Bathurst Mining Camp

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5. Bathurst Mining Camp
Global comparison of massive sulfides
GEODE

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5.1 Age and tectonic/structural setting

5.1.1 What is the age of your VMS district?

Early to Middle Ordovician (480-457 Ma).

- Extent, type and precision of geochronology? (belt scale and deposit scale).

At belt scale there are about twenty high precision U-Pb radiometric ages (see Figure 1 attached); at deposit scale there are two.

- Palaeontological control.

Three graptolite localities from slates that cap the volcanic pile; one brachiopod and two conodont localities from within the pile.

5.1.2 What is the current interpretation of the tectonic setting of your VMS district? (include a time-sequence diagram if available).

An ensialic back-arc basin that was incorporated in a subduction complex. See Figure 2 attached for cartoon model.

5.1.3 What is the tectonic interpretation based upon:

- structural mapping and interpretation? (quality of mapping?).

Good quality 1:20,000 scale mapping, lithogeochemistry and a preserved blueschist.

- gravity and/or magnetic data (has it been used?).

Regional gravity data are sparse. High resolution airborne magnetic and electromagnetic data exist for the entire camp, which to date have mainly been used as an aide to mapping; limited modelling of the digital data.

- any seismic sections?

Only a few property-scale lines and one 3D survey over the Halfmile Lake deposit, which were done by Noranda; the data are not public.

- chemistry of volcanic rocks? What geochemical-tectonic classification was used?

Yes. Pearce et al. (1977, 1984).
5.1.4 Is there a comprehensive and high quality database of volcanic geochemistry to assist with tectonic interpretation?

Yes.

- how many whole-rock/trace analyses on least-altered rocks?

Approximately 1000 analyses.

- type and quality of trace element data?

Major and minor trace elements, including REE’s for most of the analyses; quality is good (checked against standards) but several labs involved. ICP-MS/ES fusion; XRF pressed pellet.

- what isotope data are available?

Considerable S and Pb data reported; minor O and C; no compiled database.

5.1.5 Have the district-scale and deposit-scale ore-fluid plumbing structures been identified?

No and yes (for some), respectively.

Size of structures?

Difficult to determine because of polyphase deformation; in some instances, traceable for ten’s to hundred’s of metres into footwall.

How were they defined (mapping?, alteration?, aeromagnetics? geochemistry? Isotopes?).

Mostly by mapping (aided by geophysics) and alteration.

5.1.6 Have detailed structural studies of the deposits been undertaken? Which deposits?

Yes. Caribou, Brunswick No.6 and No.12, Heath Steele ACD and B, Stratmat Boundary.

5.1.7 What further research is needed to improve the tectonic interpretation?

Better delineation of major and minor thrust geometry; 3D modeling.

5.1.8 List key references.

Davis (1972); de Roo and van Staal (1994); Fyffe and Swinden (1991); Lentz (1996a); McBride (1976); McCutcheon (1997); Moreton (1994); Park (1996); Rogers (1995); van Staal (1987, 1994); van Staal and Fyffe (1991); van Staal et al. (1991, 1992).

5.2 Volcanic architecture

5.2.1 What are the scales of geological maps available for the district and the deposits?
For the district, 1:20,000 to 1:250,000 scales in digital form; for the deposits, there are few published maps but company reports have hard-copy line maps, generally at 1:4800 scale.

**Has a comprehensive systematic stratigraphy been established for the district?**

Yes, see Figure 1 attached.

**5.2.2 How do the VMS deposits relate to volcanic facies?**

Most are stratiform, in first–cycle felsic volcanic rocks and are associated with volcanogenic mudstones; some are stratabound, in first or second-cycle felsic fragmental rocks; others are in sedimentary units that overlie or are interbedded with the volcanic pile.

*Provide some sketch diagrams if available. Do the VMS deposits occur at a single stratigraphic position? No. Do the VMS deposits occur in proximal or distal volcanic facies?*

Both.

*Percentage of volcaniclastic rocks versus coherent flows or intrusions?*

About 70% and 30%, respectively, in the Nepisiguit Falls Formation of the Tetagouche Group. Do not know for other units.

**5.2.3 What is the composition (rhyolite?, basalt?) of the VMS host package?**

Rhyolite-rhyodacite.

*Is there a change in volcanic composition at, or close to, the ore position?*

None apparent.

**5.2.4 What is the interpreted range of water depth during deposition of the volcanic succession, and immediate host rocks?**

Deep to very deep.

*What criteria were used to estimate water depth (eg. volcanic facies, sedimentary structures, fossils, fluid inclusions)?*

Sedimentary facies above and below the volcanic pile.

**5.2.5 What further research is needed to define the relationship between ore formation and volcanic architecture?**

Better delineation of felsic volcanic facies.
5.2.6 List key references.

Harley (1979); McCutcheon (1992); McCutcheon et al. (1993); Rogers and van Staal (1996); Wilson (1993, 1998); Wilson et al. (1999).

5.3 Styles of ore deposits

5.3.1 Provide a table of tonnes and grade for major deposits (include economic and sub-economic or barren massive sulfides). How many additional deposits of less than 1 million tonnes are known in the district?

See figure 3 for table of tonnes. 25>1 million tonnes grade for major deposits. There are twenty known deposits in the district of less than 1 million tonnes.

5.3.2 What is the degree of metamorphism, deformation and recrystallization in the ores. Does it vary from deposit to deposit in the district?

Yes it does vary.

<table>
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<tr>
<th>Metamorphism</th>
<th>Greenschist</th>
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<tr>
<td>Deformation</td>
<td>Polyphase</td>
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<tr>
<td>Recrystallization</td>
<td>Common</td>
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</tbody>
</table>

5.3.3 What VMS deposit types occur within the belt (eg polymetallic Zn-Pb-Cu-type, Cu-Zn-type, Cu-type, Au-only, barite-only, pyrite-only)? Give a cartoon model of each type present, showing simple geology, morphology of the deposit and metal zones. Do not use genetic classifications such as kuroko type or Cyprus type, but use metal content and ratios – Cu/(Cu+Zn) and Zn/(Zn+Pb). (eg. Large, 1992: ECON. GEOL. V87, p 473).

See Figure 3.

5.3.4 Are stringer zones present or economic? What is their mineralogy? Are there any deposits that comprise only stringer sulfides?

Stringer zones are present. They are not economic. Their mineralogy is Py+Asp+Po+Cp±Sp. The Chester deposit is predominantly composed of stringer mineralization.

5.3.5 What are the major textures in the massive (>60% sulfides) sulfides – massive featureless, banded, brecciated? Massive, banded, mosaic-nodular, disseminated, locally brecciated. Are these textures interpreted to be primary or deformation-related? Both, depending upon the observer and the deposit; most are modified by deformation. Key evidence? Colloform pyrite preserved locally in some deposits; others characterized by sulfide gneiss.

5.3.6 Did most deposits form on the seafloor (strataform) or by replacement below the seafloor (stratabound) or a combination of both? Key evidence?

Sediment-hosted and volcanic-hosted, respectively.
If sub-seafloor, how far below the seafloor?

Not far.

Evidence?

Probable vent fauna in a thin volcanogenic sedimentary unit located just above one deposit.

5.3.7 Did the seafloor deposits form in brine pools (local depressions), or as mounds, or are both types represented, or did they form by some other mechanism?

Some seem to have formed as mounds or asymmetric mounds in local bottom depressions; others appear to have been widely dispersed on the seafloor.

Key evidence?

The former deposits have a lens or mound geometry and are floored by chloritic (volcanogenic) mudstone; the latter have a sheet-like geometry and are in relatively unaltered dark grey clastic rocks.

Is there general agreement on the mechanism of formation?

No.

5.3.8 List key references.

Adair (1992); Fyffe (1995); Goodfellow and Peter (1996); Jambor (1979); Lentz (1999a); Lusk (1969); McCutcheon (1992); Park (1996); Stanton (1959); van Staal and Williams (1984).

5.4 Exhalites

5.4.1 Are “exhalites” (Fe, Si or Mn, units) present at the same stratigraphic level as the ores?

Oxide iron formation is commonly associated with deposits in the Nepisiguit Falls Formation, but not with those in other formations.

Are other styles of ore-equivalent horizons developed, eg; sulfide-bearing epiclastics, pyritic black shales, limestones?

One deposit at the top of the Flat Landing Brook Formation has barite.

Are the exhalites true seafloor precipitates or simply alteration (silicification?) of tuffaceous sediments?

Seafloor precipitates.

Key criteria?

Fe/Mn ratio, anomalous Pb-Zn, layering, isotopic evidence.
5.4.2 Are exhalites developed at other stratigraphic levels above or below the ore position?

Yes.

How far above or below?

Oxide iron formations occur in the lower part of the Flat Landing Brook Formation (generally <100 m above contact with Nepisiguit Falls Formation) and locally in mafic volcanic units of the Canoe Landing Lake, Boucher Brook, Little River and Slacks Lake formations.

5.4.3 Can the exhalites be mapped along strike from the deposit (how far?), and are they useful for exploration?

Yes, up to 5 km for Brunswick No.12 but generally <1 km.

How do you distinguish ore-associated exhalites from barren exhalites?

Productive ones have anomalous Pb-Zn.

5.4.4 Is there a geochemical database for exhalites in your belt (how many samples, REE data, isotope data)?

Yes, Jan Peter has database at the GSC.

5.4.5 List key references.

Lentz et al. (1995); Peter and Goodfellow (1996); Saif (1983); Troop (1984); Whitehead (1973).

5.5 Alteration facies

5.5.1 Have hydrothermal (yes), regional diagenetic (no), and regional metamorphic (yes; greenschist and blueschist) mineral assemblages and textures been identified? See Lentz and Goodfellow (1994); Trzcienski et al. (1984) and van Staal et al. (1990), respectively. Criteria used for discrimination? Iron content is much higher in hydrothermal chlorite.

5.5.2 What (if any) is the immediate footwall alteration mineralogy and zonation?

Silicification + Fe-chlorite + disseminated & stringer sulfides (only in vent area) Æ Fe-chlorite + sericite +/- stringer sulfides Æ Sericite (feldspar destruction) + Fe-Mg chlorite.

Is the footwall alteration more commonly in stratabound zones or as pipes?

Both kinds are present in many deposits.

What is the depth extent and surface area relative to the deposit?

Stratbound alteration extends well beyond the deposit but is confined to the footwall volcaniclastic rocks (especially in the Nepisiguit Falls Fm); pipe-like stringer zones cannot be traced very far into the footwall rocks, largely because of deformation effects.
5.5.3 What (if any) is the extent and mineralogy of hangingwall alteration?

Manifested by spotty Fe-carbonate (porphyroblasts) just above exhalite in some deposits.

Give morphology, dimensions and mineral zonation.

Stratabound, thin and with extent proportional to dimensions of exhalite.

5.5.4 What particular alteration indices (vectors to ore) have been tested or proposed?

Goodfellow index: \((\frac{\text{MgO}+\text{FeO}}{\text{MgO}+\text{FeO}+\text{CaO}+\text{Na}_2\text{O}})\); Ishikawa index: \(\left(\frac{\text{K}_2\text{O}+\text{MgO}}{\text{K}_2\text{O}+\text{Na}_2\text{O}+\text{CaO}+\text{MgO}}\right)\times100\); Gandhi (Lentz) index: \((\frac{\text{Fe}_t+\text{Mg}}{\text{Na}+\text{K}})\); mass-balanced, Al-normalized ratios, e.g. \((\text{Fe}+\text{Mg})/\text{Al}\).

5.5.5 Has a single database of alteration geochemistry been compiled for the district? (number of samples?). By whom? and is it available?

No.

5.5.6 Is there a database of whole rock oxygen isotopes? Some published but not compiled into a single database. (number of samples?) Is data available on H or C isotopes?

Even less than oxygen and not compiled.

5.5.7 Have deep semi-conformable alteration zones been identified?

No deep ones identified but semi-conformable zones in the Nepisiguit Falls Fm.

What is their dimension, mineralogy, and chemical characteristics?

Feldspar partly to completely destroyed; MgO enriched felsic rocks.

Is there evidence for metal depletion?

5.5.8 Is alteration geochemistry used to assist exploration in the district?

Yes, in recent years.

5.5.9 List key references.

Adair (1992); Currie and van Staal (1999); Goodfellow (1975); Lentz (1996b, 1999a, 1999b); Lentz and Goodfellow (1993a, b, & c, 1994, 1996); Lentz et al. (1997); Luff et al. (1992); Trzcienski et al. (1984); van Staal (1985); van Staal et al. (1990).

5.6 Hydrothermal geochemistry

5.6.1 Are there systematic published studies on the mineralogy, mineral paragenesis and mineral chemistry of the ores and altered host rocks? Which deposits?

Some studies but not much on mineral chemistry. Brunswick, Heath Steele, Caribou, McMaster.
5.6.2 Are the temperature, salinity and chemistry of the ore fluid well constrained from deposit data? What is the quality of primary fluid inclusion data?

No. Metamorphic degradation of fluid inclusions common.

5.6.3 Is there any evidence for fluid boiling, give details?

See Lentz and Goodfellow (1996).

5.6.4 What hydrothermal thermodynamic modelling has been attempted? What modelling software was used (if any)?

None.

5.6.5 What additional information is required to develop robust geochemical models?

5.6.6 List key references.

Goodfellow and Peter (1996); Lentz and Goodfellow (1996); Lusk and Krouse (1997).

5.7 Source of fluids, sulfur and metals

5.7.1 How extensive is the S isotope database on ores (some), sulfates (none present) and host rocks (very limited) (numbers of analyses)?

Not all compiled but estimate less than 300. What is the range of del 34S? In Tetagouche Group deposits, 11.8-16.5 per mil; in California Lake Group deposits, 5.9-10.9 per mil.

Do the massive sulfides and stringer zones have the same mean value and range?

For Brunswick No.12, the stringer values are slightly higher than the massive values.

What is the interpreted source(s) of sulfur?

Bacterial reduction of seawater.

5.7.2 How extensive is the Pb isotope database on ores and host rocks (some) (number of analyses)?

Not all compiled but estimate less than 100.

What is the range of 206/204Pb and 207/204Pb ratios on ores?

In Tetagouche Group deposits, 18.187Æ18.279 and 15.641Æ15.663, respectively; in California Lake Group deposits, 18.230Æ18.319 and 15.647Æ15.669, respectively.

What is the interpreted source of metals?

Mostly from the underlying volcanic and sedimentary rocks.
5.7.3 Are there any other isotopic data (Os/Ir, Sm/Nd, Sr) that may assist in determining the source of metals?

Some Sr data (see Lusk and Krouse, 1997).

5.7.4 Is there any evidence for magmatic fluid/metal input? If so what is the key evidence?

Perhaps. The elevated Sn content of the sulfide deposits.

5.7.5 What further research is required to determine the source of fluids, sulfur and metals?

5.7.6 List key references.

Goodfellow and Peter (1996); Lentz and Goodfellow (1993); Lusk and Crocket (1969); Peter and Goodfellow (1996); Tupper (1960).

5.8 Subvolcanic intrusions

5.8.1 Have syn-volcanic intrusions been identified (yes) and are they associated with VMS deposits? What is their composition and are they composite?

Not obviously. Granitic to granodioritic and yes.

5.8.2 Classify them as shallow (<1000 m from the lowest VMS horizon), epizonal (1000-3000 m) or deep (>3000 m). Is there more than one level present? What is their geometry and dimensions.

Shallow to epizonal. Most are hosted by Miramichi Group sedimentary rocks but at least one intrusion cuts the felsic volcanic rocks. Lenticular; up to 50 km long and 5 km wide but generally < 10 km long.

5.8.3 Are they hosted by comagmatic volcanics? Underlying basement?

Rarely. Mostly.

5.8.4 Are they identified as comagmatic to VMS-hosting strata by: a) geology; b) igneous geochemistry, and/or c) geochronology?

All of these.

5.8.5 Are they related to district-scale alteration zones? Key evidence?

Not obviously.

5.8.6 Do they contain extensive areas of alteration? Do they contain base-metal and/or gold occurrences?

No. None known.

5.8.7 List key references.

Wilson et al. (1999); Whalen et al. (1998).
5.9 Hydrogeological modelling

5.9.1 Are there any published or unpublished hydrogeological models for the district or for individual deposits? What software package was used?

No.

5.9.2 Are there any data on the original porosity and permeability of the volcanic and sedimentary facies in the succession?

No.

5.9.3 Have regional or local hydrothermal fluid pathways been defined? Using what data or criteria?

Local pathways observed. Semi-conformable alteration zones.

5.9.4 Have any heat sources or fluid driving mechanisms been defined?

No.

5.9.5 What research is required to develop robust hydrogeological models? What computer codes are suitable and available? What computer code developments are needed to better constrain 3D heat and fluid flow modelling?

For regional modelling, palinspastic reconstruction of the fold-thrust belt.

5.9.6 List key references.

None.

5.10 Exploration criteria

5.10.1 How were the known deposits found? Provide a list with dates and the key methods. (eg. outcropping gossan, gravity, magnetics, soil geochemistry etc.).

See Figure 3 attached.

5.10.2 Currently, what are the key methods used by companies to identify 1) prospect areas, and 2) drill targets?

1. Prospecting, EM, Mag, work history. 2. Geology, soil geochemistry, Mag, IP, gravity, seismic (recently).

5.10.3 What regional exploration data sets are available from the relevant government departments: aeromagnetics? (yes, state of the art), gravity? (yes but poor coverage) EM? (yes, state of the art), stream geochemistry? (yes), soil geochemistry? (no), till geochemistry? (yes), rock-chip geochemistry? (no). Give specifications and degree of coverage.

Entire camp was flown (Aerodat helicopter-borne Mag, EM, radiometrics) in 1996 at 200 m line spacing and 60 m ground clearance. Stream sediment and water samples were collected in the northwestern
quarter of the camp as part of the EXTECH Project; entire camp is covered by older stream sediment geochemistry at 400 m spacing. Entire camp is covered by till geochemistry (one sample per four square kilometres).

5.10.4 What percentage of the volcanic district is under shallow (> 1 m of till) cover? Have any deposits been discovered in the covered areas?

80%. Yes.

5.10.5 What exploration methods need to be considered or further researched in your district?

Borehole geophysical logging, seismic methods, Q-particle geochemistry.

5.10.6 List key references.

Boyle (1995); Lentz (1994); Rickard et al. (in press).

5.11 Research strengths for your VMS district

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<td>3. Styles of deposits:</td>
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<td>4. Exhalites:</td>
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<td>7. Sources of S, metals, fluids:</td>
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<td>8. Hydrogeological modelling:</td>
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<td>9. Subvolcanic intrusions:</td>
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1 = Adequate database and extensive interpretation of data
2 = Adequate database but little interpretation
3 = Extensive interpretation but inadequate database
4 = Moderate database and interpretations (needs improvement)
5 = Inadequate database and little interpretation

5.12 List of key references

List the major references, even if the interpretations differ from those generally accepted. The key references should include those that have the major geological, geochemical etc data (maps and tables) and also those that contain important discussions and interpretations. Make sure the titles of key maps or map series are included. List key unpublished references (eg. theses) especially if they contain critical data not available elsewhere. Some provided previously; others listed below.


Lentz, D. R., 1999a. Petrology, geochemistry, and oxygen isotope interpretative of felsic volcanic and related rocks hosting the Brunswick 6 and 12 massive sulfide deposits (Brunswick Belt), Bathurst Mining Camp, New Brunswick, Canada. Economic Geology, 94: p. 57-86.


Wilson, R. A. 1998. Geology of the Roger Brook area (parts of NTS 21 O/8a, b, g, h), Bathurst Mining Camp, New Brunswick, in Current Research 1997, edited by B.M.W. Carroll, New Brunswick Department
Wilson, R. A., Fyffe, L.R., McNicoll, V., and Wodicka, N. 1999. Lithogeochemistry, petrography and
gearchronology of Ordovician rocks in the Big Bald Mountain area (NTS 21 O/1), Bathurst Mining
89-142.