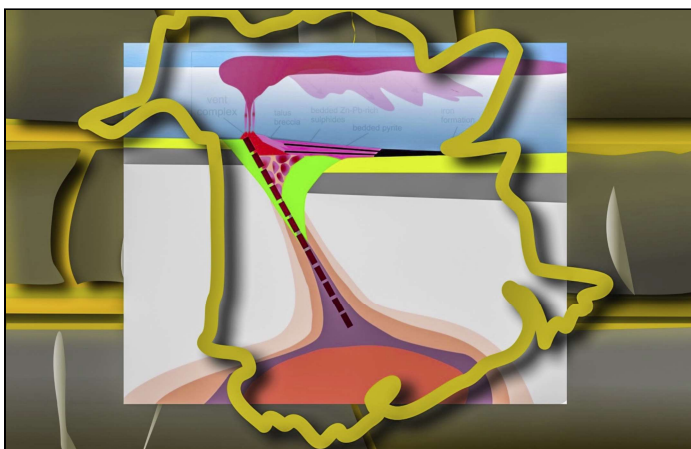


SERIES



Great Mining Camps of Canada 7. The Bathurst Mining Camp, New Brunswick, Part 1: Geology and Exploration History

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SUMMARY

The Bathurst Mining Camp of northern New Brunswick is approximately 3800 km² in area, encompassed by a circle of radius 35 km. It is known worldwide for its volcanogenic massive sulphide deposits, especially for the Brunswick No. 12 Mine, which was in production from 1964 to 2013. The camp was born in October of 1952, with the discovery of the Brunswick No. 6 deposit, and this sparked a staking rush with more hectares claimed in the province than at any time since.

In 1952, little was known about the geology of the Bathurst Mining Camp or the depositional settings of its mineral deposits, because access was poor and the area was largely forest covered. We have learned a lot since that time. The camp was glaciated during the last ice age and various ice-flow direc-

tions are reflected on the physiographic map of the area. Despite abundant glacial deposits, we now know that the camp comprises several groups of Ordovician predominantly volcanic rocks, belonging to the Dunnage Zone, which overlie older sedimentary rocks belonging to the Gander Zone. The volcanic rocks formed during rifting of a submarine volcanic arc on the continental margin of Ganderia, ultimately leading to the formation of a Sea of Japan-style basin that is referred to as the Tetagouche-Exploits back-arc basin. The massive sulphide deposits are mostly associated with early-stage, felsic volcanic rocks and formed during the Middle Ordovician upon or near the sea floor by precipitation from metalliferous fluids escaping from submarine hot springs.

The history of mineral exploration in the Bathurst Mining Camp can be divided into six periods: a) pre-1952, b) 1952-1958, c) 1959-1973, d) 1974-1988, and e) 1989-2000, over which time 45 massive sulphide deposits were discovered. Prior to 1952, only one deposit was known, but the efforts of three men, Patrick (Paddy) W. Meahan, Dr. William J. Wright, and Dr. Graham S. MacKenzie, focused attention on the mineral potential of northern New Brunswick, which led to the discovery of the Brunswick No. 6 deposit in October 1952. In the 1950s, 29 deposits were discovered, largely resulting from the application of airborne surveys, followed by ground geophysical methods. From 1959 to 1973, six deposits were discovered, mostly satellite bodies to known deposits. From 1974 to 1988, five deposits were found, largely because of the application of new low-cost analytical and geophysical techniques. From 1989 to 2000, four more deposits were discovered; three were deep drilling targets but one was at surface.

RÉSUMÉ

Le camp minier de Bathurst, dans le nord du Nouveau-Brunswick, s'étend sur environ 3 800 km² à l'intérieur d'un cercle de 35 km de rayon. Il est connu dans le monde entier pour ses gisements de sulfures massifs volcanogènes, en particulier pour la mine Brunswick n° 12, exploitée de 1964 à 2013. Le camp est né en octobre 1952 avec la découverte du gisement Brunswick n° 6 et a suscité une ruée au jalonnement sans précédent avec le plus d'hectares revendiqués dans la province qu'à présent.

En 1952, on savait peu de choses sur la géologie du camp minier de Bathurst ou sur les conditions de déposition de ses gisements minéraux, car l'accès était très limité et la zone était en grande partie recouverte de forêt. Nous avons beaucoup appris depuis cette période. Le camp était recouvert de glace au

cours de la dernière période glaciaire et diverses directions d'écoulements glaciaires sont révélées sur la carte physiographique de la région. Malgré des dépôts glaciaires abondants, nous savons maintenant que le camp comprend plusieurs groupes de roches ordoviciennes à prédominance volcanique, appartenant à la zone Dunnage, qui recouvrent de plus vieilles roches sédimentaires de la zone Gander. Les roches volcaniques se sont formées lors du rifting d'un arc volcanique sous-marin sur la marge continentale de Ganderia, ce qui a finalement abouti à la formation d'un bassin de type mer du Japon, appelé bassin d'arrière-arc de Tetagouche-Exploits. Les gisements de sulfures massifs sont principalement associés aux roches volcaniques felsiques de stade précoce et se sont formés au cours de l'Ordovicien moyen sur ou proche du plancher océanique par la précipitation de fluides métallifères s'échappant de sources chaudes sous-marines.

L'histoire de l'exploration minière dans le camp minier de Bathurst peut être divisée en six périodes: a) antérieure à 1952, b) 1952-1958, c) 1959-1973, d) 1974-1988 et e) 1989-2000, au cours desquelles 45 dépôts de sulfures massifs ont été découverts. Avant 1952, un seul dépôt était connu, mais les efforts de trois hommes, Patrick (Paddy) W. Meahan, William J. Wright et Graham S. MacKenzie, ont attiré l'attention sur le potentiel minier du nord du Nouveau-Brunswick, ce qui a conduit à la découverte du gisement Brunswick n° 6 au mois d'octobre 1952. Dans les années 50, 29 gisements ont été découverts, résultant en grande partie de l'utilisation de levés aéroportés, suivis de campagnes géophysiques terrestres. De 1959 à 1973, six gisements ont été découverts. Ce sont essentiellement des formations satellites de gisements connus. De 1974 à 1988, cinq gisements ont été découverts, principalement grâce à l'utilisation de nouvelles techniques analytiques et géophysiques peu coûteuses. De 1989 à 2000, quatre autres gisements ont été découverts. Trois étaient des cibles de forage profondes, mais l'un était à la surface.

Traduit par la Traductrice

INTRODUCTION

The Bathurst Mining Camp (BMC), formerly referred to as the Bathurst – Newcastle Mining District, is known worldwide for its volcanogenic massive sulphide (VMS) deposits, especially for the Brunswick No. 12 Mine, which closed on April 30, 2013 after 49 years in operation. During its lifetime, this mine produced 136,643,367 tonnes of ore grading 3.44% Pb, 8.74% Zn, 0.37% Cu, 102.2 g/t Ag, making it one of the largest known and longest lived, underground VMS deposits in the world. This mine and the BMC contributed significantly to the economy of northern New Brunswick for nearly 50 years. It produced almost 500 million ounces of by-product silver (from lead concentrate) during its lifetime, making it one of the largest silver producers in North America. This paper describes the geological setting of the BMC and the history of exploration in this area up to closure of Brunswick No. 12.

Location and Physiography

The BMC of northern New Brunswick is mostly encompassed by a circle of radius 35 km (Fig. 1). The surface area is approx-

imately 3800 km² but some of it is concealed by younger, shallow-dipping Carboniferous rocks to the east. The elevation ranges from approximately 50 m at Middle Landing in the east, to slightly over 600 m at Little Bald Mountain in the west, and elevation generally increases from east to west (Fig. 1). The topography consists of gently rolling hills, as a result of glacial erosion, with post-glacial, incised stream valleys. A good description of the physiography of the northern BMC can be found in Skinner (1974). Virtually all the BMC is forested. Much of it is covered by a thin (< 1 m) veneer of till but at lower elevations, till thickness increases and glacial-fluvial deposits are present. The area is drained by five major rivers and their tributaries: Middle and Tetagouche rivers in the northeast, Southeast Upsalquitch River in the northwest, Northwest Miramichi River (including the Sevogle River) in the south, and Nepisiguit River in the central part of the BMC. Provincial highways 180 and 430, and numerous logging roads currently provide easy access to the BMC, at least during the summer and autumn months, but most were not present when the BMC was discovered.

Camp Definition

In the September 10th, 1953 edition of the *Northern Miner*, is a map on page 5 of the "Bathurst Mining Area", which encompasses what we now consider to be the eastern part of the BMC. Then in the June 14th, 1956 edition of the *Northern Miner*, there is a lengthy article entitled: "Hopeful tone to exploration in Bathurst-Newcastle Camp", but no map showing the extent of this camp. The following year, in the April 18th edition of the *Northern Miner*, the technical program for the third day of the 59th CIM Annual Meeting in Ottawa is listed on page 24. The morning session of the Geology Division features a "Symposium on Bathurst – Newcastle Area", in which the first three speakers (C.H. Smith, G.S. MacKenzie, and S.H. Ward) refer to 'Bathurst – Newcastle Mining District' in their talk titles. In the July 1957 issue of the *Atlantic Advocate*, an article entitled: "The Mineral Wealth of New Brunswick 1953–1957" by G.S. MacKenzie contains a sketch map bearing the title "Bathurst – Newcastle Mining District, New Brunswick", which shows the locations of 28 known deposits. A technical paper by MacKenzie (1958) contained the same sketch map, but the limits of the district are spelled out in the text: "The Bathurst – Newcastle district may be considered, for the purposes of this paper, to include the country from the town of Bathurst southward to Newcastle (now part of the city of Miramichi), westward to the headwaters of Nepisiguit (sic) river, and northward to the city of Campbellton". Hence, the name, "Bathurst – Newcastle Mining District" is attributed to MacKenzie (1958).

Subsequently, the Bathurst – Newcastle Mining District was restricted to the belt of Cambro – Ordovician volcanic and sedimentary (now mostly Miramichi Group) rocks that were assigned to the original Tetagouche Group (Harley 1979), which extends southwestward from Bathurst. By the 1980s, the name had been shortened to Bathurst district or Bathurst camp (Franklin et al. 1981) but in the late 1990s, when a five-year, joint federal – provincial project (EXTECH-II) was conducted, the name Bathurst Mining Camp (BMC) became firm-

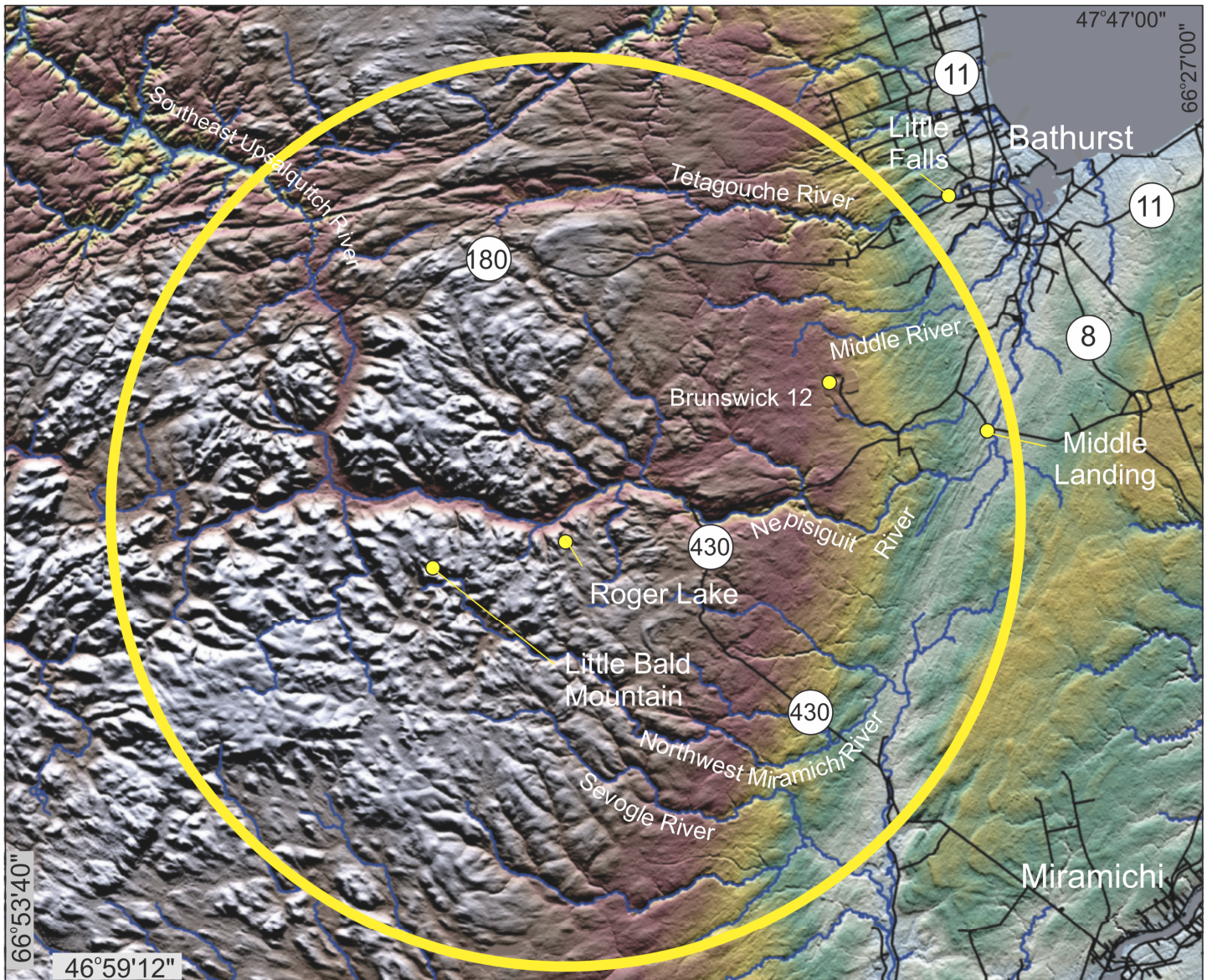


Figure 1. Digital elevation model showing physiographic features and the approximate location of the Bathurst Mining Camp, outlined by the yellow circle. Modified from the ‘Satellite Image’ of New Brunswick, which was taken from the New Brunswick Department of Energy and Resource Development (DERD) website. Available from https://www2.gnb.ca/content/gnb/en/departments/erd/energy/content/minerals/content/Surficial_mapping.html.

ly entrenched. The results of this project were published as *Economic Geology Monograph 11* (Goodfellow et al. 2003).

As a result of the EXTECH-II Project, we now know that the BMC comprises five groups of rocks, three of which are approximately coeval and contain Zn-Pb-Cu-Ag VMS deposits (van Staal et al. 2003). We also know that some of these rocks and one VMS deposit (Key Anacon East) extend eastward under Carboniferous cover. However, for the purpose of this paper, the definition of the BMC is restricted to the area that is not concealed by Carboniferous strata, i.e. to the belt of Cambro-Ordovician rocks, which extends southwestward from Bathurst, including the Bathurst Supergroup (predominantly volcanic) and the Miramichi Group (entirely sedimentary).

Camp Overview

The BMC hosts 45 known massive sulphide deposits (Fig. 2), including Brunswick No. 12 (Table 1). Most deposits were discovered in the 1950s and 1960s by airborne geophysical, geological and stream geochemical methods (McCutcheon et al. 2003).

Information Sources

Much has been written about the geology and minerals deposits of the BMC since its discovery in 1952 but the best place to start is with *Economic Geology Monograph 11* (Goodfellow et al. 2003) because the papers contained in this volume provide extensive lists of references to previous work on various topics. There are also two special issues of *Exploration and*

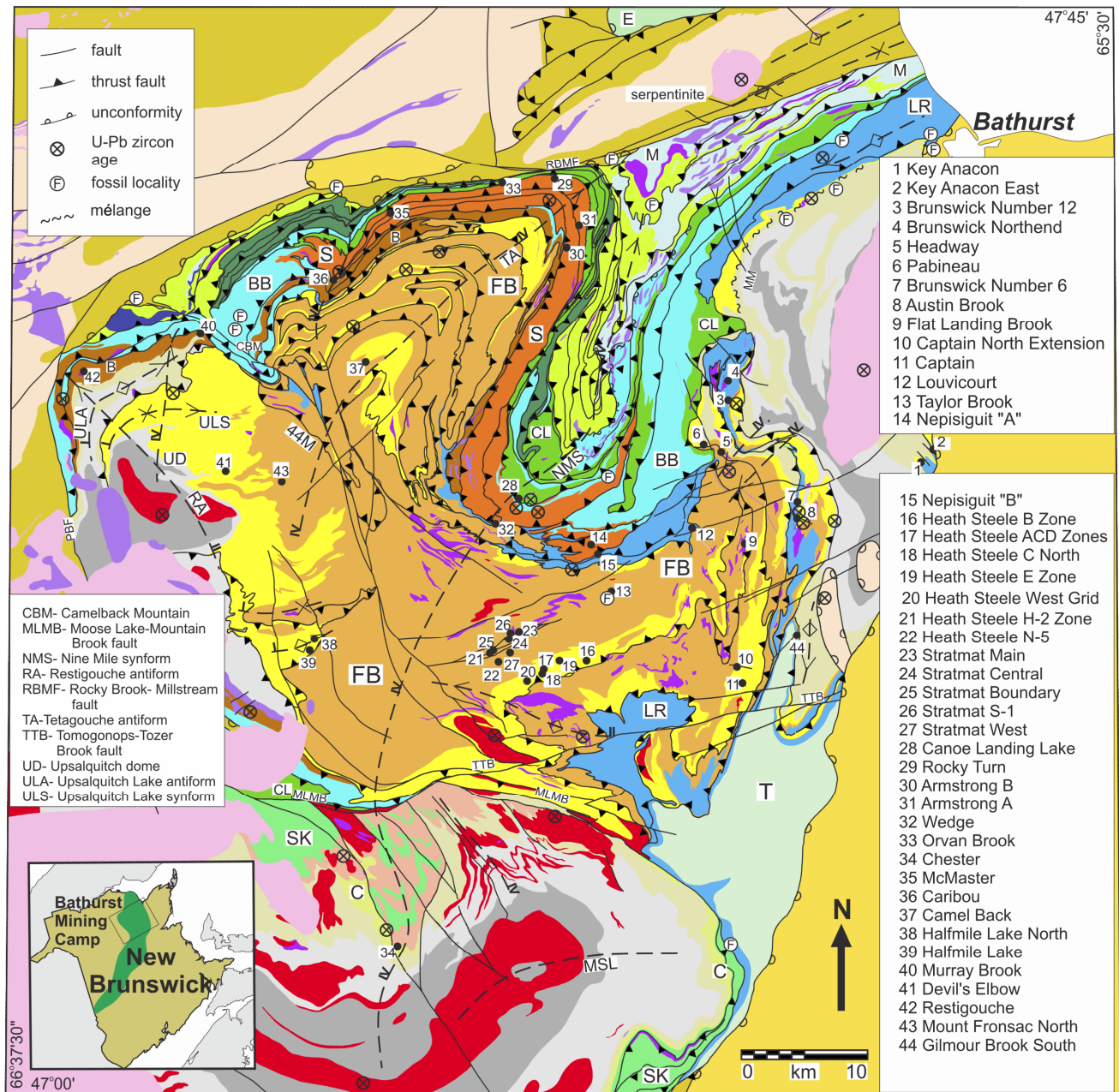


Figure 2. Geological map of the Bathurst Mining Camp showing the distribution of known massive sulphide deposits. Modified from Figure 2 of van Staal et al. (2003).

Table 1. Known massive sulphide deposits in the Bathurst Mining Camp, New Brunswick. Modified from Table 1 of McCutcheon et al. (2003).

URN	Deposit	Discoverer	Year	Method	Type	Host	Pb-Zn Resources				Cu		Tonnes	%Cu	Date	Source
							Tonnes	%Pb	%Zn	%Cu	g/t Ag	%Cu				
484	Armstrong A	Anaconda	1956	EM	BM	SL	3,377,272	0.42	3.26	0.29	25	537,400	0.67	1972	Noel 1998	
482	Armstrong B	Anaconda	1956	EM	BS	SL								1973	Mineral Occurrence Database	
069	Austin Brook	Boyleyn Group	1952	Geol	BM	NF	234,600	3.67	5.68	0.09	82			1991	Luff 1995	
054	Brunswick No. 12	Boyleyn Group	1953	Mag, EM	BM	NF	mined out							2013		
144	Brunswick No. 6	Boyleyn Group	1952	Mag, EM	BM	NF	858,600	3.01	8.08	0.17	90	1,752,000	1.06	1991	Luff 1995	
1263	Brunswick North End	Brunswick Mining & Sm.	1989	Geol	BM	NF	1,011,000	3.00	6.22	0.24	110			1992	Luff 1995	
1383	Camel Back	Noranda	1996	AEM, Mag	BM	NF	~200,000	2.7-2.9	3.0-4.0		44			2006	Walker and Carroll 2006	
242	Canoe Landing Lake	Baie Holdings	1960	Soil, EM	SD	CL	1,791,900	0.73	2.67	0.77		1,006,000	1.03	1995	Johnson 1995	
159	Captain	Captain Mines	1956	EM	BS	NF					84			2010	Mercator Geol. Services 2011	
444	Caribou	Anaconda	1955	Geol, Pros	BM	SL	7,230,000	2.93	6.99	0.43		284,000	2.78	2013	SRK Consulting 2014	
071	Chester	Chesterville Mines	1955	AEM	BS	CW					65			2008	Sim and Davis 2008	
170	CNE	Sabina	1978	Silt, IP	BM	NF	293,885	2.04	5.62			362,900	1.20	2011	McLaughlin et al. 2011a	
285	Devil's Elbow	American Metal Co.	1975	AEM	BM	NF	1,700,000	0.94	4.9		20			2006	Walker and Lentz 2006	
046	Flat Landing Brook	Sabina	1975	AEM	BM	NF	5,664,900	2.7	8.27	0.19	34			2010	McLaughlin et al. 2011b	
409	Halfmile Lake	Texas Gulf/Conwest	1955	Geol, EM	BM	NF	597,200	1.4	6.78	0.49	5			2010	McLaughlin et al. 2011b	
410	Halfmile Lake North	Sweet Grass Oils	1955	EM	BM	NF	282,572	2.06	6.2	1.43	19			1966	Parliament and Sullivan 1966	
124	Headway	K. McDonough	1957	Pros	BM	FL	553,100	4.18	11.26	0.29	111	113,900	3.56	1998	Health Steele Mines	
395	Health Steele ACD Zones	American Metal Co.	1954	AEM	BM	NF	1,439,500	2.38	5.99	1.69	101	597,400	3.18	1998	Health Steele Mines	
396	Health Steele B Zone	American Metal Co.	1954	AEM	BM	NF	2,700,000	2.04	6.03	0.39	81			1991	Noranda	
395	Health Steele C-North	Health Steele Mines	1981	Mag, EM	BM	NF	917,000	2.39	5.79	1.47	102			1990	Health Steele Mines	
397	Health Steele E Zone	American Metal Co.	1954	AEM	BS	NF	mined out							1991		
257	Health Steele N-5 Zone	Health Steele Mines	1964	IP	BM	NF	961,500	3.12	7.01	0.14	87			1991	Noranda	
1380	Health Steele West Grid	Health Steele Mines	1966	IP	BM	NF	1,670,000	2.52	6.02	0.14	74			2019	Ossisko 2019	
014	Key Anacon	New Larder U	1953	AM, EM	BM	NF	290,000	1.57	4.36	0.65	39			2019	Ossisko 2019	
1384	Key Anacon East (Titan)	Rio Algom	1964	Geol, EM	BM	NF	136,000	1.23	1.00	0.42	83			1976	Gummer 1976	
147	Louvicourt	L. Gray et al.	1964	Pros	BM	FL						250,000	0.75	1972	Mineral Occurrence Database	
477	McMaster	Anaconda	1957	EM	BM	SL	1,260,000	2.18	7.65	0.14	40			2000	Walker and Graves 2006	
1418	Mt. Fronsac North	Noranda	1999	Pros, Silt	BM	NF	5,280,000	1.80	5.24	0.46	69			2017	Puma Exploration 2017	
414	Murray Brook	Kemco	1956	Silt, EM	BM	MB	1,542,100	0.60	2.80	0.40	10			1976	Mineral Occurrence Database	
241	Nepisiguit "A"	Kemco	1956	EM	BM	SL	1,360,700	0.40	1.90	0.10	10			1976	Mineral Occurrence Database	
240	Nepisiguit "B"	Kemco	1956	EM	BM	SL	635,000	0.70	2.10	0.40	21			1976	Mineral Occurrence Database	
239	Nepisiguit "C"	Kemco	1956	EM	BM	SL	181,000	3.25	6.3		31			1966	Skinner 1974	
062	Orvan Brook	Tetagouche Exp. Co.	1938	Pros	BM	SL	uneconomic							1999	Collins 1999	
062	Orvan Brook	Tetagouche Exp. Co.	1938	Pros	BM	SL	136,000	0.87	2.65					1980	Mineral Occurrence Database	
157	Pabineau	Quebec Smelting & Ref.	1953	EM, Geol	BS	NF	861,882	5.25	7.07	0.33	78			2009	Trevali website 2019	
139	Restigouche	New Jersey Zinc	1958	Soil	BS	MB	131,000	2.69	8.43	0.28	101			1972	Mineral Occurrence Database	
479	Rocky Turn	Anaconda	1957	Pros	BS	SL	mined out							1993	Hamilton and Park 1993	
255	Stratmat Boundary	Cominco	1961	Soil, EM	BM	FL	4,700,000	2.10	5.30	0.40	49			2015	Arseneau 2015 (also encompasses URN 1377; Stratmat N-3)	
252	Stratmat S0,S1s, S1d, S5	Strategic Minerals	1956	EM	BM	FL										
253	Stratmat Central North															
406	Stratmat Main															
xxx	Stratmat New	Noranda	1988	Geol, EM	BS	FL						181,000	2.00	1981	Mineral Occurrence Database	
256	Stratmat West Stringer	Cominco	1972	IP	BM	FL	179,000	0.64	1.37	0.02	29			2011	McLaughlin et al. 2011a	
400	Taylor Brook (Cons. Mor.)	Consolidated Morrison	1977	AEM	BM	FL	545,000	1.71	5.21	1.75				1992	SLAM Exploration 2017	
052	Wedge	Cominco	1956	Geol, Pros	BM	SL	48,520,711					5,084,600				

URN = Unique Record Number; Method: AM = airborne magnetic; AEM = airborne electromagnetic; EM = electromagnetic; Geol = geology; IP = induced polarization; Mag = magnetic; Pros = prospecting; Silt = silt geochem; Soil = soil geochem; Type: BM = stratiform bimodal volcanic or sediment-hosted massive sulfides; BS = stratiform bimodal volcanic or sediment-hosted disseminated and stringer sulfides; SD = stratiform sediment-hosted sulfides; Host: CL = Canoe Landing Lake Fm; CW = Clearwater Stream Fm; FL = Flat Landing Brook Fm; MB = Mount Britain Fm; NF = Nepisiguit Falls Fm; SL = Spruce Lake Fm; Fm = Formation; Date = Year calculation was done; Note: Compiled by W.M. Luff (May, 1999); does not include Production; 5 deposits do not have calculated estimates but all are < 1 million tonnes for a total of about 2 million tonnes.

Mining Geology that are devoted to mineral deposits of the BMC; one is Volume 1, No. 2 (Davies et al. 1992), and the other is Volume 15, No. 3-4 (Lentz 2006). Finally, published maps and reports of the Geological Survey of Canada and the Geological Surveys Branch of New Brunswick Department of Energy and Resource Development are too numerous to list but can be found on the websites of these two organizations: <https://www.nrcan.gc.ca/earth-sciences> and <http://www2.gnb.ca/content/gnb/en/departments/erd/energy/content/minerals.html>, respectively. On the New Brunswick website, on-line databases also contain a wealth of information, including a “*Bedrock Lexicon*” that has a description of every formally named rock unit (formations, groups and plutons) in the province.

Historical information about exploration in the BMC comes from published books and articles. Some notable books are: *Metals and Men* (LeBourdais 1957), which contains a few pages on the discovery of the first deposits; *The Discoverers* (Hanula 1982), which contains a section on “The Bathurst-Newcastle Area”; *The Birth of the Bathurst Mining Camp* (Belland 1992), which describes the development history of the Austin Brook Iron Mine and Brunswick No. 6 base metal deposit; and *Gesner’s Dream* (Martin 2003), which contains three chapters relating to the history of mineral exploration in the Bathurst area, prior to and leading up to the discovery of Brunswick No. 6. In addition, articles in *The Northern Miner*, and New Brunswick newspapers, such as *The Northern Light*, *The Daily Gleaner*, and *Telegraph Journal* are too numerous to list. Finally, there is unpublished correspondence in the files of NB Department of Energy and Resource Development, which provides useful historical information.

GEOLOGICAL SETTING

Regional Geology

The Bathurst Mining Camp is situated towards the northern end of a northeasterly trending belt or terrane of Cambrian to Ordovician, sedimentary and volcanic rocks (Fig. 2, shaded area on inset). This terrane is unconformably overlain by or in fault contact with Silurian rocks to the north and west, and unconformably overlain by Carboniferous rocks to the east. The BMC contains rocks that belong to the Dunnage and Gander zones of the Canadian Appalachians (cf. Williams 1979) and formed during the Ordovician by rifting of an existing submarine volcanic arc (Popelogan Arc) on the continental margin of Ganderia (Fig. 3a), what was then the eastern margin of the Iapetus Ocean. Rifting ultimately produced a Sea of Japan-style basin that is referred to as the Teta gouche-Exploits back-arc basin (van Staal et al. 2003).

This Japan-style basin opened by rifting of continental crust in the Early Ordovician, initially giving rise to felsic volcanism (Figs. 3b, c) followed by mafic volcanism (Fig. 3d) and opening of a back-arc rift basin. It ultimately closed by north-west-directed subduction during the Late Ordovician to Early Silurian (van Staal et al. 2003). Dunnage Zone rocks are represented by the approximately coeval California Lake, Sheephouse Brook, and Teta gouche groups, which disconformably

overlie sedimentary rocks of the Miramichi Group (Gander Zone). They are structurally overlain by oceanic crustal rocks of the Sormany Group (formerly included in the Fournier Group). Each of the first three groups is characterized by variable proportions of felsic and mafic volcanic rocks, which were deposited in different parts of the basin but were later tectonically juxtaposed in a Subduction–Obduction accretionary wedge, i.e. the Brunswick Subduction Complex (van Staal 1994). The bulk compositions of volcanic rocks and U–Pb radiometric dating show that each of these groups evolved from felsic- to mafic-dominated volcanism through time. This change in volcanism is interpreted to reflect crustal thinning during the rifting process, i.e. extended continental to transitional oceanic crust, respectively. Most of the VMS deposits are associated with the early-erupted felsic volcanism in each of these groups.

Camp Geology

Glacial History

The glacial history of the BMC is described in detail by Parkhill and Doiron (2003), which includes a reference list of prior work on the Quaternary geology of the area. The following description is extracted from their paper.

The entire BMC was covered by ice during the last glacial maximum, referred to as the Wisconsinan (75,000 to 10,000 BP). Ice cover is indicated by the presence of a single homogeneous basal till over most of the area, erratics (exotic pebbles and boulders) in till at the highest elevations, and a similar glacial history in adjacent areas of northern New Brunswick. The preservation locally of pre-glacially weathered bedrock (grus) indicates that glacial erosion in some parts of the BMC was relatively weak, generally on the down-ice sides of hills.

The BMC was affected by multiple phases of ice flow (Parkhill and Doiron 2003), as indicated by the orientations of both small-scale features (striations, grooves, roches moutonnées, glacially sheared bedrock, and till fabrics) and large-scale features (fluted bedrock, eskers, and DeGeer moraines). A main eastward ice movement (California and Jacquet flow patterns) was followed by northeastward flowing ice (Belledune flow pattern) in the northern and central parts of the BMC. In the southern BMC, ice flow was mainly toward the southeast (Sevogle flow pattern) but in the eastern and southeastern parts, the dominant ice movement was north-northeastward (Nepisiguit flow pattern). These trends can be seen on the satellite image (Fig.1). Understanding the variable ice flow directions is important for interpreting till geochemical anomalies.

In the BMC, till thickness is variable (0–5 m) and till is locally derived (< 1 km transport). A strong correlation exists between the lithology of clasts/pebbles in till and underlying bedrock; commonly, more than 75% of them are derived from the directly underlying rock unit. However, some clasts and boulders (erratics) can be found up to 20 km down-ice from their source. Glacial dispersal patterns of clasts generally indicate east to northeast ice-flow directions. In areas where till thickness is >5 m, clasts of directly underlying bedrock are less

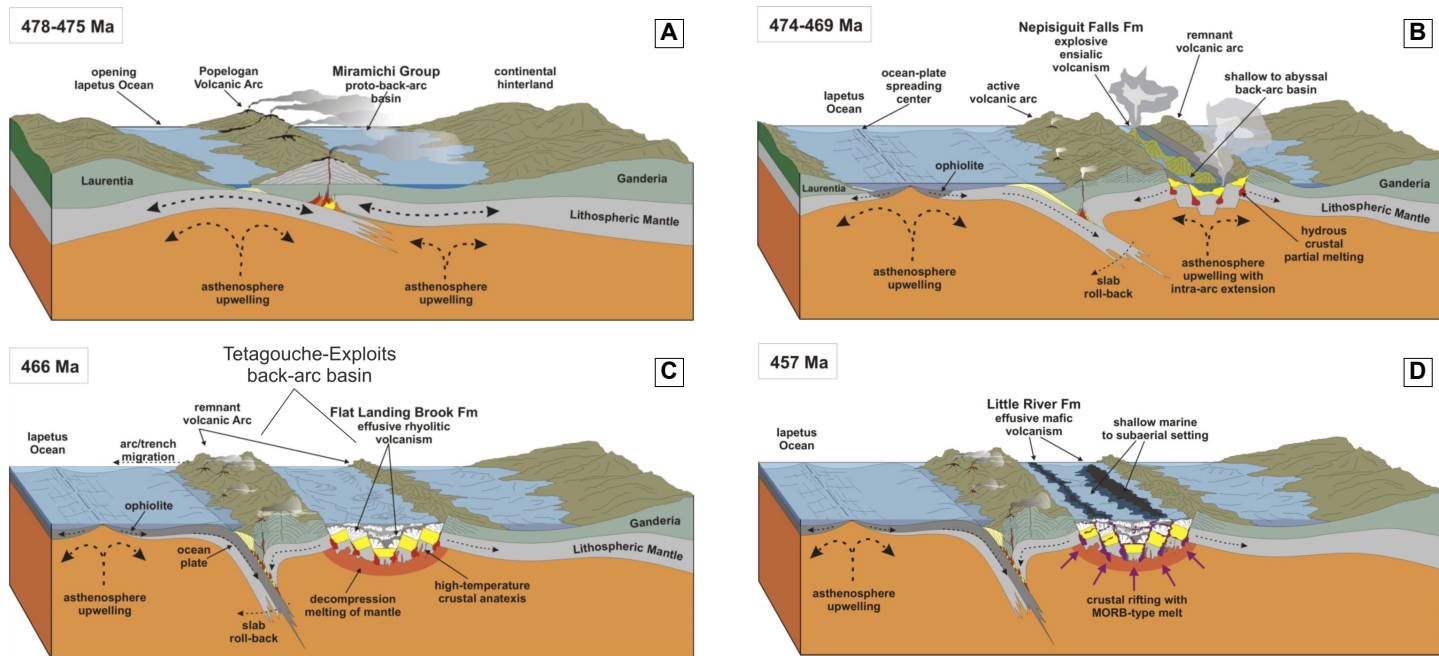


Figure 3. Schematic block diagrams portraying four time intervals: a) 478–475 Ma, b) 474–469 Ma, c) 466 Ma, and d) 457 Ma, and the depositional settings of various Ordovician rock units of the Tetagouche Group. From Figure 1.4 of Wills (2014).

numerous or even absent, and there is no geochemical expression, at surface, of underlying base metal deposits, as for example at the CNE deposit (Table 1).

Bedrock Geology

Since descriptions of all the rock units in the BMC (Fig. 2) are available on-line in the *Bedrock Lexicon* [http://dnr-mrn.gnb.ca/Lexicon/Lexicon/Lexicon_Search.aspx?lang=e], the focus here is on those units that host VMS deposits. They are the California Lake, Sheephouse Brook, and Tetagouche groups, which are shown schematically in Figure 4 with their constituent formations. Each is described below.

The California Lake Group comprises the Mount Brittain, Spruce Lake, Canoe Landing Lake and Boucher Brook formations. The latter formation overlies each of the first three in separate nappes that are named after their characteristic volcanic unit (van Staal et al. 2003). The Mount Brittain nappe is the structurally lowest and the Canoe Landing Lake nappe is the highest. Collectively, the three nappes make up the California Lake Group and account for about 15% of the surface area of the BMC (Fig. 2). The Mount Brittain, Spruce Lake and Canoe Landing Lake formations are coeval, and all contain massive sulphide deposits.

Mount Brittain Formation: This formation hosts 2 of the 13 deposits in the California Lake Group (Table 1). It is predominantly composed of feldspar-crystal and lithic felsic tuff with minor aphyric felsic rocks, but it also includes a thin sedimentary unit (Charlotte Brook Member) at the base, which gradationally overlies rocks of the Miramichi Group. This sedimentary unit, which hosts the Murray Brook deposit, comprises dark grey shale and wacke with a few thin tuff beds. Even though this formation is about the same age as the Spruce

Lake Formation (Fig. 4), no direct linkage (inter-fingering) between the two formations exists, all mutual contacts being tectonic. Lithologically, the Mount Brittain feldspar-crystal tuff more closely resembles quartz-poor crystal tuff of the Nepisiguit Falls Formation than it does crystal tuff of the Spruce Lake Formation.

Spruce Lake Formation: This formation hosts 10 of the 13 deposits in the California Lake Group (Table 1). It mainly comprises feldspar-phyric to aphyric felsic volcanic rocks, in places with intercalated basalt. Some dark grey to black, fine-grained sedimentary rocks, which overlie, underlie and/or are interbedded with this volcanic pile, are also included in this formation. The basalt is correlative with rocks in the Canoe Landing Lake Formation (van Staal et al. 2003) and shows that there was a spatial association between these two formations.

Canoe Landing Lake Formation: This formation hosts only 1 of the 13 deposits in the California Lake Group (Table 1). It predominantly consists of pillow basalts and associated rocks, including interflow chert and red shale, but also contains some fine-grained, dark grey sedimentary rocks and minor felsic volcanic rocks. The felsic volcanic rocks are lithologically like those in the Spruce Lake Formation.

The Sheephouse Brook Group comprises the Clearwater Stream, Sevogle River and Slacks Lake formations. The first formation (Fig. 4) hosts the only known deposit (Chester) in the group (Table 1). This group makes up about 5% of the surface area of the BMC (Fig. 2).

Clearwater Stream Formation: Fyffe (1995) defined this formation, which hosts the Chester deposit, as “the plagioclase-phyric felsic volcanic rocks that immediately overlie sedimentary rocks of

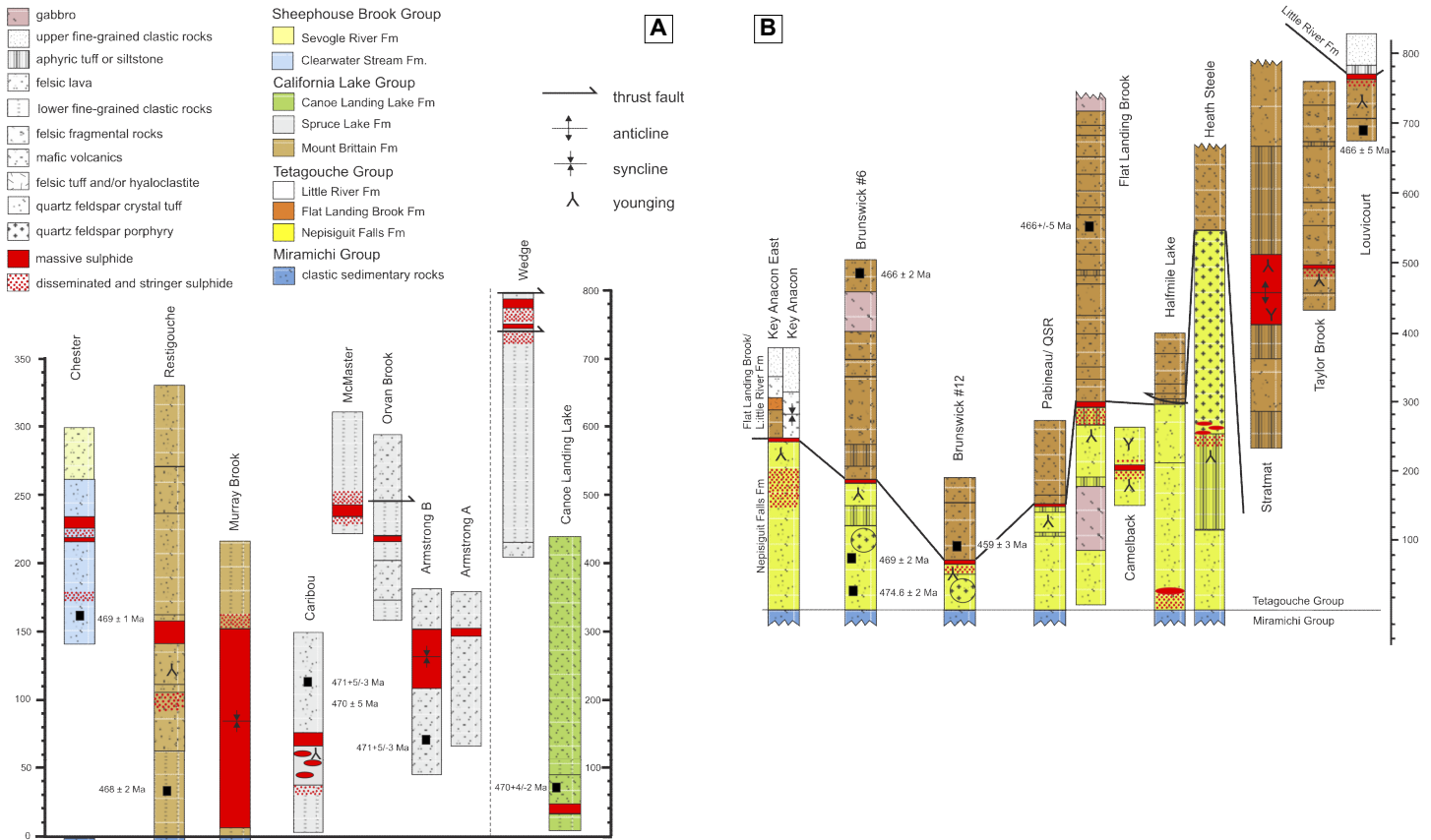


Figure 4. Schematic stratigraphic columns from deposits in various parts of the Bathurst Mining Camp: a) Selected drill-hole columns from deposits in the California Lake Group and one (Chester) from the Sheephouse Brook Group, b) Selected drill-hole columns from deposits in the Tetagouche Group. Modified from figures 7 and 10 of McCutcheon et al. (2001). QSR = Quebec Sturgeon River.

the Patrick Brook Formation south of the Moose Lake shear zone.” These volcanic rocks are approximately coeval (Fig. 4) with the felsic volcanic rocks in the California Lake Group and the Nepisiguit Falls Formation (Tetagouche Group; see below).

The Tetagouche Group comprises the Nepisiguit Falls, Flat Landing Brook, and Little River formations, in ascending stratigraphic order. The Tetagouche Group occurs in two major nappes that constitute approximately half of the surface area of the BMC (Fig. 2). Both the Nepisiguit Falls and Flat Landing Brook formations contain massive sulphide deposits.

Nepisiguit Falls Formation: This formation hosts 24 of the 32 deposits in the Tetagouche Group, and the bulk of the massive sulphide tonnage in the BMC (Table 1). The age of the Nepisiguit Falls Formation is constrained by several U–Pb isotopic ages, which suggest an age of circa 470 Ma (Fig. 4). Rocks of this formation were commonly referred to as ‘quartz augen (eye) schists’ (QAS or QES) and ‘quartz-feldspar augen schists’ (QFAS) in the pre-1990 literature (e.g. Skinner 1974, p. 29–30). The former rock type is merely an altered version of the latter.

At the type locality on Nepisiguit River, this formation is divisible into two parts. The lower third comprises massive quartz-feldspar ‘porphyry,’ and the upper two thirds comprises medium- to coarse-grained, quartz-feldspar-rich, volcanoclas-

tic rocks that are interlayered with aphyric tuff. The quartz-feldspar ‘porphyry’ conformably overlies sedimentary rocks of the Miramichi Group. It typically has a vitreous, cryptocrystalline groundmass, contains less than 30% crystals (up to 15 mm), and lacks any evidence of reworking. The volcanoclastic rocks (crystal tuff) appear to conformably overlie the massive quartz-feldspar ‘porphyry’ and generally become finer grained and thinner bedded up section (McCutcheon et al. 1993a, 1997). They also contain abundant (30% or more), commonly broken and rounded, quartz and feldspar (mostly < 5 mm) in a very fine-grained granular matrix. They exhibit primary features such as crystal sorting, graded beds and rare pseudomorphed pumice clasts. In the upper part of the section, some beds contain rare, lapilli-sized, lithic clasts of aphyric (ash) tuff or rhyolite and, at the top of the section, chloritic mudstone and silicate iron formation are present.

In the Brunswick Belt (between Brunswick No. 6 and 12), the number of eruptive/emplacement units in the Nepisiguit Falls Formation ranges from 2 to 6 (McCutcheon and Walker 2007) and individual units range from a few metres to a few tens of metres in thickness and are locally separated by narrow intervals of fine-grained sedimentary material. At the top of the Nepisiguit Falls Formation, chloritic and locally magnetic mudstone (silicate iron formation) is interbedded with dark greenish grey, fine-grained volcanoclastic rocks, which consti-

tute the “Brunswick Horizon” at the nearby Austin Brook and Brunswick No. 6 mine sites (Fig. 2). This Algoma-type Fe-Formation and the massive sulphide deposits along the Brunswick Belt are collectively referred to as the Austin Brook Member. The contact with massive rhyolite of the overlying Flat Landing Brook Formation appears to be conformable.

Elsewhere, the Nepisiguit Falls volcanic pile exhibits lateral variations in thickness and proportions of rock types. At Little Falls on Tetagouche River (Fig. 1), the section is approximately 30 m thick and mainly composed of interbedded aphyric tuff and fine-grained crystal tuff, with isolated lenses (channels) of coarse-grained volcanoclastic rocks. The coarse-grained rocks contain more than 50% crystals (quartz and feldspar) and a few intraformational clasts. Quartz-feldspar ‘porphyry’ is conspicuously absent. This section overlies calcareous rocks of the Vallee Lourdes Member (formerly formation), which unconformably overlies the Patrick Brook Formation of the Miramichi Group. At Heath Steele (Fig. 2), the Nepisiguit Falls Formation contains ‘porphyry’, but it overlies volcanoclastic rocks rather than underlies them as in the type section. The volcanoclastic rocks are interbedded with quartz wacke and carbonaceous shale, which are typical of the Patrick Brook Formation (Lentz and Wilson 1997). This implies that the contact between the Tetagouche and Miramichi groups is conformable at this locality rather than disconformable as it is in some places (cf. van Staal 1994).

Flat Landing Brook Formation: This formation hosts 8 of the 31 deposits in the Tetagouche Group (Table 1). It comprises aphyric to feldspar-phyric (\pm quartz) felsic flows, hyaloclastite, and crackle breccia, interbedded with minor aphyric tuff, basalt, mudstone and iron formation (silicate magnetite and Fe-Mn types). Feldspar \pm quartz phenocrysts are small (1–3 mm) and constitute less than 10% of the rocks; the groundmass is cryptocrystalline. Aphyric tuff and basalt appear to be most abundant in the northwestern (upper) part of the BMC where they constitute separate mappable members. The Flat Landing Brook Formation is a few million years younger than the Nepisiguit Falls Formation (Fig. 4).

Structure

Rocks of the BMC have undergone four phases of deformation in the Late Ordovician to Early Silurian, as a result of amalgamation in an accretionary wedge environment known as the Brunswick Subduction Complex (van Staal 1994). They are variably deformed and metamorphosed to greenschist facies, including local blueschist that reflects burial depths of 11 km or more in a subduction zone. Two cleavages are common in the rocks; however, four can be discerned in places, and conversely, none is visible locally.

Mineralization

Many of the massive sulphide deposits of the BMC were originally deposited as sulphide mounds in a relatively deep ocean basin at or near the sea floor from so-called ‘black smokers’, which are nothing more than metal-rich, magmatically-heated,

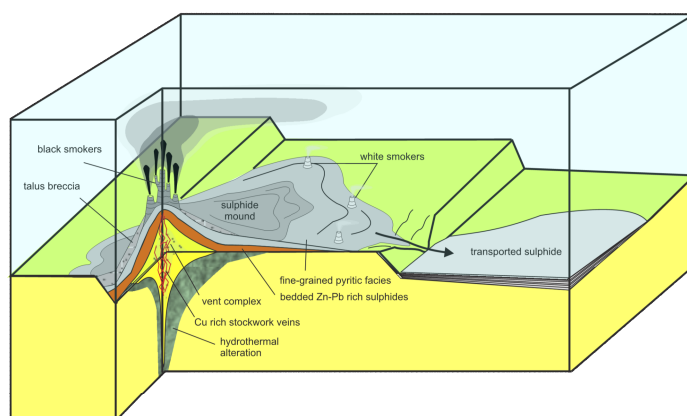


Figure 5. Idealized block model showing a sulphide mound on the sea floor. From Figure 1 of Tornos et al. (2015).

hot springs. To be called a massive sulphide deposit, sulphide minerals must constitute more than 60% of the rock (Franklin et al. 2005). The predominant sulphide minerals in most BMC deposits are pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite (Goodfellow and McCutcheon 2003); the galena tends to be silver-rich. Other sulphide minerals occur in minor amounts, including arsenopyrite, marcasite, and stannite; some sulphosalt and oxide minerals are also present. The relative proportions of sulphide minerals, which are very fine-grained and commonly layered, vary depending upon the primary depositional facies of each deposit and the amount of tectonic (post-depositional) recrystallization and mobilization that has occurred. Many of the deposits have an oxide–silicate–carbonate ‘iron formation’ that caps and extends laterally beyond the limits of the massive sulphide facies. Notably, the Fe_{Total}/Mn , Fe/Ti , Ba/Ti , Eu/Eu^* and Pb/Zn ratios (and several other element ratios) in these iron formations tend to increase toward the massive sulphide facies (Peter and Goodfellow 1996, 2003).

An idealized block model showing a sulphide mound on the sea floor is shown in Figure 5. The mound comprises a debris field of collapsed sulphide chimneys built over an alteration pipe that represents the pathway (plumbing) from depth to surface of hot (hydrothermal), metal-bearing fluids. High-temperature, copper-bearing sulphide minerals and pyrrhotite tend to be deposited in the throat of the alteration pipe, i.e. the vent complex, whereas lower temperature lead and zinc sulphide minerals and pyrite are deposited in the mound. As the mound grows over time, early-formed low temperature phases in the lower part of the mound are dissolved and re-precipitated in the upper more distal parts of the mound in a process that is called ‘zone refining’ (Ohmoto 1996).

Other massive sulphide deposits in the BMC did not form on the sea floor but were deposited from hydrothermal fluids beneath the sea floor, which reacted and replaced volcanic glass and other soluble components in permeable layers. Such deposits have similar mineralogy as the ones deposited on the sea floor, but they are generally not layered, and do not have a capping iron formation.

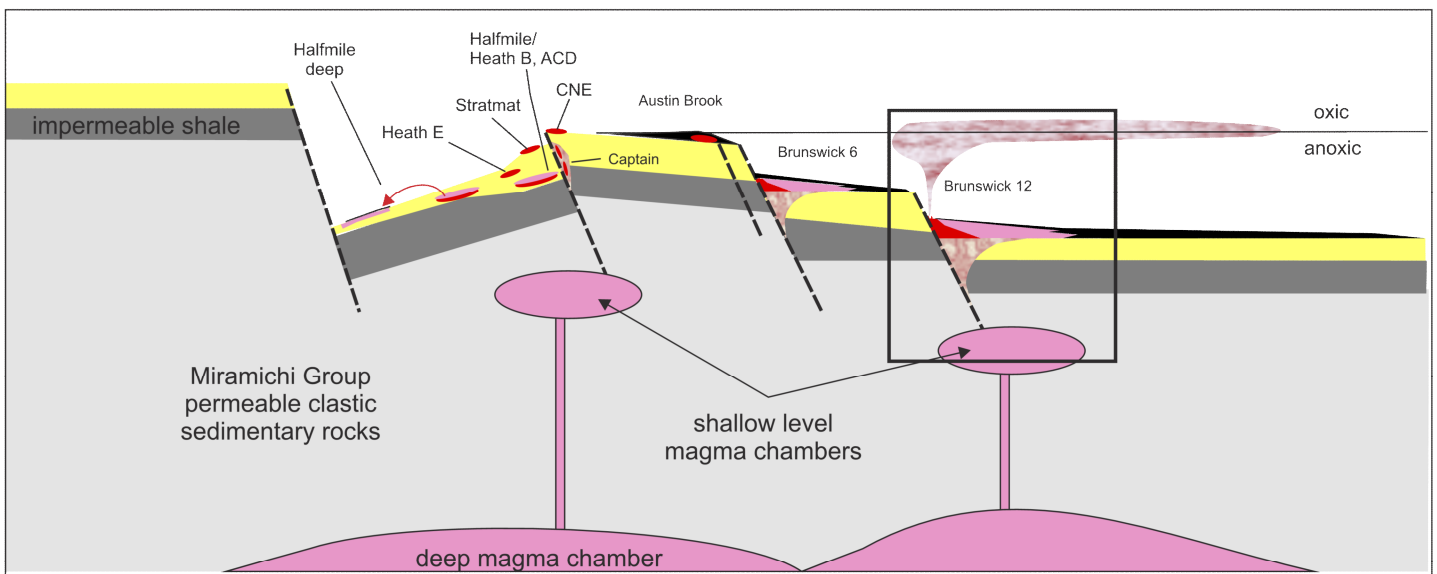
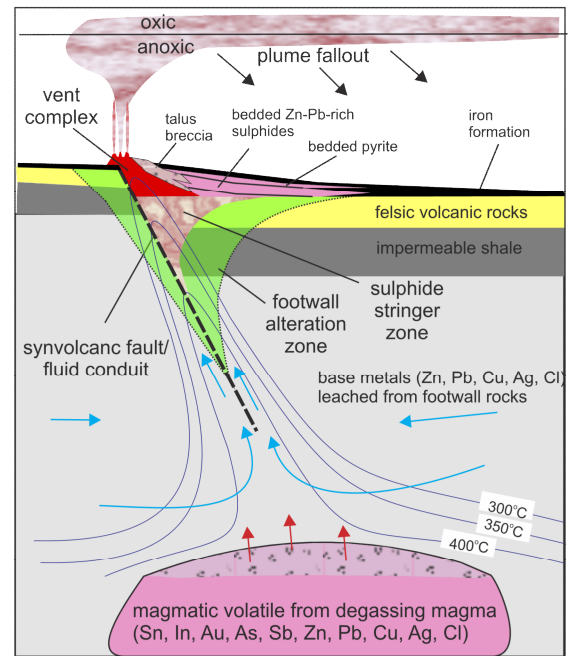


Figure 6. An idealized cross section showing the conceptual ore controls of Brunswick-type deposits. Modified from Figure 28 of Goodfellow and McCutcheon (2003). ACD = A, C, and D zones; CNE = Captain North Extension.

Deposit Characteristics

An idealized cross section showing the conceptual ore controls of Brunswick-type (Tetagouche Group) deposits is shown in Figure 6. Initially, a deep, large-volume, felsic magma chamber supplied felsic volcanic rocks (Nepisiguit Falls Formation) to the sea floor; then as pyroclastic volcanism waned, high-level (sub-volcanic), small-volume magma chambers formed and cooled *in situ* (Fig. 6). These small-volume magma bodies were probably localized along the ring-fracture zone of the caldera that must have been created by the initial pyroclastic volcanism. Each small-volume magma body supplied heat and hot metal-bearing fluids that were channeled to surface via a synvolcanic fault (feeder zone) and created a hydrothermal system

(black smoker) that formed a sulphide mound on the sea floor. These magma bodies also supplied late-stage, coarse-grained, quartz-feldspar porphyry sills that intruded the felsic volcanic pile. The hydrothermal fluids altered the wall rocks adjacent to the feeder zone, creating a range of alteration minerals that reflect the temperature of the fluid and the original composition of the wall rocks.

The alteration is zoned within and away from the feeder zone, and the mineralization is also zoned (Goodfellow and McCutcheon 2003). The most intense alteration (Zone 1) is characterized by silicification, iron-chlorite and disseminated sulphide minerals, and is at the top of the feeder zone directly beneath massive sulphide of the 'vent complex'. Zone 2 alter-

ation is deeper in the feeder zone and characterized by iron-chlorite, some sericite, and abundant sulphide stringers that disappear with increasing depth in the pile. Zone 3 alteration is outboard of the feeder zone, is feldspar-destructive (resulting in 'quartz-augen schist') and is characterized by iron-magnesium chlorite and sericite. Zone 4 is outboard of Zone 3, only partially feldspar destructive, and is characterized by phengite and magnesium chlorite. The stringer sulphide minerals in the 'sulphide-stringer zone' predominantly comprise pyrrhotite and/or pyrite with chalcopyrite and traces of sphalerite and galena. The 'vent complex' facies comprises pyrrhotite and/or pyrite breccia that is replaced and/or veined by pyrrhotite, pyrite, chalcopyrite, magnetite, chlorite, quartz, and siderite in variable proportions. The 'bedded pyrite' facies mainly consists of fine-grained, massive pyrite with minor sphalerite, galena, and chalcopyrite. The 'bedded ore' facies generally comprises interlayered, fine-grained pyrite, brown sphalerite, and galena with minor amounts of arsenopyrite, marcasite, cassiterite, stannite, tetrahedrite, and bournonite.

To summarize, the primary characteristics of Brunswick-type mineralization are: 1) stratigraphic position at, or near the top of, the Nepisiguit Falls Formation; 2) associated quartz-feldspar porphyry sills; 3) an underlying feeder zone characterized by stringer sulphide minerals (pyrrhotite and chalcopyrite); 4) proximal iron-chlorite alteration and silicification; 5) an outboard, iron-magnesium chlorite and sericite alteration that is feldspar-destructive; 6) various sulphide facies (vent complex, bedded pyrite, and bedded ore) that appear to reflect deposition in different parts of an original sulphide mound; and 7) an oxide-silicate-carbonate iron formation that caps and extends laterally beyond the massive sulphide.

Primary characteristics for massive sulphide deposits in other parts of the BMC show similarities and differences to those in the Tetagouche Group (Brunswick type). For example, other deposits are also spatially associated with felsic volcanic rocks but not necessarily hosted by them; rather, they are in sedimentary rocks that either overlie or underlie the deposits (e.g. Canoe Landing Lake, Caribou, and Murray Brook). Quartz-feldspar porphyry sills are absent. Some deposits are within felsic volcanic rocks but largely formed beneath the sea floor by replacement of permeable breccia and/or hyaloclastite (e.g. Restigouche, Taylor Brook). Oxide iron formation is absent in deposits of the California Lake and Sheephouse Brook groups. The main sulphide minerals are the same, i.e. pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite, but galena tends to be less silver rich. Also, deposits in the California Lake Group tend to have more trace gold than those in the Tetagouche Group. The associated hydrothermal alteration is similar, i.e. proximal iron-chlorite alteration with outboard, iron-magnesium chlorite and sericite alteration. Most deposits do not have a well-defined stringer zone (probably tectonically cut out), with the exception of the Chester deposit in the Sheephouse Brook Group.

Secondary ore controls on mineralization of all types exist in the BMC. Tectonic thickening of sulphide units occurs in F_1 - F_2 fold hinges with thinning on fold limbs (van Staal and Williams 1984). Tectonic remobilization of ductile sulphide

occurs locally, e.g. the pyrrhotite breccia units at Heath Steele (de Roo et al. 1991). Recrystallization of sulphide minerals in the contact aureoles of younger felsic intrusions increases their grain size, e.g. Key Anacon, Chester.

HISTORY OF EXPLORATION AND DISCOVERY

The history of mineral exploration in the Bathurst Mining Camp (BMC) can be divided into six periods: a) pre-1952, b) 1952–1958, c) 1959–1973, d) 1974–1988, e) 1989–2000, and f) post-2000. The history of mine development and mineral production follows a different time-line and is described in a companion paper (*The Bathurst Mining Camp Part 2: Mining History and Contributions to Society*). Much of the following description is extracted from McCutcheon et al. (2003); however, the pre-1952 events are more thoroughly described by Martin (2003).

Pre-1952: Prior to Discovery

Prior to the discovery of Brunswick No. 6 in 1952, the 'Bathurst District' was known for its 'Nipisiguit (sic) Iron Ore Deposit', now called Austin Brook (Table 1, Fig. 2). The history of discovery and development of this deposit is thoroughly described by Belland (1992) and Martin (2003).

In 1938, the Orvan Brook massive sulphide deposit (Table 1, Fig. 2) was found by a prospector from Nevada, Mr. Dan Sheahan, who was working for the Tetagouche Exploration Company (Wright 1939; Martin 2003). The company drilled 28 holes, outlining a deposit at least 1900 m in strike length, and demonstrated for the first time that massive sulphide occurs in the Bathurst area (Tupper 1969).

In the same year that Orvan Brook was discovered, T. LaFrance of Bathurst "opened some promising looking leads at Middle Landing on the Nepisiguit (sic) river" (Wright 1939). However, it was not until 1946 that P.J. Leger of Bathurst acquired the mineral rights to this prospect (Wright 1947). Subsequently, a 14-hole diamond-drilling program intersected copper-bearing, vein-sulphide, but massive sulphide deposits were not found (unpublished company report by M.A. Cooper 1947). We now know that the Leger Cu prospect is part of the nearby Key Anacon massive sulphide deposit (Table 1; Fig. 2).

Mr. Patrick (Paddy) W. Meahan (Fig. 7a), a mining engineer, was the catalyst that caused attention to be focused on the mineral potential of the Bathurst area in the late 1940s (McCutcheon et al. 1993b), but Dr. William J. Wright and Dr. Graham S. MacKenzie (Fig. 7b, c) set the stage (Martin 2003). Dr. Wright, the first Provincial Geologist, and Dr. MacKenzie, were both teaching at the University of New Brunswick, and working collaboratively to promote the mineral potential of New Brunswick (Martin 2003). In 1943, Dr. MacKenzie was contracted by Wright to prepare a plan and report on the geology of the iron mine at Austin Brook, which Dominion Steel and Coal Corporation Ltd. had acquired the previous year (Martin 2003). The samples that he collected at Austin Brook played an important role in the lead-up to the Brunswick No. 6 discovery (McCutcheon et al. 1993a; Martin 2003).

In 1951, A. B. Baldwin (Fig. 7d), a graduate student of Dr. MacKenzie, was working on his master's thesis, with the aid of a \$3000 James Dunn Scholarship (Belland 1992). The subject of his thesis was the Hayot Lake iron formation in Labrador,



Figure 7. Photos: a) Mr. Patrick (Paddy) W. Meahan c. 1965, b) Dr. William J. Wright c. 1930, c) Dr. Graham S. MacKenzie c. 1940, d) Mr. A. Bennett (Ben) Baldwin 1951. All photographs from the New Brunswick Department of Energy and Resource Development archives.

but one of the conditions of his scholarship was that the thesis should be, at least in part, about New Brunswick. Dr. MacKenzie suggested that he could satisfy this requirement by comparing the Hayot Lake iron formation with samples from Austin Brook, which he had collected in 1943. In examining polished sections of those samples, Baldwin observed base-metal sulphide minerals in the footwall pyrite zone of the Austin Brook deposit.

In 1952, the Austin Brook property was under license to Brudon Enterprises Limited of Montreal; Baldwin's findings were communicated to the company along with a recommendation to explore the property for base metals (MacKenzie 1958). Brudon did not follow up on MacKenzie's recommendation but instead chose to offer the Austin Brook concession to M. J. (Jim) Boylen (Fig. 8a), a prominent Toronto mining man (Martin 2003). Boylen was representing a small group of New York investors, who that year had put \$1 million in the

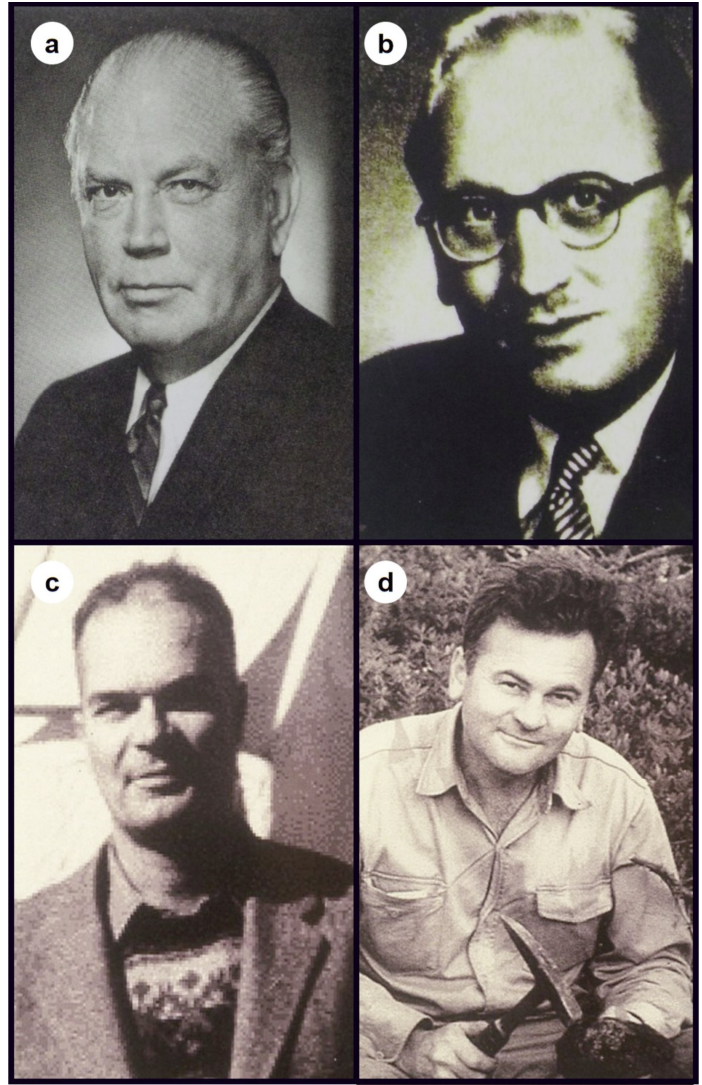


Figure 8. Photos: a) Mr. M. James (Jim) Boylen c. 1960, b) Mr. Robert (Bob) J. Issacs c. 1970, c) Dr. C. Phillip (Phil) Jenney 1955, d) Dr. Walter Holyk 1955. The first two photographs are from the Canadian Mining Hall of Fame; the last two are from the New Brunswick Department of Energy and Resource Development archives.

'M.J. Boylen Nominee Account' to find a mine in Canada (*The Northern Miner*, January 15, 1953).

In the spring of 1952, Meahan was acting as an independent scout for Boylen, who earlier that year had purchased Meahan's Elmtree Pb–Zn property, which would become the Keymet Mine (McCutcheon et al. 1993a; Martin 2003). Meahan learned of Baldwin's findings and independently sampled and assayed the footwall pyrite zone at Austin Brook (Martin 2003). One sample returned values of 9% Zn and 4% Pb (Hanula 1982), so he advised Boylen to acquire the Austin Brook property from Brudon. Consequently, Boylen optioned the Austin Brook property in the summer of 1952 (Belland 1992), which was the sixth project financed by the 'M.J. Boylen Nominee Account'. Robert (Bob) J. Issacs (Fig. 8b), Boylen's chief mining engineer, insisted that a ground electromagnetic (EM) survey be conducted to guide drilling on the property

(Martin 2003). Diamond drilling at Austin Brook began in late August; results from the first 11 holes were negative but Hole B-12, located on an EM anomaly approximately 1000 m north of Austin Brook, intersected the Brunswick No. 6 deposit on October 22nd (Belland 1992). The Bathurst Mining Camp was born.

1952–1958: The Discovery Years

Hole B-12 intersected approximately 100 m of massive sulphide and sparked a chain of events, which were described by Belland (1992): 1) Issacs told Meahan to secure the drill core and say absolutely nothing to anyone about what had been found; 2) Boylen formed Brunswick Mining and Smelting Corporation Limited (and two other companies, Martin 2003) on October 31, 1952, with head office in Saint John; 3) Fifteen additional holes were drilled in the No. 6 deposit; 4) Approximately 1000 mineral claims were staked (*The Northern Miner*, January 15, 1953) by Boylen interests, over magnetic anomalies north and south of the No. 6 Project; 5) The drill core was sent for assay to the geochemistry laboratory at St. Francis Xavier University, Nova Scotia, rather than a commercial laboratory in Ontario, to help keep the discovery a secret; 6) The discovery was announced on the front page of *The Northern Miner* on January 15, 1953.

A staking rush was predicted in the January 15, 1953 issue of *The Northern Miner* and it came to pass a week later. The headline in the January 29 edition read “*Frenzied staking in N.B. spreads far and wide*”. The number of mineral claims in the Province went from a few thousand in effect at the beginning of the year to over 41,000 claims (approximately 665,500 ha) by the end of the year. At the peak in 1956, over 43,000 claims (approximately 825,200 ha) were in effect; at no time since has there been more land claimed in New Brunswick, even during the uranium staking rushes of the early 1980s and 2007-08, or the flow-through gold rush of the late 1980s (Fig. 9). From 1953 to 1957, *The Northern Miner* had numerous articles about mining properties and activity in the Bathurst–Newcastle area.

The discoveries of the 1950s largely resulted from the application of geophysical methods (Seigel 1956; Ward 1958). Initially, ground exploration, using electromagnetic (EM) methods, focused on areas with airborne magnetic (Mag) anomalies. In early 1953, Boylen staked the second largest magnetic anomaly known in the area, located 9.7 km north of Brunswick No. 6. (Skinner 1974). A ground electromagnetic survey carried out that same year outlined a strong anomaly about 610 m east of the crest of the aeromagnetic anomaly (Skinner 1974), and subsequent drilling revealed the Anaconda-Leadrige (renamed Brunswick No. 12) orebody (Table 1; Fig. 2). Drilling of another ground EM anomaly in 1953 resulted in the discovery of the New Larder ‘U’ (renamed Key Anaconda) deposit. In 1954, Little River (renamed Heath Steele) was discovered as a result of an airborne electromagnetic (AEM) survey that was conducted by the American Metal Company (Jenny (sic) 1957), the very first in the world.

Dr. C.P. (Phil) Jenney (Fig. 8c), Canadian exploration manager for the American Metal Company (AMCO), had negotiated an agreement with the International Nickel Company

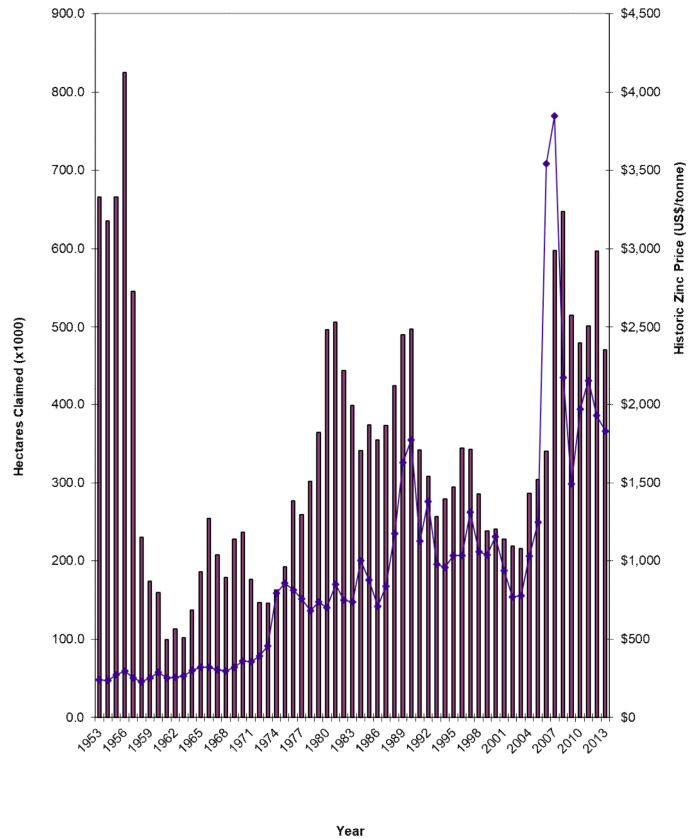


Figure 9. Bar graph showing numbers of hectares claimed in New Brunswick from 1953 to 2013, with the historic price of zinc (in US\$/tonne) superimposed. Modified from Figure 2 of McCutcheon et al. (2003).

(INCO) to fly an AEM survey in New Brunswick in 1953 (Gallagher 1999). Numerous AEM anomalies were found and the second hole of a follow-up drilling program intersected the A-Zone in 1954. Drilling of other AEM anomalies led to the discovery of the B, C, D, and E zones.

After the discovery of the Brunswick orebodies, air photos became widely used in conjunction with aeromagnetic maps as a means of selecting properties for exploration, e.g. Halfmile Lake. Dr. Walter Holyk (Fig. 8d), geologist with the Middle River Mining Company Limited (Texasgulf Sulphur Corporation), staked a block of thirty claims in the Halfmile Lake area based on data from aeromagnetic maps, aerial photographs and reconnaissance geology (Holyk 1957 and personal communication 2000). Airborne electromagnetic and magnetic surveys were performed over these claims, followed by a ground EM survey (Holyk, in Hanula 1982). The first hole drilled on the property in late 1955 discovered the Halfmile Lake deposit.

In the latter part of 1954, “The Anaconda Company (Canada) Limited” contracted Dr. Cameron G. Cheriton (Fig. 10a) to do an initial geological study of the Bathurst area (Cheriton 1960). He focused his efforts on the northern part of the BMC where Holyk was not exploring and determined that the New Calumet Zone (Orvan Brook) is hosted by intravolcanic sedimentary rocks. He traced these rocks east and west, using aeromagnetic maps, aerial photographs and ground traverses, to delineate favorable areas for further exploration.



Figure 10. Photos: a) Dr. Cameron (Cam) G. Cheriton 1964, b) Dr. C. John Sullivan 1975, c) Dr. Richard L. Stanton c. 1985, d) Mr. Claude Willett 1975. The first two photographs are from the New Brunswick Department of Energy and Resource Development archives, the third is from the University of New England, and the fourth is courtesy of George Willett.

Two target areas were identified: one to the east called Number One and the other to the west called Number Two (Cheriton 1960). Work in the Number One area led to the discovery of the Armstrong A and B deposits in 1956, and the Rocky Turn deposit in 1957. The McMaster deposit was found between areas One and Two in 1957. At the time, the Number Two area was held by Bathurst prospector Fred J. Smith (unpublished Provincial files), so in 1955 Cheriton optioned Smith's Caribou property and changed the name to Anaconda-Caribou. Follow-up exploration identified drill targets and the first hole, completed in December 1955, intersected approximately 15 m of massive sulphide (Cheriton 1960).

In 1955, Kennco Explorations (Canada) Ltd. became active in the Bathurst area. Kennco examined geological data, aerial photographs and the government aeromagnetic maps, and three areas were selected for AEM surveys, to be conducted by

Aeromagnetic Surveys Limited (Fleming 1961). Highly rated AEM anomalies were detected near Caribou, Clearwater and Murray Brook. Since, the anomaly at Caribou had already been acquired by Anaconda, only the Clearwater and Murray Brook anomalies were staked.

Ground follow-up in the Murray Brook area began with horizontal-loop and vertical-loop EM surveys to ground-truth the AEM anomalies. It was fortuitous that someone in the crew discovered copper-bearing float about 240 m south of the survey area at the end of the 1955 field season, because this justified further work the following year (Fleming 1961). The 1956 program used the newly developed stream-sediment geochemical methods of Hawkes and Bloom (1956), and led to the discovery of the Murray Brook gossan, which was drilled but none of the six packsack holes penetrated massive sulphide. Therefore, a ground EM survey was conducted over the gossan to help locate drilling targets. Drilling started in 1956 and the massive sulphide deposit was discovered about November 1st of that year (Fleming 1961).

Ground follow-up in the Clearwater Stream area began in the summer of 1955 with geological mapping and a horizontal-loop EM survey that located the AEM anomaly about 300 m south of its plotted position (Petruk 1957). In September, the ground anomaly was tested by two packsack drill holes, both of which intersected massive sulphide, discovering the Clear (later renamed Clearwater and then Chester) deposit.

In 1955, the President of Kennco Explorations (Canada) Limited, Dr. C. John Sullivan (Fig. 10b), who was an expatriate Australian, happened to read a paper by Dr. Richard L. Stanton (Fig. 10c), in which the author postulated that the Lower Paleozoic sulphide ores near Bathurst, New South Wales, had been deposited in a syn-sedimentary, volcanic island arc setting (Stanton 1955). Sullivan was so impressed with the apparent similarities to deposits in northern New Brunswick, that he wrote to Stanton and invited him to come to Bathurst (Stanton 1984). As a result of this letter, Stanton decided to accept a post-doctoral fellowship at Queen's University, which eventually enabled him to visit Bathurst for a month in the fall of 1956. During that time, he logged and sampled cores from the Brunswick deposits, which formed the basis for his paradigm-shifting papers (Stanton 1959, 1960a, b) on massive sulphide deposits.

The Consolidated Mining and Smelting Company of Canada Limited (Cominco), acquired ground in the Forty-Four Mile Brook and Nine Mile Brook areas in 1955 (Douglas 1965). However, a wedge-shaped area near Forty-Four Mile Brook was left open so it was staked by Bathurst prospectors (including Claude Willett) and named the Wedge property. A gossan outcrop was found and the property was optioned to Cominco. A ground EM survey was conducted in 1957 and one of the first holes drilled to test the EM anomaly intersected 33 m of massive sulphide, grading more than 4% Cu, thus discovering the Wedge deposit (Douglas 1965).

In the summer of 1954, Stratmat Limited, a wholly owned subsidiary of Strategic Materials Corporation, staked a group of claims (group 61) immediately north of the Heath Steele Mines property (Mowat 1957). Between then and the fall of

1956, airborne and ground electromagnetic surveys and soil geochemical surveys were performed. Diamond drilling in late 1956 discovered the “Group 61 Zone” (Johnston 1959), later renamed the Stratmat Main Zone (Dahn 1986).

Selco Exploration Co. Ltd. staked a group of claims in the Portage Lakes area in 1954, based on reconnaissance stream-geochemical work (Hawkes and Webb 1962, p. 331). Drilling of soil geochemical and ground EM anomalies discovered two small occurrences called the C-4 and C-5 zones, respectively. The property was optioned to New Jersey Zinc Exploration Co. (Canada) Ltd. in 1957 and the company drilled eight holes on the C-5 Zone and several holes on the C-4 Zone. Drilling of coincident soil geochemical and self-potential anomalies, just over 1 km to the south of the C-5 zone, discovered the Charlotte prospect in the fall of 1958 (Hawkes and Webb 1962, p. 327), which was later renamed the Restigouche deposit (*Mineral Occurrence Database*).

Eight other deposits were found in the 1950s, including the Captain, Devil’s Elbow, Halfmile Lake North, Headway, Nepisiguit A, B, and C, and the Pabineau deposits (Table 1; Fig. 2). Except for Headway, which was found by prospecting, these deposits were discovered by electromagnetic methods.

1959–1973: The Flat Zinc Price Years

Of the six discoveries that were made during this period, most are satellite bodies to known deposits. Two of them (Table 1; Fig. 2) were found by Heath Steele Mines Ltd. by drill-testing IP anomalies. In 1964, the Heath Steele N-5 zone was found in the northern part of the mining lease (Hamilton and Park 1993). In 1966, the West Grid Zone was discovered approximately 1.5 km to the west of the Heath Steele ACD zone. The Stratmat Boundary zone was discovered by Cominco in 1961 on the Stratmat group of claims, which had been purchased from Strategic Metals in 1959 (Hamilton and Park 1993). The Canoe Landing Lake deposit was intersected by two packsack diamond drill holes in 1960 and further delineated by Baie Holdings Ltd. in its 1961–1962 drilling program. The discovery of the Louvicourt deposit is attributed to prospecting. In 1964, Lawrence Gray discovered gossan in the Nine Mile Brook area, when Route 430 was being constructed. He and partners L. Gamble and C. Smyth staked claims and subsequently optioned them to Louvicourt Goldfields Corporation. Drill testing of an SP anomaly led to the discovery of the Louvicourt deposit. Drilling of IP anomalies by Cominco led to the discovery of the Stratmat West Stringer zone in 1972.

1974–1988: The First Zinc Price Shift

During the 1970s and 1980s, new low-cost analytical and geophysical techniques sparked new discoveries, including five deposits (Table 1 and Fig. 2). In October of 1975, mineralized boulders were found by Sabina industries, 6 km southwest of the Brunswick No. 6 mine, while field checking an ‘INPUT’ airborne EM anomaly from a survey flown in 1974 by Questor Surveys Ltd. These boulders returned values of 5.2% Pb, 7.75% Zn and 38 g/t Ag (*The Northern Light*, October 15, 1975). Drilling in the fall of 1975 discovered the Flat Landing

Brook deposit, which was subsequently optioned to United States Steel Corporation (Essex). In 1977, Consolidated Morrison found the Taylor Brook occurrence by drill-testing an AEM anomaly. With further drilling, this showing was upgraded to a deposit (Lutes 1997). The Captain North Extension (CNE) deposit was discovered in 1978 by Sabina Industries and Metallgesellschaft Canada Ltd. (Whaley 1992). A stream geochemical anomaly and an IP survey delineated the drill targets that led to the discovery. In 1981, the Heath Steele C-North zone was found, approximately 550 m north of the ACD zone, by drill-testing combined ground Mag and EM anomalies. In 1988, the Stratmat S-1 deposit was discovered by stratigraphic drilling at the Stratmat Central deposit to test the host sedimentary horizon between 230 m and 520 m below surface (Hamilton and Park 1993). One notable showing was found in 1975 by Claude Willett (Fig. 10d) while prospecting in the Nine Mile Brook area. He found high grade massive sulphide boulders that returned 4.55% Cu, 14.2% Pb, 8.55% Zn, and 487 g/t Ag (*Moncton Times*, August 7, 1975). A mini staking rush resulted; over 400 claims were staked by several companies and a bidding war ensued for Willett’s claims. Ultimately, he optioned them to Price Company Limited (Newmont Mining Corp.) for a six-figure cash payment, an unheard-of sum for any property at the time.

1989–2000: The Second Zinc Price Shift

From 1989 to 2000, four deposits were discovered (Table 1 and Fig. 2). In 1989, deep stratigraphic drilling at the Brunswick No. 12 deposit discovered the Brunswick North-end zone approximately 1500 m north of the northern extremity of the main No. 12 deposit and 1100 m below surface (Hussey 1992). In 1992, Rio Algom Exploration optioned the Key Anacon property from Key Anacon Mines Limited. Drilling beneath the old mine workings later that year, intersected ore grade massive sulphide in hole 92-10 and hole 92-17 at vertical depths of 750 m and 450 m, respectively. In 1993, the Key Anacon East deposit was discovered by stratigraphic drilling beneath Carboniferous cover rocks, 1.5 km to the east-northeast of the Key Anacon deposit. The discovery hole (93-42) intersected 19.9 m of 3.58% Pb, 7.86% Zn, 0.33% Cu and 78 g/t Ag within an 83 m massive sulphide intersection (Lentz and Langton 1993). In 1996, Noranda discovered the Camel Back deposit as part of a follow-up to the EXTECH airborne geophysical survey. A coincident Mag/EM anomaly 6 km southeast of the Caribou deposit was trenched and drilled in the latter part of the year. Hole 96-6 cut 17.9 m of massive and semi-massive sulphide mineralization, with a 4.3 m section returning 3.94% Pb, 8.95% Zn, 0.08% Cu and 41.9 g/t Ag, followed by a copper zone of 12.3 m grading 2.05% Cu. In 1999, Noranda found the Mount Fronsac North deposit following the discovery of a 50 m by 20 m gossan zone in a scarified forest harvest block (Graves and Mann 2000). The deposit is a 14 Mt sulphide accumulation at the contact between the Nepisiguit Falls and Flat Landing Brook formations (Walker and Graves 2006). After 1999, no new deposits were found.

IMPORTANCE OF THE BATHURST MINING CAMP TO MINERAL EXPLORATION

The Bathurst Mining Camp (BMC) was, and still is, important to New Brunswick and Canada for innovations in exploration methods and development of geological ideas.

Exploration Innovations

The BMC had several firsts vis-à-vis innovations in exploration. It was where:

- the first airborne magnetic survey was flown in New Brunswick;
- an airborne electromagnetic (AEM) survey was used for the first time to discover a VMS deposit (Heath Steele);
- ground gravity surveys were first used (starting in the 1950s) to screen electromagnetic (EM) anomalies;
- an airborne gravity system (Falcon) was first tested over a VMS deposit (Heath Steele), and that airborne gravity (Bell Geospace) was flown over an entire camp;
- directional drilling was used in a VMS environment for the first time;
- a 3D seismic survey was first used to discover the Halfmile Lake Deep deposit.

Geological Ideas

New geological ideas were developed and/or applied in the BMC. For example, the BMC was where:

- the syn-volcanic model of massive sulphide deposition was first applied (Stanton 1959) in Canada;
- it was determined that most VMS deposits formed in the Middle Ordovician during early-stage rifting of a submarine volcanic arc (floored by continental crust), which evolved into a Sea of Japan style back-arc basin situated on the eastern margin of Iapetus;
- it was determined that the present-day geology reflects amalgamation of various Ordovician rock units in a subduction/obduction complex (van Staal 1994) that formed in the Late Ordovician to Early Silurian;
- it was determined that the Miramichi Group is part of the Gander Zone and the Bathurst Supergroup belongs to the Dunnage Zone of the Canadian Appalachians.

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