1 (Moreton and Williams 1986).

Detailed mapping of sulphide-host contacts has outlined macroscopic, sheath-like fold domes of metasedimentary rocks within the B zone orebody. The dome axes plunge west, whereas their axial planes are parallel to the orebody envelope and are overprinted by S_2 (Fig. 39). The domes, therefore, are D_1 structures. This complex structure is hard to reconcile with the constant northward younging across the B zone (Fig. 38), postulated on the basis of macroscopic sulphide zoning (Lusk

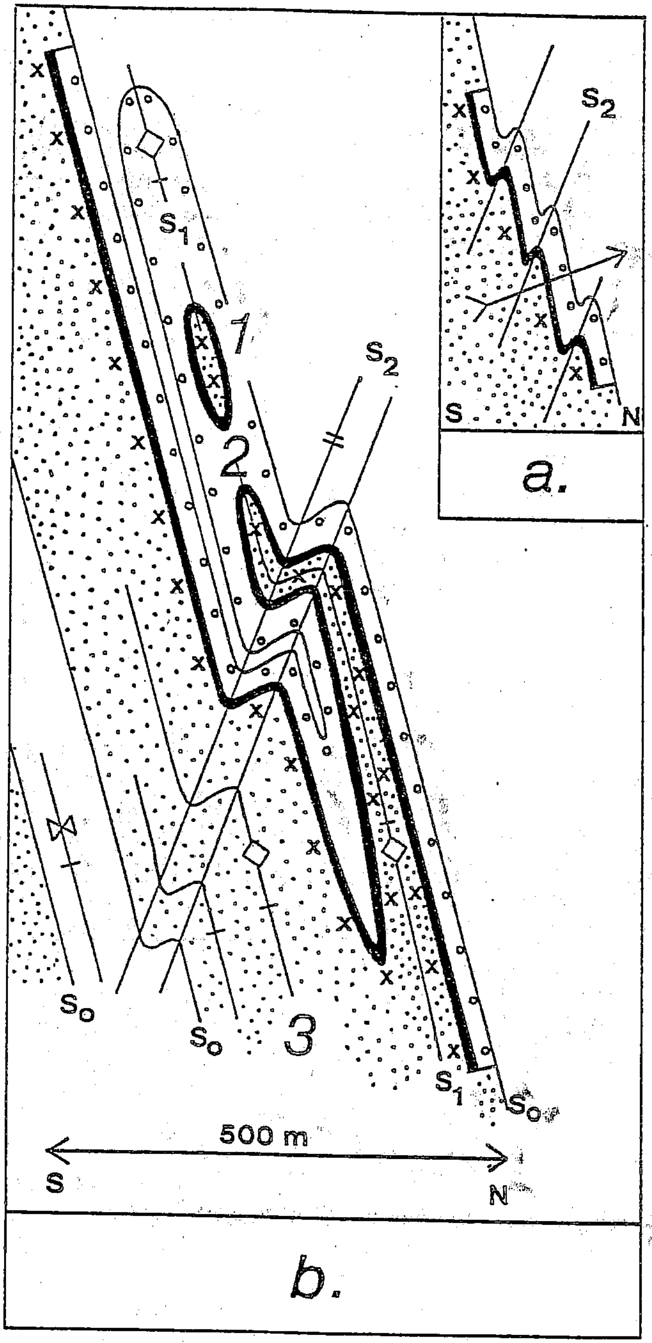

Figure 38 (after McBride 1976; Davies *et al*. 1983).

a) Schematic section of the F_2 folded Heath Steele B zone deposit (slab) with uniform younging (arrow), comprising upward: footwall metasedimentary rocks = stipple, acid tuff = crosses, Cu zone = black, Pb-Zn zone plus iron formation = open dots, hanging wall augen schists (plain).

b) The presence of westerly plunging F_1 fold domes (1; see Fig. 39c) within the ore slab requires a more complex, tectonic, stratigraphy across the Heath Steele B zone. By postulating that fold 1 is part of antiform 2, which is parasitic to 3, overall younging could still be to the north (compare with Fig. 43). The structure, and consequently ore zoning, is simplified here by omitting the observed cascades of F_2 folds (Fig. 39d) and parasitic F_1 folds. Note also that S_0 could well be a D_1 thrust plane. Structural symbols as in Figure 34.

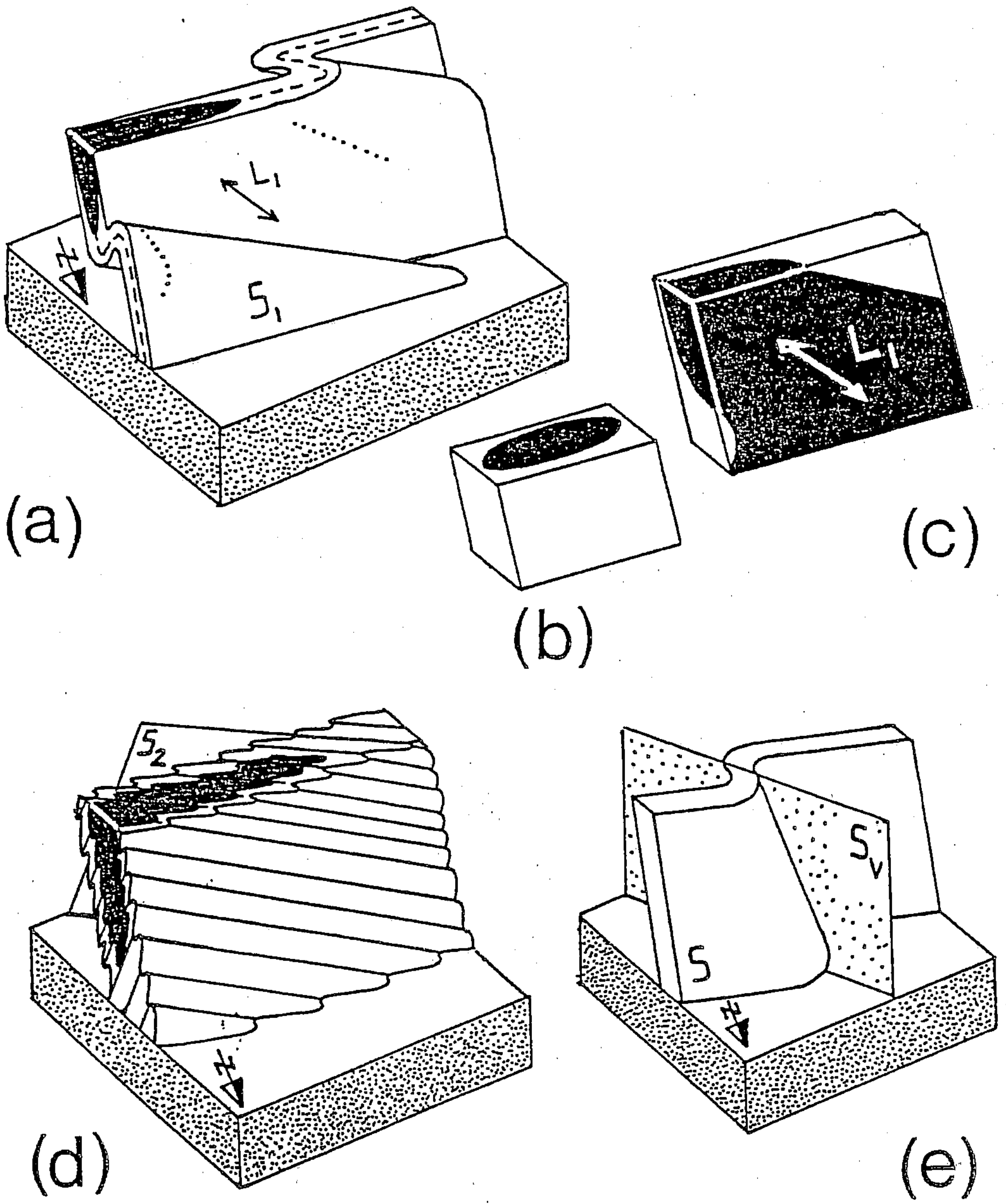

Figure 39. (a) Perspective model (looking southwest) of the Heath Steele B zone orebody (white slab), with its envelope (S_1) dipping north. The ore envelope is parallel to the axial plane of a westwrd plunging F_1 dome of metasedimentary rocks (black) within the slab; (b) and (c) cut this dome in plan and section. (d) Shows S_2 dipping to the southwest as axial plane to tight crenulations of the dome. One of the F_2 refolds is enlarged in (a). (e) The envelope (S) of the F_2-crenulated slab is deformed in F_V folds with the same asymmetry as F_2 folds.

1969; McMillan 1969; McBride 1976). These authors distinguished a Pb/Zn-zone and a Cu-zone, and placed the former stratigraphically on top, conforming to the popular model of syngenetic mineral exhalation (Franklin et al. 1981).

The E Zone Deposit: The sulphide deposits of the B and E zones dip steeply in opposite directions (compare Figs. 38, 40). The E zone consists of two sulphide bodies (here referred to as E-north and E-south) in lenses of metasedimentary rocks that pinch out to the east. In detail, the symmetry of lithologies across these lenses suggests that they are in fact isoclinal folds (Figs. 40, 41). Structural relationships in trenches near the E zone are consistently the same as in the B zone, with S_2 overprinting an east-west striking main foliation S_1 that is parallel to the axial plane of the isoclinal folds, which are, therefore, D_1 structures. In the E zone, however, S_2 dips gently in various directions. The change in dip of the axial planes to the F_1 isoclinal folds, and of S_2, between the E and B zones is therefore attributed to open, recumbent F_h folding.

Much of the E zone sulphide is concentrated in the northern limbs of the isoclinal folds, as can be seen in plan (Fig. 41) and in sections 42W and 43W (Fig. 40). Comparison of sections 37W and 41W suggests that both isoclinal folds are synforms with steep westerly plunging axes. However, if the pre-D_1 stratigraphy of the E zone was the same as in the A, C, and B zones, the augen schists should occur on top of the metasedimentary rocks. From this assumption, it would follow that both isoclinal folds define the downward facing side of overturned F_1 domes that, like their counterparts in the B zone, have a westerly plunging sheath axis (Fig. 42).

Due north of the E zone, there is a small sulphide deposit (the F zone; Figs. 40, 41) that also dips steeply to the south. Comparison of sections 42W and 43W reveals that the bulk of the F zone occupies the southern limb of an isoclinal synform, in which metasedimentary rocks occur on top of augen schists. As in the E zone, the F zone synform could represent the downward facing side of an overturned dome, but, contrary to the E and B zones, the F zone fold closure plunges steeply to the east (compare both plans of Fig. 41).

SYNTHESIS

The concentration of massive sulphides along the contact between metasedimentary rocks and augen schists could mean that all deposits are part of a single mineral horizon. Mapping, supported by trenching of predicted fold closures, has revealed that the lenticular nature of lithological units (Fig. 34) is due mainly to attenuated, doubly plunging folds with axial planes on average trending east-west, rather than to primary lithofacies variations in an east-west striking sequence. This is also demonstrated by the presence of distinct F_1 fold

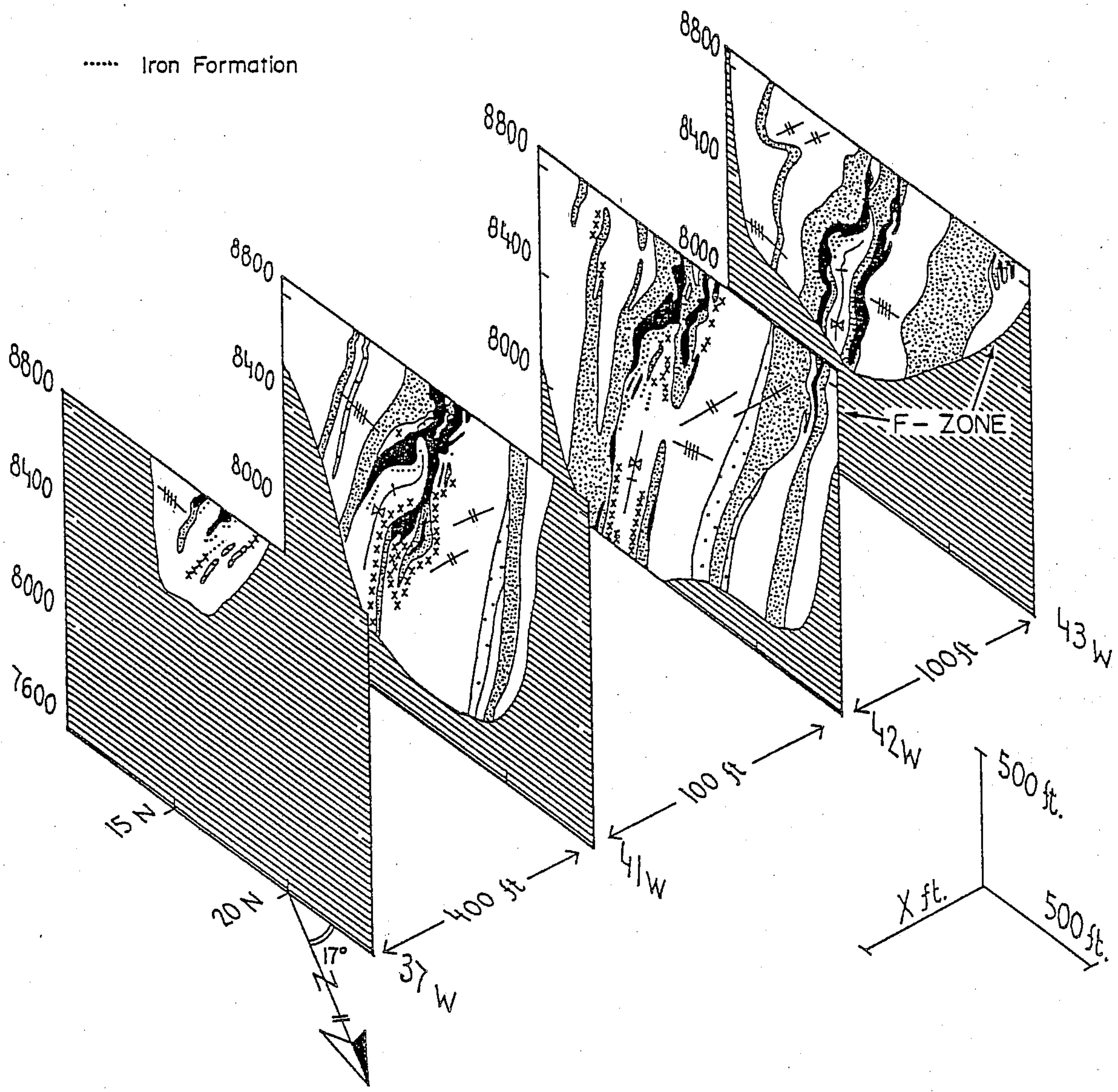

Figure 40. The structure of the Heath Steele E and F zones, constructed in the same way as Figure 35 (same grid, same symbols). See Figure 41 for section locations.

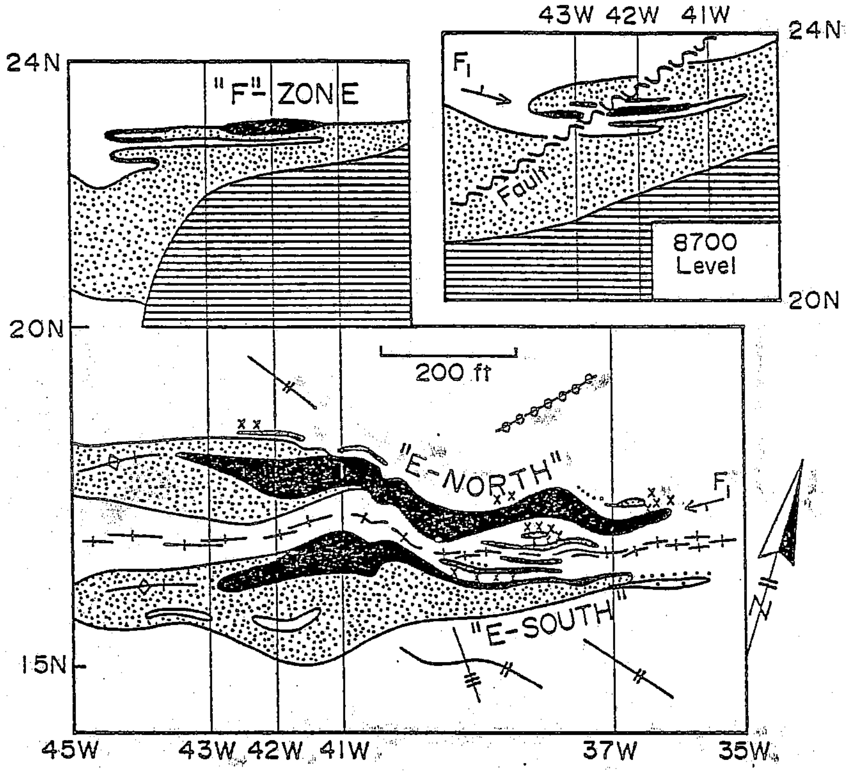

Figure 41. The structure of the Heath Steele E and F zones in plan on 8,880 mining level, just below surface. The map co-ordinates refer to the mine grid (for location and legend of symbols see Fig. 34). The F zone geology is also shown at 8,700 level; 30 metres deeper (inset, compare co-ordinates).

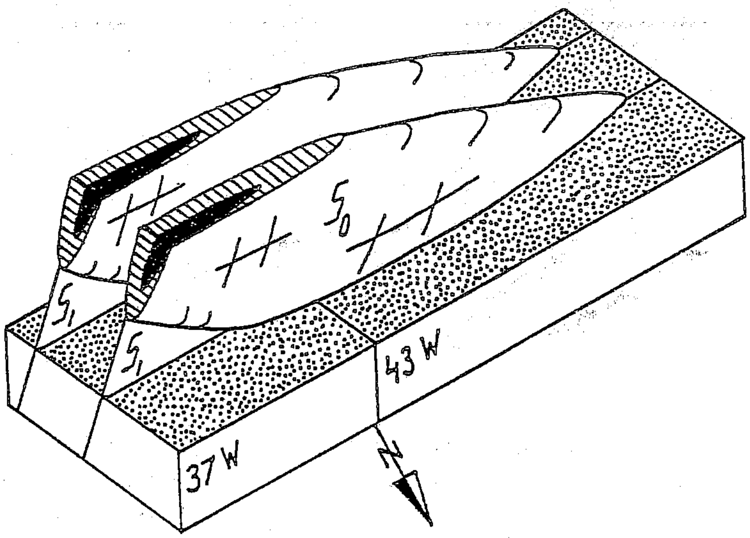

Figure 42. Sketch interpreting the two pods of metasedimentary rocks at the Heath Steele E zone (Fig. 40) as F_1 fold domes with westerly plunging dome axes. Each pod contains massive sulphides (the E north and E south zones; black).

closures with east-west striking axial planes (S_1) in the discussed sections of the sulphide zones. It follows that pattern of lithocontacts in the area reflects F_1 dome and basin folds, attenuated along S_1 (Fig. 34). The domes and basins are consistently overprinted by S_2 (compare the form surface traces of S_1 and S_2), and the irregular shape of some F_1 folds is partly due to refolding. Although F_1 folds are arranged in an erratic fashion, they are clustered in arrays that are persistent along strike, as illustrated by the three "ridges" of metasedimentary rocks and sulphides in Figures 33 and 34. The northernmost ridge is marked from east to west by the B and E/F zones, and by a prospect (the C_5 zone). The central ridge contains the B_5, A, C_1, and C_4 zones; the southern ridge is occupied by the D zone.

On a larger scale, the three ridges and the bulk of the augen schists define an east-west striking F_1 fold belt (Fig. 33). On either side, this belt is separated from metadolerites by metarhyolites and felsic schists. This symmetry in rock type distribution, and the similarity in appearance of the felsic schists on either side, indicate that the belt can be regarded as an upright megafold (Dechow 1960), to which the steeply south-dipping foliation S_1 is axial planar (Fig. 43). The core of the fold belt is marked by metasedimentary rocks, which are overlain by augen schists in the hinges of the F_1 mine folds. Also, the gradual transition of the augen schists into felsic schists predates deformation at least locally, suggesting that the metasedimentary rocks are lowermost in the lithostratigraphy. Therefore, the metasedimentary rocks could mark the antiformal culmination of the fold belt (Fig. 43), unless lithostratigraphic repetition is assumed. In the latter case, the overall structure cannot be reconstructed as easily.

The stratigraphy of the fold belt has been complicated by the presence of overturned sheath folds in S_1 (Fig. 39) marking locally intense D_1 deformation that also involved foliation transposition and microboudinage of porphyroclasts in the augen schists. Furthermore, the fold belt contains narrow shear zones, in which rocks of various lithological units are found together (e.g., Fig. 41, separating both E zones). Some of these zones contain lenses of metadolerite with a strong S_1 schistosity. Conversely, undeformed, or weakly schistose, metadolerite and meta-agglomerate are situated on either side of the fold belt, illustrating the macroscopic strain concentration in the fold belt, which can therefore be regarded as a large shear zone bounded to the south by the Heath Steele Fault (Fig. 43). This fault bends around the North Little River Lake Fold (Fig. 33), which was created most likely during D_2 deformation.

CONCLUSIONS

The Heath Steele sulphide deposits have been described here

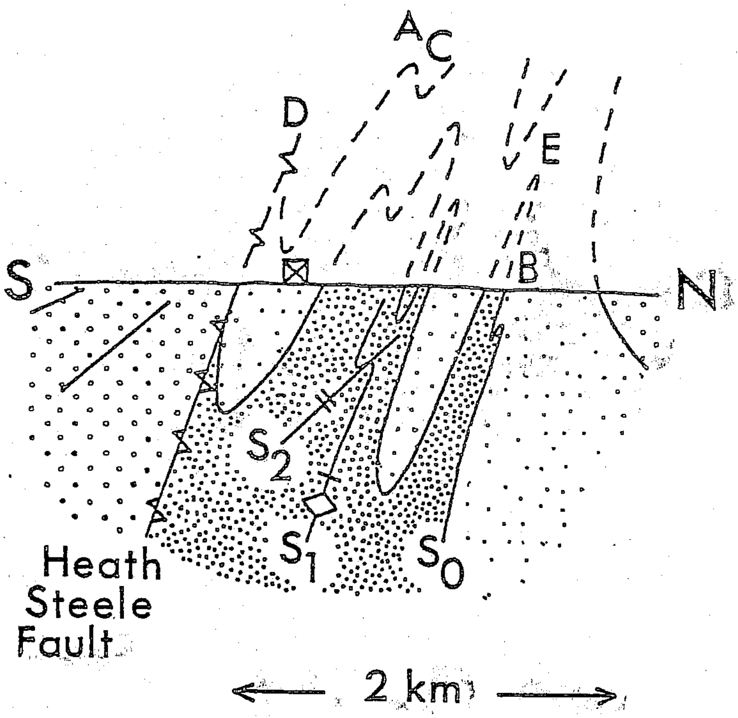

Figure 43. Schematic section of the fold belt at Heath Steele mines, disregarding the shallow plunge of conical F_1 folds, and assuming nonrepetition of stratigraphy. Symbols as in Figure 34; A-E refer to the structural position of the major sulphide zones; box is location of Heath Steele mine complex.

as pods or slabs of massive sulphide, located along contacts between metasedimentary rocks and augen schists. Comparison of sections of the A, C, and D zones (Fig. 35) suggests that the mineralized contacts are all part of a single horizon (S_0), which has been complexly folded during polyphase deformation (Fig. 34). By inference, all sulphide at Heath Steele Mines could well be part of a single marker horizon.

Much of the sulphide is concentrated in F_1 fold closures, as illustrated by the B, C_4, and A zone deposits. The A zone is situated in an antiform, and its richest Pb and Zn grades were mined from an open pit in the hinge of the fold (Fig. 34). The high grades there, when compared to the other deposits at Heath Steele, suggest concentration of galena and sphalerite in the fold hinge. Tectonically-controlled concentration of sulphide in general, and galena in particular, would be in accordance with published accounts of the mobility of sulphides relative to host silicates (McDonald 1970; McClay 1979, 1982; Pedersen 1980; van Staal and Williams 1984; Cox 1987; Cox <u>et al</u>. 1987; de Roo 1989). Thus, the thickening of the sulphide horizon in fold closures could be compared to the thickening of an incompetent layer, needed to accommodate parallel folding of more competent adjacent layers (e.g., O'Driscoll 1962, 1964; Ramsay 1962, 1974). The absence of sulphide along parts of the horizon could be ascribed to tectonic thinning or to primary impersistence of the mineralization. The latter model can be invoked to explain the selective mineralization in a single limb of an attenuated F_1 fold (e.g., the C_1, E, and F zones; Figs. 35, 40, 41).

The mineralized F_1 fold closures at the B zone are sheath-like, with axes plunging toward the west (Fig. 39). The E zone folds and the structure underneath the A zone (Fig. 36) can be interpreted likewise, suggesting an association between sulphide concentrations and conical folds. The Brunswick orebodies near Bathurst have also been explained by concentration of a mineral horizon (S_0) in overturned, conical, F_1 folds (Van Staal and Williams 1984). They described compositional sulphide zoning normal to S_0 in the fold closures, and interpreted this zoning as pre-tectonic, although the folds presumably evolved during progressive D_1 thrusting and shearing of S_0 (van Staal and Williams 1984).

GEOLOGY OF THE STRATMAT BOUNDARY ZONE AND THE HEATH STEELE N-5 ZONE

A. Hamilton

INTRODUCTION

Heath Steele Mines is located on Route 430 approximately 65 km southwest of the City of Bathurst and 50 km northwest of Newcastle in northern New Brunswick. The Stratmat property adjoins the north boundary of the Heath Steele mining lease (Fig. 44). The Boundary Deposit straddles the Heath Steele-Stratmat boundary, and the N-5 Zone lies on the Heath Steele lease. The Heath Steele Property is held under a joint venture agreement between Brunswick Mining & Smelting Corporation Ltd. and Noranda Minerals Inc. Operations on the Stratmat Boundary Zone are being carried out under an option agreement between Heath Steele Mines and Cominco Ltd.

The Stratmat property was staked in 1954 by Stratmat Limited (Strategic Metals Ltd.) during the Heath Steele staking rush and was purchased by Cominco Ltd. in 1959 (Rhodes 1978). Sulphide deposits on the Heath Steele property were initially located by an airborne electromagnetic survey carried out in 1953. This survey was followed up by ground electromagnetic and soil geochemical surveys and diamond drilling in 1954 (Archibald 1985). The Boundary Deposit was discovered in 1961 by diamond drilling of a coincident weak electromagnetic and geochemical anomaly discovered in 1960. The N-5 Zone was first drilled in 1964 to test an I.P. anomaly.

Mining started at Heath Steele with an open pit at the B-Zone in 1957, but ceased in 1958 due to poor metal prices and metallurgical problems. Operations resumed in 1962 with underground mining at the B-Zone, but poor metal prices forced another shut down in 1983. Following a feasibility study, which included driving an underground ramp at the Boundary Deposit, underground diamond drilling and extraction of a bulk sample for metallurgical testing, a decision to resume production was reached in February 1989. The current production plan includes mining the B-Zone underground at a constant rate of 1250 tonnes per day and concurrent production of 900 tonnes per day from the sequential mining of the Boundary Zone open pit, the N-5 Zone, the Boundary Zone underground and the E-Zone underground. Mineable reserves total 4,227,000 tonnes grading 2.53% Pb, 6.36% Zn, 0.71% Cu, and 67.17 g/tonne Ag. Mineable reserves for the Boundary Zone total 736,000 tonnes grading 3.51% Pb, 8.02% Zn, 0.29% Cu, and 45.91 g/tonne Ag. Mineable reserves at the N-5 Zone are 187,000 tonnes grading 3.23% Pb, 7.18% Zn, 0.37% Cu, and 28.80 g/tonne Ag.

STRATIGRAPHY

The sulphide deposits in the Heath Steele area lie within a

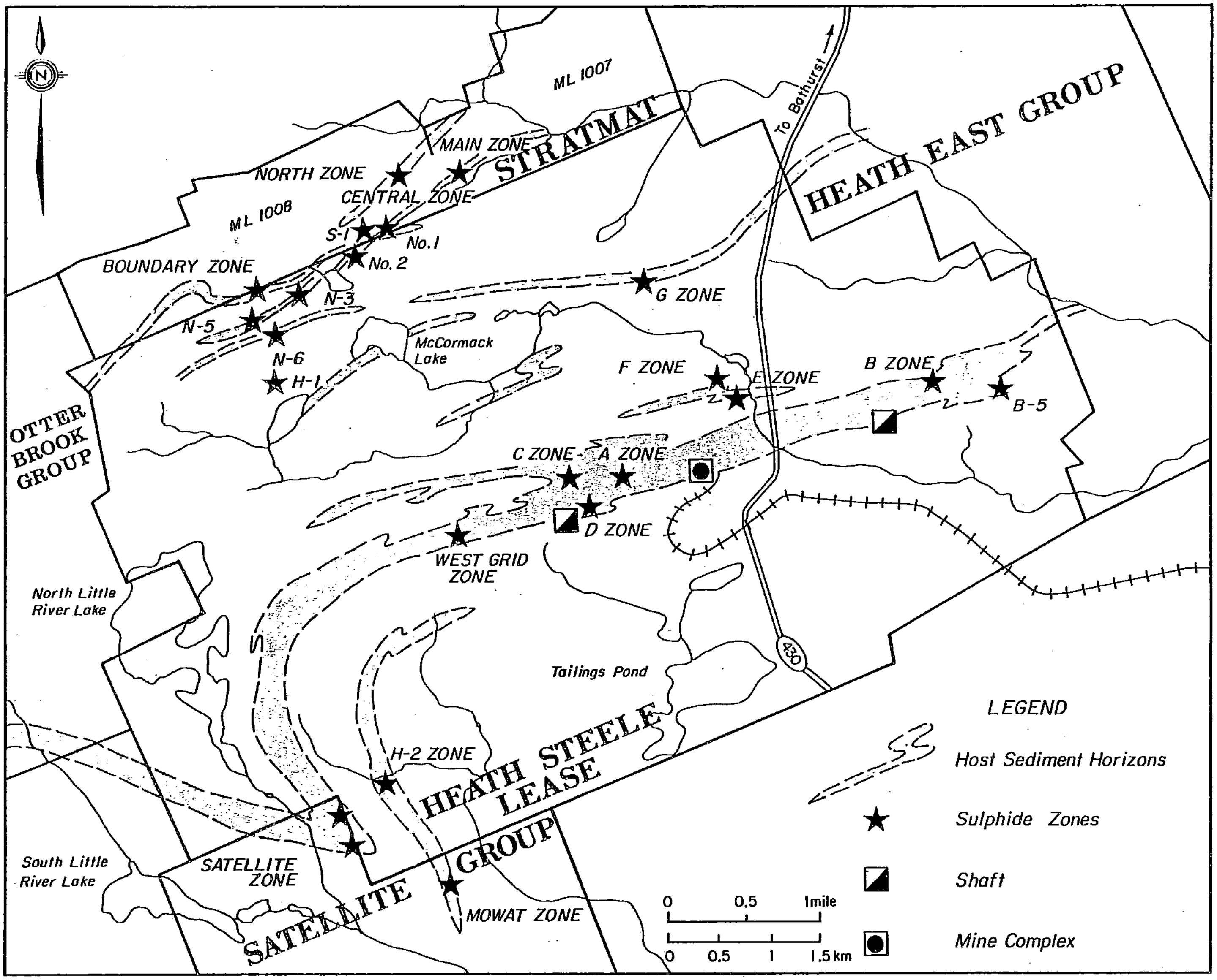

Figure 44. Location of the Stratmat and Heath Steele sulphide zones.

polydeformed sequence of felsic metavolcanic and metasedimentary rocks of the Tetagouche Group. Mineral assemblages in all rock types are typical of the greenschist facies of regional metamorphism (Skinner 1974). The N-5 Zone is considered to be a faulted extension of the Boundary Zone; the steeply dipping, east-west-trending fault between the deposits is interpreted to have dextral movement (Fig. 45).

Throughout the history of the Boundary and N-5 Zones, there have been marked differences in rock nomenclature used among geologists. The rock classification now in use by Heath Steele and Noranda Exploration geologists is essentially a modification of an earlier classification by Cominco (Dahn et al. 1987;). A preliminary classification of rocks at the Boundary and N-5 zones is as follows: (1) Southwall Fragmentals - a lapilli-rich tuffaceous unit that is in part sedimentary; (2) Stratmat Sequence - a sedimentary package which hosts the ore mineralization and stratigraphically overlies the Southwall Fragmentals; and (3) Northwall Sequence - tuffaceous rocks referred to as the Bedded Package and crystal tuffs (Fig. 45).

The predominate assemblages of the Southwall Fragmentals consist of coarse to fine lapilli tuff, argillaceous tuff, and banded siliceous tuff of highly variable composition and texture. In general, the Fragmental unit is characterized by a mixture of blue-grey to light grey, finely crystalline silica fragments embedded in a fine-grained black to dark green matrix dominated by phyllosilicates, and silica ash. One to two per cent wispy, disseminated pyrite is found throughout the unit with accumulations of up to 10% towards the top of the package. A fabric resulting from tectonic brecciation is common in the more siliceous rocks.

The basal lithology of the Southwall Fragmentals is composed of fine-grained siliceous tuffs, cherts, and rhyolites, generally of highly variable thicknesses. Up to three per cent fine-grained wispy pyrite and minor fine-grained galena has been reported. From the basal siliceous volcanic rocks, the southwall rocks grade transitionally up into coarse siliceous to phyllosilicate-rich lapilli tuffs. Lapilli fragments are light to blue-grey, poorly sorted, subangular to subrounded, slightly elongated, highly siliceous, and range from 4 mm to 5 cm in size. The fragments are closely packed and seem to consist almost exclusively of silica although up to ten per cent may be lithic. These pyroclastic rocks generally have a pale green sericite-altered siliceous matrix. The coarse pyroclastics then grade upward into the uppermost southwall unit which is composed mainly of fine-grained, distinctly banded and intercalated siliceous tuffs, lapilli tuffs, cherts, and rhyolites. This uppermost sequence varies from a few metres up to 20 m thick. The contact with the overlying chert of the Stratmat Sequence is gradational and intercalated sequences are quite common.

Immediately overlying the Southwall Fragmentals is the

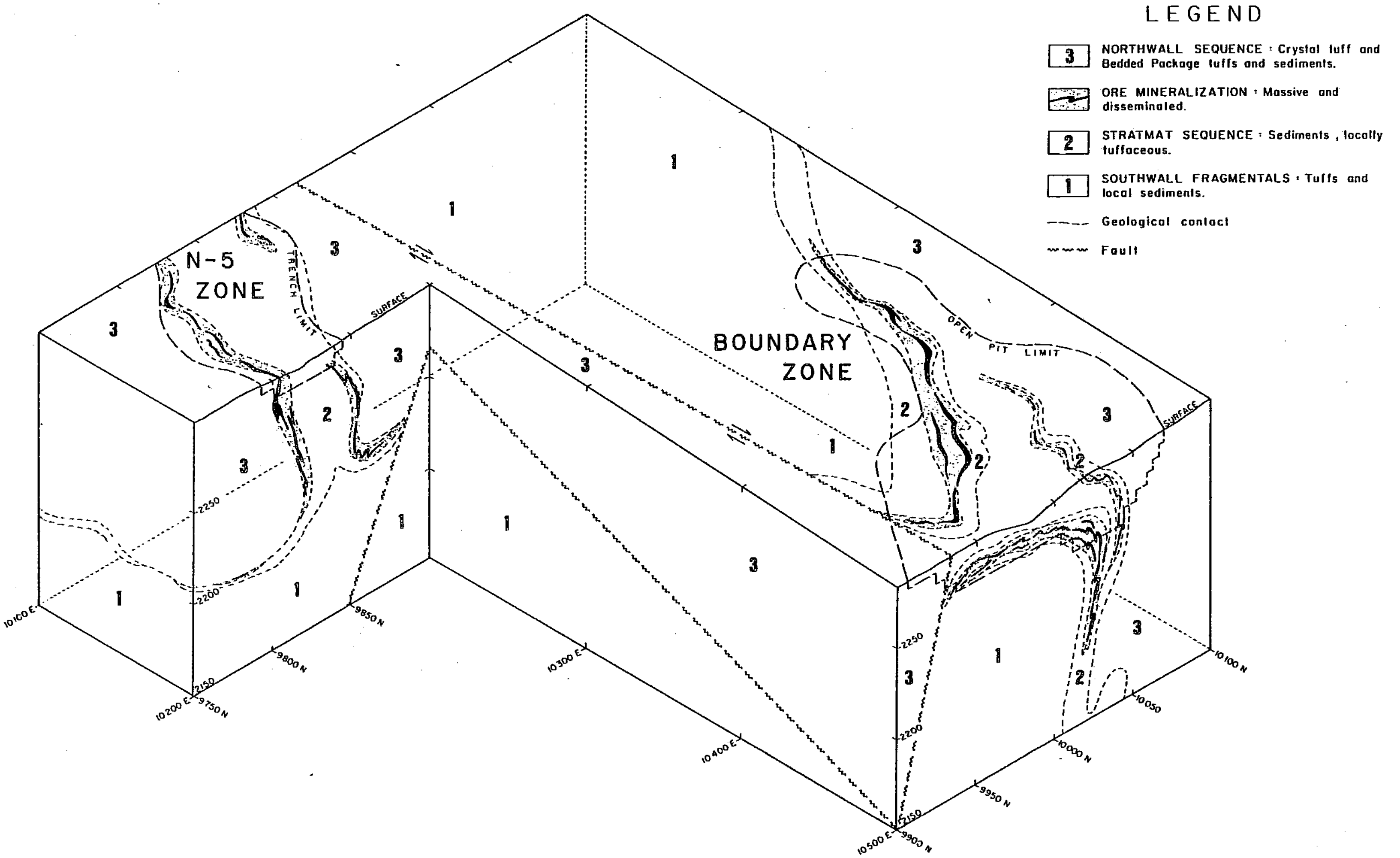

Figure 45. Schematic block diagram of the Stratmat Boundary and Heath Steele N-5 zones.

ore-bearing sedimentary package referred to as the Stratmat Sequence. This package is divided into a lower chert-rich unit which grades transitionally upwards into a distinctly bedded phyllosilicate-rich argillite. A carbonate unit, often associated with the ore, is predominately composed of calcite, but may include siderite or ankerite.

The cherts consist of rocks composed of 70% or more very fine-grained silica. They are commonly developed above the Southwall Fragmentals, although the contacts are gradational. The thickness of the chert horizon varies from a few metres up to 25 m and extends laterally as a series of discontinuous, intercalated beds and lenses between horizons of argillite and siliceous tuffs. Lesser amounts of chert occur as beds and lenses within the ore-bearing argillite rocks. They are characteristically light blue-grey in colour through to whitish grey-buff. They vary from massive to predominately laminated, and contorted showing distinct colour banding and phyllosilicate partings. A tuffaceous component is evident showing fine speckling of silica grains and few feldspar crystals. Through most of the cherts there is a 0-30% tuffaceous phyllosilicate-rich component which forms intercalated bands and partings. Mineralization within the cherts consists of pyrite, sphalerite, galena, and chalcopyrite. Pyrite forms 5 to 30% of the whole rock and is generally found within the phyllosilicate-rich portion of the chert horizon.

The argillaceous rocks both overlie and are interlayered with the cherts. Commonly, the argillite ratains a siliceous component except within and immediately adjacent to the sulphide ore horizon where talc and sericite predominate. The talc is developed as either a minor constituent of the massive sulphide and the argillite or as layers of massive talc up to several metres thick. The latter often contains ore-grade disseminated and blebby sulphides. The argillites vary from dull grey-green to dark green to black. Argillaceous layers have often been referred to as chloritic, but according to thin section examination, whole rock analysis and X-ray diffraction work by Cominco (Rhodes 1978), sericite is the predominate phyllosilicate with only minor amounts of biotite and chlorite. Pyrite content of the argillites varies form 1 to 25% with local heavier accumulations associated with the ore zone.

The sulphides are fine- to medium-grained, consisting primarily of pyrite, sphalerite, galena, and minor chalcopyrite. Pyrite is the predominate sulphide, but the average concentration is only about 15-20%. Cominco (Rhodes 1978) recognized five distinct types of ore-grade sulphide assemblages as follows: (1) Blebby/wispy - 0.1 to 5 mm ovoid to irregular sphalerite aggregates in talcose and/or argillaceous host rock; (2) Speckled - 0.1 to 0.5 mm disseminated sulphide grains varying from minor to massive concentrations in talcose and argillaceous host rock; (3) Solid sulphide mineralization - textureless solid sulphide rock of greater than 50% discrete 0.1 to 0.5 mm grains;

(4) Layered solid sulphides - layered solid sulphide rock with prominent pyrite banding and grain size between 0.1 and 1.0 mm; (5) Stringer and fracture mineralization - coarse-grained remobilized sulphides most commonly found in cherts.

A typical intersection through the ore zone would include solid sulphide as well as blebby and speckled ore. Stringer and fracture mineralization is locally found in the ore zone, but is more common in the stratigraphic footwall. Two distinct types of layered and massive solid sulphides have been found. The most common solid sulphide is zinc-lead rich with assays typically in the range of 5-15% lead and 15-35% zinc. A more localized type of solid sulphide is predominately pyrite with up to 15% disseminated to poorly layered wispy patches of chalcopyrite. The pyrite-chalcopyrite layer has been noted to occur stratigraphically below the zinc-lead-rich solid sulphide and the two layers may be in direct contact or separated by argillaceous and/or talose rock which may contain ore grade mineralization. Some solid sulphide mineralization exhibits mineralogy which is gradational between the zinc-lead-rich and pyrite-chalcopyrite types. Gangue minerals include sericite and talc with lesser amounts of chlorite, silica, and carbonate.

The Bedded Package of the Northwall Sequence consists of bedded pyroclastic rocks which overlie and intercalate with the Stratmat Sequence. In some areas, this package hosts significant mineralization. The assemblage appears to thin at depth and to the east. Individual units cannot be traced for any lateral extent, but the package as a whole, where it is developed, can be used to identify the stratigraphic hanging wall. Individual units within the package, although not necessarily in chronological order, as as follows: (1) siliceous lapilli tuff; (2) phyllosilicate-rich lapilli tuff; (3) siliceous tuff; (4) phyllosilicate-rich tuff; (5) argillite; and (6) inter-bedded sequences of all the above. The rocks are generally thinly bedded and contain a schistosity that is developed subparallel to the bedding. Some varieties show alternating silica- and phyllosilicate-rich laminations. The package, apart from hosting massive sulphide lenses, also contains up to 5% disseminated blebby sphalerite and galena, especially in proximity to the Stratmat Sequence. Pyrite also occurs along bedding planes and as sporadic disseminations.

Crystal tuff forms the uppermost unit of the Northwall stratigraphy. Although the crystal tuff shows some diversity, it is the most consistently recognizable unit and has been used as a marker when drilling from south to north. Minor horizons of argillite and bedded sequences are often intercalated within the unit. The crystal tuff generally consists of a fine-grained chlorite-sericite matrix hosting 2-20% subhedral, white feldspar crystals and 40-80% poorly defined felsic fragments. With the exception of narrow isolated stringers of Pb/Zn, mineralization is poorly developed in this unit.

STRUCTURE

The following discussion of structure was contributed by Chris Moreton. The ore and waste rocks of the N-5 and Boundary deposits are complexly deformed. At least 5 periods of deformation have been documented in the vicinity of the deposits although only the first two periods appear to be significant (see below). A late brittle movement zone, striking east-west, apparently displaces both deposits by approximately 200 m (Fig. 45). Mineable reserves for the Boundary Zone occur over a 250 m strike length and extend from surface down to a depth of 150 m (Fig. 46). Mineable reserves of the N-5 Zone occur over a strike length of 150 m and extend to a depth of 80 m below surface.

Although detailed structured studies of the two deposits have not been performed, there are indications that the structural history and geometry of the Stratmat Deposit is, as a whole, similar to that of the B-Zone at Heath Steel Mines (7 km southeast of the Boundary Zone). According to de Roo et al. (1990), D_1 is characterized by tight to isoclinal recumbent folds that locally have the geometry of sheath folds. Ductile D_1 movement zones genetically related to these structures are also present. Upright F_2 folds associated with D_2 deformation reorient bedding into its present subvertical attitude. F_2 axial surfaces strike approximately 060° true and dip steeply to the south in the Boundary and N-5 areas.

Structural repetition of lithological units reflects a combination of F_1 and F_2 folding as well as probable stacking through D_1 thrusting. Discrete thrust fault zones are not easy to document in any part of the camp and may be overlooked in the Boundary and N-5 deposits because of the dominance of the talc-rich zones. These talc zones would be mechanically weak and could therefore take up a lot of the movement during D_1 thrusting. The schistose nature of many of the talc zones suggests that this may be the case.

As in the B and A-C-D zones at Heath Steele Mines, the distribution of geologic units and overall morphology of the ore zones in the Boundary and N-5 deposits is a function of large scale F_2 folding. Cross sections 10200 E and 10500 E on Figure 2 clearly show the structures that have shallow to moderate easterly plunges. Younger deformations are less intense than either D_1 or D_2. Both F_4 and F_5 folds are upright, open structures that have axial surfaces striking northwest and northeast, respectively. F_3 folds are essentially horizontal although the dip of the F_3 axial surface may vary up to 35°, probably as a result of refolding by F_4 and F_5 folds.

FIELD TRIP PROGRAM

The field trip is to include visits to both surface and

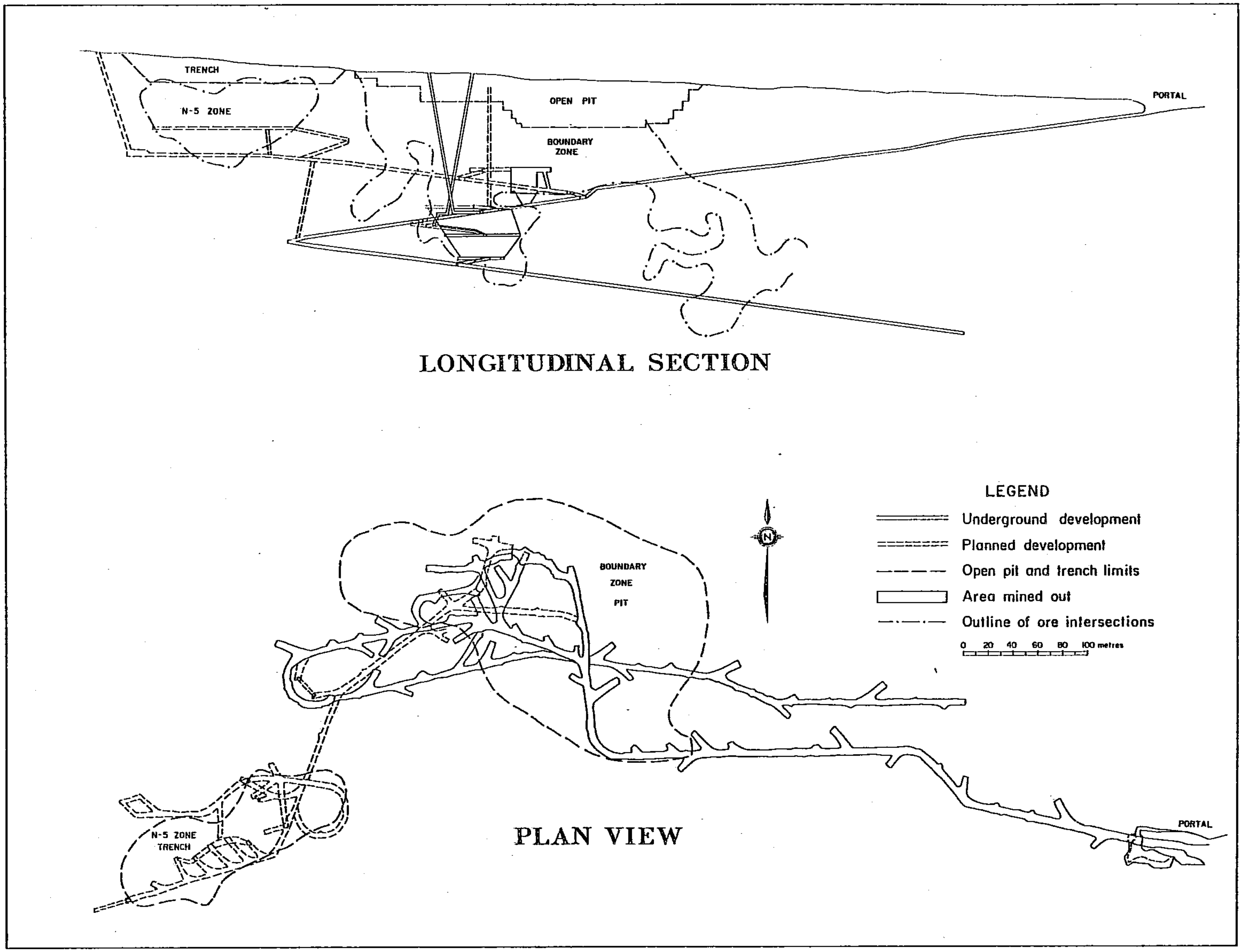

Figure 46. Plan view and longitudinal section of the Stratmat Boundary and Heath Steele N-5 zones.

underground mining areas. Exposures of the ore in underground workings will depend on the stage of drift and drawpoint development of the longhole stopes. There is only a minor amount of development ore scheduled to be mined from underground at the N-5 and Boundary zones in 1990. By June there should be at least one drift in the ore at the Boundary Zone and there may be some drawpoint exposures in the ore at both zones. Surface site visits include the Boundary Zone open pit and the trench at the N-5 Zone. Excavations of both of the surface sites were started in 1989.

THE CAPTAIN-NORTH EXTENSION (CNE) MASSIVE SULPHIDE DEPOSIT

Ken Whaley

The Captain North Extension (CNE) deposit is situated about 14 km east of Heath Steele Mines in volcanic and sedimentary rocks of the Tetagouche Group. A simplified geological map, shows the location of the deposit within the CNE claim group. The location of the Captain deposit is also shown (Fig. 47).

Four main rock units are present in the area: (1) metabasalt (Unit Omv); (2) metarhyolite (Unit Ofv_1); (3) quartz-feldspar augen schists (Unit Ofv_2) that are interpreted as a series of rhyolites, rhyolite crystal tuffs, and fragmental rhyolite tuffs; a massive quartz-feldspar porphyry (qfp), which probably represents a subvolcanic equivalent of Unit Ofv_2 was intersected in some of the drillholes; (4) argillite, greywacke, and slate (Unit Os). The orebody is hosted by sedimentary rocks (Figs. 47, 48).

The NE deposit is a good example of a near-surface, hidden, orebody that can still be discovered within the Bathurst Camp. It responds poorly to EM techniques and is geochemically masked by thick till. The first indication of mineralization was found by diamond drilling in 1978, considerably later than the majority of the other known Bathurst deposits. This drilling was done by Sabina Industries in 978 (DNRE Assessment Reports 472268 and 472394) to test an IP conductor and a stream-sediment anomaly that had been found in a tiny brook east of the deposit.

Stratabound Minerals Corp. acquired the property in August 1988 and shortly thereafter dug a deep trench that revealed unweathered Zn-Pb-Ag mineralization under 5 m of overburden. Forty-four short holes have been drilled and as a result five lenses have been delineated, numbered 1 through 5 from west to east. The trench is located on lens 2 at Line 1+75N (Fig. 48). The proven, open pittable, reserves in lenses 2 and 3 are as follow: 432,432 tonnes grading 5.28% Zn, 1.94% Pb, and 63.36 g/t Ag plus 38,992 tonnes grading 1.44% Cu and 0.514 g/t Au.

Lens 2, which forms the majority of the known deposit, is a body of massive sphalerite and galena with silver-rich tetrahedrite (ratio 3:1) and contains no more than 5 to 10% pyrite. This material commonly grades 25% combined zinc-lead and 171.4 g/t silver and is considerably coarser grained than the normal Bathurst Camp ores. The three-dimensional aspects of lens 2 are shown in Figures 49, 50, and 51. Locally, there are clasts of massive pyrite (up to 5 cm) and, in thin section, trace amounts of arsenopyrite have been observed. The massive mineralization is enclosed in a cherty horizon (Unit Os) containing fracture infills, thin beds, and 1 to 2 cm blebs of sphalerite and minor galena. This mineralization surrounding

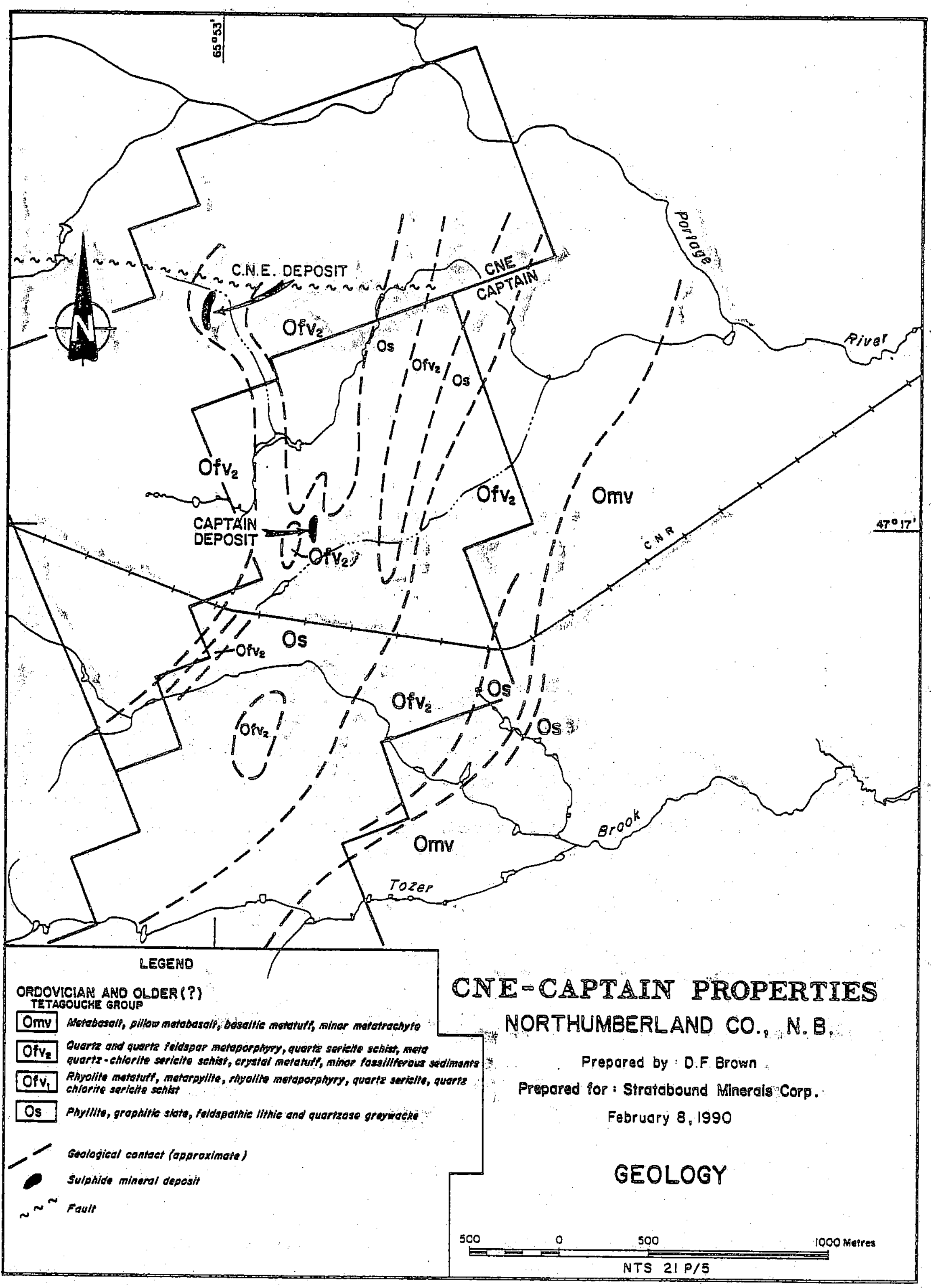

Figure 47. Simplified geologic map of the Captain and Captain North-Extension (CNE) claim groups.

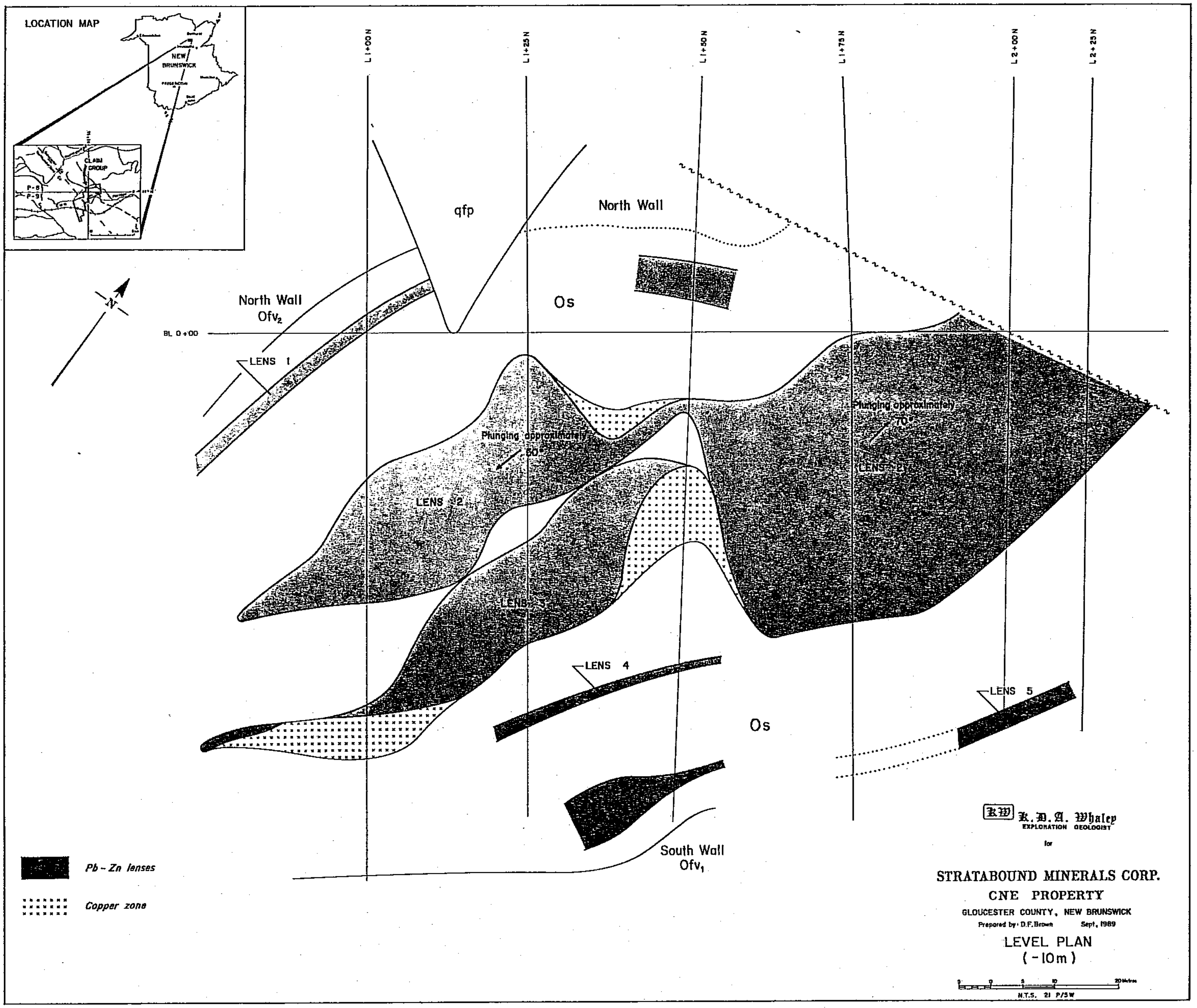

Figure 48. Level plan of the CNE deposit showing the distribution of the five massive-sulphide lenses.

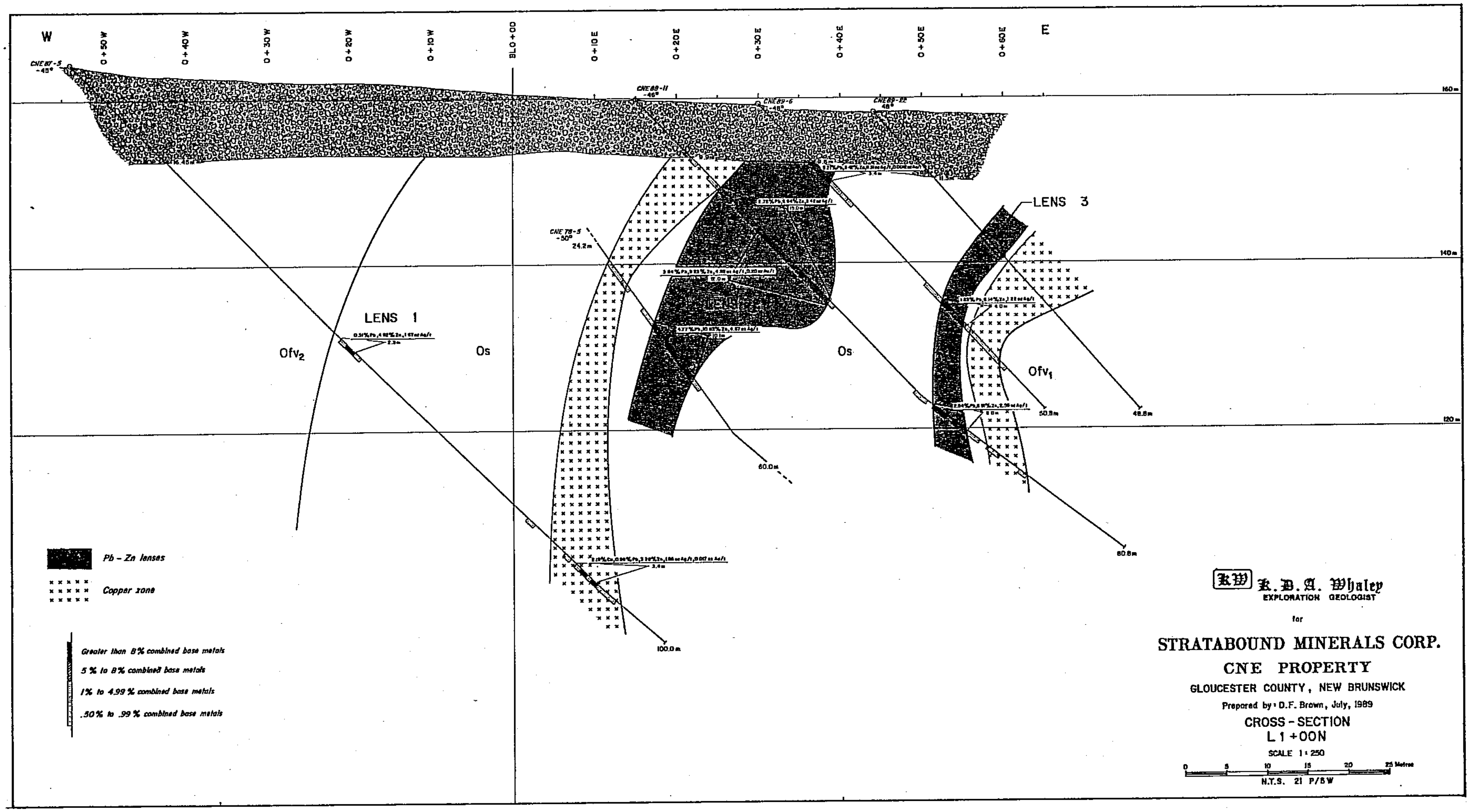

Figure 49. Cross-section of CNE deposit at Line 1+00N (See Fig. 48 for location).

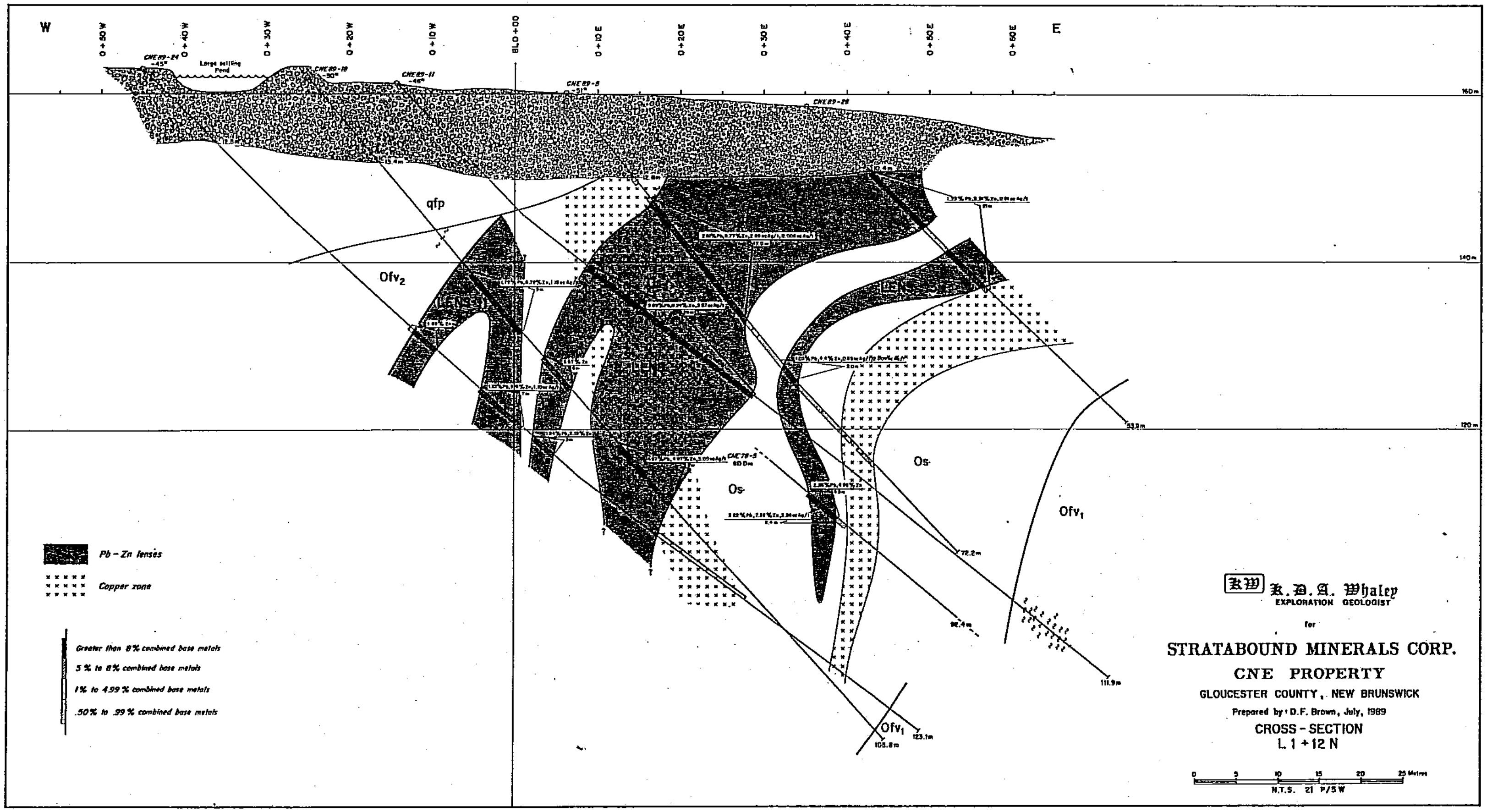

Figure 50. Cross-section of CNE deposit at Line 1+12N (See Fig. 48 for location).

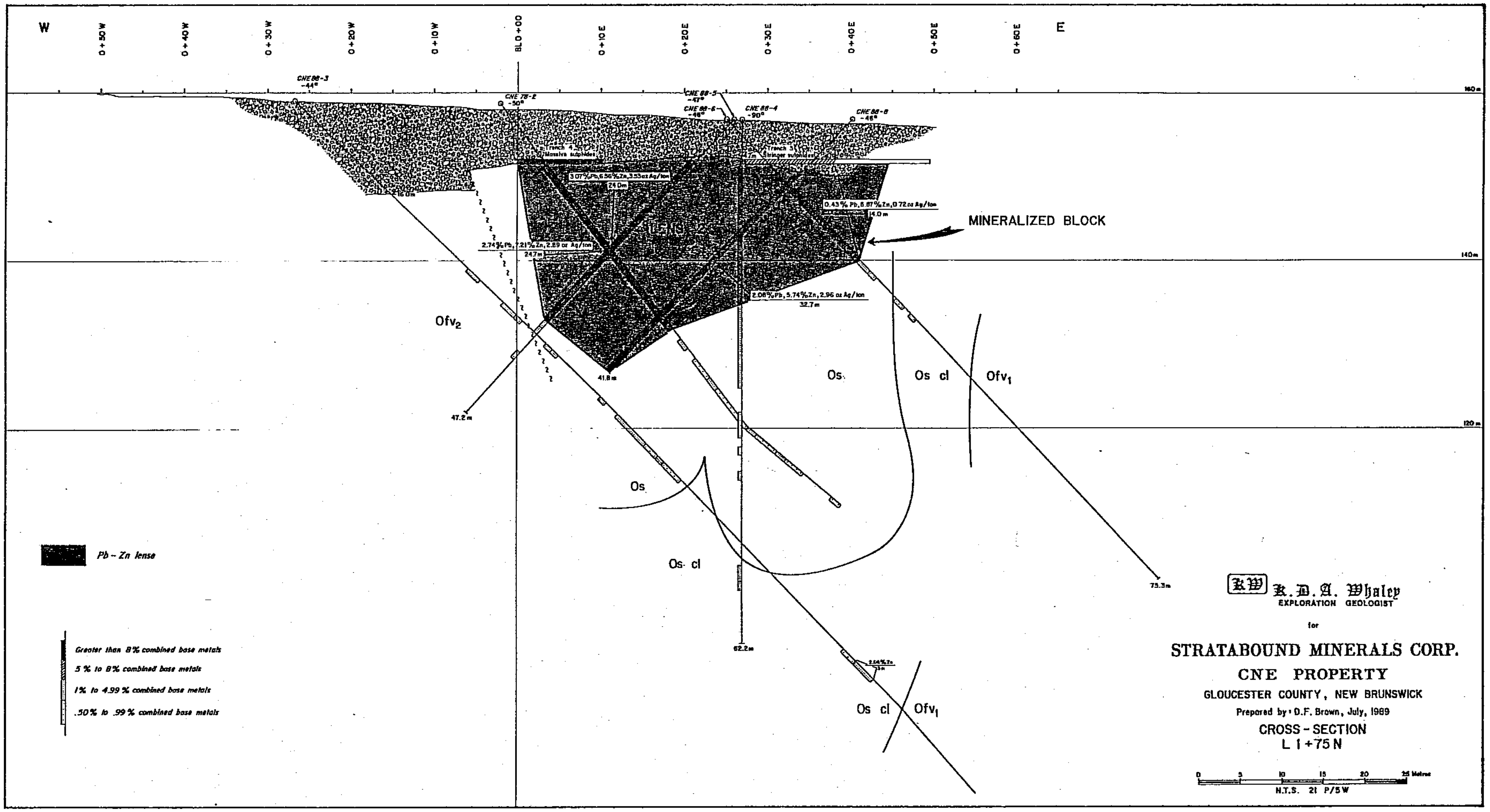

Figure 51. Cross-section of CNE deposit at Line 1+75N (See Fig. 48 for location).

the massive zone has a grade of 8 to 10% combined zinc-lead. No high concentration of talc or sericite has been observed. Chloritic phyllite (Unit Oscl) underlies the cherty rocks that host lens 2 (Fig. 51).

The lower Cu-rich part of Lens 3 is hosted by chloritic phyllite that contains variable amounts of sulphides, from massive pyrite with minor chalcopyrite and gold to trace amounts of pyrite. Local zones are developed that contain sphalerite and galena, but little or no tetrahedrite. These zones can grade up to 10% combined lead-zinc and is finer grained than lens 2. Erratic gold and copper intersections have been found, predominantly on the interface between lenses 2 and 3.

The massive Pb-Zn sulphide lenses are contained in a sequence of cherty rocks that appear to plunge south at 50°. In the north, the lenses are termined by a cross-cutting fault. Drag folding near the fault appears to have reversed the plunge to 70° north. The deposit has not been tested below the 50 m level and only in part between the 30 to 50 m level.

Drill core from the CNE deposit will be on display at the symposium. During the visit to the property, Ken Whaley, Derek Brown, and Dean Brown will describe some of the geological units seen at stops along the access road, and ore zone units will be examined in the lens 2 pit.

THE CARIBOU SULPHIDE DEPOSIT

R.A. Cavalero

INTRODUCTION

The Anaconda Company (Canada) Limited discovered the Caribou deposit on the upper reaches of Forty-Mile Brook in 1955. The interesting target area was selected following a regional geological approach, using available aerial photographs and airborne magnetic maps (Cheriton 1958). Detailed geological mapping and vertical loop electromagnetic surveys outlined the Caribou fold and the principal drill targets. The first drillhole put down intersected 15 m of massive sulphides.

Despite intensive research, the very fine-grained nature of the sulphides and the relatively low grade, remain as the major obstacles to exploitation of this deposit. Between 1970 and 1974, 910,000 tonnes of secondary copper sulphide ore (3.4% Cu) was mined by open pit methods, and 1982-83 heap leaching of 56,000 tonnes of gossan yielded 100,000 ounces of silver, and 6,600 ounces gold (Jambor 1981).

East-West Minerals purchased the Caribou property in 1986. Their first shipment of concentrate was delivered to the Australia Mining and Smelting smelter in Avonmouth, England in 1989. Subsequently, Bathurst Base Metals became the mine owner.

Total sulphide reserves to a depth of 1000 m are estimated at 60 million tonnes of 0.5% Cu,1.6% Pb, 4.3% Zn, 51.43 g/t Ag, and 1.715 g/t Au. At a 3.5 m minimum width and 10% Pb+Zn cut-off, the current geological reserve to the same depth is estimated at 12.3 million tonnes of 0.3% Cu, 3.7% Pb, 7.7% Zn, 102.86 g/t Ag, and 1.37 g/t Au.

STRATIGRAPHY

The Caribou massive sulphide deposit lies in the north-central part of the Miramichi Highlands, within volcanic rock of the Tetagouche Group (Roscoe 1971). Positioned on the east-west limb of the large, so-called Tetagouche antiform, the deposit comprises four en echelon, steeply dipping stratiform tabular lenses arranged around a local, northerly plunging synform (Fig. 52). The sulphide lenses occur within a thin footwall sequence of locally pyritic phyllite and quartz-chlorite schist at the contact with hanging wall schistose felsic tuffs. The footwall phyllite comprises highly crenulated interlayered graphite, slate, phyllite, and metagreywacke. Along the west limb of the Caribou fold pyritic, chloritic schists, and felsic metatuffs are more common in the graphitic sequence. The east limb footwall consists of metabasaltic tuff, schistose felsic tuffs and minor phyllite. These rocks are intruded by microgranite, felsite, and diabase dykes that post-date the penetrative S_1 and S_2 cleavages (see below).

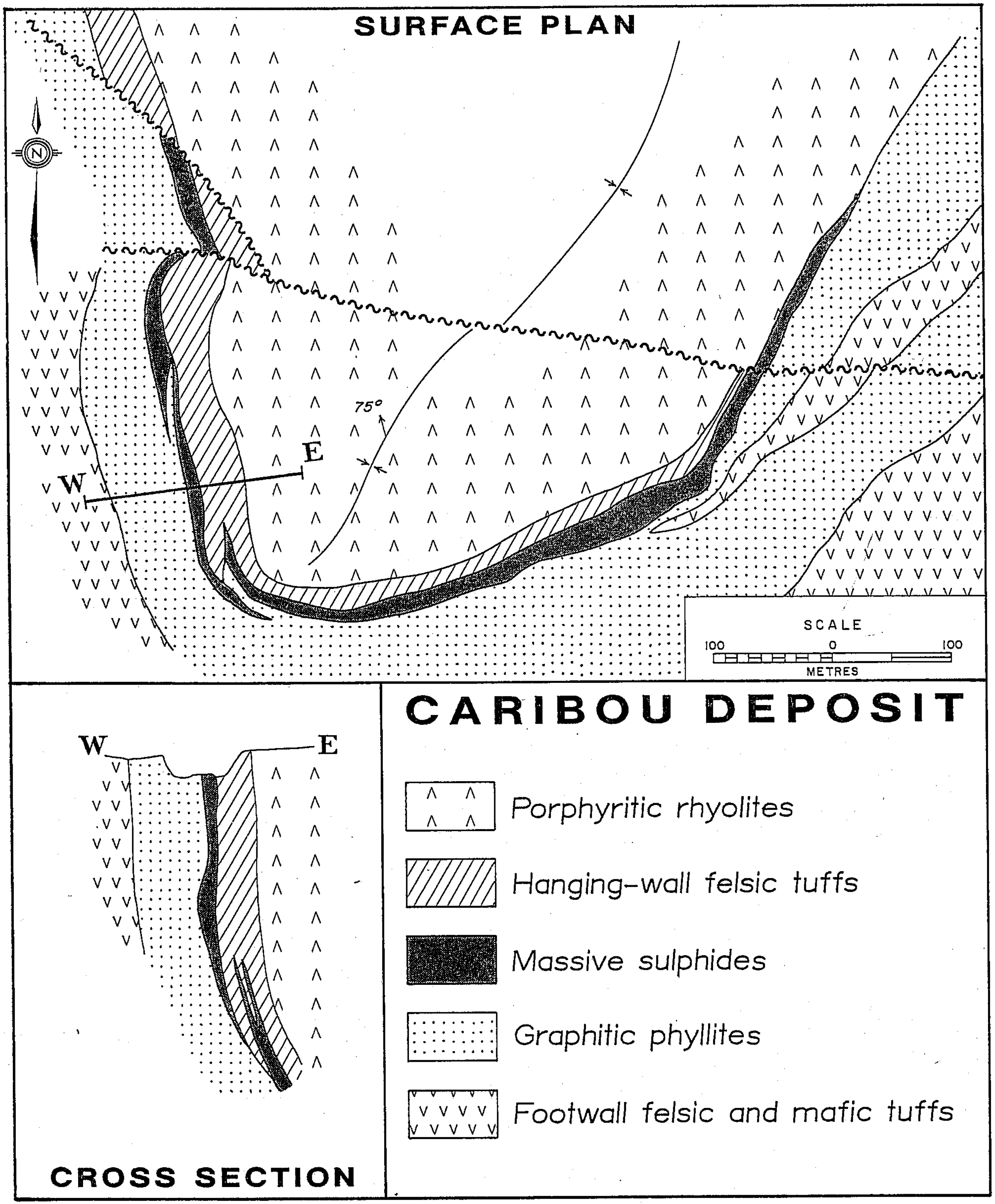

Figure 52. Plan and cross-section of the Caribou deposit.

The hanging-wall rocks are strongly foliated and crenulated schists consisting of quartz, green muscovite, pale yellow sericite, pink to buff potash feldspar, albite and minor chlorite. Although the rock is mineralogically simple, it is highly variable in colour and texture. Minor thin layers of phyllite occur throughout. The west limb hanging wall rocks, varying from light coloured, bedded tuff, to dark grey dense porphyritic tuff, are considered to be waterlain pyroclastics.

The facing direction of the volcanic-sedimentary sequence has not been determined with certainty; however, the across-layer metal zoning in the sulphide lenses indicates tops are to the northeast. The youngest supracrustal rocks (in the core of the synform) consist of alternating layers of porphyritic rhyolite and green tuffs.

STRUCTURE

Analysis of secondary structures and textures indicates at least three and perhaps four major phases of deformation have affected the Caribou rocks. The first and second were the most pervasive, and gave rise to a penetrative schistosity (S_1), (interfolial folds (F_1), and regional metamorphism, followed by a crenulation cleavage (S_2) and isoclinal folds (F_2). The formation of the massive sulphide bodies preceded the earliest episodes as indicated by deformational structures in the sulphide minerals (Davis 1972).

The shallow dipping S_2 is itself folded about the Caribou fold indicating that the structure is related to a later deformation. According to Davis (1972), the Caribou fold is a D_4. structure post-dating the Tetagouche antiform considered by Helmstaedt (1970) to be an F_3 fold.

The youngest structural events, involving faulting first in a northwesterly and then in an east-west direction, post-dated emplacement of dykes in the footwall rocks.

MASSIVE SULPHIDES

The Caribou deposit comprises four en echelon sulphide lenses arranged around a steeply plunging syncline. Three of these lenses lie in the west limb (Northwest, North and South lenses) whereas the fourth, which consists of three smaller lenses, occurs in the east limb (East lens). Hanging wall schists interfinger with the distal ends of the lenses; however, the footwall rocks generally are not intercalated with sulphides. The length of individual lenses ranges up to 300 m, and the total length of the deposit is 1300 m. The sulphide lenses are known to extend to a vertical depth of a 1200 m.

The West limb lenses comprise very fine-grained pyrite (0.017-0.03 mm) with relatively minor amounts of sphalerite, galena, chalcopyrite, arsenopyrite, tetrahedrite-tennantite, and marcasite. Several other minerals are present in trace amounts; most important are electrum, bournonite and pyrrhotite. Pyrite occurs in a variety of forms. The most abundant is the framboid or polyframboid habit that is characteristic of the relatively barren pyrite; colloform pyrite is also common in this milieu. In the sphalerite-galena-rich parts, where sulphides are laminated, pyrite occurs as aggregates of euhedral cubes, commonly embayed by sphalerite. Although a mineral lamination is a prominent feature of the zinc-lead-rich sulphides, a lamination due to contrasting grain sizes is present in barren pyrite. Allogenic pyrite is widespread in all sulphide lenses, but its proportion is higher in the East lens. The principal gangue minerals are siderite, stilpnomelane, chlorite and quartz, but minnesotaite, talc, greenalite and chamosite have also been noted.

Across-layer zoning is a prominent feature with Pb+Zn concentrated near the hanging wall and copper along the footwall. Lateral zoning is illustrated by the decrease in magnetite, chalcopyrite and Zn+Pb+Ag from the West limb lenses to the East limb. There is a positive correlation between silver and Pb+Zn content; however, gold is less dependent and seems to correlate with the occurrence of arsenopyrite rather than Pb+Zn.

The primary sulphides are capped by a zone of secondary enrichment ranging up to 45 m thick. This zone is in turn overlain by a gossan enriched in gold and silver. In the supergene zone, the primary sulphides were replaced by digenite-covellite, with digenite increasing downward. Other supergene minerals noted are luzonite $Cu_3\ AsS_4$, anglesite, brochantite $Cu_4\ (So_4)\ (OH)_6$, goethite, beaverite $Pb\ (Cu, Fe, Al)_3\ (SO_4)\ (OH)_6$ The grade of the supergene zone ranges up to seven per cent copper, but averages 3.4 per cent. Lead and zinc contents are variable, while gold and silver values are similar to the primary sulphides.

THE MURRAY BROOK MASSIVE SULPHIDE DEPOSIT AND PRECIOUS METAL MINE

M.P. Rennick, D.M. Burton, and C.N. Smith

INTRODUCTION

The Murray Brook massive sulphide deposit (Fig. 4) is located in Restigouche County, approximately 80 km west of Bathurst, New Brunswick. The deposit occurs as a lens within northerly dipping metasedimentary rocks of the Tetagouche Group. A gossan cap covers the near surface sulphides.

Total sulphide reserves are estimated at 21 million tonnes grading 0.48% Cu, 0.86% Pb, 1.95% Zn, and 31.4 g/tonne Ag (Table 7). The Murray Brook gossan, which is presently being mined is estimated to contain 1.71 million tonnes grading 1.52 g/t Au and 65.8 g/t Ag.

Since 1985, the focus of exploration and evaluation of the Murray Brook Deposit has been to define the economic potential of the precious metal-bearing gossan. Processing of the gossan began in September of 1989. Recovery of gold, silver, and mercury is accomplished by indoor vat leaching. The mine is operated by Murray Brook Resources Inc. and has a life expectancy of five years.

HISTORY OF EXPLORATION AND DEVELOPMENT

DISCOVERY

The original Murray Claim Group comprised 111 claims staked in 1955 by J. Perusse and R.W. Stephenson for Kennco Exploration. The property was staked following an airborne electromagnetic survey, which detected a number of anomalies with responses similar to known deposits in the Bathurst Camp (Perusse 1955). Ground follow-up in 1955 included selective Slingram and McPhar electromagnetic surveys soil sampling over the airborne anomalies and geologic mapping of the entire claim group. Two drillholes tested a conductor some 5 km north of the deposit and intersected graphitic schist. All airborne anomalies were found to be related to graphitic rocks and the soil geochemical results were negative. Because the Murray Brook deposit did not have an airborne response, it was not covered by the detailed surveys. The only encouragement gained in the first field season was from minor copper mineralization (up to 1.35% Cu) in "intermediate lavas", which was unrelated to the massive sulphide body. The focus of the 1956 field season shifted to prospecting in an effort to locate a source for the mineralized float.

Discovery of the Murray Brook deposit must be accredited to stream sediment geochemistry (Fleming 1961). Sampling of active and bank sediments was carried out in 1956 by J. Fortescue and J. Perusse, and field determinations of heavy metal content pinpointed an anomaly source at the head of the Gossan Creek. Trenching outlined an area of gossan measuring 760 m by 120 m. Packsack drilling to a depth of 10 m failed to intersect fresh massive sulphides. On October 3, 1956, hole R-3 was collared on a Sligram EM anomaly and intersected 89 m of massive sulphides under a cover of 16 m of gossan (Perusse 1956). Exploration and evaluation of the deposit over the past 34 years has been conducted by Kennco Exploration,Cominco Ltd., Canex Placer Ltd., Northumberland Mines Ltd., and NovaGold Resources Inc.

By 1958, Kennco had completed sufficient drilling upon which to calculate a geological reserve of 21.49 million tonnes of 2.81% combined lead-zinc (Perusse 1958). While the deposit as a whole is obviously subeconomic, the base metal zonation has permitted a number of evaluations on the copper versus lead-zinc reserves. These figures are summarized in Table 7. The open pit potential of the copper zone, which immediately underlies the gossan, is currently being evaluated by NovaGold Resources Inc.

GOSSAN DEVELOPMENT

While the discovery of the deposit immediately led to the recognition of an extensive zone of surface weathering, the precious metal content of the gossan was not evaluated until 1985. At that time, Northumberland Mines Ltd. conducted a drilling program to determine grades and tonnage. Prior to this program, only two sections of gossan core had ever been recovered for assay. Anaconda reported a 9 m section which assayed 5.38 g/t Au and 384 g/t Ag and a 6 m section of 6.21 g/t Au and 23.45 g/t Ag (Fenton and Pitman 1984). Kennco had postulated a minimum reserve figure of 340,000 tonnes of 3.79 to 4.83 g/t Au and 129.3 to 275.8 g/t Ag (Pitman 1985). The Northumberland program outlined 1,570,000 tonnes of 1.27 g/t Au and 52.1 g/t Ag (Northumberland Mines Ltd. 1986). NovaGold Resources Inc. acquired control of Northumberland Mines in 1988 and successfully completed financing of the project in December of the same year. Murray Brook Resources was incorporated to operate the mine which officially commenced production in September 1989.

GEOLOGY OF THE DEPOSIT

The Murray Brook deposit occurs as a lens within metasedimentary rocks in the upper part of the Miramichi Group (Unit Os). The sedimentary rocks are composed of quartzite, and quartzose siltstone intercalated with minor phyllitic and graphitic siltstones. The sedimentary rocks are overlain by felsic volcanic rocks (Unit Ofv) and occur in fault contact with schistose mafic volcanic rocks (Unit Omv_1), both belonging to the Ordovician Tetagouche Group (Fig. 53). The schistose mafic volcanic rocks of the Tetagouche Group are in fault contact to

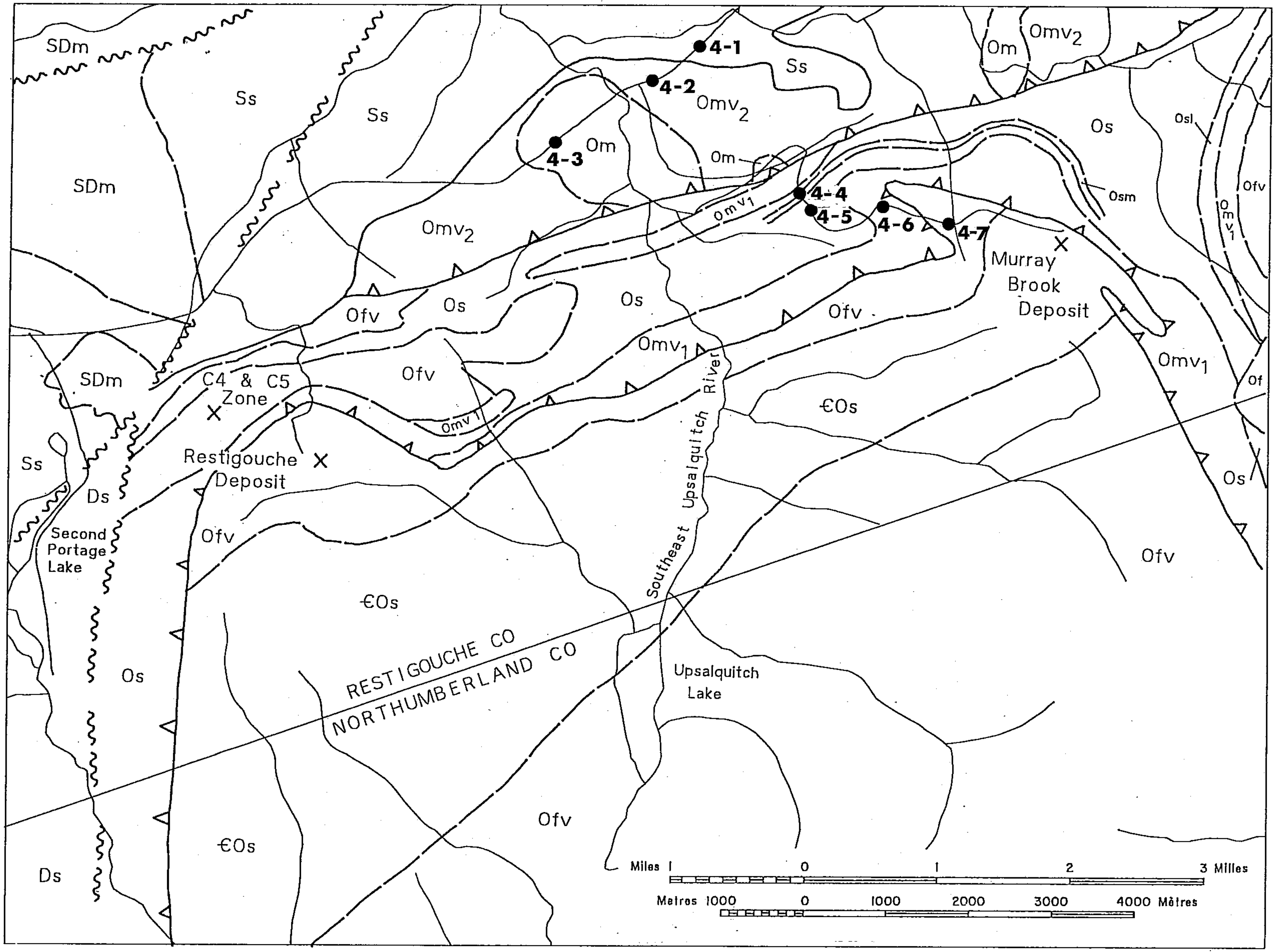

Figure 53. Geology of the Murray Brook-Restigouche area.

LEGEND

DEVONIAN

	Tobique Group
Ds	Undivided sedimentary rocks

UPPER SILURIAN TO LOWER DEVONIAN

SDm	Fine- to medium-grained, plagioclase-phyric gabbro and diorite

SILURIAN

	Chaleurs Group
Ss	Undivided sedimentary rocks

ORDOVICIAN

Of	Quartz-feldspar porphyry
Om	Gabbro, gabbroic pegmatites, diabase dykes
	Fournier Group
Omv$_2$	Massive to pillowed basalt, basaltic breccia, basaltic tuff
	Tetagouche Group
Os	Dark grey graphitic slate, feldspathic lithic wacke; minor iron formation; red, green, and black manganiferous slate and chert (Osm); minor limestone (Osl)
Omv$_1$	Foliated mafic volcanic rocks, basaltic tuff, minor feldspar porphyry; minor lapilli tuff and rhyolite (Ofva)
Ofv	Quartz and quartz-feldspar porphyry, felsic tuffs, rhyolite; minor siltstone

CAMBRIAN TO LOWER ORDOVICIAN

	Miramichi Group
€Os	Grey phyllite, quartz wacke

SYMBOLS

— — —	Geological contact
∿∿ ∿∿ ∿∿	Strike-slip fault
—Λ——Λ—	Thrust fault
×	Sulphide occurrence

TABLE 7

VARIOUS RESERVE ESTIMATES FOR THE MURRAY BROOK DEPOSIT

ZONE	Cu%	Pb%	Zn%	Ag	Au	TONNAGE
Kennco, 1958 Total Sulphides	0.48	0.66	1.95	31.4	–	21,490,000 (tonnes)
Canex Placer, 1976 Pb + Zn	–	1.97	5.37	66.7 (g/t)	–	3,800,000 (tonnes)
Canex Placer, 1979 Cu (open pit)	5.37	–	–	–	–	400,000 (tonnes)
NovaGold, 1989 Cu (open pit)	4.58	–	–	46.2 (g/t)	–	350,000 (tonnes)
Rennick, 1990 Total, Cu, Pb+Zn	0.94	1.03	2.37	0.98 (opt) (33.6 g/t)	0.003 (opt) (0.1 g/t)	9,087,000 (tons) (8,240,000 tonnes)
Cu (>1.0%)	2.04	0.35	0.80	0.56 (opt) (19.3 g/t)	0.003 (opt) (0.1 g/t)	2,573,000 (tons) (2,331,000 tonnes)
Pb+Zn (>5.0%)	0.22	2.18	5.34	2.22 (opt) (76.6 g/t)	0.011 (opt) (0.38 g/t)	2,160,000 (tons) (1,959,000 tonnes)
NovaGold, 1989 Gossan	–	–	–	65.86 (g/t)	1.52 (g/t)	1,890,000 (tonnes)

the north with pillow basalts (Unit Omv_2) correlated with the Ordovician Fournier Group (van Staal and Langton, this volume). These rocks have been intruded by gabbro, diabase, and quartz-feldspar porphyry. Late Silurian conglomerate unconformably overlies the Ordovician sequence.

The rocks of the Murray Brook deposit area have been subjected to four phases of deformation. A block diagram (Fig. 54) created using drillhole information, shows the sulphide lens has been deformed by two generations of folding, which correlate with F_1 and F_2 structures.

Drilling indicates that the massive sulphides have a moderate northerly dip, plunge gently to the east, and are commonly enclosed within a 1-3 m thick zone of disseminated pyrite or chloritized sediments. The mineralization occurs as semi-massive to massive, pyrite-rich sulphides which may be banded. Metal zoning is present within the sulphide lens and allows division of the mineralization into a copper zone, pyrite zone, and lead-zinc zone. The copper zone (>1.0% Cu) occurs along the outer contact of the sulphide lens and near the sulphide/gossan contact. The copper-rich sulphides occur as chalcopyrite infilling and enclosing fractured to brecciated pyrite. Near the sulphide/gossan contact, covellite and bornite replace chalcopyrite, sphalerite, and pyrite. The lead-zinc zone (>3.0% Pb+Zn) sulphides occur as semi-massive sphalerite enclosing pyrite and galena grains, and as sphalerite- and pyrite-rich bands. The pyrite zone is composed of massive to fractured and brecciated and locally banded pyrite with minor chalcopyrite, sphalerite, galena, and arsenopyrite. The pyrite zone typically occurs as an envelope surrounding the lead-zinc zone in the core of the lens, and thus separates the lead-zinc and copper zones.

THE MURRAY BROOK PROCESSING FACILITY

The Murray Brook processing facility is a totally enclosed system comprising four vats, a Merill-Crowe system, a pregnant tank, a barren tank and a wash tank, a mercury retort, and a bullion furnace. The life expectancy of the gossan processing is five years and provides approximately 30 full time jobs. Mining is conducted on a contract basis. The general site layout is shown in Figure 55. The process flow chart is shown in Figure 56.

VAT PREPARATION

The prepared ore, crushed to minus three-quarters inch and stockpiled, is treated with lime and/or cement for pH control and conveyed to vats inside the processing facility. The facility contains four vats which hold between 1000 and 1200 tons. The ore is placed in the vats using one of two Rotec conveyors. Sprinkler lines permit spraying weak cyanide solution (400 to 1200 mg/l) downward onto the vat surface.

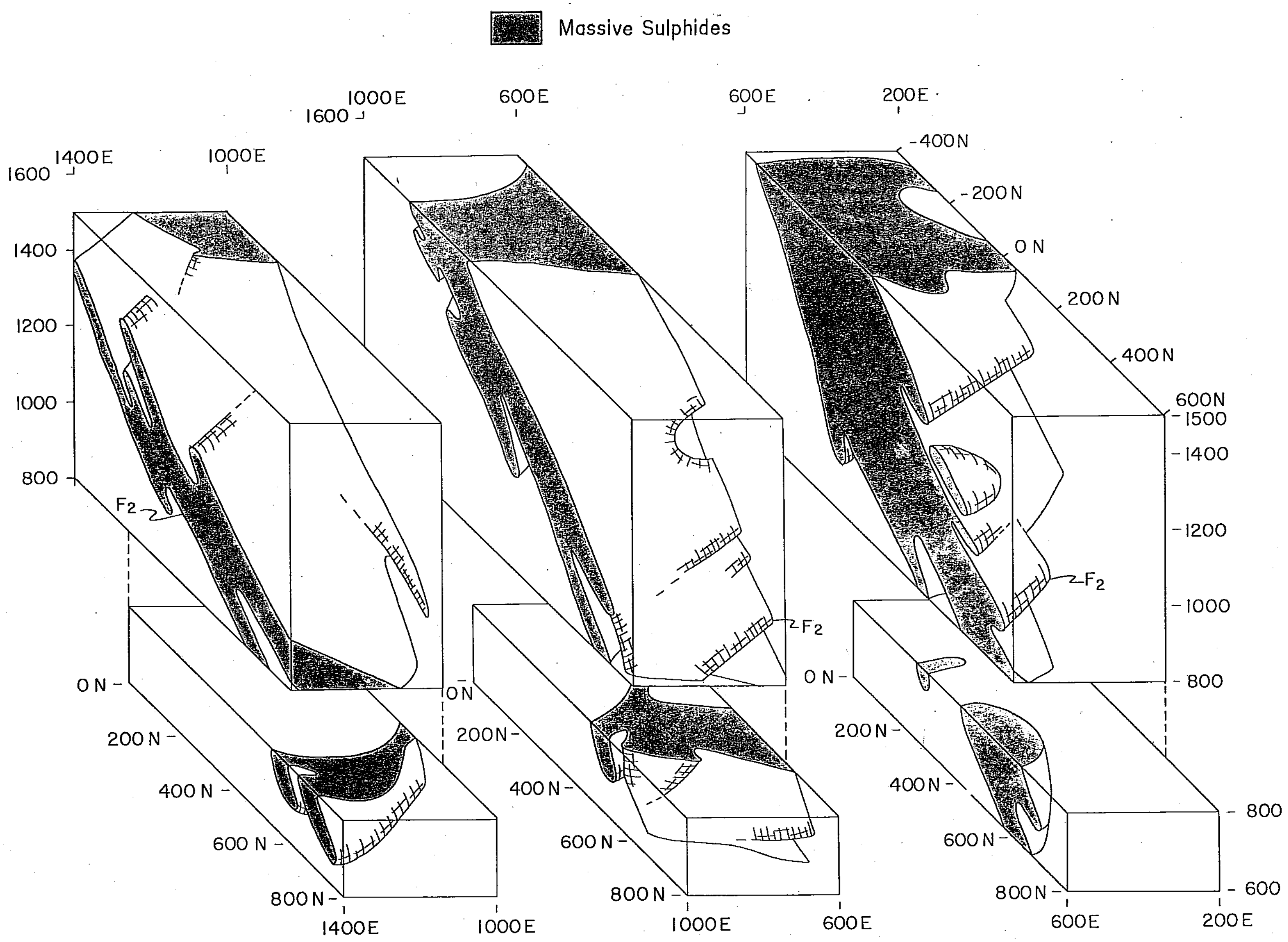

Figure 54. Block diagram of the Murray Brook deposit looking Grid South (toward Az 150°).

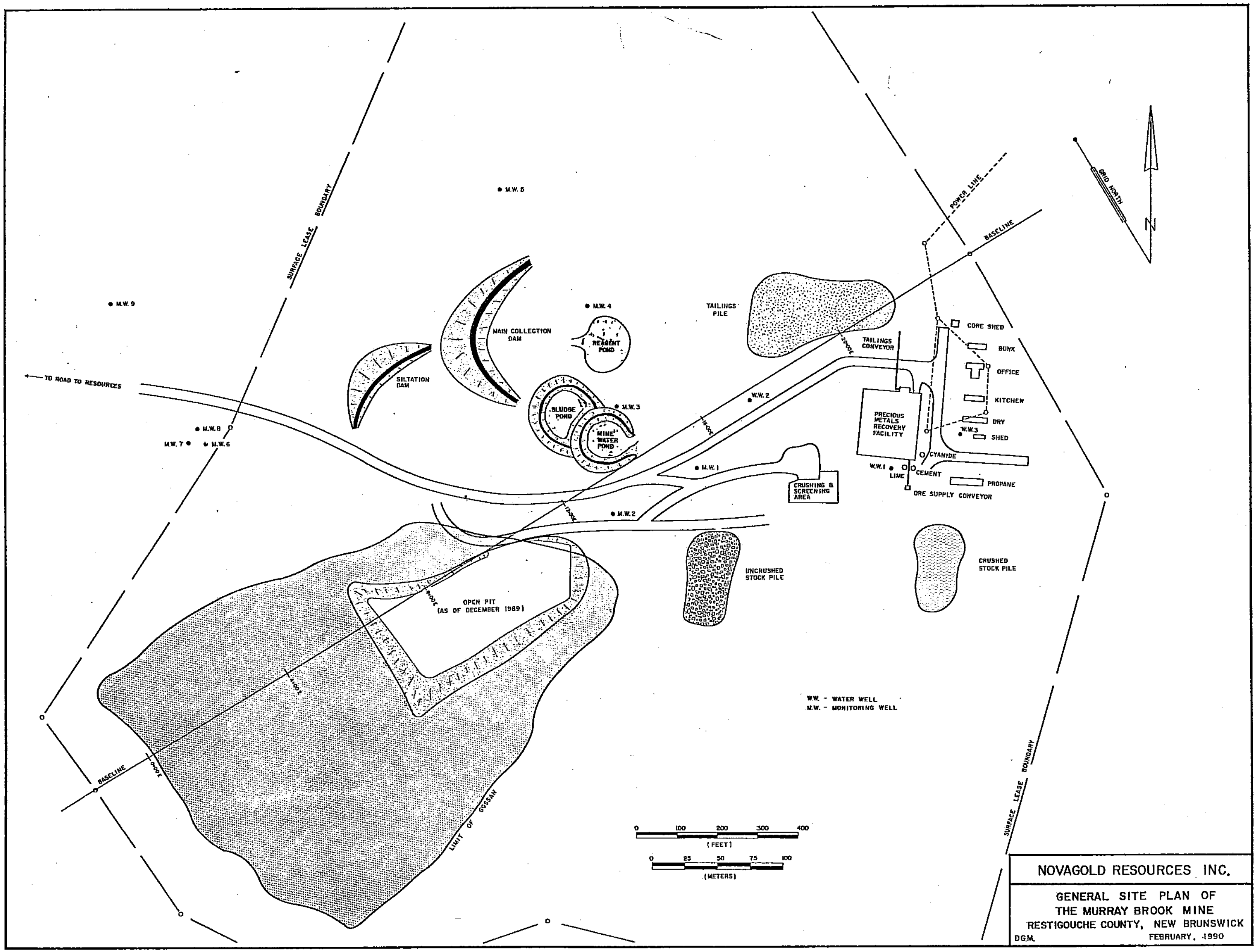

Figure 55. Site plan of Murray Brook mine.

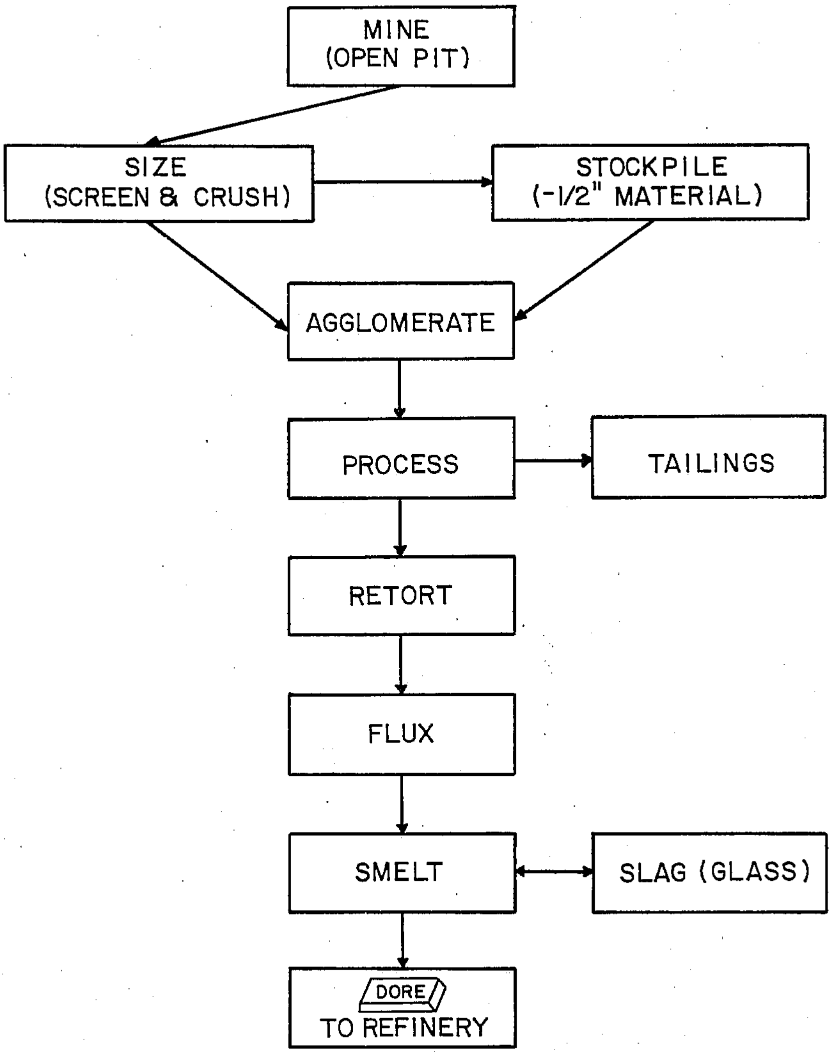

Figure 56. Process flow diagram for Murray Brook mine.

Downward spraying prevents saturation of the electrics on the conveyors and eliminates atomization, thereby reducing fog and humidity in the plant.

MERILL-CROWE SYSTEM

Barren cyanide solution is pumped from the barren tank at the rate of 17 to 20 litres/second and sprayed over the first vat. The solution passes through the ore leaching gold, silver, mercury , and small amounts of copper. This solution is then passed through the second vat and periodically through the third vat, leaching more metal before being pumped to the pregnant tank. Solution from the pregnant tank is pumped to a vacuum leaf clarifier containing filter leafs precoated with diatomaceous earth. The solution is drawn through the precoated filter leaves under vacuum into the Merill-Crowe Tower. This reduces the turbidity of the solution and draws out most of the free oxygen. Following the tower, zinc dust and lead nitrate is added to the solution, which is then pumped to a precoated pressure filter where the zinc dust caught in the precoat precipitates the gold, silver, mercury, and copper. The reduction of oxygen enables the process to work and the addition of lead nitrate acts as a catalyst enhancing recovery from solution. Flow through the Merill-Crowe Plant is regulated by manually controlled valves plus a computerized motorized valve on the tower to regulate flow through it.

Cyanide strength in the solution is maintained utilizing a "cyanamid" system which converts bulk calcium cyanide into free cyanide in solution. The calcium helps to control the pH which must be maintained at or above eleven (11) to prevent the formation of hydrogen cyanide gas. The plant is controlled utilizing an atomic adsorption unit measuring ppm silver in pregnant and barren solutions hourly. Oxygen, pH, free cyanide, and turbidity levels are measured regularly.

PRECIPITATION AND SMELTING

When the precipitate press is loaded, the solution is switched to the second press and the loaded press is blown dry using compressed air to reduce moisture. The press is then dropped (unloaded) and the precipitate (concentrate) is loaded into the retort where it is dried completely and mercury is distilled off and collected. The dried precipitate is assayed and fluxed using borax, sodium nitrate (niter), fluorspar, and silica sand in preparation for smelting.

The fluxed precipitate is smelted in a 500 pound capacity bullion furnace operating between 1200 and 1300 C. The silver-gold dore bars are shipped to Ontario for refining.

TAILINGS AND ENVIRONMENTAL CONTROLS

Following economic recoveries from each vat, the contents are purged with fresh water to remove any pregnant solution. The vat is then washed and drained after which the contents are removed using a front-end loader.

The tailings area is underlain with compacted impervious till which is bermed and sloped to direct run-off into a lined reagent pond. Liquid from this pond is pumped back to the plant for make-up. An average of 100 tons of water is consumed daily by the process. Since the system is a closed circuit, no liquid effluent leaves the processing facility. Run-off from the mining area and stockpiles is monitored continuously and flow is directed to a lined mine water pond which overflows to a sludge pond and then into the main pond (designed to sustain a 50 year storm run-off) before going to a siltation pond prior to release to the environment.

The plant contains a cyanide destruction unit utilizing hydrogen peroxide and is designed to destroy four (4) tonnes of solution hourly. Because the process is a closed circuit operation, cyanide destruction will only be necessary upon mine closure, five years hence. Acid generation tests conducted to date indicate that the gossan is not acid generating thus eliminating the introduction of heavy metals into the environment.

ROAD LOG FOR THE MURRAY BROOK FIELD TRIP ROAD STOPS

0 km - Eighteen Mile Brook culvert on Route 180, heading west (see Figure 53).

0.5 km - STOP #4-1:

Fossiliferous Silurian sandstone and conglomerate of the Chaleurs Group. Cobbles of the underlying Ordovician rocks are present in the conglomerate.

1.3 km - STOP #4-2:

Ordovician Fournier Group rocks with pillow basalt on the south side and volcanic breccia on the north side of the road.

3.0 km - STOP #4-3:

Gabbro and gabbroic pegmatite dykes intruding Fournier Group basalt.

Return east on Route 180 to the Murray Brook mine road on the east side of the Southeast Upsalquitch River bridge. Restart road log and proceed south on Murray Brook mine road.

3.2 km - STOP #4-4:

Red chert and foliated mafic volcanic rocks of the Tetagouche Group (Unit Omv_1).

3.7 km - STOP #4-5:

Lithic wacke and graphitic slate overlying foliated mafic volcanic rocks (all of Unit Omv_1) in a quarry and a roadcut.

5.1 km - STOP #4-6:

Porphyritic mafic volcanic rocks at or near the lower contact of Unit Omv_1.

5.9 km - STOP #4-7:

Fine-grained massive felsic volcanics (Unit Ofv). These rocks overlie sedimentary rocks that host the Murray Brook deposit and are in fault contact with mafic volcanic rocks (Unit Omv_1). The same horizon of felsic volcanic rocks hosts the Restigouche deposit to the west.

Continue on to the Murray Brook deposit.

THE RESTIGOUCHE DEPOSIT

Modified after L.D. Rankin (1982)

The Restigouche deposit is located at latitude 47°30.2′ and longitude 66°33.5′ (Figs. 3, 53). The deposit lies on the north limb of an F_1 anticline overturned toward the south and on the west limb of an open F_3 fold and consequently plunges to the northwest at approximately 20° (Helmstaedt 1971). Interpreted cross-sections indicate that the massive sulphide body dips at between 15° and 25° to the west. The geometry of the single massive sulphide lens was strongly modified during D_2 with the development of open folds with characteristic wavelengths of 60 to 90 m (Fig. 57).

Massive and stringer sulphides are contained within felsic volcanic flows and pyroclastic units comprising the following stratigraphic sequence in ascending order: (1) footwall breccia; (2) massive sulphide; (3) hanging wall breccia; (4) amygdaloidal felsic voclanic rocks; (5) massive, banded and pisolitic rhyolite; and (6) prophyritic rhyolite (Fig. 57). Estimated reserves are 2 million tonnes grading 6.55% zinc, 5.13% lead, 0.33% copper, and 116 g/t silver using a cutoff grade of 4% combined Pb-Zn.

<u>The footwall breccia</u> is a monolithologic breccia comprised of aphanitic rhyolitic fragments cemented by chlorite, carbonate, and/or sulphides. It is typically blue-grey to white, but is dark grey-green or black where chloritization has been more intense. The breccia grades laterally into fine-grained or porphyritic rhyolite and has been probed to a depth of 240 m.

The stringer and disseminated sulphide mineralization at Restigouche is confined to the brecciated rhyolite and extends to at least a depth of 150 m beneath the stratabound massive sulphide body. The veins (up to 0.3 m wide), veinlets, and stringers in this zone are characterized by high sulphide/gangue ratios and razor-sharp boundaries. Some veins directly below the massive sulphide are zoned with pyritic margins and sphalerite-rich cores. Reddish brown sphalerite is common in veins at, or near, the top of the rhyolite breccia with chalcopyrite becoming more prominent with depth.

<u>Massive sulphides</u> are confined to a single tabular lens 550 x 90 x 12 m, are typically fine-grained and, in contrast to those at Murray Brook, are rarely banded. Total sulphide content is consistently high, averaging more than 85% by volume. The major sulphide minerals present are pyrite, sphalerite, galena, chalcopyrite, and arsenopyrite; minor constituents include pyrrhotite, tetrahedrite, and marcasite(?). Covellite occurs in exposed massive sulphides from a trench 50 m south of Charlotte Brook.

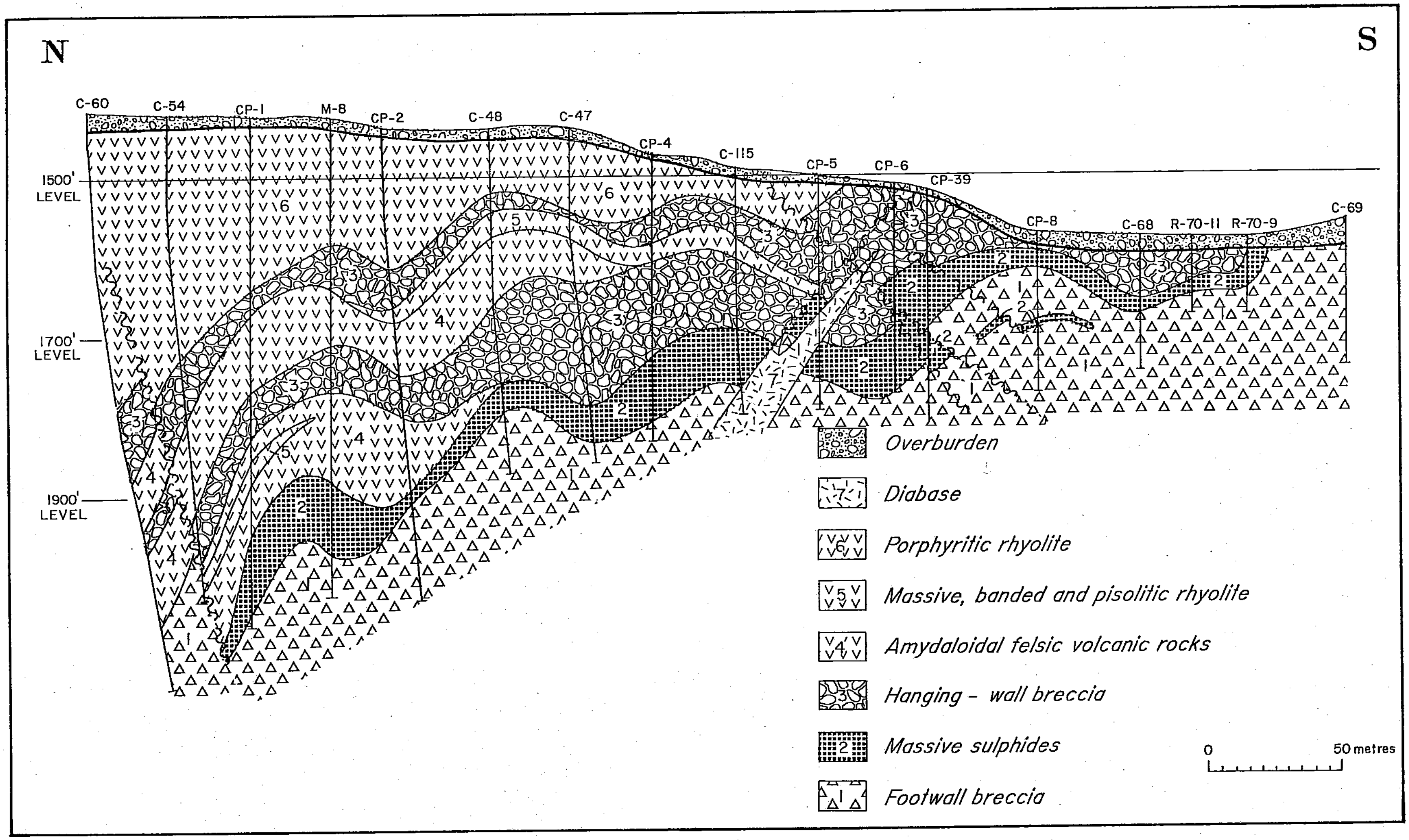

Figure 57. Cross-section of Restigouche deposit.

The distribution of major sulphide minerals in the deposit is for the most part very uniform. However, it is apparent that combined lead-zinc values are appreciably higher in two areas within the massive sulphide lens: (1) near the centre of the deposit in the vicinity of diamond-drill hole CP-6; and (2) at the north end of the zone in the vicinity of drillhole CP-1 (Fig. 57). The limited assay data also suggests an across-layer zoning with an increase in combined lead-zinc tenors toward the stratigraphic hanging wall.

The upper and lower contacts of the massive sulphide are abrupt. Near the margins of the deposit, where massive sulphide is absent, the ore horizon is commonly indicated by a narrow zone of quartz-chlorite-sericite schist.

<u>The hanging-wall breccia</u>, which directly overlies the massive sulphides, is typically 15 to 20 m thick, but locally may be up to 45 m thick. The breccia consists of grey-green felsic volcanic rocks veined by cherty material. The contact between the chert and host felsic volcanic rocks is consistently sharp. Microscopic examination shows that the chert-like material mainly consists of microcrystalline quartz with minor pale green sericite disseminated throughout. The host rocks contain minor scattered amygdules of quartz and/or carbonate and locally, well-rounded dull grey or grey-brown lapilli. Microscopic examination shows that the host rocks contain feldspar, sericite, chlorite, and carbonate with trace amounts of apatite, zircon, and opaque mienra.s The upper boundary of the brecciated unit is gradational with overlying felsic volcanic rocks similar to that hosting the cherty veins.

<u>Amygdaloidal felsic volcanic rocks</u>, which overlie the hanging wall breccia, contain 5 to 15% light grey to white quartz amygdules, ranging from 0.5 to 4.5 mm in diameter. The amygdules occur in a fine groundmass of quartz, feldspar, sericite, and chlorite with minor carbonate and opaque minerals and accessory apatite. The upper boundary of the amygdaloidal unit is generally not well-defined for near the top of the section, amygdaloidal flows are interlayered with massive, banded, or pisolitic rhyolites.

<u>Massive to well-banded rhyolites</u>, which occur in a unit about 15 m thick, are aphanitic, light grey-brown or grey-green with banding defined by alternating buff or pale blue-grey and light grey-green bands from 1 to 3 cm thick. Microscopic studies show the light green bands to contain more abundant pale green sericite. The rhyolite is mainly comprised of microcrystalline quartz and feldspar with minor amounts of sericite, chlorite, carbonate, apatite, zircon, and opaque minerals. Accretionary(?) structures (pisolites) with diffuse margins comprise up to 60% of the upper part of this unit. Individual structures average 10 to 20 cm in diameter. The pisolites consist almost entirely of microcrystalline quartz and locally possess a well- defined nucleus of pale grey-brown or

buff carbonate and pyrite; concentric zoning is rare. The upper contact of the pisolitic rhyolite with the overlying porphyritic rhyolite is usually sharp.

Porphyritic rhyolite forms a tabular, strataform body that lies 60 to 80 m above the massive sulphide horizon. It is exposed (Fig. 53) in a broad belt immediately north of the deposit and is estimated to have an overall thickness of 350 to 300 m. The porphyritic rhyolite is usually light grey-green, but varies grey, blue-grey, or light pink in places. It contains from 5 to 15% subhedral to euhedral white feldspar phenocrysts averaging 1 to 3 mm in length. Light grey quartz phenocrysts averaging 1 mm in diameter are commonly present but are rarely as abundant as those of feldspar. The quartz phenocrysts are usually well-rounded and generally embayed by finer aggregates of quartz and sericite. The groundmass is typically a fine-grained assemblage of quartz-feldspar-sericite with minor amounts of chlorite and carbonate and with trace amounts of apatite, zircon, and stilpnomelane. Drill cores of prophyritic rhyolite taken from an area immediately northwest of the deposit were found to contain 1 to 3 m thick sections of graded lapilli tuff. The latter are, for the most part, fine-grained, although clasts ranging up to 20 mm in diameter are locally present at the base of some beds. Grading in sections of the lapilli tuff observed suggest that the stratigraphic sequence in this area is upright.

HALFMILE LAKE DEPOSIT

Modified after D.N. Harley (1977)

INTRODUCTION

The Halfmile Lake deposit is located 2.5 km southwest of Halfmile Lake, near the headwaters of the Northwest Miramichi River, in Northumberland County, New Brunswick. The deposit is accessible via a good road from Heath Steele Mines, 24 km to the east on Highway 430 (Fig. 4).

STRATIGRAPHY

The Halfmile Lake deposit occurs within Ordovician rocks of the Tetagouche Group. The main stratigraphic units on the property are as follow (Fig. 58):

Argillaceous sedimentary rocks with abundant quartz wackes; contains large lenticular bodies of phyritic rhyolitic tuff.

Porphyritic rhyolite with intercalated rhyolite tuff, and sedimentary rocks.

Mafic volcanic rocks commonly grading to lithic tuff; minor sedimentary rocks and rhyolitic tuffs.

Known mineralized zones in the Halfmile Lake area occur along the southern margin of the sedimentary unit between the predominantly felsic volcanic sequence to the north, and the mafic volcanic rocks to the south. Lenticular bodies of porphyritic rhyolite tuff occur within the sedimentary rocks both above and below the mineralized horizon. Estimated reserves in the combined Upper and Lower AB zones (Fig. 58) are 15 million tonnes of 7.6% Zn, 2.4% Pb, 0.1% Cu, and 26 g/t Ag (Robin Adair, personal communication 1990).

STRUCTURAL GEOLOGY

The main penetrative schistosity, S_1, in the Halfmile Lake area is parallel with the bedding. The predominant strike of the schistosity in the western part of the area is east-northeast and swings to a north-northeast direction in the eastern part of the area (Fig. 58). Local dips range widely from one part of the area to another, but drilling has demonstrated that overall dip of lithological units increases in a northeasterly direction, from 40°N to 60°NW. The change in strike and dip across the area can be related to a major third synform (F_3), the axis of which plunges to the north along the western part of the property. A longitudinal profile constructed parallel to the second crenulation cleavage (S_2) indicates that the first folds (F_1) are overturned to the southwest (R.R. Irrinki, personal communication 1990).

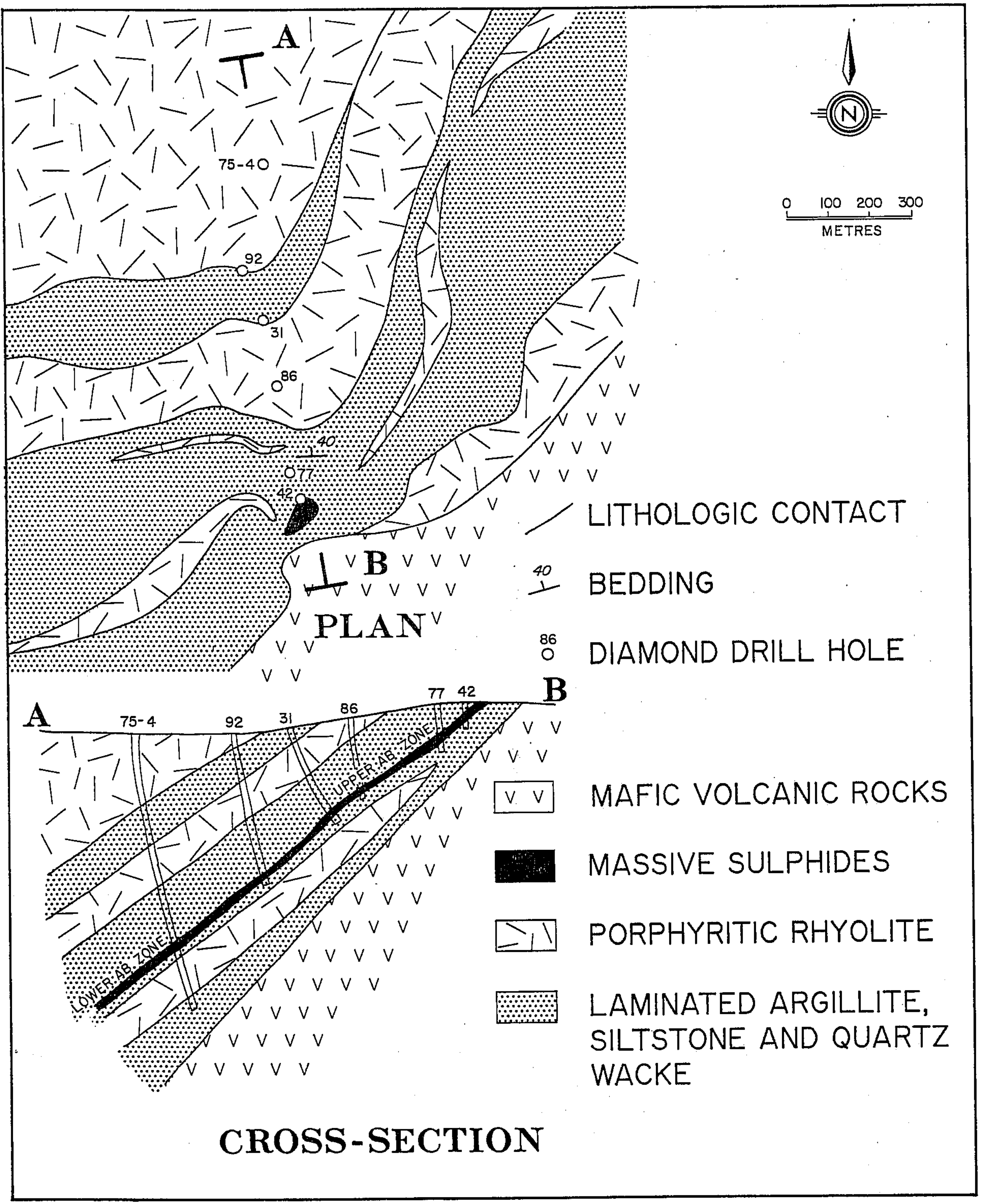

Figure 58. Plan and cross-section of Halfmile Lake deposit.

A distinct and widespread crenulation cleavage (S_2) is evident in most schistose rocks in the area and has largely transposed the earlier planar fabrics into parallelism with it. S_2 strikes roughly east-west, and intersects S_1 at angles between 30° and 90°, but averages 70°. Dips of S_2 are shallow and generally to the north. Minor second (F_2) folds of the S_1 schistosity is common in diamond-drill core. The wavelength of these minor folds ranges from several centimetres to several metres, and is probably responsible for the large variation in dips of S_1 recorded at the surface.

Faults are difficult to detect due to poor exposure, but several northwesterly trending faults are suggested from geophysical work. A major north-south fault to the west of the property, running along part of the Northwest Miramichi River, has been proposed by Smith et al. (1973).

MINERALIZATION

Two main types of sulphide mineralization occur in the Halfmile Lake deposit. A stringer zone containing local ore grade Cu mineralization lies immediately to the north of and structurally above a massive Zn-Pb sulphide zone. The stringer and massive sulphide zones are commonly separated by an interval of weakly mineralized rock ranging up to 10 m thick. Both zones crop out as discontinuous limonitic gossans and are up to 10 m in thickness.

The sulphide zones occur near the southern contact of the sedimentary unit, but eastward they become progressively further north of the contact. Very fine, massive quartz wackes, weakly to well-laminated siltstones, and siliceous to chloritic argillites are the most abundant sedimentary rock types intercalated with the massive sulphides. Greenish black chloritic argillite is confined to the massive sulphide zone, where it occurs as discontinuous lenses between individual massive sulphide layers. Siltstones and very fine to coarse wackes are the main rock types in the stringer zone. Concordant white quartz lenses are common in the sedimentary rocks within the sulphide zones, particularly the stringer zone. Siliceous, commonly cherty siltstones and argillites occur structurally below the massive sulphides.

The stringer zone is an irregularly shaped, broadly conformably but discontinuous sheet ranging between 30 and 120 m thick. The lateral extent of this sheet is uncertain, although it has been encountered in drillholes over a strike length of 1 km. The average sulphide content of the stringer zone is between 3 and 5%, but a lens of stringer mineralization, containing over 10% sulphide, occurs locally at shallow depths near the massive sulphide ore lens (see below). This lens contains ore grade Cu mineralization and has been traced down dip for 350 m. It attains a maximum thickness of 100 m, and extends along strike for 200 m.

Pyrrhotite is generally 3 to 20 times more abundant than chalcopyrite in the stringer zone. Pyrite content varies considerably, but it is usually more abundant than chalcopyrite. Pyrrhotite and chalcopyrite occur as massive patches 2 mm to 1 cm across, and less commonly as thin semi-massive streaks or more persistent bands conformable with the bedding of host sedimentary rocks. The massive patches occur within generally concordant white quartz veins, which locally crosscut the bedding of the host sedimentary rocks. Pyrite occurs in the massive patches with pyrrhotite and chalcopyrite, but is most common in thin conformable bands in well-laminated sedimentary rocks. Rarely, these bands comprise up to 30% sulphide over short intervals.

The massive sulphide zone is a conformable semi-continuous sheet-like horizon mostly less than 3 m in thickness. It has been traced in drillholes along strike for over 1 km. The sheet widens to form a lens of ore near point B on Figure 58. This lens strikes east-northeast, dips at 40°N, and plunges on a bearing of about 010°. It is 120 m wide, varies in thickness between 3 and 50 m, and has been traced down dip for approximately 1200 m. Both sulphide and base metal values diminish along strike to the northeast and southwest, away from the ore lens.

The main sulphides in the massive zone are pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite. Conformably layers rich in sulphides are separated by one or more weakly mineralized layers of host sedimentary rock containing less than 30% sulphides. The sulphide-rich layers range between 30 cm and 12 m thick, and contain up to 100% sulphide. Layers containing 50 to 70% sulphide are described as semi-massive, and those with over 70% sulphide are considered as massive. Contacts between individual sulphide-rich and mineralized host rock layers are sharp. Layers of weakly mineralized host rock range up to 10 m thick.

Most semi-massive sulphide layers are dominated by pyrrhotite, and the massive sulphide layers by pyrite, although some layers contain equal proportions of both. The principal base metal sulphide mineral in the semi-massive and massive sulphide layers is sphalerite, with smaller amounts of galena and chalcopyrite. Chalcopyrite is commonly associated with pyrrhotite, and occurs in patches throughout the massive sulphide zone. Galena is concentrated in pyrite-rich portions of the massive sulphide zone, in association with sphalerite.

Fine banding is present in some of the massive sulphide layers. The banding is comprised of alternating sphalerite- and pyrite-rich layers, which form discontinuous to laterally persistent bands between 1 mm and 1 cm thick. Galena-rich bands are less abundant, and megascopic banding is not visible in pyrrhotite-rich massive sulphide layers. The banding appears to be parallel with lithological contacts, and tight folding of the banded sulphides does occur.

Pronounced metal zoning is evident within the Halfmile Lake deposit. The overall pattern is simple, progressing from Cu-rich stringer mineralization on the northern side of the deposit, through a massive sulphide zone enriched in Zn, Pb, and Ag relative to Cu, to minor Fe-sulphides, dominantly pyrite, to the south of the deposit. Individual layers of massive sulphide within the massive sulphide zone are also zoned, showing the highest absolute Zn, Pb, and Ag content on the structurally lower side of each layer. Lateral zoning is also present in the deposit, with decreasing Cu content progressing down plunge from the surface.

GENESIS OF THE HALFMILE LAKE DEPOSIT

By analogy with the Kuroko model, the stringer zone at Halfmile Lake represents a body of rock through which hydrothermal fluids passed, and the massive sulphide zone a horizon where these fluids reached the sea floor. The sheet-like form of both zones, and their stratigraphic setting in sedimentary rocks above an extensive series of rhyolitic flows suggests that these felsic volcanic bodies were the main source of heat for rising hydrothermal fluids.

Although the sheet-like form of the stringer and massive sulphide zones indicates that the fluids rose upward over a broad area, the fluids appear to have been focussed in the more restricted ore grade Cu-rich stringers, where chlorite and sulphides are significantly more abundant. The ore grade stringer mineralization on the property probably represents a series of more permeable channelways perhaps provided by fault zones or fault intersections. The close spatial association of this richer stringer mineralization and the massive sulphide ore lens indicates that a large amount of the solutions which formed the latter passed through the former. The higher chalcopyrite content in the massive sulphide zone closest to the higher grade stringer mineralization lends some support to this speculation.

Precipitation of massive sulphides occurred as the broad stream of hydrothermal fluids reached the sea floor, forming a semi-continuous sheet-like massive sulphide zone of comparable wide areal extent. Within this sheet, thicker concentrations of sulphides occurred in small depressions on the sea floor. The narrow massive sulphide ore lens accumulated in a shallow elongate depression, perhaps bounded by faults parallel to the major fault to the west of the area. Interruption of massive sulphide deposition by the influx of clastic sediment apparently occurred at several periods during development of the massive zone. This may account for zoning in each layer of massive sulphide, and for the broad overall zonation of the massive sulphide zone. The presence of thin laminae of sulphide in the weakly mineralized layers of sedimentary rock within the massive sulphide zone indicates that some sulphide deposition continued even during clastic sedimentation, but that here the sulphides were diluted by clastic influx. Relatively rapid sulphide deposition is suggested by zones of up to 30% sulphide in wacke and siltstone layers. Partly discordant stringer mineralization in some layers of sedimentary rock in the massive sulphide zone show that solutions also passed upward through these rocks, continuing the supply of metal to the sea floor above.

The paucity of sulphide breccia in the Halfmile Lake area suggests a relatively quiet, stable environment, which is consistent with the setting of the sulphide mineralization in a dominantly argillaceous sedimentary unit. Chloritic argillite, which is confined to the massive sulphide zone, probably represents a magnesian and iron-rich mud which formed on the sea floor with the massive sulphides. Some chemical precipitation of silica in rocks stratigraphically overlying the massive sulphide zone is indicated by the occurrence of cherty sedimentary rocks structurally beneath the ore zone. Minor thin laminae of sulphides in sedimentary rocks stratigraphically above the massive sulphide zone indicate that metal bearing solutions were still reaching the sea floor for some period of time after the main stage of sulphide deposition.

The genetic model presented above accounts for the much wider lateral extent of the massive sulphide zone at Halfmile Lake than massive sulphide bodies of the Japanese Kuroko deposits (cf., Ohmoto and Skinner 1983). This important difference is believed to be largely related to differences in the style of accompanying volcanism. Small submarine felsic lava domes associated with the Kuroko deposits apparently built up relatively rugged relief on the sea floor, where thick discontinuous lenses of massive sulphides were deposited in topographic depressions near the lava domes. In contrast, the submarine flows and intercalated sedimentary rocks built a relatively flat sea floor topography in the Halfmile Lake area, which is reflected in the sheet-like form of the massive sulphide zone. However, the occurrence of ore lenses within this sheet-like zone demonstrates that some relief was present on the sea floor during sulphide deposition.

SUMMARY

The Halfmile Lake deposit is a stratabound lens comprising up to several sulphide-rich layers separated by layers of weakly mineralized sedimentary rock. The lens occurs within a thin, semi-continuous, sheet-like massive sulphide horizon striking northeast and dipping approximately 40°N. An equally widespread body of stringer mineralization occurs to the north of, and structurally above, the massive sulphide horizon. The stringer zone locally contains ore grade Cu mineralization, particularly near the massive sulphide ore lens. Pyrrhotite and chalcopyrite predominate in the stringer zone, whereas pyrite, pyrrhotite, sphalerite, and galena are the main sulphides in the massive sulphide zone.

Deposition of the massive sulphides occurred in the deeper or more distal parts of a sedimentary basin, following extrusion of a major series of submarine rhyolitic flows. The sulphides were deposited on the sea floor after relatively strong tectonism initiated rise of hot metal-rich connate fluids throughout a broad area. Richer lenses of massive sulphide were deposited in fault-bounded depressions on the sea floor with the fault zones acting as channelways for the rising ore fluids.

Subsequently, the sequence in the Halfmile Lake area was isoclinally folded an ultimately overturned to the south. Evidence for overturning includes sulphide mineral and metal zoning within the deposit, the occurrence of stringer mineralization structurally above the massive sulphides, graded bedding in host sedimentary rocks, and regional structural-stratigraphic relationships.

REFERENCES

ARCHIBALD, D.E. 1985. The sulphide deposits of Heath Steele Mines Limited. In Massive Sulphide Deposits of the Bathurst-Newcastle Area, New Brunswick, Canada, R.K. Pickerill, C.K. Mawer, and L.R. Fyffe (editors). Excursion 2. Geological Association of Canada, Mineralogical Association of Canada, Fredericton, N.B., Field Excursions, Vol. 2, pp. 28-35.

BARR, S.M. and WHITE, C.E. 1988. Petrochemistry of contrasting late Precambrian volcanic and plutonic associations, Caledonian Highlands, southern New Brunswick. Maritime Sediments and Atlantic Geology, 24, pp. 353-372.

BEVIER, M.L. 1988. U-Pb geochronologic studies of igneous rocks in N.B. In Thirteenth Annual Review of Activities, Project Résumés, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 88-2, pp. 134-140.

BEVIER, M.L. 1989. Preliminary U-Pb geochronologic results for igneous and metamorphic rocks, New Brunswick. In Project Summaries for 1989, Fourteenth Annual Review of Activities, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 89-2, pp. 190-194.

BIRD, J.M. and DEWEY, J.F. 1970. Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen. Geological Society of America Bulletin, 81, pp. 1031-1060.

BLATT, H., MIDDLETON, G., and MURRAY, R. 1972. Origin of sedimentary rocks. Prentice-Hall, New Jersey, 634 p.

BOLTON, T. 1968. Report on GSC locality 82201. Geological Survey of Canada, Paleontology Section.

BOONE, G.M. and BOUDETTE, E.L. 1989. Accretion of the Boundary Mountains terrane within the northern Appalachian orthotectonic zone. Geological Society of America, Special Paper 228, pp. 17-42.

BOYLE, R.W. and DAVIES, J.L. 1964. Geology of the Austin Brook and Brunswick No. 6 sulphide deposits, Gloucester County, New Brunswick. Geological Survey of Canada, Paper 63-24, 23 p.

CHERITON, C.G. 1958. Structure of the Caribou sulphide body of the Anaconda Company (Canada) Limited, Bathurst District, N.B. Canadian Institute of Mining and Metallurgy Bulletin, 51, No. 551, pp. 178-179.

CHURCH, W.R. 1987. The geochemistry and petrogenesis of ophiolitic volcanic rocks from Lac de l'Est, Thetford Mines complex, Quebec, Canada: Discussion. Canadian Journal of Earth Sciences, 24, pp. 1270-1273.

CLAGUE, D., RUBIN, J., and BRACKETT, R. 1981. The age and origin of the garnet amphibolite underlying the Thetford Mines ophiolite, Quebec. Canadian Journal of Earth Sciences, 18, pp. 469-486.

COISH, R.A. and ROGERS, N.W. 1987. Geochemistry of the Boil Mountain ophiolitic complex, northwest Maine, and tectonic implications. Contributions to Mineralogy and Petrology, 97, pp. 51-65.

COX, S.F. 1987. Flow mechanisms in sulphide minerals. In Mechanical and Chemical (re)Mobilization of Metalliferous Mineralization: Ore Geology Review, B. Marshall and L.B. Gilligan (editors). Volume 2, pp. 133-171.

COX, D.F., ETHERIDGE, M.A., and WALL, V.J. 1987. The role of fluids in syntectonic mass transport, and the localization of metamorphic vein-type ore deposits. In Mechanical and Chemical (re)Mobilization of Metalliferous Mineralization: Ore Geology Review, B. Marshall and L.B. Gilligan (editors). Volume 2, pp. 65-86.

CROCKET, J.H. and OSHIN, I.O. 1987. The geochemistry and petrogenesis of ophiolitic volcanic rocks from Lac de l'Est, Thetford Mines complex, Quebec, Canada: Reply. Canadian Journal of Earth Sciences, 24, pp. 1273-1275.

CUMMINGS, J.S. 1988. Geochemical detection of volcanogenic massive sulphides in humid-temperate terrain. J.S. Cummings, Inc. (publisher), Bangor, Maine, U.S.A., 298 p.

CURRIE, K.L. 1986. The stratigraphy and structure of the Avalonian Terrane around Saint John, New Brunswick. Maritime Sediments and Atlantic Geology, 22, pp. 278-295.

CURRIE, K.L. 1988. The western end of the Avalon Zone in southern New Brunswick. Maritime Sediments and Atlantic Geology, 24, pp.339-352.

DAHN, R.F., DEVEAUX, J., and ARNOLD,G. 1987. Brunswick Mining and Smelting Corporation Ltd. Report of Work - Project 4215/4217, Stratmat Group. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Assessment Files.

DAVIES, J.L. 1972. The geology and geochemistry of the Austin Brook area, Gloucester County, New Brunswick, with special emphasis on the Austin Brook iron formation. Unpublished Ph.D. thesis, Carleton University, Ottawa, Ontario, 254 p.

DAVIES, J.L. 1979. Geological map of northern New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map NR-3.

DAVIES, J.L. and SMITH, R.N. 1966. Geology of the Brunswick No. 6 and No. 12 sulphide deposits. In Guidebook, Geology of parts of Atlantic Provinces, Geological Association of Canada/Mineralogical Association of Canada, Annual Meeting, Halifax, 1966, pp. 45-57.

DAVIES, J.L. and McALLISTER, A.L. 1980. Geology and massive sulphides of the Bathurst area, New Brunswick, Trip 16. Geological Association of Canada/Mineralogical Association of Canada, Field Trip Guidebook, 56 p.

DAVIES, J.L., FYFFE, L.R., and MCALLISTER, A.L. 1983. Geology and massive sulphides of the Bathurst area, New Brunswick. In Field Trip Guidebook to Stratabound Sulphide Deposits, Bathurst Area, New Brunswick, Canada and West-Central New England, U.S.A., D.E. Sangster, (editor). International Geological Correlation Program-Correlation of Caledonian Stratabound Sulphides Symposium, Ottawa, Ontario, Canada, Miscellaneous Report 36, pp. 1-30.

DAVIES, J.L., LUFF, W., VAN STAAL, C., ARCHIBALD, D., and FYFFE, L.R. 1985. Massive sulphide deposits of the Bathurst-Newcastle area, New Brunswick, Canada. Geological Association of Canada/Mineralogical Association of Canada, Excursion 2, 73 p.

DAVIS, G.H. 1972. Deformational history of the Caribou strata-bound sulfide deposit, Bathurst, New Brunswick, Canada. Economic Geology, 67, pp. 634-655.

DECHOW, E.W.T. 1960. Geology, sulphur isotopes and the origin of the Heath Steele ore deposits, Newcastle, New Brunswick, Canada. Economic Geology, 55, pp. 539-556.

DEAN, W.T. 1975. Report on sample submitted by L. Fyffe, New Brunswick Department of Mines, G.S.C. Catalogue Number 91889. Geological Survey of Canada, Eastern Paleontology Section.

DE ROO, J.A. 1989. The Elura Ag-Pb-Zn mine in Australia - ore genesis in a slate belt by syndeformational metasomatism along hydrothermal fluid conduits. Economic Geology, in press.

DE ROO, J.A., MORETON, C., WILLIAMS, P.F., and VAN STAAL, C.R. 1990. The structure of the Heath Steele Mines Region, Bathurst Camp, New Brunswick. Atlantic Geology, 26.

DE ROSEN-SPENCE, A.F., PROVOST, G., DIMROTH, E., GOCHNAUER, K., and OWEN, V. 1980. Archean subaqueous felsic flows, Rouyn-Noranda, Quebec, Canada and their Quaternary equivalents. Precambrian Research, 12, pp. 43-77.

DEWEY, J.F. 1980. Episodicity, sequence, and style at convergent plate boundaries. In The Continental Crust and its Mineral Deposits, D. Strangeway (editor). Geological Association of Canada, Special Paper 20, pp. 553-573.

DIMROTH, E., COUSINEAU P., LEDUC, M., and SANSCHARGRIN, Y. 1978. Structure and organization of Archean subaqueous basalt flows, Rouyn-Noranda area, Quebec, Canada. Canadian Journal of Earth Sciences, 15, pp. 902-918.

DOSTAL, J. 1989. Geochemistry of Ordovician volcanic rocks of the Tetagouche Group of southwestern New Brunswick. Atlantic Geology, 25, pp. 199-209.

DOSTAL, J. and STRONG, D.F. 1983. Trace-element mobility during low-grade metamorphism and silicification of basaltic rocks from Saint John, New Brunswick. Canadian Journal of Earth Sciences, 20, pp. 431-435.

EWART, A. 1979. A review of the mineralogy and chemistry of Tertiary-Recent dacitic, latitic, rhyolitic and related salic volcanic rocks. In Trondhjemites, dacites and related rocks. Edited by F. Barker. Elsevier, New York, pp. 13-111.

FENTON, J.O. and PITMAN, P.W. 1984. Economic evaluation and potential of the Kennco Murray Brook deposit, New Brunswick. Kennco Explorations (Canada) Limited, Internal Report.

FLAGLER, P.A. 1989. A petrogenetic study of the Fournier oceanic complex, northern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 251 p.

FLAGLER, P.A., SPRAY, J.G., and DUNNING, G.R. 1989. Oceanic dynamothermal effects within the Fournier oceanic fragment: Petrological and U/Pb constraints. In Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, St. John's, Newfoundland, Program with Abstracts, 14, p. A26.

FLEMING, H.W. 1961. The Murray deposit, Restigouche County, N.B.: A geochemical-geophysical discovery. Canadian Institute of Mining and Metallurgy, Bulletin 54, No. 587, pp. 230-235.

FRANKLIN, J.M. 1986. Volcanogenic massive sulphide deposits - an update. C.J. Andrew, R.W.A. Crowe, S. Finlay, W.M. Pennell, and J.F. Pyne, Eds., In Geology and genesis of mineral deposits in Ireland, Edited by Irish Association for Economic Geology, Dublin, Ireland, pp. 49-69.

FRANKLIN, J.M., LYDON, J.W., and SANGSTER, D.F. 1981. Volcanic-associated massive sulfide deposits. Economic Geology, 75th Anniversary Volume, pp. 485-627.

FYFFE, L.R. 1976. Correlation of geology in the southwestern and northern parts of the Miramichi Zone. In 139th Annual Report Department of Natural Resources, Province of New Brunswick, pp. 137-141.

FYFFE, L.R. 1982. Taconian and Acadian structural trends in central and northern New Brunswick. In Major Structural Zones and Faults of the Northern Appalachians, P. St-Julien and J. Bèland (editors). Geological Association of Canada Special Paper 24, pp. 117-130.

FYFFE, L.R. 1986. A recent graptolite discovery from the Fournier Group of northern New Brunswick. In Eleventh Annual Review of Activities, Project Resumés, 1986, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Information Circular 86-2, pp. 43-45.

FYFFE, L.R. and NOBLE, J.P.A. 1985. Stratigraphy and structure of the Ordovician, Silurian and Devonian of northern New Brunswick. In Field Guide, Excursion 4, Geological Association of Canada, Mineralogical Association of Canada, Fredericton, N.B., II, pp. 1-56.

FYFFE, L.R., IRRINKI, R.R., and CORMIER, R.F. 1977. A radiometric age of deformed granitic rocks in north-central New Brunswick. Canadian Journal of Earth Sciences, 14, pp. 1687-1689.

FYFFE, L.R., PAJARI, G.E., and CHERRY, M.E. 1981. The Acadian plutonic rocks of New Brunswick. Maritime Sediments and Atlantic Geology, 17, pp. 23-36.

FYFFE, L.R., FORBES, W.H., and RIVA, J. 1983. Graptolites from the Benton area of west-central New Brunswick and their regional significance. Maritime Sediments and Atlantic Geology, 19, pp. 117-125.

FYFFE, L.R., BARR, S.M., and BEVIER, M.L. 1988a. Origin and U-Pb geochronology of amphibolite-facies metamorphic rocks, Miramichi Highlands, New Brunswick. Canadian Journal of Earth Sciences, 25, pp. 1674-1686.

FYFFE, L.R., STEWART, D.B., and LUDMAN, A. 1988b. Tectonic significance of black pelites and basalts in the St. Croix Terrane, coastal Maine and New Brunswick. Maritime Sediments and Atlantic Geology, 24, pp. 281-288.

FYFFE, L.R., VAN STAAL, C.R. and Winchester, J.A. 1990. Late Precambian-Early Paleozoic volcanic regimes and associated massive sulphide deposits in the northeastern mainland Appalachians. Canadian Institute of Mining and Metallurgy, Bulletin 83.

GILES, P.S. and RUITENBERG, A.A. 1977. Stratigraphy, paleogeography, and tectonic setting of the Coldbrook Group in the Caledonia Highlands of southern New Brunswick. Canadian Journal of Earth Sciences, 14, pp. 1263-1275.

GOODFELLOW, W.D. 1975. Rock geochemical exploration and ore genesis at Brunswick No. 12 deposit, New Brunswick. Unpublished Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick, 411 p.

GROSS, G.A. 1967. Geology of iron deposits in Canada. Volume 2: Iron deposits in the Appalachian and Grenville regions of Canada. Department of Energy, Mines and Resources, Economic Geology, Report 22, 2, 111 p.

GUMMER, P.K., VON GUTTENBERG, R., FERGUSON, L. 1978. A recent fossil discovery in the Tetagouche volcanic complex of New Brunswick. Canadian Institute of Mining and Metallurgy, Annual Meeting, Bathurst, New Brunswick, Paper.

HARLEY, D.N. 1977. Half Mile Lake sulphide deposit. Unpublished M.Sc. thesis, University of Western Ontario, London, Ontario.

HARLEY, D.N. 1979. A mineralized Ordovician resurgent caldera complex in the Bathurst-Newcastle mining district, New Brunswick, Canada. Economic Geology, 74, pp. 786-796.

HARNOIS, L. 1989. Geochemistry of Mount Orford ophiolite complex, northern Appalachians, Canada. Chemical Geology, 77, pp. 133-148.

HELMSTAEDT, H. 1970. Geology of map area 0-6, head of Middle River and Wild Cat Brook (northern New Brunswick). New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Series 70-1, 18 p.

HELMSTAEDT, H. 1971. Structural geology of Portage Lakes area, Bathurst-Newcastle District, New Brunswick. Geological Survey of Canada, Paper 70-28, 52 p.

HELMSTAEDT, H. 1973. Structural geology of the Bathurst-Newcastle district. In Geology of New Brunswick, Field Guide to Excursions, N. Rast (editor). New England Intercollegiate Geological Conference, pp. 34-46.

HOPWOOD, T.P. 1976. "Quartz-eye"-bearing porphyroidal rocks and volcanogenic massive sulphide deposits. Economic Geology, 71, pp 589-612.

HUTCHINSON, R.W. 1973. Volcanogenic sulphide deposits and their metallogenic significance. Economic Geology, 68, pp. 1223-1246.

HYNES, A. 1976. Magmatic affinity of Ordovician volcanic rocks in northern Maine, and their tectonic significance. American Journal of Science, 276, pp. 1208-1224.

HYNES, A. 1980. Carbonatization and mobility of Ti, Y, and Zr in Ascot Formation metabasalts, southeast Quebec. Contributions to Mineralogy and Petrology, 75, pp. 79-87.

IRRINKI, R.R. 1986. Geology of Big Bald Mountain map area (NTS 21 O/1), New Brunswick. New Brunswick Department of Forests, Mines and Energy, Mineral Resources Division, Map Report 86-2, 55 p.

JAMBOR, J.L. 1979. Mineralogical evolution of proximal-distal features in New Brunswick massive sulphide deposits. Canadian Mineralogist, 17, pp. 649-664.

JAMBOR, J.L. 1981. Mineralogy of the Caribou massive sulphide deposit, Bathurst area, New Brunswick. Energy, Mines and Resources Canada, Canmet Report 81-8E.

JOSEY, W.L. 1981. Preliminary geology of the Bald Mountain massive sulfide deposit (abstract). Geological Society of America, Abstracts with Programs, 13, p. 140.

JURAS, S.J. 1981. Alteration and sulfide mineralization in footwall felsic metapyroclastic and metasedimentary rocks; Brunswick No. 12 deposit, Bathurst, New Brunswick, Canada. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 208 p.

KAMO, S.L., GOWER, C.F., and KROGH, T.E. 1989. Birthdate for the Iapetus Ocean? A precise U-Pb zircon and baddeleyite age from the Long Range dikes, southeast Labrador. Geology, 17, pp. 602-605.

KENNEDY, D.J., BARNES, C.R., and UYENO, T.T. 1979. A Middle Ordovician conodont faunule from the Tetagouche Group, Camel Back Mountain, New Brunswick. Canadian Journal of Earth Sciences, 16, pp. 540-551.

KETTLES, K.R. 1987. The Turgeon mafic volcanic associated Fe-Cu-Zn sulphide deposit in the ophiolitic Fournier Group, northern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 202 p.

KUMARAPELI, S., ST. SEYMOUR, K., PINTSON, H., and HASELGREN, E. 1988. Volcanism on the passive margin of Laurentia: an early Paleozoic analogue of Cretaceous volcanism on the northeastern American margin. Canadian Journal of Earth Sciences, 25, pp. 1824-1833.

LABBÉ, J.-Y. and ST-JULIEN, P. 1989. Failles de chevauchement acadiennes dans la région de Weedon, Estrie, Quebec. Canadian Journal of Earth Sciences, 26, pp. 2268-2277.

LANGTON, J.P. and VAN STAAL, C.R. 1989. Geology of the Ordovician Elmtree Terrane. In Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, St. John's, Newfoundland, Program with Abstracts, 14, p. A11.

LARGE, R.R. 1977. Chemical evolution and zonation of massive sulphide deposits in volcanic terrains. Economic Geology, 72, pp. 549-572.

LAURENT, R. 1975. Occurrences and origin of the ophiolites of southern Quebec, northern Appalachians. Canadian Journal of Earth Sciences, 12, pp. 443-455.

LAURENT, R. and HÉBERT, R. 1989. The volcanic and intrusive rocks of the Québec Appalachian ophiolites (Canada) and their island-arc setting. Chemical Geology, 77, pp. 287-302.

LEO, G.W. 1985. Trondhjemite and metamorphosed quartz keratophyre tuff of the Ammonoosuc Volcanics (Ordovician), western New Hampshire and adjacent Vermont and Massachusetts. Geological Society of America Bulletin, 96, pp. 1493-1507.

LUFF, W.M. 1975. Structural geology of the Brunswick No. 12 open pit. Canadian Institute of Mining and Metallurgy, Bulletin 68, No. 758, pp. 64-74.

LUFF, W.M. 1977. Geology of the Brunswick No. 12 Mine. Canadian Institute of Mining and Metallurgy, Bulletin 70, No. 782, pp. 109-119.

LUSK, J. 1969. Base metal zoning in the Heath Steele B-1 orebody. Economic Geology, 64, pp. 509-518.

LUSK, J. 1972. Examination of volcanic-exhalative and biogenic origins for sulfur in the stratiform massive sulfide deposits in New Brunswick. Economic Geology, 67, pp. 169-183.

LYDON, J.W. 1984. Volcanogenic massive sulphide deposits, Part 1: a descriptive model. Geoscience Canada, 11, pp. 195-202.

LYDON, J.W. 1983. Volcanogenic massive sulphide deposits, Part 2: Genetic models. Geoscience Canada, 15, pp. 43-65.

MACKENZIE, G.S. 1958. History of mining exploration, Bathurst-Newcastle District, New Brunswick. The Canadian Institute of Mining and Metallurgy, Bulletin, 51, pp. 156-161.

MATTHEW, G.F. 1863. Observations on the geology of Saint John County, New Brunswick. Canadian Natural Geologist, 8, pp. 241-260.

MCALLISTER, A.L. 1960. Massive sulphide deposits in New Brunswick. Canadian Institute of Mining and Metallurgy, Bulletin 53, No. 573, pp. 88-98. 1960. Transactions, 63, pp. 50-60.

MCBRIDE, D.E. 1976. The structure and stratigraphy of the B-zone, Heath Steele Mines, Newcastle, New Brunswick. Unpublished Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick, 227 p.

MCCUTCHEON, S.R., BREWER, A., and BELLAND, M. 1989. Brunswick project, Gloucester County, New Brunswick. In Project Summaries for 1989, Fourteenth Annual Review of Activities, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 89-2, pp. 110-118.

MCCLAY, K.R. 1979. Folding in the silver-lead-zinc orebodies, Mount Isa, Australia. Canadian Institute of Mining and Metallurgy, Transactions, 88(B), pp. 5-14.

MCCLAY, K.R. 1982. Tectonic and sedimentary structures in sulphide orebodies of Munt Isa, Australia, and Sullivan, Canada. Canadian Institute of Mining and Metallurgy, Transactions, 91(B), pp. 146-151.

MCDONALD, J.A. 1970. Some effects of deformation on sulfide-rich layers in lead-zinc ore bodies, Mount Isa, Queensland. Economic Geology, 65, pp. 273-298.

MCLEOD, M.J. 1986. Contrasting geology across the Cradle Brook thrust zone: subaerial vs marine Precambrian environments, Caledonia Highlands, New Brunswick. Maritime Sediments and Atlantic Geology, 22, pp. 296-307.

MCMILLAN, R.H. 1969. A comparison of the geological environments of base metal sulfide deposits of the B Zone and North Boundary Zone at Heath Steele Mines, New Brunswick. Unpublished M.Sc. thesis, University of Western Ontario, London, Ontario, 192 p.

MORETON, C. and WILLIAMS, P.F. 1986. Structural and stratigraphic relation-ships at the B-zone orebody, Heath Steele Mines, Newcastle, New Brunswick. In Current Research, Part B, Geological Survey of Canada, Paper 86-1B, pp. 57-64.

MURPHY, B. and NANCE, R.D. 1989. Model for the evolution of the Avalonian-Cadomian belt. Geology, 17, pp. 735-738.

NAKAMURA, N. 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. Geochimica et Cosmochimica Acta, 38, pp. 757-775.

NEUMAN, R.B. 1984. Geology and paleobiology of islands in the Ordovician Iapetus Ocean: Review and implications. Geological Society of America Bulletin, 95, No. 10 , pp. 1188-1201.

NORTHUMBERLAND MINES LIMITED. 1986. Murray Brook project feasibility study. Prepared by Kilborn Limited, Toronto, Ontario.

NOWLAN, G.S. 1981. Some Ordovician conodont faunules from the Miramichi Anticlinorium, New Brunswick. Geological Survey of Canada, Bulletin 345, 35 p.

NOWLAN, G.S. 1983b. Report on three samples from limestone in pillow basalts from the Pointe Verte Formation (northern New Brunswick). Submitted for Conodont Analysis by L.R. Fyffe and W.H. Poole. Geological Survey of Canada, Ottawa Paleontology Section, Report 002-GSN-1983, 2 p.

NOWLAN, G.S. 1988a. Report on twelve samples from Lower Paleozoic strata of northern New Brunswick. Geological Survey of Canada, Paleontology Subdivision, Report 011-GSN-1988.

NOWLAN, G.S. 1988b. Report on fifteen samples from Ordovician and Silurian strata of northern New Brunswick. Geological Survey of Canada, Paleontology Subdivision, Report 010-GSN-1988.

O'BRIEN, S.J., WARDLE, R.J., and KING, A.F. 1983. The Avalon Zone: A Pan-African terrane in the Appalachian Orogen of Canada. Geological Journal, 18, pp. 195-222.

O'DRISCOLL, E.S. 1962. Experimental patterns in superposed similar folding. Alberta Society of Petroleum Geologists, Journal, 10, pp. 145-167.

O'DRISCOLL, E.S. 1964. Cross fold deformation by simple shear. Economic Geology, 59, pp. 1061-1093.

OHMOTO, H. and SKINNER, R.J. 1983. The Kuroko and related volcanogenic massive sulphide deposits: introduction and summary of findings. Economic Geology Monograph 5, pp. 1-8.

OSHIN, I.O. and CROCKET, J.H. 1986. The geochemistry and petrogenesis of ophiolitic volcanic rocks from Lac de l'Est, Thetford Mines complex, Quebec, Canada. Canadian Journal of Earth Sciences, 24, pp. 202-213.

OWSIACKI, L. 1980. The geology of the C Zone, Heath Steele Mine, New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 224 p.

OWSIACKI, L. and MCALLISTER, A.L. 1979. Fragmental massive sulphides at the Heath Steele Mine, New Brunswick. Canadian Institute of Mining and Metallurgy, Bulletin, 72, No. 811, pp. 93-100.

PAJARI, G.E. Jr., RAST, N., and STRINGER, P. 1977. Paleozoic volcanicity along the Bathurst-Dalhousie geotraverse, New Brunswick, and its relations to structure. In Volcanic Regimes in Canada, W.R.A. Baragar, L.C. Coleman, and J.M. Hall (editors). Geological Association of Canada, Special Paper 16, pp. 111-124.

PEARCE, J.A. and CANN, J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth and Planetary Science Letters, 19, pp. 290-300.

PEARCE, J.A., LIPPARD, S.J., and ROBERTS, S. 1984. Characteristics and tectonic significance of supra-subduction zone ophiolites. In Marginal Basin Geology; Volcanic and Associated Sedimentary and Tectonic Processes in Modern and Ancient Marginal Basins, B.P. Kokelaar and M.F. Howells (editors). Geological Society of London, Special Publication 16, pp. 77-94.

PEDERSEN, F.D. 1980. Remobiliation of the massive sulfide ore of the Black Angel Mine, Central West Greenland. Economic Geology, 75, pp. 1022-1041.

PERUSSE, J. 1955. Report on Murray Claim Group. Kennco Explorations (Canada) Limited, Internal Report.

PERUSSE, J. 1956. Murray Group Progress Report for 1956. Kennco Explorations (Canada) Limited, Internal Report.

PERUSSE, J. 1958. Final report on Murray Brook project 1956. Kennco Explorations (Canada) Limited, Internal Report.

PETRUK, W. 1959. The Clearwater copper-zinc deposit and its setting, with a special study of mineral zoning around such deposits. Unpublished Ph.D. Thesis, McGill University, Montreal, 122 p.

PHILPOTT, G.R. 1988. Precious-metal and geological investigation of the Charlo River area. In Thirteenth Annual Review of Activities, Project Résumés, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Information Circular 88-2, pp. 20-31.

PICHLER, H. 1965. Acid hyaloclastites. Bulletin Volcanoloque, 28, pp. 293-310.

PINTSON, H., KUMARAPELI, P.S., and MORENCY, M. 1985. Tectonic significance of the Tibbit Hill Volcanics: geochemical evidence from Richmond area, Quebec. In Current Research, Part A. Geological Survey of Canada, Paper 85-1A, pp. 123-130.

PITMAN, P.W. 1985. Diamond drill report on the surface exploration of the precious metals enriched gossan zone, Murray Brook. Northumberland Mines Limited, Internal Report.

POTTER, R.R. 1969. The geology of Burnt Hill area and ore controls of the Burnt Hill tungsten deposit. Unpublished Ph.D. thesis, Carleton University, Ottawa, Ontario, 199 p.

RAMSAY, J.G. 1962. The geometry and mechanics of formation of "similar" type folds. Journal of Geology, 70, pp. 309-327.

RAMSAY, J.G. 1974. Development of chevron folds. Geological Society of America, Bulletin, 85, pp. 1741-1754.

RANKIN, L.D. 1982. The geology of the Portage Lakes-Caribou area, northern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 220 p.

RAST, N. and SKEHAN, J.W. 1983. The evolution of the Avalonian Plate. Tectonophysics, 100, pp. 257-286.

RAST, N. and STRINGER, P. 1974. Recent advances and the interpretation of geological structure of New Brunswick. Geoscience Canada, 1, No. 4, pp. 15-25.

RAST, N. and STRINGER, P. 1980. A geotraverse across a deformed Ordovician ophiolite and its Silurian cover, northern New Brunswick, Canada. Tectonophysics, 69, pp. 221-245.

RAST, N., O'BRIEN, B.H., and WARDLE, R.J. 1976. Relationships between Precambrian and Lower Palaeozoic rocks of the 'Avalon Platform' in New Brunswick, the northeast Appalachians and the British Isles. Tectonophysics, 30, pp. 315-338.

RAVENHURST, C.E., VAN STAAL, C.R., and RODDICK, J.C. 1990. ^{40}Ar/Ar^{39} dating of blueschists in northern New Brunswick: onset of Acadian accretion. Geological Society of America, Northeastern Section, Abstracts with Programs, p. 64.

RHODES, D. 1978. Stratmat 61, New Brunswick, 1977 year-end report. Cominco Ltd., 54 p.

RIVA, J. and MALO, M. 1988. Age and correlation of the Honorat Group, southern Gaspé Peninsula. Canadian Journal of Earth Sciences, 25, pp. 1618-1628.

RODGERS, J. 1971. The Taconic orogeny. Geological Society of America, Bulletin, 82, pp. 1141-1178.

ROSCOE, W.E. 1971. Geology of the Caribou Deposit, Bathurst, New Brunswick, Canada. Canadian Journal of Earth Sciences, 8, pp. 1125-1136.

RUTLEDGE, D.W. 1972. Brunswick Mining and Smelting Corporation, No. 6 and No. 12 mines. In Mineral Deposits of Southern Quebec and New Brunswick, Field Excursion Guidebook A58, A.L. McAllister and R.Y. Lamarche (editors). XXIV International Geological Congress, Montreal, Quebec, pp. 58-67.

RUITENBERG, A.A. 1970. Mineralized structures in the Johnson Croft, Annidale, Jordan Mountain, and Black River areas. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 13, 28 p.

RUITENBERG, A.A., GILES, P.S., VENUGOPAL, D.V., BUTTIMER, S.M., MCCUTCHEON, S.R. and CHANDRA, J. 1979. Geology and mineral deposits, Caledonia area. New Brunswick Department of Natural Resources, Mineral Resources Branch, Memoir 1, 213 p.

SAIF, S.I. 1980. Petrographic and geochemical investigation of iron formation and other iron-rich rocks in Bathurst district, New Brunswick. In Current Research, Part A. Geological Survey of Canada, Paper 80-1A, pp. 309-317.

SAIF, S.I., MCALLISTER, A.L. and MURPHY, W.L. 1978. Geology of the Key Anacon Mine area, Bathurst, New Brunswick. Canadian Institute of Mining and Metallurgy, Bulletin, 71, No. 791, pp. 161-169.

ST-JULIEN, P. and HUBERT, C. 1975. Evolution of the Taconian orogen in the Quebec Appalachians. American Journal of Science, 275A, pp. 337-367.

SAUNDERS, A.D. and TARNEY, J. 1984. Geochemical characteristics of basaltic volcanism within back-arc basins. In Marginal Basin Geology, B.P. Kokelaar and M.F. Howells (editors). Geological Society of London, Special Publication 16, pp. 59-76.

SAUVÉ, P., CLOUTIER, J.P., and GENOIS, G. 1972. Base metal deposits of southeastern Quebec. International Geological Congress Guidebook, Excursion B-07, 24 p.

SCHENK, P.E. 1971. Southeastern Atlantic Canada, northwestern Africa, and continental drift. Canadian Journal of Earth Sciences, 8, pp. 1218-1251.

SCHUMACHER, J.C. 1988. Stratigraphy and geochemistry of the Ammonoosuc volcanics, central Massachusetts and southwestern New Hampshire. American Journal of Science, 288, pp. 619-663.

SCULLY, M.V. 1988. Geology and petrochemistry of the Mount Chase massive sulfide prospect, Penobscot County, Maine. Unpublished M.Sc. thesis, University of Missouri at Rolla, Missouri, U.S.A., 117 p.

SHIROZU, H. 1974. Clay minerals in altered wallrocks of the Kuroko-type deposits. In Geology of Kuroko deposits. Edited by S. Ishihara. Society of Mining Geologists of Japan, Mining Geology Special Issue No. 6, pp. 303-310.

SKINNER, R. 1956. Tetagouche Lakes, Restigouche, Glouchester and Northumberland counties, New Brunswick. Geological Survey of Canada, Paper 55-32, 1 p.

SKINNER, R. 1974. Geology of Tetagouche Lakes, Bathurst and Nepisiguit Falls map areas, New Brunswick. Geological Survey of Canada, Memoir 371, 133 p.

SMITH, R.L. 1976. Ash-flow magmatism. In Ash-flow tuffs. Edited by C.E. Chapin and W.E. Elston. Geological Society of America, Special Paper 180, pp. 5-27.

SMITH, C.H. and SKINNER, R. 1958. Geology of the Bathurst-Newcastle mineral district, New Brunswick. Canadian Institute of Mining and Metallurgy Bulletin 51, No. 551, pp. 150-155.

SMITH, C.H., SKINNER, R., and POOLE, W.H., 1973. Geology of California Lake, New Brunswick. Geological Survey of Canada, Map 1341A (with marginal notes).

SOLOMON, M. 1976. "Volcanic" massive-sulphide deposits and their host rocks--a review and an explanation. In Handbook of strata-bound and strataform ore deposits. Edited by H.K. Wolf. Elsevier, pp. 21-54.

SPENCER, C., GREEN, A., MOREL-à-l'HUISSIER, P., MILKEREIT, B., LUETGERT, J., STEWART, D., UNGER, J., and PHILLIPS, J. 1989. The extension of Grenville basement beneath the northern Appalachians: Results form the Quebec-Maine seismic reflection and refractor surveys. Tectonics, 8, pp. 677-696.

SPRAY, J.G., FLAGLER, P.A., and DUNNING, G.R. 1990. Crystallization and emplacement chronology of the Fournier oceanic fragment, Canadian Appalachians. Nature, 344, pp. 232-235.

STANTON, R.L. 1959. Mineralogical features and possible mode of emplacement of the Brunswick Mining and Smelting orebodies, Gloucester County, New Brunswick. Canadian Institute of Mining and Metallurgy, Bulletin, 52, No. 570, pp. 631-643.

STEPHENS, M.B., SWINDEN, H.S., and SLACK, J.F. 1984. Correlation of massive sulphide deposits in the Appalachian-Caledonian Orogen on the basis of paleotectonic setting. Economic Geology, 79, pp. 1442-1478.

STOCKMAL, G.S., COLMAN-SADD, S.P., KEEN, C.E., MARILLIER, F., O'BRIEN, S.J., and QUINLAN, G.M. 1990. Deep seismic structure and plate tectonic evolution of the Canadian Appalachians. Tectonics, 9, pp. 45-62.

STRINGER, P. 1975. Acadian slaty cleavage noncoplanar with fold axial surfaces in the Northern Appalachians. Canadian Journal of Earth Sciences, 12, pp. 949-961.

STRONG, D.F. 1974. Plate tectonic setting of Newfoundland mineral deposits. Geoscience Canada, 1, pp. 20-30.

STRONG, D.F. 1977. Volcanic regimes of the Newfoundland Appalachians. In W.R.A. Baragar, L.C. Coleman, and J.M. Hall (editors). Geological Association of Canada, Special Paper 16, pp. 61-90.

STRONG, D.F., DICKSON, W.L., and PICKERILL, R.K. 1979. Chemistry and prehnite-pumpellyite facies metamorphism of calc-alkaline Carboniferous volcanic rocks of southeastern New Brunswick. Canadian Journal of Earth Sciences, 16, pp. 1071-1085.

SULLIVAN, R.W. and VAN STAAL, C.R. 1989. Age of a metarhyolite from the Tetagouche Group, Bathurst, New Brunswick, fromU-Pb isochron analyses of zircon enriched in common lead. Geological Survey of Canada, Paper 88-3.

SULLIVAN, R.W., VAN STAAL, C.R., and LANGTON, J.P. 1989. U-Pb zircon ages of plagiogranite and gabbro from the ophiolitic Devereaux Formation, Fournier Group, northeastern New Brunswick. Geological Survey of Canada, Paper 88-3.

SUTHERLAND, J.K. 1967. Chlorites of the Anaconda-Caribou deposit, New Brunswick. New Brunswick Research and Productivity Council, Research Note 8, 14 p.

SWINDEN, H.S. and THORPE, R.I. 1984. Variations in style of volcanism and massive sulphide deposition in Early-Middle Ordovician island arc sequences of the Newfoundland Central Mobile Belt. Economic Geology, 79, pp. 1596-1619.

SWINDEN, H.S., JENNER, G.A., KEAN, B.F., and EVANS, D.T.W. 1989. Volcanic rock geochemistry as a guide for massive sulphide exploration in central Newfoundland. In Current Research. Newfoundland Department of Mines, Geological Surveys Branch, Report 89-1, pp. 201-219.

THOMAS, M.D. and WILLIS, C. 1989. Gravity modelling of the Saint George Batholith and adjacent terrane within the Appalachian Orogen, southern New Brunswick. Canadian Journal of Earth Sciences, 26, pp. 561-576.

TREMBLAY, A. and BERGERON, M. 1988. Tectonic collage of distinctive volcanic suites in the Ascot Formation: geochemical evidences. In Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, St. John's, Newfoundland, Program with Abstracts, p. A126.

TREMBLAY, A., HÉBERT, R. et BERGERON, M. 1989. Le complexe d'Ascot des Appalaches du sud du Québec. Pétrologie et géochimie. Canadian Journal of Earth Sciences, 26, pp. 2407-2420.

TROOP, D.G. 1984. The petrology and geochemistry of Ordovician banded iron formations and associated rocks at the Flat Landing Brook massive sulphide deposit, northern New Brunswick. Unpublished M.Sc. thesis, University of Toronto, Toronto, Ontario.

TROTTIER, J., GAUTHIER, M. and BROWN, A.C. 1987. Geology and lithogeochemistry of the Huntingdon deposit, Cyprus-type mineralizations in the ophiolite belt of the southeastern Quebec Appalachians. Economic Geology, 82, pp. 1483-1504.

URABE, T., SCOTT, S.D and HATORI, K. 1983. A comparison of footwall-rock alteration and geothermal systems beneath some Japanese and Canadian volcanogenic massive sulphide deposits. Economic Geology, Monograph 5, pp. 345-364.

UYEDA, S. 1983. Comparative subductology. Episodes, 1983, No. 2, pp. 19-24.

VAN DER PLUIJM, B.A. and VAN STAAL, C.R. 1988. Characteristics and evolution of the central mobile belt, Canadian Appalachians. Journal of Geology, 96, pp. 535-547.

VAN STAAL, C.R. 1985. Structure and metamorphism of the Brunswick Mines area, Bathurst, New Brunswick, Canada. Unpublished Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick, 484 p.

VAN STAAL, C.R. 1986. Preliminary results of structural investigations in the Bathurst Camp of northern New Brunswick. In Current Research, Part A, Geological Survey of Canada, Paper 86-1A, pp. 193-204.

VAN STAAL, C.R. 1987. Tectonic setting of the Tetagouche Group in northern New Brunswick: implications for plate tectonic models of the northern Appalachians. Canadian Journal of Earth Sciences, 24, pp. 1329-1351.

VAN STAAL, C.R. and FYFFE, L.R., in press. The New Brunswick Dunnage and Gander Zones. In The Appalachian/Caledonian Orogen: Canada and Greenland, H. Williams (co-ordinator), Decade of North American Geology, Volume F-1.

VAN STAAL, C.R. and LANGTON, J.P. 1988. Correlation between the Elmtree and Miramichi terranes: evidence for the Caledonian Orogeny in northeastern New Brunswick. Geological Association of Canada/Mineralogical Association of Canada, Program with Abstracts, p. A129.

VAN STAAL, C.R. and WILLIAMS, P.F. 1984. Structure, origin, and concentration of the Brunswick 12 and 6 orebodies. Economic Geology, 79, pp. 1669-1692.

VAN STAAL, C.R., LANGTON, J.P., and SULLIVAN, R.W. 1988a. A U-Pb zircon age for the ophiolitic Deveraux Formation, Elmtree Terrane, northeastern New Brunswick. In Radiogenic Age and Isotopic Studies: Report 2. Geological Survey of Canada, Paper 88-2, pp. 37-40.

VAN STAAL, C.R., WINCHESTER, J. and CULLEN, R. 1988b. Evidence for D_1-related thrusting and folding in the Bathurst-Millstream River area, New Brunswick. In Current Research, Part B. Geological Survey of Canada, Paper 88-1B, pp. 135-148.

WATTERS, S.E. 1987. Gold-bearing rocks - Bay of Fundy coastal zone. In Twelfth Annual Review of Activities, Project Résumés, S.A. Abbott (editor). New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Information Circular 87-2, pp. 41-44.

WHALEN, J.B., HAGNER, E., and JENNER, G.A. 1989. Nature of Canadian Appalachian basement terranes as inferred from a Nd isotopic transect. Geological Society of America, Abstracts with Program, Annual Meeting, St. Louis, Missouri, Volume 21, No. 6, p. A201.

WHITEHEAD, R.E.S. and GOODFELLOW, W.D. 1978. Geochemistry of volcanic rocks from the Tetagouche Group, Bathurst, New Brunswick, Canada. Canadian Journal of Earth Sciences, 15, pp. 207-219.

WHITEWAY, P. 1989. King of zinc. The Northern Miner Magazine, April 1989, pp. 10-16.

WILLIAMS, H. 1964. The Appalachians in northeastern Newfoundland - a two-sided symmetrical system. American Journal of Science, 262, pp. 1137-1158.

WILLIAMS, H. 1979. Appalachian Orogen in Canada. Canadian Journal of Earth Sciences, 16, pp. 792-807.

WILLIAMS, H. and ST-JULIEN, P. 1982. The Baie Verte-Brompton Line: Early Paleozoic continent ocean interface in the Canadian Appalachians. In Major Structural Zones and Faults of the North Appalachians, P. St-Julien and J. Béland (editors). Geological Association of Canada, Special Paper 24, pp. 177-207.

WILSON, J.T. 1966. Did the Atlantic close and then re-open? Nature, 211, pp. 676-681.

WINCHESTER, J. and VAN STAAL, C.R. 1988. Middle Ordovician volcanicity in northern New Brunswick: geochemistry and probable tectonic setting. In Geological Association of Canada/Mineralogical Association of Canada, Joint Annual Meeting, St. John's, Newfoundland, Program with Abstracts, p. A135.