DV 98-04

GEOLOGY AND METALLOGENY OF THE CHAPAIS-CHIBOUGAMAU MINING DISTRICT

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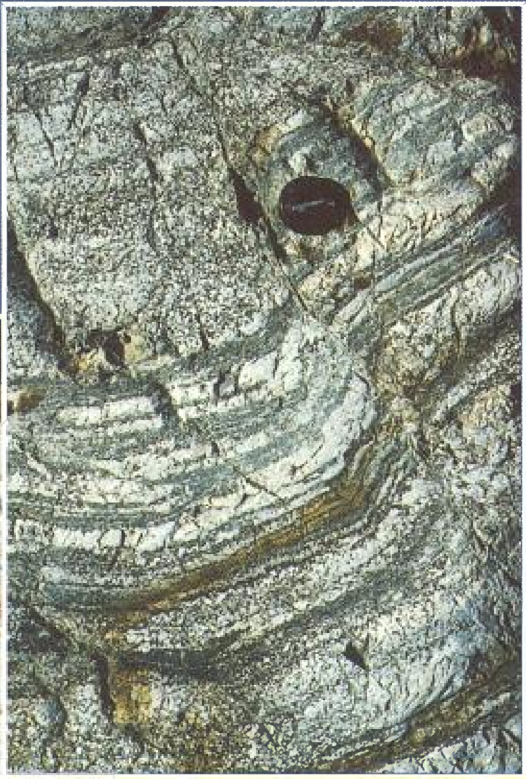
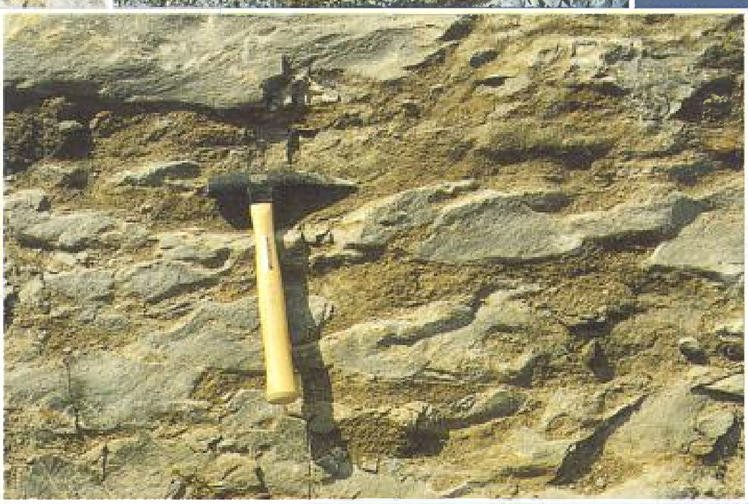
A NEW VISION OF THE DISCOVERY POTENTIAL

Editor : Pierre Pilote





DV 98-04

Québec

Geology and Metallogeny of the Chapais-Chibougamau Mining District : a New Vision of the Discovery Potential

Proceedings of the Chapais-Chibougamau
1998 Symposium

Editor : Pierre Pilote

With the contributions from :

G.O. Allard, Y. Bellavance, A. Blais, B. Boily, H. Brisson,
E.H. Chown, R. Daigneault, H. de Corta, C. Dion, D. Gervais,
P.A. Girard, R. Girard, J. Guha, R.V. Kirkham, V. Larouche,
G. Lavallière, G. Maltais, R. Morin, W. Mueller, P. Pilote,
F. Robert, L. Schmitt, M. Simard, W.D. Sinclair

ICM Institut Canadien des Mines
Chapais - Chibougamau

Gouvernement du Québec
Ministère des Ressources
naturelles

Association des
Prospecteurs du Québec

DIRECTION DE LA GÉOLOGIE
Director : J.-L. Caty

SERVICE GÉOLOGIQUE DU NORD-OUEST
Chief : R. Marquis

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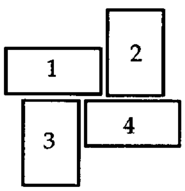

1 - Intermineral dyke crosscutting a pyritic bearing stockwork, Clark Lake section, Doré Lake Complex;
2 - Volcaniclastic rocks showing a selective substratiform sericitization and chloritization propagating along bedding, Blondeau Formation, Bourbeau hill;
3 - Layered Zone of the Doré Lake Complex (South limb), mineralized in vanadiferous magnetite;
4 - Hydrothermal breccia mineralized in cp-py-Au, Troilus mine, Frotet-Évans greenstone belt.

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FOREWORD

This volume will focus on both the Chibougamau segment and the Southern Caopatina segment of the Northern Abitibi Belt, an area which has been actively explored over the past 15 years.

The objective of this volume is to present a summary of the talks and field excursions given for the "Symposium Chapais-Chibougamau 1998", organized by the Chibougamau-Chapais section of the Canadian Institute of Mining (CIM) for the centenary celebrations (1898-1998) of this organization. This volume will tend to show a new vision of the discovery potential of this region. This meeting is organized to help to promote investments and exploration in this high potential, but inadequately explored area.

This guidebook, which is inspired by Chown et al. (1990) contribution, presents an overall view of the volcanic stratigraphy (from deep water to subaerial environments), mafic to ultramafic sills and plutonic intrusions (tonalite to carbonatite), structures (Archean synvolcanic to late tectonic Grenvillian) and their various controls on ore formation. This leads to an examination of the exploration significance of various types of deposit with respect to their regional setting.

Previous guidebooks (Allard et al., 1972; Allard et al., 1979; Guha and Gobeil, 1984) focused mainly on the Chibougamau region. In their guidebooks, Chown et al. (1990) and Pilote et al. (1995d and 1998c) attempted to consider the regional geology in the light of possible global tectonic settings, both at the time of formation of the supracrustal and intrusive rocks, and during regional deformation. This approach is conserved in this volume.

Two contrasting depositional settings, a southern basalt plain and a northern volcanic arc, occur and affect syngenetic deposits in the two domains, whereas the entire region is united by a common deformation and intrusion pattern. Porphyry copper-type mineralization occurs mainly in the arc environment. However, mesothermal, or "orogenic", lode-type gold mineralization occur in both domains, without apparent discrimination. The geology of the Frotet-Évans greenstone belt is also described, with an exhaustive description of the Troilus mine, which is operated by Inmet Minimg Corp. The area was marked by geological processes throughout the Proterozoic and culminating in the Late Proterozoic Grenvillian Orogeny.

This volume has been structured to present an updated version of the geology of the area, according to the most recent published or ongoing work in this region, followed by stop or deposit descriptions. The latter section presents, in some cases, new views and ideas concerning the origin of some deposits in the Chibougamau mining camp. We hope this excursion will generate stimulating discussions between participants, authors and exploration geologists involved in this symposium.

ACKNOWLEDGMENTS

Preparation for this excursion has involved the efforts of numerous organizations and companies. We would like to thank SOQUEM, Meston Lake Resources, MSV Resources, Inmet Mining Corp., GéoNova, the Université du Québec à Chicoutimi, and the Ministère des Ressources naturelles du Québec.

The editor : Pierre Pilote

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E. H. Chown, Réal Daigneault, Wulf Mueller

Sciences de la Terre, Centre d'Études sur les Ressources Minérales, Université du Québec à Chicoutimi, 555 boul. Université, Chicoutimi, Québec, G7H 2B1;

and Pierre Pilote

Ministère des Ressources naturelles du Québec, 400 boul. Lamaque, Val-d'Or, Québec, J9P 3L4.

(modified from Chown et al., 1990)

INTRODUCTION

The Chibougamau-Caopatina region (CCR) is located in the northeastern corner of the Abitibi belt (Figure A1). Differences in lithology, such as presence of komatiites in the south, and the greater abundance of plutons and extensive mafic to ultramafic sills in the north, as well as a difference in stratigraphic thickness prompted Dimroth et al. (1982, 1984) to divide the Abitibi belt into a northern, Internal Zone and southern, External Zone. In the same manner, Ludden et al. (1986) have made a distinction between the two segments, and called them the Northern Volcanic Zone and the Southern Volcanic Zone. The (CCR) forms part of the Northern or Internal Zone which is limited on the north by the Opatica belt, and on the east by the Grenville Province (Figure A2). The contact zone between the two provinces, the Grenville Front (Wynne-Edwards 1972; Rivers and Chown 1986; Rivers et al., 1989), is marked by a disruption in the common East-West tectonic trend. The metamorphic grade, typically greenschist facies, rises to amphibolite facies near the Grenville Front.

The CCR (Figure A2) is the most extensively studied part of the northern Internal Zone. Initial mapping was carried out by Norman (1937; 1938), Beach (1941a, 1941b) and later continued by the Quebec provincial survey (Gilbert 1949, 1955), following the building of the St-Félicien all-weather road. Duquette (1970) first attempted to establish a coherent stratigraphy, composed of an older Roy Group and a younger, essentially epiclastic group, the Opemisca Group. Allard (1976a) subsequently redefined the volcanic formations of the Roy Group. Recent mapping by Tait and Chown (1987), Tait et al. (1987) and Lauzière et al. (1989) led to the recognition of a sedimentary unit, the Caopatina Formation, interstratified with the Roy Group volcanic rocks in the southern part of the CCR (Sharma et al., 1988). The detailed mapping programme of the Québec Ministère des Ressources naturelles (formerly Ministère de l'Énergie et des Ressources) has shown a need to reevaluate the stratigraphy in specific areas of the CCR. Recently

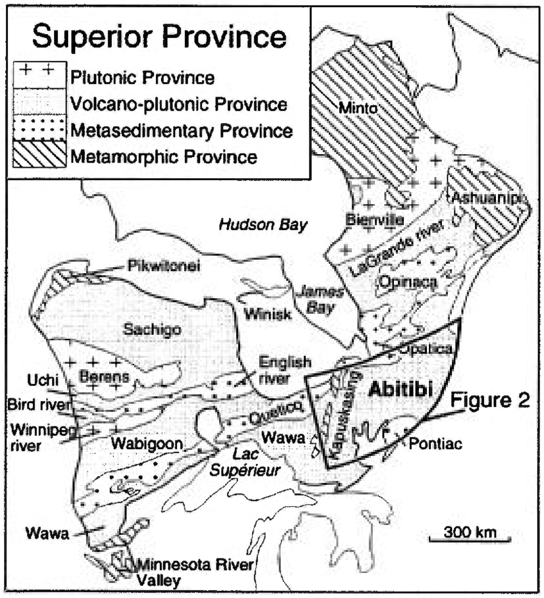


Figure A1: Geology of the Superior Province (Card and Ciesielski 1986).

Mueller (1987; 1991) and Mueller et al. (1989) have described the evolution of this region in terms of volcanic cyclicity, sedimentation, and plutonic emplacement history, and Daigneault and Allard (1990) described the structural setting and give a detailed overview of the formations and groups in the Chibougamau Segment.

Chown et al. (1992) provided a geochronological framework for the geological evolution of the Chibougamau area. According to their data, they

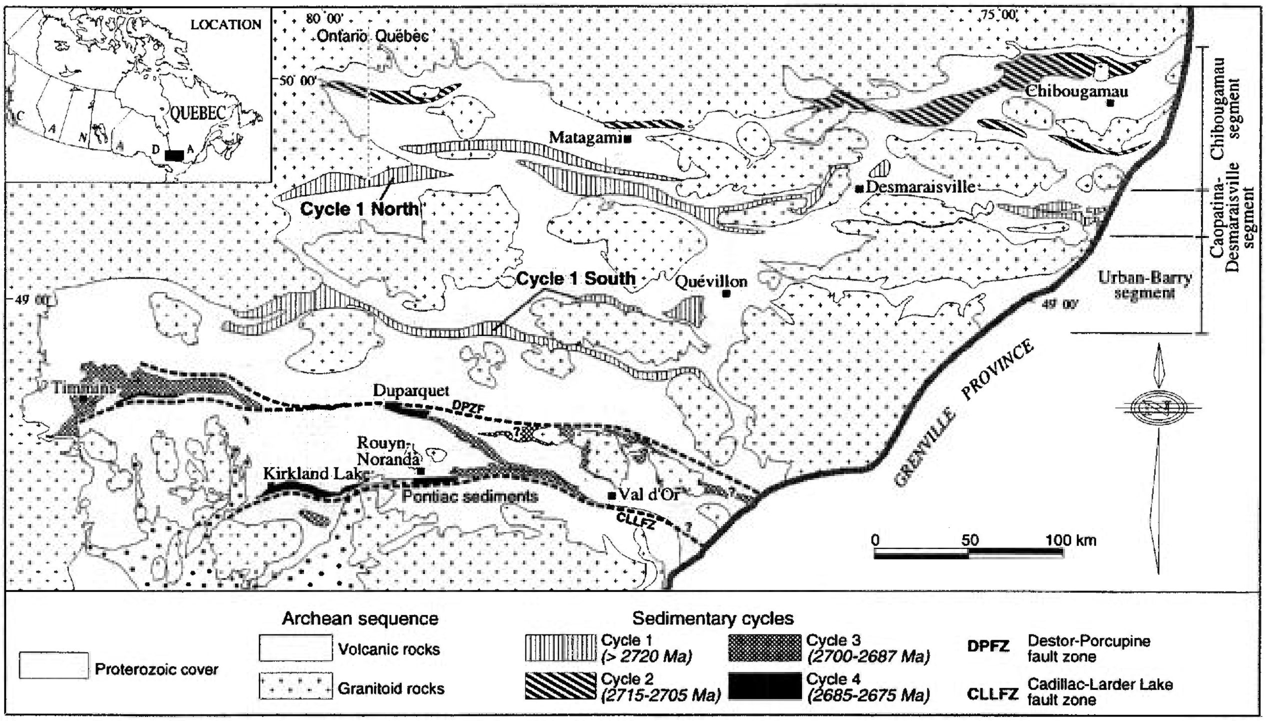


Figure A2: General geology of the Abitibi Sub-province and location of the Chibougamau area.

subdivided the northern part of the Abitibi in monocyclic volcanic zone and polycyclic volcanic zone. The later includes the Chibougamau area. Mueller and Donaldson (1992), based on sedimentological studies, recognized four major periods of sedimentary bassins formation, related to specific events in the evolution of the whole Abitibi belt. Daigneault and Allard (1994) discriminated between Archean deformation features and aspects related to the Grenvillian heritage near the Grenville Front East of Chibougamau.

HISTORY OF THE CHIBOUGAMAU CAMP

The history of prospecting and mine development in the Chibougamau area is a long one. Mineralization was first observed and reported in the region during the year 1870 by J. Richardson, a geologist with the Geological Survey of Canada. The first discovery was made in 1903 by a fur trader, Peter McKenzie, when he found copper and asbestos on Asbestos Island at the north end of Lake Chibougamau. This aroused interest in the area and from 1903 onwards, well known men in Canadian mining history have visited and reported on the Chibougamau area. As a result it became known to the outside world that the region was potentially favourable for mining ventures. Of special importance were early reports by J. Richardson (1871), A. P. Low (1893), J. Obalski (1905), J.E. Hardman (1885) and A.E. Barlow (1911). By 1905, the area was already known as the Chibougamau mining region.

In 1908, E. Dulieux described the quartz vein on Merrill Island and the mineralized zone on the nearby mainland. By 1910 there was sufficient interest in the Chibougamau area to warrant an investigation to decide whether a railway was justified to open the area for mining purposes. This resulted in 1911 in the Report on the Chibougamau region by the Chibougamau Mining Commission headed by A.E. Barlow. This report gives a very full account of the initial exploration of the area up to 1910. The main mineral under consideration at the time of the report was asbestos, and although previous examiners had been highly optimistic, the Mining Commission was pessimistic, and upon its recommendations the idea of building a railroad to Chibougamau was abandoned. With the advent of World War I, Chibougamau was virtually forgotten for nearly 10 years. Several factors, however, combined to revive interest in the area during the speculative 1920's. The completion of the Canadian National Railway from Quebec City to Cochrane, Ontario, made the region more accessible, and the rich finds in the Rouyn-Noranda district to the west once more turned the prospector's attention to

Chibougamau. Many of Chibougamau's most promising deposits were discovered in the 1920's.

When the stock market crashed in 1929, venture money became scarce and activity in the area slowed to a virtual standstill. As the effects of the Great Depression began to taper off, interest and investment in Chibougamau were renewed. In subsequent years there was much activity in the Chibougamau area on numerous gold finds and prospects, these being the only deposits of possible economic interest before the construction of motor roads and railroad.

Numerous publications by the Quebec and Canadian Geological Surveys in the 1930's attest to the area's revival. Retty produced in 1930 the mapping of the McKenzie township. In 1935, J.B. Mawdsley and G.W.H. Norman completed Memoir 185 which gave a comprehensive account of the local geology. With Chibougamau on the verge of actual production, World War II broke out. Once more operations halted. The war ended in 1945 and the building of the highway from St-Félicien commenced. Several economic booms occurred through the years but not until the opening of the highway from St-Félicien in the fall of 1949 did Chibougamau develop into a copper-gold mining area.

The building of this road was followed by a project of detailed regional geological mapping of the Chibougamau area by the Quebec Bureau of Mines. The details of mine and property development were reported on by Graham (1953), Graham et al. (1953) and Assad (1957). Detailed mapping in the Doré Lake area include the work of Horscroft (1958), Smith (1960) and Allard (1960), whilst the north half of Obalski township, which includes Merrill Island, was mapped by Graham (1956). Allard (1976a), Gobeil and Racicot (1983) and Daigneault and Allard (1990) produced an exhaustive geological review of this region and of the various exploration works and mining developments that took place in the Doré Lake Complex.

Today there are still two producing mines in the Doré Lake area, Copper Rand and Portage, both belonging to MSV Resources Inc. There is also a strong possibility that a former operation, the Cedar Bay mine, may reopen in a near future.

VOLCANO-SEDIMENTARY SUPRACRUSTAL SEQUENCE - GENERAL ASPECTS

Archean volcano-sedimentary sequences are generally characterized by volcanic cycles and interstratified sedimentary units (Windley, 1986) and the CCR is no exception (Allard et al., 1979, 1985; Allard and Gobeil, 1984; Dimroth et al., 1985; Mueller, 1986). Recent advances in the study of both modern and ancient environments enables a direct comparison between ancient sequences and those from known modern tectonic regimes. As a preliminary step, the significance of the volcanic and sedimentary phases of the supracrustal suite will be considered, based both on studies from the area, as well as other Archean and modern areas.

Volcanic phase

Ideal volcanic cycles are represented by an extensive komatiitic and/or tholeiitic base and an upper andesitic-dacitic-rhyolitic part (Goodwin and Ridler, 1970; Goodwin, 1982; Dimroth et al., 1982; Jensen, 1985). The former has been interpreted as a subaqueous basalt plain, composed of massive, pillowed, and brecciated basalts and comagmatic sills (Dimroth et al., 1982; 1984; Mueller et Dimroth, 1989). The felsic part of the cycle represents a volcanic edifice (Ayres, 1982; Easton, 1984) of highly varying dimensions (from 0.2-2.5 km thick / 5-20 km in diameter to 10-14 km thick / 80-120 km in diameter; Goodwin, 1982; Mueller et al., 1989). The felsic lava flows, pyroclastic flows and their reworked counterparts reveal a prevalence of subaqueous deposition. Hydrothermal alteration of these centres is a common feature (Guha, 1984). Preservation of subaerial deposits around these centres is negligible due to a high rate of erosion. Evidence of emergence of these edifices is found in the adjacent sedimentary basins (Mueller and Dimroth, 1987) and synvolcanic plutons, which represent the core complexes of these edifices (Tarney et al., 1976, Dimroth et al., 1985, Chown and Mueller, 1992).

Sedimentary Phase

Continued volcanic construction documented by pyroclastic deposits, effusive lavas, and thick sill intrusions (Ayres, 1982; Staudigel and Schmincke, 1984), as well as plutonic emplacement and uplift after cessation of volcanic activity (Mueller et al., 1989) result in emergence. Erosive process then came into effect so that abundant volcanic detritus is shed into the adjacent elongated basins bordering these islands. Some of these volcanic centres were eroded down to their plutonic roots, as documented by the abundance of tonalitic/dioritic clasts in the conglomerates (Tarney et al., 1976; Mueller and Dimroth, 1984; 1987; Chown and Mueller, 1992).

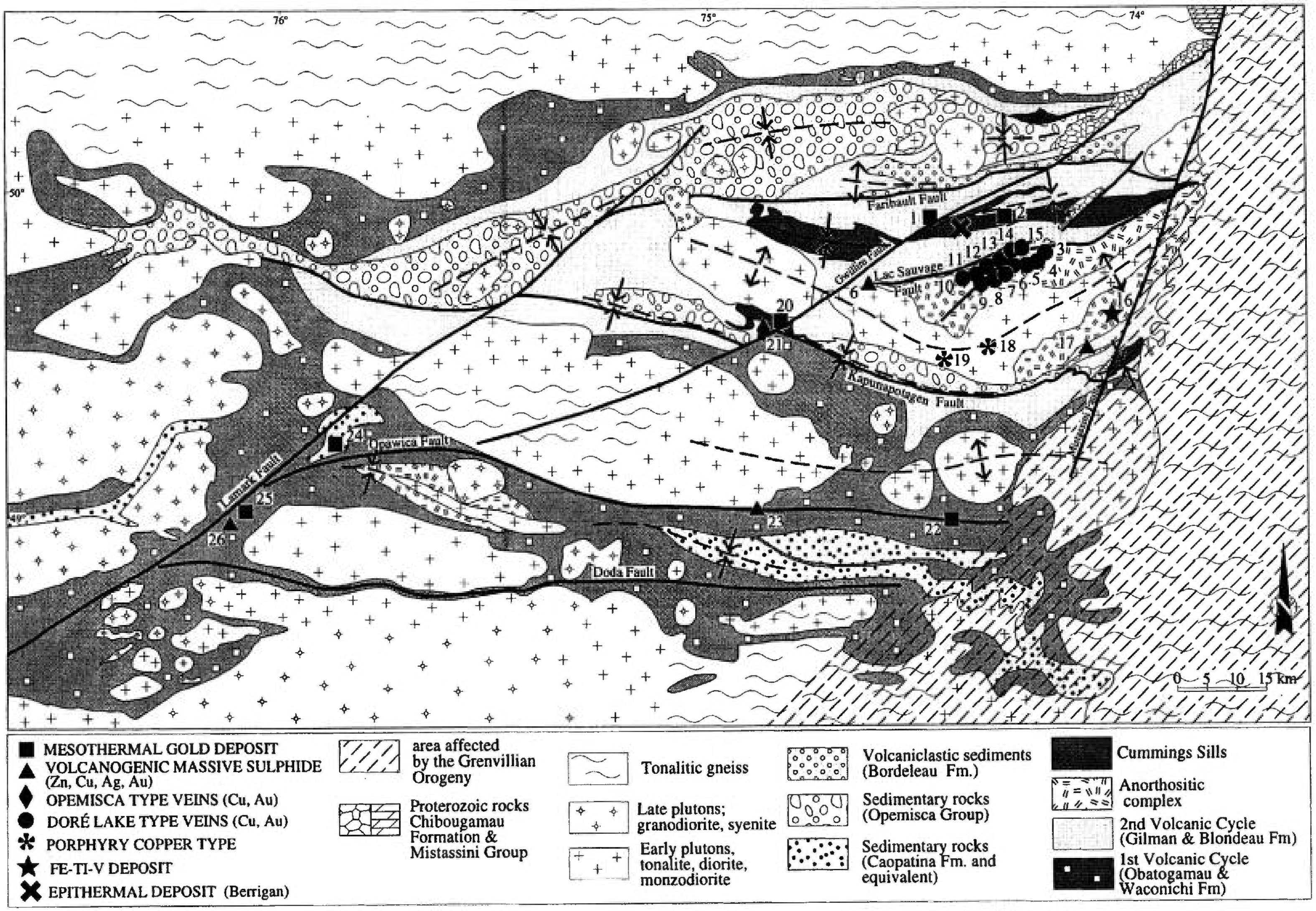


Figure A3: General geology and ore deposits of the Chibougamau-Caopatina region. 1= Gwillim Mine, 2=Norbeau Mine, 3=Portage Mine, 4=Henderson 1 Mine, 5= Henderson II Mine, 6= Bateman Bay Mine, 7= Copper Rand Mine, 8= Merrill Mine, 9= Campbell Main Mine, 10= Obalski Mine, 11= Kokko Creek Mine, 12= Quebec Chibougamau Mine, 13= Cedar Bay Mine, 14= Copper Cliff Mine, 15= Jaculet Mine, 16= Vanadium Showing, 17= Lemoine Mine, 18= Devlin, 19= Queylus breccias, 20= Cooke Mine, 21= Opemisca Mine, 22= Chibex Mine, 23= Lac des Vents showing, 24= Lac Shortt Mine, 25= Bachelor Mine, 26= Coniagas Mine.

CHIBOUGAMAU-CAOPATINA REGION (CCR)

The CCR is subdivided in a Southern Caopatina Segment (SCS) and a Northern Chibougamau Segment (NCS) based on the recognition of sedimentary formations at different stratigraphic levels (Figures A3, A4 and A5). Due to the complex stratigraphic relationships inherent in all volcano-sedimentary terranes several columns are employed (Figure A5). In the SCS (Figure A5.a), an essentially volcaniclastic sedimentary formation is interdigitated with the summital part of cycle 1 volcanic rocks. In contrast, the NCS features an extensive sedimentary unit developing after two volcanic cycles (Figure A5.b, .c, .d and .e). The volcanic cycles and sedimentary units can be related to three paleogeographic evolutionary phases (Table A1): (1) an early extensive subaqueous basaltic plain, (2) development of central volcanic complexes, their gradual emergence and emplacement of synvolcanic plutons, and (3) denudation of the volcanic centres with deposition of the volcano-plutonic detritus in the adjacent basins.

Southern Caopatina Segment

An extensive primitive basalt plain with small interspersed volcanic centres (Figures A3, A5.a) and capped by an early sedimentary sequence defines the SCS. The deep marine basalt plain is composed of masive, pillowed and brecciated basalts. A local increase in brecciation and vesicles is tentatively employed to indicate shoaling of shield volcanoes (Jones, 1969; Wells et al., 1979).

Small, time equivalent felsic volcanoes appear to be omnipresent, some clearly intercalated in the mafic volcanic sequence, and some superposed on it. The volcaniclastic sediments of the first sedimentary unit (Figures A5.a and .c) feature clastic material deposited by sediment gravity flows and minor intercalations of fine- to coarse-grained tuff. The latter documents ongoing volcanic activity. Contacts between the basalt were observed to be conformable and gradational. Erosional contacts were not observed, but this may be an artifact of outcrop exposure.

Stratigraphy of the Caopatina Segment

The Obatogamau Formation is a tholeiitic basalt unit, commonly porphyritic, 3-5 km thick. This unit is very extensive and has been recognized laterally from the Grenville Front to the east (Daigneault, 1986; Hébert, 1980) to the Miquelon area to the west (Gauthier, 1986), a distance over 150 km; and it is common to both the Caopatina and Chibougamau segments. The basalts are tholeiitic in composition (Midra, 1990), and are characterized by abundant phenocrysts of plagioclase distributed throughout some flows, but commonly restricted to phenocryst-rich zones usually, but not always, near the top of flows.

Local felsic volcanic units such as the Lac des Vents Complex in the east, the Wachigabau Member and the Ruisseau Dalime Formation (Sharma and Gobeil, 1987; Sharma et al., 1988; Mueller et al., 1988) in the west, are intercalated or superposed on the Obatogamau Formation. The Lac des Vents Complex (Figures A4, A5.a and .b), a 2-2.5 km thick sequence, is representative of one of these edifices. The mafic-felsic centre is composed of five felsic units interstratified by basalt flows and gabbro sills (Mueller and Chown, 1989; Mueller et al., 1994). The initial three units have the following components: (1) massive to brecciated felsic (dacitic) lava flows, (2) primary and reworked pyroclastic debris, (3) pelagic background sediments, and (4) volcaniclastic sediments deposited by turbidity currents. The upper unit documents the destruction of the edifice and is characterized by framework-supported conglomerates followed by epiclastic volcaniclastic sediments. The former is interpreted as a slope deposit and the latter is allocated to a high-energy, volcanic shelf or nearshore setting (Mueller and Chown, 1989). Renewed volcanic island subsidence and cessation of volcanic activity caused submergence.

The Caopatina Formation represents a 1-2 km thick volcaniclastic sedimentary unit, locally interstratified with primary ash flow tuffs. Conglomerate, sandstone and argillite are the prevalent lithological components deposited in this sedimentary basin. Thick sequences of thin-to-medium-bedded volcaniclastic sandstone display the grading typical of turbidity current deposits, whereas argillite/shale indicates normal pelagic deposition settling out of the water column. Associated massive, stratified and graded bedded conglomerates suggest deposition from high-density turbidity currents or laminar debris flows (Lowe, 1982). Sedimentary features of these deposits suggest moderate to deep water depths, definitely below storm wave base (>200m). This unit, interstratified with pillowed basalts, supports a marine setting. Local occurrence of tuff deposits corroborate ongoing volcanic activity. An early phase of extension must have occurred in order to accomodate a significant sedimentary sequence.

Layered Intrusions

The Opawica River Complex (Maybin, 1976)

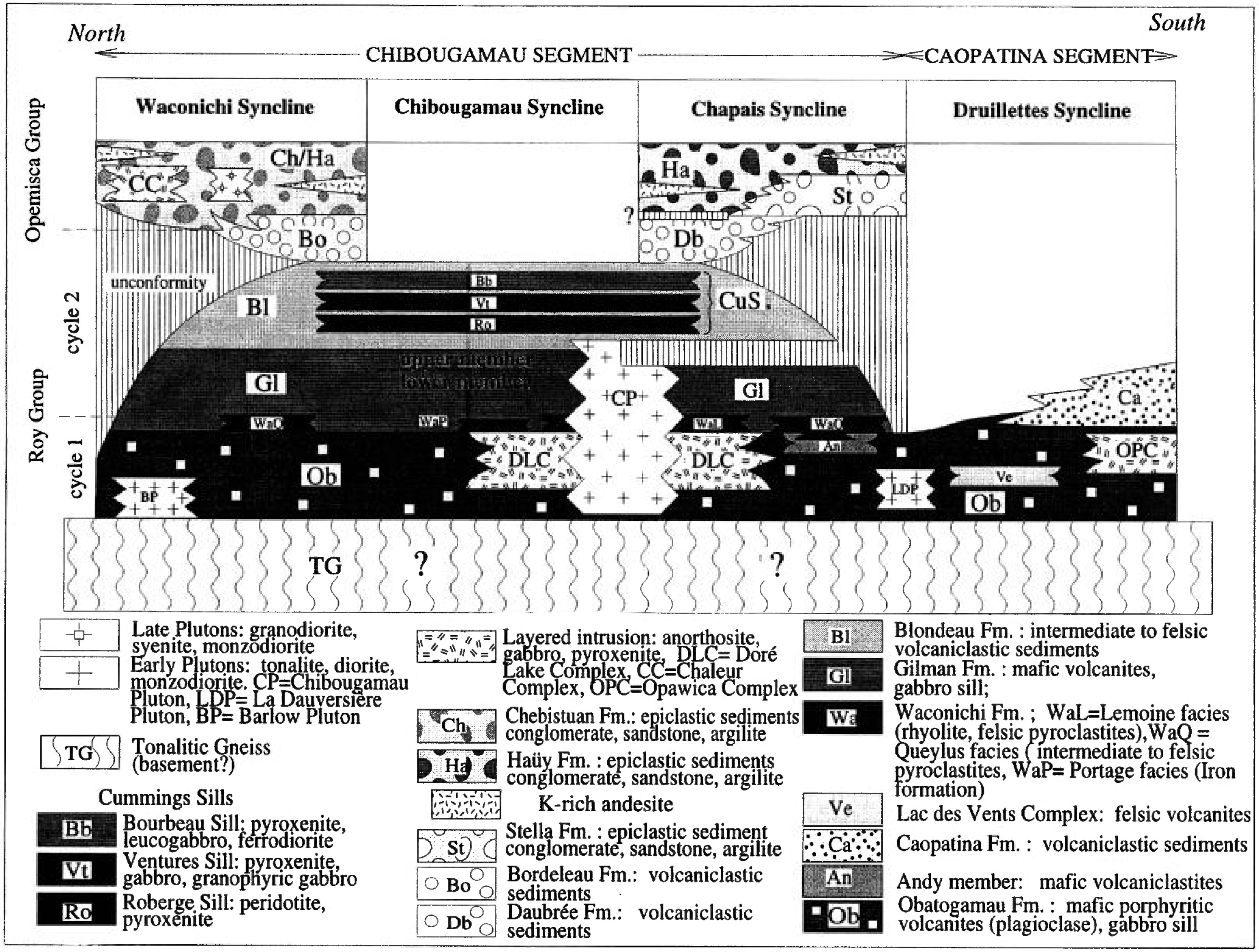


Figure A4: Generalized tectonostratigraphic relationships in the Chibougamau-Caopatina region with respect to the position in synclines. Modified from Daigneault and Allard (1990), Dimroth et al. (1984), and Mueller et al. (1989).

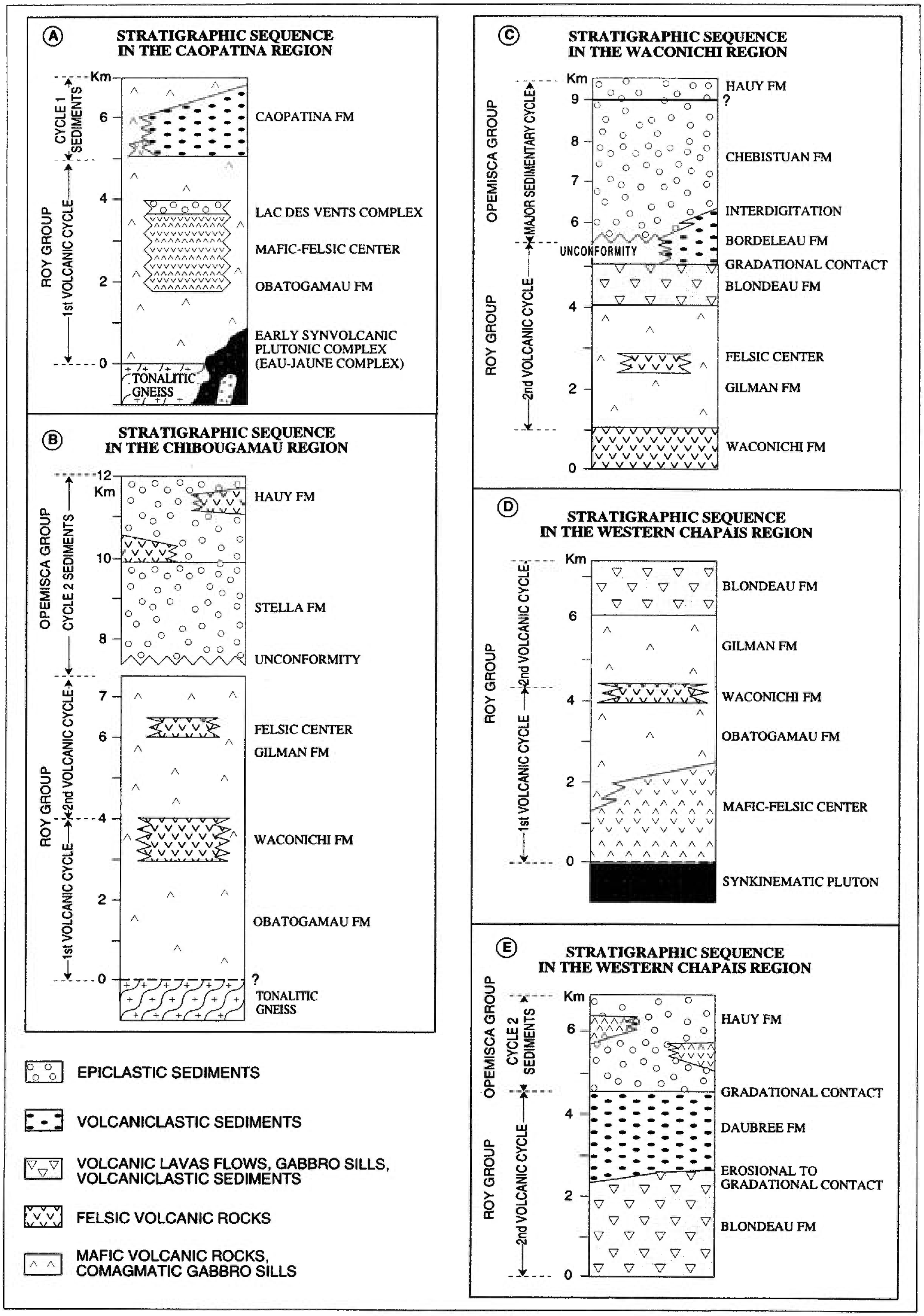


Figure A5: Stratigraphic sections, Chibougamau-Caopatina region (Mueller et al. 1989).

PALEOGEOGRAPHY AND PALEOTECTONIC EVOLUTION

Paleogeographic Phases	INTERNAL ZONE: *N* (Chibougamau)	INTERNAL ZONE: *S* (Caopatina)	EXTERNAL ZONE: (Rouyn-Noranda)
Late Evolutionary Stage	3b Uplift and erosion of volcanic edifices down to plutonic roots; development of fault-bounded sedimentary basins containing plutonic detritus		3 Uplift and erosion of volcanic edifices rarely down to subvolcanic plutons; development of fault-bounded sedimentary basins
Late Evolutionary Stage	2b Emergence and growth of felsic volcanic islands, substantial plutonic accretion and rise of tonalitic gneiss		2 Emergence and growth of felsic volcanic islands, plutonic accretion
Late Evolutionary Stage	1b Renewed basaltic volcanism		1 Extensive submarine lava plain composed of little-differentiated komatiitic, low-K tholeiitic, and calc-alkaline sequences
Early Evolutionary Stage		3a Uplift and erosion of volcanic edifices; development of fault-bounded sedimentary basins.Plutonic detritus is rare.	
Early Evolutionary Stage	1a Local shoaling of small felsic complexes	2a Emergence and growth of felsic volcanic islands, plutonic accretion and rise of tonalitic gneiss	
Early Evolutionary Stage	1a Extensive (100 x 100 km), low-K tholeiitic basalt plain	1a Extensive (100 x 100 km), low-K tholeiitic basalt plain	

Modified from Dimroth et al. 1984, 1985 a.

Table A1: Paleogeography and paleotectonic evolution of the Abitibi Belt (Mueller et al. 1989).

intrudes the Obatogamau Formation near its base. It consists of a Lower Anorthosite Zone (3500 m), composed of gabbroic anorthosite, gabbro and anorthositic gabbro, overlain by Gabbro-Ferropyroxenite Zone (900m). The rocks of the complex are coarse-grained and display a well-preserved cumulus texture and rhythmic layering despite the effects of regional metamorphism. Plagioclase phenocrysts are larger and more abundant in Obatogamau basalts near the complex (Midra, 1990) suggesting a close affinity between the two, which is borne out by their similar chemistry.

The Chutes de l'Esturgeon Complex (Lamothe, 1983) is 1300m thick and is composed of peridotite at the base grading to quartz gabbro at the top. This layered intrusion also has a tholeiitic affinity (Quirion, 1990).

Northern Chibougamau Segment (NCS)

The NCS displays two volcanic cycles (Figures A5.b and A7) followed by a terminal sedimentary unit. Cycle 1 volcanic rocks in the NCS are similar to those described in the SCS and will not be dealt with in further detail. Recent U-Pb zircon age dating of felsic cycle 1 at 2730 ± 2 Ma constrains the age of volcanic cycle 1 (Mortensen, 1993). Cycle 2 volcanic rocks show that a primitive plain with overlapping shield volcanoes developed (Allard and Gobeil, 1984) and central volcanic edifices evolved upon these. The felsic part of cycle 2 is characterized by volcanic activity centred around the synvolcanic Chibougamau pluton (2718 ± 2 Ma, Krogh, 1982), which Dimroth et al. (1985) described as Chibougamau Island. This centre was the locus of paroxysmal volcanism and felsic to intermediate lava flows (Figure A6.a). Documentation of volcanic activity is given in the surrounding basins where marine volcaniclastic deposits prevail (Archer, 1984). Some areas to the north and west of the major centre experienced local volcanism. Mafic to ultramafic sills, up to 1,2km thick, the youngest of which has been dated at 2717 ± 1 Ma (Mortensen, 1993) are related to synvolcanic pluton emplacement. The coeval emplacement of felsic plutons and mafic sills high in the stratigraphic succession contributed considerably to the uplift of this central volcanic complex (Mueller et al., 1989).

The unconformably overlying sedimentary cycle largely derives its detritus principally from cycle 2

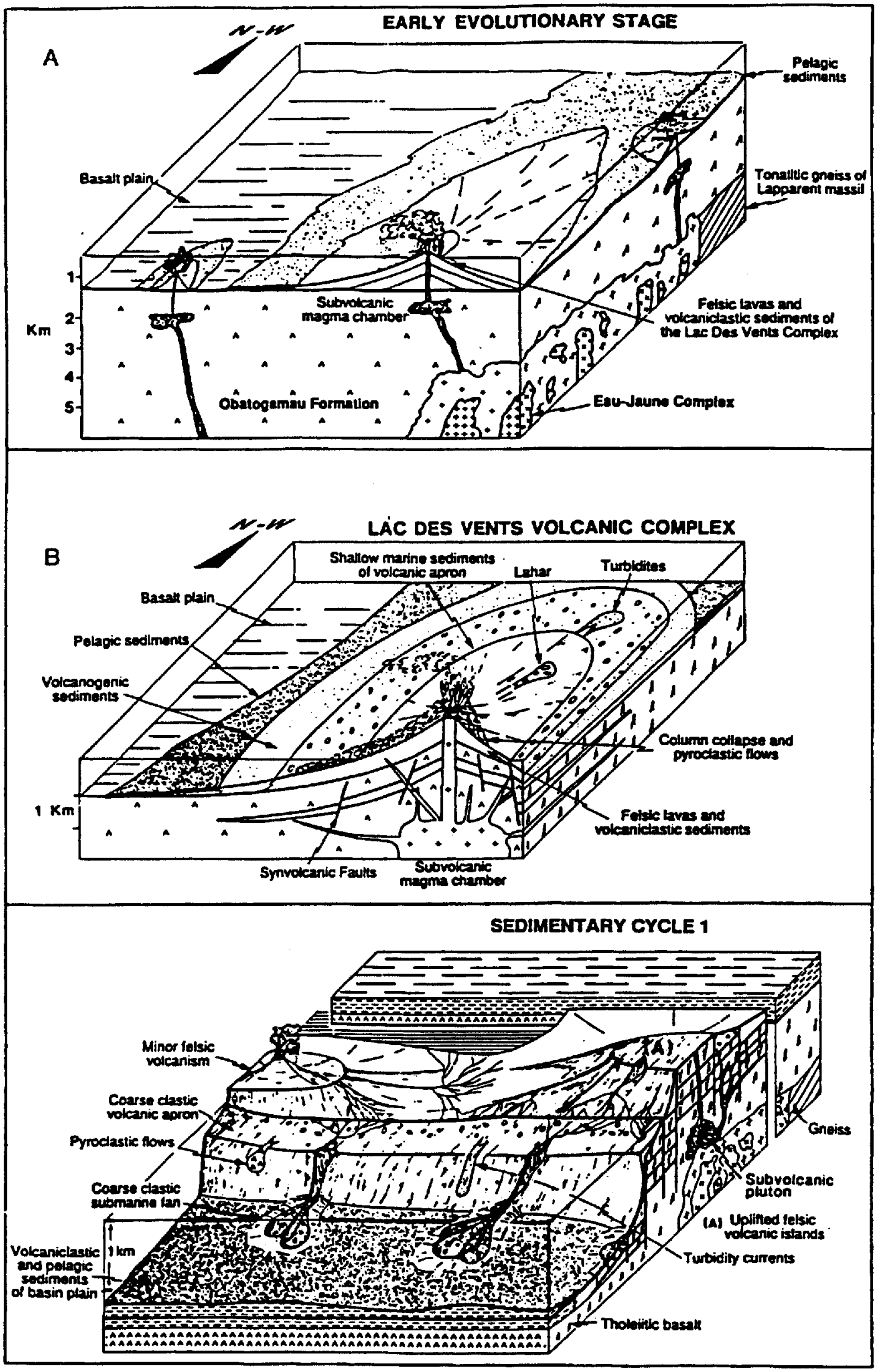


Figure A6: Evolution of the first volcanic cycle (Mueller et al. 1989).

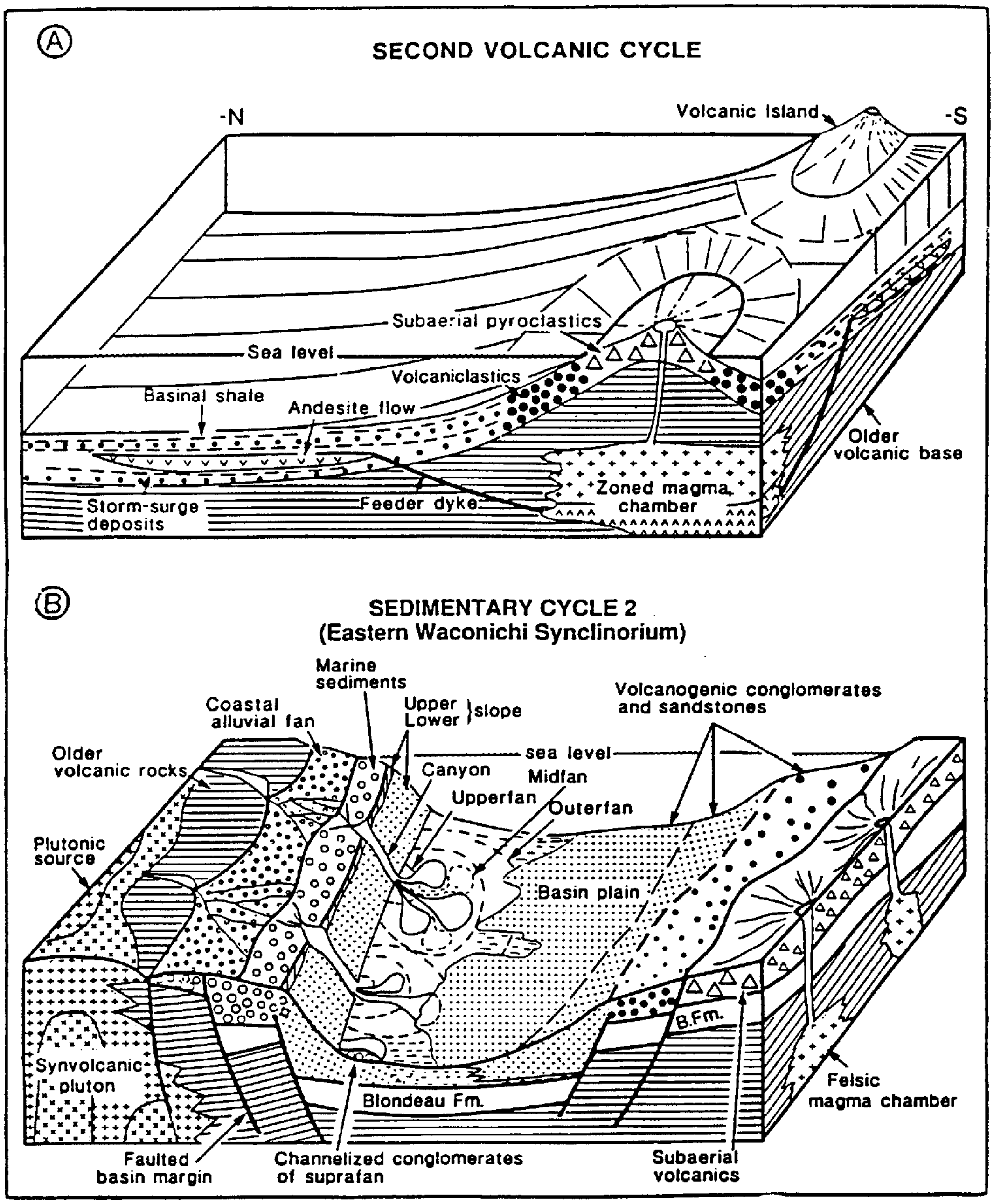


Figure A7: Evolution of the second volcanic cycle (Mueller et al. 1989).

rocks and synvolcanic plutons (Figures A6.b and A7). This sedimentary group can be divided into an initial epiclastic formation where the detritus originates from the cycle 2 volcanic rocks, sills, and synvolcanic plutons (Mueller and Dimroth, 1984, 1987). A second and terminal epoch is characterized by shoshonitic-dominated volcanism (Dostal and Mueller, 1992) in a marine (Mueller, 1986) and terrestrial environment interstratified with coarse clastic sediments (Mueller and Dimroth, 1987). An overview of the different facies and facies associations in the northern and southern basin of the NCS is given in Figures A6 and A7.

Stratigraphy of the Chibougamau Segment

The stratigraphy of the Chibougamau Segment (Figures A4, A8 and A9) is divided into two groups: the Roy Group dominated by volcanic rocks and the Opemisca Group dominated by sedimentary rocks (Allard et al., 1985). The older Roy Group is

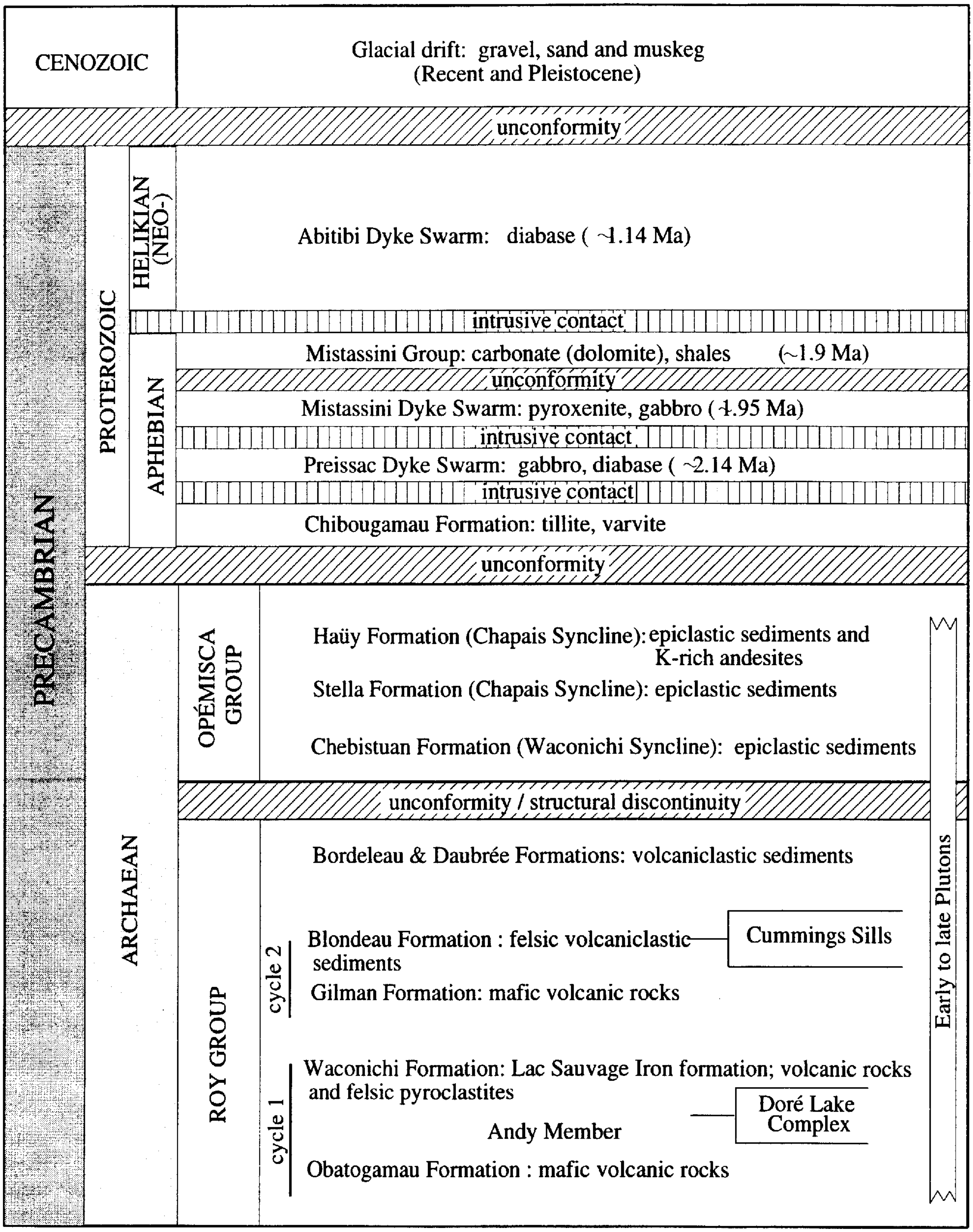


Figure A8: Stratigraphy of the Chibougamau segment.

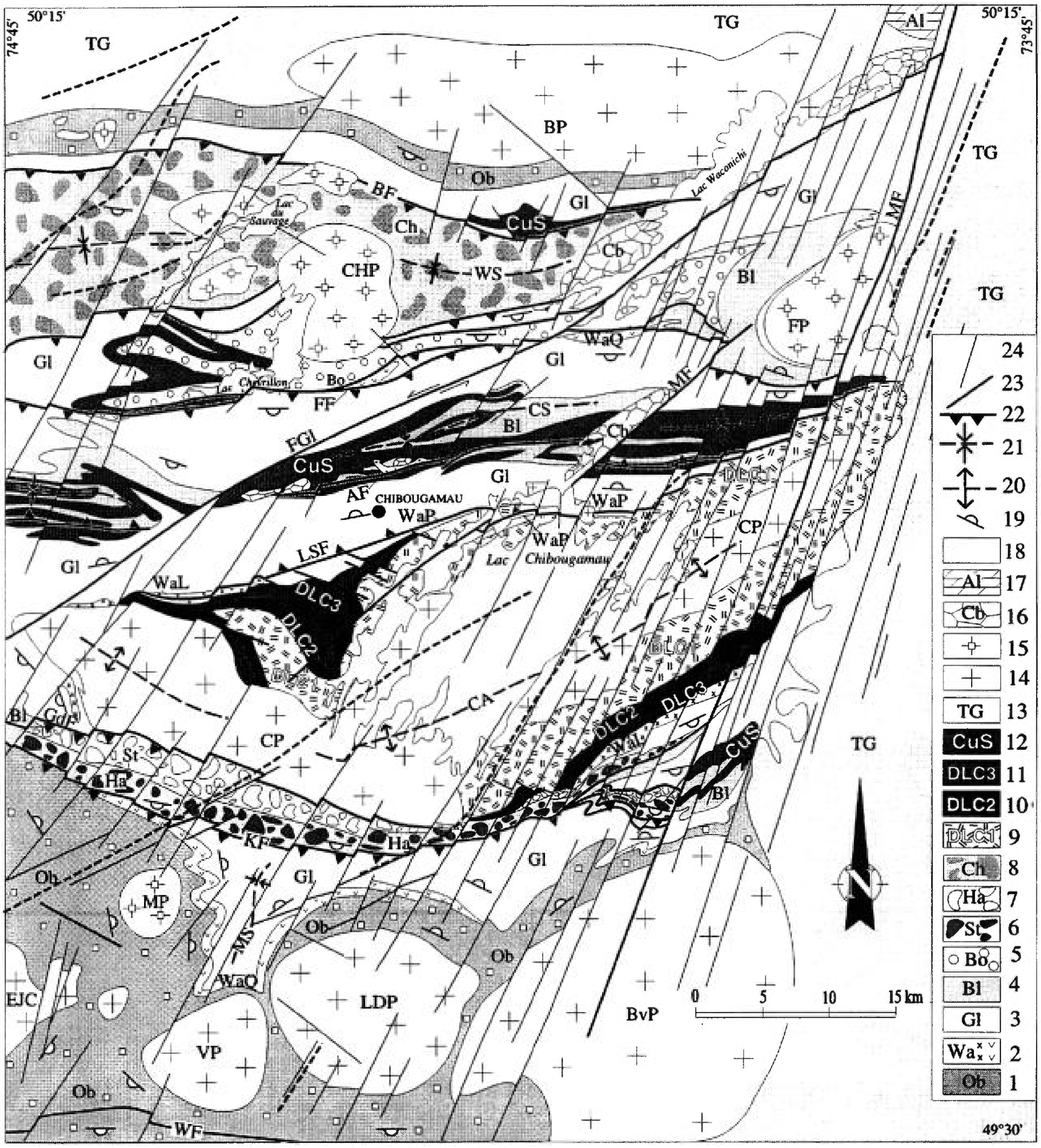


Figure A9: Detailed structural map of the Chibougamau area (adapted from Daigneault and Allard, 1990). 1 (Ob) = Obatogamau Fm. (mafic porphyritic volcanite); 2 (Wa) = Waconichi Fm., WaL= Lemoine type (rhyolite, felsic pyroclastite), WaQ = Queylus type (intermediate to felsic pyroclastite), WaP= Portage type (Iron Formation); 3 (Gl) = Gilman Fm. (mafic volcanite); 4 (Bl) = Blondeau Fm. (intermediate to felsic volcaniclastite); 5 (Bo) = Bordeleau Fm. (felsic volcaniclastite); 6 (St) = Stella Fm. (sedimentary rocks); 7 (Ha) = Haüy Fm. (sedimentary rocks and K andesitic lava); 8 (Ch) = Chebistuan Fm. (sedimentary rocks); 9 (DLC1) = Doré Lake Complex, anorthositic Zone (anorthosite, gabbro); 10 (DLC2) = Doré Lake Complex, layered Zone (gabbro, magnetitite); 11 (DLC3) = Doré Lake Complex, granophyric Zone and Upper border Zone (gabbro, anorthosite); 12 (CuS) = Cummings Sills (gabbro, pyroxenite, peridotite); 13 (TG) = Tonalitic Gneiss; 14 = Early plutons (tonalite, diorite, monzodiorite); 15 = Late Plutons (granodiorite, syenite);

made up of five formations composed of volcanic rock of various compositions. The Opemisca Group, is divided into three formations composed of conglomerates, sandstone and argillite. The Opemisca Group overlies the Roy Group, the contact is locally unconformable but in most cases, is marked by E-W trending longitudinal faults (Daigneault et Allard, 1987).

The Obatogamau Formation (3-4 km) represents the base of the volcano-sedimentary succession and is the most important volcanic episode of the lower Group. Centimetric megacrysts of plagioclase make up 3 to 20% of the pillowed to massive basalts. This stratigraphic unit systematically occupies the base of the supracrustal assemblage. Felsic and intermediate tuffs and breccia constitute a very small portion of the unit.

The Waconichi Formation (800m) is volumetrically less important; it is constituted of dacitic and rhyodacitic rocks which mark the end of the basaltic volcanism of the first cycle. The Waconichi Formation is divided in three principal facies. The Lemoine facies is composed of rhyolitic porphyry and rhyolite, the Queylus facies consists of an intermediate to felsic pyroclastic assemblage and finally the Portage facies is an exhalite typified by the lac Sauvage Iron Formation (Henry and Allard, 1979). The Lemoine facies is economically the most important since it contains the Lemoine mine on the south limb of the Chibougamau anticline and a good prospect on the north limb. The dominant rhyolitic porphyry of the Lemoine facies is interpreted to be subvolcanic intrusion. The presence of rhyolitic volcanoclastites and minor lobed rhyolite are also characteristic of this facies. Synvolcanogenic mineralization is characterized by well-laminated massive sulphide lenses rich in sphalerite and chalcopyrite.

The Gilman Formation (3-4 km) is a return to, or a continuation of, the mafic volcanism. The lavas are commonly very similar to those of the Obatogamau Formation (Ludden et al., 1984; Picard and Piboule, 1986) but they are generally aphyric. Around the town of Chibougamau, the unit can be locally divided into two members. The lower Gilman, characterized by basaltic flows and the upper Gilman, slightly more evolved, by andesitic to dacitic flows. Small lenses of intermediate volcaniclastites occupy the limit between the two members. This more evolved member has only been recognized at this one locality and it represents less than 5% of the Gilman Formation.

The Blondeau Formation (2-3 km) is constituted of volcaniclastic rocks of varying composition. The principal rock types are felsic and cherty tuff, volcanogenic sandstone, graphitic shales and rhyodacitic flows. Some comformable disseminated and massive sulphide lenses are present in the pile. Mafic variolitic flows and hyaloclastite are also present in this unit. The Blondeau Formation hosts the three mafic sills of the Cummings Complex.

The Bordeleau Formation and its equivalent the Daubrée Formation, are composed of a monotonous sequence of felsic to intermediate volcaniclastic rocks constituted by volcanogenic sandstone, argillite and minor conglomerate, probably derived from the Blondeau Formation, and representing a transition to the sedimentary rocks of the Opemisca Group (Dimroth et al., 1985).

The Opemisca Group is composed of three formations. The time-equivalent Stella and Chebistuan Formations (Figures A4 and A9) are epiclastic sedimentary units derived from volcanic cycles one and two. Conglomerate, sandstone, argillite and shale are the major constituents of these formations. Abundant granitoid fragments in the conglomerates are principally derived from the Chibougamau Pluton, an unroofed synvolcanic pluton. The different sedimentary facies of these formations are summarized in Figures A6 - A7 (Mueller et al., 1989) and indicate that depositional environments range from deep marine, slope, shallow marine to fluvial.

The younger Haüy Formation is characterized

Figure A9 (continued): Detailed structural map of the Chibougamau area (adapted from Daigneault and Allard, 1990). 16 (Cb) = Chibougamau Fm., Proterozoic (sedimentary rocks); 17 (Al) = Albanel Fm., Proterozoic (carbonates); 18 = diabase dyke, Proterozoic; 19= younging direction; 20= anticline; 21= syncline; 22 = high angle reverse fault; 23= NE trending fault; 24= NNE trending grenvillian fault.

For the plutons: BP= Barlow Pluton, ChP= Chevrillon Pluton, FP= France Pluton, CP= Chibougamau Pluton, EJC= Eau Jaune Complex, MP= Muscocho Pluton, VP= Verneuil Pluton, LDP= La Dauversiere Pluton, BvP= Boisvert Pluton.

For the structural elements: BF= Barlow Fault, FF= Faribault Fault, AF= Antoinette Fault, LSF= Lac Sauvage Fault, GdF= Goudreau Fault, KF= Kapunapotagen Fault, GlF= Gwillim Fault, MF= McKenzie Fault, MF= Mistassini Fault, WF= Winchester Fault, WS= Waconichi Syncline, CS= Chibougamau Syncline, CA= Chibougamau Anticline, MS= Muscocho Syncline.

by a late shoshonitic type volcanism (Picard and Piboule, 1986b; Dostal and Mueller, 1992) forming massive and brecciated andesite/basalt flows. The depositional environment, as documented by the intercalated sedimentary facies, varies from fluvial to marine (Piché, 1984; Mueller and Dimroth, 1987).

Doré Lake Complex

The Doré Lake Complex, is an anorthositic layered intrusion (Allard, 1970; 1976a; Caty, 1970) that originated from the differentiation of a tholeiitic magma, similar to the one that produced the basalts of the Obatogamau Formation (Midra, 1990). It was emplaced at the base of the Waconichi Formation. A schematic map summarizing the principal subdivision of the Doré Lake Complex is shown in Figure A10 and the detailed division of the complex is presented in Table A2. Of the three major subdivisions of the complex, the Lower Series is the thickest. The most important part of the Lower Series is the Anorthositic Zone except for a minor magnetitite zone that occurs locally at the base of the intrusion and a peridotite zone that occurs in the northwestern part of the intrusion (Figure A10).

The Anorthositic Zone is essentially made up of 2500 to 3600 m of gabbro and anorthosite and contains most of copper-gold deposits. It is characterized by very coarse cumulus bytownite crystals, up to 30 cms in places, replaced by albite speckled with zoisite. The intercumulus magnesium-rich pyroxene is replaced by chlorite and locally by actinolite. An intrusive breccia related to the mafic phases of the Chibougamau commonly occupy the lower contact of the Anorthositic Zone. At the top of the sequence, the gabbro and anorthosite change abruptly to magnetite-rich rocks of the Layered Series.

The Layered Series is well developed on the south flank and in the north-west part of the complex. On the south flank, five zones are distinguished, three rich in oxide phases (P1, P2 and P3) and two others similar to the Anorthositic Zone (A1 and A2; see Table A2). At the base, the 30 to 90 m thick P1 Zone contains economic vanadium values in the magnetitite horizon. The P2 Zone (9-60 m) resembles the P1 Zone except for the lower vanadium values. A ferrogabbro and a magnetitite characterize its upper part. The P3 Zone is made

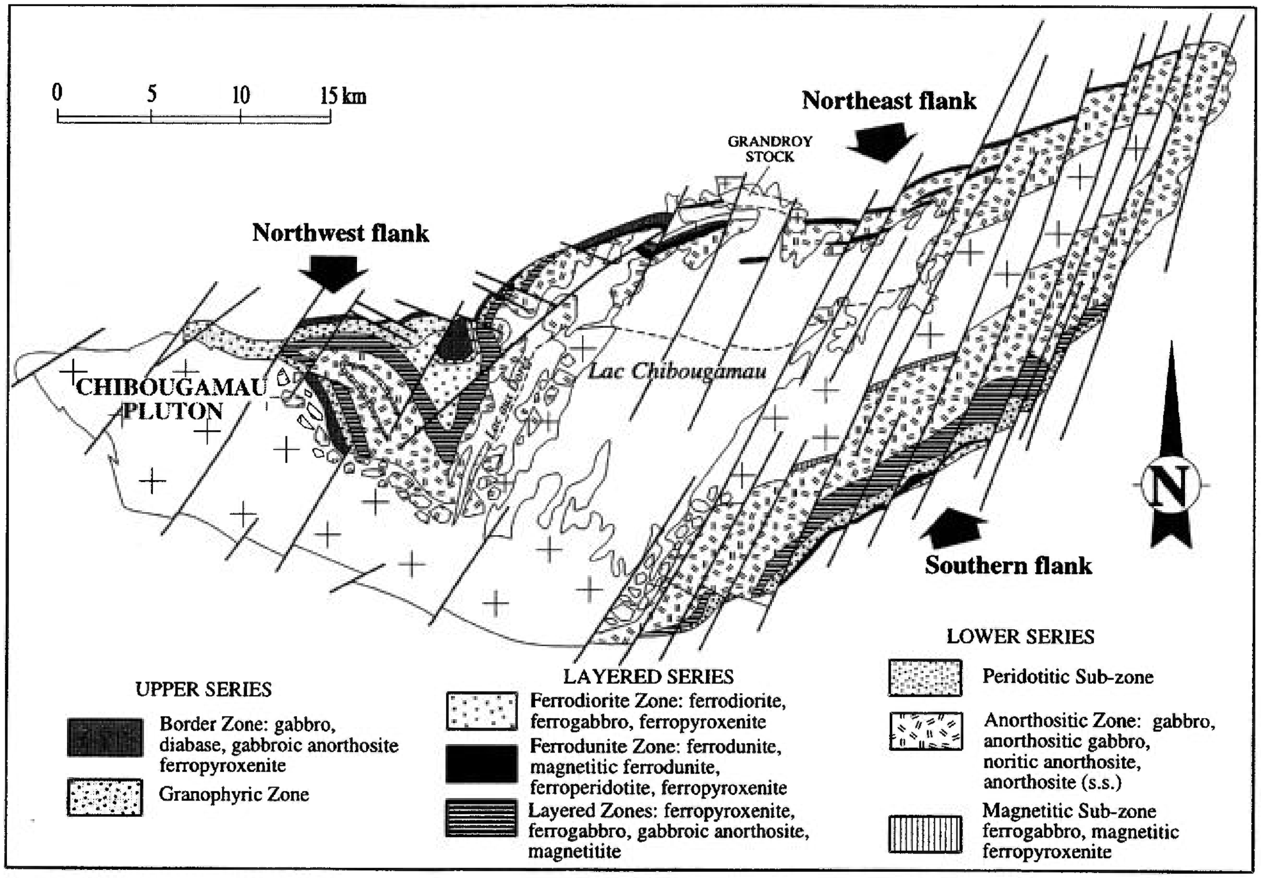


Figure A10: Schematic map of the Doré Lake Complex, adapted from Daigneault & Allard (1990).

	South flank			North flank				
				western segment			eastern segment	
	ZONES	SUB-ZONES	LITHOLOGY	ZONES	SUB-ZONES	LITHOLOGY	ZONES	LITHOLOGY
UPPER SERIES	BORDER GRANOPHYRE		Gabbro Gabbroic Anorthosite	BORDER GRANOPHYRE		Gabbro Diabase Gabbroic anorthosite	BORDER	Ferropyroxenite Anorthositic gabbro
LAYERED SERIES				FERRODIORITE S.l.	F_3 F_2 F_1	Ferrodiorite (s.s.) Ferrogabbro Ferropyroxenite	FERRODUNITE* S. l.	Ferrodunite (s.s.) Magnetitic ferrodunite Ferroperidotite Ferropyroxenite
	LAYERED ZONES P_3	*quartz* *apatite and ilmenite* *ilmenite and ferrosilicates*	Ferropyroxenite Ferrogabbro	LAYERED ZONES NP_3		Quartz- ferropyroxenite		
	A_2		Gabbroic anorthosite					
	P_2		Magnetitite Ferropyroxenite Ferrogabbro	NP_2		Apatite-ilmenite- ferropyroxenite		
	A_1		Gabbroic Anorthosite					
	P_1		Magnetitite Ferropyroxenite Ferrogabbro	NP_1		Magnetitic ferrogabbro		
LOWER SERIES	ANORTHOSITE s.l.		Gabbro Anorthosic gabbro Noritic anorthosite Anorthosite (s.s.)	ANORTHOSITE S.l.		Gabbro Anorthositic gabbro Noritic anorthosite Anorthosite (s.s.)	ANORTHOSITE S.l.	Gabbro Anorthositic gabbro Noritic anorthosite Anorthosite (s.s.)
		Magnetite	Ferrogabbro Magnetitic ferropyroxenite		*Peridotite*			

* Note: unlayered rocks outcropping on Mont du Sorcier and lac Robert area.

Table A2: Stratigraphy of the Doré Lake Complex (Daigneault & Allard 1990).

up of a dark green ferropyroxenite interlayered with thin ferrogabbro horizons.

The Upper Series includes the Granophyre Zone and the Upper Border Zone. The Granophyre Zone is found in the south flank and on the Northwest part of the complex in juxtaposition with rhyolitic rocks of the Waconichi Formation. The rocks of the Granophyre Zone ressemble leucocratic tonalites. On the south flank the thickness of the Granophyre Zone varies from 150 to 900 m. The Upper Border Zone forms thin discontinuous lenses in contact with the volcanic rocks of the Roy Group which overlie the complex. Where the Upper Zone is absent, the granophyric zone is in direct contact with the volcanites. The Upper Zone consists of fine-grained gabbro (diabase), ferropyroxenite rich in magnetite, anorthosite and gabbro. Enclaves of Upper Border gabbro are found in the Granophyre Zone and are the considered to be good evidences of a chilled zone. In several localities, many blocks of rhyolitic porphyry can be seen which represent remnants of rocks overlying the intrusion that have been incompletely melted.

The Granophyre Zone and the Layered Zone are present only where the complex is in contact with the rhyolitic rocks of the Waconichi Formation. Where the complex is in contact with mafic rocks on the north-east flank, the Granophyre and Layered Zones are absent and the upper contact of the complex is characterized by the presence of massive magnetite-rich ferropyroxenite and ferrodunite typified by the presence of olivine.

The parent magma of the Doré Lake Complex is a tholeiitic basalt of Obatogamau type containing over 10% plagioclase phenocrysts. The main pulse corresponding to a huge magma surge produced the main body of the complex (Figure A10). A chilled zone (Upper Border Zone) was formed at the border of the magma chamber in contact with the host rock. Coarse plagioclase megacrysts suggest very slow crystallization. The accumulation of plagioclase produced the Anorthositic Zone. The accumulation process may have been accelerated by expulsion of liquid during compaction. Heat loss at the top of the complex is responsible for melting the rhyolitic rocks of the Waconichi Formation. The interaction between two magmas, one rich in iron, the other rich in silica, radically transformed conditions in the magma chamber. The input of silica contributed to the formation of plagioclase and iron-rich pyroxene (two saturated minerals). The formation of abundant primary magnetite is favoured by a change in oxygen fugacity in zones P1 and P2. The conditions change in the zone A2 and become radically different in zone P3 where the magnetite is replaced by ferroaugite and ferrohypersthene. After deposition of the P3, the input of more siliceous magma gave rise to the formation of the granophyre. Pieces of Upper Border Zone gabbro were broken off and fell into the viscous magma.

Cummings Complex

The Blondeau Formation is intruded by a trio of differentiated sills called the Cummings Complex (Duquette, 1976). These sills represent an excellent marker horizon since the petrography, texture, and chemistry of each sill is characteristic and their order of superposition is identical throughout the district: the Bourbeau Sill at the top, the Ventures sill in the centre and the Roberge sill at the base. They have been mapped from the Grenville Front westward for a distance of 160 km. The total thickness for the three sills is approximately 1200 metres, each sill varying in thickness between 200 and 1000 metres. These sills have been recognized in the core of the three major syncline of the Chibougamau Segment (Figure A9) . They have been described on the north limb of the Waconichi Syncline (Caty, 1978; Boudreault, 1977), from both limbs of the Chibougamau Syncline (Duquette, 1976) from the Chapais Syncline in two places, around the Chapais area copper mines (Duquette, in Allard et al., 1972) and and near the Grenville Front area (Allard, 1981).

The Roberge sill is composed of ultramafic rocks varying in composition from dunite to pyroxenite and wehrlite. The olivine is transformed in serpentine and magnetite and the pyroxene is uralitised. The Ventures sill includes a dark green pyroxenite at the base, a foliated gabbro, a coarse poikilitic gabbro named "Ventures Gabbro" and locally, small lenses of granophyric gabbro. The Bourbeau sill, the more evolved, is composed of a thin pyroxenite at the base overlain by a leucogabbro and a large ferrodiorite and quartz ferrogabbro unit.

Chaleur Lake Complex

The Chaleur Lake Complex (Durocher, 1985) intrudes rocks of the Opemisca Group (Gobeil, pers. comm), and is intruded by the Opemisca pluton. The complex, although strongly deformed, appears to be composed of leucogabbro overlain by a Layered Zone (gabbro, pyroxenite and anorthosite) overlain in turn by a gabbroic anorthosite containing lenses of peridotite and dunite, particularly near the contact with the Layered Zone.

STRUCTURAL GEOLOGY

The Chibougamau area is part of an Archean Greenstone Belt representing a large synclinorium of volcanic and sedimentary rocks enclosed within tonalitic gneisses. Within this basin, several E-W trending regional folds are responsible for the verticalization of the strata. Synclinal structures, with younger sediments enclosed within the core, are well outlined and are clearly associated with an axial plane regional schistosity. Anticlines, on the other hand, either form domes with a core occupied by early tonalitic to dioritic plutons or are destroyed by E-W trending longitudinal faults. In the latter case, the presence of an anticline is deduced by reconstitution of stratigraphic sequences dismembered by reverse movements along E-W trending deformation corridors.

The Kenoran Orogeny caused the major deformation of the area and accounts for the large folds and the regional schistosity (Dallmeyer et al., 1975). The age of deformation in the Abitibi Belt is considered to be 2680-2700 Ma (Corfu et al., 1989) corresponding to the Shebandowan event of the Kenoran Orogeny. The actual age of deformation in the Northern Abitibi Zone is poorly constrained, although ages of syntectonic plutons (Table A3) appear to agree with those from the Southern Zone. Model Pb ages for a number of East-West-trending shear-hosted mineral deposits in the Chibougamau district (Thorpe et al., 1984) also fall in this range.

Folding

Four important folding events are distinguished (D_1, D_2, D_3 et D_4). Three of those events are Archean, the fourth one is Grenvillian and limited to the eastern border of the Belt where it is in contact with the Grenville Orogen. The three Archean deformation phases can be considered as part of a deformation continuum and not as chronologically separate and distinct phases. Figure 8 summarizes the main structures of the area.

An early phase of deformation (D1) produced broad north-south folds lacking a schistosity. In the southern portion of the area, an important regional north-south striking fold the Muscocho Syncline has been identified (Daigneault and Allard, 1983). The early development of this structure was determined by the inversion of the structural facing in axial zones of the folds associated with the regional schistosity and by the fact that the regional foliation clearly cuts across both limbs of this early flexure. The early deformation may be the precursor of the regional deformation; in this phase flexures are caused by the simple sinking of the crust under its own weight. The location and attitude of the folds may be controlled by paleogeographic factors responsible for the thickness of the volcanic prism (i.e. volcanic centres).

The regional deformation (D2) is responsable for the large east-west folds. Six major structures of regional extent control the attitude of the rocks of the belt (Figures A3 and A11); From north to south, the Waconichi Syncline, the Chibougamau Syncline, the Chibougamau Anticline, the Chapais Syncline, the La Dauversière Anticline, and the Druillettes Syncline.

The combination of both north-south and east-west systems produces the framework of the regional dome and basin interference pattern (Figure A9). The climax of regional deformation generated a regional schistosity, vertical stretching lineations and tightening of folds with verticalization of their axes.

The regional schistosity is a flow schistosity generally well developed throughout the whole area. It is an axial-plane structure and it contains a subvertical stretching lineation. The principal tectonic fabric is locally disturbed in the vicinity of early plutons showing an interaction between a north-south horizontal shortening and a local stress field generated or deviated by granitoid masses. A greater level of deformation (L-S and L type tectonites) is observed in areas adjacent to the early plutons when compared to the rest of the region. A concentric schistosity trajectory around the plutons act as an obstacle to the regional E-W trajectories, thus producing small interaction zones

PLUTON	AGE (Ma)	METHOD	SOURCE	PETROGRAPHIC SUITE
WASWANIPI	2616 ± 19	Pb-Pb	1	GRANODIORITE
MUSCOCHO	>2698	U-Pb	2	
FRANQUET	2692 ± 4	U-Pb	3	
OLGA	2693 ± 3	U-Pb	2	TONALITE-GRANODIORITE
RENAULT	2718 ± 12	Pb-Pb	1	
RENAUD	2700 ± 2	U-Pb	2	
ABITIBI	2690 ± 4	U-Pb	2	
PALMAROLLE	2696 ± 1	U-Pb	2	
LA DAUVERSIÈRE	2720 ± 2	U-Pb	2	
BARLOW	2695 ± 3	Pb-Pb	1	MONZODIORITE
OPEMISCA	2695 ± 8	Pb-Pb	1	
OPEMISCA	2697 ± 2	U-Pb	3	
RADIORE	2715-2721	U-Pb	2	TONALITE / DIORITE
CHIBOUGAMAU	2718 ± 2	U-Pb	5	
TASCHERAU	2718 ± 2	U-Pb	3	
DETOUR	2722 ± 3	U-Pb	4	
QFP	2718 ± 2	U-Pb	2	
LAPPARENT	2708 ± 12	U-Pb	2	TONALITIC GNEISS

1) Gariépy and Allègre (1985); 2) Mortensen (1993); 3) Frarey and Krogh (1986); 4) Marmont and Corfu (1988); and 5) Krogh (1982).

Table 6: Age dates of plutons of the Northern Abitibi Blet.

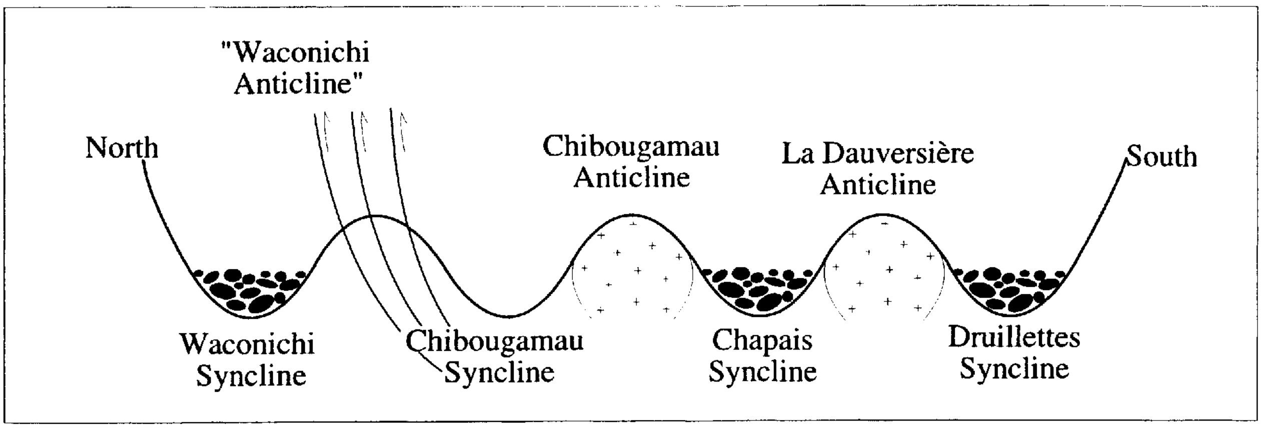


Figure A11: Schematic cross section of the Chibougamau-Caopatina region, adapted from Daigneault & Allard (1990). The Chibougamau area consist of one large synclinorium constituted by 4 major synclines. Three of them contain younging sediment in the core. Two anticlines are occupied by early plutons while the other one is destroyed by a series of E-W trending longitudinal faults.

characterized by strong vertical extension. These relations suggest an interference between a regional stress field producing a north-south horizontal shortening, and local stress fields controlled or deviated by granitoid plutons acting as resistant nuclei.

The third event (D3) includes several phenomena superposed on elements generated during events 2 and 1. It is not necessarily a distinct phase since it could be the continuation of the regional deformation (D2). These manifestations tend to be more developed in anisotropic zones. Their main characteristic is the presence of a northeast-trending crenulation cleavage with a subvertical dip. Where this cleavage becomes more developed, asymmetric Z folds may be seen. These folds are generally open and their plunge is moderate to abrupt with a tendency to be coaxial with the stretching lineation.

Faults and shear zones

Four fault populations can be distinguished on the basis of direction and structural signature. These include an East-West, Southeast, Northeast and a North-Northeast System. The last fault system like the D4 deformation is related to the Grenvillian Orogeny.

The East-West trending faults belong to a system of large regional breaks found throughout the Abitibi Belt. It consists of ductile shear zones varying in thickness from 100 to 1000 metres and representing the oldest faults in the area and the most important in their impact on the stratigraphy and metallogeny. These faults, with reverse movement, represent the final stage of the regional deformation. Notably, they occasion a repetition of portions of the stratigraphic sequence and, in other cases, truncate regional folds, juxtaposing different structural domains (Daigneault and Allard, 1987). Locally, reverse movement along these faults places unusual stratigraphic units in contact.

The Kapunapotagen Fault (Figure A12.a) is well outlined by the contact between the Opemisca sedimentary Group with the Roy volcanic Group. This fault is recognized for a length of 90 km, and it occupies the axial plane of the Chapais syncline. The structural cross-section in Figure A12.a shows the position of the fault in the hinge of the syncline. The presence of strong vertical stretching lineation in the fault zone is suggestive of a vertical movement. A south over north movement sense is indicated for this fault.

The Faribault Fault (Figure A12.b) separate a sedimentary basin to the north from volcanic asssemblage to the south. It is characterized by important shear zones concentrated in the volcanic domain, and the sedimentary domain is more or less unaffected by the deformation. A strong subvertical stretching lineation in the volcanic domain and a relative absence in the sedimentary domain is suggestive of a vertical movement of south over north.

The Doda Fault (Figure A3) is located in the Druillettes Syncline (Lauzière et al., 1989). It consist of a large East-West trending high strain zone slightly different of the East-West discontinuities belonging to the northern Chibougamau segment by its prominent subhorizontal stretching lineation. This deformation zone seems to have a complex strain history since the variability in the attitude of the stretching lineation and contradictory kinematic indicators. The influence of the Grenvillian Orogeny on this fault remains to be evaluated.

The Lac Sauvage Fault (Figure A12.c) includes several East-West trending shear zones, part of a large anastomosing deformation corridor. The high strain zone locally reaches a width of 400 m. The presence of a down-dip stretching lineation favours a vertical component of movement. Kinematic indicators are suggestive of a north over south movement which explains the repetition of slices of the Doré Lake Complex and other stratigraphic units.

The Southeast-trending shear zone system represents in some cases large corridors reaching 300 m in width. However, their extent is limited, varying from 2 to 5 km, most occur in the Doré Lake Complex between the Chibougamau Pluton and the lac Sauvage Fault. Generally these structures have a strong dip (60-80°) to the southwest. They contain most of the copper-gold mineralization contituting the Chibougamau mining camp and they are interpreted as to be subsidiary faults associated to the Lac Sauvage fault.

The Northeast-trending faults are younger than the East-West trending system. Their principal representative is the Gwillim Fault which may be traced for150 km. The latest movements on this fault post-date the deposition of the Lower Proterozoic Chibougamau Formation producing mylonite in these rocks. The horizontal offset deduced from a series of marker horizons gives a sinistral component of a few kilometres. The McKenzie and Lamarck faults are also members of this system. The Lamarck fault, which is 200 km long, shows a similar sinistral offset, whereas the McKenzie fault gives a dextral movement.

PLUTONIC ROCKS

The compilation map of the plutons of the region (Figure A13) gives an appreciation of the spatial distribution of the intrusive bodies, which, combined with an estimation of their probable time of emplacement, allows a an evaluation of their influence in the structural evolution of the belt. A recent preliminary classification of the granitic rocks of the region (Racicot et al., 1984) has been modified and extrapolated for the entire northern Abitibi (Chown et al., 1989; Chown and Mueller, 1992). The model is based on detailed mapping and petrologic studies in the northeast coupled with reconnaissance mapping and petrographic examination of plutons farther west. Further information has been gleaned from the relatively sparse literature available. All

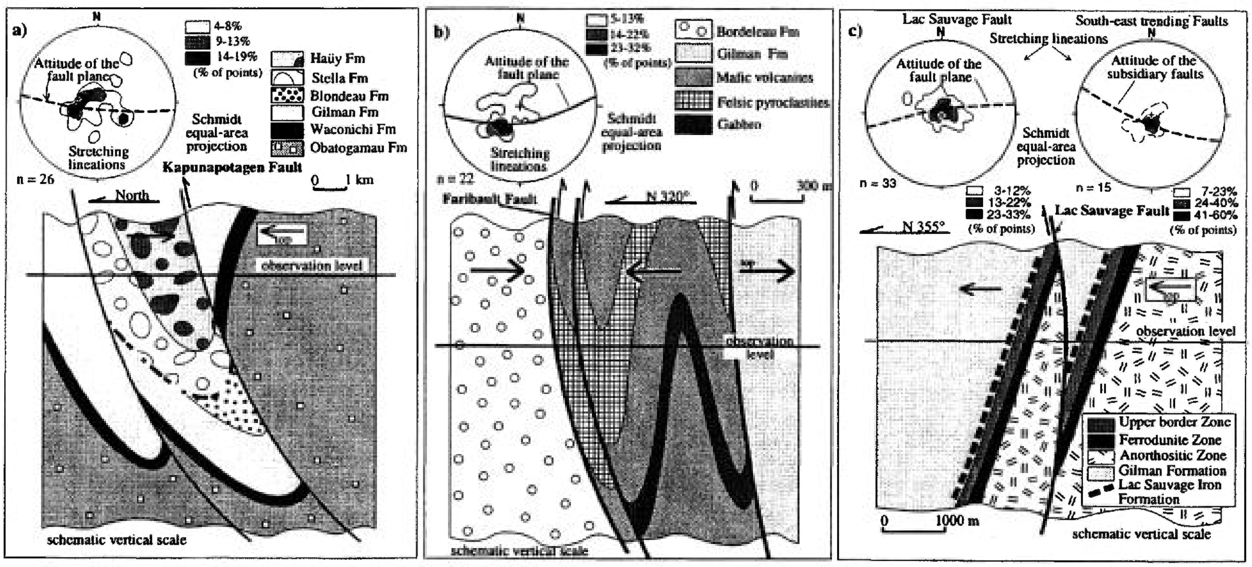


Figure A12: (a) Schematic cross-section across the Kapunapotagen Fault in the northern Chibougamau segment. The fault is responsable for the juxtaposition of the sedimentary domain of the Opemisca Group and the volcanic domain of the Roy Group. The subvertical stretching lineation is indicative of the vertical component of movement; (b) Schematic cross-section across the Faribault Fault in the northern Chibougamau segment. The fault creates an anormal contact between the volcaniclastic sediment of the Bordeleau Formation and the volcanic rocks of the Roy Group; (c) Schematic cross-section across the Lac Sauvage Fault in the northern Chibougamau segment. The fault is responsable for the repetition of the sequence "anorthosite zone - ferrodunite zone - Border zone - Lac Sauvage Iron Formation - Gilman".

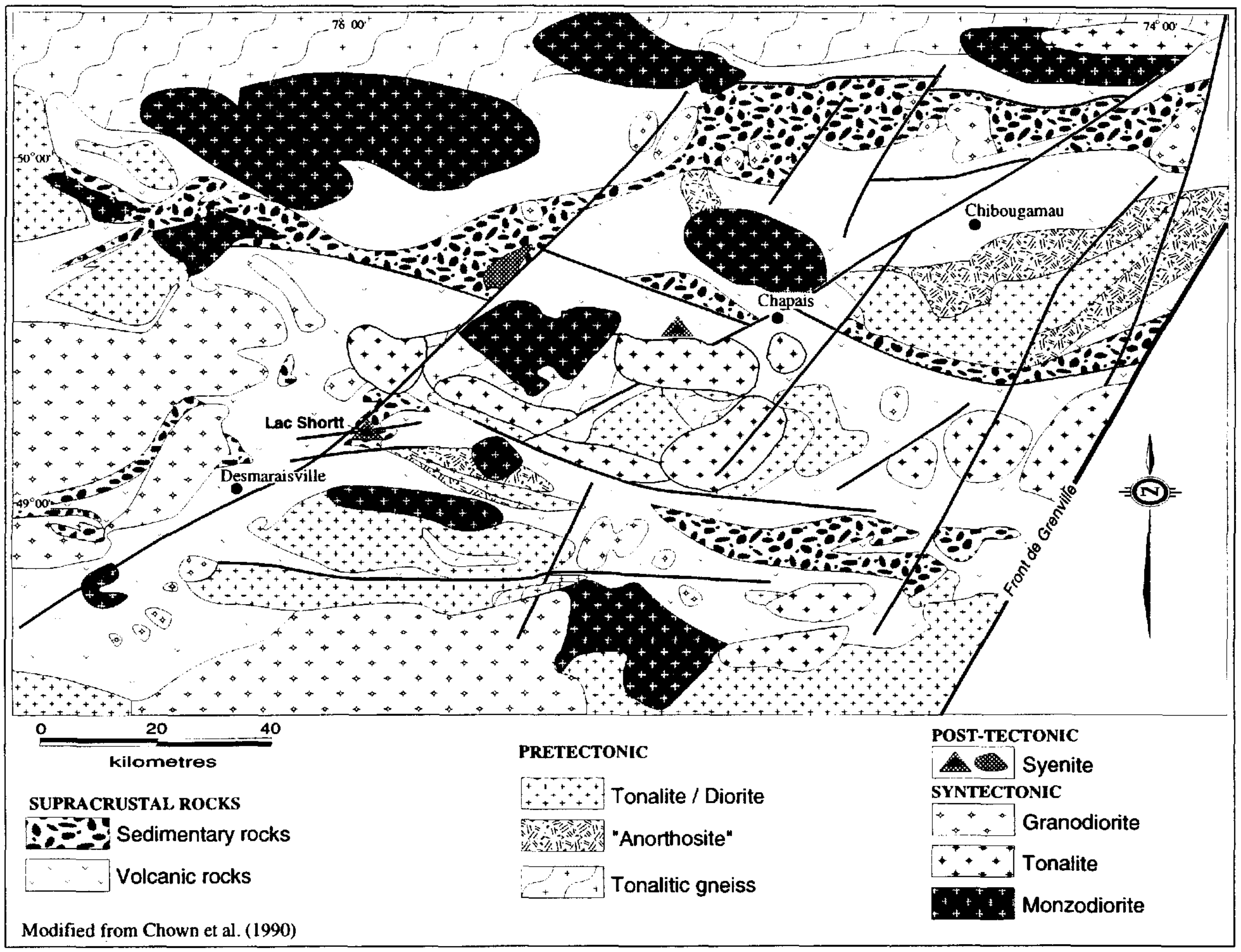


Figure A13: Distribution of felsic plutons, Chibougamau-Caopatina region.

the plutons in the Northern Zone of the Abitibi Subprovince are I type (Chappel and White, 1974). Further classification is difficult without extensive geochemical studies, but at present relatively few intrusions have been the subject of recent geochemical studies including rare earths, although some studies are in progress.

The available age dates (Table A3) show a clear division into two distinct periods ca. 2718 and 2700-2695 Ma corresponding to a period of volcanic activity and to the main Abitibi deformation respectively. The plutonic rocks may be divided into three categories in terms of tectonic age, synvolcanic (or pretectonic) plutons, syntectonic plutons and post-tectonic plutons. The plutons of various ages fall into different petrographic families, although there is considerable overlap in the suites. Tonalitic gneiss, which may be remnants of an older "basement", or may be part of the plutonic suite, has been identified in a number of places within the belt and along the north border.

The synvolcanic plutonic suite includes tonalite/diorite related in part to the genesis of the volcanic sequence, but intrusive into it. Syntectonic plutons intruded during the late stages of regional deformation, and their emplacement was controlled by it. Three overlapping suites of syntectonic intrusions are recognized; a monzodiorite suite, a tonalite/granodiorite suite, and a granodiorite suite. The genesis of these suites of plutons must ultimately be related to the deformational history. Post-tectonic plutons are generally controlled by late tectonic structures cutting across the regional deformation and are, in part, deformed by these structures. The post-tectonic suite includes both a granodiorite suite and a less voluminous syenite/carbonatite suite. Absolute age determinations (Table A3) give a broad framework for the intrusive episodes, but insufficient studies are available as yet to detail the succession of intrusive episodes from monzodiorite to tonalite/granodiorite to granodiorite which appears evident from field relationships, nor to separate the syntectonic from the post-tectonic granodiorites.

All the plutonic rocks intruded into the supracrustal rocks creating contact metamorphic aureoles, and engulfing large quantities of inclusions, and many of the rock compositions of successive suites are similar. Classification, therefore, depends on an accurate evaluation of the structural relationships. Many polyphase intrusions are charged with cognate inclusions, particularly of the earlier mafic phases, which may easily be confused with inclusions of mafic volcanic rocks.

Synvolcanic Plutons

The synvolcanic plutons have been resolved into five large masses scattered throughout the belt (Figure A13). Some are clearly separate individual plutons, but others are an agglomeration of plutonic masses including numerous adjacent elongate slivers resulting from the principal deformation. The plutons often occur in the cores of anticlines, and regional structures swirl around them as they form resistant knots in the deformation pattern. Strong L-fabrics with steeply plunging lineations are developed in the intensely deformed zone around such plutons (Daigneault and Allard, 1990). Syntectonic plutons have exploited the contacts of many of these complexes as an intrusion corridor, adding to the complexity of the plutonic mass and commonly causing confusion in the geologic evaluation of the plutons.

Synvolcanic plutons are thought to be largely subvolcanic cauldron subsidence complexes probably developing as a series of annular or eccentric intrusions. They may be expected to be relatively flat bodies (Hansen et al., 1988; Bateman, 1984). The Aulneau batholith, in the western Superior Province, which is petrologically and structurally very similar, has been shown, by gravity analysis, to form a shallow saucer 7 km thick (Brisbin and Green, 1980). The present elongate form of most of the plutons is in part the result of deformation, and in part the surface expression. Regional deformation patterns may be seen to swing around the batholiths and many of their margins are wide fault zones, although some flattening of these large masses is possible. Distant from the batholith margins, regional deformation is more evenly distributed, with occasional concentration into major shear zones. Within the batholiths, the rocks have deformed along discrete mylonite zones transposing dykes and elongating enclaves to produce a banded rock. Apart from these zones the rocks show only local development of regional schistosity.

The plutons are polyphase intrusions, generally ranging from dioritic early phases to tonalitic and leucotonalitic, and occasionally granodioritic later phases. A composite model batholith may be envisaged from three better studied batholiths (Chibougamau, Eau Jaune and Lichen). Distribution of the phases is typically irregular, in part because the present exposure is the result of the hazards of tectonism, but more importantly because the pluton did not have an originally symmetrical zonal arrangement. Contacts between phases of the same pluton may be gradual or irregular and are characterized by zones of cognate inclusions (Racicot, 1980; 1981). Septa of volcanic country rock also mark the partition between successive phases (Tait et al., 1987), which commonly become mylonite zones during regional deformation. All stages of plutonic activity are witnessed by a vast array of dykes, chiefly porphyritic, intruding both earlier phases of the pluton and occurring widely through the adjacent country rock. Unlike later tonalites, few of the dykes are pegmatitic. The intrusions are commonly charged with foundered blocks and xenoliths of country rock.

The irregular, polyphase nature of the plutons, the asymmetric distribution of these phases, their vast array of dykes coupled with their close relation to the volcanic sequence (Jolly, 1980; Ludden et al., 1984) lead to the conclusion that these were intruded at shallow depths. The Chibougamau Pluton has been eroded before deformation (Mueller et al., 1989) and the presence of plutonic clasts in sediments elsewhere in the Northern Zone suggests that other early plutons have also been uplifted and eroded. This places a probable limit of 5-6 km depth for the intrusion. Near surface expression of porphyry copper (Cimon, 1970, 1973; Guha et al., 1984) and epithermal (Pilote, 1987; Guha et al., 1988) mineralization associated with the Chibougamau Pluton is characteristic of an even shallower depth of intrusion. Estimates of depth of intrusion of 2-4 km based on barometric studies (Feng and Kerrich, 1989) for plutons of the Southern Abitibi appear to confirm this.

All the complexes must have had an original contact metamorphic aureole, which should have been reasonably extensive, judging by the volume of the intrusion. Few of these aureoles are more than partly preserved, as they have been either retrograded to greenschist facies or obliterated by a regional amphibolite facies metamorphism. The effects of regional metamorphism are variable within the plutons. The more mafic phases, with a more susceptible mineralogy, are particularly affected, with hornblende and biotite being retrograded to chlorite, and the plagioclase sericitized and saussuritized. The relatively dry plutonic rocks are generally not affected far from their contacts.

Tonalitic gneiss is a coarse-grained orthogneiss with a strong foliation and relatively little compositional layering. The gneiss does not contain xenoliths of supracrustal rocks, in contrast to all the other plutonic rocks. The gneiss is intruded by a regular succession of dykes related to synvolcanic plutons (Chown and Mueller, 1992). These dykes are in turn cut by the regional deformation structures and dykes related to the syntectonic plutons. Although it appears to be structurally older than all other plutonic rocks, the gneiss may represent early ductile deformation in deeper parts of synvolcanic plutons. The close relation between the gneiss and syntectonic intrusions indicates that the emplacement of the gneiss at its present structural level took place during regional deformation.

Syntectonic Plutons

The syntectonic plutons are nearly all elongate, parallel to the predominant tectonic fabric of the belt. Most occur at the discontinuity between crystalline rocks (synvolcanic plutons or mafic stratiform complexes) and the more anisotropic supracrustal rocks. The intrusions are tabular in shape, up to 30 kilometres in length, appearing as lenses or ellipses on the map as a consequence of the dominance of vertical structures in the belt. Some, however, intrude as sheets or phacoliths exploiting the subhorizontal top of earlier intrusions, and these may have extremely irregular shapes as a result of the erosion of shallow-dipping tabular bodies. A relatively small number of syntectonic plutons occur as isolated intrusions wholly within the supracrustal rocks, commonly along major structures.

Syntectonic plutons have narrow amphibolite grade contact metamorphic aureoles imprinted on the regional greenschist metamorphism. Their close association with regional deformation suggests the probable level of intrusion was 6 to 8 km, the level of formation of the greenschist facies.

The magmatic flow foliation within syntectonic plutons defined by oriented tabular minerals and flattened xenoliths follows the outline of the body and is commonly subparallel to regional deformation. Most plutons have a wide marginal zone of ductile deformation, producing rocks with a mylonitic fabric, and pronounced flattening of xenoliths. The width of this ductile deformation zone varies from intrusion to intrusion, in general it is much wider in the tonalites than in the monzodiorite or granodiorite intrusions.

The three petrographic suites of syntectonic plutons, monzodiorite, tonalite/granodiorite and granodiorite appear to occur in that order in individual areas (Benn et al., 1989; Chown and Mueller, 1992; Benn et al., 1992), although the available absolute age determinations (Table A3) do not bear this out. Inclusion of the granodiorite suite as late syntectonic intrusions is a departure from earlier classifications (Racicot et al., 1984). Recent work (Benn et al., 1989, 1992; Midra et al., 1994; Moukhsil, 1991) demonstrates that larger granodiorite intrusions were also intruded under regional tectonic control, and were affected by the last phase of strike-slip movements during emplacement.

The principal rock type of the monzodiorite suite is a coarse-grained monzodiorite to quartz monzodiorite ranging to granodiorite with changing quartz content, and is a consistently mafic-rich rock with an mafic index "M" of 15 to 22. Hornblende dominates over biotite as the principal mafic mineral, and pyroxene is common. Hornblende, and less commonly pyroxene, form primary layers. A wide variety of cognate mafic phases occur as an inclusion-rich border zone enclosed in a leucogabbro to tonalite matrix in many of these intrusions (Bédard, 1993). The mafic early phases are also present as amphibolite dykes intruding both the adjacent crystalline rocks, and rarely the supracrustal suite. Similar suites of rocks have been described from elsewhere in the Abitibi belt and adjacent belts (Stern et al., 1989; Sutcliffe et al., 1989). The plutons rose along the faulted margin of a synvolcanic pluton, spreading laterally along the roof of the pluton and projecting up into the overlying supracrustal rocks, possibly ballooning slightly.

Tonalitic intrusions show a multi-stage evolution from melatonalite at the border to granodiorite near the centre The border phases have been intruded by successive dykes documenting the petrologic evolution of the pluton. Ductile deformation affects most of the early phases probably related to the emplacement of the pluton and is in turn cut by ductile deformation zones parallel to regional deformation. The structures of a typical tonalite pluton are almost identical to those of the monzodiorite plutons.

Granodiorite plutons are the most numerous intrusions in the region. Two distinct types of pluton are noted, large sheet-like bodies, generally intruding along a contact, and discrete small stocks, commonly in clusters of two to four plutons. Mineralogic and textural similarity among groups of small stocks suggests they are derived from larger underlying plutonic masses. The larger plutons usually demonstrate syntectonic structural characteristics, with the development of magmatic and ductile fabrics particularly related to the latest regional strike-slip movements. The smaller stocks, circular in plan from several hundred metres to 10 km in diameter display concentric structures, and are interpreted as cylindrical structures. Granodiorite bodies in the Opatica belt to the north are observed to contain inclusions of both tonalite and monzodiorite (Benn et al., 1989; 1992).

Post-Tectonic Plutons

At least three small leucogranodiorite to syenite stocks with associated carbonatite and lamprophyre dykes have been observed associated with northeast trending faults (Bédard, 1987; Morasse, 1988; Proulx, 1990; Bédard and Chown, 1992). The leucogranodiorite is zoned inward to syenite (Bedard, 1987) and cut by many aplite dykes of granodiorite composition. Later pyribole dykes show more alkalic tendencies. Biotite sovite dykes with narrow zones of fenitization occur in close association. Olivine-biotite lamprophyres are the latest phase of the suite. Some porphyritic granodiorites may well have intruded during this later period of deformation. Lauzière (1989) has demonstrated the close relationship between a small granodioritic stock and the late northeast-trending fault system. The association of small plutons with late northeast-trending faults may indicate that they are part of an extensive period of late tectonic activity.

TECTONIC MODELS

Based on similarities with other studied areas tentative models may be proposed relating the origin of the volcano-sedimentary supracrustal sequence, the deformation and the sequence of intrusions.

Modern analogues of the described supracrustal and associated plutonic suite can be found in the Western Pacific, the Andaman Sea marginal basin and the western coast of South America. Plate tectonic movements at convergent plate boundaries and intra-arc settings are responsible for this type of succession and volcano-sedimentary configuration in modern-day environments. Plutonic activity associated with volcanic accumulation produced polyphase batholiths composed of relatively primitive tonalite/diorite on a fairly regular spacing across the belt. Some of these occur within evolved volcanic complexes, but most intrude the basalt plain. This synvolcanic tonalite/diorite suite appears to be consistent with a derivation from one or more subducting oceanic plate. The petrographic composition and tectonic setting of these intrusions, when compared to other areas (Beakhouse et al., 1989, Type 1; Martin, 1986) supports this interpretation.

The principal driving mechanisms in the Archean have not been established with certitiude, but it is generally believed that plate tectonics in a modified form operated at this time (Tarney et al., 1976; Tarney and Windley, 1981; Windley 1986). The Northern Abitibi Zone (Chown et al., 1992), composed of an initial volcanic cycle (2720-2730 Ma) and a second cycle restricted to the Chibougamau Segment (2705-2720 Ma) are both characterized by terminal sedimentary cycles which indicate an extensional phase. Mueller et al. (1989) consider this type of succession to represent an incipient island arc that evolved in certain sections into a mature arc, as documented by the late-stage shoshonitic volcanism. The presence of volcanics of the same age (2718 Ma) in the Southern Abitibi (Corfu et al., 1989), suggests a volcanic arc along the south margin of the Northern Zone, with a broad back-arc area to the north where a shallow-dipping subducting plate generated tonalite/diorite magma over a relatively wide area.

The initial phase of deformation formed either by gravitational subsidence or by the earliest effects of the north-south horizontal shortening (Figure A14.b). The broad north-south trending folds developed before regional foliation and may have originated at the same time as juvenile East-West folds. Their origin may be related to a topographic depression in the volcanic terrane or to a distinct phase of deformation. These early flexures did not produce an axial plane foliation but the combination of the North-South and East-West systems generated the framework of a regional interference pattern of domes and basins dominated by the large East-West synclines.

Juvenile synclines formed from marginal grabens filled with sediment derived from the eroding volcanic edifice (Figure A14.c). North-South horizontal shortening followed this early extensional phase and developed the dominant, pervasive regional east-west foliation. The isotropic synvolcanic plutons interfered with the north-south horizontal shortening (Figure A14.d) participating in the upturning of the enclosing strata to the vertical, and creating a wrap-around pattern in the

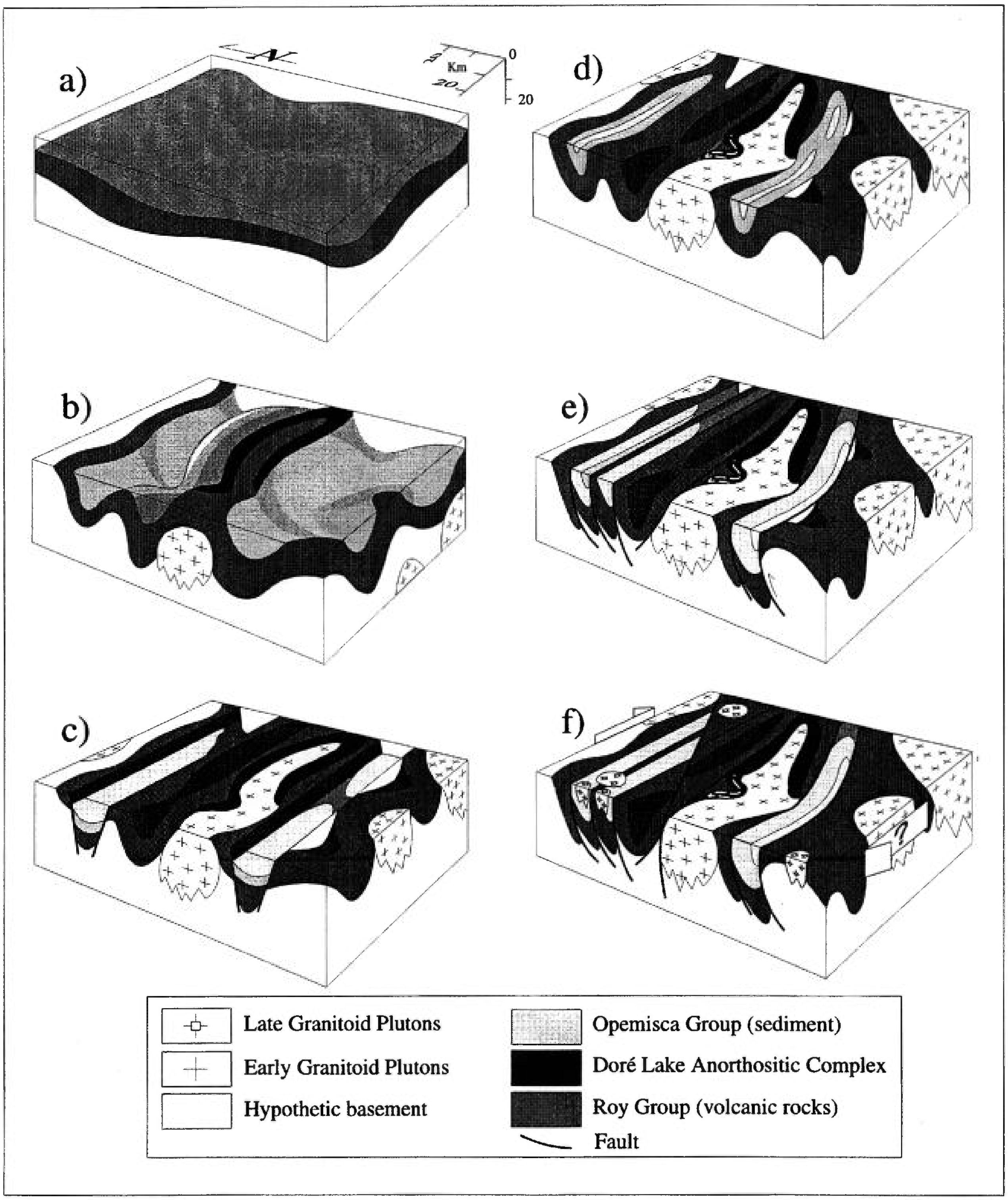


Figure A14: Structural evolution of the Chibougamau region.

regional schistosity. These structural aureoles are characterized by the development of strongly linear tectonites.

The climax of the regional deformation is responsible for the tightening of the large East-West folds and the steepening of their axial planes parallel to the vertical stretching lineation. Finally, the last episode of the regional deformation (Figure A14.e) led to the development of the long East-West reverse faults and zones of intense shearing. Many of these major faults appear to be reactivated early normal faults.

The most evident result of the regional deformation is the important North-South horizontal shortening which created the dominant East-West foliation and regional isoclinal folds. The origin of the North-South shortening may be related to plate convergence and possibly subduction. Accretion of a series of volcanic arcs onto other arcs in a north-to-south progression across the Superior Province (Card, 1989), by a northerly dipping flat-plate subduction as initially inferred by Dimroth et al. (1983) probably caused N-S compression resulting in E-W trending folds.

The persistant vertical regional schistosity and down-dip stretching lineation is the major constraint to tectonic evolution models for the region. However, it is well documented in Phanerozoic orogenic belts that the most efficient horizontal shortening is produced by low angle thrust faults and nappes. These processes are postulated for the Himalayas (Gansser, 1964), the Western Cordillera (Coney, 1989) and Eastern Appalachian Belt of North America (St-Julien and Hubert,1976; Williams and Hatcher, 1982). These examples are clearly cases of sub-horizontal strain zones associated with a stretching lineation parallel to the transport direction. The low energy budget of this process is an attractive alternative to the high energy processes required for a vertical response to deformation by the supracrustal pile. To apply the thrust model to the Abitibi Belt, one can propose that the regional east-west high angle reverse faults are, in fact, subhorizontal faults, rendered subvertical by continued horizontal shortening.

The large east-west longitudinal faults represent the final stage of the regional deformation. The structural elements observed in these large faults suggest high angle thrusting. In spite of their great lateral persistence within the Chibougamau area, the transport was never great enough to obliterate the stratigraphic relationships and the area is part of an contiguous domain, and not a series of nappes. The coherent stratigraphic sequence suggests that the much of Chibougamau Segment behaved in a coherent manner, and a thrust fault model must consider the whole Chibougamau Segment to be one terrane.

Examination of the major East-West faults in conjunction with the Southeast faults which display strong subhorizontal stretching lineations clearly indicates a dextral movement sense (Daigneault and Archambault, 1990). This suggests a late dextral movement superimposed on the reverse movement recognized in the majority of these faults (Figure A14.f).

Syntectonic plutons consist of largely tabular bodies intruding around synvolcanic plutons and clearly controlled by the deformation. This took place in an extension event following the major compression (Sawyer et al., 1990). Petrologic evolution in the suites, from monzodiorite to tonalite/granodiorite to granodiorite is observed, based on field relations. Plutons follow the principal deformation and were affected by the latest phases of deformation. The monzodiorite and tonalite/ granodiorite suites are intruded during, or slightly after, the main period of folding and development of regional schistosity. The granodiorite suite, on the other hand, appears to have intruded during the final period of dextral strike-slip faulting which concluded the major deformation. Small stocks of granodiorite within the supracrustal sequence are believed to be offshoots of deeper large granodiorite bodies. These rarely show unequivocal relations to the major structures, and most may well be late syntectonic in age. Thus arc-arc collision and major regional deformation from 2700 to 2695 Ma (Corfu et al., 1989) produced successively monzodiorite, tonalite/granodiorite and granodiorite magmas as products of partial fusion of the lower crust and mantle, the former thickened by the deformation. The basic similarity between the syntectonic tonalite/granodiorite and granodiorite suite suggests derivation from much the same source, either from the mantle (Sutcliffe et al., 1989) or possibly by partial fusion of the base of the folded volcanic pile. Monzodiorite magmas were probably subduction related, from a deep crustal or mantle source (Stern et al., 1989; Bédard et al., 1989).

A small suite of syenites with associated carbonatites, as well as some granodiorites, line up along late northeast structures suggesting that their emplacement took place during the latest period of post-tectonic adjustment. These latest intrusions of porphyritic granodiorite and syenite/carbonatite are thought to be controlled by late tectonic faults, and are petrologically consistent with derivation from beneath a thickened crust.

PROTEROZOIC

The Chibougamau region underwent periodic activity during the Proterozoic. Two periods of sedimentation and four separate igneous (dyke) events are known. In addition, the Chibougamau region lies on the border of the Archean craton; and was the autochthonous foreland to the Grenville Orogen, and much of the district has been moderately to profoundly affected by this major deformational event.

Both sedimentary formations, the Chibougamau Formation and the Mistassini Group are relatively undisturbed, except near faults, and have undergone little more than low grade burial metamorphism.

Chibougamau Formation (2450-2490 Ma)

The Chibougamau Formation consists of up to 200 m of boulder to pebble conglomerate and sandstone lying unconformably on the folded Archean basement. The conglomerates are made up of fragments of granitic and metavolcanic rocks representing all the Archean lithologies, contained in a fine-grained angular matrix. The sedimentary structures and distribution of facies led Long (1974) to postulate a fluvial origin for the formation, and the presence of mixtites, and dropstones in banded argillites suggests an ultimate glacial origin. The formation is derived from the northwest. The Chibougamau Formation is tentatively correlated with the Gowganda Formation of the Huronian Supergroup, 400 km to the southwest (Young, 1970).

The Chibougamau Formation occurs in a series of outliers north and west of the town of Chibougamau. Clastic dykes undoubtedly related to the formation are found within the Archean basement up to 80 km west of the outliers (Chown and Gobeil, 1990) strengthening Young's (1970) correlation and indicating that the present erosion surface was similar to that immediately post-Archean.

Mistassini Group (1950-1750 Ma)

The Mistassini Group consists of a thick dolomite sequence (Lower and Upper Albanel Formations) composed of stromatolitic and argillaceous dolomite with interspersed black shale units. This is overlain by a mixed formation of quartzite, argillite and iron formation (Temiscamie Fmn.). Clastic fluviatile formations (Papaskwasati and Cheno Fmns.) delineate the northern margin of the sedimentary basin. The group overlies the Archean basement unconformably, the unconformity being marked by a thick paleosol which has been largely replaced by carbonate during the diagenesis of the overlying dolomites (Chown and Caty, 1983). The southernmost extent of these sediments is just north of Chibougamau.

Diabase dykes

The diabase dykes have similarly suffered only local deuteric alteration and minor development of prehnite. Dykes are seldom more than 100 m thick, and typically have sharp glassy contacts. Most may be traced by their prominent positive linear anomalies on regional aeromagnetic maps (MRN, 1972).

Diabase dykes belong to four swarms in the Chibougamau district: (1) Preissac dyke swarm - age of 2140 Ma (Fahrig et al., 1986); (2) Mistassini dyke swarm - age of 1960 Ma (Fahrig et al., 1986), a northwest-trending dyke system which occurs in a spectacular fanning array just north of Chibougamau; (3) Otish dyke swarm - age of 1730 Ma; and (4) Abitibi dyke swarm - age of 1140 Ma, intruded along fractures generated by crustal flexure during the early stages of the Grenville Orogeny (Ranalli and Ernst, 1986; Ernst et al., 1987).

GRENVILLIAN OROGENY

The Grenville Orogen, a complex belt of Late Proterozoic deformation belt, lies southeast of the Chibougamau region. Although existing mapping of the Archean Abitibi Belt suggests the latter effectively terminates against the Grenville Front, just southeast of the town of Chibougamau, the results of recent reconnaissance mapping indicate that major units may be traced across the front into the Parautochthonous belt of the Grenville (Daigneault and Allard, 1983; 1986; 1994). The Grenville Orogen is interpreted to be the result of a continent-continent collision (Rivers et al., 1989), in which the Grenville mobile belt was shortened against the Archean (Superior Province) foreland to the north. The Grenville Front is mapped locally as the limit of readily recognizable Archean formations and structure. Elsewhere the Grenville Front is mapped as the northern limit of Grenville structure and metamorphism, which has resulted in some confusion in its location in the Chibougamau area.

It is important to realize that two major structural events took place in the Archean Parautochthon during the Grenville Orogeny. First large nappes were thrust from southeast to northwest, and following the thickening of the crust produced by the first event, isostatic adjustment took place on a series of high-angle reverse faults.

The first structural event produced a pervasive southeast-plunging stretching lineation in all the rocks of the Parautochthonous belt (Ciesielski and Ouellet, 1985), and a high temperature/high pressure regional metamorphism on the Proterozoic rocks bordering and within the parautochthon. Grenvillian metamorphic effects on the already metamorphosed Archean rocks are more difficult to characterize because of variable overprinting relations. The principal manifestation is the development of large garnet and hornblende porphyroblasts in the abundant metabasites, commonly overprinting a background greenschist facies assemblage, and occurring in conjunction with the development of younger structures (Ouellet, 1988). High pressure assemblages, in particular kyanite bearing assemblages, are noted in some Archean rocks, similar to the assemblages developed in Proterozoic rocks and in contrast to the typical medium pressure andalusite bearing assemblages of the Abitibi Belt (Jolly, 1978). Feathery hornblende porphyroblasts yielded Ar^{39}/Ar^{40} plateau ages from 1105 Ma at the upper greenschist facies to 953 Ma in the amphibolite facies (Baker, 1980). Proterozoic diabase dykes also develop coronitic structures and grade into garnet amphibolites within the Parautochthonous Belt, although the metamorphic changes in these relatively dry rocks do not appear as far north as corresponding changes in the metabasites. The imprint of Grenvillian amphibolite grade metamorphism along the edge of the foreland is relatively clear, leaving a vast zone to the northwest where Grenville-related greenschist and lower grade metamorphism must have overprinted Archean metamorphism, but whose effects are not readily identified. North-East trending folds associated with an axial plane crenulation cleavage and the amphibolite facies metamorphism are common.

The isostatic readjustment phase of Grenvillian deformation resulted in a spectacular series of 010°-020° trending reverse faults (Figure A9). These faults have a combined sinistral and east-side-up movement. Faults in the south and east deformed in a dominantly ductile manner, whereas those farther west display brittle characteristics. Late brittle movements on the ductile faults are shown by the presence of pseudotachylite (Daigneault and Allard, 1990), which have produced a systematic sinistral throw of a few 100 to 1000 metres. These faults, in particular the Mistassini fault, the most pronounced member of the system, dictate much of the configuration of the mapped location of the Grenville Front in the Chibougamau region. It is clear that some, if not all, Archean faults (eg Gwillim) have been reactivated during the Grenvillian Orogeny.

A major result of the Grenville Orogeny has been to uplift the Archean rocks of the Parautochthonous Belt so that the supracrustal rocks of the Abitibi belt are in juxtaposition with tonalite, tonalite gneiss and small lenses of metabasite from deeper levels of the Archean crust. Clinopyroxene-garnet rocks are widespread within the Parautochthon, partly retrograded to garnet amphibolites. Thermobarometric analysis of these assemblages yields 800° C and 1000 mpa (Ouellet, 1988). It is suggested, but not yet proven, that these high pressure rocks are the product of Grenvillian, rather than Archean metamorphism.

PART B - METALLOGENY OF THE EASTERN EXTREMITY OF THE ABITIBI BELT

Pierre Pilote
Ministère des Ressources naturelles du Québec, 400 Lamaque, Val-d'Or, Québec, J9P 3L4;

and Jayanta Guha
Sciences de la Terre, Centre d'Études sur les Ressources Minérales, Université du Québec à Chicoutimi, 555 boul. Université, Chicoutimi, Québec, G7H 2B1.

(modified from Guha, 1990, and Guha et al., 1990; and Pilote and Guha, 1995)

INTRODUCTION

From 1954 to the beginning of 1990 the Chibougamau mining district, known as "shear-zone-related-vein country" (Guha and Chown, 1984), produced roughly 1,2 million tonnes of copper, 115 000 kg of gold, 650 000 kg of silver, 115 000 kg of zinc and 4 000 kg of lead. The district contains numerous types of ore deposits and occurrences in a variety of settings (Figure A3), making it somewhat different when compared with the southern part of the Abitibi belt (Gobeil and Racicot, 1984). The multitude of vein type mineralizations makes the task of correlation harder, but examined within the geological framework, a pattern emerges. There have been a number of publications detailing different deposits and settings and in recent publications there has been an attempt to sort out the different types of occurrence in relation to their mode of emplacement (Guha, 1984, 1990; Guha et al., 1988, 1990). This section will provide a short overview in order to visualize the geological position of some of the occurrences that will be visited and summarize the earlier classifications in the context of recent advances in the understanding of the tectono-stratigraphic evolution of the area.

Although precise dates of the mineralization/alteration are unavailable, the dating of some of the important lithologies makes it possible to correlate the mineralizing events with the evolutionary cycle of the deformed Archean belt. Mineral deposits can be divided into five broad categories (each having sub-categories), based on their characteristics, settings and the geological process(es) that played a role in their emplacement:

- I - Mineralization related to the emplacement of mafic intrusions (oxides and sulphides of magmatic origin);
- II - Sulphide deposits related to the synvolcanic period;
- III - Mineralization related to high level plutonic activity and associated volcanic landforms:
  - Porphyry type and associated mineralization - the Cu-Au veins of the Doré Lake camp;
  - Epithermal precious metal veins;
- IV - Archean mesothermal gold deposits spanning major deformation and plutonic activity;
- V - Deposit of uncertain age - Opemiska-type veins.

This is not an attempt to classify all the mineralized occurrences of the camp nor a detailed description of the deposit types. A number of prospects are currently being studied and their position in this scheme is an important element in their evaluation. In the following section each category will be examined briefly. Deposits within the Proterozoic Mistassini basin and metamorphosed equivalents of Archean mineralization in the Grenvillian Orogen have not been considered

I - MINERALIZATION RELATED TO THE EMPLACEMENT OF MAFIC INTRUSIONS (OXIDES AND SULPHIDES OF MAGMATIC ORIGIN)

Fe-Ti-V

These are occurrences related to the emplacement of the major mafic and ultramafic sills such as the Doré Lake Complex (DLC). The DLC, described in detail by Allard (1976a) and Allard et Daigneault (1989), presents economic grades for vanadium in the P1 member in Rinfret township

(Gobeil, 1976). Nearly 245 000 000 tonnes of ore with an average grade of 27,6% Fe and 1,1% TiO_2 have been outlined from the Mont du Sorcier and Magnetite Bay area. Assessment of PGE associated with sulphides indicates that no enrichment has occurred probably due to an early scavenging of the PGE from the magma at depth (Barnes et al., 1994). A Ni-Cu sulphide showing (Lantagnac township) in a metapyroxenite intrusion, on the other hand, does contains PGE concentrations (Barnes et al., 1994).

II - SULPHIDE DEPOSITS RELATED TO THE SYNVOLCANIC PERIOD

The development of incipient island arcs (Mueller et al., 1989) with active felsic centres gave rise to hydrothermal systems resulting in volcanogenic sulphide deposits. Evidence of synvolcanic alteration-mineralization is widespread. This includes silicification of large tracts of the Gilman Formation (Couture, 1986; Trudeau, 1981) as well as the Lac des Vents complex. The collapse of small volcanic edifices produced megabreccias overlying pyroclastic debris flows and tuffs accompanied by mineralization associated with synvolcanic faulting and sulphidized pillow rims (Bouchard, 1986). Discharge of fluids into the volcaniclastic rocks or into paleotopographic depressions gave rise to bedded sulphides, which can be seen in the upper units of all the cycles. Most of these accumulations are pyrrhotite/pyrite rich with varying amounts of Cu, Zn, and precious metals.

Significant deposits discovered so far are Lemoine (728 000 tonnes at an average of 4,2% Cu, 9,6% Zn, 4,5 g/t Au and 83,85 g/t Ag - mined out), Lac Scott (680 000 tonnes at an average of 0,55% Cu, 6,9% Zn and 13,3 g/t Ag - reserves), Cooke 8-5 (Bélanger et al., 1984), Lac des Vents (100 000 tonnes at 2% Cu?) and Coniagas (700 000 tons. at an average of 10,7% Zn, 1,0% Pb and 10,3 g/t Ag - mined out). The Waconichi Formation was been considered to be a favourable felsic stratigraphic unit following the discovery of the Lemoine deposit and the Lac Scott prospect, supporting the idea that volcanogenic massive sulphide deposits occur in clusters confined to specific horizons. Why should this felsic sequence be favoured? The probable answer to this is the development of a heat source capable of generating the hydrothermal system. The porphyritic rhyolite of the Waconichi Formation at Lemoine formed at 2728 $\pm$ 1.5 Ma and the DLC (Granophyre Zone) at 2728 $\pm$ 1 Ma (Mortensen, 1993). This time frame indicates that the DLC was available to provide the heat to generate the hydrothermal sytem required for metalliferous sea-floor deposits (Guha, 1990). The presence of such a hydrothermal system can be envisaged from indications that a large volume of rock was affected by hydrothermal fluid-rock interaction. Gobeil (1980) has observed Ca and Na depletion in rocks stratigraphically below and laterally more than a kilometre to either side of the Lemoine mine. Felsic centres such as this were instrumental in developing high heat flow areas which then acted as foci for fluid discharge. The nature of the Lemoine deposits (bedded/laminated sulphides and structures indicating flow on a slight slope of an edifice) points more to of a slope-plus topographic-low type of accumulation than a mound type.

The supposition that DLC acted as the subvolcanic heat engine is indirectly supported by the fact that the "Obatogamau bridge rhyolite", dated as 2728 $\pm$ 1 Ma (Mortensen, 1993), which represents a possible stratigraphic equivalent of the Waconichi Formation away from the influence of DLC, does not show this hydrothermal activity. Moreover the hydrothermal activity in the Gilman Formation on the northern flank of the DLC, indicated by silicification with large lateral extent, could well be due to a hydrothermal system kept active by the DLC. A similar scenario has been advocated for the volcanogenic massive sulphide deposits of the Matagami camp (located in the northwestern part of the Abitibi greenstone belt) where the heat source is related to the Bell River Complex (Piché et al., 1990).

The preservation of the deposits in the Waconichi Formation is the result of a number of post-depositional factors such as the final position of the DLC, the intrusion of the Chibougamau Pluton, deformational events and erosion (Cimon and Gobeil, 1976). The ore of the Scott Lake deposit, located at the NW corner of the DLC was metamorphosed by the intrusion of the Chibougamau Pluton and ore lenses were dismembered by post depositional events (Saunders and Allard, 1990). The Lac des Vents Complex, showing a preliminary age of 2759 ± 1,6 Ma (Mortensen, 1993), presents more explosive activity which favours a mound type evolution with repeated fluid surges and eruptive breccias giving way to lenticular deposits with the rapid build-up of the volcanic edifice. The emergence of the volcanic edifice to subaerial conditions did not seem to favour the formation and / or the preservation of massive sulphide accumulations (Guha et al., 1990; Mueller et al., 1990).

III - MINERALIZATION RELATED TO HIGH LEVEL PLUTONIC ACTIVITY AND ASSOCIATED VOLCANIC LAND FORMS

Porphyry type and associated mineralization - the Cu-Au veins of the Doré Lake mining camp

Historical and geological background

The existence of Archean plutons containing porphyry-type Cu mineralization is known for numerous years in Quebec (Kirkham, 1972), and particularly in the Chibougamau (Cimon, 1970; 1973), Rouyn-Noranda (Goldie et al., 1979) and Val-d'Or regions (Tessier, 1990).

In a general way, porphyry-type Cu and Cu-Au mineralizations are best described as veinlets and disseminated sulphides located in complex fracture swarms and breccias. These structures are hosted within or close to the margins of granitoid plutons of intermediate to felsic composition, typically showing a zoned alteration pattern (Lowell and Guilbert, 1970; Gustafson and Hunt, 1975). The mineralized parts are commonly located within the most evolved parts of the pluton or within the adjacent host rocks. These deposits are considered epizonal, which mean they are mostly formed at a depth varying between 1 and 2 km (McMillan and Panteleyev, 1987).

The emplacement of tonalite/diorite synvolcanic plutons, generated by a subducting oceanic plate, has taken place during the development of the polycyclic volcanic zone in the Chibougamau area (Chown et al., 1992). The formation of high level cauldron subsidence complexes are extremely favourable to the development of porphyry type mineralization. This is well illustrated by the Chibougamau pluton, on the south flank of the Chibougamau anticline, where porphyry copper-type mineralization is exposed. The Queylus prospect is considered to be a typical porphyry showing on the basis of the large areal extent of its alteration, its hydrothermal breccia zones and its stockwork/disseminated copper mineralization (Cimon, 1970; 1973; 1976; 1979; Kavanaugh, 1978; Bureau, 1980; Bureau et al., 1979; Racicot, 1980). The Devlin deposit is a flat-lying vein system partly hosted within distinctive breccia zones (Bureau, 1980; Gobeil, 1982). These breccias are surrounded by a widespread selective alteration pattern (Guha et al., 1984; Lange-Brard, 1986). From the alteration characteristics, the presence of breccias and fluid data, Guha et al. (1984) proposed that the Devlin deposit is the near-surface expression of a porphyry system.

On the north flank of the Chibougamau anticline, which produced the steep tilting to the north of the magmatic layering observed in the DLC, porphyry Cu-Mo-Au mineralization has been found in the Clark Lake (Kirkham, 1972; Ford, 1974; Pilote et al., 1993, 1994a, 1994b; Sinclair et al., 1994) hosted by the anorthositic units of the Doré Lake Complex (DLC), dated at 2728 Ma. This porphyry-type mineralization has been observed to be adjacent and/or superimposed on the Main and Merrill mines typical of the massive sulphide veins of the Doré Lake camp.

Cu-Au massive sulphide veins of the Doré Lake camp

The discovery of Cu-Au deposits of the DLC, historically known as the "Chibougamau type" mineralization, along with the Opemiska Mines, gave the start to the Chibougamau mining camp. Since 1954 to the end of 1997, 15 deposits have been discovered and in production periodically. The total production amounts 44 million tonnes at 1,76% Cu and 2,08 g/t Au. At present two mines are still in operation in the Doré Lake camp, Copper Rand and Portage. A third one, Cedar Bay, could be reopened in the near future depending on the economic situation. Until the discovery of the Corner Bay deposit (Bertoni and Vachon, 1984) in the southern limb of the Chibougamau anticline, all the deposits in the DLC were found in the northern limb.

The origin of the "Chibougamau-type" veins has been the subject of numerous studies in the past but no consensus has been reached so far. Examples of the "Chibougamau-type" are illustrated by, among others, the Main, Merrill, Copper Rand, Cedar Bay, Henderson, and Portage mines. Allard (1976a) did an exhaustive historical review of the exploration and mining works realized in the DLC. Many theses, completed mostly between the late '50 to the end of the '70, describe various aspects of this type of deposit (Allard, 1976a).

Most of the Cu-Au deposits of the DLC are located in NW trending shear zones in the Upper Meta-anorthosite layer of the Doré Lake Complex, except Henderson and Portage which are in NE trending shear zones. The host rocks are quartz-carbonate-sericite and/or chlorite (chloritoid) schists produced by the shearing and alteration of the meta-anorthosite with potassium enrichment and iron-rich chlorites associated with the ore zones (Allard, 1976a; Guha, 1984). The sulphide minerals are predominantly chalcopyrite, pyrite and pyrrhotite with minor amounts of sphalerite and galena and a large number of accessory minerals. Gold occurs mainly as discrete grains associated with pyrite and chalcopyrite in contrast with the free gold that is observed in the mesothermal lode type deposits in the region. Nugget gold, however, formed late in

	Mines	Years	Tonnes (s.t.)	Cu (%)	Au (oz/t)	Cu (lbs)	Au (oz)
MSV RESOURCES	Copper–Rand	1959-1994	14 624 746	1,80	0,088	534 754 343	1 287 003
	Portage	1960-1994	5 682 152	1,73	0,113	202 790 414	643 409
	Jaculet	1960-1974	1 202 119	1,93	0,055	46 401 793	66 117
	Copper Cliff	1970-1974	951 830	1,60	0,028	30 458 560	26 651
	Henderson I*	1959-1971	1 818 976	2,23	0,045	81 126 330	81 854
	Henderson II*	1960-1988	6 483 479	1,60	0,041	207 471 328	265 823
	Corner Bay	1996-	1 059 841	5,28			
	Cedar Bay*	1958-1989	3 782 850	1,57	0,091	118 781 490	344 239
	Sub-total		35 605 992	1,85	0,076	1 221 784 258	2 715 096
	* Mines formely owned by Campbell Chibougamau Mines Ltd						
OTHER Co.	S–3	1985-1989	316 732	0,37	0,106	2 343 817	33 574
	Bateman Bay	1969-1971	565 000	2,09	0,090	23 617 000	50 850
	Quebec Chib.	1970-1974	264 000	1,74	0,090	9 187 200	23 760
	Kokko Creek	1959-1975	745 169	1,15	0,007	17 138 887	5 216
	Main Mine	1954-1981	4 840 946	1,82	0,033	176 210 507	159 751
	Open pit (M.M.)	1970-1981	1 036 733	0,64	0,004	13 270 182	4 147
	Open pit (Merrill)	1967-1981	1 509 702	2,05	0,010	61 897 782	15 097
	Canadian Merrill	1958-1967	1 182 804	2,33	0,010	55 118 666	11 828
	Chib-Kayrand	1965-1972	114 000	1,36	0,014	3 100 800	1 539
	Obalski	1963-1965	7 500	1,20	0,084	180 000	627
	Obalski	1984-1985	8 337	0,94	0,347	156 338	2 894
	Grandroy	67-69, 74-75	349 000	1,24	0,022	8 655 200	7 630
	Devlin	X	1 270 000	2,00	0,014		
	Sub-total		12 209 923	1,73	0,027	370 876 379	316 914
TOTAL			47 815 915	1,82	0,064	1 592 660 637	3 032 010

Table B.1: Total mining production in the Doré Lake Complex and vicinity to January 1st, 1995 (taken from M.R.N.Q. files and A. Blais, MSV Resources).

the history of emplacement of these deposits (Guha and Kanwar, 1987).

Although they can be classed as structurally controlled vein-type deposits, certain features make them somewhat different than the Archean mesothermal gold deposits found in the region. In contrast to the mesothermal deposits, the dilation zones are extremely large and the ore types vary from laminated sulphide schist to dilation type fillings with large blocks of rubble breccia at the margin of dilation zones (Guha and Koo, 1975; Guha et al., 1983). The geometry of the veins in the Henderson 2 mine indicates reverse oblique movements. Works by Archambault et al. (1984), Magnan (1993b), and Magnan et al. (1994; 1995a; 1995b) indicates superposition of structures of different episodes in the Copper Rand mine. Tessier et al. (1994) reached similar conclusions at the Portage mine and are at present examining the possibility of remobilization of gold from the Portage orebody to the quartz veins of the McKenzie shear zone. The ore-forming fluids were characteristic $CaCl_2$-NaCl rich brines with a coexisting methane rich fluid (Guha et al., 1979). Fluid inclusion characteristics and sulphur isotope values of the NE and NW trending deposits of the northern limb as well as the mineralization of the R1 Group, located 800 m east of the Corner Bay deposit, are the same (Guha, 1984).

Review of earlier and current models

The mineralized veins, "Chibougamau-type" lodes, occurring in the DLC have been the subject of various works during the previous years. Different genetic models have been proposed in order to explain their origin. Here is a review of the main models developed from the late 50's to the present:

- during the 50's: the Cu veins were thought to have been produced by hydrothermal replacement which the origin could be the Chibougamau Pluton;
- 1959: the Grenvillian orogeny could be at the origin of the mineralization, according to Vollo's works at the Henderson mine;
- from the late '50 to the end of the '70: Numerous consistent observations made in all mines of the Doré Lake camp established spatial links between different porphyry dyke swarm generations, the "Chibougamau-type" mineralization and specific intrusive phases related, according to field criteria, to the Chibougamau Pluton (Miller, 1957; Jeffery, 1959; Blecha, 1966; Duquette, 1970; Allard, 1976a; Maillet, 1978; and Tremblay, 1980). A consensus is obtained on the observation that the vein-type mineralization seems commonly cut the various dyke swarm generations. However, even at this time, Jeffery (1959) described the occurrence of an actinolite-rich dyke clearly croscutting the vein-type mineralization between the 1500' and 1700' levels at the Campbell Main mine.
- 1970-74: Discovery by Cimon in the Queylus township and by Campbell Ressources (Ford, 1974) in the Clark Lake area of porphyry-type Cu-Mo mineralized showings. These discoveries initiated numerous exploration works in the southern part of the Chibougamau Pluton, in the Queylus area, and also on the north shore of the Doré Lake.
- 1975-79: Guha and Koo (1975) recognized the fact that the ores in the Henderson 2 mine were deformed and pre- to syn-metamorphic in age.

Allard (1976a and 1976b), following a trip to visit the Upper Pliocence Gutai Mountains ore deposits in Roumania, described as volcanogenic epigenetic deposits, proposed a volcanogenic vein-type model for the ores of the Doré Lake area. He suggested that a major fracturing event took place on top of the intrusive dome, followed by dyke injection associated with the late phase volcanism and the pluton emplacement along those fractures. The ore solution, travelling along fractures and dykes, deposited their copper content in dilation zones within the fracture-dyke swarm. A prononced halo of alteration surrounded each copper-rich vein. The Kenoran orogeny, accompanied by widespread low grade greenschist metamorphism and folding of the volcanic assemblage, transformed the previous incompetent alteration halos in paragonite-sericite-chlorite ± chloritoid schist which encloses the orezones, the so-called "shear zones" or "Chibougamau-type" veins of the Doré Lake camp. A general recrystallisation of the sulphides took place, the regional deformation giving locally rise to the "sulphide schist ore" of Guha and Koo (1975). Chalcopyrite was preferentially remobilized and became veinlets and veins cutting across the reorganized schists, dykes and country rocks. Then, according to Allard (1976a), the Doré Lake orebodies could thus be called volcanogenic in origin. epigenetic in geometry, and synvolcanic-premetamorphic in chronology.

A pre-metamorphic age for the mineralization is also suggested by Christmann (1979) at the Copper Cliff mine, according to various field relationships. Guha et al. (1979) highlighted also the hypersaline character of the fluid inclusions related to those deposit, and discussed the possibility of a genetic link with the Chibougamau Pluton.

- 1981 and 1984: Thorpe et al. (1981; 1984) established a model-age of ca. 2160 to 2240 Ma (according to lead isotopic data in galena) for the Doré Lake deposits, and Guha (1984) demonstrated the strong input of a Proterozoic fluid. These findings lead them to suggest that (1) the vein-type mineralization is late; or (2) the mineralization is early in age but has been remobilized more or less efficiently by these fluids, with a possible concomitant contribution of a new mineralizing event.
- 1990: Daigneault and Allard suggested, according to field observations, an apparent relationships between E-W trending faults, such as the "lac Sauvage fault", and those striking ESE and typically encountered in the Doré Lake area. These workers proposed an early premetamorphic event for the setting of the vein-type mineralization, without however been able to define that setting accurately or the process behind that mineralizing system.
- 1993-98: Pilote et al. (1994, 1995a, b, and c; 1997, 1998a and b) and coworkers (see Robert, 1994; Sinclair et al., 1994, Kirkham et al., 1997a and b) suggested that the porphyry-type and the vein-type mineralizations encountered in the Doré Lake area are parts of a same large scale pretectonic magmatic-hydrothermal mineralizing event, contemporaneous to the buildup of the volcanic cycle 2 in the Chibougamau area. The various mineralization styles observed in that mining camp, particularly well illustrated on the north and south flanks of the Chibougamau Pluton, are best described by different movements along reverse or normal major fault planes and by the local erosion level.

Magnan (1994) and Tessier (1994) independently reached similar conclusions and demonstrated that a major part of the Cu-Au veins at the Copper Rand and Portage mines are early and premetamorphic in age. Magnan also describes one particular type of porphyry dyke at the Copper Rand mine that crosscuts the sulphide-rich veins.

Major post-Archean influence

There is strong evidences of a major post-Archean influence on the Cu-Au veins of the Doré Lake Complex, as demonstrated by Guha (1984; 1990) and co-workers. The following points (Guha 1990; Guha et al., 1990) summarize the main observations, facts and interpretations about the Doré Lake deposits and underline some problems pertaining to their genesis.

1) The ore fluids as well as the character and attitude of the different ore lenses evolved with the shearing (Guha et al., 1983) indicating an emplacement *or remobilization* synchronous with the shearing at the Henderson 2 mine;

2) The ore fluids have a strong "surface" water signature and the sericite and chlorite is also in isotopic equilibrium with these waters (Tremblay, 1987);

3) A systematic homogeneous Proterozoic model-age (ca. 2160 to 2240 Ma) is obtained for galenas from the ore deposits (Thorpe et al., 1981, 1984). As pointed out by Guha (1984) the 2.0 Ga event is not restricted to the DLC vein deposits but is also recorded in stringers and minor veins within the volcanic and volcanoclastic rocks. Opemiska vein deposits do not show the 2.0 Ga event but sulphide stringers in the vicinity do reflect this age, making it impossible to rule out the importance of the Aphebian event and its tectonic and hydrothermal contributions. This evidence led Guha (1984; et al., 1988) to the interpretation that the deposits, in their present geometric forms, are post-Archean.

4) A number of deposits that have undergone deformation and remobilization whether lode-gold or volcanogenic massive sulphides, may be reconstructed from their original features. Although entry of later fluids in pre-existing gold deposits has been documented, the signature of the primary mineralizing fluid can still be seen as in the case of Macassa mine (Kerrich and Watson, 1984).

5) In the event of an early Cu-Au mineralization a direct hydrothermal input from a felsic pluton cannot produce zones with 1% nickel which have been observed in certain mines. It is necessary that nickel has to be scavenged by hydrothermal fluids from an alternative source such as specific layers within the DLC.

Discussion

There is no doubt that there have been pre-existing Archean deposits which could have been

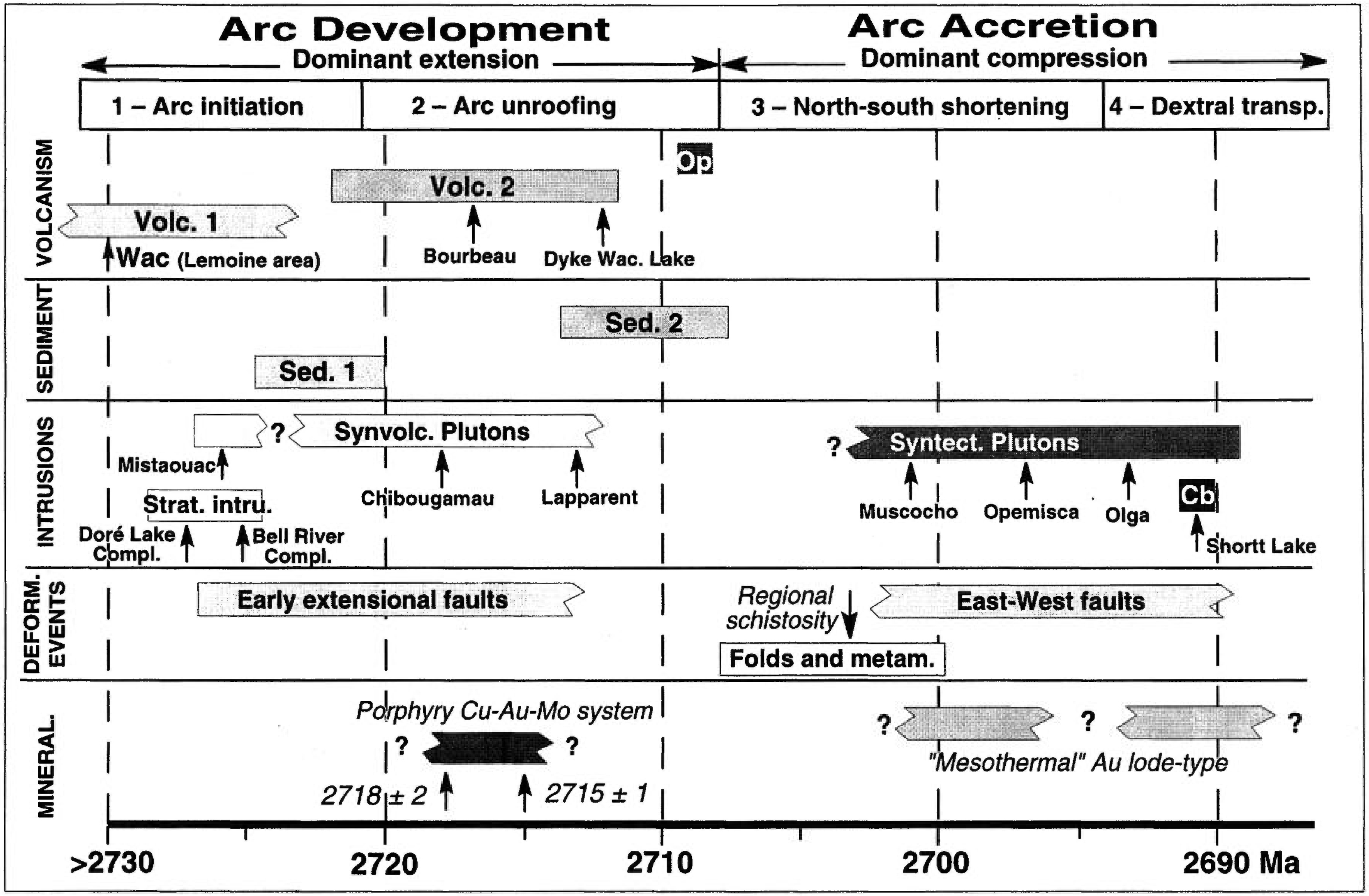


Figure B.1: Setting of the porphyry mineralizing system in the Chibougamau area and the Northern Volcanic Zone of the Abitibi belt (modified from Chown et al. 1992).

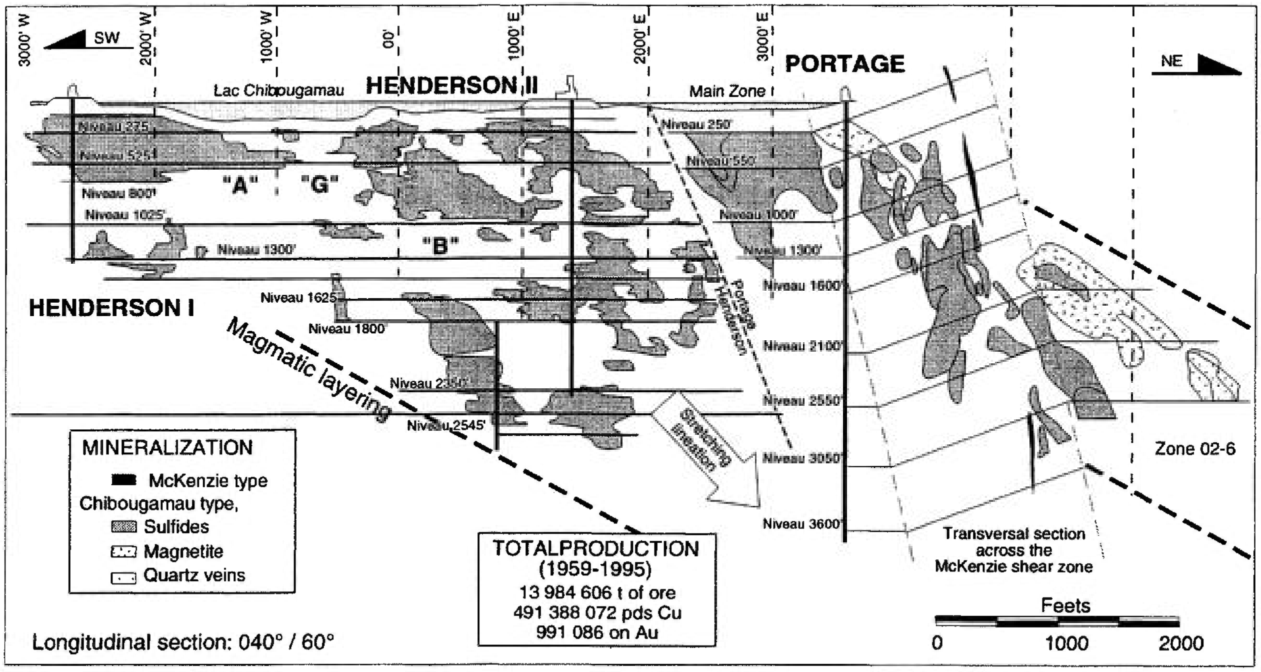


Figure B.1: Composite longitudinal section of the Henderson-Portage mineralized system with tranversal view of the McKenzie shear zone. The rake of the mineralized lens is subparallel to the trace of the magmatic layering, as observed on Portage Island (Henry and Allard, 1979), and slightly oblique to the stretching lineation. Compiled from Campbell Chibougamau Mines Ltd (1986) and MSV Resources Inc. unpublished files, and from Tessier et al. (1995).

remobilized or "reworked" during regional metamorphism and also a strong evidence of a later undefined post-Archean or Proterozoic imprint. Numerous observations and field evidences demonstrate clearly that the Doré Lake type deposits are deformed and metamorphosed by the Kenoran event.

The ore - dyke crosscutting relationships represent a key element in the understanding of these deposits. Dykes of various compositions and aspects (felsic to mafic, aphanitic to porphyry) are located in the vicinity of the ore zones, the mafic and intermediate dykes being generally cut by the felsic ones. It has been shown by many workers as well that these dykes can be related to the Chibougamau Pluton (Jeffery, 1959; Miller, 1961; Blecha, 1966; Duquette, 1970; Allard, 1976a; Maillet, 1978). These dykes acted as an excellent competency contrast during deformation and large ore-filled dilation zones are observed at their contacts, indicating that mineralized veins could have been emplaced synchronously during the intrusion of some specific phases of that pluton. Guha (1984), in a discussion about the possibilities of an early mineralizing Cu-Au event in the Doré Lake camp, pointed out the synchronous character of the ore-dyke emplacement, based on Maillet's (1978) work.

At the Merrill mine, dyke - ore relationships are very well exposed and illustrate the setting and the chronology of the various types of dyke (see outcrop descriptions for Clark Lake and Merrill mine in Section 2). At the Merrill mine, detailed mapping shows that the ore veins and lens are subparallal to slightly oblique to a swarm of tonalitic porphyry dykes striking 120°. These dykes are connected to a tonalitic porphyry plug, similar in composition to an equigranular tonalite dated by Krogh (1982) at 2718 ± 2 Ma and representing a late intrusive phase of the Chibougamau Pluton. The ore zones are commonly hosted by shear zones but in a few cases it can be seen, as in the Merrill pit, that the shear zones drag and overprint both massive sulphide veins and these late tonalitic porphyry dykes. At Clark Lake, intermineral dykes are observed and are geochemically similar to the Merrill tonalitic phase. One of these intermineral dyke has been dated at 2715.2 ± .7 Ma (G.S.C. unpublished data). The short time gap between these two dyke generations strongly suggest that the two type of mineralizations, porphyry type (Clark Lake) and the vein type (Main Mine and Merrill) are the products of the same district-scale magmatic-hydrothermal event.

In summary, numerous features indicate collectively that the hydrothermal system responsible of these vein-type deposits is most likely

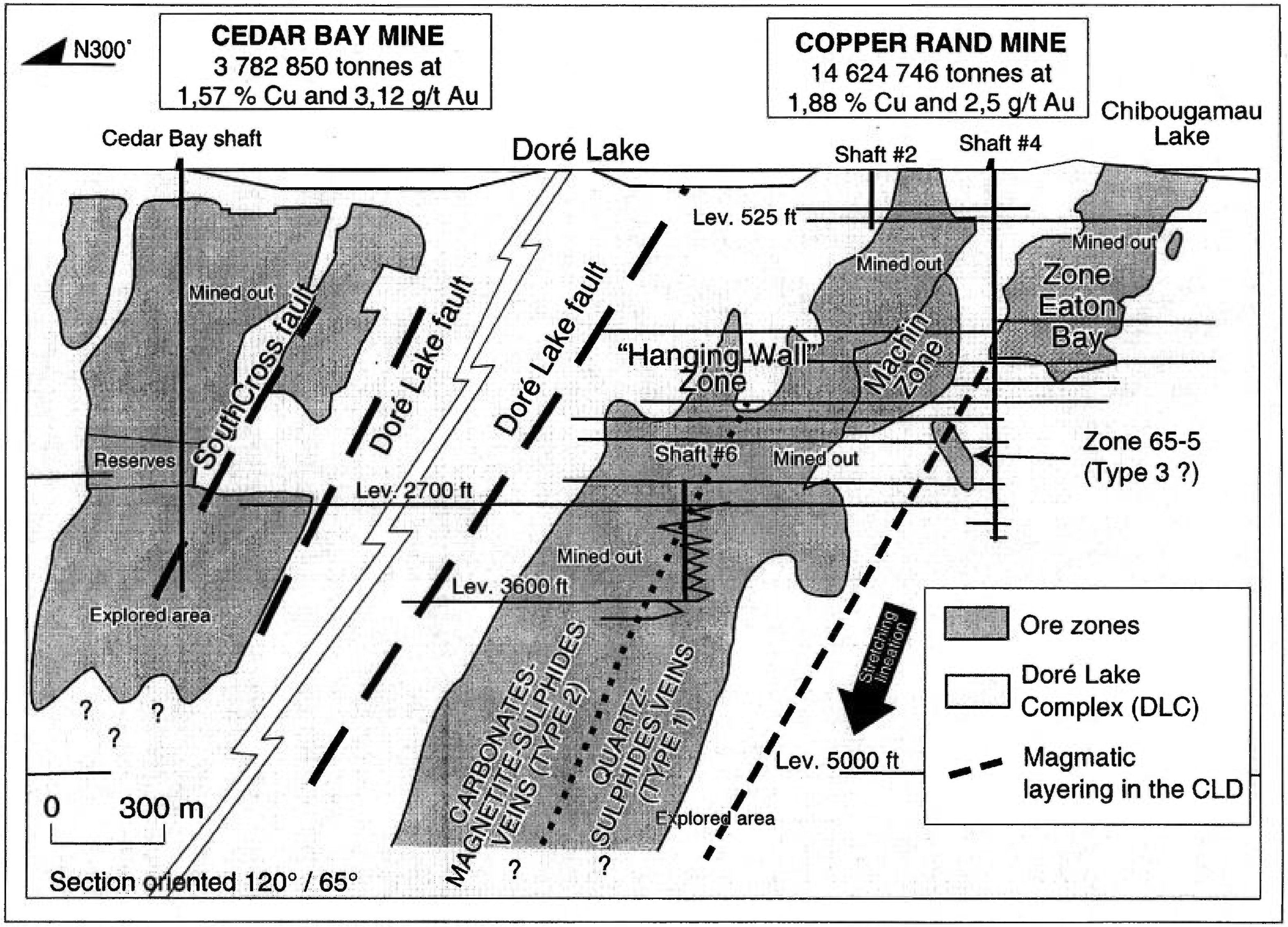


Figure B2: Composite longitudinal section of the Copper Rand and Cedar Bay mines, note that the rake of the mineralized zones is subparallel to the zonation of the various mineralization types, to the stretching lineation and to the magmatic layering, all those elements beeing observed in the plane hosting the mineralization. Modified after Krause (1968), Parrish (1968), MSV RESOURCES Inc. (unpublised data), and Magnan et al. (1995b). Production statistics : january 1st, 1995.

related to magmatic activity. These observations are the occurrences of intermineral dyke at Clarke Lake (see Pilote et al. in Section 2) and Portage mine (Tessier et al., 1994) and of dyke cross-cutting relationships at Copper Rand mine (Magnan et al., 1994; 1995a; 1995b); alteration zones with chloritoid, indicating metamorphism of early paraluminous alteration zones; the dragging of vein-type material and dyke in shear zones at Merrill; and the folding, deformation and cataclasis of massive sulphide veins. The hydrothermal system has to be of kilometric-scale and was active before the regional metamorphism and deformation. The magmatic-hydrothermal event which originated the Doré Lake vein-type mineralization is best described as a large-scale porphyry like system which is related to the evolution of the late tonalitic porphyry phase of the Chibougamau Pluton, dated at 2718 ± 2 Ma (Table B2). The emplacement of that specific phase is contemporanous with the buildup of the second volcanic cycle observed in the Chibougamau camp. The regional deformation, more intensely developed in zones previously altered and which produced the brittle-ductile shear zone hosting the sulphide veins, could have remobilized some parts of the ore zones.

The regional deformation appears responsible in part of the actual steep rake of the mineralized ore bodies, as they are now preserved. It also produced the tilting of the magmatic layering in the DLC. That deformation, however, does not seem to have obliterated the original subparallelism between the rake of the mineralized lens and the trace of the magmatic layering. This point is well illustrated by longitudinal sections from the Merrill and Main mines (see Figure 2.8 in Section 2), the Henderson-Portage mines (Figure B1) and the Copper Rand mine (Magnan et al., 1994; 1995a; 1995b). The factors which affect the observed rake in these various Cu-Au mines are mainly the intersection of the magmatic layering with the plane hosting the ore body itself. The regional deformation, naturally more intensely developped in the early altered zones, is responsible of the production of the shear zones, mainly by flattening. That regional deformation could also have produced in some parts of those mines major remobilization (Guha and Koo, 1975). Finally, this deformational event appears of local importance when the global geometry of these mines, as observed today, is considered.

Proterozoic hydrothermal activity seem to have reworked preexisting mineralized zones and could have produced locally enriched areas with grades spactaculary higher than those observed commonly in the DLC mines (Guha and Kanwar, 1987).

Epithermal precious metal veins

The development of epithermal mineralizing systems and the type of deposit associated with felsic plutons is related to the physical evolution of the volcanic system. Cimon and Gobeil (1976), Archer (1984) and Dimroth et al. (1984) have shown that there was growth and subsequent uplift of volcanic islands during the deposition of the Stella and Blondeau Formations and that this volcanic island was probably underlain by plutonic rocks. In such a subaerial condition any porphyry-like hydrothermal system developing at deeper levels within or centred around subvolcanic felsic intrusions would manifest itself in the upper parts of the volcanic pile (Sillitoe, 1991; Arribas et al., 1995) as epithermal Au-Ag-Cu-Pb-Zn-As veins controlled by synvolcanic faults or intrusion-related faults related to cauldron subsidence. This has been recognized in this mining district (Pilote, 1986; 1987). The setting of this type of mineralization is idealy controled by synvolcanic faulting or faults associated with sector collapse or half-grabbens. These faults could have channelized hydrothermal fluids or have been intruded by late intrusions and/ or various generation of dikes.

One possible example of the epithermal vein type of mineralization could be illustrated by the Berrigan prospect (Guha, 1984; Pilote, 1987; Guha et al., 1988) described in detail as one of the stops. Although affected by subsequent deformation, this epithermal mineralization can be identified by its geometry which is controlled by synvolcanic faults; and by the associated breccia zones and vein textures indicating extensional regimes although subsequent deformation, restricted to the altered host rocks, has obliterated parts of the latter criteria. The epithermal veins are best developed in the mafic to ultramafic sills due to the competence of the these units. The segmentation of these early faults by late E-W trending regional faults during the regional deformation makes the identification of the synvolcanic faults possible.

IV - ARCHEAN MESOTHERMAL GOLD DEPOSITS SPANNING MAJOR DEFORMATION AND PLUTONIC ACTIVITY

This category of deposits spans the range of deformation and felsic plutonic intrusion. In spite of the lack of precise age dating of the mineralization and alteration, the structural setting provides a clue to the late syntectonic emplacement of these deposits with respect to the major deformation of the Archean rocks. The major deformation period, probably related to arc-arc collision (Chown et al., 1992), also enabled the intrusion of late syntectonic plutons. The hydrothermal alteration associated with the gold mineralization, which is superimposed on regional greenschist facies metamorphic assemblages, also demonstrates this late emplacement.

In the Chibougamau Segment the mesothermal deposits are best developed in the Bourbeau sill, a differentiated unit belonging to the Cummings Complex. This sill shows certain similarities with the Golden Mile Dolerite (Dubé, 1990; Dubé and Guha, 1989; Allard, 1982). In the Caopatina Segment mesothermal gold occurrences are found along an East-West axis stretching for several kilometres from Joe Mann mine (Dion and Guha, 1994) to the Lac Bachelor mine (Brisson and Guha, 1993). In the Doré Lake area, mesothermal gold is found in the McKenzie shear zone, at the Portage mine (Tessier et al., 1994; 1995). This mineralized shear zone cross cut the Portage Cu-Au massive sulphide veins, providing an age relationships between these two events.

Although specific features vary from one deposit to the other, there are some common traits. Most of the mesothermal gold deposits occur in East-West trending shear zones or conjugate NE and NW systems and are part of, or subsidiary to, East-West trending regional shear zones. Carbonate alteration is ubiquitous. The geometry of the ore lenses is due to dominant vertical reverse movements. However, the vein geometry is controlled by the effect of layer anisotropy for deposits hosted by the Bourbeau sill (Dubé et al., 1989). Several deposits and showings show a spatial relationships to regional NE or NW trending faults (Guha et al., 1988; Dubé et al., 1992). The host unit is commonly a mafic intrusive and in some cases porphyritic felsic dykes are closely associated. Some occurrences are hosted by felsic plutons or stocks, such as Meston Lake (Dion and Guha, 1989; 1994) and showings in the Chibougamau pluton where this category of mineralization post-dates the greenschist facies metamorphic assemblage (Ouellet, 1986). Not all are vein type deposits but some, such as the Tadd prospect in the Bourbeau sill (Dubé et al., 1987) and the Philibert prospect (Dion and Guha, 1989; 1994), are associated with disseminated pyrite in altered and sheared host rocks.

There are some marked differences in the composition of the ore bodies even though they are controlled by the same structural event and hosted by a similar lithology as in the case of Cooke and the Norbeau mines hosted by the Bourbeau sill. The former is more Cu rich and has a poorly developed carbonate alteration, and the latter is gold rich and has well developed carbonate alteration. Significantly different deposits which show a strong correlation with late tectonic porphyritic granodiorite and syenite/carbonatite intrusions such as Lac Shortt (Morasse, 1988; Morasse et al., 1988; Quirion, 1990; Brisson and Guha, 1993) and the Bachelor Lake Mine (Lauzière, 1989) are observed. A marked hematization and potassic alteration is present in both Bachelor Lake and Lac Shortt mines and a sodic amphibole alteration is present in the latter (Morasse, 1988, Lauzière, 1989). The carbonatite have been dated by Joanisse (1994) at 2691 +5/-3 Ma. Although not directly pertinent to this section, the carbonatite bodies may themselves be classed as a distinct group for their rare earth and strategic metal potential since more and more carbonatite intrusions are being noted and evaluated (Bédard, 1987; Quirion, 1990; Prud'homme, 1991).

The genesis of these deposits may be summarized as follows. The emplacement is evidently structurally controlled and the host rock plays a dual role. Firstly a mechanical role as shown by the more competent rocks such as gabbroic sills and felsic porphyries, and secondly a chemical role where fluid-rock interaction not only produced alteration assemblages but helped fix the gold (Dubé et al., 1987; Guha et al., 1988 and 1991).

Although a distinct spatial relationship between deposits and regional NE trending faults is evident, a preliminary explanation advanced invoking superposition of local stress fields (Guha et al., 1988), may require further thought.

The overall signature of the fluids responsible for the emplacement of the mesothermal gold deposits is similar to other gold deposits in the Abitibi belt and elsewhere, with varying contents of CO_2-H_2O-C_2H_6-CH_4-N_2-H_2S (Guha, 1984; Guha et al., 1991). Although the source of the fluids is not known precisely, a distinct trend of gas composition (according to the CO_2-H_2O-CH_4 contents) has been noted. An example of that is a systematic change of CO_2/H_2O ratios of the fluid spatially related to the change of alteration facies in an alteration hosted mineralization. This observation emphasizes that precise fluid rock interaction took place during the emplacement of these type of deposits (Guha et al., 1991). These observations further imply either a variation in the source area or differences due to diverging fluid flow paths (Guha et al., 1991). Metamorphogenic fluid cannot be ruled even though the hydrothermal activity appears to post-date peak regional metamorphism slightly in a majority of examples. A reconnaissance oxygen-hydrogen isotope study (Tremblay, 1987) which indicates a possible magmatic affiliation for the Cooke deposit is based on only two analyses. A case may be made for a magmatically derived hydrothermal fluid for the Bachelor Lake and Lac Shortt deposits (Morasse, 1988; Morasse et al., 1988; Lauzière, 1989; Quirion, 1990; Brisson et Guha, 1994). A diffuse pyrite-gold "halo" type mineralization in the Lac Shortt deposit appears to be a hydrothermal event related to the syenite intrusion which precedes mylonitization although its extent and geometry are not completely known (Guha et al., 1991). The presence of syenite, carbonatite and shear zones is a good three point indicator for gold mineralization in the sector. More recently, See (1994) has been able to demonstrate more clearly the relationship between ore fluids and the intrusions for both Bachelor Lake and lac Shortt deposits.

In spite of overall fluid similarities, the lode gold deposits of the Chibougamau mining district, compared to deposits elsewhere in the Abitibi belt stand out by their conspicuous absence of scheelite and paucity of tourmaline. Tourmaline, for example, has been observed mostly in late veins post-dating the gold bearing veins in the Val-d'Or camp (Robert, 1994).

Similarities in the overall structural pattern and characteristics of fluids between the Archean mesothermal gold deposits of the Chibougamau area and other parts of the Abitibi underline the fact that these deposits formed during a crustal scale episode, but the divergences even within the Chibougamau camp as to the type of magmatic activity, variation of the composition of the orebodies and alteration, indicate controls exercised by local factors as well as possible local variations in the time frame when these deposits were emplaced.

V - DEPOSIT OF UNCERTAIN AGE - OPEMISKA TYPE VEINS

The reason for placing the Opemiska veins, a general term representing the sulphide-quartz-rich veins mined in that area, in a category of their own is the fact that they are encountered in the Chapais area only. In fact, the occurrence of these veins is practically restricted to fracture systems in strongly folded and faulted coarse gabbroic portions of the ultramafic Ventures Sill, one of the three sill composing the Cummings Complex, and they have not been recognized elsewhere in the Chibougamau district. They comprise chalcopyrite, pyrite and pyrrhotite, with minor quantities of sphalerite, magnetite, galena, molybdenite, arsenopyrite and gersdorffite. Native Au occurs with pyrite and chalcopyrite. Non metallic vein gangue minerals include quartz, calcite, chlorite, and lesser biotite, stilpnomelane and actinolite. This sill and adjacent volcanic rocks underwent polyphase deformation which resulted in overturend folds with moderately plunging axes. Conjugate sets of radial fractures formed open spaces in ophitic-textured, coarse gabbroic phases of the Ventures Sill during deformation. These fractures host the economic sulphide mineralization.

The following description is taken from Watkins and Riverin (1982) and Morin and Boivert (1990). Historically the first showings have been discovered in 1929 by Léo Springer, but it is only in 1954 that large scale production began with the building of the Springer shaft, followed later by the Perry shaft (1958), Robitaille shaft (1969), and Cooke shaft (1977), all operated by Minnova Inc, now Metall Mining Corp. The Opemiska Division, operating these four shafts, closed in 1991 and produced 23 534 942 t at 2,24% Cu and 1,17 g/t Au. The veins from the Springer, Perry and Robitaille mines are similar and they have higher copper than gold content compared to mesothermal deposits of category IV, illustrated in that area by the previously described Cooke mine, which is a mesothermal lode-type gold-quartz veins hosted in narrow E-W trending shear zones.

At the Springer mine, the mineralized veins are hosted in E-W trending fractures dipping to the north. These fractures are parallel to the axial plane of a regional synformal anticline. The structural position of these veins is still open to discussion. Derry and Folinsbee (1957) relate the structures to the Gwillim fault whereas Lavoie (1972), Watkins and Riverin (1982) and Morin and Boisvert (1990) indicate that the structures related to the Opemiska veins could be correlated with the major folding events. From the works of Dimroth et al. (1984) and Daigneault et Allard (1990), it is known that the major movement on the Gwillim fault post-dates the regional East-West trending shear zones and have little to do with this mineralizing event.

The Main Vein (vein #3), was the biggest, with a strike length of 900 m, a width of 6 m and a depth of more than 1 000 m. A total of 6 491 793 t at a grade of 2,61% Cu and 0,69 g/t Au were mined. The vein #7 has a lenght of 606 m, a thickness of 2,4 m and a depth extension of 1 000 m. That vein produced 616 320 t at a grade of 1,88% Cu and 2,37 g/t Au. Numerous smaller other veins have been mined out at the Springer mine, for a total in excess of 12 500 000 t of ore at a grade of 2,56% Cu and 1,23 g/t Au.

The Perry shaft was located 400 m to the East of the Springer mine. The mineralized fractures were trending NNW with a dip to the NE. They were localized on the north flank of a synform anticline, and occured at high angle to the axial trace ot that fold. The regional folding is assumed to be the cause of that fracturation pattern. The "B" and "D" were the biggest mineralized ore zones, with a length of 455 m, a thickness of 12 m and a depth of 600 m for the "B" zone, and a length of 330 m, a thickness of 7,6 m and a depth of 750 m for the "D" zone. The total production was more than 9 Mt of ore at a grade of 2,16% Cu and 0,24 g/t Au.

The Robitaille mine was located 2,4 km NE of the town of Chapais. The host rocks and the ore structures are similar to those observed near the Perry and Springer shafts. The Robitaille mine produced 200 000 t of ore at a grade of 1,87% Cu and 0,21 g/t Au.

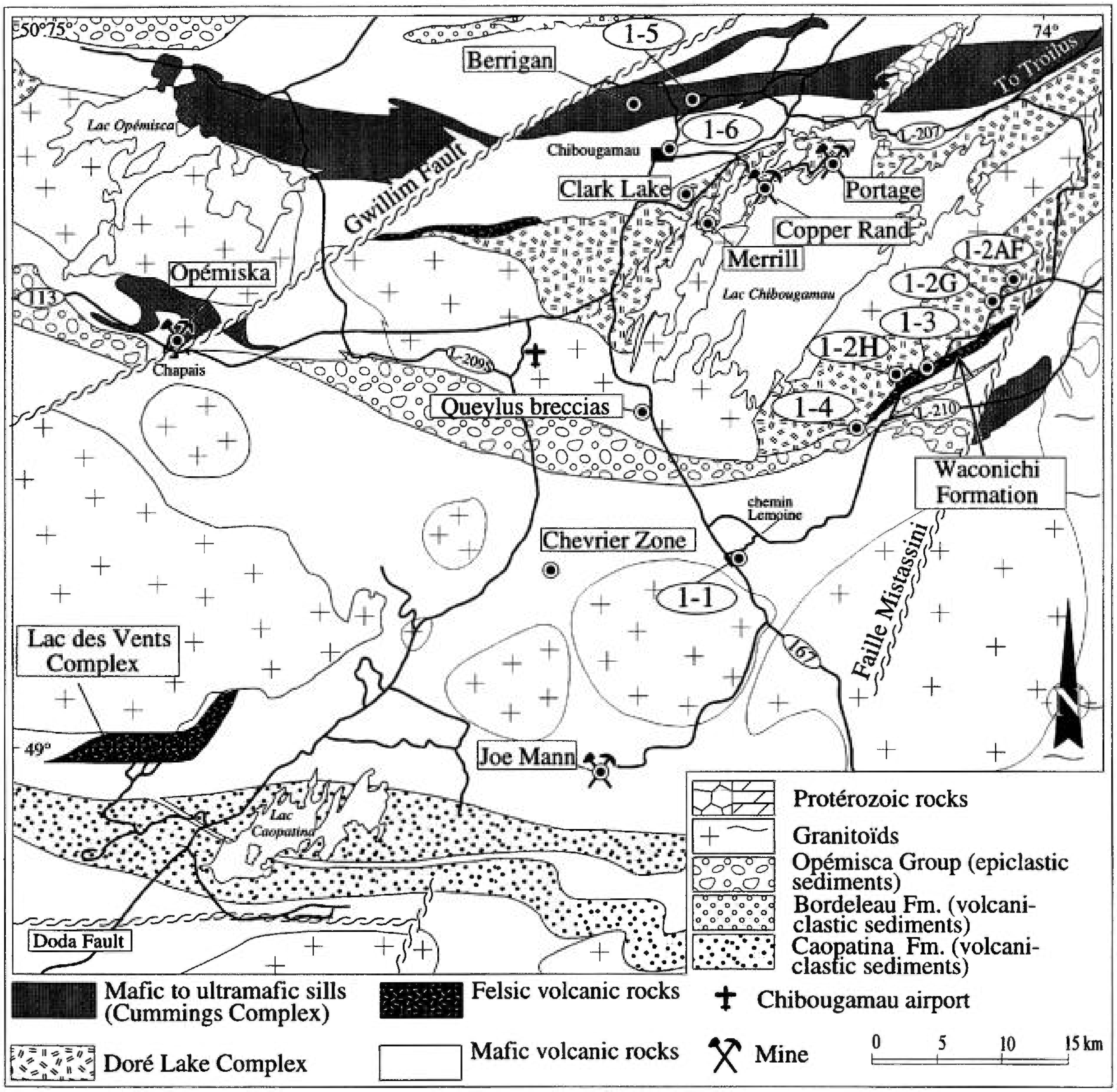
A characteristic feature of the Opemiska veins is the presence of significant quantities of scheelite, and molybdenite which are rare or non-existant in the mesothermal type (category IV) and occur only locally (Merrill and Grandroy mines) in the Cu-Au veins of the Doré Lake Complex. In these aspects, they share some similarities with deposits of Category III (porphyry-type). The main mineralization of the Opemiska vein is overprinted by late pitchblende-uraninite-molybdenite mineralization of an uncertain age (Guha, 1984).

CONCLUDING REMARKS

This overview indicates the multiple periods of both base metals and precious metal mineralization related to the magmatic and structural evolution of the Chibougamau-Caopatina segment of the Abitibi greenstone belt. The various intrusive bodies controlled directly or indirectly emplacement of all the category of mineralization in the district: generating heat flow for volcanogenic massive suphide deposits; porphyry type, Cu-Au vein type to epithermal mineralization; host for mesothermal gold deposits and in some cases a direct link can be established between the intrusions and gold mineralization.

Although the majority of the mineralization in the Chibougamau camp are structurally controlled, each type has its own characteristics features and recognizing these features in a prospect or applying this knowledge in a blind area, would help to orient exploration strategies.

LOCATION MAP



PART C - REGIONAL GEOLOGY
GOLD MINERALIZATION AND MINING POTENTIAL OF THE SHORTT LAKE REGION

Harold Brisson
Université du Québec à Chicoutimi
555 boul. Universté, Chicoutimi, Québec, G7H 2B1
Present address: Mines Aurizon Ltée, C.P. 487, Val-d'Or, Québec, J9P 4P5

INTRODUCTION

The Shortt lake region is located 120 km southwest of Chibougamau (Figure C.1). It is part of the monocyclic segment of the Northern Volcanic Zone of the archean Abitibi subprovince (Chown et al., 1992) and it constitutes the western portion of the Caopatina-Desmaraisville segment. This E-W segment, which joins toward the west the Harricana-Turgeon segment (Lacroix et al., 1990), is formed of volcanic and sedimentary rocks metamorphosed to the greenschists facies.

The Shortt lake region has been the site of an important gold mineralization as indicated by the presence of two ancient gold mines - Bachelor lake and Shortt lake mines - and by a large number of gold showings. Within this set, two descriptive types of gold mineralization are presently recognized. Most of the gold showings are classified in the common *quartz-carbonates veins* type (Robert, 1995). By contrast, the two mines of the region are classified in the *disseminated replacement* type deposit (Poulsen, 1995). The ore of these two mines is in fact essentially associated with hydrothermal replacement zones where mineralization are dissseminated and quartz veins absents or accessories. The two mines also have the characteristic of exhibiting alterations including hematite and potassic feldspar and of being closely associated with small felsic and alkaline intrusions. The Bachelor lake deposit is associated with a granitoid intrusion; the Shortt lake deposit is associated with an alkaline intrusion (archean) including carbonatite and syenite.

Furthermor, the Shortt lake region is located at the intersection zone of two majors faults of the Abitibi subprovince : the E-W Opawica fault and the NE Lamarck fault (Chown et al., 1992). Several showings are spatially associated with the Opawica fault, illustrating the common association in the Abitibi subprovince between gold and E-W faults. A characteristic of the Shortt lake region is that there are gold showings associated with the NE Lamarck fault which appears to be chronologically subsequent to the Opawica fault.

In order to further highlight the gold mining potential of the region, we defined more precisely the setting context of the two types of gold mineralization identified. The approach consisted more specifically in studying the replacement disseminated type Shortt lake deposit and numerous showings of quartz-carbonates vein type mineralization associated in space with the E-W and NE regional faults. At present, as well as the abondance of the mineralizations, their typologic variety and the complexity of the geological setting suggest a far from exhausted mining potential for the Shortt lake area.

REGIONAL GEOLOGY

The stratigraphy of the region has been divided in two major units by Sharma and Gobeil (1987): at the base the Obatogamau Formation, and at the top the Dalime formation (Figure C.2). The Obatogamau Formation is a 1 to 3 km-thick succession of tholeiitic plagioclase-phyric basalts. The formation includes the Wachigabau member which is a less than 1 km unit of felsic effusive and pyroclastic rocks. The Dalime formation is a unit of volcanogenic sedimentary and pyroclastic rocks which is part of the first sedimentation cycle of the Abitibi subprovince (Mueller and Donaldson, 1992).

Numerous intrusion types are present in the region. Gabbroic sills and dykes comagmatic with the Obatogamau Formation basalts and two large stratiform intrusive complexes are found. Pretectonic to late tectonic granitoid plutons are also

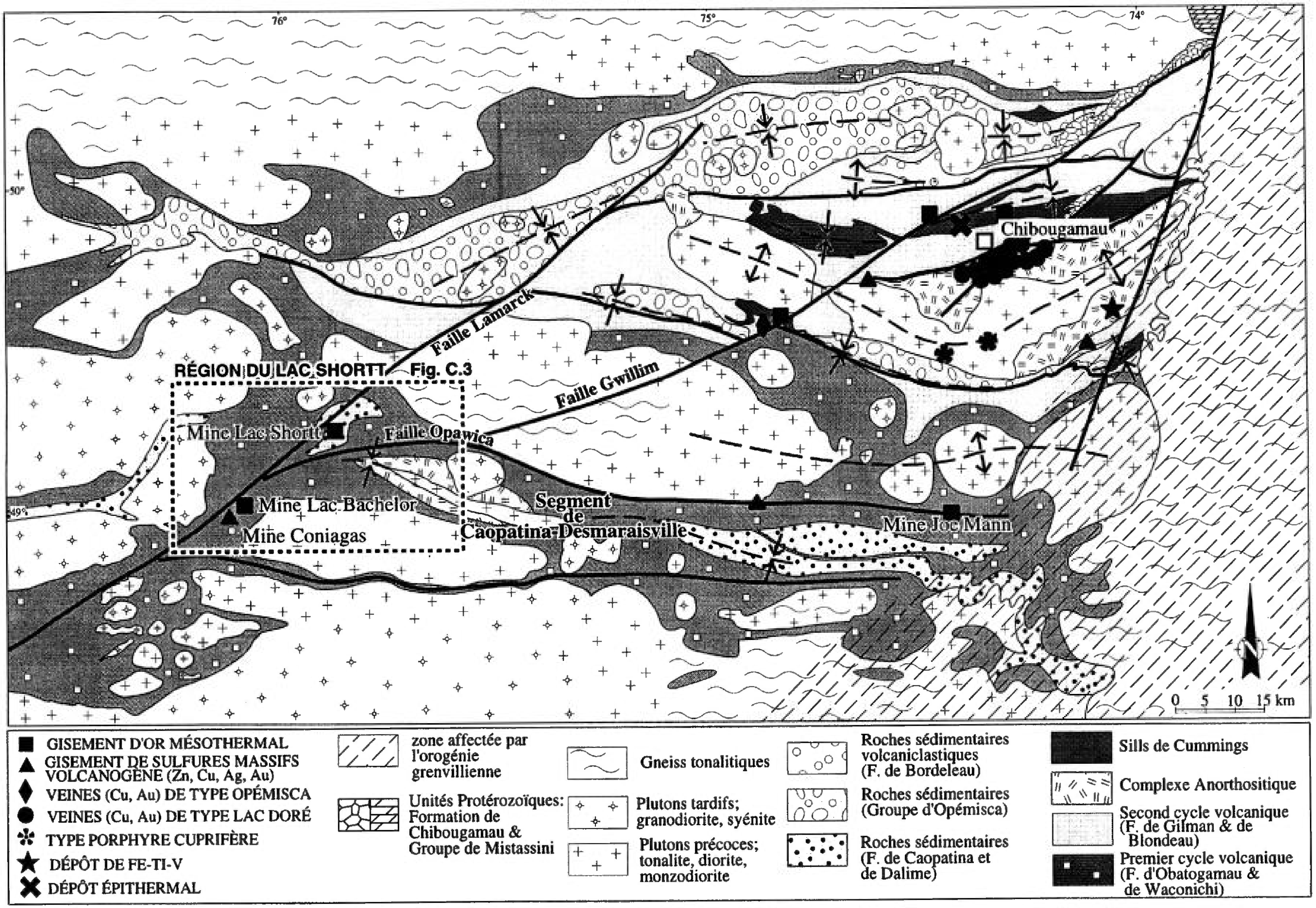


Figure C.1: Simplified geology and ore deposits of the north-eastern part of the Abitibi sub-Province, with the localization of the Shortt Lake area.

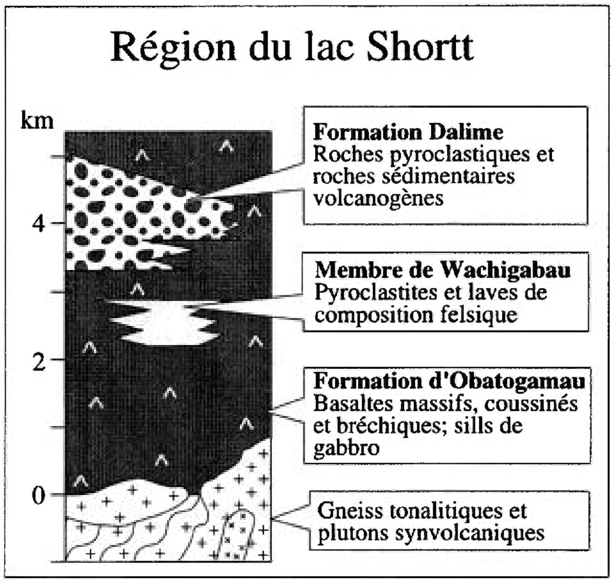


Figure C.2: Stratigraphic subdivision in the Shortt Lake area.

enclosed. The felsic and alkaline intrusions associated with the Bachelor and Shortt lake deposits are late tectonic.

The volcanosedimentary framework is affected by regional folding oriented ENE. The folds are isoclinal with subvertical plunging axes and are comparable to the preeminant E-W folds of the Abitibi subprovince. A flux schistosity, omnipresent on a regional scale, is axial plane with the folds.

Two major sets of faults are identified in the region : 1) ENE and 2) NE. These two types of faults cut the regional E-W folds. The ENE trending faults correspond to the E-W type identified across the entire Abitibi subprovince. The Opawica fault is the predominant structure of this set in the region. It is characterized by a large ductile deformation enveloppe. The most important example of the NE set is the Lamarck fault, which has a fragile character and shows a senestral slip of kilometric scale. This latter cuts the ENE faults.

QUARTZ-CARBONATES VEIN TYPE GOLD MINERALIZATION

Geological contexts

The quartz-carbonates vein type gold mineralizations were studied on showings located in an area east of Opawica lake, in another area northwest of Shortt lake, and in the Opawica island area (Figure C.3).

These three geological contexts reveal that the gold bearing veins are enclosed in all the archean rocks identified. The veins are found in different contexts of ductile deformation. The general ductile deformation is negligeable at the showings northwest of Shortt lake and at those in the area of the Opawica island. By contrast, the rocks at the east of Opawica lake showings show more intense ductile deformation than is observed on the regional scale, in illustration of the context of the Opawica fault. These last showings indicate that the Opawica fault is marked by a minimal plurihectometric deformation enveloppe within which the mineral and stretching lineation has an abrupt plunge in general.

Mesoscopic characteristics of the mineralized zones

The gold bearing veins are found in shear fractures, in extension fractures and as cement in breccia associated with shear fractures. The veins located in shear fractures have thickness reaching 1 m; they are massive or show mylonitic rubanement. The walls of the veins exhibit hydrothermal alteration and disseminated mineralizations from a few centimeters to several meters thick.

Sructural controls

All studied showings studied reveal that the setting of the gold bearing veins is essentially controlled by fragile faulting. In general, there is little ductile deformation or little increasing of ductile deformation in association with shear fractures controlling veins.

Two families of faults occupied by gold bearing veins are recognized : 1) predominant dip slip, inverse and inverses-dextral faults; 2) strike and oblique slip faults. The faults of the first family, observed in the three areas studied, have directions between NE and ESE and abrupt dips, N or S. The second family, observed in the area northwest of Shortt lake and the area of Opawica island, includes faults having directions between NNE and ESE with senestral and senestral-oblique slip, and faults having directions NO to NNO with dextral-oblique slip, all having abrupt dips. The oblique slip component is normal in the inclined faults of this second family.

Petrographic and geochemical characteristics

All the mineralizations are dominated by pyrite. Gold is in the native state and in close association with the pyrite or it is free in the veins. The mineralizations have precipitated later than most of the gangue minerals. The hydrothermal alteration is revealed by the formation of carbonates, chlorite, sericite, biotite, clear green muscovite, albite and quartz.

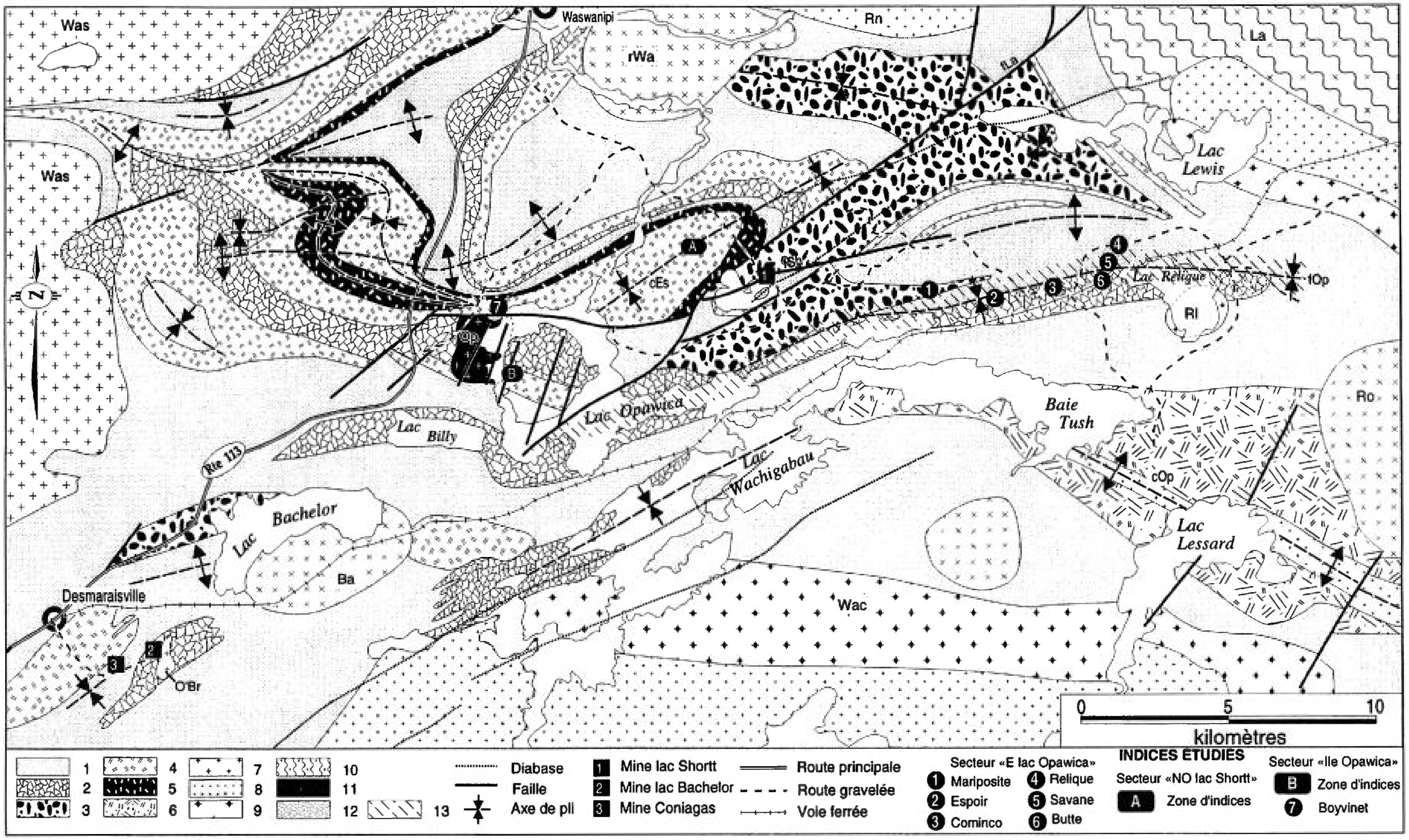


Figure C.3: Simplified geology of the Shortt Lake area with the localizations of the various studied gold showings. 1: Obatogamau Fmt, basalts; 2: Wachigabau menber, pyroclastic rocks and felsic lavas; 3: Dalime Fmt, pyroclastic and sedimentary rocks; 4: gabbro; 5: pyroxenite; 6: anorthosite; 7: tonalite; 8: granodiorite; 9: monzodiorite; 10: gneiss; 11: syenite; 12: carbonatite; 13: deformation corridor. Plutons and other intrusions: Ba, Bachelor; cEs, Esturgeon complex; cOp: Opawica complex; La, Lapparent; O'Br, O'Brien; Op, Opawica; Rl, Relique; Rn, Renaud; Ro, LaRonde; rWas, Waswanipi river; Wac, Wachigabau; Was, Waswanipi. Faults (f): fLa, Lamarck; fOp, Opawica; fSh, Shortt.

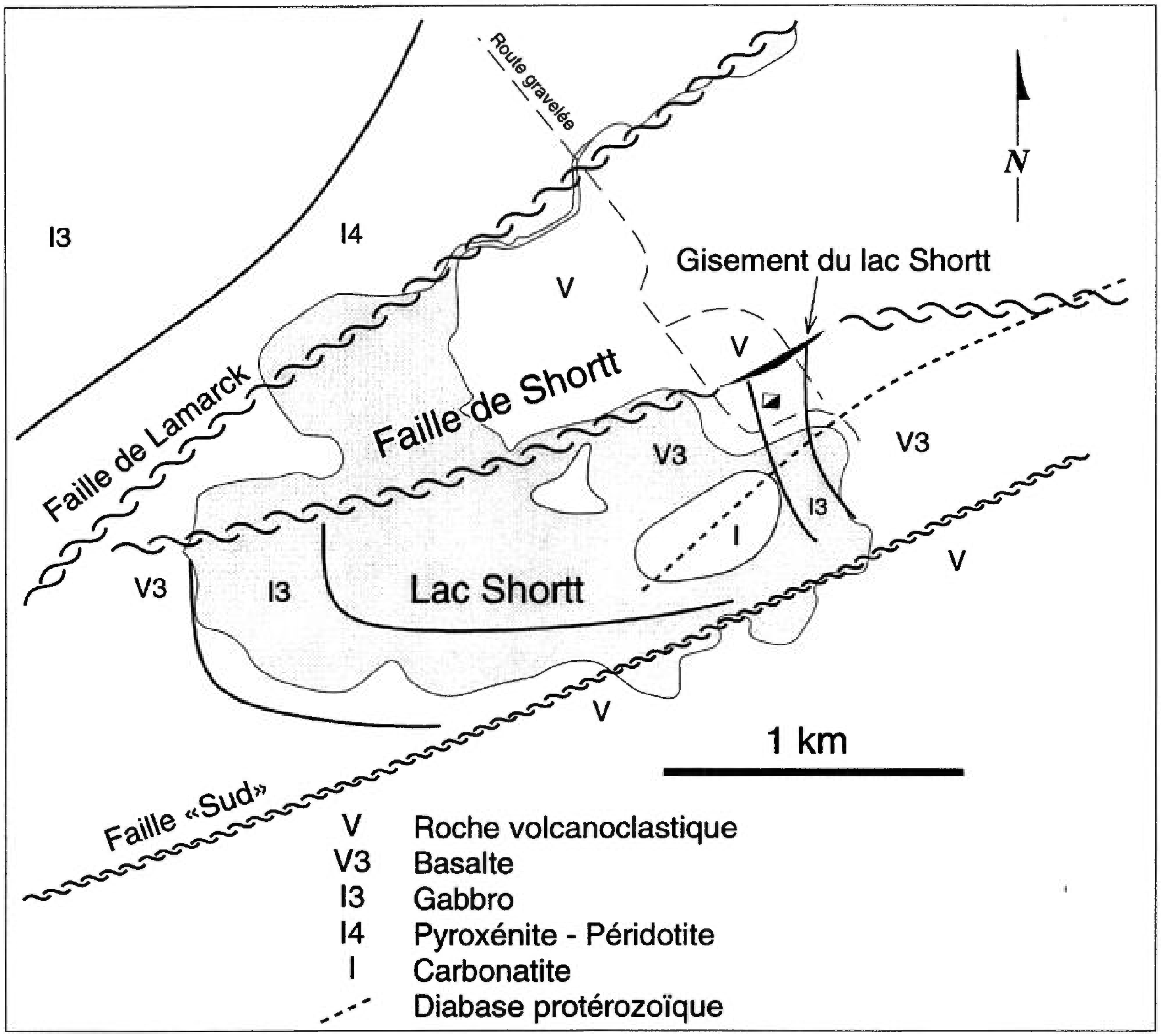


Figure C.4: Simplified geology of of the area surrounding the Shortt Lake mine.

Lithogeochemical studies of the alteration zones indicate the general addition of C, S, H et K. The trace elements which are most systematically added with gold are As and W.

Chronological Aspects

The hydrothermal alteration minerals associated with the gold bearing veins replace the minerals produced by the regional metamorphism to the greenschists facies. The east of Opawica lake showings reveal that the predominant dip slip gold bearing faults are late in relation to the formation of the ductile deformation of the Opawica fault. According to the intersection relations observed at the showings of the Opawica island, the strike and oblique slip gold bearing faults were formed after the predominant dip slip gold bearing faults.

DISSEMINATED REPLACEMENT TYPE MINERALIZATION - THE EXAMPLE OF THE SHORTT LAKE MINE

Lithologic setting

The south wall of the ore body includes basalts of the Obatogamau Formation and comagmatic gabbro sills (Figure C.4). In the north wall are found volcanoclastic rocks of the Dalime formation. The lithologies of the south wall are intruded by an intrusive alkaline body made of carbonatite and syenite. The chronological order of intrusion is the syenite first followed by the carbonatite (Prud'homme, 1991). In connection with this intrusive body, the rocks of the south wall were subjected to extended fenitization illustrated notably by the apparition of sodic amphibole in the basalts and gabbros. U-Pb datation on zircon gives an age of 2 691 +5/-3 Ma for the carbonatite (Dion et al., 1995).

Structural setting

The south wall domain is located in the hinge of an ENE fold. The regional schistosity, coplanar with the axial surface, is weakly developped in the area.

The deposit is associated with an important structural discontinuity : the Shortt fault (Boisvert, 1986). This fault strikes ENE and dips 75 à 80° toward the north. The fault is materialized by a 30 to 40 m wide ductile deformation enveloppe. The deformation is illustrated by schistose, foliated and ribbonned rocks. The stretching and mineral lineation and the shear senses indicators favor the idea of an inverse-dextral fault.

Mineralization and alteration

The deposit represents 2,7 Mt of ore grading 4,6 g/t gold. The Au/Ag ratio is 30. The principal mineralized zone is a lenticular body of 5,5 m in thickness, having a depth of 950 m and an horizontal extension of 300 m. This mineralized body is closely associated with the Shortt fault deformation zone. The oreshoots are located where the Shortt fault cuts gabbroic sills comagmatic with the Obatogamau Formation.

Three types of gold bearing rocks are distinguished in the main mineralized zone : 1) iron carbonates rich rocks, 2) syenites intrusions and 3) carbonatite intrusions. Most of the mineralizations are found in iron carbonates rich rocks containing porphyroclasts of syenite. The mineralization in those rocks are dominated by pyrite. Gold is in the native state, in inclusion in pyrite or free in the gangue. The mineralization are essentially found in the iron carbonate rich matrix of the porphyroclastic rock; the porphyroclasts are nearly devoid of mineralization. The porphyroclastic rocks presents a nearly down dip mineral and stretching lineation and the mineralization it contains clearly draw the tectonic ribbonning, illustrating that these latter have recorded all the least a part of the inverse shearing associated with the Shortt fault. The mineralizations in the syenite and carbonatite intrusions are similar to those observed in the iron rich carbonate rocks and they are also closely associated with mylonitic zones. Geochemically, the mineralization is marked by the addition de C, S, H et K (Morasse, 1988). The W is the trace element which is more remarquably added with gold.

chronological aspects

The gold bearing alteration at Shortt lake replaces the minerals related to the regional metamorphism (Morasse, 1988). The syenite and carbonatite intrusions are sheared in the ductile deformation zone of the Shortt fault and they present a nearly down-dip mineral and stretching lineation. The setting of the alkaline intrusions therefore occured before or during the inverse shearing associated with the Shortt fault. The gold mineralization are closely associated with the Shortt fault and there is no indication of a gold concentration that could be earlier than the development of this fault. The mineralizations are thus interpreted as occuring during the inverse shearing of the Shortt fault. According to the relations observed, the gold mineralization can be synchroneous or later to the setting of the syenite and carbonatite intrusions. The observations thus led to interpret a unique periode of gold concentration synchroneous or later to the setting of the alkaline intrusions and having occured during the development of the ductile inverse Shortt fault.

ELEMENTS OF REGIONAL SYNTHESIS

The study led to recognize that the setting of the gold mineralization examined covers three steps of the structural regional evolution : 1°) predominent dip slip ductile faults (Shortt and Opawica faults); 2°) predominant dip slip fragile faults 3°) strike and oblique slip fragile faults. The replacement disseminated Shortt lake deposit appears during the first of these three steps, whereas the quartz-carbonates vein deposits appears durint the second and third step. The three steps are successive and occur after the metamorphic peak and the formation of the E-W regional folds. The time length between the three stpes is not constrained and can be short. All the gold mineralizations studied would have developped after or from 2 691 Ma approximatively, which is the age of the carbonatite at Shortt lake.

The study reveals that the late period of the regional evolution presents a diversity in the expression of the mineralization and in the nature of its structural controls. In the chronological scheme elaborated, the Shortt lake deposit takes place before the quartz-carbonates veins type deposits studied.

REMARKS FOR THE EXPLORATION

The dip slip ductile Shortt fault is directly comparable to the common E-W faults found elsewhere in the Abitibi subprovince. The gold bearing preeminant dip slip fragile faults are interpreted as later E-W structures. The gold bearing strike and oblique slip faults are observed in spatial assoication with the Lamarck fault and they are indeed analog to NE type R, R' and P subsidiary faults. The spatial association of the gold mineralizations with NE faults is thus significative.

At large scale, it is notable that the Shortt lake region is located in a auriferous axis which appears more important as the exploration continues : the Casa-Berardi - Joe Mann axis. This gold bearing axis follows the Harricana-Turgeon and Caopatina-Desmaraisville segments and is associated with the Casa-Berardi and Opawica tectonic zones. These structures seem to join together and form a unique major tectonic auriferous E-W zone. In the auriferous axis, the Shortt lake region appears very interesting by the fact that is it located at the intersection of major E-W and NE structures with which are linked chronologically distinct gold concentration events.

ACKNOWLEDGMENTS

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GEOLOGICAL AND METALLOGENIC COMPILATION OF THE CAOPATINA SEGMENT

Claude Dion[1] and Martin Simard[2]
[1]*Ministère des Ressources naturelles du Québec*
400 boul. Lamaque, Val-d'Or, Québec, J9P 3L4,
[2]*Ministère des Ressources naturelles du Québec*
375, 3e rue, Chibougamau, Québec, G8P 1N4

INTRODUCTION

The Caopatina project was initiated in 1992 with the goal of compiling and integrating into a global synthesis the available geological and metallogenic data of the Caopatina segment. The study area corresponds to the central and eastern segments of the Caopatina-Desmaraisville volcano-sedimentary belt and is located approximately 40 km south of Chibougamau. This project represents the continuation of work done between 1985 and 1991 by the MRNQ, in collaboration with the Université du Québec à Chicoutimi, which included regional 1:20 000 scale mapping and detailed studies of the main deposits and showings. Recently, the MRNQ and the Ministry of Natural Resources of Canada have completed a detailed airborne geophysical survey of most of the belt, a geochemical till survey and related quaternary studies in the central portion of the belt. These studies as a whole have led to a better understanding of the geology and metallogeny of the Caopatina-Desmaraisville belt.

REGIONAL GEOLOGY

All the rocks in the region are archean in age and belong to the Superior Province, with the exception of Proterozoic diabase dykes. The Obatogamau Formation forms base of the stratigraphic sequence and is composed of tholeiitic basalts, thought to represent a vast deep-sea plain. The presence of large plagioclase phenocrysts is characteristic of this unit.

The Obatogamau Formation contains the Vents and Phooey members. The Vents Member is composed of a 2-2,5 km thick mafic-felsic volcanic edifice which includes 5 felsic units interlain with basaltic flows and gabbroic sill of the Obatogamau Formation. The lower units represent the constructional phase of the edifice whereas the upper unit, composed of volcanic sandstones and conglomerates, is related to its destruction. The Phooey Member is poorly documented. It includes a volcanoclastic sequence related to an intermediate to mafic volcanic centre, located in the SE part of the region.

The Obatogamau Formation is overlain by the Caopatina Formation, a 1 to 2 km thick sedimentary sequence derived from the erosion of volcanic rocks. The sediments include sandstones, conglomerates and argillites locally interbedded with ash tuffs and basalt flows, which indicates coeval volcanic activity. To the E of the Surprise pluton, the metamorphosed equivalent of the Obatogamau Formation is assigned to the Messine Formation.

In the western end of the region, the Obatogamau Formation is intruded by the Opawica River anorthosite complex. This stratiform intrusion is the product of fractional crystallisation from a tholeiitic magma, its morphological and chemical characteristics suggests an affinity to the Obatogamau Formation basalts.

The granitoid intrusions of the region are divided into 2 groups, syn-volcanic plutons, which generally core regional anticlines, and syn-tectonic plutons. The syn-volcanic intrusions are generally polyphase and were emplaced prior to regional deformation. They are related to the volcanic sequences. An example would be the Eau Jaune Complex which probably represents the magmatic chamber which fed the felsic centre of the Vents Member. Regional deformation controlled the emplacement of the syn-tectonic intrusions. They are generally elongated parallel to regional foliation and were intruded along the margins of syn-volcanic plutons.

STRUCTURAL FEATURES

The region underwent N-S shortening during the Kenoran orogeny which resulted in regional scale folds and an E-W trending schistosity. This deformation event is thought to be responsible for the development of large deformation zones related to E-W trending faults and NE trending brittle-ductile faults in the Caopatina segment. The rocks are also affected by late brittle NE to NNE trending faults probably related to the Grenville orogeny. Evidence for a pre-regional deformation event has also been documented in several localities in the belt.

MINERALIZATION

The presence of the Joe Mann gold mine and the abundance of important gold and base metal showings indicates a high mineral potential for the Caopatina segment. Further W of the Caopatina segment, the belt also contains the Lac Shortt and Lac Bachelor gold deposits in addition to the Coniagas Zn-Pb-Ag deposit.

Base metal mineralization

Base metal showings are not large or significant, the information available for them is sparse and of poor quality. Nevertheless, it is possible to subdivide these showings into 4 main categories:

I- Cu Zn Au Ag volcanogenic massive sulphide type mineralization related to mafic-felsic volcanic centres;

II- Zn Cu Au Ag shear zone hosted mineralization in mafic flows, sediments and graphitic tuffs;

III- Cu Au Ag Mo vein hosted mineralization related to E-W or NE trending shear zones in mafic volcanic rocks and related intrusions;

IV- Cu-Ni EGP magmatic type mineralization in mafic volcanic rocks and related intrusions.

Gold mineralization

Gold showings have been grouped into 4 categories based on the host lithology and structural setting. One of these has been further divided into 2 subgroups based on the type of mineralization. Based on our compilation work, we propose the following classification scheme:

I- Gold mineralization related to E-W trending, stratification parallel, shear zones in mafic volcanics and associated mafic intrusions:

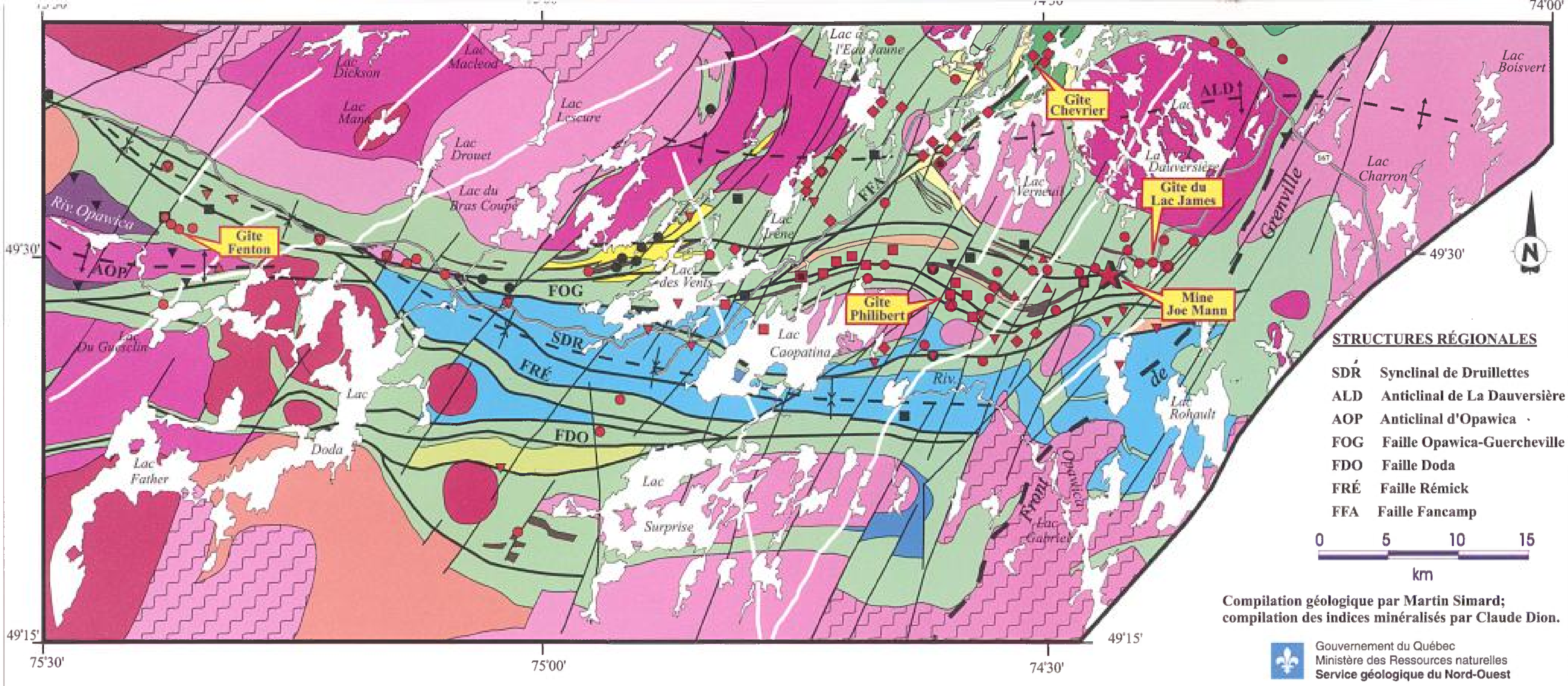
a) Quartz-sulphide vein type gold mineralization;

b) Disseminated pyrite type mineralization;

II- Gold mineralization related to NE and NW trending shear zones that cross-cut mafic volcanics and associated mafic intrusions;

III- Gold mineralization hosted by intermediate to felsic intrusions;

IV- Gold mineralization hosted by felsic volcanic rocks, more or less graphitic sediments and/or "iron formations".



LÉGENDE LITHOSTRATIGRAPHIQUE

PROTÉROZOÏQUE

- Dyke de diabase

ARCHÉEN

INTRUSIONS SYNTECTONIQUES
- Granodiorites
- Tonalites/granodiorites
- Monzodiorites

INTRUSIONS SYNVOLCANIQUES
- Diorites et tonalites
- Gneiss tonalitiques
- Complexe anorthositique de la Rivière Opawica

FORMATION DE CAOPATINA
- Grès, argilites, conglomérats, formations de fer

FORMATION DE MESSINE
- Paragneiss et gneiss à biotite-grenat

FORMATION DE GILMAN
- Basaltes, filons-couches de gabbro

FORMATION DE WACONICHI
- Tufs felsiques à intermédiaires, rhyolites

FORMATION D'OBATOGAMAU
- Tufs intermédiaires à felsiques
- Gabbros
- Basaltes, filons-couches de gabbro

MEMBRE DES VENTS
- Pyroclastites, laves felsiques, sédiments volcanoclastiques, basaltes

MEMBRE DE PHOOEY
- Roches volcanoclastiques intermédiaires

INDICES MINÉRALISÉS

INDICES AURIFÈRES

- Type Ia : Minéralisations du type veines de quartz et sulfures dans des zones de cisaillement est-ouest
- Type Ib : Minéralisations du type faibles disséminations de pyrite dans des zones de cisaillement est-ouest
- Type II : Minéralisations liées à des zones de cisaillement nord-est et nord-ouest
- Type III : Minéralisations encaissées dans des intrusions de composition intermédiaire à felsique
- Type IV : Minéralisations encaissées dans des roches volcaniques felsiques, des roches sédimentaires et/ou des formations de fer

INDICES DE MÉTAUX USUELS

- Type I : Minéralisation de Cu ± Zn ± Au ± Ag du type des sulfures massifs volcanogènes associées aux édifices volcaniques mafiques à felsiques
- Type II : Minéralisation de Zn ± Cu ± Au ± Ag dans des laves mafiques cisaillées, des roches sédimentaires ou des tufs graphiteux
- Type III : Minéralisation de Cu ± Au ± Ag ± Mo du type filonien liés à des zones de cisaillement est-ouest ou nord-est dans des volcanites mafiques
- Type IV : Minéralisations de Cu ± Ni ± EGP dans des roches volcaniques mafiques et des intrusions associées

SYMBOLES

- Anticlinal régional
- Synclinal régional
- Zone de cisaillement
- Faille cassante
- Routes et chemins forestiers

PRINCIPAUX GÎTES

MINE JOE MANN	type Ia :	Réserves - 3,2 Mt à 8,88 g/t Au, 5,83 g/t Ag, 0,27 % Cu.
GÎTE CHEVRIER	type II :	Réserves - 1 Mt à 6,36 g/t Au avec des ressources de 8,3 Mt à 2 g/t Au
GÎTE PHILIBERT	type Ib :	Réserves - 1,4 Mt à 5,32 g/t Au
GÎTE FENTON	type Ia :	Réserves - 320 976 t à 4,24 g/t Au
GÎTE DU LAC JAMES	type Ia :	Réserves - 105 000 t à 2,06 g/t Au (zone sud) et 66 000 t à 4,25 g/t Au (zone nord)

Québec

Carte géologique et distribution des indices aurifères et des métaux usuels du Segment de Caopatina, région de Chibougamau

PRO 97-04

GEOLOGICAL SYNTHESIS OF THE FROTET-TROILUS REGION

Charles Gosselin
Ministère des Ressources naturelles du Québec
375, 3e rue, Chibougamau, Québec, G8P 1N4

INTRODUCTION

The Frotet-Troilus region is located in the oriental part of the Frotet-Evans Archean volcano-sedimentary belt approximately 100 km north of Chibougamau (Figure C.5). The region's most important deposit is the Troilus mine, a porphyric copper-gold type deposit exploited by the open-pit method since 1997. One equally finds numerous volcanogenic massive sulfur deposits (Moléon, Domergue, Tortigny and De Maurés) as well as numerous copper-gold and gold indexes and prospects.

The MRNQ offers a detailed geological coverage of the Frotet-Troilus region of 1 : 20 000. This was completed between 1978 and 1983 as well as between 1991 and 1993. These initiatives led in the mid-1980s to an evaluation of the auriferous potential of the region (Simard and Roy, 1984). This study contributed to the promotion of the region's potential and brought about a significant revival of exploration in 1986. Following the discovery of the Troilus deposit in 1987, the Québec government consider completing the geological coverage on a 1 : 20 000 scale. These studies permitted the presentation of a regional geological synthesis that proposes a stratigraphic scheme for the whole of the region (Gosselin, 1996). The outcome is that the primary mineralization of volcanogenic massive sulfurs are found within a well-defined stratigraphic interval, which provides an interesting guideline for exploration works.

The exploration of the region began in 1957 with the discovery of an erratic mineralised block of Cu-Ni, which then brought about an intense period of staking and the funding of an airborned MAG-EM survey. The first mineralization found (1958-59) were vein types and underscored an interesting copper-gold or gold potential, particularly in the Troilus South sector. In 1961, exploration work had considerably diminished and most permits were expired. The discovery in the same year of the volcanogenic Moléon deposit (184 000 t at 3,4% Zn and 1,56% Cu) relaunched exploration activities. Some volcanogenic indexes are rapidly found (prospects Yorbeau and Diléo) and other vein gold indexes are unearthed until 1970 in the South Troïlus, La Fourche and De Maurès.

The region's potential in base metals will truly be consecrated in 1970 with the discovery of the Domergue deposit(1,2 Mt at 3,35% Zn, 1,96% Cu, 42,9 g/t Ag and 0,72 g/t Au). It will be yet another 17 years, in 1987, before other significant volcanogenic indexes are discovered (Troilus South sector), following an important exploration campaign by Kerr Adisson on the whole of the northern half of the region. This campaign will also lead in 1987 to the discovery of an important porphyric-type deposit (Fraser, 1993), being the Troilus mine (49 Mt at 1,38 g/t Au, 1,23 g/t Ag, and 0,12% Cu).

The exploration companies' interest in searching for volcanogenic mineralizations (Zn-Cu-Ag-Au) has increased since 1993, the year Inco discovered the PK zone. Noranda extended their project and discovered the Tortigny deposit the following year (531 000 t at 6,49% Zn, 3,59% Cu, 85,23 g/t Ag and 0,43 g/t Au). During this period SOQUEM's projects will lead in 1996 to the discovery of the De Maurès deposit evaluated at 350 000 t at 7,8% Zn, 1,4% Cu and 22,0 g/t Ag. It is worthwhile to mention that all these new volcanogenic mineralizations are found within the favourable stratigraphic interval identified by our efforts.

STRATIGRAPHY

Simard (1987) defines the Troilus Group in the

Lake Troilus sector and also distinguishes three volcano-sedimentary complexes in the southern part of the region : the Complexes of Domergue north, Domergue south and De Maurès correspond roughly to the sectors of the same names identified in Figure C.5. The regional stratigraphic scheme that we propose (Figure C.6) integrates, within the Troilus Group, the whole of the units encountered in Simard's three volcano-sedimentary complexes (1987). Its elaboration was made possible in great

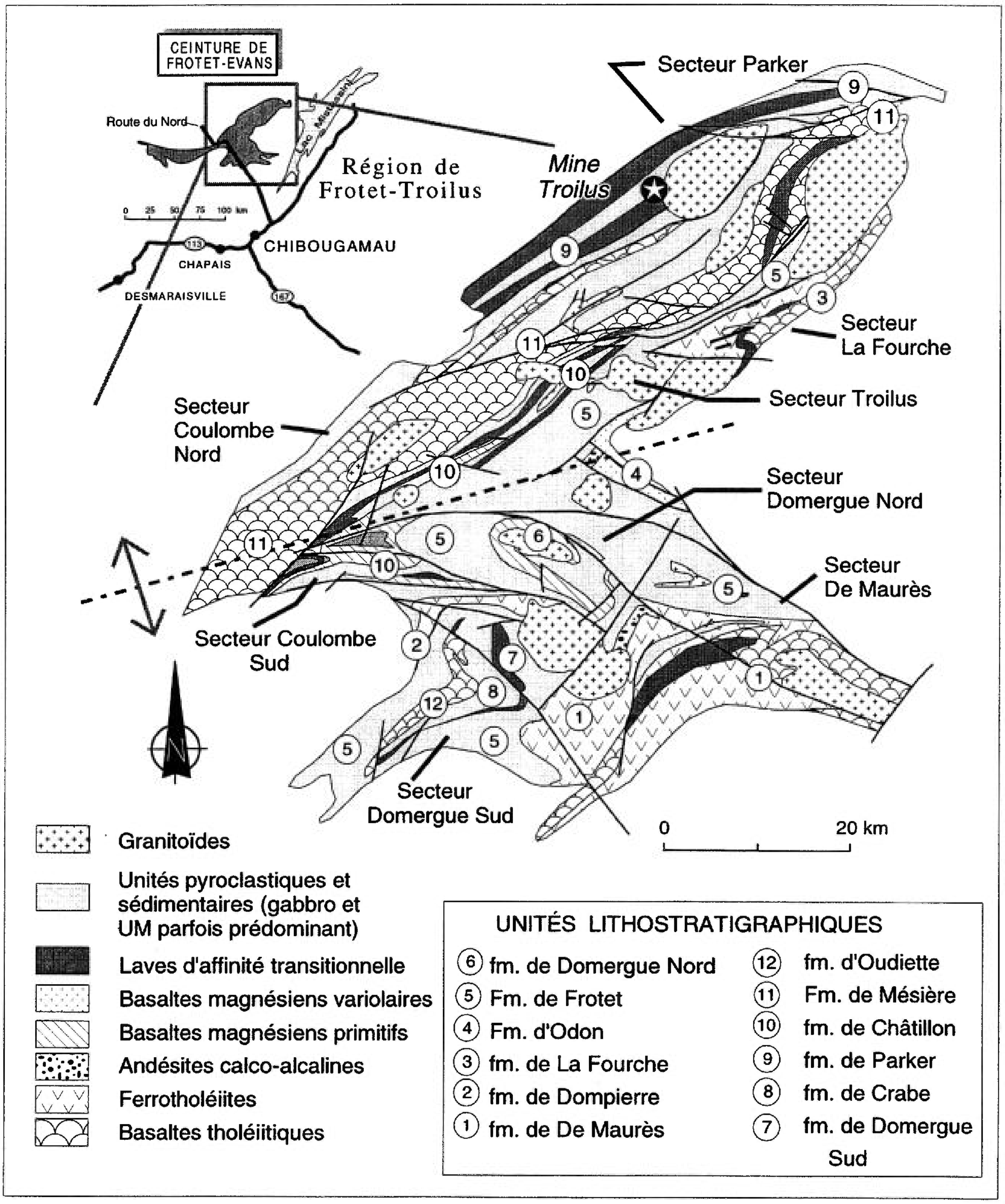


Figure C.5: Simplified geology of the Frotet-Troilus region.

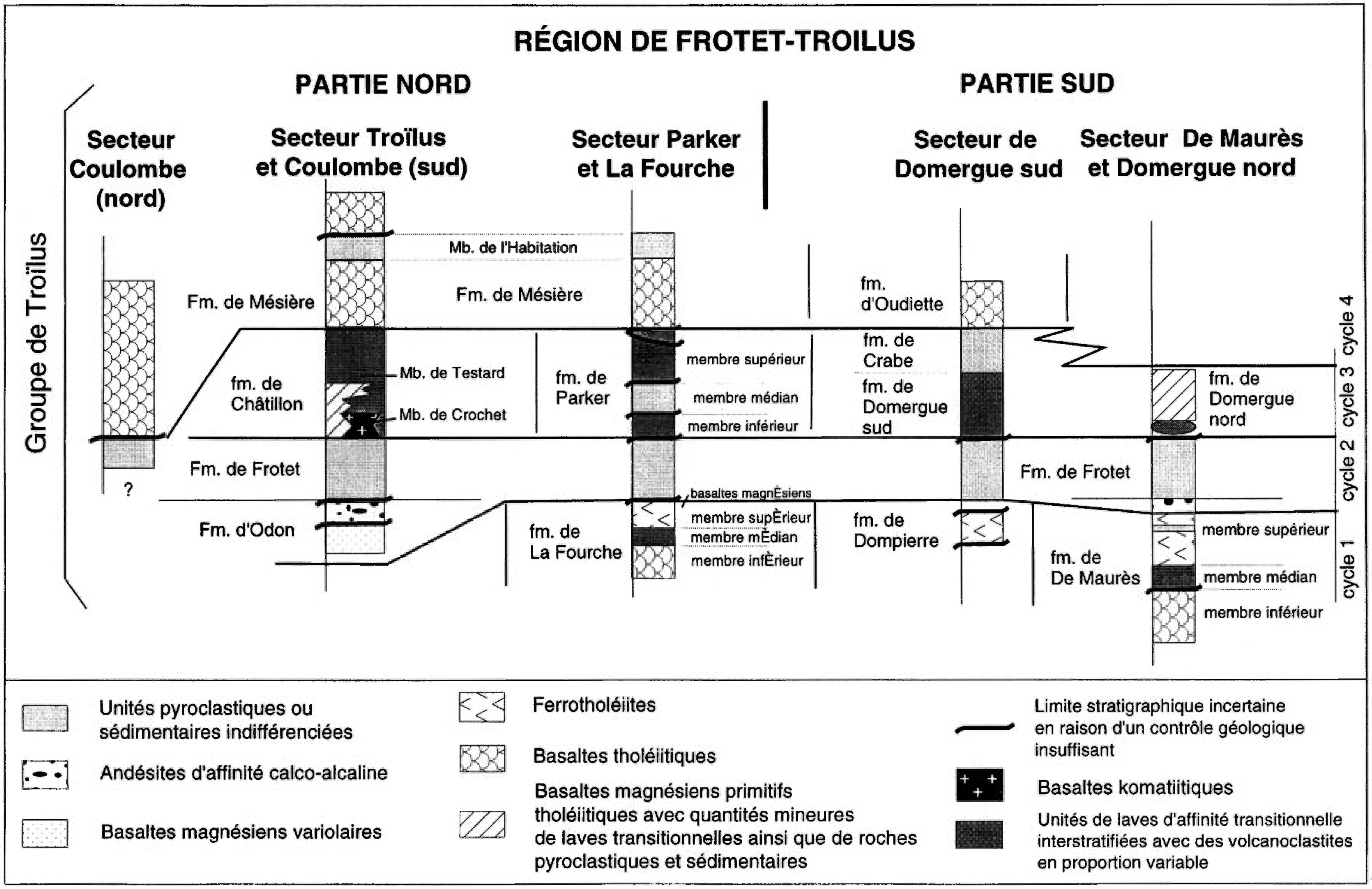


Figure C.6: Lithostratigraphic correlations between the varions formations and members within the Troilus Group.

part due to the lithogeochemical characterisation of the intermediary lava and mafics that enable one to better define the units and obtain additional interpretation elements of particular interest concerning the evolution of the sequence.

During Simard's continuation of the project (1987), all the analyses results were revised and completed by a systematic sampling of the lava units on the whole of the territory. A total of approximately 500 analyses were thus considered. Figure C.7 presents a series of diagrams Zr vs Y that show the distribution of the main lava units of the region. We find (a) tholeotic units with a Zr/Y ratio of 3,0 and 3,3; (b) units with a Zr/Y ration of 4,0 and 4,4 that we consider transitional affinities (ideally the ratio would be between 5 and 7); and (c) calco-alkaline units with a Zr/Y ration superior to seven. In addition, certain tholeiitic units were able to be characterized according to their level of differentiation, that is to say their concentration in zirconium and in yttrium. A lava unit showing a weak concentration of these elements (Zr less than 50 and Y less than 17) will be considered "primitive" while greater concentrations (Zr greater than 80 and Y greater than 25) will be defined as "evolved".

STRATIGRAPHY AND VOLCANOGENIC MINERALIZATIONS

The stratigraphic scheme established in the region enables the division of the volcano-sedimentary sequence into four principal volcanic cycles (Figure C.6) and to present the volcanogenic massive sulfur mineralizations according to their stratigraphic position and their position in one or the other of these cycles.

Cycle 1

Cycle 1 corresponds to a tholeiitic volcanism represented by the De Maurès, La Fourche and Dompierre formations. The lavas associated with this cycle are composed of a basalt base more or less magnesian that correspond to the inferior members of the De Maurès and La Fourche formations, the summit by ferrotholeites of the superior members as well as those of the Dompierre formation (Figure C.6). Geochemically, these units are considered to belong to a continuous differentiated tholeiitic volcanic series (Figures C.7a, C.7b and C.7c). The median members present in the formations of De Maurès and La Fourche are, in this sense, atypical. In effect, they are composed of andesitic basalts and locally variolitic basalts with a transitional affinity with a Zr/Y ration of 4,4. The level of andesite with a calco-alkaline affinity situated at the summit of the superior member of the De Maurès formation will be considered within cycle 2 (Figure C.6) described below.

The volcanogenic mineralizations encountered in these formations are associated to sedimentary and/or pyroclastic levels inserted in the volcanic sequence. They are generally rich in iron sulfurs (pyrrhotine-pyrite) in widths of 1 to 4 metres but only give weak metal values (tr at 0,4% Cu, tr at 0,2 % Zn, tr at 4,5 g/t Ag, and tr at 0,3 g/t Au). Most were found in the superior member of the De Maurès formation but some indices were encountered at the summit of the median member in the sector of the same name (Figures C.5 and C.6). Remember that this member is composed of lavas with transitional affinities which is atypical of the volcanic cycle associated with these formations. We also find pyroclastic felsic deposits as well as quartz porphyres that seem to correspond to a favourable context for base metals. The exploration work completed to date within this unit is modest (less than 10 bores) and cover only a part of its area.

Cycle 2

Cycle 2 is represented by the pyroclastic calco-alkalines units of the Frotet Formation. This formation is composed of blocks of tuffs, crystal tuffs and leucocratic tuffs with minor quantities of fine grain sedimentary rock and felsic lavas. We also associate with this cycle the level of amygdaloidal andesite of calco-alkaline affinity situated at the summit of the superior member of the De Maurès formation as well as the variolary magnesian basalts and the calco-alkaline andesites of the Odon Formation (Figure C.6). The andesites would be the effusive representatives of the explosive volcanism of Frotet.

Little notable volcanogenic massive sulfur mineralizations have been detected in this unit. If the Yorbeau prospect, considered for the summit of the Frotet formation seems to be an exception, SOQUEM's works (Yvon Bellavance, pers. comm.) indicates the presence of lava well beneath the index that brings us to reconsider the superior limit of the formation in the sector.

The limit between cycle 1 and cycle 2 could be the target of an interesting exploration. It represents the end of an important period of tholeiitic volcanism (ferrotholeiitics of De Maurès) and the beginning of a calco-alkaline volcanism. This contact and the units situated above deserve to be evaluated for their metal potential; we think of here the Odon Formation, the calco-alkaline andesite unit at the summit of the De Maurès formation as well as the

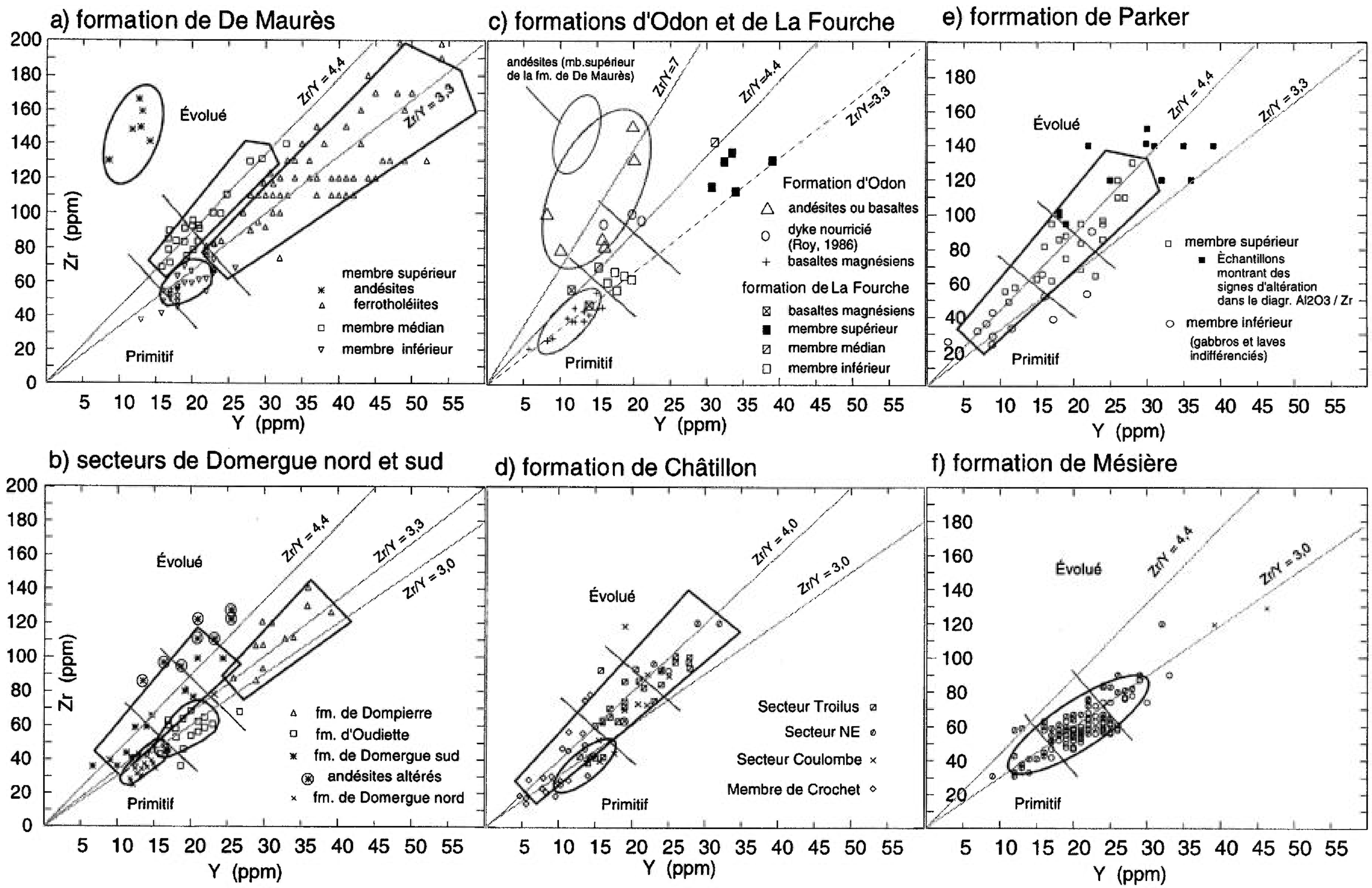


Figure C.7. Zr/Y diagramms showing the composition of the main volcanic units located in the Frotet-Troilus area: a) De Maurès fmt, b) formations located in the Domergue North and South areas, c) Odon and La Fourche formations, d) Châtillon formation, e) Parker formation, f) Mésière formation.

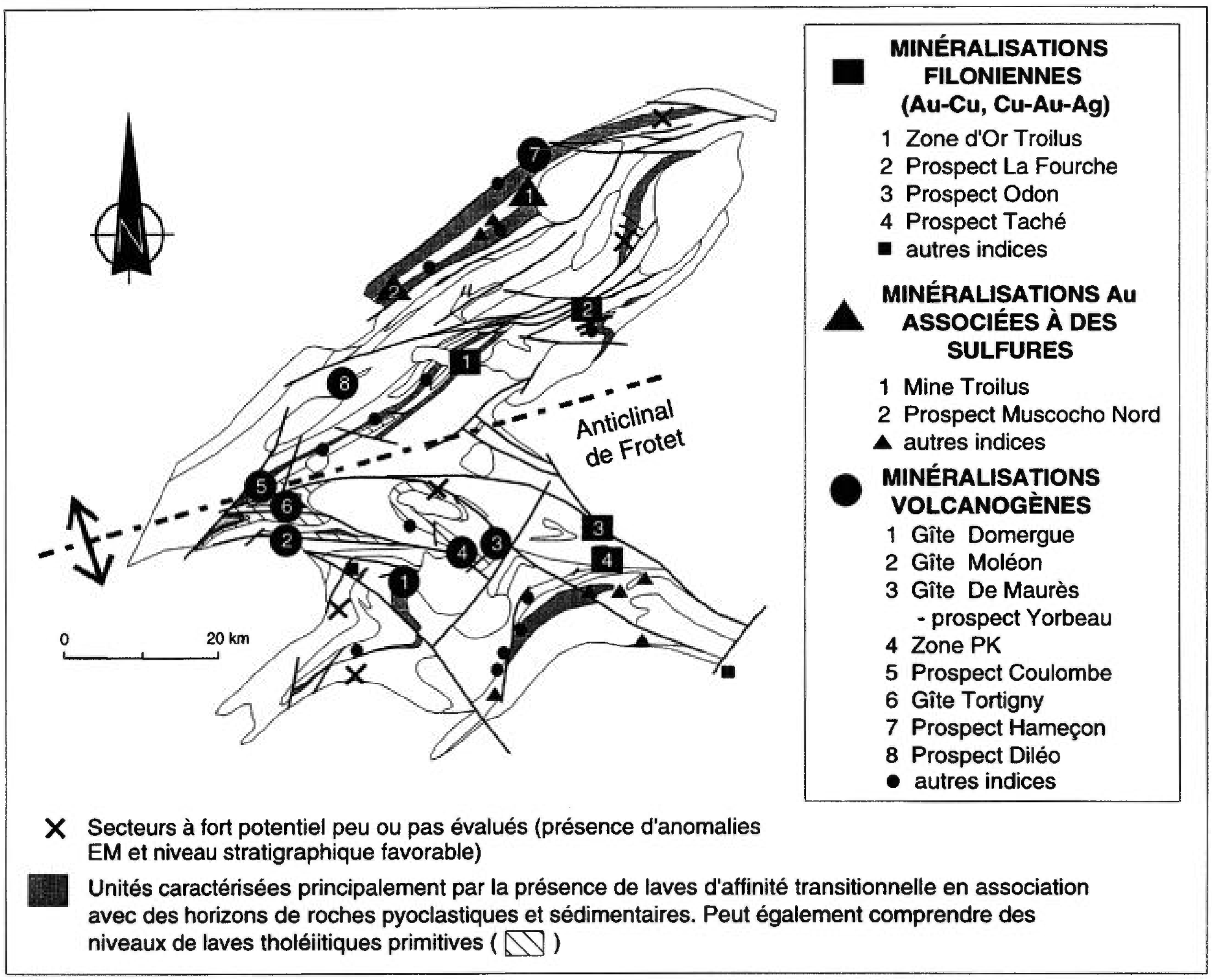


Figure C.8: Location of the main showings and mine in the Frotet-Troilus region.

base of the Frotet formation. It is to be mentioned that this stratigraphic level is the area of injections for 0,15 metres.

GOLD MINERALIZATIONS

This type of mineralization, equally associated with the Troilus porphyric deposit, is found primarily in the Parker sector (Figure C.5 and C.8). Most of the indices were discovered by drilling during the exploration work and the development of the deposit (GM 45114, GM 46338). The gold is associated to the presence of disseminated sulfurs or in semi-massive to massive this ribbons within meta volcanoclastics belonging to the median member of the Parker formation. Values of 1 to 3 g/t Au and sometimes attaining 12 g/t Au on layers greater than one metre are often encountered. Considering the omnipresence of the gold values found in the area around the Troilus mine, the abnormal zone would be more than 10 km long and 1 to 2 km wide. In addition, the presence of the Muscocho North prospect located 15 km to the SW (Figure C.8) bears witness to the considerable gold potential of the whole of the Parker sector. This prospect is associated to a level of intermediary tuffs enclosing a silicified horizon 1 to 2 metres wide at 4 to 7 g/t Au that was traceable over 350 metres in length (GM 48341).

Other gold indices of this type are listed in the De Maurès sector (Figure C.8; Simard, 1988; GM 52492). It consists of concentrations of gold varying from 1 to 5 g/t Au associated with disseminated sulfurs within various lithologies including sheared mafic rock, rhyolitic to porphyric quartz rock and felsic tuffs. A value of 2,0 g/t Au was also obtained in graphitic schists located approximately 4 km SSE of the "Taché" prospect (GM 52492).

CONCLUSION

The Frotet-Troilus region has been the object of more or less intense exploration work for base and precious metals since the beginning of the 1960's. Its gold potential was rapidly identified and many vein indices remarkable for their high concentration in gold have been brought to light. It is, however, a porphyric deposit, of high tonnage and low content that which, against all expectations, has been put into production (the Troilus mine). Otherwise, little exploration work has been done specifically to search for this type of mineralization, this despite the fact that the Odon vein prospect (Cu-Mo-Au) has been long considered as possibly being linked to porphyric type system.

Since the discovery in 1961 of the Moléan deposit, the search for massive sulfurs has been primarily oriented towards the verification of EM abnormalities, which are omnipresent within the volcano-sedimentary sequence and this, at all the stratigraphic levels. In this context, the stratigraphic scheme proposed represents a certain interest for exploration. It enabled, among other things, the definition of a stratigraphic interval offering the best potential and thus to better target exploration work. Figure C.8 shows the regional distribution of this level as well as certain sectors that still remain little or unexplored.

PART D - ECONOMIC GEOLOGY

PORPHYRY-TYPE MINERALIZATION IN THE DORÉ LAKE COMPLEX : CLARK LAKE AND MERRILL ISLAND AREAS

P. Pilote
Ministère des Ressources naturelles du Québec, 400 boul. Lamaque, Val-d'Or, Québec, J9P 3L4;
F. Robert
Barrick Gold Corporation, 7257 Dunver Crescent, Verdun, Québec, H4H 2H6
R.V. Kirkham
Kirkham Geological, 213-7198 Vantage Way, Delta, British Colombia, V4G 1K7
R. Daigneault
Sciences de la Terre, Centre d'Études sur les Ressources Minérales, Université du Québec à Chicoutimi, 555 boul. Université, Chicoutimi, Québec, G7H 2B1
et W.D. Sinclair
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8

INTRODUCTION

Archean porphyry-type mineralization has been known in the Chibougamau area for more than 20 years (Kirkham, 1972; Cimon, 1970 and 1973). The Chibougamau region is distinct in that porphyry-type Cu-Mo-Au mineralization, such as in the Clark Lake area for example, is spatially adjacent to/or are telescoped by Cu-Au lode-type mineralization which is generally described as the "Chibougamau-type mineralization". Examples of this lode-type are represented by Main, Merrill, Copper Rand and Portage mines (Figure D.1). These deposits are hosted by ductile shear zones within the anorthositic facies of the Doré Lake Complex (DLC), a differentiated mafic stratiform intrusion yielding an age of 2727 Ma. These mines are located close to a porphyritic tonalite apophysis of the Chibougamau Pluton, providing an age of 2718 ± 2 Ma (Krogh, 1982). The mineralization occurs on the north limb of a regional anticline which has tilted magmatic layering in the anorthositic complex steeply to the north.

These ductile shear zones typically contain several types of porphyry dykes. Many of these are geochemically and texturally similar to the most differentiated intrusive facies of the Chibougamau Pluton (Racicot et al., 1984). Some specific porphyry dykes are also intermineral to the porphyry-type mineralization, i.e. they cut and are cut by this type of quartz-sulphide veins. Other dykes, among the oldest, are geochemically analogous to specific lithologies found within the DLC.

The various locations visited during this part of the field trip will contrast porphyry-type and lode-type (or "Chibougamau-type") deposits, and will emphasize their relationships. Even if the lode-type is generally hosted in large-scale ductile shear zones, many observations lead to conclude that this spatial association is probably not a primary feature, the mineralized veins being emplaced early in the tectonic evolution of this region, synchronously with specific parts of the volcanic pile.

EXPLORATION HISTORY IN MERRILL ISLAND AREA

Merrill Island, on which Campbell Chibougamau Main Mine and Merrill pit are situated, was named after Arthur J. Merrill, a surveyor attached to the Chibougamau Mining Commission of 1910. Various mineral discoveries were made on the island and adjacent islands and peninsula prior to that which formed the orebody of Campbell Chibougamau Mine and Merrill Island Mining Corp. (Figure 2.2). These discoveries were made by H.A.C. Machin in 1906 (today the location of the Copper Rand mine on the Gouin Peninsula) and John Kokko in 1907 (the former Kokko Creek deposit on the shore of Doré Lake) in their search for gold deposits.

In 1920, an iron oxide-stained outcrop on the shore of Merrill Island was discovered by a

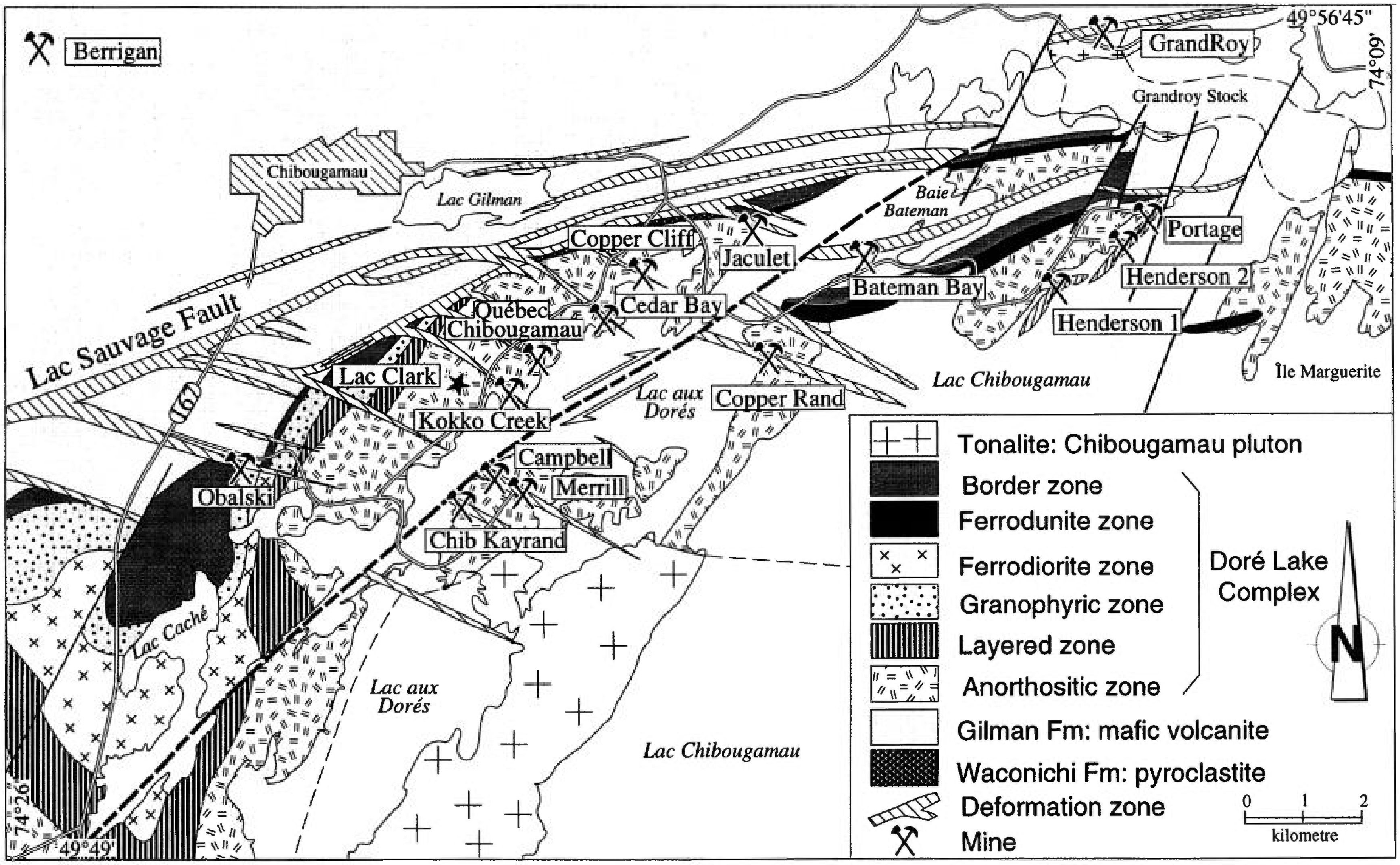


Figure D.1: Geologic map of the Chibougamau mining camp showing the relationships between the Cu-Au deposits of the Doré Lake area and the SE shear zones (modified from Daigneault and Allard 1990).

prospector called Blake and this was the first discovery of what eventually proved to be the main orebody of Campbell Chibougamau Mines, Limited. Also in that year, further work on Merrill Island disclosed numerous copper showings. The Blake Mining Syndicate was formed in 1921 and reorganized in 1922 as the Blake Development Company Limited. This latter company held Mining Concession 136, part of which, Block C, covered all the deposits on Merrill Island, except those under the lake.

By 1927, trenching on Block C had revealed a mineralized shear zone striking 130°, 30 feet wide, dipping subvertically and extending 250 feet southeastward from the Blake showing and the shore (Mawdsley, 1935). In 1928, the Blake Development Company Limited lengthened and deeped these trenches, but sold out to the Blake Chibougamau Mining Corporation the following year. The strike length of the mineralized zone had been extended to 400 feet from the shore (Retty, 1929), but the intensity of mineralization and shearing along strike had greatly decreased. Following these events, Chibougamau Prospectors Ltd. had acquired four water claims off the shore of Merrill Island (Retty, 1930). During the winter of 1928-29 the northwestern extension of the Merrill Island showings under the waters of Doré Lake were tested by diamond drilling by this company. Ten holes were drilled on the ice, of which five were reported as intersecting a mineralized shear zone striking 315° and dipping 63° NE, consisting of chalcopyrite, pyrite, pyrrhotite, and quartz. This extension contained ore at depths from 100 to 500 feet and shown an average tenor of 2,69% Cu and $5,68 per ton of gold (or 6,09 g/t Au) over a horizontal width of 13 feet (3,96 m).

In 1934, Consolidated Chibougamau Goldfields Limited, a subsidiary of Consolidated Mining and Smelting Co. of Canada Ltd., acquired the assets of Chibougamau Prospectors Ltd., which included the offshore claims adjacent to Merrill Island and also a portion of mineralized ground at Cedar Bay on Doré Lake. Work was concentrated on the gold-quartz veins at Cedar Bay and from 1934 to 1936 considerable underground development was carried out; this included a 522-foot shaft, 4 732 feet of drifts and crosscuts and about 34 000 feet of surface and underground diamond drilling. However in the winter 1934-35 Consolidated Chibougamau Goldfields drilled 12 holes offshore but all within 800 feet from Merrill Island, along the strike of the main zone. This diamond drilling programme proved that mineralization persisted strongly for a distance of about 500 feet northwest of the island, beyond which it became less intense (McKenzie, 1936). The positions of the core intersections indicated that here the zone deviate from the northwest strike observed on the island toward an east-west strike. Some holes showed continuous mineralization over widths up to 31 feet. In the five holes within 200 feet of the island, good copper and gold values were present over horizontal widths up to 10 feet. Narrower intersections were recorded in the holes further northwest.

In the winter of 1935-36 the Consolidated Mining and Smelting Company, under an agreement with Blake Chibougamau Mining Corporation, put down 26 diamond drill holes on the island itself proving that the zone extended 2000 feet southeastward from the shore of the island. Nearly all the holes revealed substantial amounts of copper and gold over widths of 10 feet; some were 60 feet or more. Gold values over these widths ran less than 0,1 oz/t Au and were mostly less than 0,05 oz/t Au. Copper, however, was consistently present and ranged as high as 5,04% over a horizontal width of 23 feet, though more commonly it was between one and two percent. Thus, as McKenzie (1936) pointed out, in that year the mineralized zone on Merrill Island and extending out under the lake, had been proved over a strike length of 2 500 feet with appreciable values of gold and copper throughout. Parallel mineralization, 300 to 500 feet north of the southeast part of the main zone, was also disclosed. Operations were suspended in 1936, as the occurrence was too low grade for development at the existing metal prices and under difficult operation conditions.

In 1949, the new highway from St-Félicien was completed and this allowed the large-scale development of mineral resources in that area. This was mostly because the improved access and transportation allowed for copper to be considered as the principal economic mineral, whereas previously this had been out of question. The building of this road was followed by a project of detailed regional geological mapping of the Chibougamau area by the Quebec Bureau of Mines.

Development of the Merrill and Main mines

Merrill Island Mining Corp. Ltd. acquired their property from Blake Chibougamau Mining Corp. in 1950. The same year, Campbell Chibougamau Mines Limited acquired the assets of Consolidated Chibougamau Goldfields Limited, which included both Cedar Bay and the claims offshore from Merrill Island, on a share transfer basis (Figure D.1). Between August 1950 and April 1951, an extensive program of drilling (41 183 feet) and geophysical

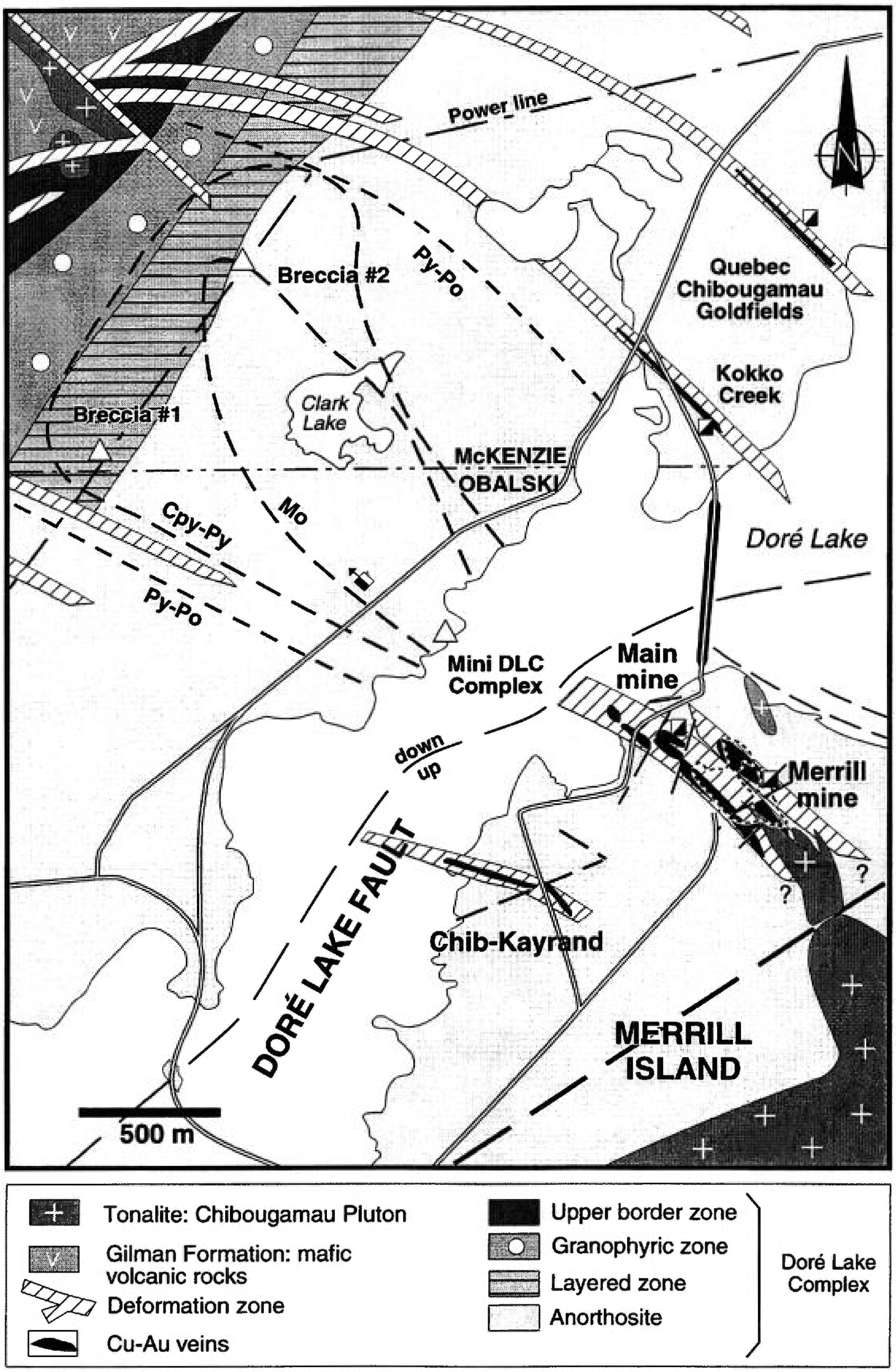


Figure D.2: Simplified geology of the Clark Lake area, with the location of the various mineral zonings observed in the upper part of the Doré Lake anorthositic Complex.

work was carried out on the Cedar Bay property and the Merrill Island offshore claims owned by Campbell Chibougamau Mines. This work had outlined one million short tons of ore grading 3,56% Cu and 0,15 ounces/ton in gold down to the 750-foot horizon, the Blake showing off the west shore of Merrill Island developing at depth into a significant ore body, resulting in a decision to proceed with mining operations.

In 1957-58, work concentrated on bringing the mine into production. The Merrill mine went into production on February 14, 1958 with 1 027-foot three compartment shaft. The shaft was deepened to 2 300 feet in 1961-62, the deepest at 2 100 feet. A 650-ton mill was installed on the property and production started February 11, 1958. Concentrates were shipped to Noranda for treatment. Main A and B zones, as well as C and D zones to the northeast, were developed. In 1964, attempts at open pit mining resulted in large amounts of dilution. In November 1967, when the ore was nearly exhausted, Merrill Island Mining Corp. Ltd. sold properties and other assets to Campbell Chibougamau Mines Limited, including underground workings, development ore and stockpiles on surface and underground, but retaining the mill on leased ground.

Campbell's problem of a site for the shaft, mill and surface buildings was solved by an agreement with Merrill Island Mining Corporation. Merrill, in 1951, granted Campbell Chibougamau Mines a 99-year lease until 2050 AD on two claims adjoining Campbell, which contains the northwest extension and Kokko Creek (Figure D.2) ore zones. Campbell agreed to develop and mine ore from leased sections and production started June 1955 from Northwest zone, and October, 1959, from Kokko Creek zone. This working agreement necessitated the establishment of a vertical boundary approximating the shore line of the island. All ore to the west of this boundary under Doré Lake was owned by Campbell Chibougamau Mines outright and has been termed "A" ore. The ore in the leased portion, east of the division and under Merrill Island, was termed "B" ore.

With this background, undergroud development commenced in November, 1951 at the Main Mine of Campbell Chibougamau. Development up to June 1, 1955 included a four compartment shaft to 1 225 feet. Milling with 1 700 ton per day flotation concentrator commenced on June 1, 1955. Subsequent development in 1954-55 included the deepening of the shaft to 2250 feet, the deepest at 2 100 feet. An internal shaft was sunk from 1 900 foot to 3 814 foot in 1960-61 to open 10 levels at 150-foot intervals to 3 750 feet. Milling capacities increased to 2 000 tons in 1959, to 2 400 tons in 1960, and to more than 3 000 tons in 1960-61. In 1970 fiscal year, capacity was increased to appproximately 4 000 tons per day. In 1979, a new cyanide plant for gold recovery operating at 200 ton per day was added. In the beginning of the 1980s, the mill operated at about 1 500 tpd.

In 1968, a long range exploration study initiated on Merrill and Main Mine property, indicated more than 1 500 000 tons of possible ore, averaging 1% Cu, within 500 feet of Campbell mill, including an open pit area estimated to contain ore reserve of 220 000 tons. Open pit mining of the low-grade material left as surface pillar and along the walls of the main ore zone previouly mined by underground methods by Merrill Island Mining Corp. started in 1971 at 15 000 tons per month, and continued in 1972, 1973 and 1974 from several pits developed in mill area. Production shut down May 1975 due to shortage of manpower and low copper price. The Merrill pit reopened May 1977 and closed early 1978.

The Main Mine closed in May 1975. In 1979 and 1980, some surface pillars were recovered within 500 yards of the mill; by end of 1979, 18 000 tons of ore had been milled. Campbell Chibougamau Mines Ltd. changed name to Campbell Resources Ltd. in July 1980. In March 1981, all Quebec properties were transferred to Camchib Resources Inc.

CLARK LAKE AREA

Introduction

The Clark Lake porphyry Cu-Mo deposit is located in the southern part of Mackenzie township (N.T.S. sheet 32G/16), on the west side of Doré Lake and close to the former Kokko Creek and Quebec Chibougamau mines (Figures D.1 and D.2). A short exploration adit (Mainland project) was driven on the southern periphery of the Clark Lake deposit in the 1970s by Campbell Resources Limited. It is interesting to note that, following Kirkham's (1972) works in that area, Campbell Resources recognized the porphyry nature of the Cu-Mo mineralization in numerous internal reports (see, among others, Ford 1974).

Lithologies

The deposit occurs in granophyre and gabbroic anorthosite of the Doré Lake Complex. Dykes of different types, both aphanitic and porphyritic, with phenocrysts of quartz and feldspar, are associated with the Clark Lake deposit. The phenocryst-bearing dykes commonly cut the aphanitic ones.

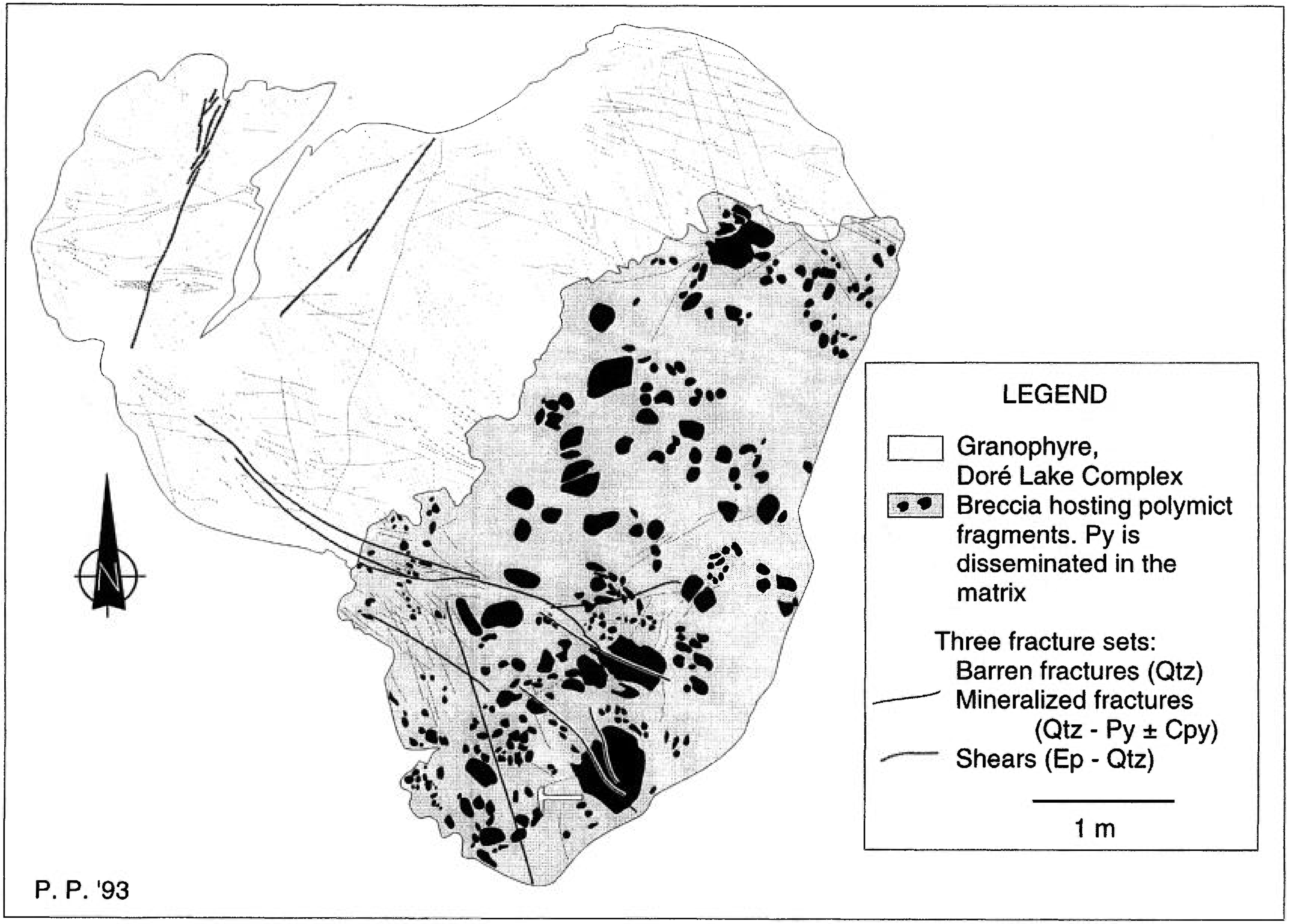


Figure D.3: Intermineral breccia, Clark Lake area. Some of the mineralized veins are cut by the breccia but some veins, with the same mineral paragenesis, crosscut it.

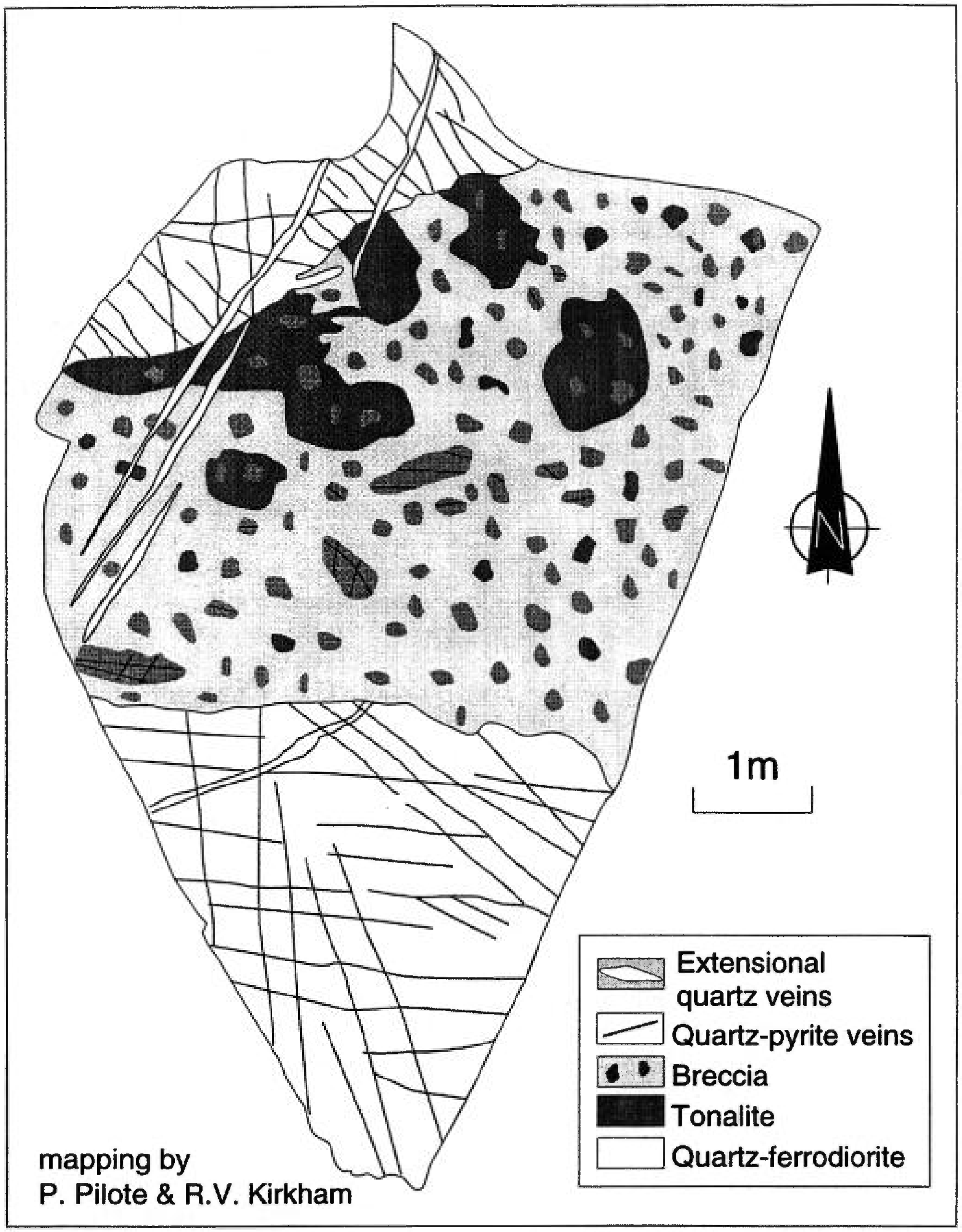


Figure D.4: Multiphased postmineralization breccia, Clark Lake area.

Fracture development and sulphide mineralization

The mineralization, although sparse, is present over a surface area of 1,5 km^2, which excedes the original size established by Ford (1974). It consists of extension fractures and veinlets of quartz-pyrite, quartz-pyrite ± chalcopyrite and quartz-molybdenite. These veinlets occur mainly in three distinct, approximately elliptical, concentric zones around Clark Lake (Figure D.2): (1) quartz-molybdenum veinlets occur in the central zone; (2) chalcopyrite-bearing veinlets extend to the limits of the intermediate zone; and (3) quartz-pyrite veinlets form a peripheral zone. The latter are responsible for a strong, doughnut-shaped electromagnetic anomaly. Within these zones, systematic crosscutting relationships are typically observed between fracturing and emplacement of unmineralized veinlets, which are typically more oxidized, and mineralized veinlets, which are more reduced. The sequence of emplacement, from oldest to the youngest, is as follows:

(1) quartz-chlorite veinlets;
(2) quartz-magnetite-chlorite veinlets;
(3) quartz-pyrite ± chalcopyrite-bearing fractures and veinlets;

(4) quartz-molybdenite veins and veinlets; and
(5) epidote veinlets.

The position in the sequence of the quartz-molybdenite veins is uncertain; they cut the anorthosite, quartz-pyrite veinlets and all types of dykes encountered. On the other hand, they occur in fragments in certain types of breccia. Epidote veinlets are a late-stage feature present mainly in gabbroic rocks in the peripheral zone. The Cu content in that area at the present erosion level is quite low, generally below 500 ppm, even in the area with quartz-pyrite ± chalcopyrite-bearing fractures and veinlets. In the samples analysed along the power line (Figure D.2) the gold content is also very low, generally below the detection limit of 5 ppb.

This sequence, typical of porphyry copper deposits (cf. Gustafson and Hunt, 1975), is generally observed on the north flanks of the Doré Lake Complex, and also in the Queylus breccia on the south flank of the Chibougamau anticline, which is described elsewhere in this guidebook.

The density of the mineralized brittle fractures in the Clark Lake area is both high and regular, typically with one fracture every 2 to 5 cm. The fractures are systematically lined with pyrite, which constitutes 2 to 5% of the rock by volume. The areas surrounding these zones are characterized by a significant decrease in the density of fractures. Furthermore, the fracture pattern clearly shows a preferred orientation rather than a random stockwork; fracture direction varies mainly between 120° and 150°, which is also the dominant orientation of dykes in the area. The extension fractures are in places parallel to, and in many places are cut by, ductile shear zones with similar orientations and of varying scales. The reactivation of these earlier-formed extension fractures and overprinting by shear zones seems to be a feature characteristic of all of the the Cu-Au vein deposits in the Doré Lake area. This phenomenon is particularly well exposed in outcrops of the Miniature Doré Lake Complex (see below; Robert, 1994).

The dykes in places cut, and in other places are cut by, mineralized fractures related to the porphyry deposit and are clearly intermineral as defined by Kirkham (1971). One of these dykes has yielded a radiometic age of 2715,2 ± 0,7 Ma, based on U-Pb dating of zircon (Geological Survey of Canada, unpub. data). This confirms that the porphyry mineralization was contemporaneous with plutonic and volcanic activity related to Volcanic Cycle 2 in the Chibougamau area (Chown et al., 1992) which apex is composed by felsic volcanic rocks of the Blondeau Formation. Based on their age, composition and spatial relationships, the dykes likely correspond to the latest and most evolved phases of the Chibougamau pluton (Maillet, 1978; Pilote et al., 1994b; 1995a, b, and c, and this work).

At least two types of breccia are exposed in the Clark Lake area. The first type, an example of which is shown in Figure D.3, forms small pipes or dyke-like bodies up to several metres across. It is characterized by fragments of various rock types, including different phases of the Doré Lake Complex and of dyke rocks, both aphanitic and quartz porphyritic. The matrix consists of small and finely-comminuted rock fragments and contains disseminated pyrite. Early mineralized fractures (mainly quartz-magnetite-chlorite veinlets), trending 120°, are cut by the breccia and occur in larger fragments in the breccia. In contrast, later fractures containing quartz-pyrite veinlets, also oriented at 120°, crosscut the breccia. Thus, this type of breccia can also be considered as intermineral breccia.

The second type of breccia (Figure D.4) is well represented in the northern part of the power line on the west side of Clark Lake. This breccia contains subangular fragments of Doré Lake Complex rocks cut by pyrite-bearing fractures as well as porphyritic dykes with quartz phenocrysts. The fragments of the dykes themselves contain small xenoliths of anorthosite and gabbro. This suggests that the dyke could have brecciated the host rock when it was emplaced and was itself, in turn, brecciated. Some of the dyke fragments contain quartz-molybdenite veins. The matrix of the second type of breccia consists of small fragments and powdered rock with disseminated pyrite, similar to the matrix of the first type. It also consists, in places, of igneous material which appears to represent small batches of melt that were entrained in the breccia.

All mineralized fractures and veinlets in the surrounding host rocks are cut by the second type of breccia, which indicates that emplacement of this breccia was later than that of the first breccia. The second type of breccia represents one of the latest manifestations of the porphyry mineralizing system at this level of erosion.

Interpretation

These features, the fracture pattern, the zonation of the minerals filling these fractures, and the intermineral character of some tonalitic porphyry dykes and breccias, lead to conclusion that the Clark Lake deposit represents the upper part of an Archean porphyry deposit. Comparable relationships between the early fracture systems and different generations of porphyritic dykes are commonly observed over a surface area of more than 100 km^2 in the Doré Lake mining camp.

Stop description

Several outcrops illustrating key relationships between the mineralized fractures, breccias, and the dykes will be examined in detail. These occur along the powerline shown in Figure D.2, which transects the porphyry system at a high angle.

MINIATURE DORÉ LAKE COMPLEX

Introduction

A small outcrop along the northwest shore of the Doré Lake across from the Chib-Kayrand and Campbell deposits (Figure D.5), locally known as the Miniature Doré Lake Complex and previously described by Allard (*in* Allard et al., 1972) and Allard (1984), illustrates most of the structural features and relationships among shear zones, fractures and mineralization that are observed in the Chibougamau Camp. At that time, the main points were related the description of the sulphide lens and their location within shear zones.

This outcrop consists of anorthosite and gabbroic anorthosite, with small southeast-trending, semi-massive sulphide zones originally exposed in trenches by Campbell Resources Inc. in 1970. These trenches are now partially overgrown. In the portion of the outcrop remapped in detail (Figure D.5; see Robert, 1994), the anorthosite is cut by a metre-wide siliceous, porphyritic grey dyke striking north, and both are overprinted by abundant barren fractures, as well as barren faults and shear zones, described separately below. The dyke contains up to 5% pyrite, distributed along quartz-filled, hairline fractures.

Fractures and faults

Two sets of southeast and northeast-striking subvertical fractures are observed in outcrop, the southeast set being the most abundant (Figure D.5). The two sets have similar characteristics and comprise both barren and mineralized fractures. All

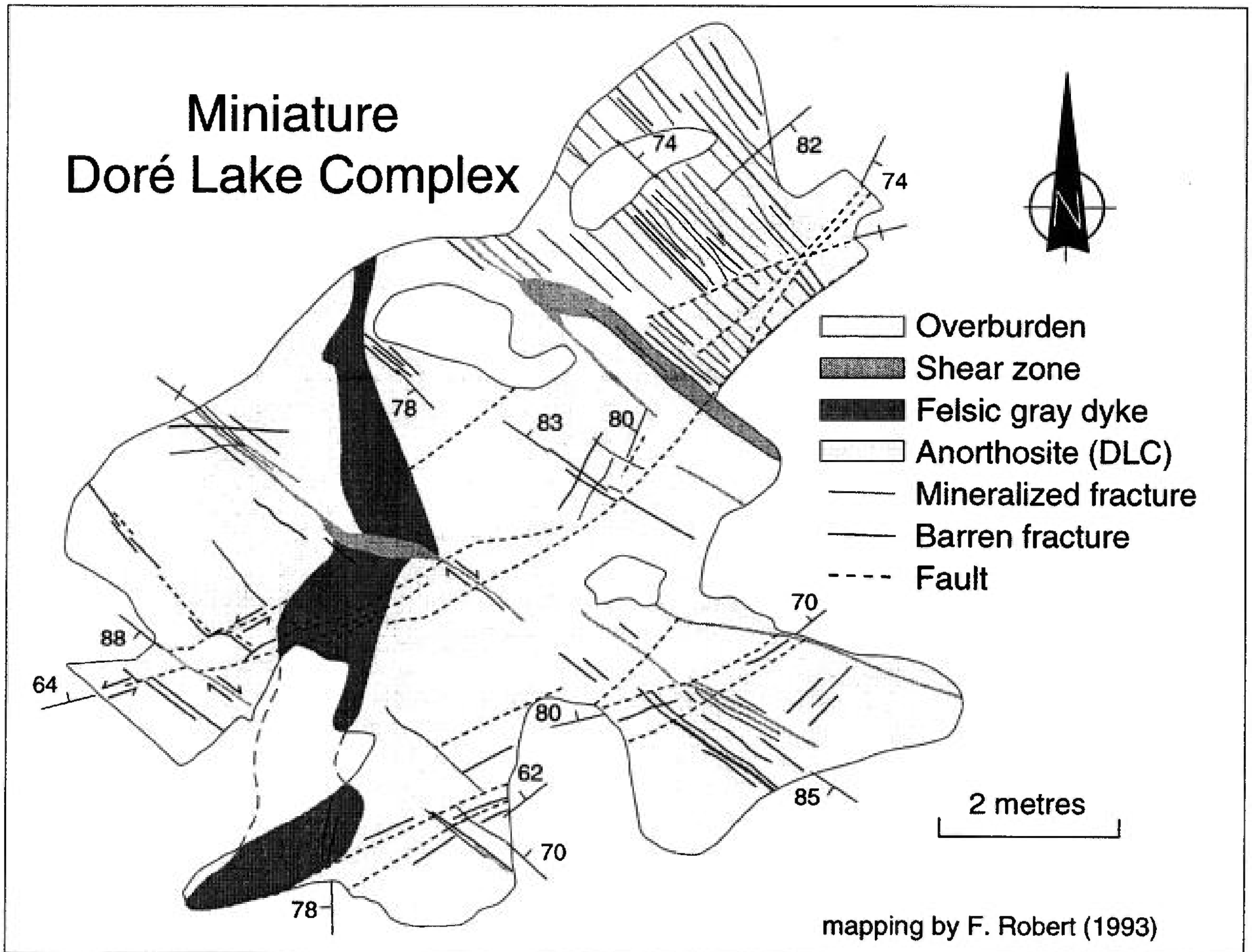


Figure D.5: Miniature Doré Lake Complex (modified from Allard, In Allard et al., 1972; Allard, 1984; and Robert, 1994a).

fractures are planar and the intensity of fracturing is highly heterogeneous. Mineralized fractures are typically lined with fine-grained Fe-Cu sulphides and locally contain a central quartz veinlet up to a few millimetres thick. They are also fringed by centimetre-wide sericite alteration haloes. The majority of the mineralized fractures and their sericitic haloes do not display any foliation. A certain number of these fractures, however, have well-developed foliation in the adjacent sericitized wallrocks (see below).

A set of barren, northeast-striking faults is also present on outcrop (Figure D.5). These faults cut and offset mineralized southeast-striking fractures, as well as the grey dyke.

Shear zones and mineralization

Several narrow shear zones occur parallel to, and are spatially coincident with, mineralized southeast-trending fractures. The shear zones have a well-developed internal foliation and range in width from <1cm to 40 cm. The orientation of the internal foliation and the offset of the grey dyke (Figure D.5) indicate a dextral horizontal component of movement along these shear zones, similar to that observed on the Chib-Kayrand outcrop (Figure D.2).

The mineralization is not very well exposed; it consists of a pyrite-chalcopyrite lens and veins. There is a weak alteration front in dark chlorite at the margins of the sulphide lens, which are hosted in foliated sericitized anorthosite. In the shear zones that are coincident with mineralized southeast-trending fractures (Figure D.5), it is noteworthy that the foliated zone appears well localized and restricted to the sericitic alteration halo around the fractures. In some cases, the shear zone is developed only along a segment of a given fracture. In addition, the widest shear zone on outcrop has sharp boundaries coincident with southeast fractures, in contrast to the expected gradational nature of shear zone boundaries. It is also striking to note the first occurrence of iron carbonate in that area, that is within the ductile shear. All these relationships indicate that the southeast-trending shear zones overprint the earlier southeast-striking fracture set.

At several locations on the outcrop, the northeast-striking faults are in turn clearly offset by the shear zones. The fact that these faults cut the non-sheared mineralized southeast fractures elsewhere indicates that the southeast shear zones overprint the early mineralized fractures and result from their reactivation during later deformation. The sericitic alteration haloes around these fractures likely played a major role in localizing foliation development given their incompetent nature. There is no evidence in outcrop for additional mineralization being introduced during development of the southeast shear zones.

Discussion

The Miniature Doré Lake Complex provides another example of early mineralization that has been overprinted by shear zones developed during subsequent deformation. It also illustrates the role of sericite alteration haloes associated with Fe-Cu sulphide fractures in localizing shear zones, as indicated by the confinement of the shear zone foliation to such haloes on the Miniature Doré Lake Camp outcrop. The common spatial coincidence of shear zones, broad sericite alteration zones and Cu-Au mineralization in the Chibougamau camp may reflect the role of early sericite alteration in localizing subsequent deformation and shear zone development. This role may not be readily apparent in the large Cu-Au deposits of the camp (as Copper Rand, Cedar Bay, Portage, and Main mines) because of the greater magnitude of the effects of shearing (Figure D.1).

THE MAIN MINE

Introduction

This mine, also known as the Campbell Main Mine, does not constitute a formal stop to that excursion. However, it shows many similarities with the Merrill mine, the main one being the fact that this deposit represents the western part of a bigger and continuous orebody containing the Merrill mine as well (Figure D.6). The description of that mine, in operation from 1954 to 1981, then represents a worthwhile contribution. The following description is taken and adapted from Malouf and Hinse (1957), Jeffery (1959), Blecha (1966), and Allard (1976a).

The Merrill and the Campbell Main mines exploited a small number of subparallel orebodies consisting of up to 50 volume percent of pyrrhotite, chalcopyrite, and pyrite. All orebodies occur within a southeast-trending composite shear belt, a few hundred metres wide and over a kilometre long (Figure D.1), containing abundant dykes and shear zones of similar orientation.

Total production from the Campbell Main mine, from underground and some small open pits, reached 4 840 946 short tonnes of ore at an average grade of 1,82% Cu and 0,033 oz/t Au (1,13 g/t Au) (see Table B.1).

Lithologies

Mineralization at Campbell and Merrill mines is hosted in shear zones cutting anorthosite and

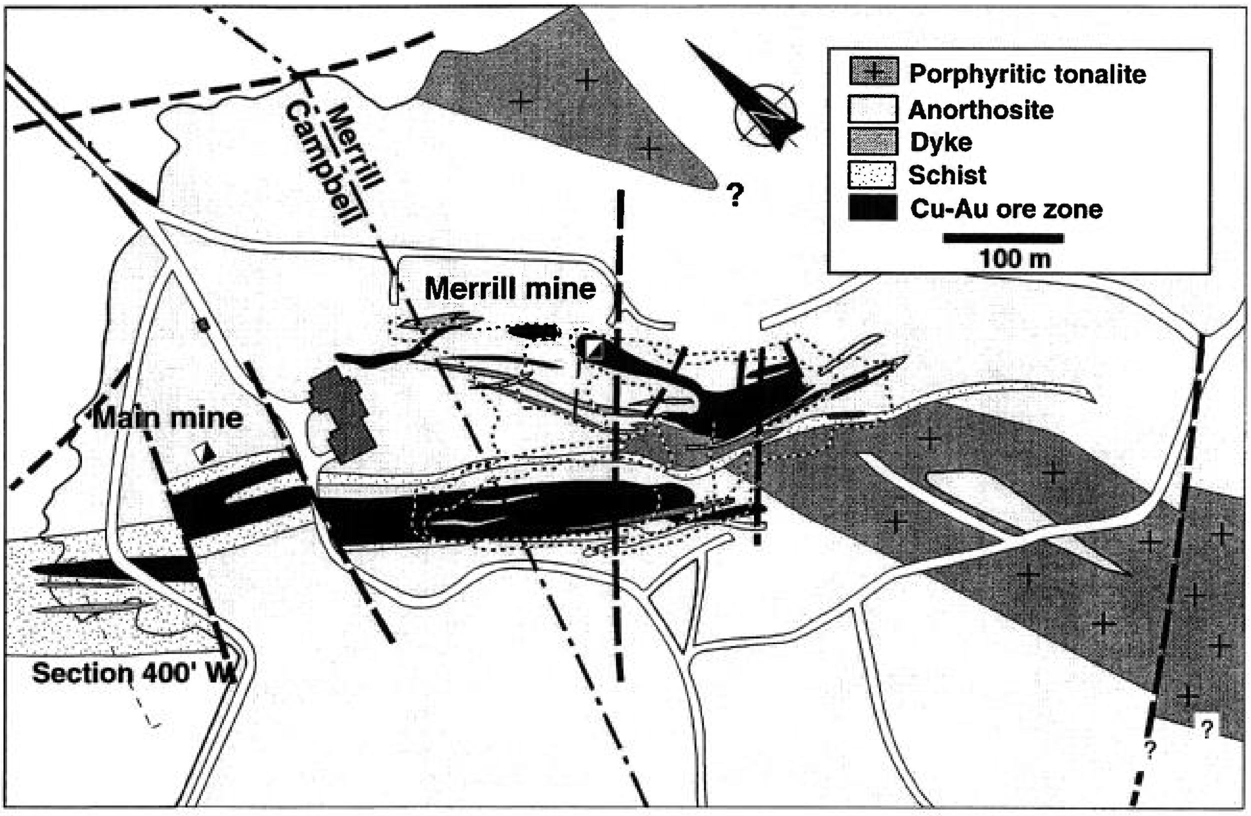


Figure D.6: Simplified geology of the Main and Merrill mines mineralized system (modified from Campbell Resources Ltd. and Canadian Merrill Inc. mapping).

gabbroic anorthosite of the Doré Lake Complex. Different kind of dykes are observed close to or near these shear zones. Magmatic layering has been observed locally underground at the Main Mine. It strikes northeast and dips from steeply to moderately to the northwest, from near the surface to the 1900 foot level (Jeffery, 1959). Historically, the anorthosite has often been called a breccia because it consists of angular plagioclase in a matrix of chlorite. It is not a breccia, in fact, but a normal cumulus rock with the plagioclase forming the cumulus phase and the chlorite replacing an original intercumulus pyroxene.

Numerous types of aphanitic to porphyritic dykes are observed within the mine area. They strike southeast and show an overall steep southerly dips (Figures D.6 and D.7). Jeffreys (1959) postulated that because of petrological similarities these dykes could be genetically related to the Chibougamau pluton, a large stock intrusive into the Doré Lake layered Complex. In order of introduction, these dykes are diorite porphyry, quartz diorite, feldspar and quartz porphyry and grey siliceous dykes. A small mass of older diorite, now extensively propylitized, is found on the hanging wall of the ore zone. Another dyke, possibly dioritic in origin, but described in the mining operations as a dark green or black amphibolite, occurs in the lower levels. Evidence suggests that it is a multiple intrusion. Cross-cutting relationships between it and the porphyry and grey dykes indicated that the black amphibolite is the youngest type of dyke in the Main mine sector.

Structure

The copper and gold-bearing deposits on, and northwest of, Merrill Island occur in a composite shear belt having an overall width of 900 feet. Operations from the Campbell Main Mine have been directed at the northermost component of the shear along a band ranging in width from 10 to 150 feet. The other orebodies have been developed from the Merrill Island Mining Corp. shaft, located 1 100 feet southeast of the Campbell headframe in the southeast part of that shear zone (Figure D.6).

Underground mapping has shown that in the Campbell area, the composite shear zone strikes about 120° with an overall dip of 70° south, with numerous offshoots tending to strike 315° . The shear zone is 900 feet long and has an average width of 36 feet. Dip changes are sudden and range from

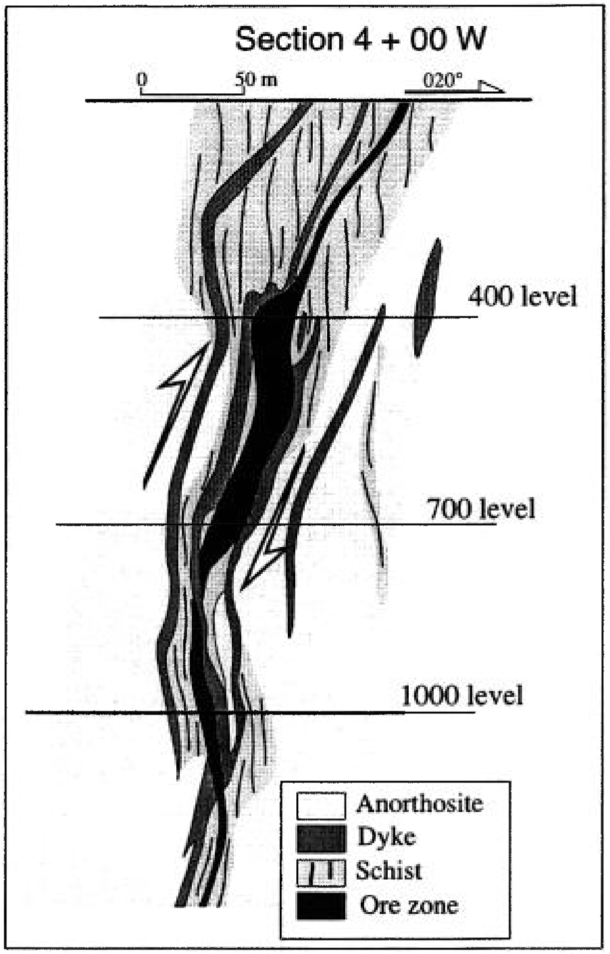


Figure D.7: Section 4+00 W, Main mine. Ore zones and dykes are all located in schistose areas (Modified from Malouf and Hinse, 1957).

60° southwest to 80° northeast, with a net dip of 70° southeastward (Figure D.7). The host rock is also sheared in an irregular manner in the vicinity of the main shear. Many of these sheared zones are discontinuous, although they retain a common southeast trend parallel to the main shear and have steep dips. North to 020° trending shears with flat westerly dips are also present. These are believed to be early structures, since they are offset by the steeply-dipping ore-bearing shears. Associated faults are uncommon and show up little apparent displacements. Many dyke swarms appear preferentially located in the shear zones (Figure D.6).

Sulphide mineralization

Sulphide mineralization occurs as sulphide-rich veins and as zones of semi-massive sulphide impregnations and abundant veinlets. The orebody extends from the surface to at least 3750 feet depth and has dips varying between 60° south and 80° north with a steep rake to the northwest (Figure D.8). This rake seems subparallel to the magmatic layering observed underground in the DLC, according to Jeffery's (1959) data. The ore lenses are located in shear zones and are best developed in the vicinity of dykes. Many subparallel dykes and ore zones can be found within this area. The better ore values appear to be localized where the shears strike 290° and approach a vertical dip. Minor ore-bearing shears occur in the hanging wall and in the footwall of the main shear. Many of these are subparallel to the main shear, but have dips of 65°-70° to the NE.

The orebodies are accompanied by widespread alteration which includes chloritization, sericitization, silicification, and carbonatization. According to Jeffery's studies (1959), the main minerals of the ore are pyrrhotite, chalcopyrite, pyrite, and gold with minor sphalerite and galena. The trace element work by Nichol (1958) has shown that the ores of the Main Mine are richer in cobalt and nickel than many other hydrothermal pyrrhotite-chalcopyrite ores, and these two elements are probably associated with basic rocks. The gangue minerals are chlorite, quartz, calcite, epidote, and actinolite. The shear zones contain also siderite and chloritoid. Jeffery (1959) described three ages of quartz, two or three ages of chlorite and three ages of calcite. Alteration accompanying ore formation has permeated the wall rocks to an apparently minor and erratic extent, but has extended along the strike of the shear zone on approximately 300 feet beyond the limits of the ore. Along strike, greater permeability of the sheared ground has allowed the iron-rich solutions to develop chlorite which is high in iron content relative to the chlorite found elsewhere. Chlorite in unsheared meta-anorthosite is relatively deficient in iron, and chlorite in sheared meta-anorthosite barren of mineralization contains a moderate amount of iron.

Some exposures on the 1 900 foot level suggested that the youngest type of dyke observed in the Main Mine area, described earlier as an amphibolite dyke, may crosscut the sulphide veins (Jeffery, 1959). Late sulphide remobilization is illustratred by thin py-cpy veinlets cutting this dyke.

Interpretation and discussion

In relation to the neighbouring mines within the meta-anorthosite, Main mine ore differs in its ore mineral assemblage. Other properties to the north, Cedar Bay, Copper Rand and Jaculet, have lesser amounts of pyrrhotite, a greater proportion of pyrite in the ore, and a higher gold content (see Table B.1 in Part B). The Cedar Bay mine, for example, has a more complex structure, but the remainder are essentially similar to the Main mine and Merrill ore zones in that they are vein-type deposits hosted within southeast-trending shear zones. It is interesting to note that the variable characteristics of mineralization throughout the Chibougamau area have been described and attributed to a zonal pattern, according to Miller's (1957) study at the Cedar Bay mine, indicating that zoning of minerals may occur in the Doré Lake area. Data for zoning studies are currently being gathered by Pilote and co-workers (see Pilote et al., 1994a, 1994b, 1995a, 1995b, 1998a, 1998b; Robert, 1994; and Sinclair et al., 1994) and tentative reconstruction of the early hydrothermal systems are under way.

The spatial distribution of ore zones in the area of Doré Lake commands attention and has been for a long time the subject of many interpretations. The mines are scattered along the length and on either side of the Doré Lake Fault. Following these observations, Jeffery (1959) supported Graham's (1956) interpretation that it was hard to avoid the conclusion that there must be some form of structural control by the Doré Lake Fault. That opinion was still considered highly probable, even in the recent years (see, among others, Archambault et al., 1984). However the Doré lake Fault is totally barren, on all its length, and crosscuts the mineralized shear zones. Furthermore it was recently demonstrated (Pilote et al., 1994b) that this fault, dipping north, has a near down-dip normal movement, indicating that the northern block went down by about 2 550 ft to 3 000 feet. Considering that the Main Mine mineralized system occurs over vertical length of more than 3 900 feet, unexplored ground exists on the northern part of the Doré Lake Fault, starting at about the elevation corresponding to this normal displacement.

THE MERRILL MINE

Introduction

In the Merrill mine, as in the Campbell Main mine, mineralization occurs as sulphide-rich veins and as zones of sulphide impregnations and abundant veinlets consisting of up to 50 volume percent of pyrrhotite, chalcopyrite and pyrite (Figure D.6).

The Merrill open pit exposes the fringes of pyrrhotite-chalcopyrite-pyrite orebodies mined from underground and open pit operations (Figure D.9). Several types of dykes, shear zones, and other styles of mineralization, all spatially associated with Cu-Au ore, are exposed, as well as their overprinting relationships. The Merrill pit represents a key locality for deciphering the geological history and origin of Cu-Au mineralization. Accessible pit walls and surrounding outcrops have been mapped in detail at the scale of 1: 500 (Figures D.10 and D.11).

Total underground production from the Merrill mine, in operation from 1958 to 1967, was 1 182 804 short tonnes of ore at an average grade of 2,33% Cu and 0,010 oz/t Au (0,34 g/t Au). The open pit operation, belonging to Campbell Resources Inc. and in activity from 1970 to 1981, mined 1 036 733 short tonnes of ore at an average grade of 0,64% Cu and 0,004 oz/t Au (0,14 g/t Au) (see Table B.1 in Part B).

Lithologies

Mineralization at Merrill and Campbell Main mines is hosted by anorthosite and gabbroic anorthosite of the Doré Lake Complex. Locally observed magmatic layering in the Merrill pit strikes northeast and dips steeply to the northwest, parallel to the regional aeromagnetic trend observed within the different zones the Doré Lake Complex (Sial Géoscience, 1989).

One important aspect of the Merrill pit geology is the high abundance of dykes, nearly all of which strike southeast and have subvertical dips. They range from a few centimetres up to 50 metres, and the largest can be traced laterally and down dip (from old mine plans) for distances in excess of 500 m (Figures D.6 and D.9). Three main categories of dykes have been distinguished on the basis of their composition and cross-cutting field relationships: (1) intermediate, (2) tonalitic and (3) quartz diorite dykes. Intermediate dykes are not common and the best and largest example occurs along the southwest margin of the pit (Figure D.9). These dykes are aphanitic to very fine grained and have a medium grey color, and where not altered. They are overprinted by, and locally contain, pyrrhotite-chalcopyrite-pyrite impregnations and predate Cu-Au mineralization (see below). To these aspects, they are pre-mineral.

Tonalitic dykes are by far the most abundant type, include the largest and most continuous dykes. As shown in Figure D.9, a 50 m wide tonalite plug is exposed at the southeast end of the pit. This large plug, referred to as the Merrill phase, is continuous at depth and subvertical as determined from mine plans; it terminates abruptly to the northwest where it branches into a number of smaller dykes that can be traced across the pit (Figure D.9). Tonalitic dykes display a wide range of textures, including fine to coarse equigranular textures, to porphyritic textures with aphanitic to medium-grained matrices. These textural variations may be gradational or relatively sharp; some can be attributed to cooling effects

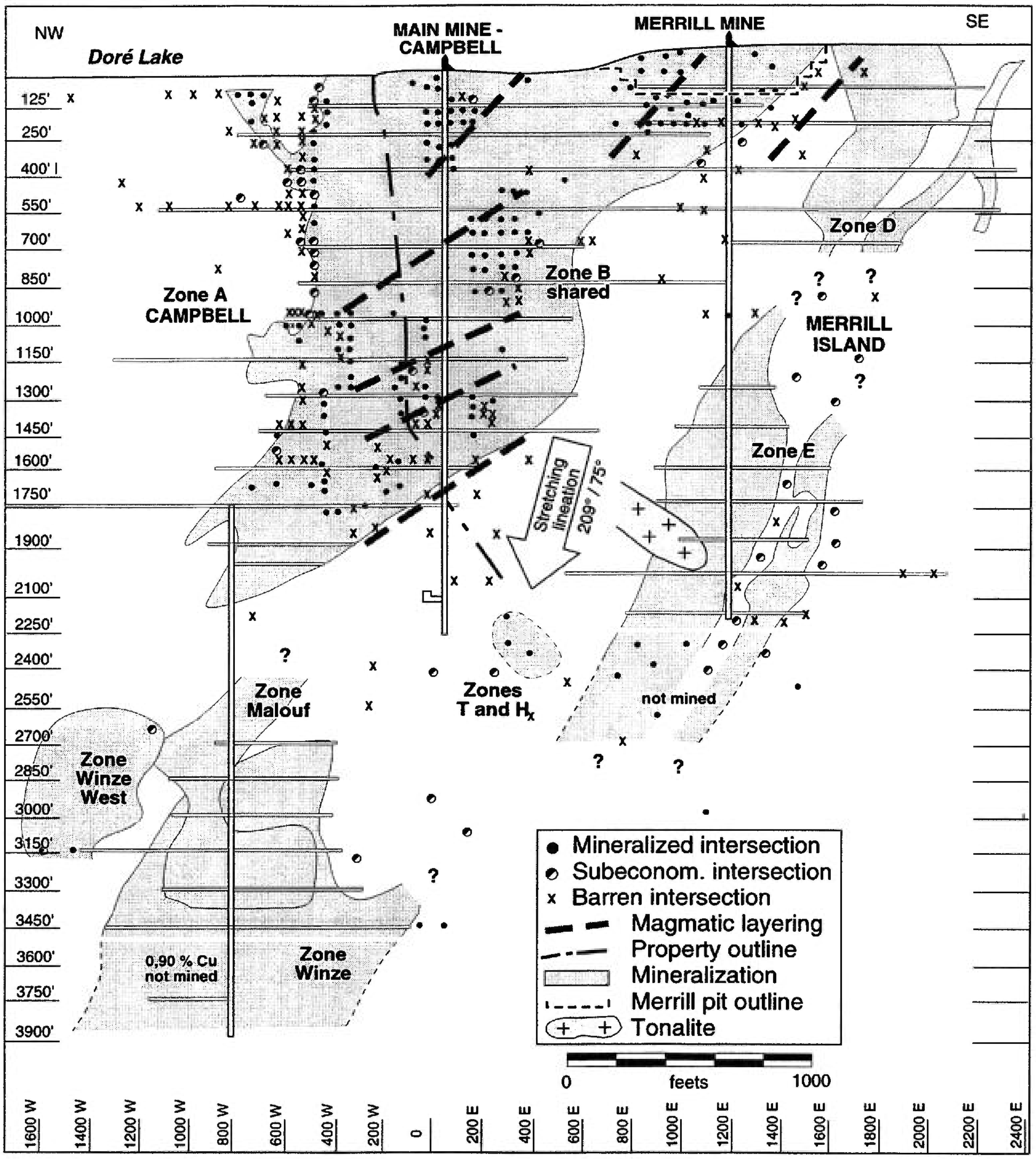


Figure D.8: Longitudinal projection of the south ore zone - Merrill and Campbell Main mines. The plane of this section is striking N120°/70°. The outlibes of the Merrill pit and the rake of the stretching lineation are indicated. The rake of the various ore lenses is subparallel to the trace of the magmatic layering. A tonalitic plug, belonging to the Chibougamau pluton, crosscut the Zone "E". Modified from Jeffery (1959), Krause (1968) and from unpublished mapping done by Canadian Merrill Inc. and Campbell Inc.

(chilled margins, thin dykes), whereas others probably represent distinct intrusive phases of tonalite. Igneous breccias are locally present along the edges of some of the larger dykes; they contain fragments of anorthosite and of tonalite, including some identical to the apophysis of the Chibougamau pluton occurring in the southeastern extension of the Merrill pit (Figure D.2). That apophysis has been dated by Krogh (1982) and yielded an age of 2718 ± 2 Ma. These relations support multiple tonalitic

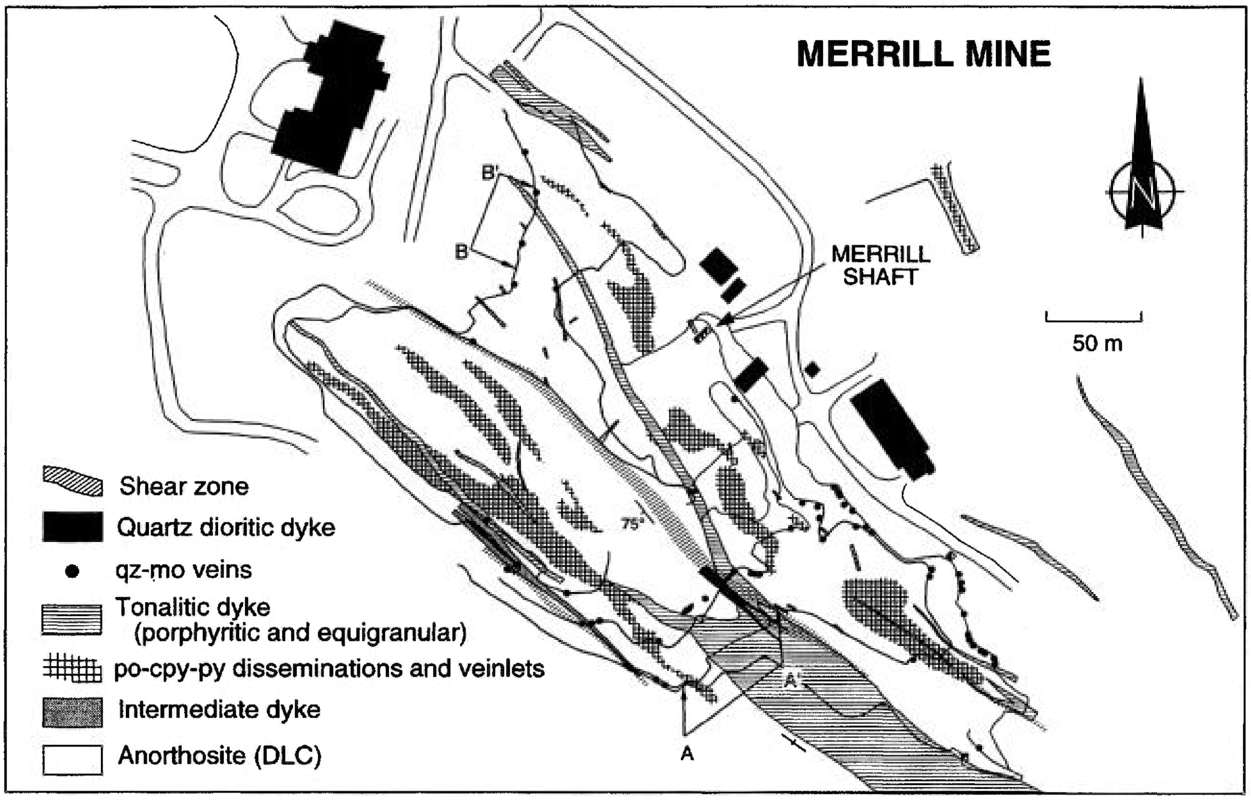


Figure D.9: Simplified geology od the Merrill pit.

intrusions and suggest that some may be related to, or originating from, the Chibougamau pluton, as also inferred from the similarities in chemical compositions (Blecha, 1966; Maillet, 1978). As discussed below, tonalite dykes crosscut pyrrhotite-chalcopyrite-pyrite mineralization, but they are overprinted by pyrite veinlets and disseminations and quartz-molybdenite veins.

Quartz diorite dykes occur at a few locations in the pit. These dark green to black, fine-grained dykes have either steep or shallow dips, and they cross-cut the Merrill phase and its associated tonalitic dykes (Figure D.10). Quartz diorite dykes are typically barren and can be considered as post-ore dykes.

Mineralization

In the Merrill mine area, the orebodies occur within a southeast-trending belt, about 150 metres wide and nearly 300 metres long (Figure D.9), containing abundant dykes and shear zones of similar orientation. Within this belt, orebodies typically strike southeast and dip at 70° to the southwest, with a steep rake to the northwest (Figure D.8). Their sizes are similar to those found on the Campbell side. Mineralization has been traced to a depth of approximately 300 m.

Several types of sulphide-bearing mineralization have been observed in the Merrill pit: pyrrhotite-chalcopyrite-pyrite (po-cpy-py) veins and impregnations, pyrite fractures and disseminations, and quartz-molybdenite-pyrite ± chalcopyrite (qz-mo-py-cpy) veinlets. Each type has its own spatial distribution and age relative to other geological features. These types are described here from the oldest to the youngest.

Economic mineralization (Cu-Au) at Merrill, as the one at Campbell Main mine, is represented by zones of po-cpy-py veins, veinlets and impregnations described in the introduction. As illustrated in Figure D.9, several parallel zones of this type of mineralization are present in the pit and its immediate surroundings. This type of mineralization does not occur within any of the tonalite dykes and it is in fact crosscut by tonalite dykes, as can be observed along the southwest margin of the pit (Figure D.9). However, po-cpy-py mineralization does overprint older aphanitic dykes.

All exposed rock types within and around the pit, with the exception of the quartz-diorite dykes, contain pyrite disseminations and fractures. The anorthosite and the tonalite dykes contain at least 1-2% pyrite, but in many places up to 5%. Pyrite occurs as fine disseminations in the rock, or as coatings and fillings of fractures which can be very closely spaced and enhanced by sericite alteration

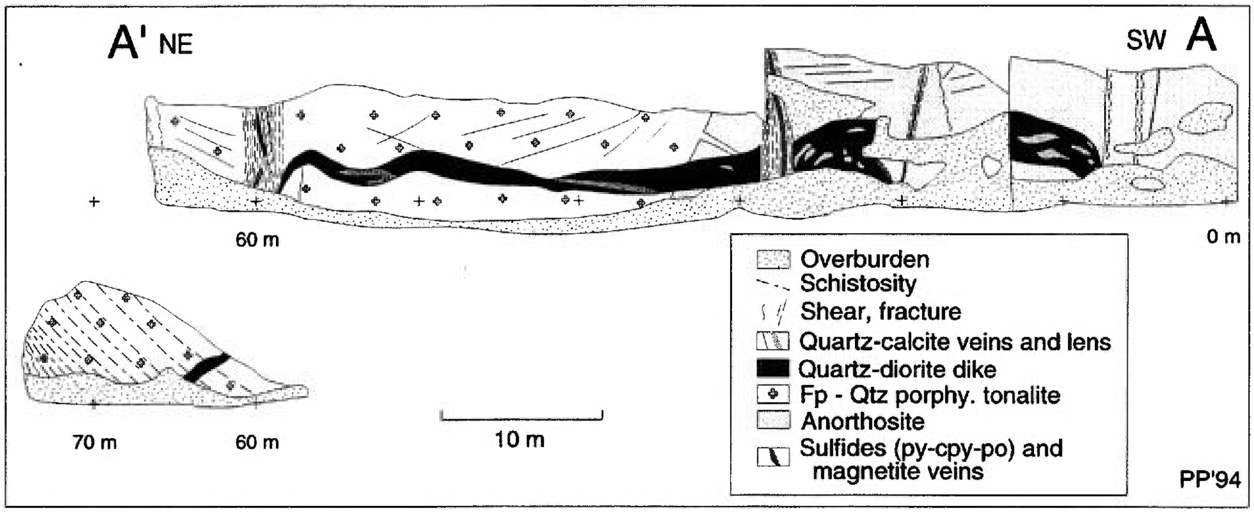


Figure D.10: Section A-A', showing the mapping of the second bench, south-east wall, Merrill pit. See figure D.9 for location.

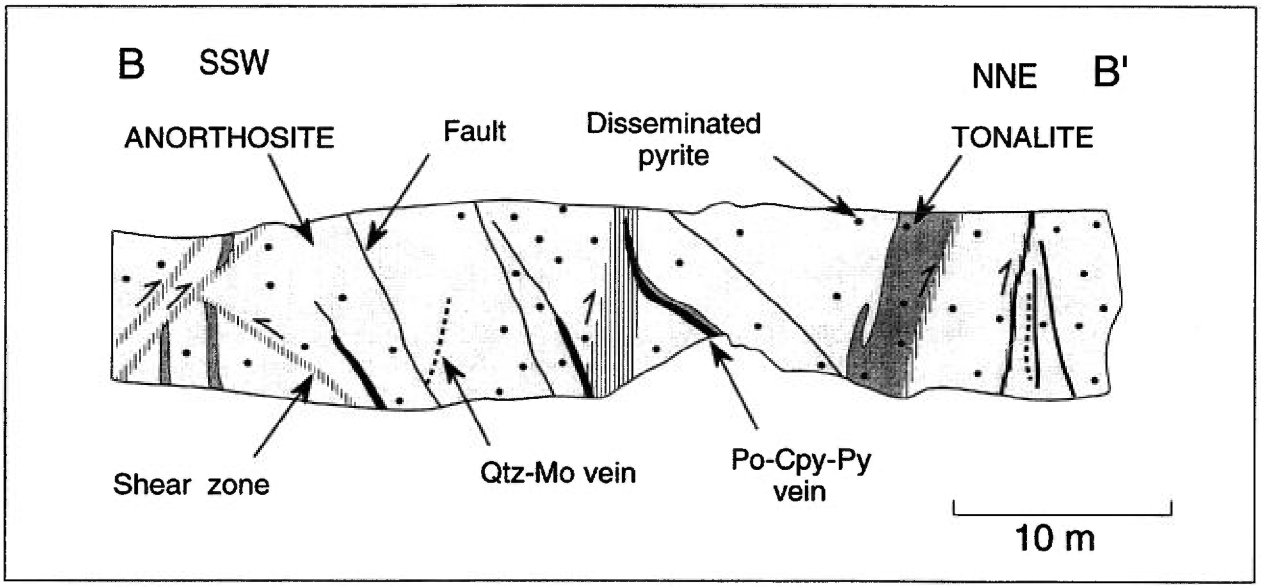


Figure D.11: Section B-B', showing the mapping of the second bench, north-west wall, Merrill pit. See figure D.9 for location.

fringes. A 50 cm wide massive pyrite vein showing similar age relationships is perhaps of the same generation as disseminated pyrite. It is not known at present if such pyrite disseminations are continuous with the large pyrite halo mapped around the Clark Lake deposit to the northwest.

Quartz-molybdenite veins are common throughout the Merrill pit, but none were observed on outcrops and trenches on the northeast side of the pit (Figure D.9). Molybdenite in the veins is mostly fine-grained and qz-mo veins are largely identified from the a typical blueish hue of the quartz. These veins range from 0,5 to 10 cm in thickness, and rarely exceed a few metres of strike or dip length. Qz-mo veins overprint all rock types except quartz diorite dykes. The exact age relationships between qz-mo veins and pyrite disseminations and fractures are not known at Merrill because no clear crosscutting relationships have been observed. However they seem to be late, as at Clark Lake, according to field observations available in the SE corner of the pit.

Finally, a number of quartz and carbonate veins are also present. A few metre-wide quartz veins are reported on mine plans and one is exposed in the pit. They strike southeast, have subvertical dips and cut all rock types, including quartz diorite. Blueish calcite veins, typically sub-horizontal, are

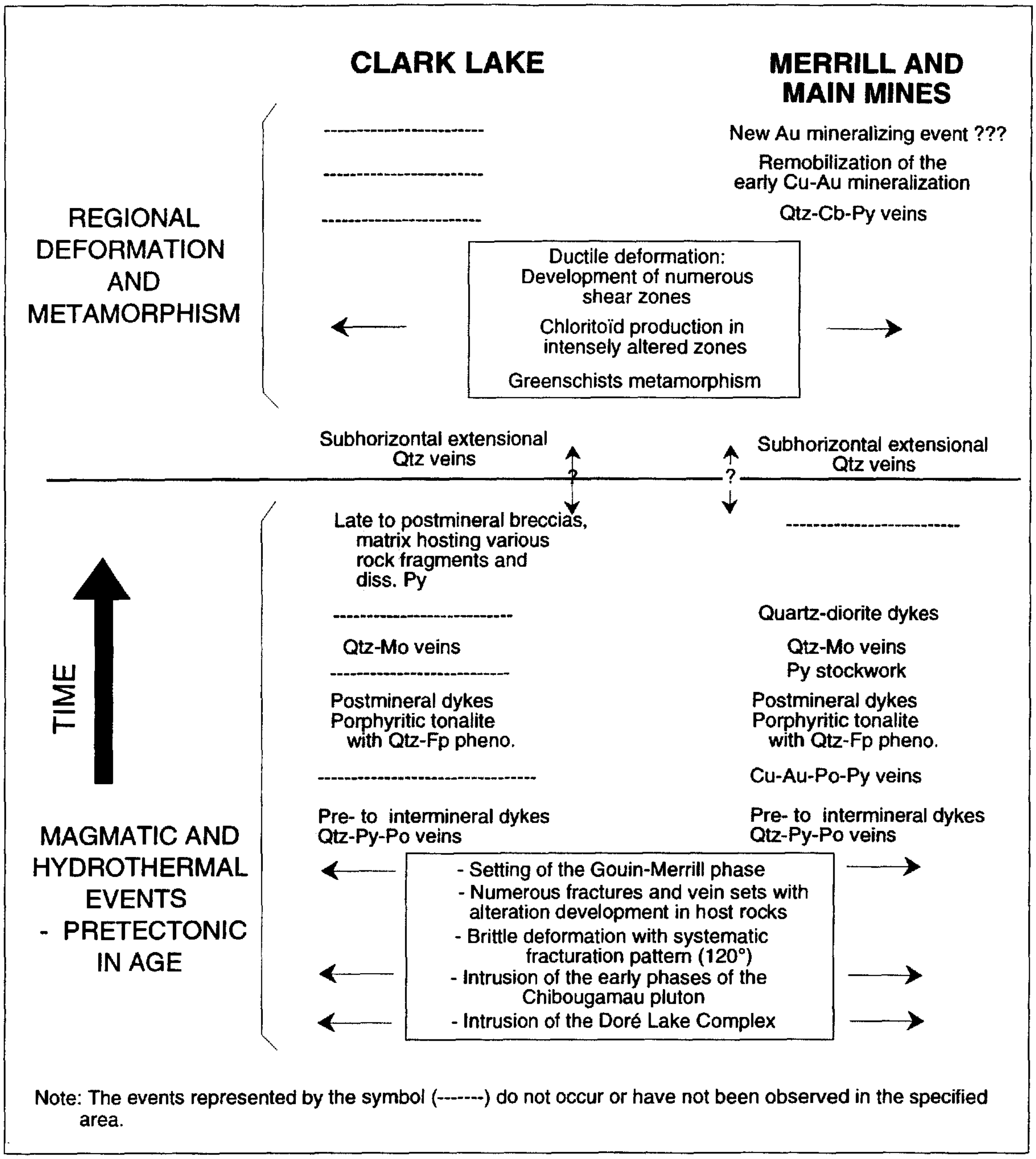


Table D.1: Chronological sequence describing the various events related to the development of the porphyry Cu-Au system in the Clark Lake - Merrill - Main mine areas.

relatively common. They are up to a few metres long and a few tens of centimetres long, and overprint all rock types, including quartz-diorite dykes (Figures D.9 and D.10).

Structure

Rocks of the Merrill pit are well preserved and record little, if any, penetrative strain. They are, however, overprinted by shear zones and brittle faults. Both are late structures which overprint mineralization.

Two significant and several smaller shear zones are present. They strike southeast and dip to the southwest at 50-70° (Figures D.6 and D.9). They range in width from 10 cm to 5 m; one extends across the pit for nearly 500 m. Shear zones are characterized by the development of an intense penetrative foliation and by a pronounced sericitization of the rock, especially within the anorthosite. Shear zones overprint all dyke types, and are observed at a few locations to drag po-cpy-py veins (Figure D.11). The shear zone foliation contains a nearly down-dip lineation which, together with the presence of reverse shear bands and reverse dragging of po-cpy-py veins, indicate reverse movement along the shear zones. Shear zones overprint po-cpy-py mineralization and cut all dyke types, including the youngest quartz diorite (Figure D.10). A metre-wide southeast-striking quartz vein in the main shear zone shows evidence of significant boudinage, which suggests that such veins either predated, or formed during the early stages of, shear zone development.

A number of relatively small, brittle faults are also present. They strike northeast and have moderate dips to the southeast, and are reverse faults. These faults are the youngest structures observed in the Merrill pit and, because of their strike and reverse nature, they have little effect on the map distribution of geological elements.

Time and space relationships

The observed crosscutting and overprinting relationships allow reconstruction of a detailed sequence of geological events in the Merrill pit, summarized in Tables D.1 and D.2. The main Cu-Au mineralization, represented by po-cpy-py, is bracketed in time by intermediate and tonalitic dykes, the latter being likely derived from the Chibougamau pluton. This main stage of mineralization is followed in time by post-tonalite, widespread pyrite disseminations and fractures and more restricted qtz-mo veins. Such intimate time and space relations between various styles of mineralization and these two types of dykes, as commonly observed in porphyry systems (see, among others, Gustafson and Hunt, 1975), suggest genetic relationships between plutonism and hydrothermal activity. The shear zones overprint dykes and sulphide veins, and have little to do with the Cu-Au mineralization in the area.

In summary, on Merrill Island, Cu-Au mineralization is associated with veins and lenses of semi-massive to massive po-cpy-py, which are cut by tonalite dykes. These dykes are in turn injected by qtz-mo veinlets. These dykes are chemically similar to a late tonalitic phase of the Chibougamau Pluton dated at 2718 ± 2 Ma (Krogh, 1982). Cu-Au ore zones on Merrill Island are overprinted by narrow NW-trending shear zones, indicating that mineralization predated regional folding and metamorphism (Figure D.12). These features are consistent with the age of the intermineral dyke at Clark Lake (2715,2 ± 0,7 Ma, GSC unpub. data).

Field trip stops

All the above-described geologic relationships will be examined, if time permits. However, the following geological elements and relationships will be emphasized:

- Merrill phase and other tonalite dykes, as well as their overprinting by pyrite disseminations and fractures;
- crosscutting relations among intermediate, tonalite and quartz diorite dykes;
- porphyritic tonalite dyke cutting across a zone of po-cpy-py impregnations;
- a small sericitic NW striking ductile shear zone in the anorthosite dragging a massive po-cpy-py vein and a porphyritic tonalite dyke. Note the chloritoid development within the shear zone and the restricted occurrence of the schistosity to the sericitized alteration zone. There are also two types of slickensides on the shear plane, an early set down plunging and a late set with a subhorizontal plunge.

Table D.2: Sequence of geological events at Merrill mine, from the oldest to the youngest

- setting of the Doré Lake Complex;
- extensive northeast-striking brittle normal faulting (ground preparation);
- injection of the quartz diorite dykes;
- setting of the Cu-Au mineralization (lenses, fractures and veins) with injection of numerous generations of tonalitic dykes (multiple equigranular and porphyritic phases), early to intermineral in age;
- setting of the porphyry-type Mo-Cu±Au mineralizations, pyrite fractures and disseminations in the Clark Lake area and around the Merrill phase, late hydrothermal breccias associated;
- early tilting of the layering in the DLC and in the hosting volcanic rocks;
- regional deformation, brittle-ductile southeast-striking reverse shear zones and metamorphism (chloritoid production);
- late quartz veins and / or calcite veins, relative age unknown;
- northeast-striking reverse faults.

THE BERRIGAN LAKE SHOWING, A POSSIBLE EXAMPLE OF AN ARCHEAN EPITHERMAL-TYPE Au-Ag-Cu-Pb-Zn-As MINERALIZATION

Pierre Pilote
Ministère des Ressources naturelles du Québec, 400 boul. Lamaque, Val-d'Or, Québec, J9P 3L4;

and Jayanta Guha
Module des Sciences de la Terre, Université du Québec à Chicoutimi, 555 boul. Université, Chicoutimi, Québec, G7H 2B1

modified from Pilote and Guha (1990)

INTRODUCTION

The Berrigan showing, located on the north shore of Berrigan Lake approximately 6 km to the NW of the town of Chibougamau, can be divided into two mineralized sectors: (1) the North Zone (or Taché Zone or Main Zone); and (2) the South Zone. The two sectors are respectively located north and north-east of Berrigan Lake. Both zones have recently been the sites of important exploration work (Anderson, 1988; McRoberts, 1992).

This excursion will principally deal with the Berrigan North Zone, and will allow excursionists to take a look at a presumed example of Archean epithermal-type Au-Ag-Cu-Pb-Zn-As mineralization (Pilote, 1987). Many features suggest that the mineralizing event occurred before the onset of the regional deformation and metamorphism.

LOCAL GEOLOGICAL FRAMEWORK

The Berrigan showing is hosted by ultramafic facies of the Roberge Sill, which together with the Ventures and the Bourbeau sills compose the Cummings Complex. U-Pb age dating of the Bourbeau Sill yields an age of 2717 ± 1 Ma (Chown et al., 1992). This complex, intrusive within the Blondeau Formation, is composed of various volcano-sedimentary rocks and epiclastic sediments. Some tonalitic to locally syenitic dykes, located 1 km east of the showing, crosscut these rocks and are probably related to the Line Lake tonalitic stock. This intrusion is interpreted as late- to post-tectonic in age (Pilote et al., 1984a and 1984b). The axial trace of the Chibougamau syncline, striking ENE, is located at about one km to the north of this showing. All these units are unconformably covered by the Proterozoic Chibougamau Formation, of which there are only a few isolated remnants. One of these remnant outcrops occurs just south of Berrigan Lake.

HISTORY AND PREVIOUS WORK

These showings were discovered in 1929 by two prospectors, D. Berrigan and L. Larone. Cominco optioned the property in 1930 and undertook the first exploration work. In 1944, O'Leary Malartic Mines Ltd. acquired the claim group and granted an option to Noranda Exploration from 1947 to 1948. In 1951, O'Leary Malartic Mines Ltd. sold the entire property to Taché Lake Mines Ltd, and this company drilled until 1968 17 000 m in 106 holes. In 1969, Canadian Merrill Ltd acquired control of the property by financing the drifting of a 70 m exploration ramp dipping at 10°, and of two 30 and 37 m long crosscuts (Bidgood, 1969). The overall grade for the lateral development was 3,135 Zn and 0,054 oz/t Au (1,85 g/t) over an average width of 14,3 ft (4,4 m). This company drilled 4 991 ft on the property until 1977. In 1980, Francana Oil and Gas Ltd (now called Sceptre Energy Ltd) acquired all Canadian Merrill Ltd assets, which included the Berrigan property. An option was later given to Camchib Mines, who subsequently bought the Chibougamau properties from Fancanca.

In 1981, Camchib Mines deepened the original exploration drift (Figure D.12A), undertook a major diamond drill hole program in 1982, and a new reserve calculation in 1984. Since 1986, Greenstone Resources Inc. and Bitech Energy Resources Ltd, the latter having the possibility to earn 505 of that property in exchange of financing the exploration works, have owned the property. In 1987 and 1988, these two companies did stripping and mapping of the North Zone, some drill programs, and considered the possibility of operating the deposit as an open pit (Anderson, 1988). During the period from 1991 to 1994, Teck Exploration Ltd. optioned some parts of the property in a search for volcanogenic massive sulphide deposits hosted within the Blondeau Formation (McRoberts, 1992).

NORTH ZONE

This mineralized zone, located some 200 m from the north shore of Berrigan Lake, is hosted by peridotites and dunites of the Roberge Sill (Figure D.12A). The Roberge Sill strikes ENE and dips steeply to the north. The Antoinette Lake fault (Pilote, 1986 and 1987), located in a creek at about 100 m to the north of the portal of the former exploration drift, produced repetition of specific units of the Roberge and Ventures sills. Near the portal of the exploration drift, the lithologies consist of variably serpentinized peridotites and dunites. Pyroxenitic layers outcrop mainly to the SE (Huang, 1976; Pilote, 1987). Pyroxenitic and peridotitic layers alternate periodically from the bottom of the hill, where the portal is located, to the north shore of Berrigan Lake (Figure D.12A).

The mineralization is exposed on the flank of this hill, due to stripping by Bitech Energy Ressources Ltd. in 1987. The best mineralized exposures are located at about 85 m to the south of the portal, within an alternating sequence of variably carbonatized and silicified pyroxenite and peridotite. These features, and the stratigraphic study of the Cummings Complex done by Poitras (1984), suggest that the North Zone is located somewhere between the middle and the top of the lower part of the Roberge Sill. This part, contrary to the upper one, shows a well-developed magmatic layering illustrated by alternating werhlite-dunite-pyroxenite layers. This alternation of ultramafic units in this part of the Roberge Sill is common and variable, making it difficult to establish large-scale stratigraphic correlation within that sill. In addition, the North Zone is cut by different fault sets striking mainly NE. All these features illustrate the typical difficulties that many geologists working in this area have had in trying to correlate the geological units and the mineralized structures, during their property mapping as well as in their various drilling programs.

MINERALIZATION

At the North Zone, the mineralization is composed of veinlets and breccias containing sphalerite, pyrrhotine, galena, arsenopyrite and chalcopyrite, with locally pyrite and significant amount of gold and silver. Pyrrhotite and sphalerite commonly represent more than 75% of the volume of the veinlets. The grades in gold and silver are high, varying from 100 ppb Au to 8,3 g/t Au and from 14 g/t Ag to 380 g/t Ag (Pilote, 1987). The veinlets strike 010° to 040°, and dips vary from subvertical to 45° to the NW.

The pyroxenitic and peridotitic units hosting the mineralization are intensely brecciated along a slightly undulating, 3 to 5 m thick corridor striking NE. The mineralized veinlets, from 3 mm to 4 cm in thickness, fill the fractures and subdivide in numerous branches, which are intermittently connected at various intervals to the main mineralized corridor. These observations also illustrate the cyclic behavior of the fracturation and the mineralizing events. It can be commonly seen that some secondary branches belonging to a main group of veinlets completely wrap around large pyroxenite fragments from 2 to 3 m in diameter.

The mineralized structures contain many highly silicified country rock fragments, commonly cut by numerous generations of narrow quartz veins. These fragments are wrapped by sulphide-quartz bands of variable thickness, but generally less than 2 cm. The silicification of the pyroxenitic and peridotitic fragments is locally so intense that they have erronously been called cherty fragments in the past. The central part of the veinlets is highlighted by an intensely-developed brecciation, whereas the borders show a ribbon aspect, due to the sequential deposition of quartz, pyrrhotite and arsenopyrite. Usually, the sphalerite and quartz occur at the margins of the veinlets, and the pyrrhotite in the central part. The pyrrhotite also occurs as disseminations in silicified country rock fragments, and in the adjacent host rocks.

In the brecciated parts of the veinlets, all the sulphides show deformation, recrystallization and recovery textures, with pyrrhotite and sphalerite presenting a granoblastic texture. On polished sections, all the sulphide grains commonly show triple junctions. The more brittle sulphides, such as arsenopyrite and pyrite, have their fractures commonly filled by the adjacent softer sulphides, such as sphalerite and pyrrhotine.

The host rocks are intensely carbonatized, contrary to the veinlets themselves which contain less carbonate. However, silicification is limited to the brecciated and mineralized zones and to a narrow fringe of less than 0,5 m in the host rocks. Variably intense chloritization, is apparent in the

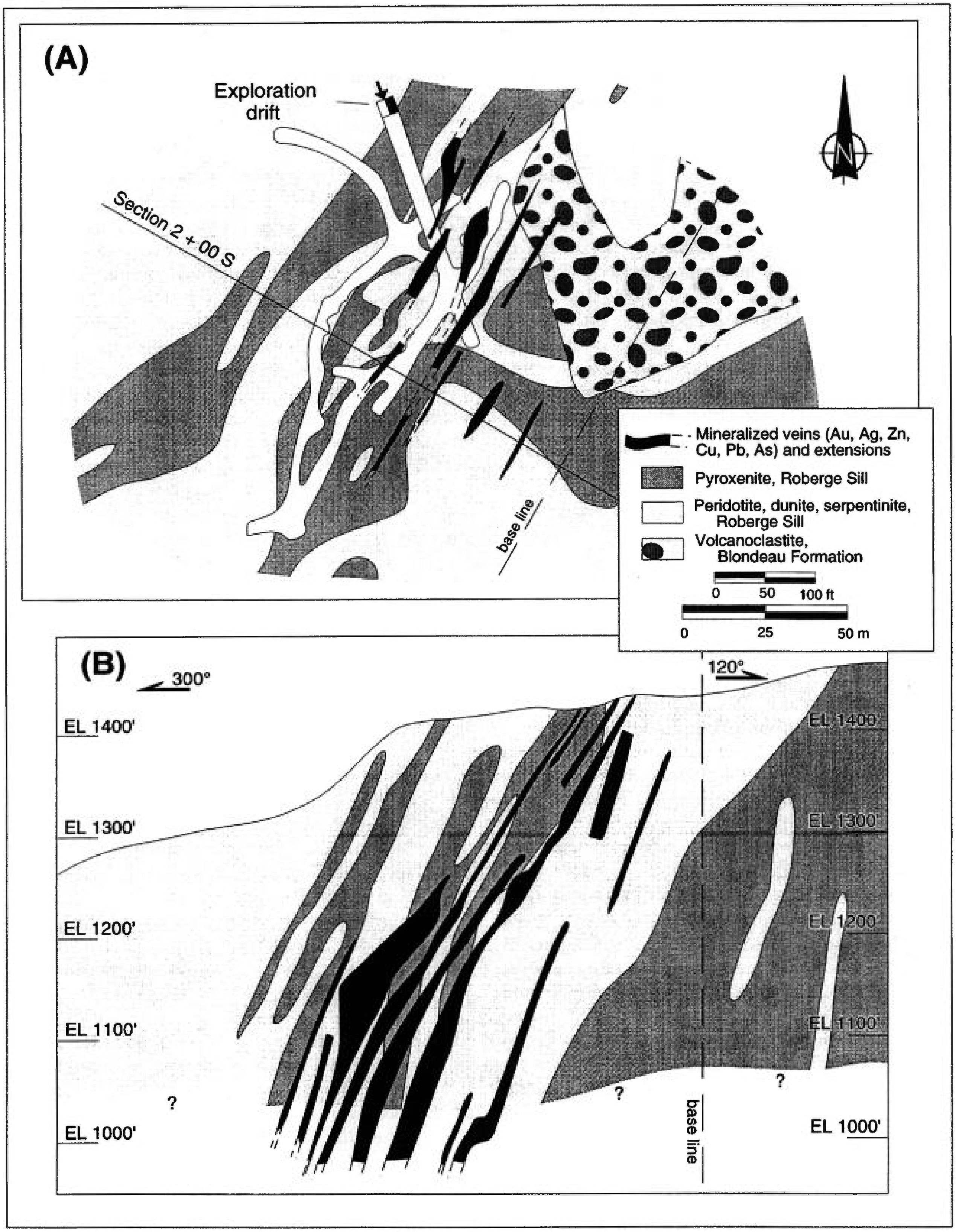


Figure D.12: Berrigan Lake showing, North Zone. (A) Simplified geology, elevation 1300', with projection of the exploration drift. Tops in igneous rocks face NW. (B) Simplified geology, section 2+00 S. Modified from Pilote (1987), Anderson (1988) and Pilote et Guha (1990).

host rock over a thickness of 2 to 4 m on both sides of the mineralized corridor. Even at 20 m away from the mineralized veinlets, the pyroxenite is still variably carbonatized. Pyroxene uralization is nearly complete but some primary igneous textures are still preserved locally, even within the silicified fragments.

In 1977, proven reserves reached 346 000 tonnes at a grade of 7,5% Zn, 34,1 g/t Ag and 7,5 g/t Au. In 1984 a second reserve calculation done by Les Mines Camchib Ltées indicated 840 730 metric tonnes in the probable category with a grade of 4,12% Zn and 2,4 g/t Au. In 1988 a new calculation, which included the proven, probable and possible categories, indicated 1 430 000 metric tonnes at a grade of 3,31% Zn and 1,9 g/t Au. This amount contains a higher grade part which yielded probable reserves of 568 700 metric tonnes at a grade of 4,06% Zn and 2,4 g/t. Au. It was this higher grade portion, occurring from the surface until the 350 foot level (-107 m), that was considered for an open pit operation (Anderson, 1988). However, this project appeared uneconomic.

STRUCTURAL DEVELOPMENT

The sequence of events illustrating the setting of this type of mineralization can be summarized in the following order, according to work done by Landry (1984), Pilote (1987) and Guha et al. (1988): (1) the intrusion of the Roberge Sill was accompanied by a contemporaneous autometamorphic event producing alterating talc-carbonate in the various ultramafic rock units; (2) localized fracturing along many undulating corridors and intense silicification (barren in the first steps) in the lithologies within these corridors, with intermittent fractures sealed by quartz and later refractured; (3) weak mineralization in pyrrhotite and sphalerite associated with the silicification; (4) occurrence of the main mineralizing event, producing the bulk of the sulphides now observed and associated with another brecciating phase taking place in previously-silicified host rocks; (5) minor scale brecciation and weak silicification heralding the end of the major mineralizing event, as suggested by the occurrence of variably oriented barren quartz-carbonate veinlets which crosscut the mineralized veinlets; and (6) brittle-ductile deformation noted along some segments in the brecciated mineralized zones, as well as deformation, recrystallization and recovery textures in the sulphide assemblages indicating the overprinting of mineralization by the regional Kenoran greenschist metamorphism. The regional deformation and its associated features could explain also the partial sulphide remobilization.

The NNE striking faults, of which some are mineralized, are cut by regional-scale brittle-ductile reverse faults striking E-W to ENE (Pilote, 1987), which in Berrigan Lake area are well illustrated by the Antoinette Lake fault. The scale of the displacement along these faults is unknown. The reverse movements produced unit doublings or blanks in the stratigraphic record, this being particularly evident in the Cummings Complex. The whole North Zone, and areas located between Berrigan and Larone lakes, have been affected by late NNE striking faults of great extension, with apparent sinistral horizontal movements and dips varying from subvertical to steep to the SE. These faults also displace the Antoinette Lake fault. According to Dimroth et al. (1984; 1985), these late faults could belong to a ENE striking set, named the Riedel or R fault that occurred during the evolution of the Gwillim Lake shear belt. These faults could be late-Kenoran and possibly even late-Archean in age. Such a correlation could explain the deformation, recrystallization and remobilization textures observed in the sulphide assemblages.

DISCUSSION

The following is a brief overview of the various characteristics presented by the mineralization of the North Zone of Berrigan showing (Pilote, 1987):

1) the mineralization occurs within brecciated zones located along many undulating corridors;
2) the limited thickness of the mineralized zones at the surface, becoming thicker at depth according to diamond drill hole data (Figure D.12B);
3) the angular shape, and the intense silicification, of the fragments and the matrix;
4) the apparent minor quantity of milled rock (overprinted by the silicification ?) in the matrix of the breccias;
5) the cyclic character of silicification and brecciation, from pre- to late-mineralization time;
6) the occurrence of subeconomic to economic mineralization at the surface, with grades improving at depth.

According to the classification of Sillitoe (1985), these features suggest that the North Zone is part of an epithermal mineralized system belonging to the category of the phreatic breccias. These host rocks, pyroxenitic and peridotitic units, are quite uncommon in this type of environment. However, the epithermal model allows one to suggest the occurrence of a marginal collapsing basin, demonstrated by detailed mapping (Pilote, 1987), under a prevailing extensional regional constraint regime (Guha et al., 1988; Chown et al., 1992).

Thorpe et al. (1984) analysed Pb isotopes of a galena sample from a mineralized veinlet of the North Zone. On a plot of ^{207}Pb / ^{204}Pb, the sample falls in an Archean cluster, and provided a model-age of c.a. 2720 Ma, similar to ages from volcanogenic deposits such as Lemoine and Coniagas. However, the age of the Cummings Complex, tentatively represented by the age of the Bourbeau Sill, is 2717 ± 1 Ma, which means that these mineralizations are still younger then that but older than the regional metamorphism. It is suggested that they are contemporaneous with the second volcanic cycle in that area. This volcanic cycle produced the Blondeau Formation, which was still forming at this time (Guha et al., 1988; Chown et al., 1992).

In conclusion, although affected by subsequent deformation, this epithermal mineralization can be identified by its geometry which is controlled by synvolcanic faults, and by the associated breccia zones and vein textures indicating extensional regime. Subsequently, the Kenoran orogeny, accompanied by widespread low grade greenschist metamorphism, folding and deformation of the volcanic assemblage, transformed the previously incompetent alteration halos in chlorite-actinote schists. These schists enclose the ore zones and impart to them locally an apparent shear zone aspect.

From an exploration point of view, epithermal-type targets should be sought out in mafic to ultramafic sills of the Cummings Complex due to the competence of the these units, especially in that part of the Chibougamau mining camp. The segmenting of these sills during subsidence makes the identification of the synvolcanic faults possible, as illustrated by aeromagnetic surveys (Sial Géoscience, 1989).

MERRILL ISLAND Cu-Au VEINS AND CLARK LAKE Cu-(Mo) PORPHYRY DEPOSIT, DORÉ LAKE MINING CAMP, CHIBOUGAMAU

R.V. Kirkham
Kirkham Geological, 213-7198 Vantage Way, Delta, B. C. V4G 1K7

P. Pilote
Ministère des Ressources Naturelles du Québec, 400 boul. Lamaque, Val-d'Or, Québec, J9P 3L4

W.D. Sinclair
Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario, K1A 0E8

F. Robert
Barrick Gold Corporation, 7257 Dunver Crescent, Verdun, Québec, H4H 2H6

R. Daigneault
Sciences de la Terre, Centre d'Études sur les Ressources Minérales, Université du Québec à Chicoutimi, 555 boul. Université, Chicoutimi, Québec, G7H 2B1

ABSTRACT

The Chibougamau district has had a relatively long mining history, mainly of high-sulphide Cu-Au veins but it also contains a number of subeconomic Cu(-Mo) porphyry occurrences. Both of these deposit types are spatially and genetically related to the Archean tonalitic Chibougamau pluton. The Cu-Au veins are regionally spaced over about 15 kilometres and formed prior to the more localized Cu-(Mo) porphyry stockworks. The hydrothermal systems evolved from early Cu deposition with Au, to intermediate Cu deposition with Mo, to late Mo deposition without significant Cu or Au. These Archean magmatic-hydrothermal deposits show similiarities to those in younger island-arc settings, such as the Lower Jurassic massive sulphide Au(-Cu) veins and porphyry Mo deposit at Rossland, British Columbia and the tonalite-related Batu Hijau porphyry Cu-Au deposit in Indonesia.

INTRODUCTION

The Chibougamau district, in the eastern part of the Abitibi belt of Québec, is a relatively unusual greenstone belt mining camp. Athough it contains some small volcanogenic massive sulphide (VMS) and shear-zone-hosted Au deposits, it is characterized by high-sulphide Cu-Au veins and porphyry Cu(-Mo) occurrences (Figure D.13). The Cu-Au veins have been the main source of production in the camp and, except for minor production from Grandroy (349 000 tonnes grading 1,24% Cu and 0,022 g/t Au; Pilote and Guha, 1995), the porphyry occurrences have proven to be subeconomic. The Queylus (Talbot) porphyry deposit contains a large drill-indicated resource grading about 0,08 to 0,1% Cu with local areas of higher grade and the R-2 deposit a drill-indicated resource of about 10 900 000 tonnes grading 0,36 % Cu and 0,015 % Mo (Kirkham et al., 1982), but it is under about 30 m of water in the southwest end of Chibougamau Lake. The high-sulphide Cu-Au veins, 1954 to 1994, yielded some 43 377 866 tonnes of ore averaging 1,82% Cu and 2,2 g/t Au at Chibougamau and, 1954 to 1991, 23 534 942 tonnes of ore averaging 2,24% Cu and 1,17 g/t Au at the Opemiska Division, in Chapais (Pilote and Guha, 1996). Modest production has come from the Lemoine VMS (1975 to 1983 produced 728 000 tonnes of ore grading 4,2% Cu, 9,6 % Zn, 4,6 g/t Au and 83,8 g/t Ag; Daigneault et al., 1998). If we take a look at the shear-zone-hosted gold deposits: the Gwillim mine produced, from 1980 to 1984, about 230 000 tonnes at 4,81 g/t Au and 5,08 g/t Ag (Dubé and Guha, 1989); the Norbeau mine (1964 to 1969) produced 380 000 tonnes of ore grading 13,47 g/t Au and 1,71 g/t Ag (Dubé and Guha, 1989; Dubé et al., 1989); the McKenzie deposit (in the Portage mine) produced 272 155 tonnes grading 8,2 g/t Au and 0,92% Cu, Tessier et al. 1995a, 1995b), and the Cooke mine (at the Opemiska Division in Chapais) produced, from 1977 to 1989, 2 Mt of ore

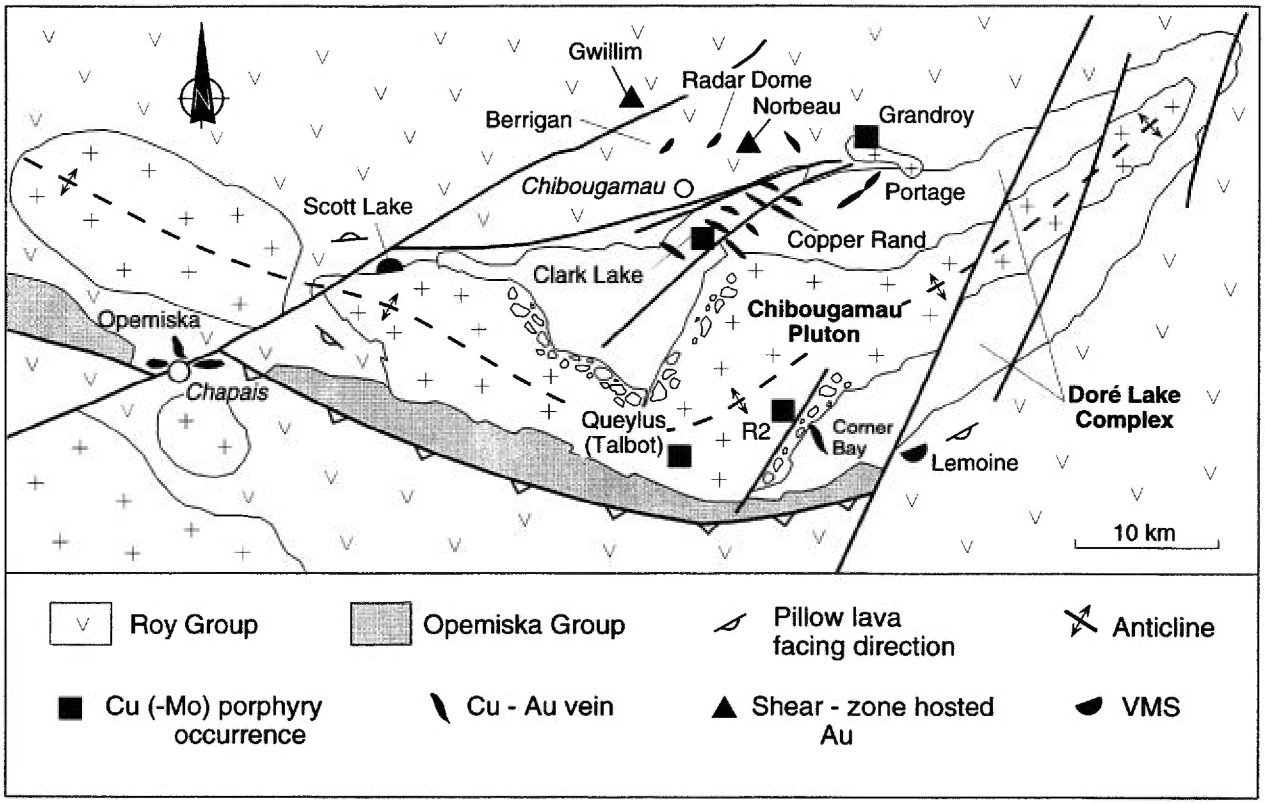


Figure D.13: Generalized geology of the Chibougamau area showing the location of selected mineral deposits.

grading 5,0 g/t Au, 10 g/t Ag, and 0,66% Cu (Dubé and Guha, 1992).

The geology and mineral deposits of the region have been described by many authors, including Duquette (1970), McMillan (1972), Allard (1976a,b), Watkins and Riverin (1982), Guha and Chown (1984), Daigneault and Allard (1990), Chown et al. (1992), Pilote (1995), and Pilote et al. (1998a). Comments about the porphyry occurrences had been made by Kirkham (1972), Cimon (1973), and Ford (1974). Despite these and many other studies the characteristics of the porphyry occurrences and the relationship to the veins were not well understood, so a joint study of the Clark Lake-Merrill Island system was carried out during the period of 1993 to 1995 by the Geological Survey of Canada, Ministère des Ressources Naturelles du Québec, and Université du Québec à Chicoutimi (Sinclair et al., 1994; Robert, 1994; Pilote et al., 1995a, 1995b, 1995c; Pilote et al., 1998a; Kirkham et al., 1997). M. Magnan and A. Tessier were conducting Ph. D. theses studies on the Copper Rand and Henderson-Portage mines, respectively, during this same period (Magnan and Blais, 1995; Magnan et al., 1995a, 1995b; Tessier et al., 1995a, 1995b). This paper summarizes some of the main findings of this work and discusses general geological relationships of the Cu-Au veins on Merrill Island and the Clark Lake porphyry deposit. J. Cimon, M. Magnan, R. Morin, A. Tessier, A. Blais, R. Fournier and several geologists with Meston Lake Resources, MSV Resources, and SOQUEM, and the mentioned companies are acknowledged for their contributions to this work. R. Lancaster and T. Williams kindly prepared the diagrams.

REGIONAL GEOLOGY

The Chibougamau area contains two Archean mafic to felsic volcanic cycles, the Roy Group, which are overlain by a volcanic-sedimentary sequence, the Opemiska Group (Daigneault and Allard, 1990; Daigneault et al., 1990; Chown et al., 1992). Roy Group volcanic rocks include, in ascending stratigraphic order, the dominantly submarine Obatogamau Formation (mafic volcanic rocks), Waconichi Formation (felsic volcanic rocks; 2729,7+1,9/-1,6 Ma and 2728+1,5/-1,4 Ma; Mortensen, 1993), Gilman Formation (mafic volcanic rocks), and Blondeau Formation (felsic volcanic, mafic volcanic, and sedimentary rocks) intruded by subvolcanic mafic Bourbeau sill dated at 2716+1,0/-0,4 Ma (Mortensen, 1993). The Blondeau Formation

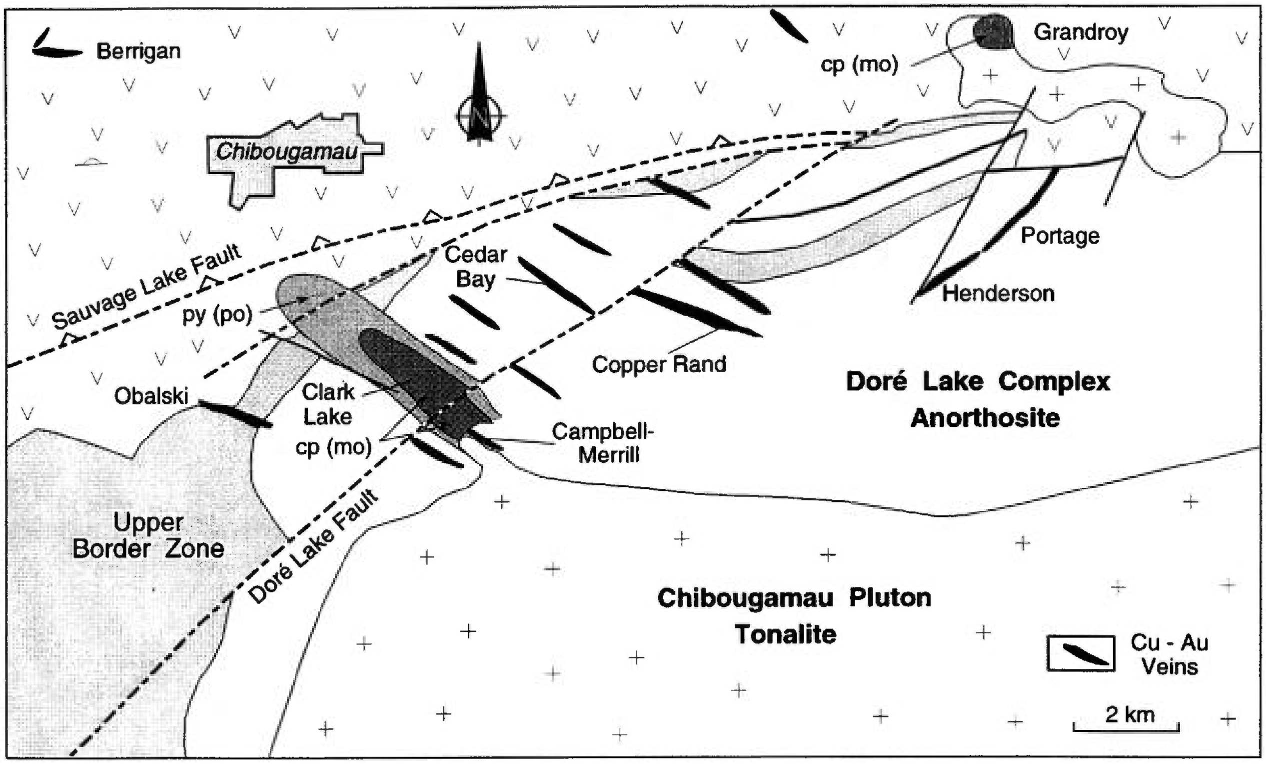


Figure D.14: Diagram of the Doré Lake mining camp at Chibougamau showing the relative locations of high-sulphide Cu-Au veins and the Clark Lake porphyry deposit.

was not completely consolidated at the time of emplacement of the Bourbeau sill (Lefebvre, 1991), hence, this date is probably also the same as, or slightly younger than that of the Blondeau Formation.

The Waconichi and Gilman formations have been intruded by the Doré Lake Complex, a major layered complex of gabbro and anorthosite (Allard, 1976a; Daigneault and Allard, 1990). The lowest exposed part of the Doré Lake Complex is composed of gabbroic and anorthositic rocks that form a massive unit as much as 2 500 to 3 600 metres thick. These rocks are characterized by coarse-grained, cumulus plagioclase crystals which are replaced typically by albite and zoisite. Dates of 2728,3 +1,2/-1,1 Ma on granophyre and 2727,0 +/-1,3 Ma on quartz-bearing pyroxenite indicate that it is a subvolcanic intrusion similar in age to the Waconichi Formation (Mortensen, 1993). The Doré Lake Complex also contain most of the important Cu-Au veins of the Chibougamau camp.

The Chibougamau pluton was emplaced during the second volcanic cycle and occurs in axial zone of the Chibougamau anticline (Duquette, 1970; Daigneault and Allard, 1990; Chown et al., 1992). It comprises hornblende meladiorite, hornblende quartz diorite, biotite tonalite, and leucotonalite (Racicot et al., 1984). Recent U/Pb zircon dates indicate that the Chibougamau pluton and intermineral dykes related to both the Cu-Au veins and porphyry Cu(-Mo) occurrences were emplaced about 2716 to 2714 Ma (unpublished data; A. Joanisse, personal communication, 1997; Pilote et al., 1997, 1998b). During the second volcanic cycle some of the volcanoes were subaerial and unroofed down to their plutonic cores, the derived sediments being deposited in the synclinal troughs between the volcanoes (Cimon and Gobeil, 1976; Dimroth et al., 1982; Daigneault and Allard, 1990; Mueller and Donaldson, 1992; Chown et al., 1992).

The area has undergone strong north-south compression with prominent east-west-trending folds and has been metamorphosed to greenschist facies (Duquette, 1970; Daigneault and Allard, 1990). Syntectonic plutons in the area have been dated at about 2701-2693 (Chown et al., 1992; Mortensen, 1993).

DEPOSIT GEOLOGY

The high-sulphide Cu-Au veins at Chibougamau (Figure D.14) are characterized by pyrrhotite-pyrite-chalcopyrite-magnetite-quartz-siderite mineral assemblages. On Merrill Island they occupy steeply-dipping, southeasterly-trending structures that predate the regional shearing (Robert, 1994; Sinclair

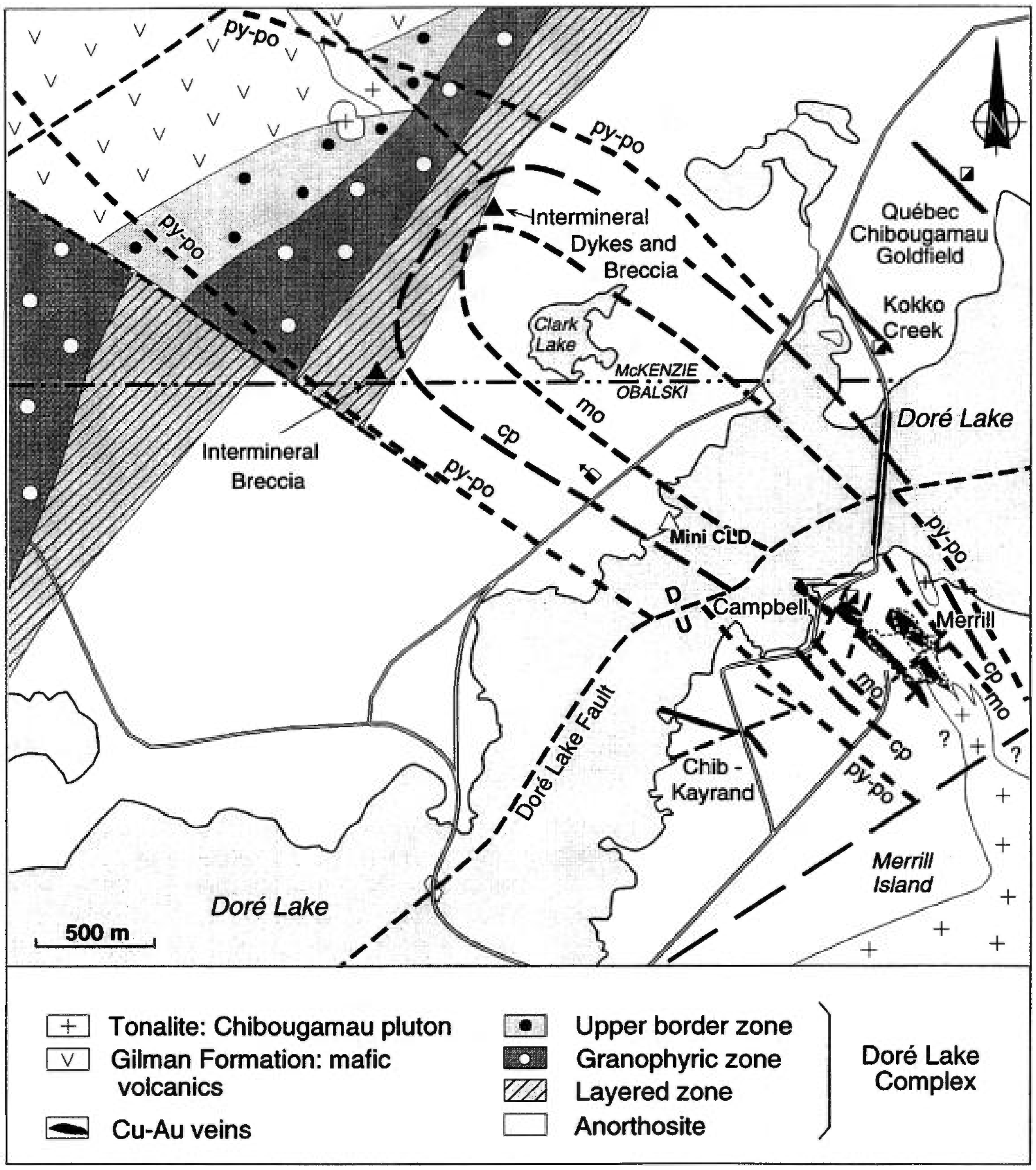


Figure D.15: Diagram illustrating sulphide and metal zoning in the Clark Lake porphyry deposit and the location of some high-sulphide Cu-Au vein deposits.

numerous tonalitic intermineral dykes demonstrating that the veins were related to the emplacement of the Chibougamau pluton. Chlorite, sericite, quartz, and carbonate are typical alteration minerals. Phyllosilicate alteration, particularly sericite and chlorite have been important in development of post-mineral, high-strain shear zones during subsequent regional deformation.

Au and Cu in the shear-related quartz-carbonate-sulphide(-tourmaline) veins at both the Portage and Copper Rand mines are thought to have been

ic,
al
deformation (Tessier et al., 1995a and 1995b; Magnan et al., 1995a and 1995b). The Cooke Au(-Cu) deposit at Chapais might have had a somewhat similar origin but it is located 5 kilometres northeast of the larger Springer and Perry deposits, which are similar to the intrusion-related, high-sulphide Cu-Au veins at Chibougamau (McMillan, 1972; Watkins and Riverin, 1982; Dubé and Guha, 1992).

The Clark Lake (formely described as Garth Lake in Kirkham, 1972) porphyry deposit is characterized by an extensive pyritic(-pyrrhotitic) stockwork about

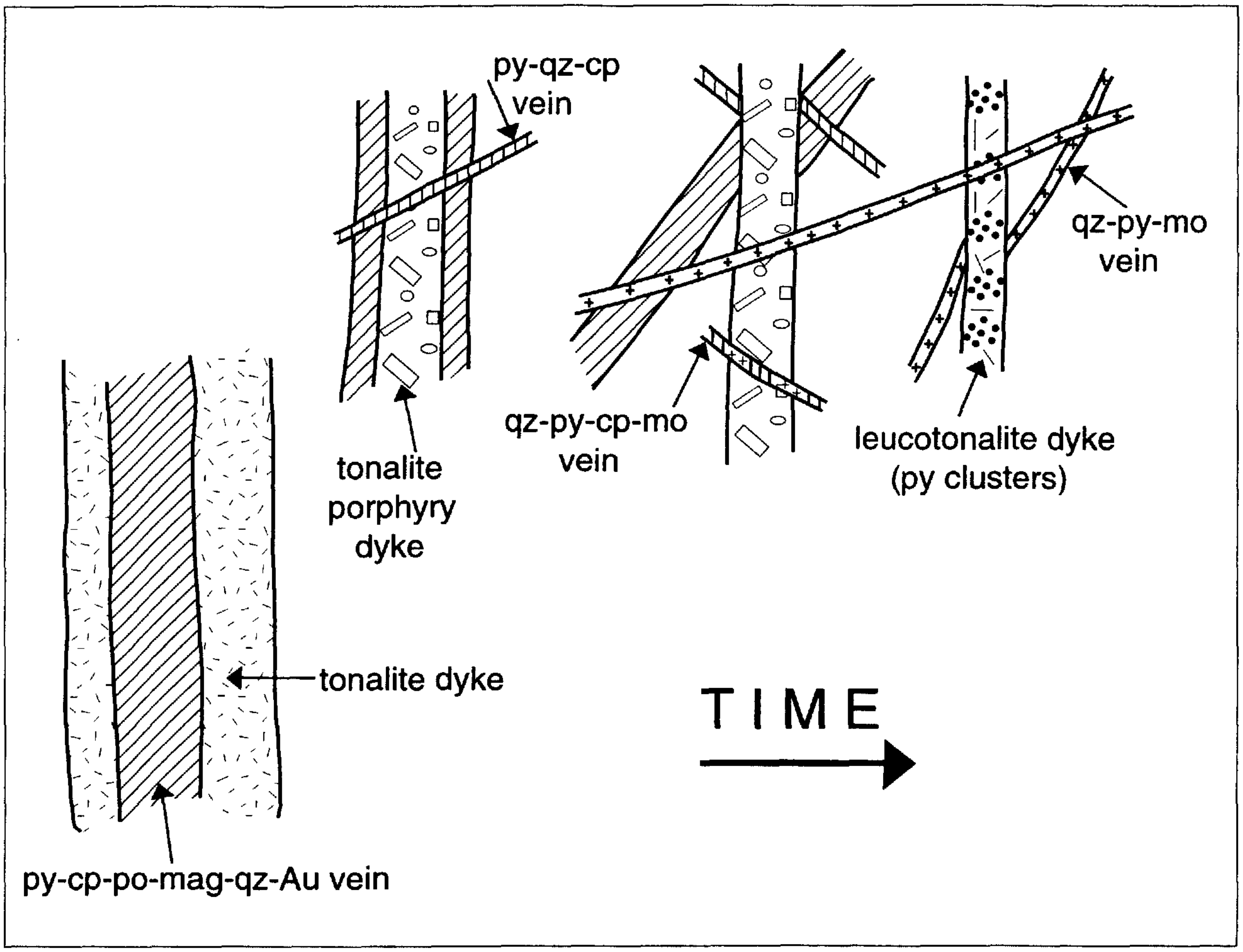


Figure D.16a: Diagram illustrating paragenetic relationships of veins and intermineral dykes in the open pit on Merrill Island.

5 km long in a northwest-southeast direction and up to 1,5 km wide centred on Clark Lake (Figures D.15). Locally the pyrite content is up to 15 per cent of the rock but more typically is in the range of 1 to 10 per cent. For some unknown reason, pyrrhotite is more abundant on the east side of the stockwork east of Clark Lake. Magnetite occurs in the outer part of the stockwork, especially on the west side and quartz-pyrite veins with sparse chalcopyrite and molybdenite occur in the central part of the stockwork (Figure D.15). Several tonalitic intermineral dykes and two intermineral breccias with sulphide-bearing rock flour matrices have been recognized in the deposit (Figure D.15), also confirming a relationship with the Chibougamau pluton and indicating that the stockwork is part of a porphyry deposit. One of the intermineral dykes along the power line at Clark Lake has a U-Pb zircon age of 2715,2 +/- 0,7 Ma (GSC, unpublished data), further confirming a relationship with the Chibougamau pluton. Chloritic and epidotitic propylitic alteration occurs in the outer part of the stockwork and siliceous and sericitic alteration occur in more central parts. Chemical analyses do not show any area with a marked increase in potash alteration, which is consistent with the low Cu and Mo grades found in outcrop (mostly < 0,1% Cu and < 20 ppm Mo). However, the chemical analyses indicate that much of the stockwork is distinctly anomalous in Zn (100's of ppm), consistent with being the outer part of a porphyry deposit.

Layering in the Doré Lake Complex, assuming it was approximately horizontal at the time of formation of the Clark Lake deposit, indicates that the deposit could have been tilted about 70 to 75 degrees to the northwest and could be siting on its side with a possible normal displacement on the Doré Lake Fault in the order of 1000 metres, north side down. If such deformation can be confirmed, then the main part of the deposit is sliced through the pyrite zone with Merrill Island and the

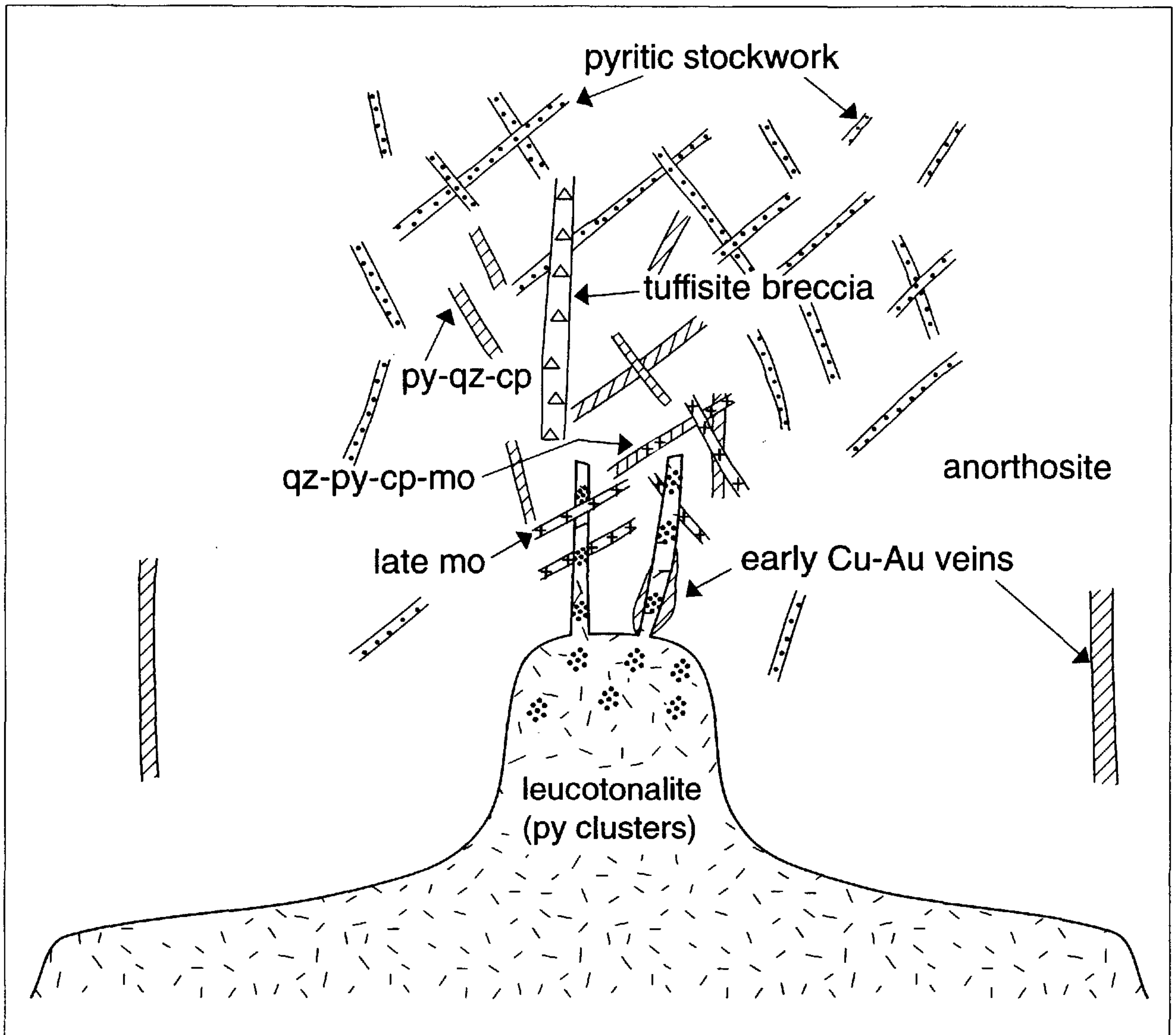


Figure D.16b: Schematic reconstruction of possible paragenetic and spatial relationships of veins, breccias, tonalitic intrusions, and late-stage magmatic pyrite clusters in leucotonalite on Merrill Island and the Clark Lake porphyry deposit.

apophysis of the Chibougamau pluton being in the root zone of the deposit (Figure D.15).

Careful documentation of numerous intermineral dykes in the open pit on Merrill Island and along the power line at Clark Lake have permitted a detailed chronology of the mineralizing events. These are illustrated schematically in Figure D.16. Deep in the system at Merrill Island early high-sulphide Cu-Au veins cut a tonalite dyke and are cut by several generations of tonalite porphyry dykes and Cu and Cu-Mo-bearing veinlets with low Au and finally by Mo-bearing veinlets with neglible Cu and Au. The Merrill phase of the Chibougamau pluton in the southeast end of the pit on Merrill Island and on the north shore of the island contains unusual clusters of pyrite that are considered to be late-stage magmatic phase (Figures D.15 and D.16; Kirkham et al., 1997a).

DISCUSSION

The Cu-Au veins and porphyry deposits at Chibougamau probably formed in a magmatic arc during the second volcanic cycle at a time when at least parts of the arc were subaerial (Cimon and Gobeil, 1976; Chown et al., 1992; Mueller and Donaldson, 1992). High-level intermineral porphyry dykes with chilled margins and aphantic matrices; small, intermineral tuffisite diatreme breccias with rock flour matrices; and typical porphyry-type mineralization and alteration indicate a high-level, subvolcanic, subaerial emplacement of the

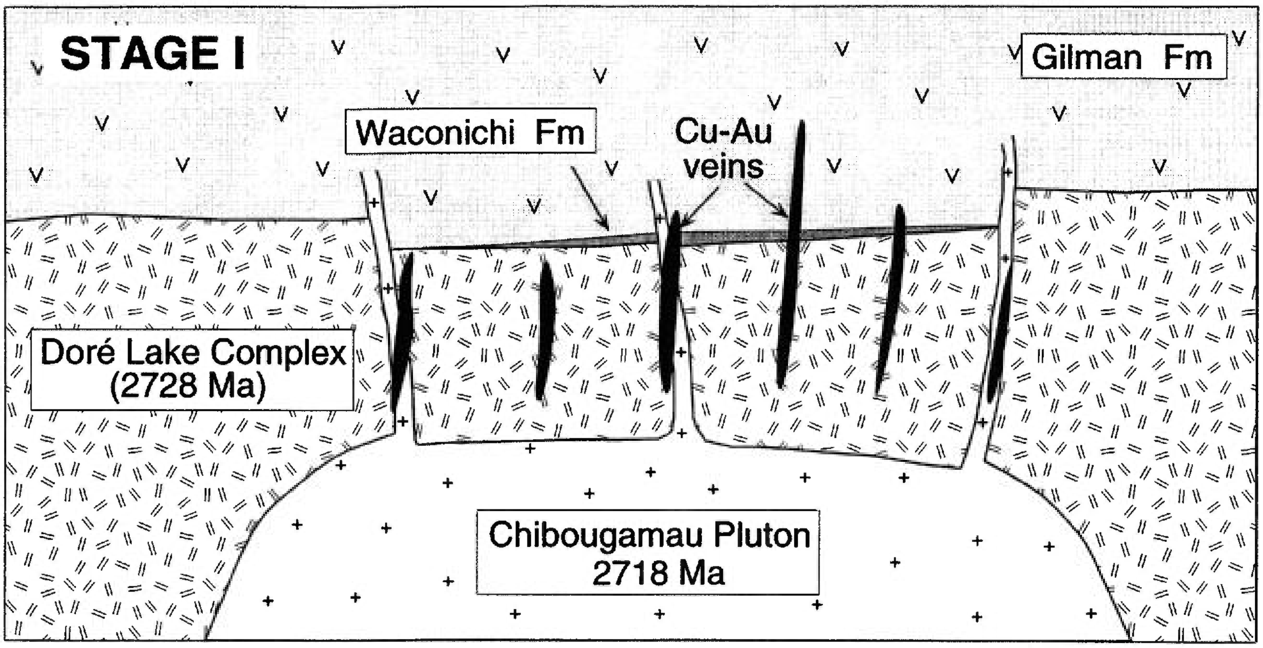


Figure D.17a: Schematic diagram illustrating the environment of formation of early high-sulphide

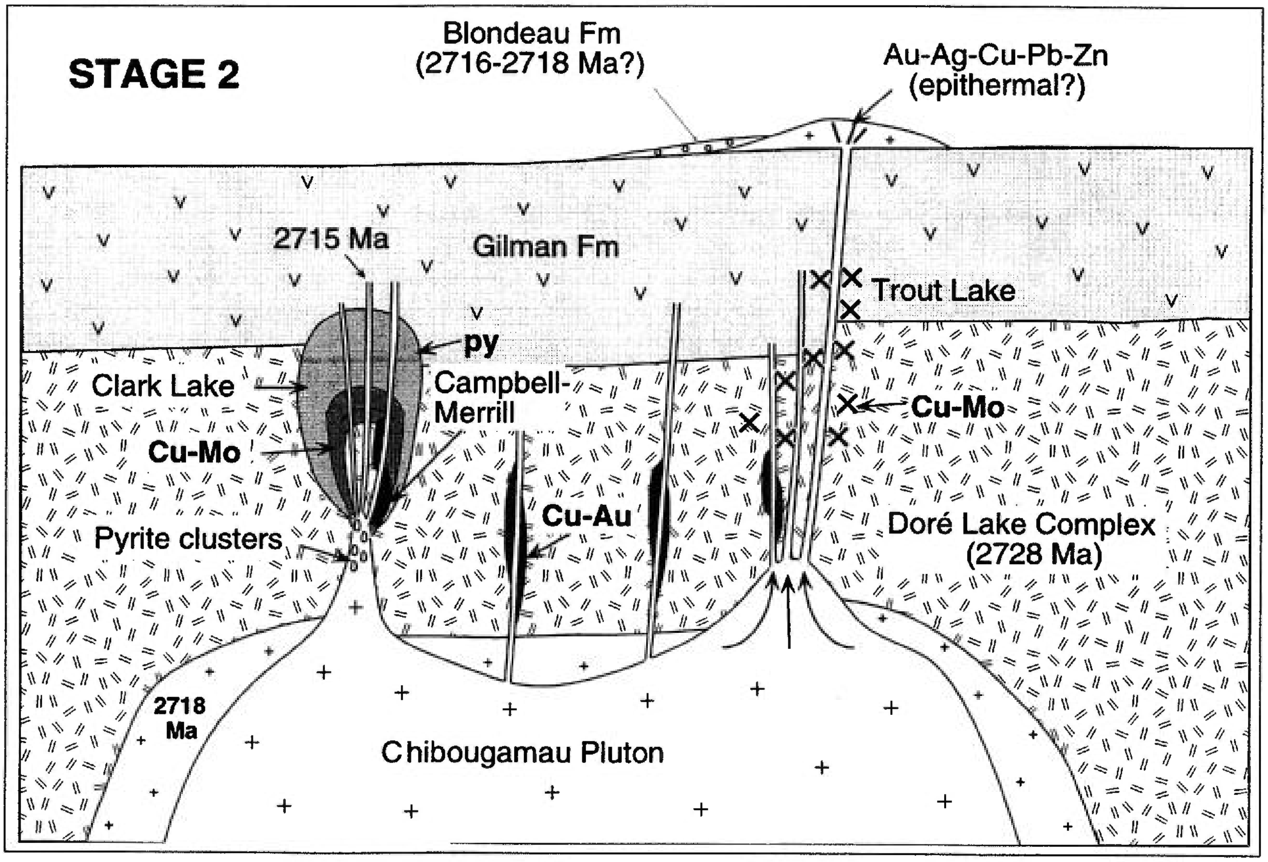


Figure D.17b: Schematic diagram illustrating the possible environment of formation of the stockwork porphyry Cu-(Mo) deposition during a later resurgent stage of intrusive activity in the Chibougamau pluton.

intermineral dykes and associated porphyry mineralization. Figures D.17a and D.17b are schematic reconstructions of the possible environments of formation of the early high-sulphide Cu-Au veins (Figure D.17a) and the slightly younger porphyry Cu-Mo stockworks (Figure D.17b). As indicated in Figure D.17a, the formation of the early Cu-Au veins might have been accompanied by caldera subsidence of roof rocks into the Chibougamau pluton and the area might have been slightly below sea level. However, by the time of formation of the porphyry deposits the area was probably emergent and subject to extensive erosion.

During strong regional compression that closely followed the formation of this arc and its related mineral deposits, the large intrusions in the axis of the arc acted as buttresses and stayed virtually upright and formed the cores of regional anticlines (Duquette, 1990; Chown, et al., 1992). The upper part of the arc was largely eroded away, the detritus accumulating in the adjacent synclines (Cimon and Gobeil, 1976; Dimroth et al., 1982; Chown et al., 1992; Mueller and Donaldson, 1992). However, arc rocks and deposits on the limbs of the anticlines were rotated on their sides and partly protected from erosion. Younger block faults uplifted some areas and down-dropped others, elevating the level of exposure of some veins and porphyry occurrences and depressing others.

Some deposits in younger geological terranes might be analogous with the Archean deposits in the Chibougamau area (e. g., Kirkham and Sinclair, 1996). Recent work by Höy and Dunne (1997) and Höy et al. (1998) in the Rossland area of British Columbia show some interesting parallels with the Chibougamau area. Lower Jurassic massive pyrrhotite(-pyrite)-chalcopyrite veins were the main producers in the area, yielding some 5,4 Mt of ore grading 15,7 g/t Au (Höy et al., 1998). The formation of these veins was followed by the development of a skarn, breccia, porphyry molybdenum deposit and subsequently the entire system was tilted on its side.

Newmont is also developing the large tonalite-related Batu Hijau porphyry Cu-Au deposit on Sumbawa Island in the Sunda-Banda arc system in Indonesia (Meldrum et al., 1994). The deposit has an indicated resource of 907 185 000 tonnes grading 0,53 % Cu and 0,3 g/t Au (Northern Miner, July 13-19, 1998, page 11). The deposit is about 7-9 Ma years old (I. Munajat, personal communication, 1997) and occurs at an elevation of about 550 metres about 10 kilometres north of the south coast of the island. This is a recently extinct part of the arc with the axis of the modern arc shifted farther north. An area of about 900 by 300 metres at surface graded 0,53 % Cu and >0,2 g/t Au. The Cu-Au zone has a Mo halo grading >30 ppm Mo. Diamond-drilling has demonstrated that the deposit has an inverted cup-shaped core grading > 1,0% Cu with the best Au grades overlapping and beneath the best Cu grades. The deposit is related to multiple tonalite intrusions; has associated biotitic potassic alteration; a halo of propylitic alteration; and has superimposed, both advanced argillic and phyllic alteration (Meldrum et al., 1994). Subeconomic high- and low-sulphidation epithermal precious metal and peripheral Cu veins occur in the area. Cu-Au-Mo association in a multiple-phase tonalitic intrusive-hydrothermal system in an island-arc setting is very similar to that envisaged for deposits in the Chibougamau district.

CONCLUSIONS

The Chibougamau district demonstrates that porphyry Cu-(Mo) and intrusion-related vein Cu-Au deposits, considered by many only to form only in young geological terranes, also formed in older Archean terranes. Economically important, regional-spaced, high-sulphide Cu-Au veins formed before more localized porphyry Cu-(Mo) deposits. Deposits such as this were probably preserved as they were rotated on their sides, block faulted, and then covered by younger formations during periods of crustal scale extension (Kirkham, 1998).

THE "CORNER BAY" COPPER DEPOSIT

Valère Larouche and Alain Blais
Les Ressources MSV Inc., C.P. 8000, Chibugamau, Québec, G8P 2L1
Yvon Bellavance
SOQUEM, 462 3e rue, Chibougamau, Québec, G8P 1N7

INTRODUCTION

The Corner Bay property (Inner Block) is at the limits of the Obalski, Lemoine, and Queylus townships, approximately 47 kilometres southeast of Chibougamau. It is accessible by road, 17 kilometres from the fork at kilometre 200 of route 167.

PREVIOUS WORK

The Corner Bay deposit is the second important discovery on the south flank of the Doré Complex Lake, after the titaniferrus and vanadiferrous magnetite found in the 1960s. The discovery was made in March 1982 following several exploration programmes spread over a 26-year period

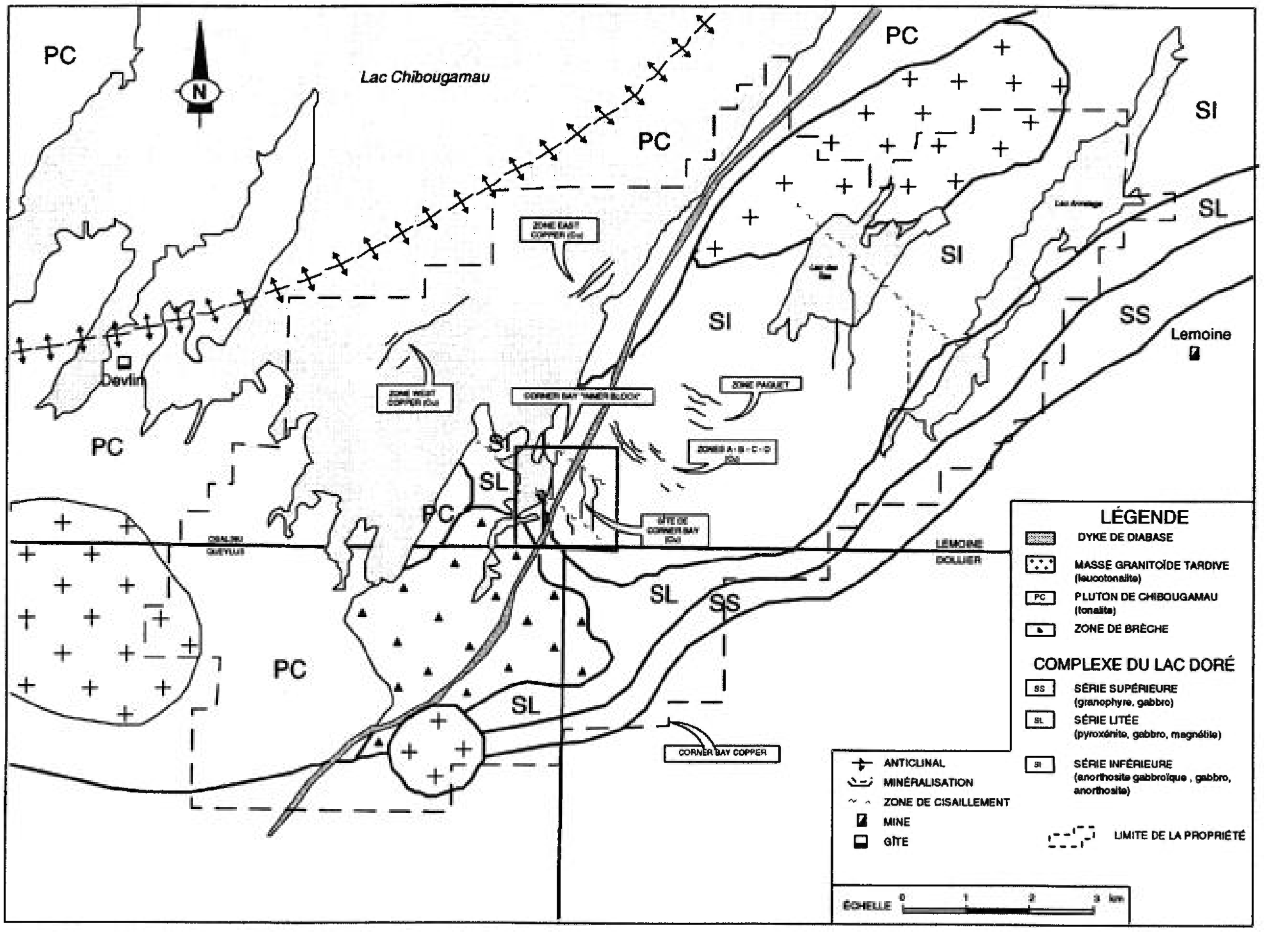


Figure D.18: Simplified geology of the Corner Bay area (modified from Cimon, 1976; and SOQUEM)

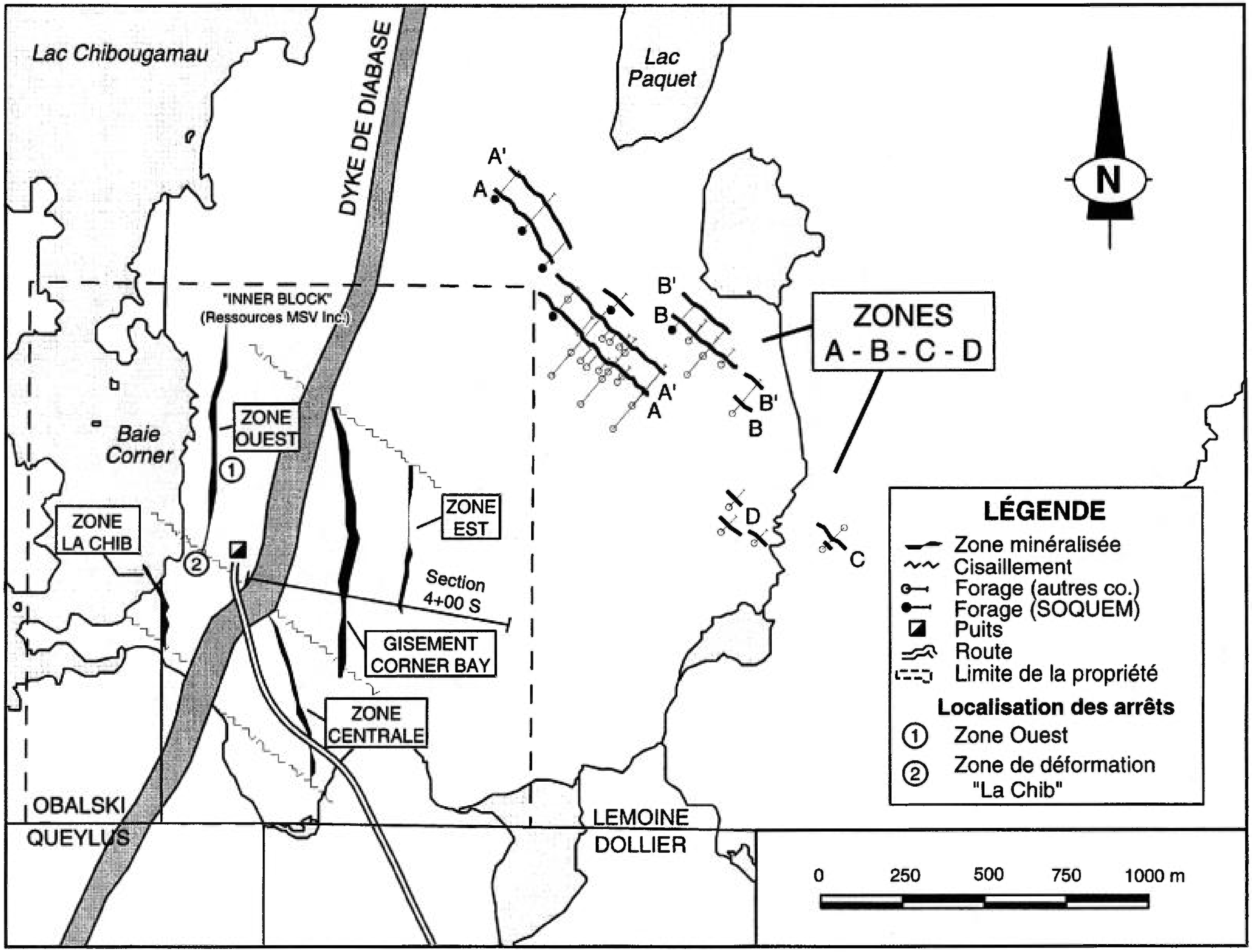


Figure D.19: Location of the various mineralized zones in the Corner Bay area.

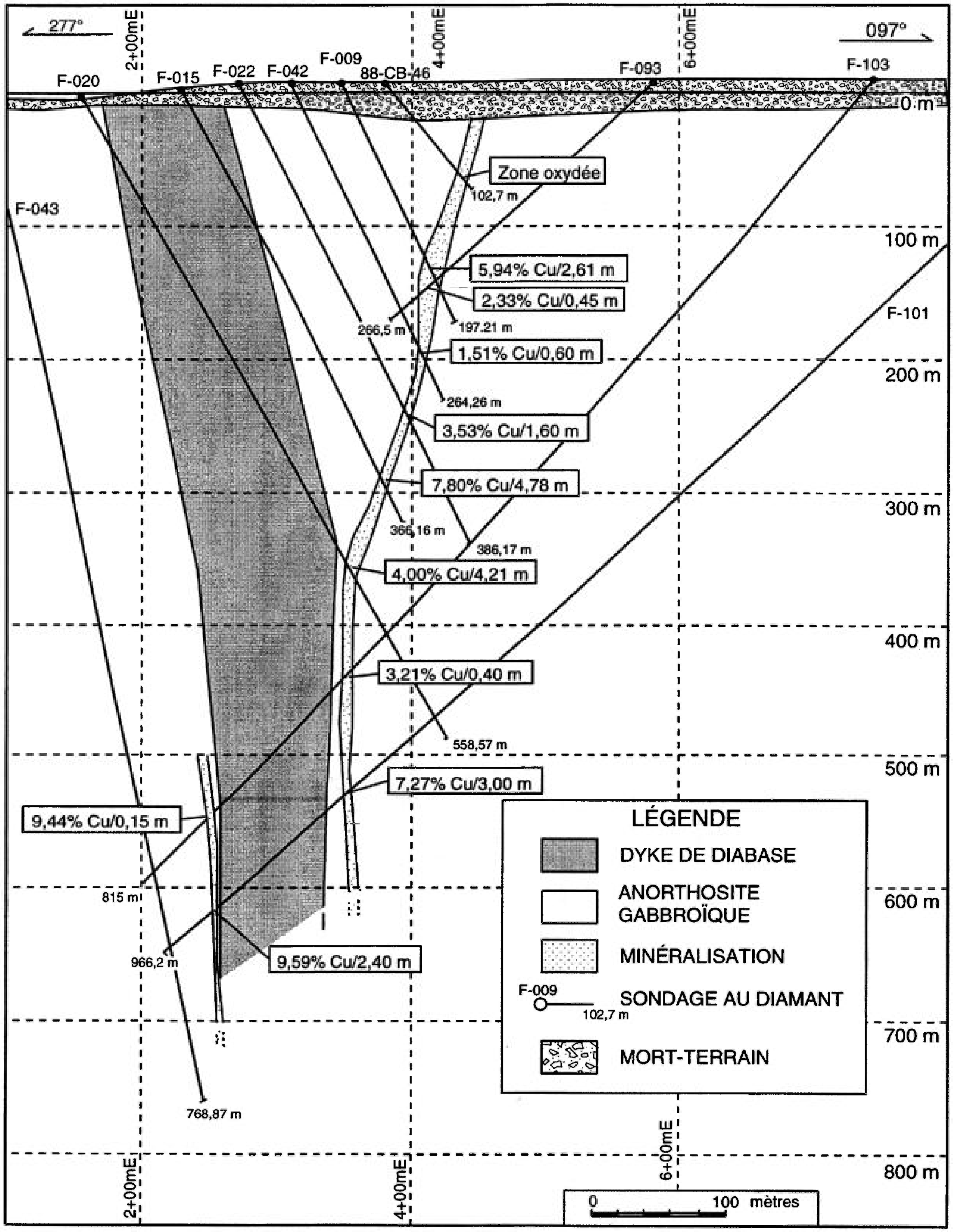


Figure D.20: Simplified geology of section 4 + 00 S, Corner Bay deposit.

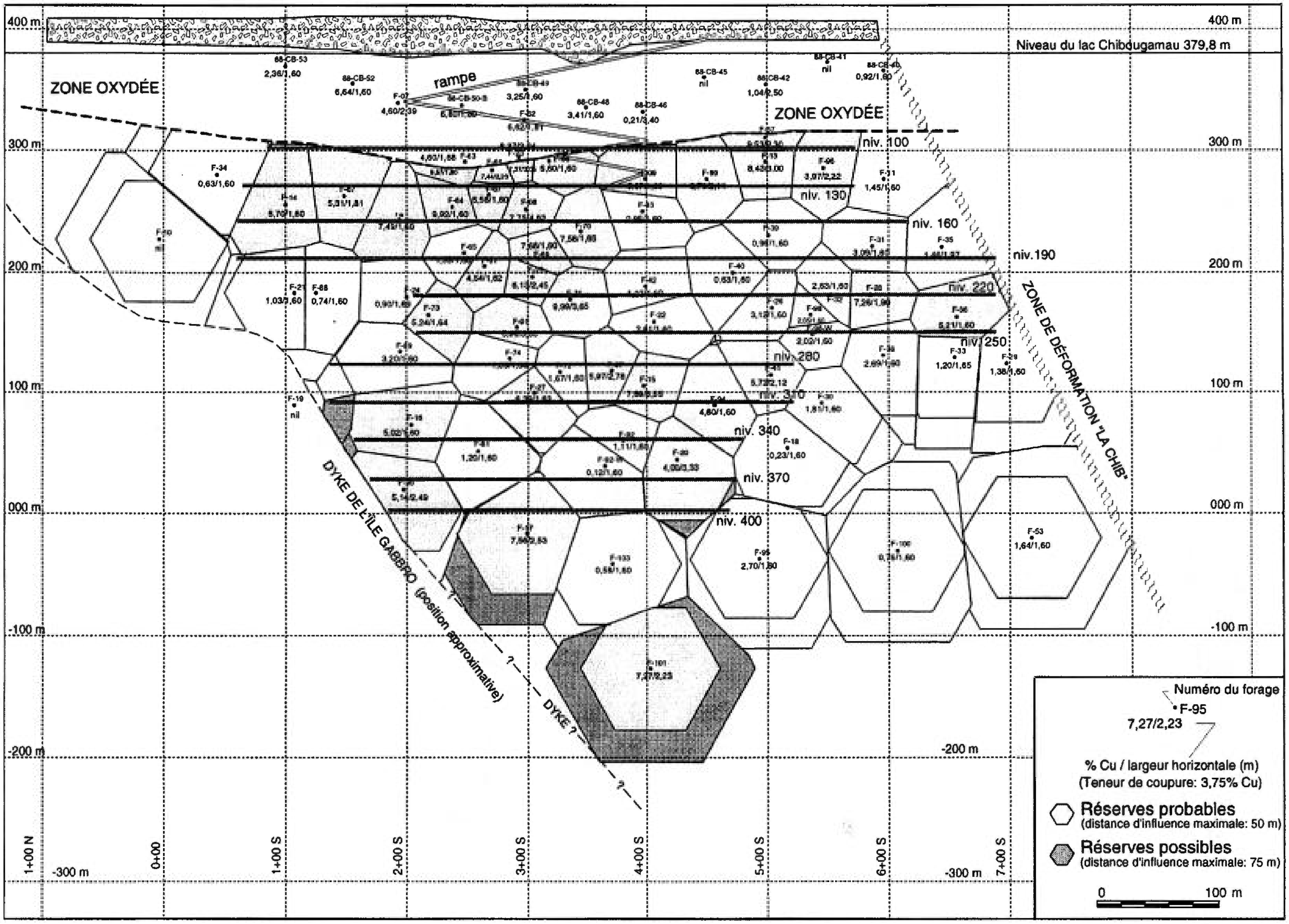


Figure D.21: Longitudinal section of the Main Zone, Corner Bay deposit. Proposed decline and levels locations are indicated.

(Flanagan, 1983). Team work linking Rio Algom Inc. and Corner Bay Ltd led to the discovery (Bartoni and Vachon, 1984). Between 1992 and 1994 SOQUEM (after having optioned from Corner Bay Minerals Inc.) completed three drilling campaigns totalling 13515 metres. These campaigns permitted the evaluation of the mineral resources (diluted by 25% to 0,67% Cu) for the Primary zone, from 986 600 mt at 5,28% Cu with a content cut of 3,75% Cu (Lachance, 1993) to a depth of 600 metres. Exploration Cache Inc. (45%) and Ressources MSV Inc. (55%) acquired the Corner Bay deposit in July 1994 counterpart to the completion of the work necessary to begin production from the deposit. Following the fusion of Exploration Cache Inc. and Ressources MSV Inc. in November 1995, Ressources MSV Inc. holds 100% of the deposit.

LOCAL GEOLOGY

The Corner Bay area is located on the south flank of the Chibougamau anticline within the Doré Lake Complex or DLC (Allard, 1976a). The hinge zone is cored by the Chibougamau Pluton, a pretectonic, multiphased intrusion, resulting from successive intrusion of differentiated magmas (Racicot 1980; 1981). The DLC is formed of the inferior, layered and superior series (Caty, 1970). The layered series is particularly well developped throughout the south flank of the complex. It hosts a considerable tonnage of vanadiferous and titaniferous magnetitites. The Corner Bay deposit itself is located in the inferior serie. The latter is composed mainly of units ranging from gabbroic anorthosites to anorthositic gabbros. To the southwest it is overlain by a succesion of pyroxenites, gabbros and magnetitites part of the layered serie (Figure D.18). The presence of numerous dykes of varying composition betrays the importance of magmatic activity related to the Chibougamau Pluton. Furthermore this area is highlighted by porphyry-Cu style mineralization as observed at the Devlin deposit and at the Queylus breccia (Cimon 1973; Bureau 1980). A Proterozoic diabase dyke, Gabbro Island Dyke, traverses the whole region. This dyke strikes NNE and cuts the Corner Bay deposit.

The copper mineralization observed in this area is vein type and associated with shear zones whose reverse motion is characterized by two distinct orientations, N-S and NW-SE. The Corner Bay deposit (or Main Zone) belongs to the NS system as do several other zones of lesser importance, such as the West, Central and East Zones. A, B, C and D Zones are hosted in the NW-SE system (Figure D.18). Albeit different orientations, these zones show similar alteration halos, these are caracterised by a sericitic front ranging to an intense chloritisation towards the mineralized lenses. Late NE to NNE faults with apparent sinistral displacement are equally observed.

THE CORNER BAY DEPOSIT

The Corner Bay deposit (Main Zone) is hosted by a N190°/83° trending shear more or less continuous over a surface strike length of 700 m (Bertoni and Vachon, 1984). The host gabbroic anorthosite is sericitized and sheared over variable widths, 2 to 25 m (Figure D.19). The deposit is limited to the north by a diabase dyke. To the south it is limited by the La Chib shear oriented N150°/ 60°.

The mineralisation is composed of veins and/or lenses of massive to semi massive sulphides + quartz +/- carbonates (calcite); the most obvious sulphides are chalcopyrite and pyrite with lesser amounts of pyrrhotite, sphalerite and molybdenite. The sulphide mineralization is essentialy associated with brecciated quartz veins. Stringer sulphides generally occur about the mineralized lenses. Lens thickness can vary from 30 cm to 2,0 m. Some lenses can range up to 5 m thick. The alteration is most intense and characterized by schistose black chlorite immediately next to the vein.

Vein distribution is irregular. In plan view the lenses are subparallel to the schistosity. This schistosity dips steeply to the east (85°-90°) and defines an angular relation with the walls of the shear zone, the latter dipping west. This feature indicates a vertical reverse movement, i.e. west to east thrusting. A steeply plunging mineral lineation is another argument in favor of a vertical movement. A weak rake towards the south suggest a slight sinistral lateral component. This stretching lineation is well illustrated by the rake of the mineralized zone (Figure D.20).

Glacial till (30 m thick) covers the Main Zone. The top portion of the orebody has been oxydized by meteoric seepage to a depth of 100 meters. Here the alteration products are a variety of secondary minerals such as limonite, chalcosite, malachite and native copper.

A second zone has been identified at a 500-metre depth. The presence of this zone in the footwall of the diabase dyke, enhances the deposit's potential.

DEVELOPMENT PROJECT

To develop this deposit, Ressources MSV Inc. studied two main scenarios, those being either a shaft or a ramp. They finally opted for a ramp for the following reasons :

a) accelerate pre-production;
b) lessen capital costs;
c) access more readily to the mineralised zone (6 months vs. 14 months);
d) possibility of profiting from better copper prices;
e) the resources from the superior levels are more certain than those below 400 m.

The ramp option will be completed in two phases. The first consists of bringing a ramp to levels 100 m and 130 m in order to develop the drifts to verify the continuity of the mineralisation, its content, and to collect a 30 000-ton bulk sample for metallurgical testing and calibration at the Ressources MSV Inc. concentrator, at the Copper Rand mine.

If the results are conclusive and the price of copper is favourable, pre-production will be completed to a depth of 400 metres. The resources calculated with the marginal tons (content cut of 1,99% Cu) come to 872 000 metric tons at 4,49% Cu. This tonnage includes a dilution of 25% with content at 0,67 Cu. These resources do not include the 100 000 tons of oxidized ore (limonite, chalcosite, malachite and native copper) that make up the first 100 metres from the surface. The surface pillar could be retrieved at the end of the exploitation of the deposit.

The targeted production rate is 500 tons per day, an average annual production of 184 000 metric tons. For the mining of the deposit, the long hole extraction method will be used in sequences of 50 metre lengths. A "Cubex" type drill will be used as well as diesel shuttle-loaders and 30-ton trucks, to dispatch the ore to the surface. From there, the ore will be brought to the Copper Rand mill by truck to be concentrated.

POTENTIAL

In the existing borings, certain holes brought back results from elsewhere than in the primary zone. It is possible that other lentils exist in proximity, of lesser importance, but that offer the possibility of increasing exploitable tonnage. Below level 400, there are a few holes with good results and others that intersected the structure without being economical. The spacing between each hole being important, lateral and depth definition are needed because the potential is very interesting. That which remains the most promising is the lentil intersected in the diabase dyke inferior footwall. Two holes intersected it, the best being at a depth of 600 metres. Thus, the two sides of the dyke present an excellent depth extension potential.

THE LAC DORÉ VANADIUM DEPOSIT, CHIBOUGAMAU

Réjean Girard
IOS Services Géoscientifiques Inc.
C.P. 158, Jonquière, Québec, G7X 7V9
and Gilles O. Allard
McKenzie Bay Resources Ltd.
225 Hampton Court, Athens, Georgie, États-Unis, 30605-1403

INTRODUCTION

The lac Doré Complex, in the region of Chibougamau, is known to be the host of the various copper and gold mines of this mining camp. Its potential for the discovery of other types of deposits is lesser known although it encases that which seems likely to become the most important mining operation of the region. The vanadium deposit, located on the south flank of the complex, could in 2001 become the first mining operation of this iron alloy of the Americas.

Although the presence of titaniferous magnetite has been known since the late 1950s, their vanadium content was discovered only in 1966. The presence of this metal had been determined by Dr. Gilles O. Allard following an analogy with the Bushveld Complex in South Africa, and was subsequently confirmed by CRM analysis. The deposit was then staked in the name of the Crown and subsequently transferred to SOQUEM. In 1997, McKenzie Bay Resources Ltd. optioned the property and expects to deliver a feasibility study before the end of 1999.

LOCAL GEOLOGY

The lac Doré Complex is a differentiated mafic sill of the Archean age, which is observed in the heart of the Chibougamau anticlinal. Its flanks outcrop on the north and south shores of the lac Chibougamau. Its stratigraphy is basically composed of thick sequences of anorthosite which encase the copper-gold deposits. The anorthosite is surmounted by a layered sequence which contains the vanadiferous magnetites, layered ferrogabbros, and ferropyroxenites. The layered sequence is finally surmounted by a granophyre and a contact zone with the felsic volcanites of the Waconichi Formation.

The layered sequence has been subdivided into various units, separated by discontinuous anorthosite screens (Figure D.22). One notes, at the base of the summit :

P0 : Anorthosite sequence interspersed by thin layers of magnetite.

P1 : Dominant anorthositic sequence interspersed by abundant layers of magnetite of metric thickness. This sequence is considered a low grade magnetite resource but one that is of high grade vanadium. This resource is probably economic.

P2 : Sequence dominated by layers of magnetite and magnetite ferrogabbro with a high grade of vanadium. This sequence constitutes the major part of the vanadiferous magnetite deposit.

P3 : magnetite and ilmenite ferrogabbro sequence. The magnetite of these layers, although abundant, presents a grade of vanadium too low to be exploitable.

ECONOMICAL ASPECTS

The vanadium is essentially linked to the crystalline structure of the magnetite. Typically, its grade in the magnetite decreases from the base to the summit (± 1,5% in the P0, P1 and the base of P2, and ± 0,7% in the P3). Inversely, the grade in free and exsolution ilmenite increases from the base to the summit of the sequence (Figure D.23).

The magnetite layer sequence forms an amalgam whose average power in the order of 100 metres. These layers cause an aeromagnetic anomaly that occurs over more than sixteen kilometres parallel to the layers. This horizon is truncated in the north-east by the faults related to the Grenville Front and is dismembered in the south-west by the tip of the Chibougamau anticlinal.

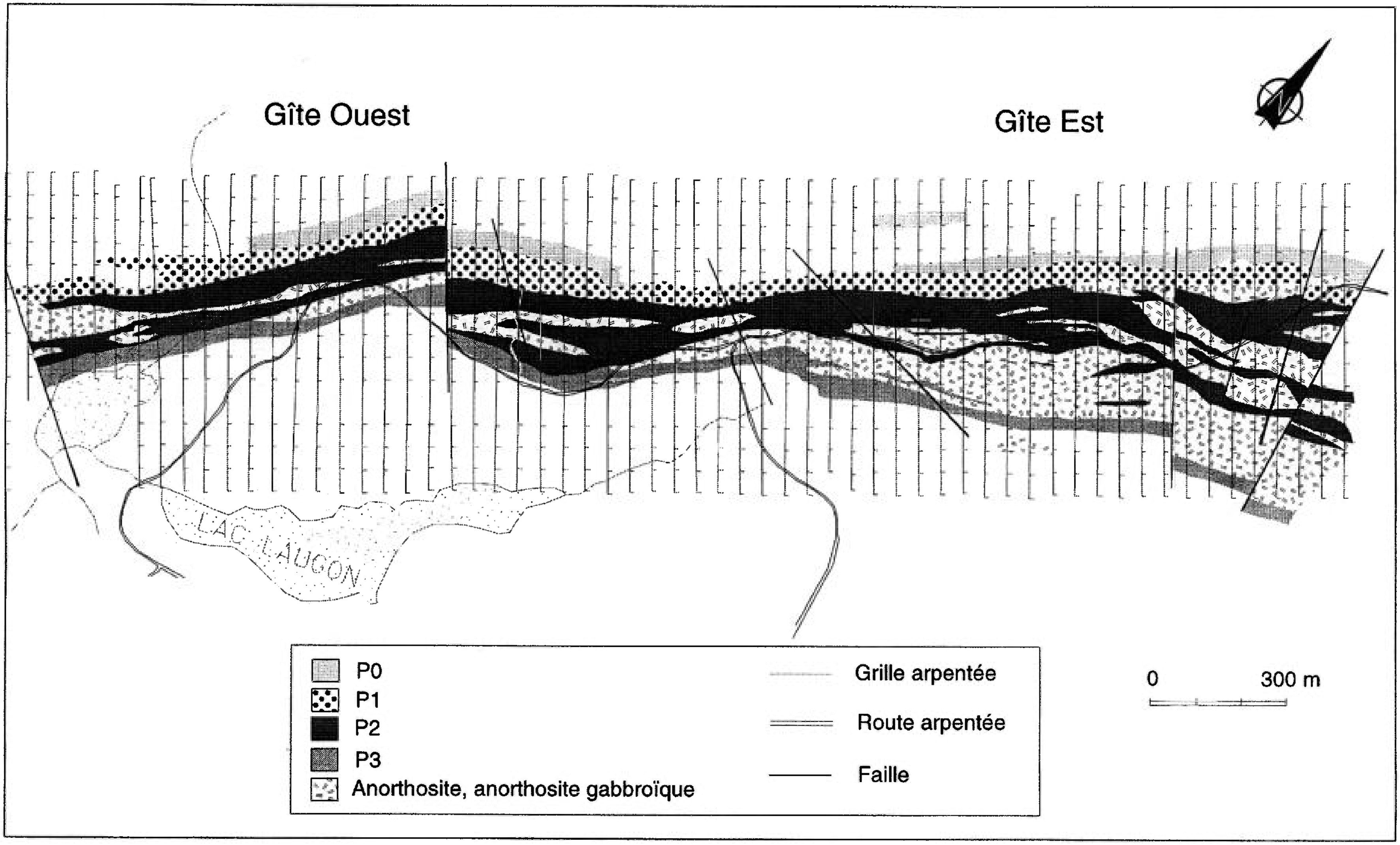


Figure D.22: Simplified geology - East and West deposits, South limb of the Doré Lake Complex.

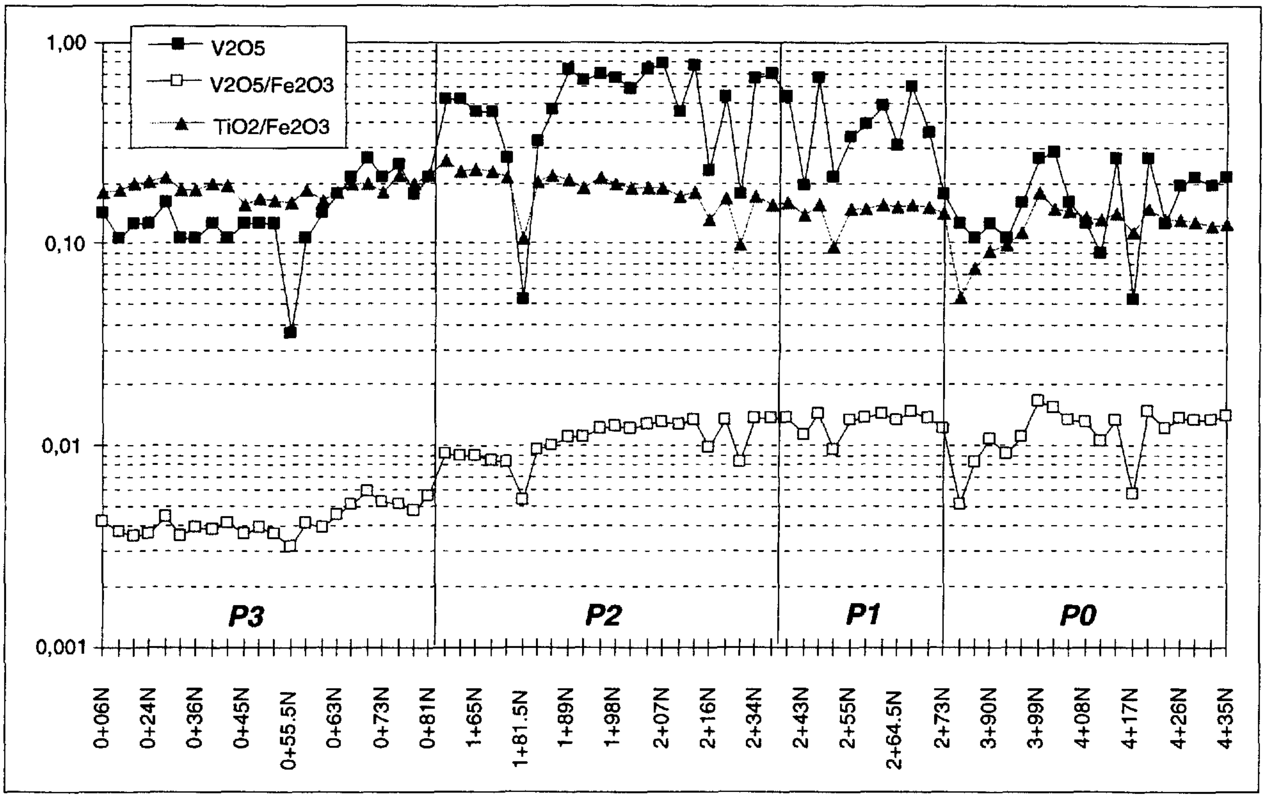


Figure D.23: Vanadium (V_2O_5), iron (Fe_2O_3) and titanium (TiO_2) grades shown by the various host units: P0, P1, P2 et P3, Doré Lake Complex, trenches 14+50 E and 15+50 E.

The deposit has been evaluated solely in that which concerns a thickening in the sector of the Rinfret township. This sector, known by the names of the east and west deposits extends 3,5 kilometres and attains a thickness of 200 metres. The resources measured for these two deposits are of one million tonnes per vertical metre.

The summary of the resources for the sum of the project can be established as follows (as of April 20, 1998) :

Deposit	Class	Tonnage	V_2O_5	Ditch
Eastern	Measured	32,2 MT	0,57%	100 m
Eastern	Indicated	87,5 MT	0,47%	200 m
Western	Indicated	84 MT	0,45%	200 m
South-West	Inferred	60 MT	0,45%	100 m
Armitage	Inferred	100 MT	0,45%	100 m
North-East	Inferred	90 MT	0,45%	200 m
Total	**All classes**	**450 Mt**	**0,45%**	

McKenzie Bay Resources Ltd. is planning the construction of an industrial complex that will include an open pit mine and a concentrator with a nominal capacity of 6000 tonnes a day as well as a refinery with a tonne of vanadium pentoxide an hour capacity. The mine's shape will be that of a linear ditch with an ultimate depth of 200 metres for an ore/sterile ratio of 1 : 1. It will be operated with the help of a conveyor system fitted with an in-pit crusher. The concentrator is expected to be composed of a millstone, a low intensity magnetic separator, a pin crusher and lastly, a high intensity triple magnetic separator. A silicate flotation cell is also under consideration as well as a gravitational concentrator for the recuperation of ilmenite. With a concentration factor of 1 : 3,2, an 80 tonne per hour production of magnetite is projected. The refinery is composed of a rotating oven 100 metres long by 6 metres in diameter with a hydro-metallurgical complex. The process consists of roasting a mixture of magnetite and sodium carbonate at 1200 C for six hours. The magnetite oxidises into hematite and the vanadium trioxide reacts with the sodium oxide to form a sodium vanadate that is water-soluble. The cinder is washed then precipitated the vanadate into ammonium lixiviate. This salt is then burnt in ammonia and vanadium pentoxide is the final product. The cost of the construction of the project is estimated at 150 million Canadian dollars. The project is calculated for a forty-year life span.

CONCLUSIONS

Vanadium is used primarily as a steel alloy. Its market increases by about 7% every year, without taking into consideration the new uses found in the field of electro-chemistry. In addition, the exhaustion of world-wide reserves brings about a diminishing production currently concentrated in the aging South African deposits. It is expected that the nominal capacity of operations of lac Doré will take up 10 to 15% of the world market, percentage that could be subsequently increased.

THE CHEVRIER ZONE, AN IMPORTANT MINERAL RESOURCE FOR THE CHIBOUGAMAU REGION

Hugues de Corta
GéoNova Explorations Inc.
1700, rue de l'Hydro, Val-d'Or, Québec, J9P 4P8

INTRODUCTION

The Chevrier project is located approximately 30 km south-east of Chapais and 35 km south of Chibougamau, Québec (Figure D.24). It is comprised of five distinct blocks of claims that are from the south-west to the north-east : Dolbo, Haufan, Fancamp, Diana-Obatogamau, and Diana.

The partner's interests on these blocks are distributed as follows :
Dolbo - INMET (63,83%), Cambior (36,17%)
Haufan - INMET (100%)
Fancamp - INMET (65%), Fancamp Res. (35%)
Diana-Obatogamau - INMET (100%)
Diana - INMET - (100%)

GéoNova has the option to acquire 100% of INMET's interest in these blocks in consideration of the work accomplished and the production of a feasibility study. Upon receipt of the study, INMET has the option to buy back 50% of the interests by reimbursing GéoNova's expenses. GéoNova has the option to acquire 100% of Cambior's interest in the Dolbo block in consideration of exploration work. Fancamp Ressources seems disposed to dilute their

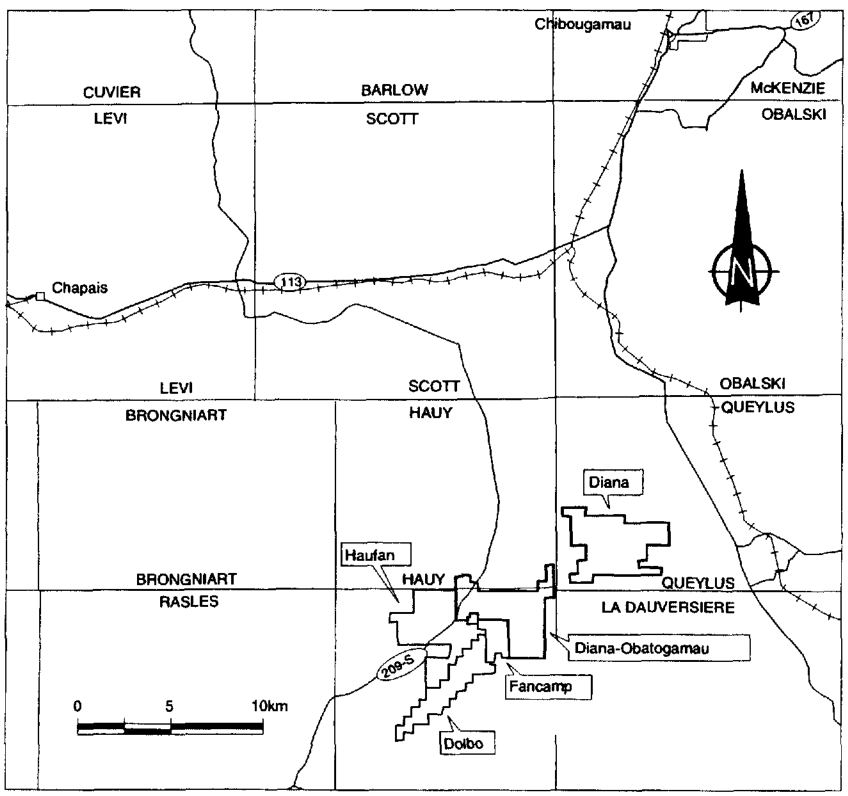


Figure D.24: Location of the Chevrier project, Chibougamau area.

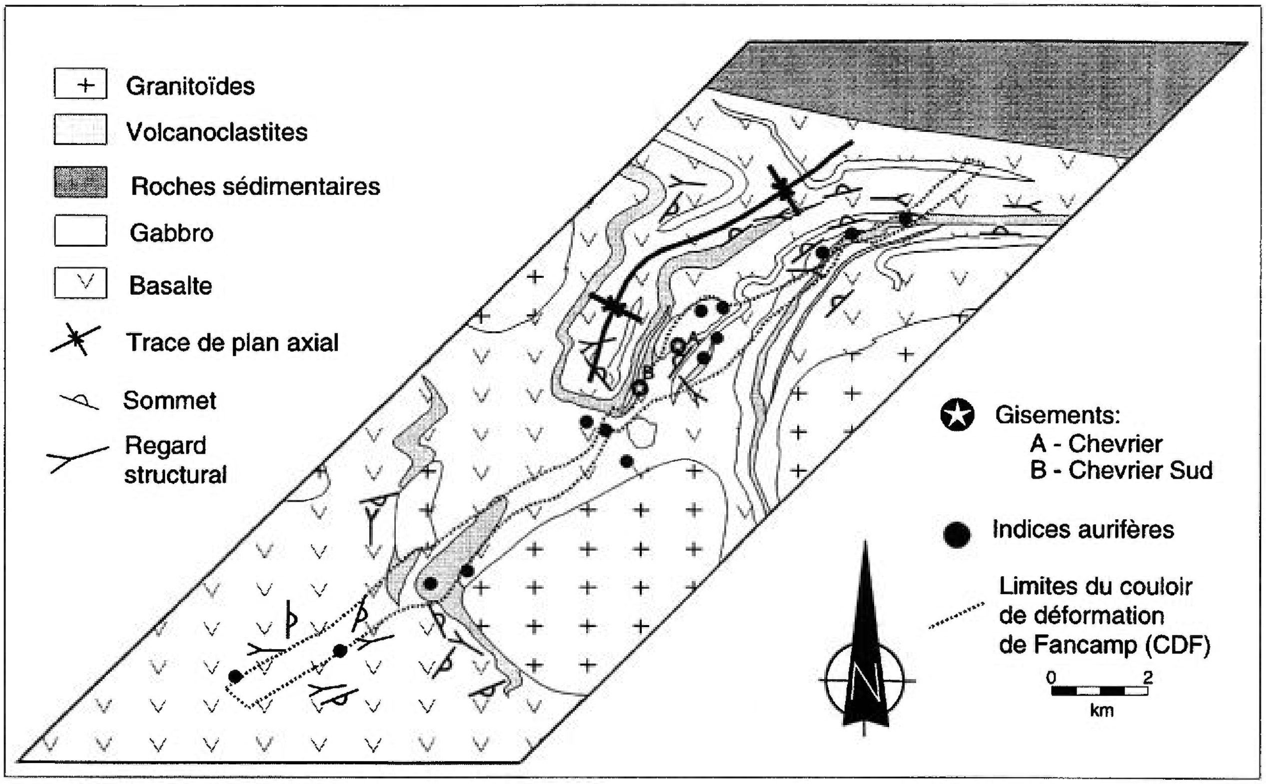


Figure D.25: Local geology of the Chevrier area (modified from Legault et al., 1997 et 1998).

interest in the Fancamp block. These claims are subject to royalties in the order of 3% NSR and some of them to an additional NPI of 7,5 to 10%.

HISTORY OF EXPLORATION WORK

Three periods of exploration work can be identified on the group of properties :

- 1950 to 1987 : Discovery of the East, West and Lipsett indices. Many companies, Teck, Campbell, Ressources Diane, Patino, and Serem carry out exploration work and evaluations in the most interesting sectors.
- 1988 to 1994 : Minnova (INMET) acquires or options a group of properties covering the major part of the Fancamp corridor and discovers the Chevrier Zone. A systematic exploration of the sector is undergone and brings the discovery of secondary indices as well as a calculation of resources in the Chevrier Zone, the EAST indices and the Chevrier South Zone.
- 1995 to 1998 : GéoNova options INMET's five blocks and carries out the ground geophysics as well as some exploration and definition drilling on the Chevrier and Chevrier South Zones. A preliminary inventory of resources is carried out in Autumn 1997 on the Chevrier Zone.

REGIONAL GEOLOGY

The property is located near the north-east extremity of the Abitibi sub-Province, in the mining district of Chibougamau. The lithologies found in this region can be subdivided into two groups : the first, the Roy Group, consists of two volcanic cycles evolving from mafic to felsic. Cycle 1 is composed of Obotagamau Formation basalts and felsic volcanites of the Waconichi Formation. Cycle 2 is composed of Gilman Formation basalts and volcanoclastics and Blondeau Formation lava. The mafic lava are often interdigited with comagmatic gabbro sills. The second group, that of the Opémisca, lies in discordance on the Roy Group and is composed of the sedimentary Stella Formation and the Haûy Formation intermediate volcanites.

Many intrusions, varying from ultramafic to felsic, made their way into the rock including that of the Lac Doré Complex, the Chibougamau intrusion, and the Cummings Complex.

Two primary phases of folds affect this rock., a precocious system forming folds open north-south and the primary system of symetrical and isoclinal east-west folds that form a large synclinorium oriented east-west.

Five large fracture or shear systems are observed.

These are the NE, NO, N-S, NNE systems, the fifth consisting of many directional faults.

The Chevrier property is located along the Fancamp NE fault, upon the west flank and near the nose of the Muscocho precocious synclinal (Figure D.25).

LOCAL GEOLOGY

The property is divided into three distinct zones based upon their structural characteristics (Figure D.25).

The western zone shows a N240° foliation and a stratigraphy varying from N030° to N010°. One essentially observes mafic lava interdigited with a unit of gross tuffs 300 to 500 metres thick and with gabbro veins commonly containing pyroxenic porphyres.

The central zone is located east of that described above and is characterised by a general NE orientation of the units and the schistosity. It corresponds to the Fancamp fault deformation corridor. The same units as in the west are found but these are dislocated by the deformation. In addition, a hectometric quartz felsic to porphyric intrusion is observed. It is this zone that contains most of the mineralisation.

The south zone is characterised by a generally east-west foliation and by a higher magnetic signature. It is little known and consists mostly of gabbros and basalts.

Four intrusions frame this sequence, the intrusions of La Dauversière, Verneuil and Muscocho as well as the Chico stock.

A number of auriferous indices are distributed along the central zone or Fancamp deformation corridor. They generally consist of altered sheared zones injected with quartz veins and auriferous pyrite. The indices found on the property are the following. : East, West. RO. Lipsett, Coyote, Des Tranchées, Chevrier Zone and Chevrier South Zone. A detailed description is given in Legault et al. (1995, 1997 and 1998). The Chevrier Zone is the most important identified indices to date.

THE CHEVRIER ZONE

The lithologies that form the host rock of this mineralisation are typical of the sector and can be described as follows: generally massive basalts with 20% cushioned or breached features form the base of the sequence. Many metric to decametric bands of intermediate tuffs with crystals and lapillis are observed in the bores. They show finely laminated minor block and chert features and are a privileged host of the ductile deformation. Thick gabbro sills invade these volcanites. They present three principal features ; a fine massive and homgenius feature similar to basalts, a macrogranular ophitic textured leucratic feature, and a pyroxenic porphyric feature, these features are rich in magnetite and in cumulations of plagioclases in some areas. A potassic felsic intrusion is found in contact with the tuffs and the gabbro. It presents a porphyric aspect with large eyes of rounded quartz. Its thickness is variable and surpasses a hundred metres in some areas. The preceding lithologies exhibit all the principal shistosity and crenellation. They are at varying degrees host of the mineralisation and the alterations that accompany them. The late felsic dykes, often porphyric, intersect all the other lithologies as well as the mineralisation and the principal schistosity. They are not crenallated but are often foliated and folded.

MINERALISATION

The Chevrier Zone is located inside the Fancamp deformation zone and possesses approximately the same orientation (N045°). It can be divided into three overlapping zones characterised by their degree of deformation and alteration :

1) A large envelope foliated by many tens of metres thickness and often surpassing a hundred metres (Figures D.25 and D.26). It intersects the host lithologies mineralisation and is intersected by the late dykes. The lithologies and the textures are recognisable although intersected by a penetrative fabric. The dominant alterations are carbonisation (calcite) and chlorisation. The pyrite is rare or absent and the gold value rarely surpasses 100ppb. The schistosity is associated to the D2 deformation, on a regional scale;

2) A sheared envelope contained in the earlier description, the thickness varying from 10 to 60 metres and forming inside it a anastomosed, coiled and folded pattern (Figure D.26). It is characterised by the near total obliteration of the primary textures by reason of a very intense schistosity and crenellation. Its beige-grey colour is due to an alteration heavy in sericite and in the appearance of iron carbons (ankerite). The content in pyrite and in veins of quartz-ankerite increase and generally reach 5%. The gold value rarely surpasses 2 g/tm and generally varies around 0,5 to 1,5 g/tm;

3) The heart of the shear zone (Figure D.26) is represented in a number of areas, according to a pattern that remains to be determined, by a mylonite. This is a greatly altered rock, of sericite,

containing a high percentage of sometimes metric quartz-ankerite veins of which the host rocks are washed with silica (concentrated in the veins) and enriched with pyrite (5 to 20%) and fuschite (2 to 5%). The structural fabric has lost its preferential orientation, the crenellation is omni-present, breaches and folds are common. The gold value systematically surpass 1 g/t and sometimes reach 20 g/t, the average being around 3 to 7 g/t. Visible gold is sometimes observed in the veins while they are generally poor in pyrite and of a low gold value.

The metallic paragenesis of the Chevrier Zone shows four phases (Magnan, 1990). The pyrite is most abundant in the high alteration zones situated at the heart of the shears and they show an

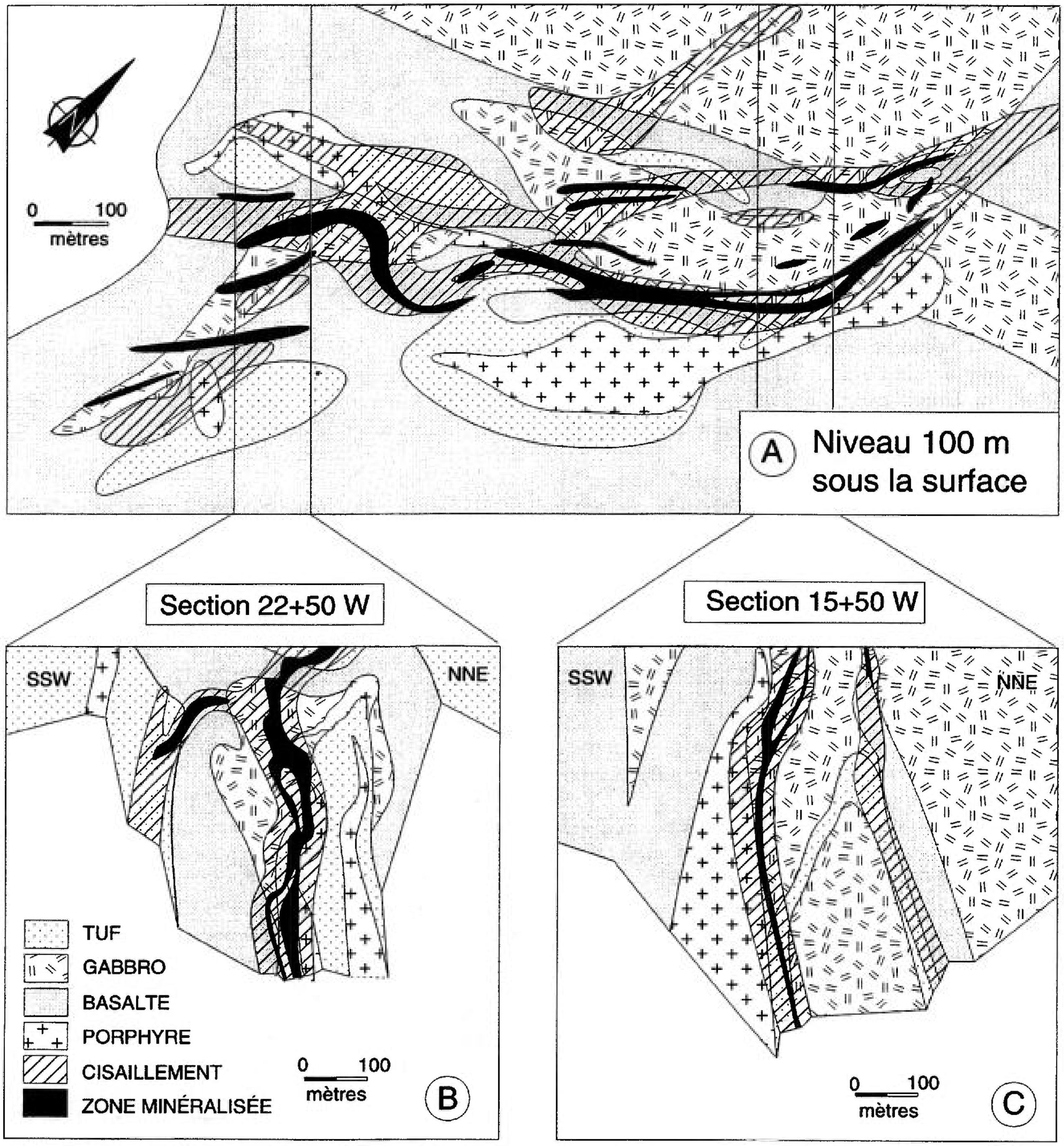


Figure D.26: (A) Level plan, 100 m below the surface, and simplified sections (B) 22+50 W and (C) 15+50W of the Chevrier Zone. The legend is the same for all figures.

association with the leucoxenes. It is in the form of granular aggregates oriented in the foliation and often fractured. The chalcopyrite is in the form of intergranular layers in pyrite fractures. The ilmenite is found only as inclusion in the leucoxenes. Native gold is in intergranular layers in pyrite fractures and rarely in the form of inclusions. It is thus posterior to the pyrite. Its spatial association with the chalcopyrite is more difficult to establish with certainty.

GEOMETRY AND RESOURCES

The Chevrier Zone presents a complex geometry (Figures D.26a, D.26b and D.26c), the perception of which has strongly influenced the evaluation of mining resources:

	thousands of tonnes	grade g/t Au	thick. m
- INMET, preliminary inventaire (1991)	8 306	2,28	-
- INMET, mine scenario (1991)	1 225	5,61	3,60
- GéoNova (1995)	1 060	6,36	2,87
- GéoNova (1997)	2 358	6,33	2,90

The first estimates considered a long subvertical tabular plan hosted in the shear zone, with a large envelope of low value including a zone of higher value (Coulombe, 1991). The addition of definition drilling permitted the consideration of many more or less tabular and subparallel mineralized zones, displaced by faults (Tremblay, 1997). A work in progress, based upon new definition drilling, aims to develop a computer generated three-dimensional model describing the Chevrier Zone (lithology, deformation, alteration, mineralization, etc ...), in order to have a more precise picture and to facilitate the evaluation of the mine resources in the context of this anastomosed geometry.

During the last drilling campaign (de Corta, 1997), a procedure of validation of laboratory analyses was carried out by inserting standards in the samples as well as by comparing the results of two laboratories and re-analysing the rejects by metallic sieve. Generally, the values obtained presented a variability of ± 10%. A calculation of the density of the mineralized zones gives 2,95 and the preliminary results of a metallurgical test indicate a recuperation of 97,8% by direct cyanidation during 48 hours for a 53 um size.

CONCLUSION

The Chevrier Zone and the showings that surround it represent an important mineral resource for the Chibougamau region. The geometric complexity of the mineralized zones require sophisticated analytical tools (computer-generated) to clearly delimit the economic sectors. The proximity of the principal deposit to the surface and the absence of metallurgical problems make it an interesting target. GéoNova intends to pursue its investigative efforts by additional definition drilling.

GEOLOGY OF THE JOE MANN MINE

Claude Dion
Service géologique du Nord-Ouest, Ministère des Ressources naturelles, 400, Boul. Lamaque, bur. 1.02, Val-d'Or, Québec, J9P 3L4;

and Germain Maltais,
Ressources Meston Inc., C.P. 400, Chibougamau, Québec, G8P 2X8

LOCATION

The Joe Mann mine (formerly known as the Chibex mine) is a gold-copper lode deposit situated at the eastern part of the Caopatina Segment, near the border of Rohault and La Dauversière townships (N.T.S. sheet 32G/08), approximately 64 km SW of the town of Chibougamau (Figure D.27). The mine is 19 km to the west along the unpaved road at km 191.5 along the Chibougamau - St-Félicien highway (Rte 167).

MINE GEOLOGY

The following description is drawn largely from a report by Dion and Guha (1994) that constitutes the first stage of a continuing gold metallogeny study of the eastern part of the

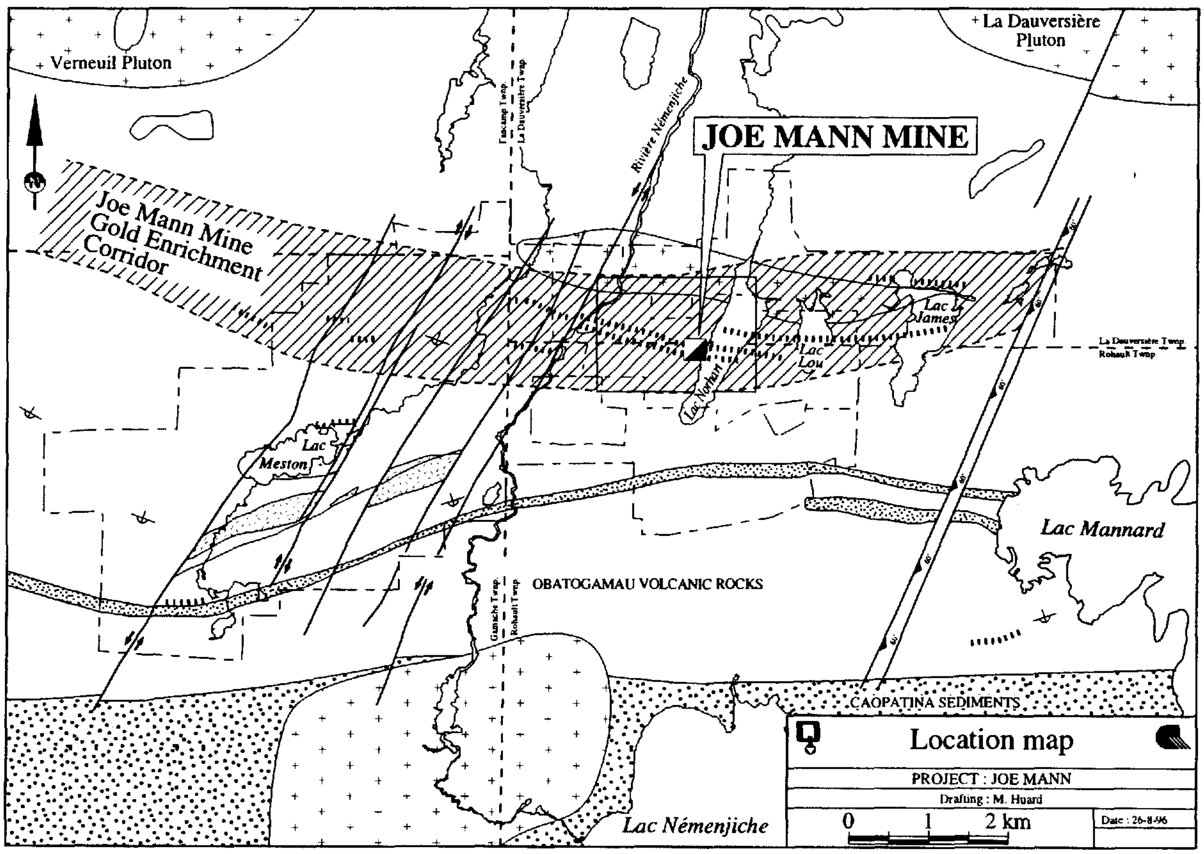


Figure D.27: Location of the Joe Mann Mine in the south-east part of the Chibougamau area.

1950-1955		Exploration by Chibougamau Explorer Ltd. and finding of the Main Zone during winter 1951. The company was renamed Anacon Mines Ltd. in 1956.
1956-1960		Sinking of a 450 ft shaft, deepened to 1250 ft then 1925 ft (actual depth). Production of 685 868 tons at 0,222 oz/t Au by Anacon Mines.
1960-1973		Standby.
1973-1975		Production of173 143 tons at 0,154 oz/t Au by Chibex ltd.
1975-1981		Geophysical survey conducted by SDBJ, dewatering of the mine by SDBJ and Meston Lake Resources inc.
1983		Campbell Resources takes the option.
1984-1987		Pumping of the mine, surface and underground exploration
1987		Campbell owns 100% interest and production start-up (april 1987).
1989 and 1992		Sinking of the no 2 shaft to 2650 ft.
1996		Deepening of the no 2 shaft to 2 to 3450 ft.

Table D.1: Discovery and exploitation history of the Joe Mann mine.

• Life production (Jan. 1st 1997):	3 712 044 tons (3,37 Mt) @ 0,243 oz /ton Au (8,33 g/t Au) or 901 703 oz Au (28 046 kg Au)
• Ore reserves (Jan. 1st 1997), all categories included	3 616 000 tons (3,28 Mt) @ 0,256 oz/ton Au (8,78 g/t Au) or 925 700 oz Au (28 792 kg Au)
• Total production and reserves	7 328 044 tons (6,65 Mt) @ 0,2498 oz/ton Au (8,54 g/t Au) or 1 827 723 oz Au (56 849 kg Au)

Table D.2: Production statistics and reserves of the Joe Mann mine (jan. 1st 1997).

Caopatina Segment as commissioned by the Ministère des Ressources naturelles du Québec. The mine was also the subject of an M. Sc. study by Wagner (1979).

From north to south and base to top, the mine stratigraphy consists of (Figures D.28 and D.29): (1) a gabbro sill; (2) deformed and altered basalt; (3) a thin horizon of rhyolite or felsic tuff; and (4) basalt. This sequence is typical of the upper part of the Obatogamau Formation. Strata are oriented E-W and dip sub-vertically, and are metamorphosed to the upper greenschist facies (epidote amphibolite facies). Exploitation history and production statistics are given in Tables D.1 and D.2.

Gold mineralization is hosted by decimetre-scale quartz-carbonate veins hosted within three E-W (N275°/85°) ductile-brittle shear zones which are sub-parallel to stratigraphy and to one another. These shear zones form part of the Opawica-Guercheville deformation zone, a major E-W deformation corridor cutting the mafic volcanic rocks of the Obatogamau Formation in the north part of the Caopatina Segment. The gabbro sill hosts the Main Zone, while the South Zone is found in the "rhyolite". The newly-discovered eastern (1987) and western extensions (1995) of the Main Zone possesses the same characteristics as the Main zone. There is some other small mineralized structures (North, E.I. and South-South) with limited vertical and horizontal extensions. The thickness of the shears varies from 8 to 20 m in the gabbro, and from 5 to 6 m in the rhyolite. Gold-bearing quartz-carbonate veins are generally sub-parallel to the shears, and occupy the central zones of these structures. The dominant schistosity direction is parallel to the envelope of the shears at approximately N095°, but the steep dip to the south of the schistosity (80 to 85°) is at an angle with the walls of the shear zone envelopes, which dip to the north. This structural relationship indicates that an inverse vertical movement, i.e., a thrusting from north to south, took place. Steeply-plunging (80-85°) mineral or stretching lineations also argue in favor of a vertical movement with a small lateral component. The stretching lineation is particularly well-defined in the South Zone. The elongation of

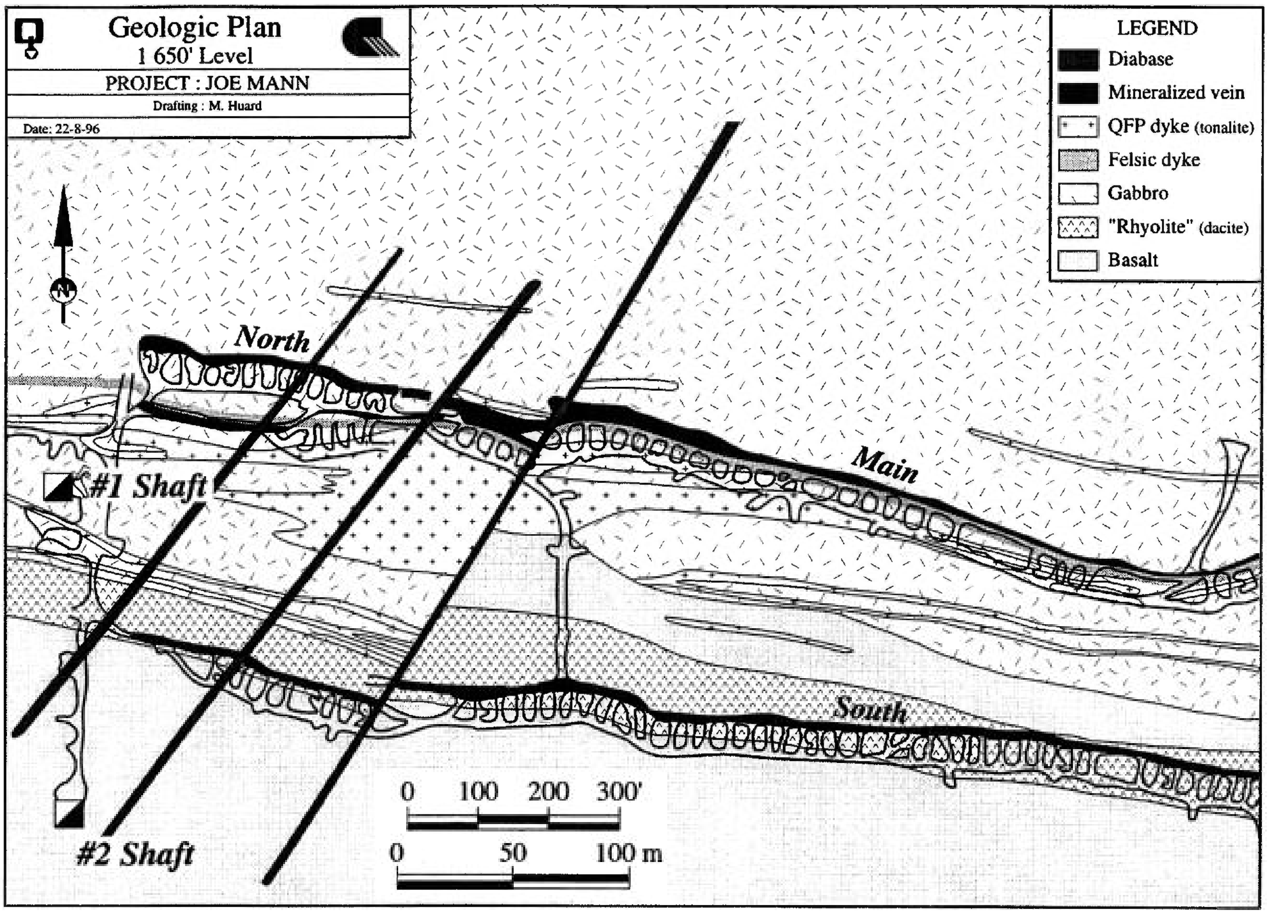


Figure D.28: Simplified geologic plan of the Joe Mann mine, 1 650 ft level.

the mineralized lens in the Main Zone visible on the longitudinal section (Figure D.30) is parallel to this lineation.

Other evidences of inverse movement are given by Z-shaped drag folds with sub-horizontal hinge seen in the shear zones. These centimeter- to meter-scale folds affect the schistosity, quartz veins and felsic dykes. Other microscopic-scale cinematic indicators (C-S fabrics, asymetric porphyroblasts or shear bands) confirm these observations.

The mineralized zones are displaced by late, east- or west-dipping NE faults (Figure D.28). These faults moved in many directions, although the apparent movement appears sinistral. Proterozoic diabase dykes 1 to 3 m thick have been injected in some east-dipping NE faults. A NNW-SSE mineralized system is also observed in the western portion of the North Zone.

The periphery of shear zones that affect the gabbro (Main and North zones) is composed of more or less schistose rock exhibiting retrograde chlorite-carbonate alteration. As the mineralized zones are approached, deformation and alteration become progressively more intense, and the gabbro is transformed into a biotite-sulphide ± Fe carbonate ± plagioclase (andesine) schist, or a chlorite-Fe-carbonate-plagioclase-sericite-sulphide schist. Gold-bearing quartz veins occur at the centre of the shear zones within altered gabbro. Hydrothermal alteration in the highly-sheared zone is characterized by K, Rb, Ba, S, Cu and Au enrichment, and Ca and Mg depletion.

Veins are associated with two types of felsic dykes: (1) weakly-deformed, quartz-feldspar porphyry dykes; and (2) highly-deformed, aphyric dykes. These dykes are often in direct contact with the veins and are sub-parallel to them. Zircons extracted from an aphyric dyke yied an U-Pb age of 2717 +5/-2 Ma (Dion et al., 1995), identical within error to the La Dauversière Pluton, an synvolcanic intrusion located a few kilometre north of the mine. No zircon suitable to radiometric datation was found in porphyric dykes but we assume that their emplacement is synchronous (2690-2699 Ma; Dion et al. 1995) to the syntectonic Lac Meston intrusion located west of the mine (Figure D.27). These relationships and the fact that the Lac Meston intrusion is cut by auriferous quartz-tourmaline

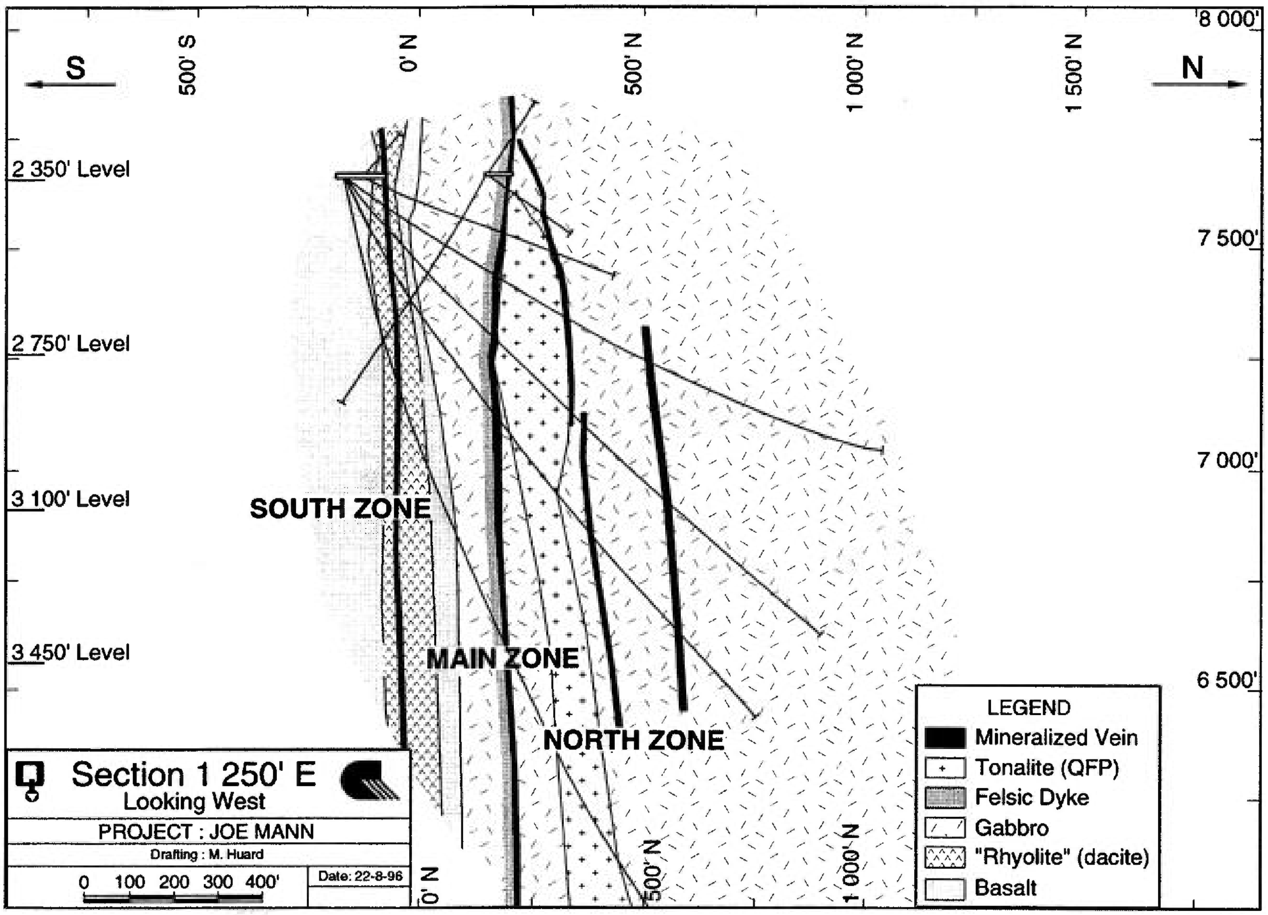


Figure D.29: Schematic view of the 1250 ft East section of the Joe Mann mine.

veins suggest that the gold mineralization at Joe Mann is posterior to the emplacement of syntectonic porphyric dykes.

The South Zone (Figure D.28) occurs in a shear which cuts the "rhyolite" (actually of dacitic composition) unit below the 1050 feet (320 m) level. The most highly-deformed zone exhibits an intense sericite-sulphide hydrothermal alteration. This alteration corresponds to Si, K, S, Cu, As and Au enrichment, and Mg, Ca, Na and CO_2 depletion. The veins, of irregular form, are intensely boudinaged. The South Zone is the only locality where arsenopyrite occurs in abundance.

The mineralized veins of the Joe Mann mine are hosted by highly altered and sheared rock mineralized with pyrite, pyrrhotite and chalcopyrite disposed in lenticles and veinlets parallel to schistosity. The veins are dominated by vitreous white quartz, with minor plagioclase and Fe-carbonate. They are intensely brecciated and often boudinaged and folded. Furthermore, these veins are characterized by their laminated or banded structure, consisting of alternating ribbons of quartz and mineralized wall rock. Strictly speaking, the major part of vein sulphide mineralization is contained in these wall-rock fragments. Mineralization is composed of native gold associated with a variable quantity of chalcopyrite, pyrrhotite and pyrite, with some arsenopyrite in the South Zone.

STOP DESCRIPTION

Part 1 : mine visit

It is not possible to present at this time a precise itinerary for the underground visit at Joe Mann. Points of interest of the Main Zone are:

- E-W shear zone with schistosity plane and sub-vertical stretching lineation;
- Quartz-carbonate veins associated with 2 types of felsic dykes;
- Sheared gabbro grading to biotite-sulphide schist near quartz veins;
- Cp-py-po mineralization, associated with visible gold;
- Late NNE to NE faults cutting the mineralization.

Points of interest of the South Zone are:

- The felsic host rock;
- E-W shear zone with schistosity plane and sub-vertical stretching lineation;
- Relatively thin and deformed (compared to the Main Zone) quartz-carbonate veins;
- Sericite alteration affecting the felsic tuff (rhyolite) near veins;
- Highly-deformed contact zone between felsic tuff and basalt;
- Locally-present massive arsenopyrite.

Part 2 : Trench to the west of the no 1 headframe (optional)

This N-S oriented trench exposes the Main and North zones (Figure D.31). The South Zone outcrops on the flank of a ridge on the opposite side of the road. Various wall rocks and mineralized zones are observable.

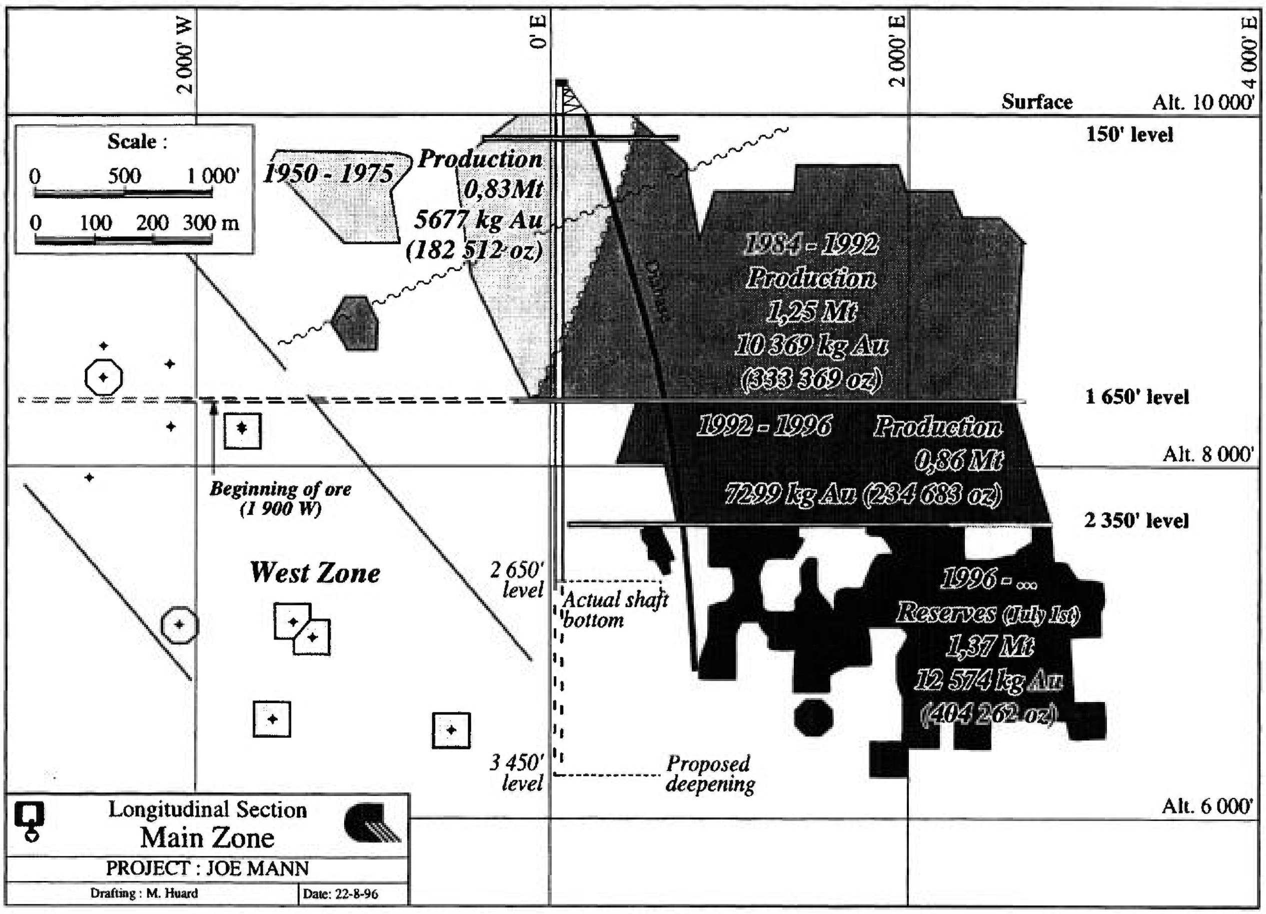


Figure D.30: Longitudinal section of the Main Zone, Joe Mann mine, with the production statistics for the different ore lens exploited during the mine history.

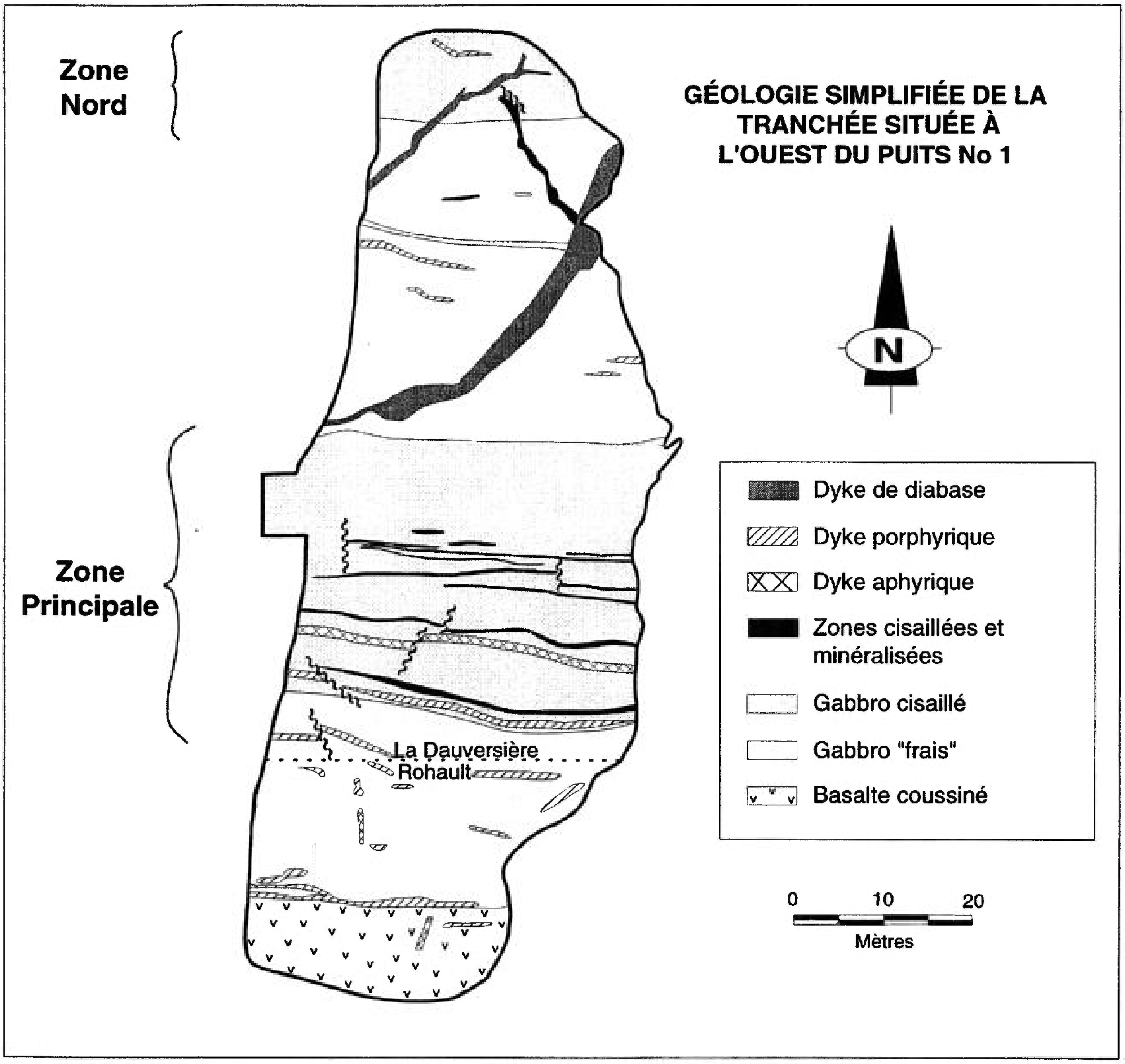


Figure D.31: Simplified geologic plan of the trench located 120 m west of no. 1 headframe.

THE JOE MANN AURIFEROUS DEFORMATION ZONE

Laury Schmitt
SOQUEM, 462 3e rue, Chibougamau, Québec, G8P 1N7
Germain Maltais
Ressources Meston Inc., C.P. 400, Chiougamau, Québec, G8P 2X8.

INTRODUCTION

The Joe Mann mine (formerly Chibex) is a load gold deposit located approximately 48 km south of Chibougamau (Figure D.32). As of January 1, 1998, the cumulative production total was 816 319 oz Au (3,38 Mtm at 8,33 g/t Au) and the reserves were estimated at 848 397 oz Au (3,03 Mtm at 8,71 g/t Au) for a resource total of 6 414 000 tm grading 8,51 g/t. The mine is located in the eastern part of the Caopatina-Desmaraisville archean volcano-sedimentary segment, more precisely inside the Guercheville deformation zone. The lithologies present on the property belong to the Obatogamau formation of the Roy Group.

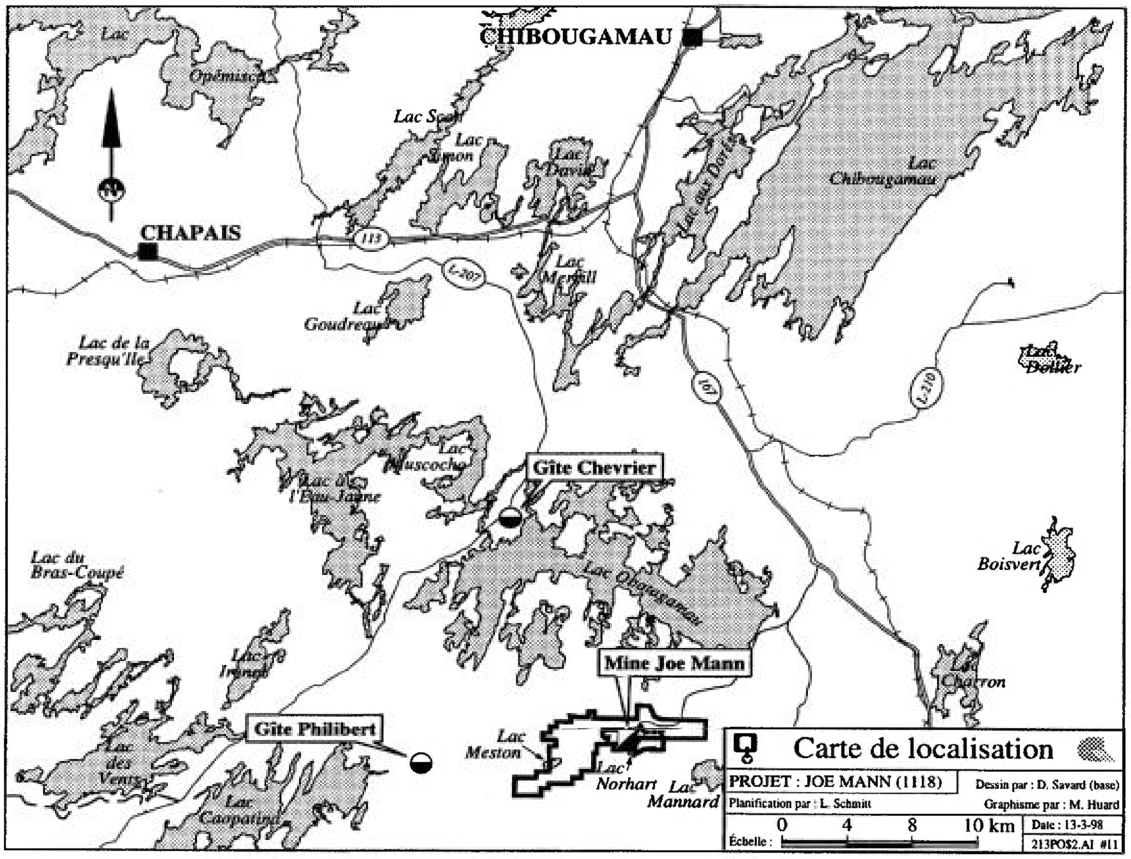


Figure D.32: Localisation de la mine Joe Mann et du gîte Chevrier.

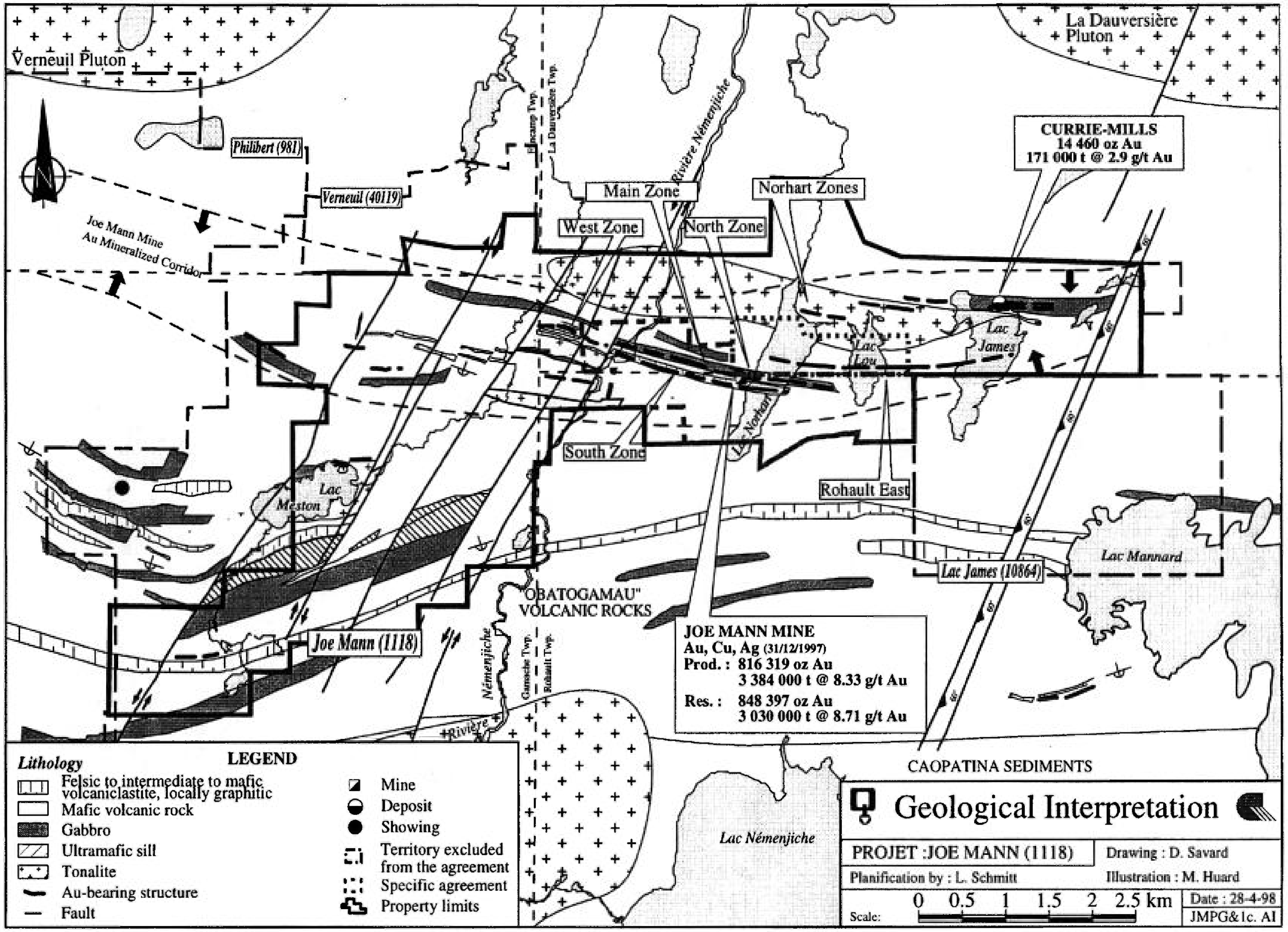


Figure D.33: Simplified geology of the area surrounding the Joe Mann mine.

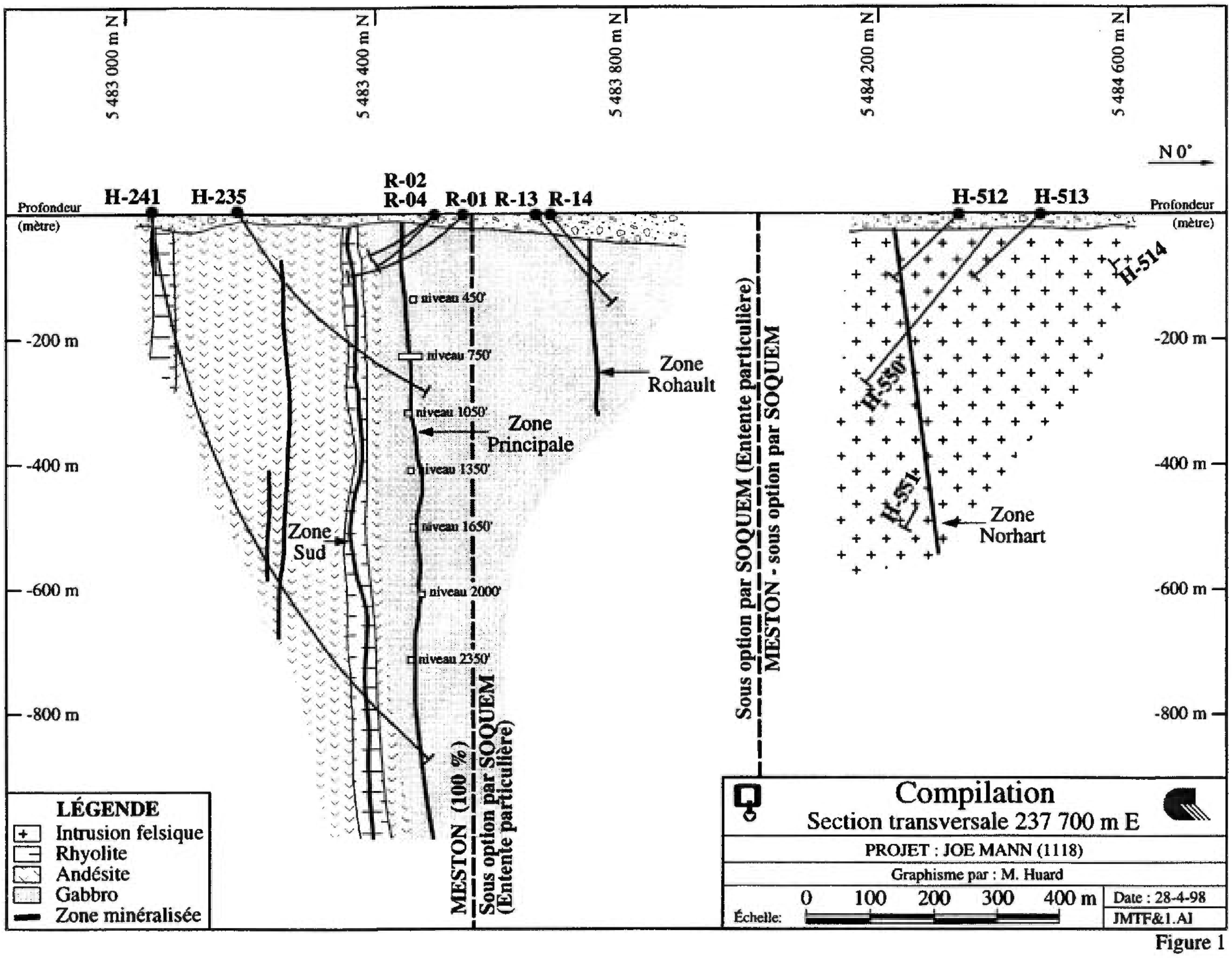


Figure D.34: Simplified geology, section 237 700 m East, Joe Mann mine.

LOCAL GEOLOGY

The rocks that forms the platform of the property are composed primarily of basalt flows and gabbro sills (Figure D.33). Of a more secondary nature, many horizons of volcaniclastic mafic to felsic sediments are found at the point of contact with lava flow. The finely layered horizons are often silicified and qualified as acid or felsic tuffs. They are also often sheared, in an area with the propensity to develop faults. Finally, many metric to decametric felsic dykes crosscut these units. Their contact with the host rock is generally sheared and sulfurised (pyrite and pyrrhotite). Two felsic intrusions, La Dauversière and Verneuil, are found respectively to the north-east and north-west of the property.

From a structural point of view, the property is located on the south flank of the overfold La Dauversière anticlinal. The regional schistosity (S2) is considered to be east-west, with a subvertical dip. In addition, many intense and decametric NE to NNE proterozoic and/or grenvillian fault structures affect the lithologies.

ECONOMIC GEOLOGY

The mineralised zones of the Joe Mann mine are within a stratigraphic package composed of gabbro sills, sheared basalts, and intermediate to felsic tuffs intruded by various felsic intrusions. The layers are oriented east-west with subvertical dips (Figure D.34). Mineralized zones are subparallel with the stratigraphy, with up to a hundred metres of separation between them. The mineralized zones (Principal, South, North) are lenses and veins of quartz, carbonates, and plagioclase (see Dion and Maltais, this volume). The thickness varies between five centimetres to 1,5 metres, averaging 0,75 metres. A recent compilation of available data demonstrates that gold is closely linked with sulfides (Py-Cp-Po-Asp-Sp) and more particularly with chalcopyrite.

The exploration work accomplished in the last few years has increased the economic potential of

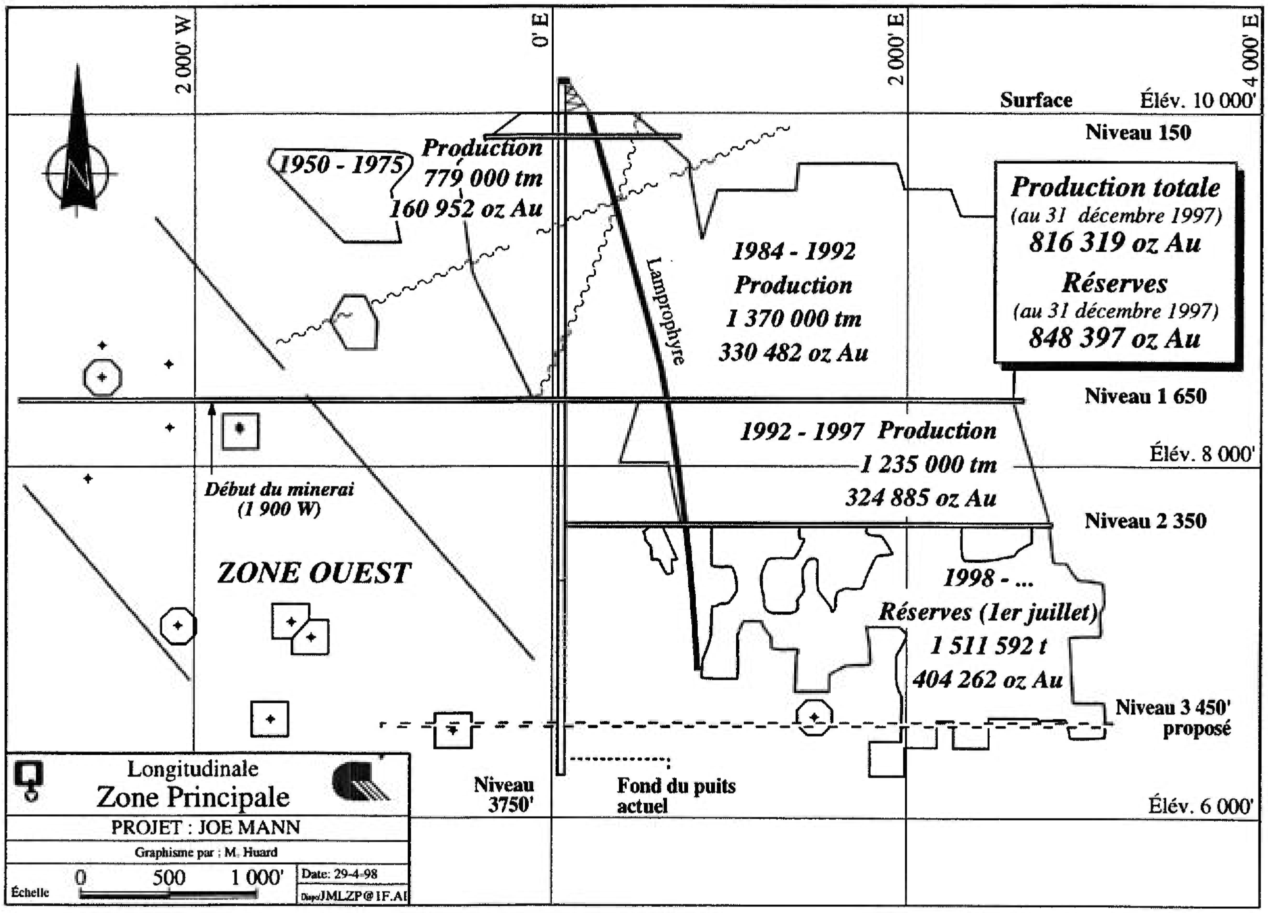


Figure D.35: Longitudinal section of the Main Zone, Joe Mann mine.

the sector. By identifying the western extension of the Principal zone, it is now known over a distance of three kilometres. The mined out and/or economic stopes (including the west zone of the mine) represent a length of 1 980 metres (6 500 feet). The reserves are identified up to a depth of 1 140 metres (3 750 feet) and the structure is still open in all directions (Figure D.35). The preliminary data indicate an enrichment of the in-depth auriferous value. By identifying Rohault zone's eastern extension, the gold bearing structure is known over more than two kilometres. The compilation of data concerning the Currie-Mills zone (171 000 tm at 2,9 g/t Au) indicates that it is still open in depth and to the east.

CONCLUSION

In conclusion, the proximity of the Philibert (1,4 Mtm at 5,3 g/t) and Chevrier (3,7 Mtm at 5,1 g/t Au) deposits combined with the Joe Mann mine (total resources of 6,4 Mtm at 8,52 g/t Au) demonstrates the potential of the Guercheville and Fancamp deformation zones to find there other major deposits. The figures on the following pages clearly show the potential of the Joe Mann mine sector.

THE TROILUS Cu-Au DEPOSIT

Bernard Boily
Inmet Mining Corporation, Exploration Division, 1300 boul. Saguenay , Suite 200
Rouyn-Noranda, Québec, J9X 7C3

modified from Boily (1995)

HISTORY

The Frotet-Troilus area is located 125 km north of the town of Chibougamau, Quebec (Figure D.36). Exploration in the area began in 1958 when boulders mineralized in Cu and Ni were found. No nickel showing was found but several Cu and Zn occurrences were discovered between 1958 and 1967. From 1971 to 1976, most exploration work had been directed towards base metals.

Kerr Addison acquired a large block of claims in 1985 following a mapping program by the Quebec Ministry of Natural Resources, which indicated good potential for gold and base metal mineralization (Simard and Roy, 1984; Simard, 1985). More geochemical, geophysical and geological work was carried out by Kerr Addison in 1985 and 1986 and drilling began in 1986. In 1987, more claims were added to the property and a large gold float dispersion train was found by prospecting. During the same year, hole KN-12, collared immediately up-ice from a glacial float dispersion train, intersected significant Au-Cu mineralization over several metric intervals which turned out to be part of the 87 Zone. In 1988, initial drill testing of a

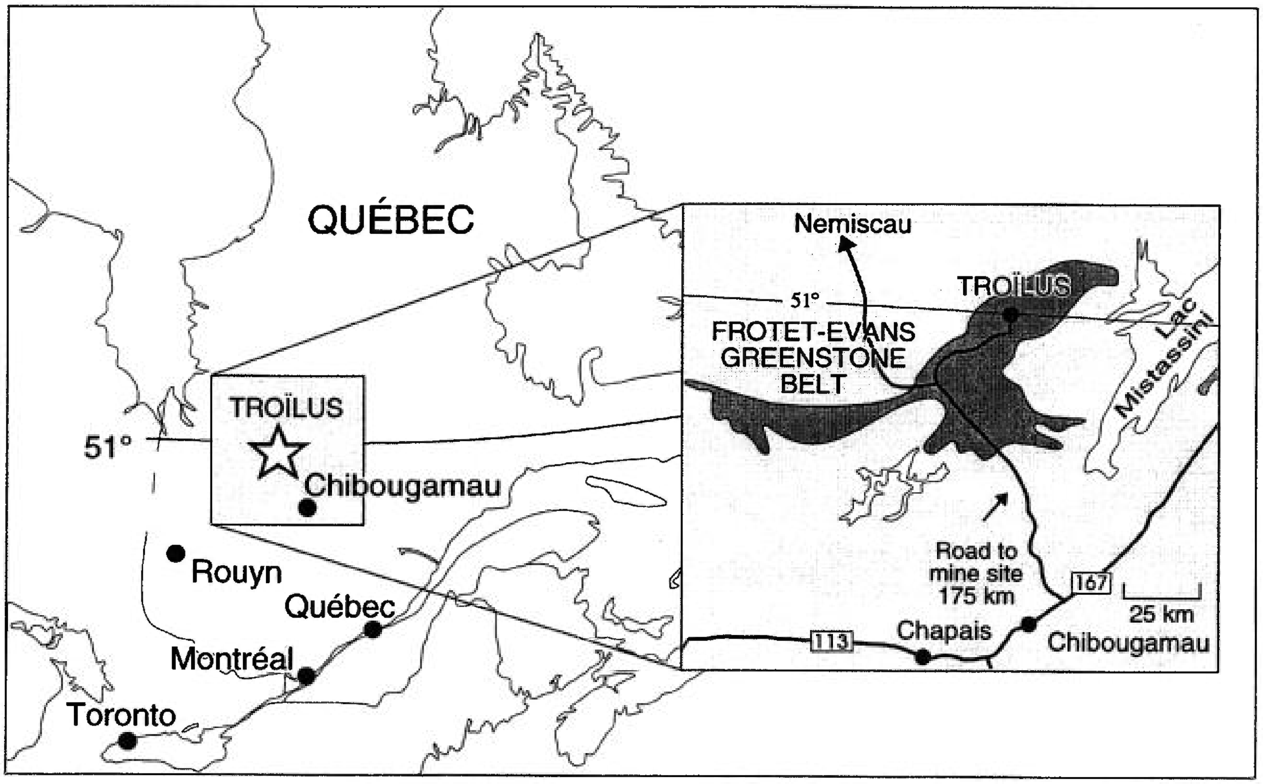


Figure D.36: Location of the Troilus deposit in northern Québec.

nearby weak HEM anomaly intersected anomalous Au-Cu mineralization in what was confirmed to be the J4 Zone in 1991.

Between 1989 and 1998, several drilling programs (565 holes/84 600 metres) were carried out. In 1993, definition drilling was completed on the 87 and J4 Zones, which together form the Troilus deposit.

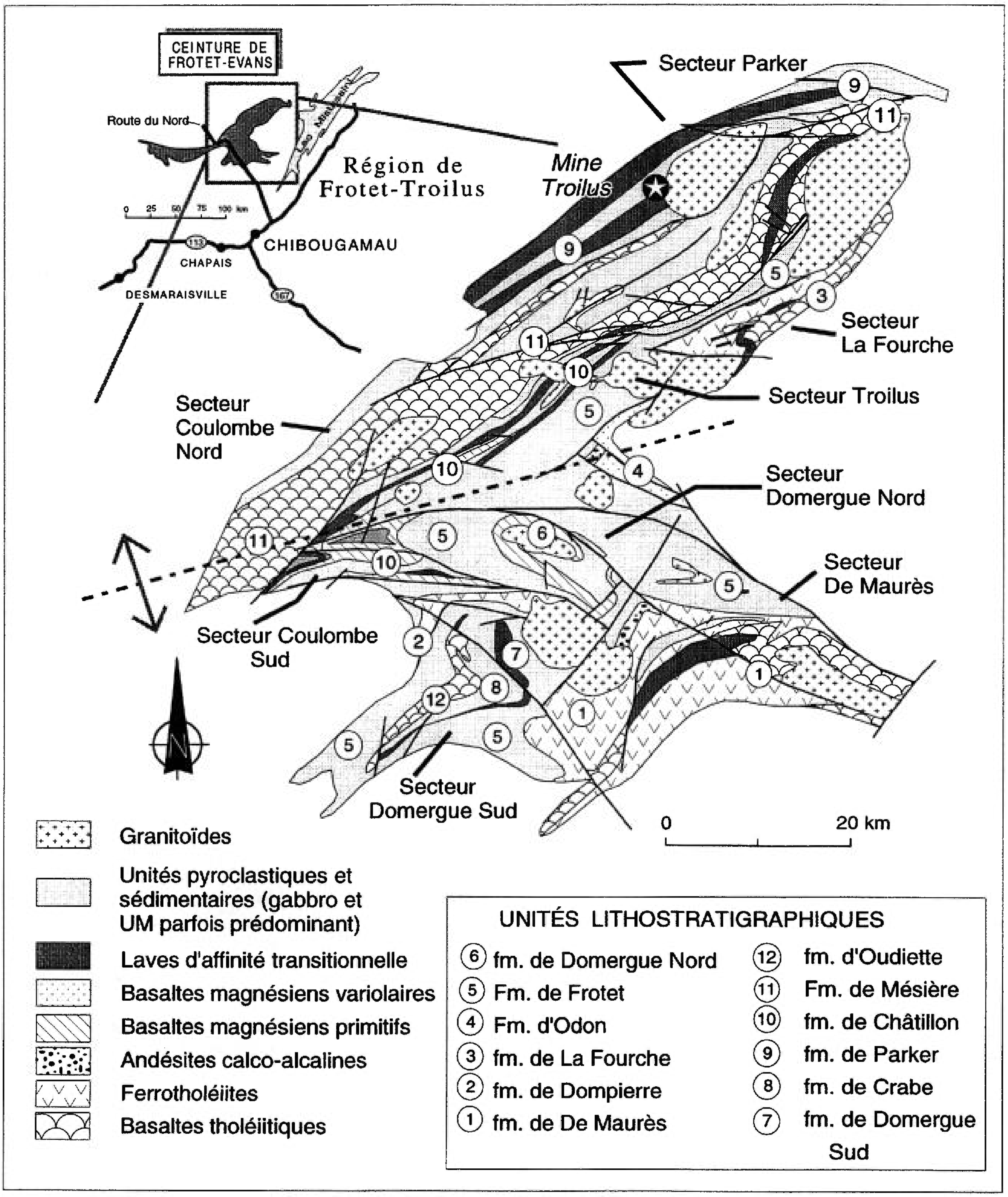


Figure D.37: Generalized geologic map of the Frotet-Troïlus area (Gosselin, 1995, 1996, and this volume).

A porphyry-type model was first proposed in 1989 and subsequent works seemed to confirm the presence of this style of mineralization (Fraser, 1990a, 1990b, 1993; Magnan, 1993a).

REGIONAL GEOLOGY

The eastern segment of the Frotet-Evans Archean greenstone belt is underlain by a supracrustal sequence of submarine mafic volcanics with intercalated cogenetic mafic intrusions (Figures D.37; see Simard, 1988; Gosselin, 1990, 1995, 1996, and this volume). Felsic volcanic and pyroclastic rocks and minor epiclastic sedimentary rocks as well as ultramafic horizons are also found. These supracrustal rocks are intruded by granitoid plutons and dykes which probably range from pre-tectonic to post-tectonic in age.

The rocks are variably deformed and are affected by a strong regional foliation. Subhorizontal mesoscopic to megascopic folds are common, affecting both regional foliation and primary layering.

The metamorphic grade in the North Troilus area ranges from greenschist to lower amphibolite facies, the higher grades appearing around the borders of certain intrusions and towards the margins of the greenstone belt.

The association of molybdenite, gold and base metal mineralization with granitoid plutons is striking. The three largest base metal VMS (Figure 3.4) occurrences are the Lessard deposit (1,46 Mt @ 1,73% Cu and 2,96% Zn), the Tortigny deposit (0,53 Mt @ 3,59% Cu, 6,49% Zn, 85,2 g/t Ag, 0,43 g/t Au and 0,27%Pb) and the Clairy deposit (0,35Mt @ 7,84% Zn, 1,35% Cu and 22,3 g/t Ag). The largest gold occurrence is the Troilus deposit.

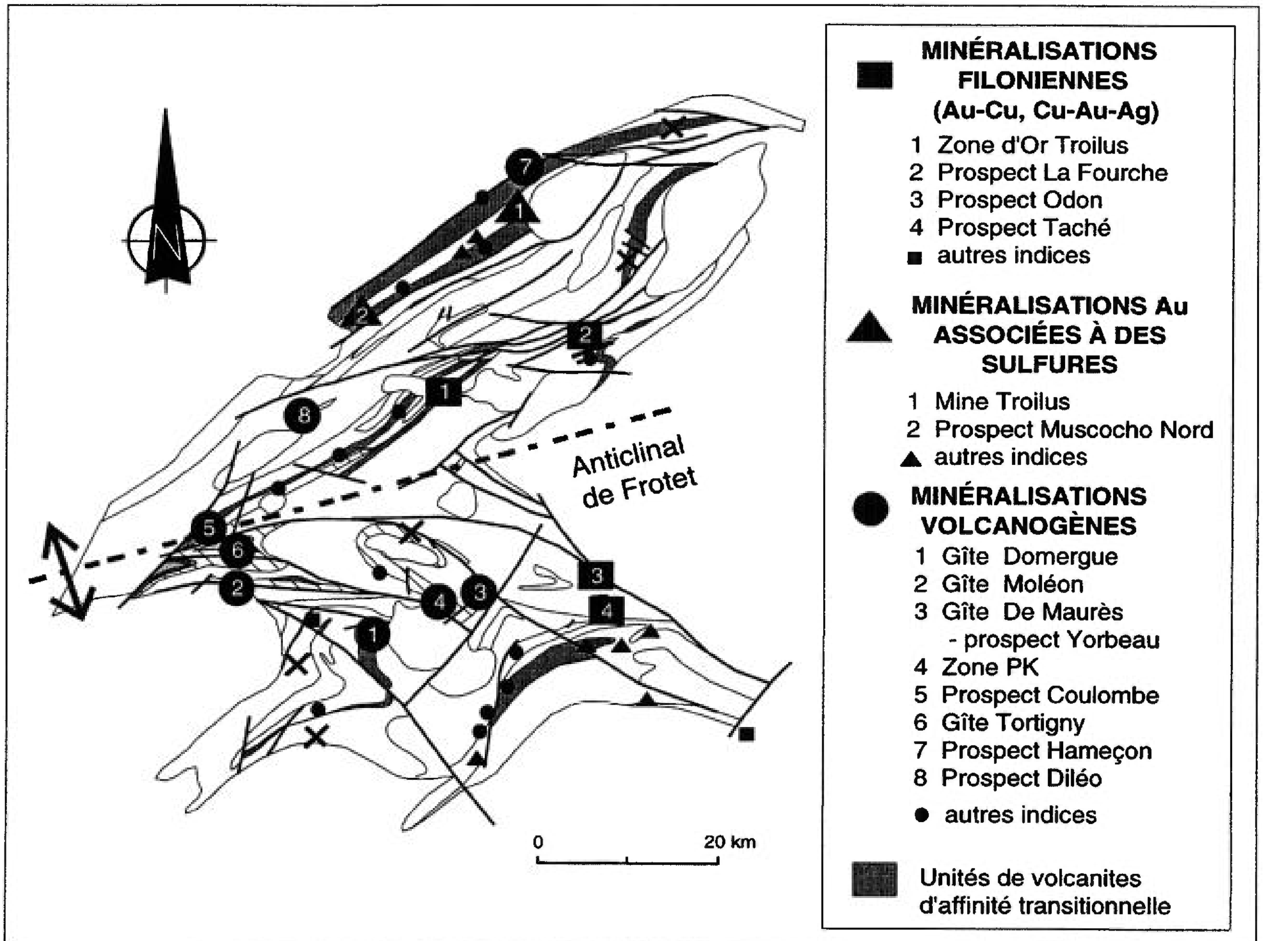


Figure D.38: Location of the main VMS and gold deposits and showings and Mo occurrences in the Troïlus-Frotet greenstone belt (modified from Gosselin 1995, 1996, and this volume; and Inmet Mining Corp. exploration works).

GEOLOGY AND ALTERATION OF THE TROILUS DEPOSIT

Both the 87 and J4 Zones are hosted within an intermediate porphyritic volcanic sequence, which encloses elongated zones of hydrothermal breccia and coeval feldspar- and quartz-porphyritic dyke/sill swarms (Figures D.39, D.40A and D.40B). Breccia, porphyries and mineralization show a moderate (60-65°) northwesterly dip.

Ore controls in the 87 Zone (Figure D.40A) can be summarized as follow:

i) lithological contacts, particularly the dyke-breccia contacts;
ii) felsic dykes, which commonly form ore;
iii) breccia, when enclosed by major felsic dykes;
iv) inclusions of dacitic tuff within important dykes;
v) inclusions of minor felsic dykes in breccia.

The central part of the mineralized zone coincides with an "in situ" hydrothermal breccia which exhibits "pseudo-fragments" of porphyritic intermediate volcanic rocks in a strongly foliated and altered (biotite-amphibole) matrix. The brecciated texture of the rock comes from the development of polygonal fracturing which channelled hydrothermal solutions. The white colored albitized "pseudo-fragments" in the breccia represent the less altered portion of the rock.

The breccia is injected by porphyritic felsic dykes swarms, by few mafic dykes and by several deformed small chalcopyrite-bearing quartz veins. Polygonal fractures are abundant in the felsic dykes and are interpreted to have formed during the cooling process of the dykes (columnar jointing). These fractures are also mineralized and Au-bearing thus suggesting that the dykes and the mineralization are contemporaneous. One of the felsic dykes has yielded a radiometric age of 2786 ± 6 Ma, based on U-Pb dating of zircon (Pilote et al., 1997, 1998c). All these observations suggest that the formation of the Troilus orebody is pre-metamorphic.

The main alteration facies (Figure D.41) defined during the course of core-logging and geological observations made in the pit include, from earliest to latest:

i) hornfels (very fine biotite);
ii) potassic (biotite - actinolite - K-feldspar);
iii) inner Propylitic (actinolite - albite - epidote);
iv) outer Propylitic (albite - epidote - calcite);
v) phyllic (sericite - quartz)

The formation of the hydrothermal breccias and the intrusion of the dyke swarms are contemporaneous. Both are deformed and it is interpreted that the effects of tectonism must have ceased during the formation of the potassic assemblage. Potassic, propylitic and phyllic alteration facies are spatially associated with ore.

MINERALIZATION

Chalcopyrite and pyrrhotite, with subordinate pyrite, are the main sulphides encountered in the central part of the deposit. The sulphides are most abundant in the breccia matrix. This forms a definite copper-gold enrichment zone in the orebody (Figures D.42A and D.42B), which coincides approximately with the potassic alteration facies. However, the felsic dykes intruding the breccia contains almost exclusively pyrite. They usually form ore but are poor in copper.

Outwards from this copper/gold-rich zone, chalcopyrite becomes subordinate and pyrite, with lesser pyrrhotite, predominates and is particularly abundant over the northern portion of the 87 Zone. This zone overlaps the transition between the potassic and the inner propylitic alteration facies. This area is often characterized by sodic, rather than potassic, alteration.

STRUCTURE / FOLIATION

Three main fracture orientations were observed in the starter pit. The first set, oriented at 215° and dipping at 63°, is sub-parallel to the regional foliation and represents the major fracture system in the pit area. The other two sets (035°/39° and 320°/85°) cuts the regional foliation almost at right angle. The combined effect of these fractures has induced local instability in the pit and is directly responsible for the blocky nature of the walls. Faulting is observed in several areas of the pit but their attitude has not been well documented so far.

Regional deformation has strongly flattened and stretched the geological assemblages and the alteration pattern. In the pit area, the effects of this deformation can be observed as follow: strongly elongated felsic dykes (all parallel to the regional foliation); heavy stretching of the hydrothermal

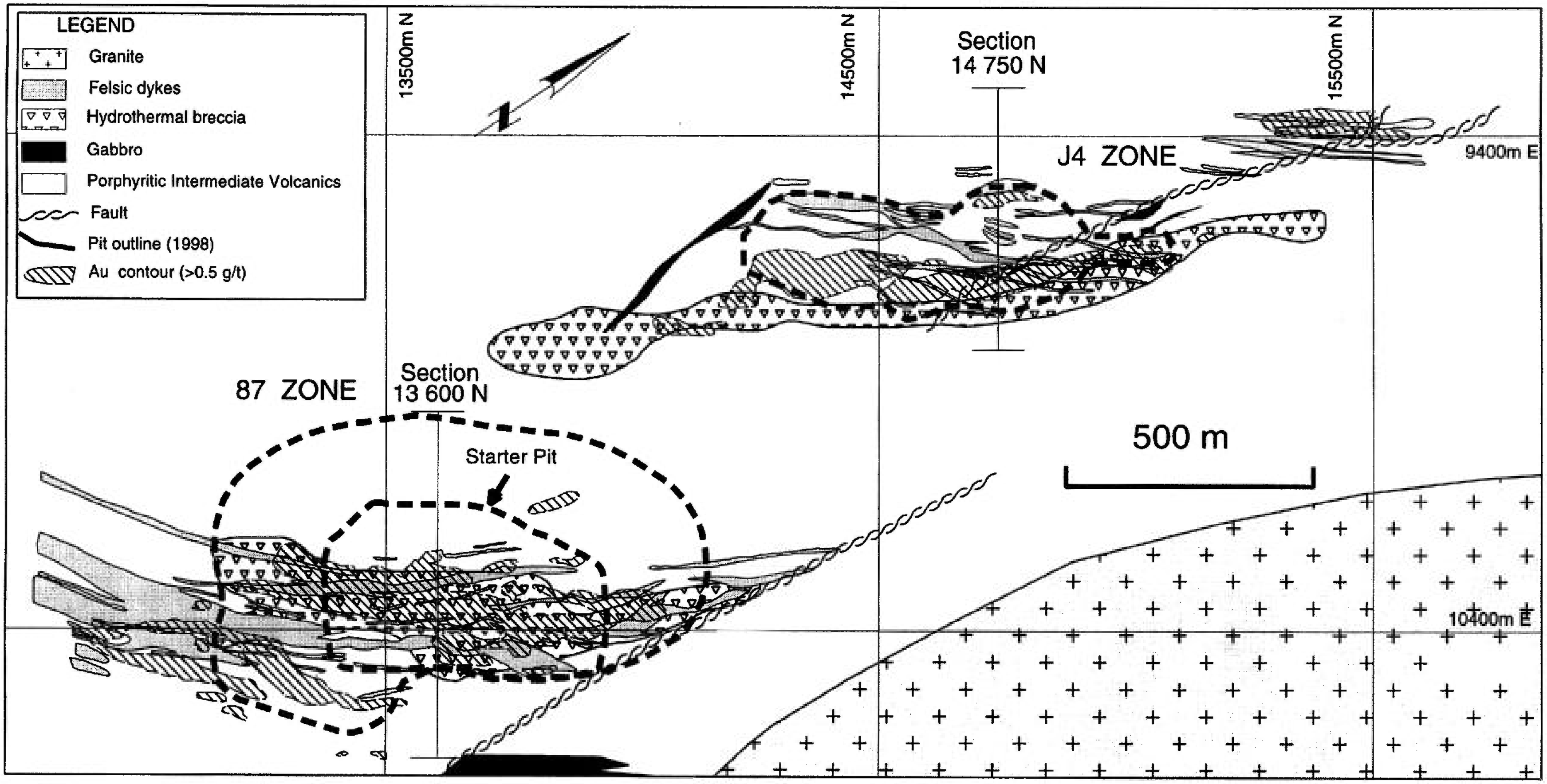


Figure D.39: Surface geological plan of the 87 and J4 Zones of the Troilus orebody.

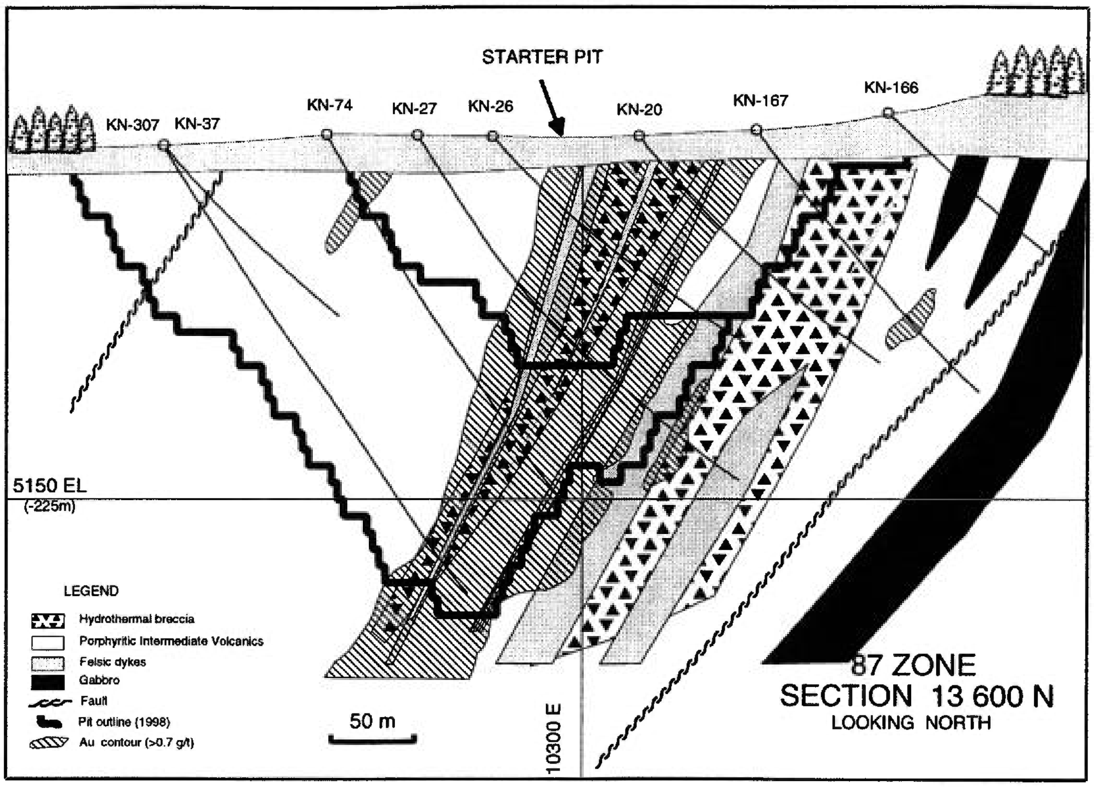


Figure D.40A: Geologic cross section 13 600 N, 87 Zone.

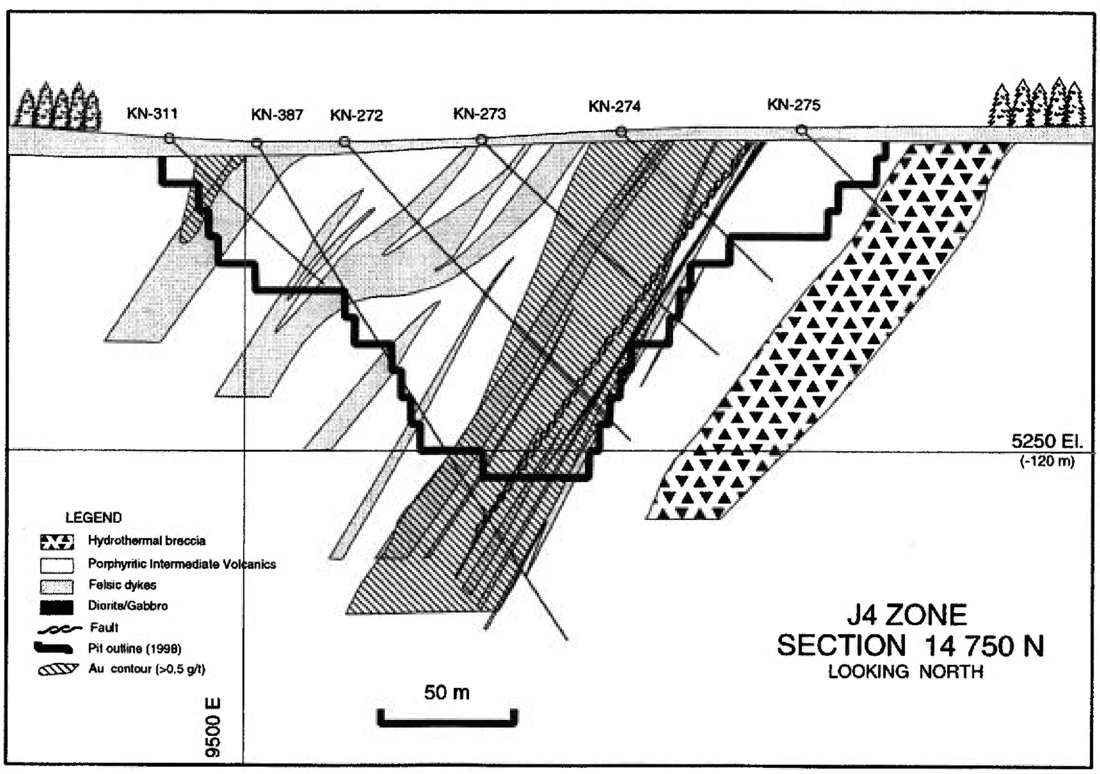


Figure D.40B: Geologic cross section 14 750 N, J4 Zone.

breccia; strongly "boudinaged" late mafic dykes and quartz veins.

GENETIC MODEL

Since Lowell and Guilbert's classic paper in 1970, the wide range of characteristics for porphyry-type deposits has been extensively documented. Several subclasses, themselves highly variable, have been defined. Based on the present data, the Troilus deposit appears to best fit a Volcanic Porphyry model as described by Sutherland Brown in 1976 (Figure 3.9). The geological similarities between the Troilus deposit and the Volcanic type porphyry deposits are: the spatial association of the ore zones with mineralized felsic porphyry dyke swarms, the hydrothermal breccias, the intense fracturing of the wall rocks, the typical zoning in mineralization and alteration, the large tonnage, the widespread and continuous Cu-Au mineralization (Fraser, 1993).

ECONOMICS

Cumulative production to January 1st, 1998 amounted to 4,0 Mt grading 1,40 g/t Au, 0,16% Cu and 1,33 g/t Ag. Geological resources of 84,3 Mt grading 1,3 g/t Au were calculated for the Troilus deposit, using a cut-off grade of 0,7 g/t Au and down to a depth of approximately 270 metres for the 87 Zone and 120 metres for the J4 Zone. Drilling done at the -500 m level indicated that the ore zone is still present at depth, with good grades. Therefore, the Troilus deposit contains at least 100 Mt, using the same cut-off grade.

The pre-production ore reserves as calculated by Inmet Mining Corp. are as follow:

ZONE	TONNAGE	Au (g/t)	Cu (%)	Ag (g/t)
87	43 040 000	1,25	0,13	1,41
J4	6 470 000	1,19	0,06	1,06
TOTAL	49 510 000	1,24	0,12	1,36

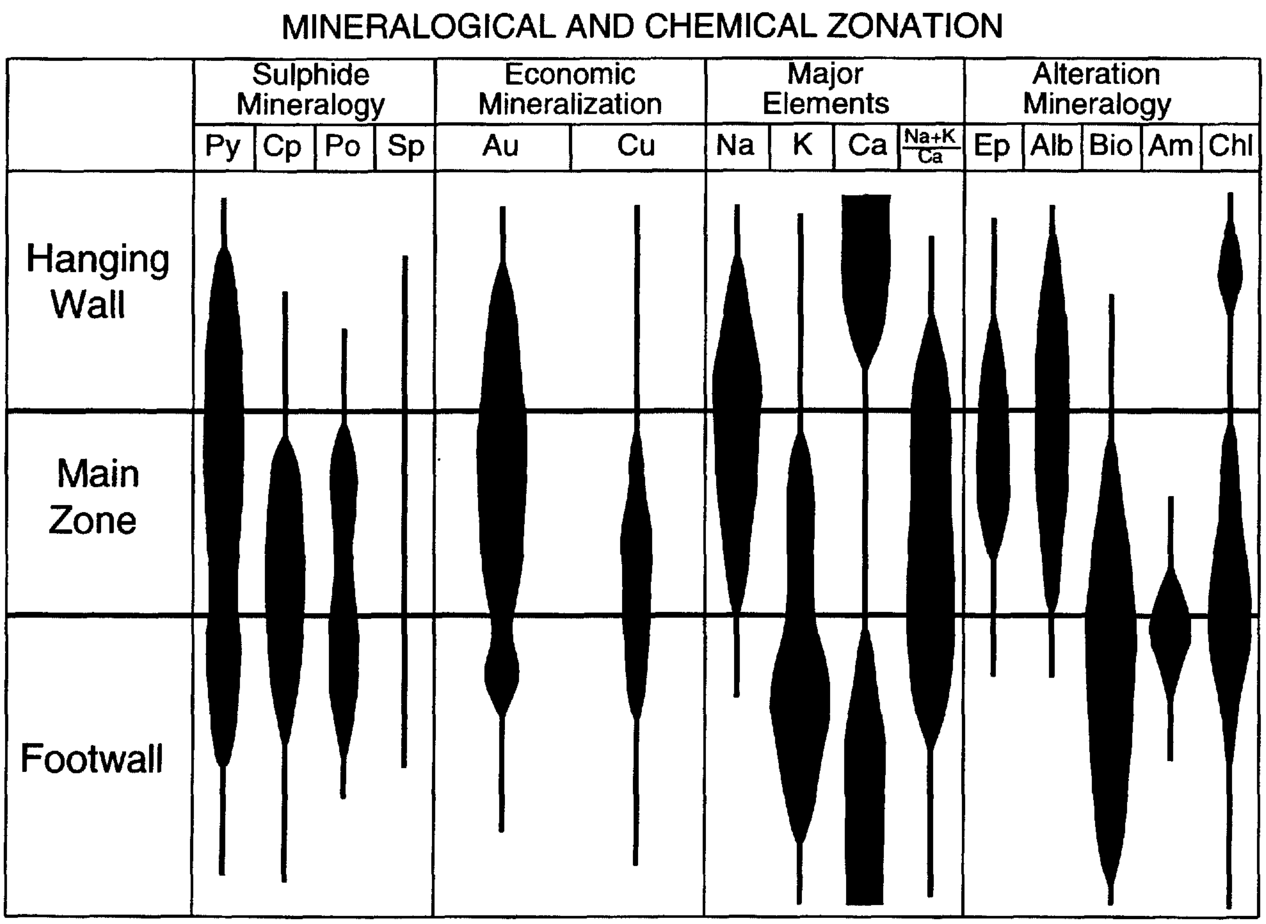


Figure D.41: Mineralogical and chemical zoning associated with the 87 Zone of the Troilus orebody.

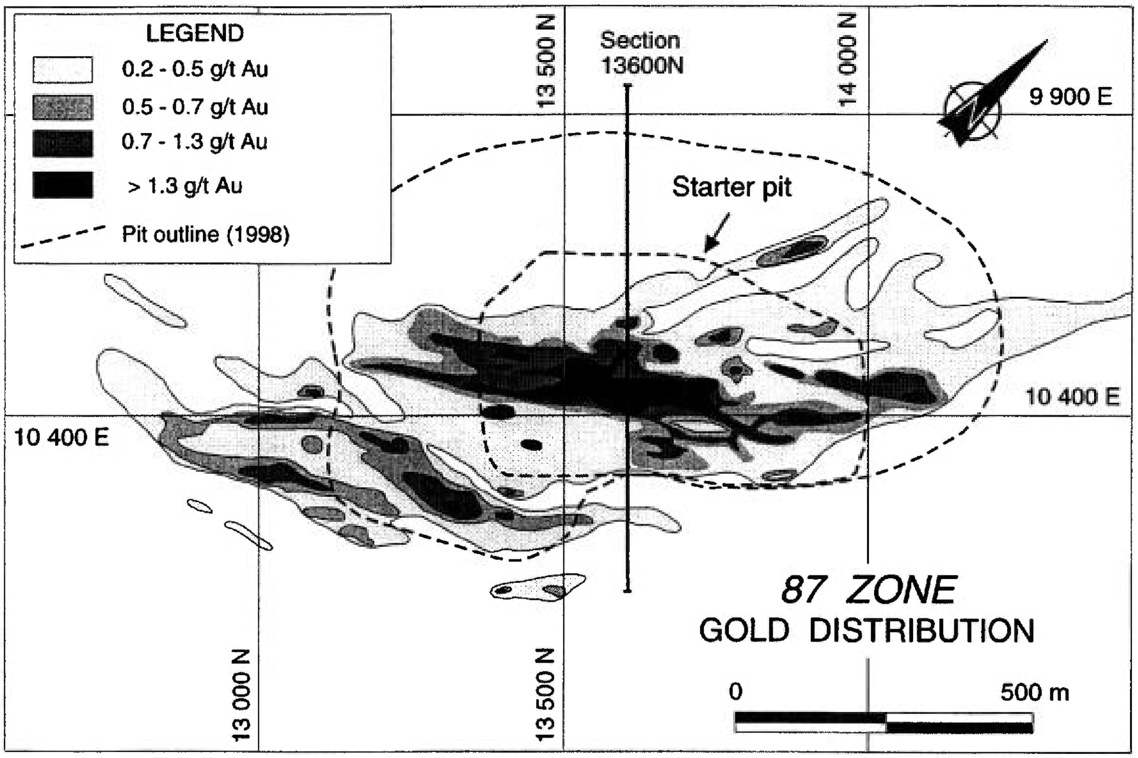


Figure D.42A: Gold distribution in the 87 Zone.

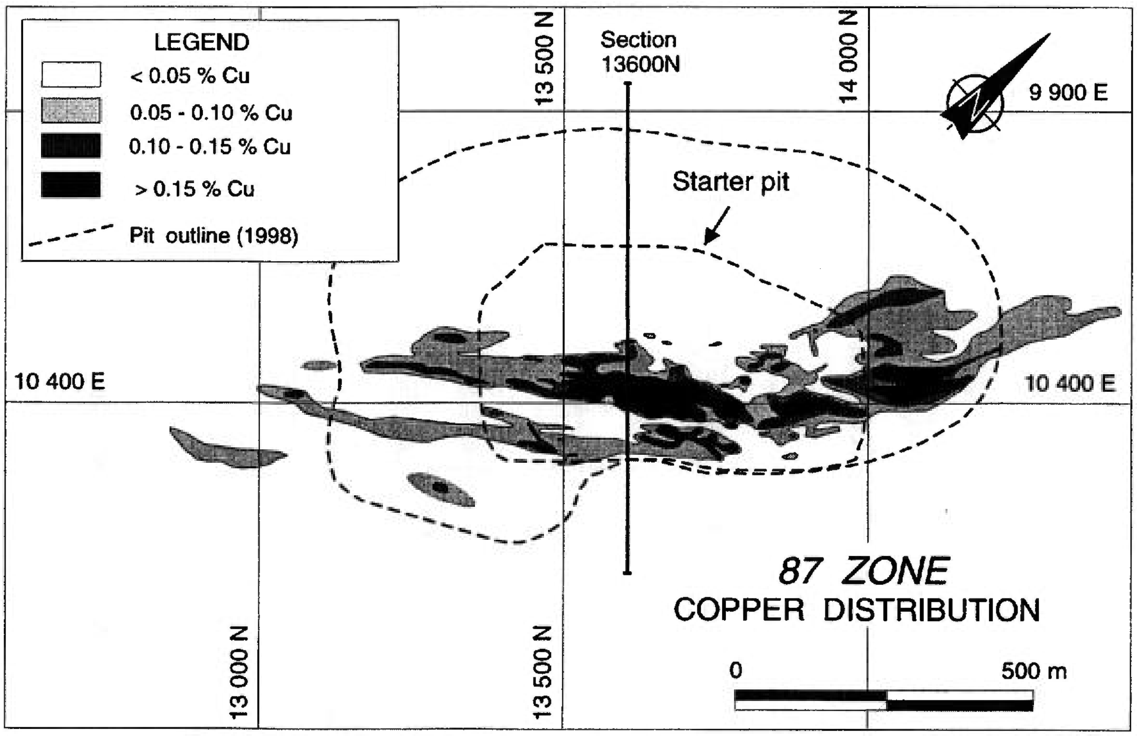


Figure D.42B: Copper distribution in the 87 Zone.

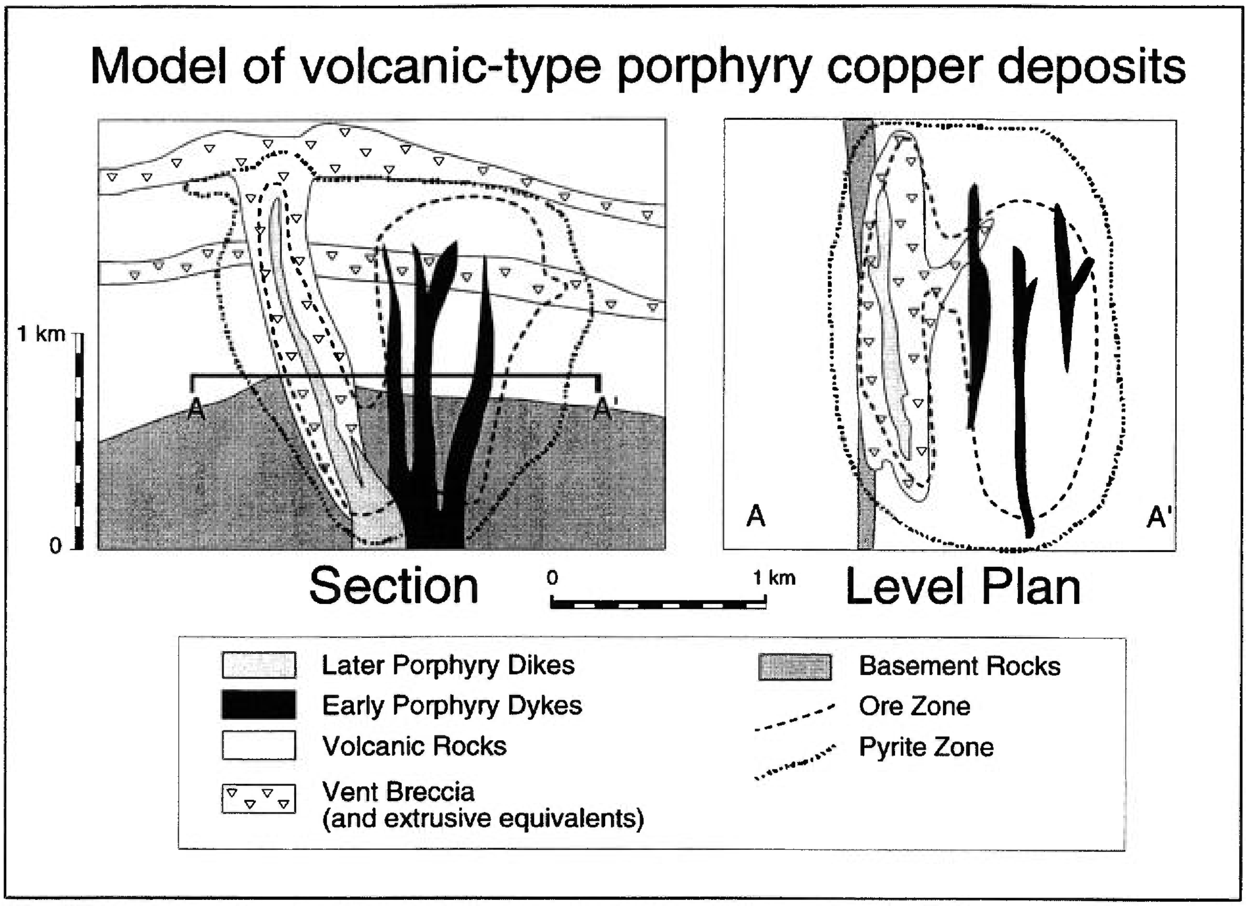


Figure D.43: Volcanic-type porphyry deposit model (after Sutherland Brown, 1976; and McMillan and Panteleyev, 1987).

The deposit will be mined from two open pits but most of the tonnage will come from the 87 Zone. The later is also higher grade in Au and Cu than the J4 Zone.

The Troilus deposit is being exploited by open pit mining methods with a production rate of about 11 000 tonnes per day (4,0 Mt per year). The average annual metal production will be approximately 129 000 ounces of gold and 9,25 million pounds of copper.

ACKNOWLEDGEMENTS

The author which to thank Inmet Mining Corporation and especially the Troilus Mine staff, Doug Cater (chief geologist), Bruno Perron and Claude Savard for their cooperation.

EPITHERMAL GOLD DEPOSITS : STYLES AND POTENTIAL FOR DISCOVERY IN ANCIENT TERRANES

Benoît Dubé

Geological Survey of Canada, Québec Geoscience Center, 2535 Boul. Laurier, P.O. Box 7500, Ste-Foy, Québec, G1V 4C7

INTRODUCTION

Epithermal gold deposits represent attractive targets for gold exploration around the world due to their potential to form world class (eg. El Indio, Chile; Hishikari, Japan) and even giant gold deposits (eg. Pueblo Viejo, Dominican Republic, >600 t Au). Formed at depths of less than 1-2 km, they are more susceptible to erosion and consequently most sub-aerial epithermal deposits are Tertiary in age or younger (e.g. Arribas, 1995). Furthermore as they are subduction-related, their current distribution is mostly concentrated along the Pacific Rim of Fire. However, there is a potential for such type of mineralization in ancient terranes.

EPITHERMAL GOLD DEPOSITS

The best example in Canada of ancient epithermal gold deposits are of high sulfidation styles and the Hope Brook gold mine (45 t Au) is a clear example of such gold mineralization in metamorphosed terrane (Dubé et al., 1998). The deposit is hosted by Late Proterozoic rocks of the Northern Appalachian Avalon Zone. It is enclosed within a zone of hydrothermal alteration >3 km long and up to 400 m wide. This zone of alteration is characterized by: (1) extensive advanced argillic alteration with pyrophyllite, kaolinite, andalusite and alunite, and (2) two main stages of massive silicic alteration. The first, a buff-color stage of massive silicic alteration, extends for 3 km and constitutes a barren to weakly auriferous unit which likely results from the pervasive acid leaching of the original host(s). The second stage of grey massive silicic alteration is spatially coincident with gold mineralization and is characterized by vuggy quartz. The mineralization consists of several percent of pyrite and lesser amounts of chalcopyrite and bornite and some tennantite with local traces of enargite. The ages of altered (pre- and late-ore) QFP and of an unaltered (post-ore) intermediate dike cutting altered rocks bracket the age of mineralization/alteration between 574 and 578 Ma (Dubé et al., 1998). This temporally and genetically links mineralization-alteration and Roti Intrusive Suite plutonism (Dubé et al., 1998).

The existense of such high sulfidation gold mineralization ot Late Proterozoic age at Hope Brook highlights the potential for such epithermal deposits in older volcanic and magmatic arcs and suggests that they may represent an important exploration target in terranes as old as the Archean. Furthermore, Hope Brook demonstrates that despite the intensity of the deformation and metamorphism, it is still possible to recognize their main characteristics in terms of mineralogy, geochemistry, texture and metal content. These features are not only preserved at Hope Brook since widespread advanced argillic alteration zones with associated gold mineralization are present elsewhere in the Late Proterozoic Newfoundland's Avalon Zone (O'Brien et al., 1998) and four gold deposits (Brewer, Haile, Ridgeway, Barite Hill; >75 t Au) in the South Carolina Slate Belt within the southern segment of the Avalon Zone (e.g. Feiss et al., 1993; Zwaschka and Scheetz, 1995) share characteristics with Hope Brook and with high sulfidation style.

DISCUSSION

The potential for preservation of such epithermal gold deposits is higher than commonly thought. One of the key factors for their preservation is the early tilting of their host volcanic successions as proposed for some Archean Greenstone Belts (e.g. Daigneault et al., 1990; Pilote et al., 1995c, 1998b). The shallow-water to submarine geological setting of some of the high sulfidation, in particular the gold-rich VMS deposits is another key element in their preservation. Such an environment has most probably significantly reduced the rate of erosion.

The Canadian exemples of Archean world-class gold deposits sharing analogies with epithermal style mineralization include the Campbell-Red Lake gold deposit in Red Lake, Ontario which has recently been described as a metamorphosed Archean pre-Kenoran, fault-controlled deposit largely hosted by low-sulfidation epithermal style veins and stockworks (Penczak and Mason, 1997) and the Bousquet 2-LaRonde deposit which could represent a type example of submarine high sulfidation volcanogenic massive sulfide system sharing strong analogies with its sub-aerial epithermal counterpart (Sillitoe et al., 1996). The locally auriferous pyrophyllite deposit in the Carpentier township, Senneterre as well as the dumortierite zone in the Bevcon pluton near Louvicourt (Taner and Martin, 1993) also illustrate advanced argillic alteration sharing definite analogies with high sulfidation or magmatic systems. In the Chibougamau area, the Cu-Pb-Zn-As-Ag-Au Lac Berrigan deposit potentially represents an Archean example of an epithermal system (e.g. Pilote, 1987; Guha et al., 1988; Pilote et al., 1995c) whereas the calc-alcaline sub-aerial felsic pyroclastic volcanics and felsic domes of the Blondeau Fm suggest that this formation could represent an exploration target for such epithermal and porphyry style mineralization, especially in the vicinity of known disseminated Cu or Cu-Au mineralization (e.g. Guha et al., 1988).

SOQUEM'S VISION

Gaétan Lavallière
SOQUEM, 462 3e rue, Chibougamau, Québec, G8P 1N7

GENERAL PRESENTATION OF SOQUEM

"July 15, 1965, the Québec National Assembly adopted the "Law for the Québec Mining Exploration Society"(LRQ, chapter S-19). This Society, that can also be designated by the acronym "SOQUEM", is constituted as a socially funded company that is a part of the public domain, thus entirely owned by the government".

Since its creation, the work accomplished by SOQUEM has permitted (Bouchard, 1995) :
- the discovery of eight mines of which three are still in operation;
- the discovery of a number of sub-economic deposits;
- the creation of more than 1 500 permanent positions;
- the realisation of exploration work worth 320 million dollars;
- the offering of numerous contracts to service companies;
- the diversification of the Québec mineral base (Niobium, salt, phosphorus and vanadium);
- the creation of the multinational society Cambior Inc.;
- the creation of two risk capital societies - SODEMEX 1 and 2.

In 38 years, a number of mandates have been given to SOQUEM whose primary mandate has been and continues to be even more so today, the discovery of deposits in Québec. In order to attain this objective, SOQUEM (Laplante, 1997) :
- accomplishes exploration work on the whole of the Québec territory and more particularly, in the far regions;
- favours partnerships with junior and major societies in order to enable them to maintain exploration activities in Québec;
- supports junior exploration societies in order to enable them to maintain exploration activities in Québec;
- maintains, trains and develops competent, experienced personnel in that which concerns Québec mining in addition to favouring the diffusion of geological information likely to stimulate interest in exploration in Québec;
- promotes and encourages current research to discover new methods and new technologies in order to increase exploration efficiency.

The application of this optimal approach facilitates the rise to a part of the major challenges that currently confront the Québec mining industry. However, SOQUEM's presence and maintenance of activities in the whole of Québec is essential so that investors believe in the government's will to discover and develop its excellent mineral potential (Laplante, 1997).

Since April 1st, 1998, SOQUEM is a part of the Metals and Minerals Division of the SGF (General Financing Society of Québec). This restructuring aimed to incite an acceleration of the rhythm of private investment in the course of the next five years, will enable SOQUEM to contribute to the energization of the economy and the creation of employment for all the regions of Québec. SOQUEM however, conserves its exploration mandate in addition to being able to participate in up to a 49 % interest in developing mining projects that have not necessarily been initiated by the State Society (Harvey, 1998).

DESCRIPTION OF SOQUEM'S CHIBOUGAMAU REGIONAL OFFICE MINING DISTRICT

SOQUEM's regional office district, based in Chibougamau, is comprised of 222 townships that cover a vast area of 50 000 km2 between the locality of Desmaraisville in the south-west and Lake

Mistassini in the north-east (Figure D.44). SOQUEM has some forty-odd projects and gold, base-metal, and vanadium deposits in this district that are distributed within four sectors of interest : Frotet, Chibougamau, Joe Mann, and Lac Shortt (Figure D.44). Exploration work is carried out on average on 15 to 20 of these projects each year, funded by a budget equivalent to that of the other districts in Québec to the order of 2,5 million dollars. However, contrary to the other regions, the financial contribution of partners in the accomplishment of this exploration work in the Chibougamau region is very minor. Thus SOQUEM actively seeks partners for a number of its projects that are at an advanced stage of exploration and that in some cases, possess deposits with resources.

The mining resources of the Chapais-Chibougamau district are responsible for the creation of the Chapais and Chibougamau mining camps as well as the towns of the same names with a population of 15 000 inhabitants of which 1000 were specialised personnel who worked directly for the mining industry at the beginning of 1997. This industry, of capital importance to the region, is the motor generating other jobs in the secondary and tertiary sectors. Since the birth of the district in 1953, the mining industry has enabled the exploitation of thirty-odd mines that produced more than 75 million tonnes of ore which attained in 1980 an annual production value of 237 million dollars.

THE DISTRICT'S PROBLEM

The Chapais-Chibougamau mining district possesses an excellent geological potential for the discovery of the next Québec mines. However, the last ten years have left the area in a difficult situation in that which concerns the financing of its mining exploration and operation activities. In addition, the situation of the industry in the region has been aggravated in the autumn of 1997 by the closing of two mines that led to the lay-off of 400 specialised workers. The decrease in the price of gold and copper combined with the lack of confidence in the mining industry of investors since the BRE-X fraud in Indonesia, have created a difficult global context for the mining industry. The chronology of these difficulties, that are actually combined for Chapais-Chibougamau, seriously menace the survival of the latter which is a pole of great importance for the economic development of the Middle-North and Northern Québec.

Interesting investors in the district's excellent potential requires foremost the modification of the negative image they have of it. The rest of this document has as its objective to explain the reasons for this misperception and the presentation of the district's discovery potential, accompanied by concrete means of intervention that could enable the discovery of the next Québec mine.

Little Explored District Offering An Excellent Potential For The Discovery of New Mines

Since the origin of the district, the mines in operation and the peripherical lots are the property of three groups composed of numerous companies. Although these companies were the owners of the lots, very little exploration work had been carried out on them. Investments were primarily devoted to the definition of deposits as well as to exploitation operations that produced revenue, and assigned little importance to the long term exploration so vital to the renewal of resources. This situation monopolised an important number of very good lots for the discovery of new deposits had a dissuasive effect on exploration companies who perceived the Chapais-Chibougamau mining district as the preserve of privileged companies.

This context contributed to why the district did not profit from the important quantity of work generated in Québec by the accrediting financing program of 1983 to 1988. Only 7 % of the financing generated was invested in the region, primarily by junior companies. Also, the Québec Mining Exploration Support Program (PSEMQ) initiated by SOQUEM in 1991 generated very little work in the district (20 %) in comparison with the regions of Rouyn-Noranda and Val-d'Or (75 %). The consequence of the non-realisation of exploration work at the right moment is that which we are currently experiencing, a lack of resources to pursue mining activities. Considering the imposing quantity (60) of exploited deposits and those with significant resources in the district, as well as the large area with a high potential of discovery that has as yet been little explored even in the proximity of mines, due to the different monopolies, it is easy to conceive of the excellent discovery potential of new mines that the region offers today.

False Vision of the Profitability of Exploitation

For the past ten years, a second factor has been disseminating a false vision of the economic potential of the region's deposits thus accentuating the problem of insufficient investment in the district. The mineral reserves of the voluminous deposits exploited in the Chibougamau mining camp were drawing to an end and so the companies exploited the residual sites located in the periphery of the

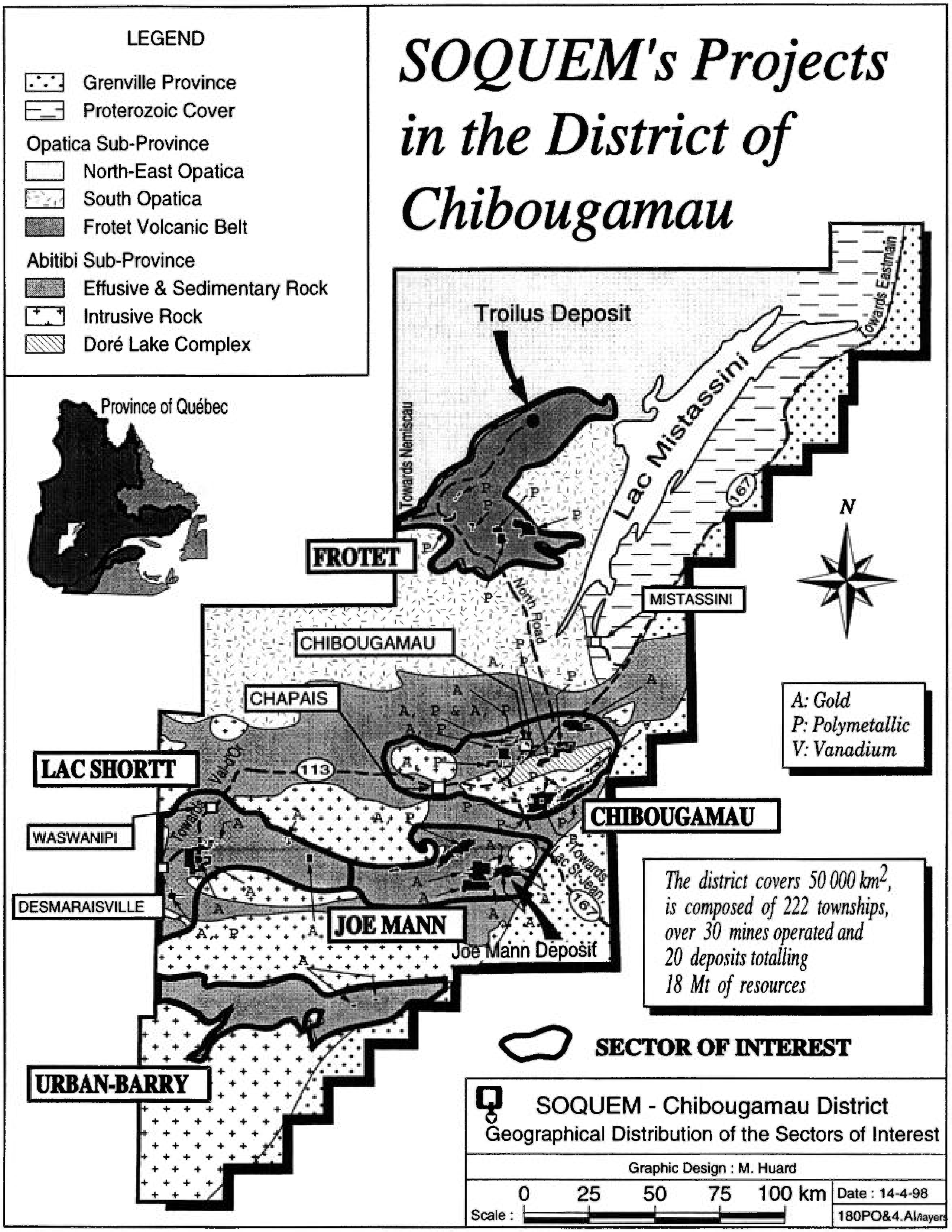


Figure D.44: SOQUEM's projects in the Chibougamau district.

deposits. These zones whose grade was poorer, were also farther from the shafts thus increasing transport costs. These factors had as consequence a significant reduction of revenue generated by these operations. The last companies to exploit these deposits went through a period where revenue diminished at a time when reserves had to be renewed by onerous exploration work.

The message broadcast in the field led one to believe that the exploitants, in search of capital to finance their exploration work, were not succeeding in making significant profits from the high-volume deposits. This message made one overlook the important revenue from these deposits as well as masking the revenue of a very rich mine, the base metal Lemoine Mine. The Norbeau Mine also produced very appreciable revenue and the Troïlus and Joe Mann Mines, respectively 4th and 6th gold producers in Québec, continue to do so. The potential for discovering these small, very rich mines, as well as for the discovery of the next high-volume deposits, remain very great. However, the flawed image of the regional economic potential hinders the flow of investment necessary to the completion of exploration work.

Exhaustion of the Mineral Reserves Due to the Insufficiency of Exploration Work

Since 1988, the region has survived the closing of eight mines, including the complete close-down of the Chapais mining camp in 1991. The closing of the Portage and Copper-Rand Mines in the fall of 1997, brought about the lay-off of 400 employees and now the population face the complete closing of the Chibougamau mining camp. Only the Joe Mann and Troïlus Mines, that are beyond the two mining camps, remain in operation. These two mines employ a total of 500 employees and possess reserves respectively of 4 million tonnes at 9 g/t gold and 44 million tonnes at 1,2 g/t gold and 0,12 % copper, and have a life span estimated at a dozen years.

SOQUEM'S INTERVENTIONS, TO DATE, IN THE DISTRICT

The closing of the Chapais mining camp in 1991, of two mines in the Chibougamau mining camp and of the Lac Shortt mine in Waswanipi in a context where very little exploration work was being done in the district seriously preoccupied SOQUEM. It is for this reason the Society made a great effort, during the most difficult period, from 1987 to 1994, by investing 48 % of its annual budget. These efforts paid off. First, an intensive exploration program permitted the discovery of the Philibert deposit, possessing reserves of 1,4 Mt at 5,3 g/t gold, as well as the De Maurès deposit whose resources are estimated at 350 000 tonnes at 7,8 % Zn, 1,4 % Cu and 22 g/t Ag.

SOQUEM also created, in 1991, a collaboration program with local producers in order to renew mineral reserves in time to save exploitation installations and specialized jobs. In proximity of Ressources Meston Inc.'s Joe Mann Mine, SOQUEM's work, that was successful, permitted the increase in mineral reserves of up to one million tonnes, as well as adding value to another million tonnes of resources of similar grade. The sector, with the Troïlus Mine, temporarily ensures the survival of the mining district. The collaboration between SOQUEM and Ressources MSV Inc. also enabled the discovery, in the Chibougamau mining camp, of the Copper Rand 5000 deposit that possesses mineral reserves of 4 million tonnes. SOQUEM has also completed with this company definition work on the Corner Bay deposit that has proved the reserves of close to one million tonnes.

In the region of Waswanipi-Desmaraisville, the efforts deployed with INMET Mining Corporation could not save the exploitation installations nor the concentrator that were dismantled in the summer of 1997. However, a large part of the workforce was relocated to the Joe Mann and Troïlus Mines. The work completed in the sector has all the same permitted the development of high discovery potential lots that must be methodically explored.

With the aim to increase the flow of investment that is necessary to the completion of exploration work in the Chapais-Chibougamau district, SOQUEM expends a great deal of energy to make known the district's potential by all possible means so that companies can share the costs associated with exploration with the Society. The SDBJ, the mining companies of the region, the Québec Ministry of Natural Resources, the Chibougamau Chamber of Commerce as well as the two municipalities provide remarkable support in this endeavour. In 1997, SOQUEM associated with an important partner, Ressources McKenzie Bay Ltd, to develop the Lac Doré vanadium deposit that possesses 200 million tonnes of resources. The exploitation of this deposit would constitute an asset for the region enabling it to diversify its economy and by that factor alone, be less vulnerable to the economic cycles that affect the mining industry. In addition, the exploration work led, extensively since 1997, in partnership with Northern Mining Explorations in the Lac Shortt sector has permitted the discovery of a number of signs that enhance this high discovery potential sector.

THE MEANS OF INTERVENTION PUT FORWARD BY SOQUEM

In this first part of 1998, we returned to the 1987 starting point and a second strategy, adapted to the situation, was launched. In the short term, it is a question of preserving the mining activities of the Chibougamau mining camp by evaluating the resources that present a profitability potential as well as ensuring the survival of the mining district by the optimisation of the exploration stratagem of favouring partnerships that will permit the discovery of the next important deposit. However, in the two cases, the deadline is tight and the collaboration of all concerned will be capital.

In the short term, it is imperative to maintain in the region a large part of the 400 workers specialised in mining operations as well as the ore processing infrastructures of the Chibougamau mining camp. In the case where qualified personnel are obliged to leave the region and the ore processing infrastructures and railway are closed or dismantled, as in the regions of Chapais and Waswanipi, it will be difficult afterwards to make a significant profit from the available mineral resources in the district and to interest companies in completing exploration work. From this view, after evaluation of the profitability of the Copper Rand 5000 project, SOQUEM contracted an important investment in the project in order to accelerate the start-up of the deposit's exploitation operations.

The Chapais-Chibougamau mining district with its 19 auriferous and/or base metal deposits encloses approximate 18 million tonnes of resources, as its vast little explored area possesses an excellent discovery potential. These resources have roused little interest on the part of the owners because they are geographically distributed in a number of points. They were economically less attractive than the high-volume deposits of the two mining camps. In addition, these deposits that are not all held by the same owner are not, in some cases, sufficiently high-volume and rich to be interesting, if they are evaluated individually. In this perspective, SOQUEM will evaluate the possibilities of partnership that could, during supplemental exploration work, permit the development of one or many of these deposits, little worked to date.

In the long term, if one considers that the rate of discovery of a mine, ready to be exploited, in Canadian mining camps is actually to the order of one mine per ten years, it is essential to begin an intensive program of resource renewal of the last two mines of the district in order to ensure their survival in a dozen years. In 1996, an amount to the order of nine million dollars was invested in exploration work in the district. SOQUEM contributed 35 % of that investment. In 1997, the investment in the district was about 6,5 million dollars, 2,5 million less than in 1996 due to the retreat from the region of a few major companies. SOQUEM's contribution still amounted to 46 % of investments in the region. For 1998, the situation will be even more critical. With the junior companies' financing difficulties and the retreat from Québec territories by a number of major companies, it is realistic to estimate at four to five million dollars the investment in mining exploration in the region. We estimate that SOQUEM will contribute more than 70 % of mining exploration investment although the budget devoted to the region by the Society remains constant. SOQUEM invests 20 % of its annual budget in the district and in the current economic context, it is difficult to imagine that SOQUEM alone can compensate for the decrease in investments in the region. The situation must be redressed, partners are sought to join their efforts to those of SOQUEM to explore this high discovery potential territory.

The sums invested in the district are insufficient to renew the mineral reserves. The people of the area estimate that an investment of about fifteen million dollars per year would be the minimum level in order to attain the established goal in time. If exploitation activities were to come to an end in the district and the rail link abolished along with the other regions following the exhaustion of mineral reserves, exploration activities would diminish in a dramatic fashion. Companies would interest themselves in mining camps that are still active or the larger regions that are in the phase of geological recognition (Québec North, South America, Africa, Indonesia) in the hopes of making a grand scale discovery at the soil surface. This former mining camp, far from the populations that no longer offer the possibility of treatment and transport of ore would be of mitigated interest but the mineral reserves would continue to exist without anyone profiting from them !

An intensive effort must be maintained to promote the excellent discovery potential of this mining district. In order to attain this objective, the tools available must all be put to work and new means of dissemination of information and promotion, such as the 1998 CIM Symposium, must be made to work effectively.

MSV RESOURCES CORPORATIVE VISION

Alain Blais
Les Ressources MSV Inc., C.P. 8000, Chibugamau, Québec, G8P 2L1

SUMMARY

Ressources MSV Inc. is a society that exploits gold and base metal deposits and develops mining properties. In the course of the next few years, MSV intends to develop various projects (base metals : Cu, Zn ; precious metals : Au, Ag) located in the Chibougamau region, all the while prioritizing the Copper Rand 5000 project whose reserves are of 2,2 million metric tonnes at 1,7% Cu and 3,7 g/t Au.

HISTORY

Ressources MSV Inc. was incorporated November 10, 1959 initially under the designation of Mines Massaval. In September 1986 the company underwent a reorganisation and saw its name change to Ressources MSV Inc.

After the October 1986 reorganisation, MSV concluded an option agreement whose aim was the acquisition of a 49% participation in the Eastmain property in return for exploration work totalling $ 9 million. This participation was obtained in 1988. In the course of the same year, the company acquired the remaining 51% interest due to financing from the Northgate Exploration Ltd, thus becoming the sole owner of the Eastmain project.

In February 1993, the company became a copper and gold producer by acquiring the Copper Rand and Portage mines that had been closed since November 1992 by Westminer. In March 1993, the two mines resumed production under MSV. An important exploration program worth $ 5,2 million was put forward in order to increase the known reserves of the two mines. This program, 50% financed by the two levels of government (Québec-Canada Agreement), 25% by SOQUEM and the last 25% by MSV, prolonged the operational life span of the mines from 1993 to 1997 and began the exploration work that ulteriorly led to the elaboration of the Copper Rand 5000 project.

In June 1993, MSV acquired the Cedar Bay, Henderson 1 and Henderson II properties from Ressources Meston Inc., an exclusive property subsidiary of Ressources Campbell Inc. This acquisition enabled MSV to consolidate its position in the heart of the Chibougamau mining camp.

In July 1994, MSV concluded an agreement concerning the acquisition of a 55% participation in the Corner Bay "Inner Block" property located 55 km south of the Chibougamau installations. This deposit contains exploitable reserves of approximately 1,0 million metric tonnes containing on average, 5,26 % copper. In October 1995, the company acquired the remaining interest, 45%, by joining its activities with those of the partner in this venture, Explorations Cache Inc.

In the second half of 1994, the Eastmain mine began its exploration activities and generated 14,595 ounces of gold. 1995 was marked by the closing of the Eastmain mine after less than a year of pre-production. The site's distance as well as the difficulties inherent in the transport of the ore via a winter route considerably affected the profitability of the project and amply justified the temporary abandonment of activities.

In April 1996, the MSV board of directors brought in a new management team with Mr. André Y. Fortier as president of the board and CEO. The new management had as objective the consolidation of Ressources MSV's position in Chibougamau. The first step was to ensure the development of the Copper Rand 5000 project, this project being MSV's base in the region. The treatment plant with its 2,700 metric tonne/day capacity is one of MSV's important assets. The Copper Rand concentrator possesses a nominal capacity of 2700 metric tonnes per day, being a little more than 0,9 metric tonnes

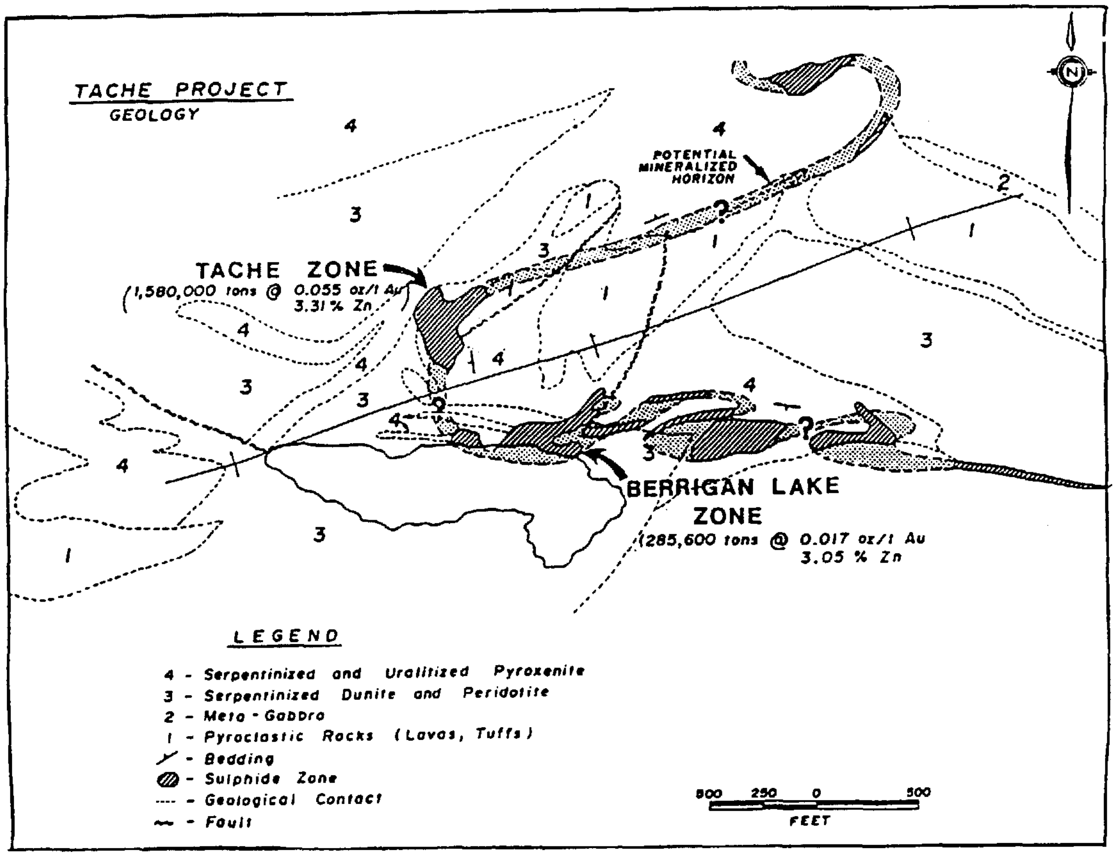


Figure D.45: Simplified geology of the Taché deposit (modified after Anderson, 1988, and numerous other works).

per year. It treats the ore at an average rhythm of 114 metric tonnes per hour. It is equipped with a flotation circuit, a gravity circuit for the recuperation of free gold and a smelter to mould the gold thus recuperated.

The Copper Rand 5000 project will provide ore for only 50% of the plant's capacity. Thus, MSV gave itself as second objective the identification and acquisition of all projects located in the Chibougamau region liable to be developed in the short term, operated for profit and whose ore could be treated at the plant. Finally, as third objective, MSV wishes to increase the reserves of the Eastmain property and resume the exploitation of this deposit.

Within the framework of its objective to identify projects liable to be developed in the short term in the Chibougamau region, MSV concluded an agreement with Noranda Exploration enabling it to acquire the Tortigny property located 135 kilometres north-west of Chibougamau. The Tortigny deposit encloses geological resources equal to 450 000 metric tonnes containing 2,5% Cu, 7,0% Zn, 0,3% Pb, 66 g/t Ag and 0,3 g/t Au. The deposit and geological context of the property present an excellent potential that could lead to an increase in the resources already present.

MSV also proceeded with the purchase of a group of properties belonging to 150990 Canada Ltd. The 26 properties acquired are all located in the region of Chibougamau. Of this group the lac Taché property located 5 kilometres north of Chibougamau is retained. The property is held conjointly with Bitech Corporation in a 50/50 partnership. The property encloses geological resources as indicated by drilling, to the order of 840,800 metric tonnes containing 4,12 % Zn and 2,4 g/t Au. This property possesses a significant mining potential and the geometrical configuration of its resources enable the company to consider an open-pit operation. The Gwillim property, also acquired from 150990 Canada Ltd., encloses geological resources estimated at more than 272 000 metric tonnes at 10 grams of gold per metric tonne. This property had been in commercial production from 1980 to 1984. A total of 231 355 metric tonnes at 4,9 grams of gold per metric tonne was extracted. The exploitation was accomplished with the use of a ramp.

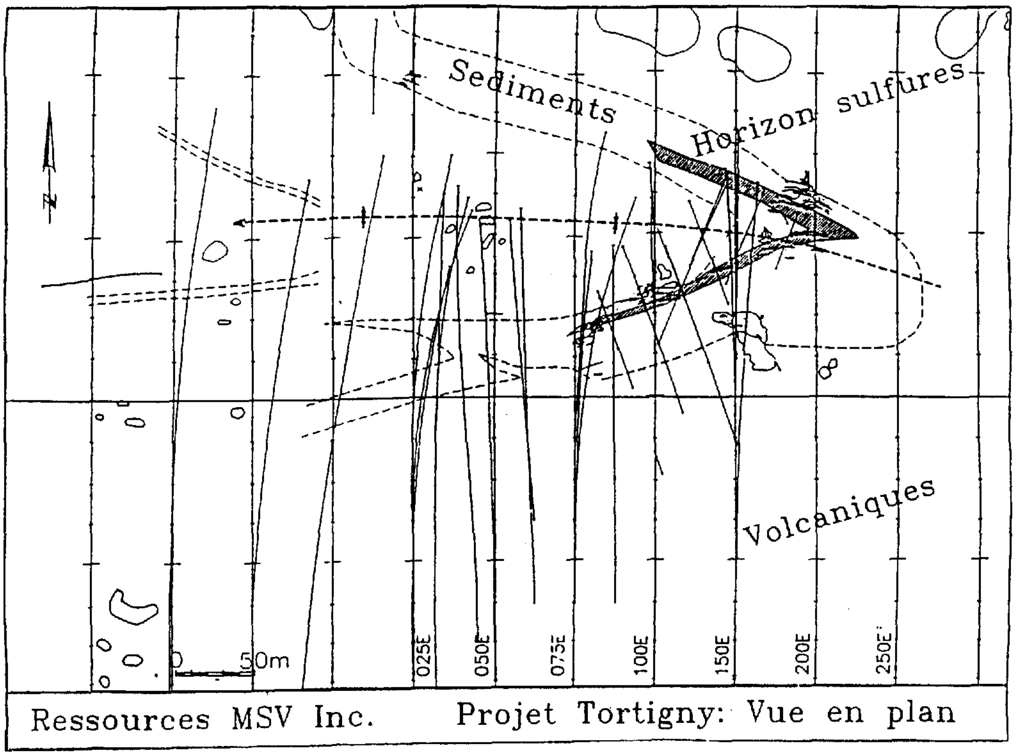


Figure D.46: Simplified surface geology of the Tortigny deposit.

PERSPECTIVES

-) Copper Rand 5000 project

Ressources MSV intends to devote most of its activities in 1998 and 1999 to the development of the Copper Rand 5000 project. This project is the centre point in MSV's development strategy in Chibougamau. The development of this project will ensure the company gold and copper production for a minimum period of five years as of the beginning of 2001. The cost of production will be of 40 $/tonne, which represents an important savings in relation to the costs of production for 1996 (65,95 $ per tonne). In addition, this project will enable the exploration and definition of the resources indicated by drilling under the Cedar Bay mine (potential at 1,0 to 2,0 million tonnes at 1,00% copper and 5,0 grams gold per tonne) as well as all of the lac Doré sector, located south of the Copper Rand and Cedar Bay mines.

MSV also intends to highlight the development of the Corner Bay project and the development of the mining projects acquired in 1997, lac Taché and Tortigny.

-) Corner Bay project

The Corner Bay project is located 45 km south of Chibougamau. It encloses close to one million metric tonnes containing 5,28% copper. MSV aims for an annual production of 180 000 metric tonnes when the price of copper will be superior to 1,05 $ a pound (US). An exploration ramp requiring an investment of 4,5 million dollars will be necessary when the price of copper is such as to consider that production could be profitable.

-) Lac Taché property
(by D. Gervais)

Introduction

The lac Taché property, 50% owned by MSV (the other 50% belonging to Bitech) is located 5 km north of Chibougamau. It encloses resources estimated at 840 800 metric tonnes containing 4,12% Zn and 2,4 g/t Au. The geometry of the deposit is favourable for an open pit operation.

The mineralization is composed of pyrrhotite, sphalerite, pyrite and galena (chalcopyrite and arsenopyrite) lenses and veins, hosted in or located close to the contact with the ultramafic Roberge sill, which belongs to the Cummings Complex. The

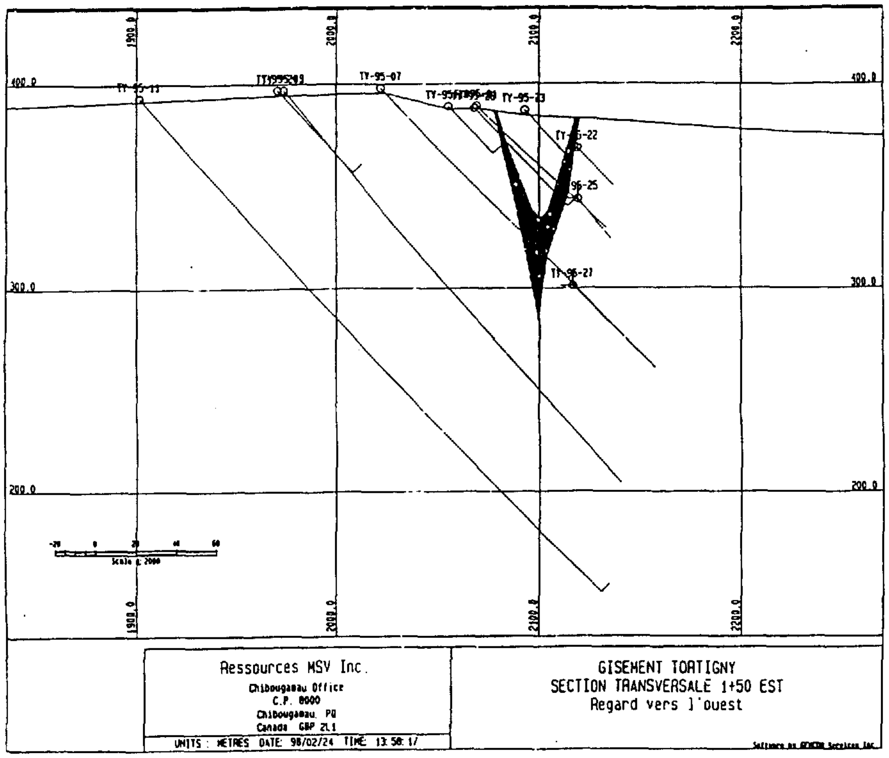


Figure D.47: Simplified cross section 1+50 Est, Tortigny project.

mineralization is in the proximity of or in contact with intermediate to felsic volcaniclastic rocks. According to some interpretations (Anderson, 1988), the lithologies of this sector seem to have been folded in a anticlinal isoclinal fold oriented north-east and plunging 50° - 70° towards the south-east (Figure D.45).

Economic Geology

From 1929 to 1994, the Lac Taché deposit has been the subject of multiple geological forays including over 215 diamond drill holes totalling no less than 30 000 metres, many geophysical readings as well as the boring of a 200 metre-long ramp 30 metres deep. Between 1959 and 1987, there have been no less than 7 resource calculations. Although still very uncertain today, the resources indicated establish themselves within two zones :

	tc	% Zn	oz Au/t
Lac Taché zone :			
(Anderson, 1988)			
(a) from surface to level -120m	626 900	4,06	0,07
(b) below level -120m	953 100	2,82	0,045
sub-total	1 580 000	3,31	0,055
Lac Berrigan zone :			
(Brett, 1959)	285 600	3,05	0,017
Total of the two zones	**1 865 600**	**3,27**	**0,049**

A very complex structural domain caused the abandonment of the development work on the Lac Taché deposit by a number of companies that had optioned the property in the past. However; a pre-feasibility report compiled in 1989 by James Wade Engineering Ltd for Bitech Corporation indicated that there existed a true recovery potential of part of this deposit via an open pit operation. Based on the 1988 Anderson resource calculation, the study indicates that it would be possible to recover some 2 million short tons of material assayed at 0,96% zinc and 0,018 oz Au/t. In addition, the sulfured horizon remains open in depth and constitutes a excellent bore target to prove the continuity of the mineralisation and to increase the resources known to date. The company Les Ressources MSV are currently validating the latest resource calculations and verifying the open pit mining potential of a part of the deposit.

By its size and stratigraphic position, the Lac Taché deposit resembles that of the Zenith in Ontario (165 000 tons at 16,5% zinc) that was the

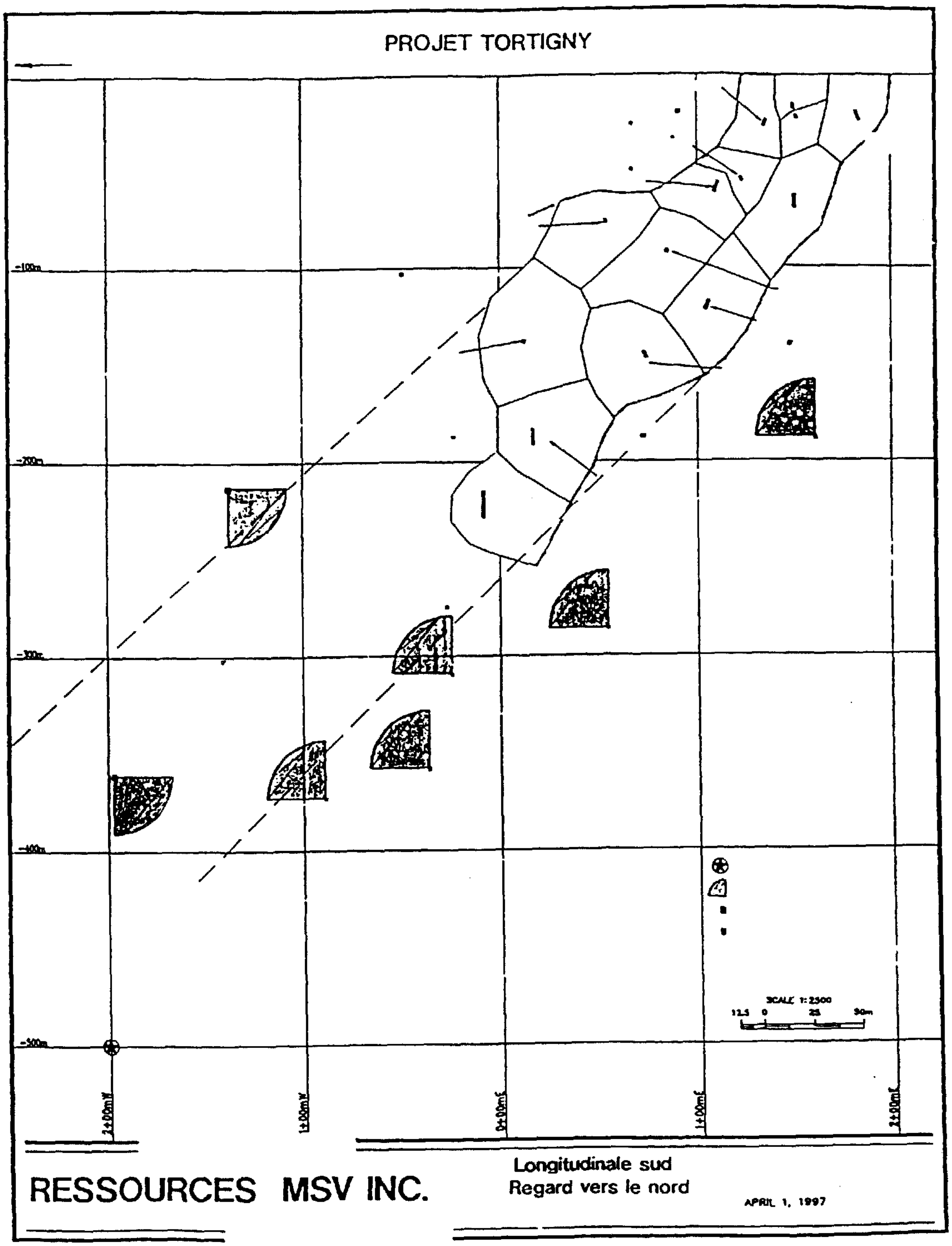


Figure D.48: South longitudinal section, looking North, Tortigny project.

origin of the discovery of the Winston Lake volcanogenic massive sulfides deposit (3,1 Mt at 15,20% Zn, 1,10% Cu, 31,00 g/t Ag, and 1,00 g/t Au). It could thus be possibly interpreted as a xenolith derived from a sulfurous mass of greater proportions. This interpretation opens the door to potential major discoveries of deposits of the same type in the immediate vicinity.

The Tortigny property
(by D. Gervais)

Introduction

The Tortigny deposit is located some 100 km north of Chibougamau. It is a horizon of massive sulfurs composed of pyrrhotite, sphalerite, and chalcopyrite located in the Testard volcanic member, inside the Châtillon andesitobasaltic formation, in the Frotet-Troïlus volcanic belt . This polymetallic deposit is located at the hinge of a synform that opens and plunges 45° west (Figure D.46). The Tortigny property encloses resources 450 000 metric tonnes containing 2,44% Cu, 7,07% Zn, 66,1 g/t Ag, and 0,32 g/t Au.

Economic geology

The trenching completed by Noranda Exploration in 1994 brought to light a sulfured horizon some 200 m long with an average width of 2 m. Forty drill holes, from which 1028 samples were taken and analysed, served to circumscribe this deposit. It is characterised by three distinct zones : the south arm attitude 250° with a dip at 70° northward, the north arm attitude 290° with a weight at 70° southward, and the hinge zone (Figures D.46 and D.47).

In April 1997, a first resource calculation of the Tortigny deposit permitted the identification of some 450 000 metric tons assessed at 6,17% Zn, 2,24% Cu, 61,84 g/t Ag, 0,33 g/t Au, and 0,24% Pb going from the surface to level -260 m. In early 1998, the company Ressources MSV Inc. calculated a net revenue after smelting (NSR) of 108,47 can./t taking its own operating realities into consideration as well as the following economic parameters :

the price of zinc at	0,75 $US/lb.
the price of copper at	1,00 $US/lb.
the price of silver at	5,00 $US/oz
the price of gold at	375,00 $US/oz
the Canadian dollar at	0,72 $US

The Tortigny deposit remains open in depth and the multiple EM pulse readings indicate a strong possibility of finding other sulfurs along the favourable horizon (Figure D.47). In addition, the metamorphic assembly of the sediments containing the deposit (quartz, muscovite, biotite, andalousite) as well as the absence of pre-metamorphic (chlorite) alteration suggests that the deposit is not associated to its alteration aura but represents instead a facies of re-sedimented distal placement. This would imply the presence of a sulfurous source of great importance favouring a strong potential for major discoveries in the vicinity.

MSV will be required to invest a minimum of 2,0 million dollars in services before the end of December 2001 in order to acquire 100% interest in the property.

-) The Eastmain mine project

The Eastmain mine, located 300 km north of Chibougamau holds 800 000 metric tonnes containing 10,1 grams of gold per tonne. An investment of 10 million dollars is required for the installation of an ore treatment plant on the site, including a tailings park as well as for the transformation of the existing north route into a permanent road. MSV intends to start up the project again once these conditions are met and when the price of gold will have attained the 400 dollar (US) per once level. MSV is confident that the reserves on this property will increase following the exploration work to be undertaken by ARCA Exploration, who have a 50% acquisition option on the secondary block in return for an investment of 3,0 million dollars in various exploration work done before the end of December 2002.

CONCLUSION

The new management at MSV have been occupied putting into place the elements that will enable the company to develop positively after a period of transition between the exploitation such as it was until 1997, and the pre-production of new projects as 2000 approaches. At the moment, MSV will have attained a global production level of more than one million metric tonnes annually thus ensuring a solid, diversified and profitable base.

CHIBOUGAMAU: SPEARHEAD OF NORTHERN MINING

Paul-A. Girard
NORTHERN MINING Explorations
Place du Canada, 1010 de la Gauchetière, bureau 2255,

Following targeted geoscientific evaluations and due to a variety of circumstantial factors, it has become obvious to the administration of NORTHERN MINING Explorations that the Chapais-Chibougamau mining district offers excellent business and mining development opportunities. To the extent that NORTHERN MINING has decided, by way of a resolution, to devote the major part of their Québec exploration budgets to the district.

With forty-five years of solid experience behind them, in the course of which numerous crucial decisions were taken, NORTHERN MINING now believes that the current decision to invest here will be favourably viewed in future... especially after the passing of the new millenium.

Although the Society took its first steps in the Obalski and Lemoine townships in the early 1950s, their renewed interest in the Chapais-Chibougamau district is explained first and foremost by the results from the work done by the society on the Le Tac township property that is held conjointly with SOQUEM.

Afetr reading the information compiled to this day, Le Tac presents many zones of interest for gold and base metals, notably zinc and copper. The most recent work done has permitted the identification of a P.P.-type conductor, a gold-zinc-copper-silver ore, more than 700 metres long. In addition, a investigation parallel to this zone, also with a P.P. survey, has permitted the discovery of fourteen new drilling targets that gave up, amongst others, results of 7,44 g/t Au, 4,82% Zn, and 41,5 g/t Ag over a four metre-depth as well as 2,72% Zn along 12,5 metres.

The evolution observed on the Le Tac property is also based on a partnership that can be qualified as exemplary with SOQUEM. It is another dimension - a circumstantial factor- that has made it so that we are here to stay. Proof positivet: the joint development NORTHERN MINING/ SOQUEM that we intend to conduct on one of the best projects in the sector, that of the lac Shortt.

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