RAPPORT ANNUEL
2009

Sous projet SC33

The Misema and New Senator calderas: Volcanology, volcano-tectonic structures and targeting VMS-deposits, Blake River Group

Par

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Soumis à l'administration de DIVEX
Mai 2009 – Québec

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ABSTRACT

The study focuses of the Misema and New Senator calderas of the Blake River Group in the Abitibi greenstone belt. Two major aspects were emphasized in 2008: the timing of felsic and mafic volcanism of selected areas and the physical volcanology and volcaniclastic rocks of the Glenwood rhyolite. An important aspect of this multi-disciplinary study is constraining caldera evolution by using precise U-Pb age determinations of zircons (TIMS, thermal ion mass spectrometry). The various stages of multiple caldera formation were chronicled. The oldest shield and summit caldera forming phase has ages of 2702.9 ± 4.1 Ma and and 2704.3 ± 2.0 Ma for intrusive rocks (gabbro and diorite), whereas U-Pb age determinations of 2701.5 ± 1.4 Ma for a ring dyke in the Montsabrais volcanic complex and a 2701.3 ± 3.4 Ma age for a linear dyke in the Clericy area, suggest younger ages for summit caldera events. The shallow-water volcaniclastic deposits associated with the ring dykes support the notion that some of the summit calderas were close to, or breeched the Archean ocean surface. Subaqueous pyroclastic deposits in the Clericy area may be related to explosive summit caldera volcanism. Younger thick dyke systems, such as the McPhee dyke, with an age of 2698.5 ± 1.6 Ma, intruding the caldera wall or triple junction rifts, such as the Horseshoe dyke system, with an age of 2695.8 ± 1.5 Ma, show the complex emplacement history of mafic rocks. The New Senator rhyolites, especially quartz-feldspar phyric dykes and rafts in the central Noranda mining camp, yield ages of 2703.2 ±1.5 Ma and 2702.3 ± 5.6 Ma for the Glenwood rhyolite, respectively, and 2701.9 +/- 1.7 Ma for entrained felsic fragments in subaqueous mafic flow fields.

The physical volcanology of the ca 800-1000m thick Glenwood rhyolite in Rouyn-Noranda was the principal mapping project in 2008. This subaqueous felsic dome-flow complex overlies the basal mafic flows and ponded magmas (subaqueous lava lakes) of the New Senator caldera. Based on detailed mapping and petrography two major rhyolite suites were recognized, and include: (1) an early constructive dome-flow building stage composed of aphyric lavas, and (2) a late, quartz-feldspar-phyric, rhyolite, endogenic dyke and dome stage responsible for edifice inflation. The 100-400m-thick aphyric flow units are highly viscous and display a volcanic facies architecture of proximal to distal. The felsic flows have a 5-50 m-thick massive lobate interiors that display well-developed flow-banding and local columnar joints. *In-situ* brecciated lobate facies, 20-200 m-thick, surround the massive lobes. Local m-scale flow banded lobes are readily observed, but the prevalent feature is brecciated clasts in a viscous lava flow. The most distal segment is the felsic flow breccia facies with angular to amoeboid-shaped clasts were both connected and loosely connected to the lava flow. The quartz-feldspar-phyric units (QFP-units; 2-5% quartz and 20-40% feldspar) intrude the aphyric volcanic flows, and represent dykes that balloon into endogenous lobes-domes. Excellent 5-15 cm thick columnar jointed segments are present in the elongated dome-lobes, and flow-banding and *in-situ* breccias are observed. The mafic dykes represent the final volcanic phases of this segment and they feed the overlying mafic pillowed and brecciated lava flows. The larger mafic dykes delineate the margins of the Glenwood rhyolite. The 0.20-5.0 m-thick dykes are massive, have flow-banded margins, and display vesicle enrichment and brecciation close the Archean seafloor.

1. GENERAL GEOLOGY

The 300 x 700 km Abitibi greenstone belt (Figure 1) is a well studied supracrustal sequence with numerous known (e.g. Noranda) and inferred calderas (e.g. Gemini), which are located in the northern (NVZ) and southern volcanic zones (SVZ). The notion of volcanic zones is based on the initial study of Dimroth et al. (1982) and elaborated by Chown et al., (1992) and correlates to arc-forming and arc collision processes. The 10-15 m.y. brackets are the general timeframe for individual arc sequences, and the term volcanic cycle represents this evolutionary trend (Table 1), but new terms such as <assemblages> have been introduced (Thurston et al., 2008). We prefer to retain the initial term <volcanic cycle>, as it best reflects arc evolution (Mueller et al., 2009). Sedimentary cycles are basin-forming events. The study focuses on the Blake River Group, now referred to as the Blake River megacaldera complex, composed of three distinct calderas (Pearson and Daigneault, 2009).

The 2900 km^2 subaqueous Blake River megacaldera complex (Figures 1, 2a, b) is a world class mining camp with respect to both hydrothermal Cu-Zn massive sulfides and gold-rich massive sulfides (Hannington et al., 1999). The Blake River Group was subdivided into the Misema and Noranda subgroups by Goodwin (1977) and these subgroups now define the two oldest calderas of the Blake River caldera complex, and include (1) the predominantly tholeiitic basaltic, E-W striking, 40x80 km, Misema caldera volcanic rocks and the both tholeiitic and calc-alkaline NW-striking, 15x30 km, New Senator caldera. The dominantly felsic, ENE-striking, 15x20k km, Noranda

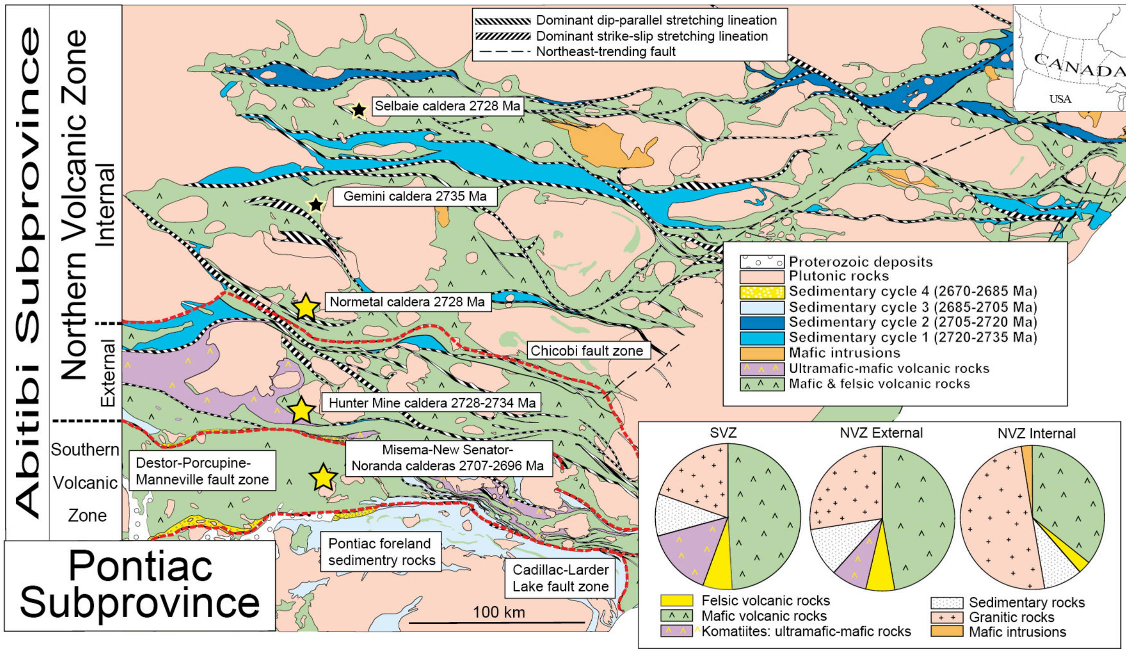

Figure 1: General geology of the Abitibi greenstone belt with the location of numerous calderas including the Misema-New Senator-Noranda complex, and the Hunter Mine, the Normetal, Gemini, and Selbaie calderas. The pie diagrams show the distribution of lithological units (modified from Daigneault et al., 2002, 2004).

caldera is the youngest event (de Rosen-Spence, 1976). The caldera complex is comparable to the overlapping Las Cañadas caldera (Marti and Gudmundsson, 2000), whereby the New Senator and Noranda calderas are tectonically-controlled, nested, graben structures (Figures 1, 2a; Mueller et al., 2009). Nested calderas have been well documented in the Campi Flegrei field, Naples (Orsi et al., 1996). Oblique subduction can explain the structural geometry of the nested calderas in Blake River megacaldera complex. Location of the VMS deposit is controlled by the faults, whereby the largest deposit favours the caldera margin or the segment between inner and outer ring faults (Figure 2a).

1.1. Methodology

Numerous field and laboratory techniques were employed. Volcanic facies mapping and gridding was conducted at the outcrop scale. A N-S- and E-W-orthogonal baseline with a 5 m spacing were placed over the entire Glenwood rhyolite in the Cap d'Ours section. All other parallel grids were conducted at 20 m intervals. Contouring of outcrops was conducted at a scale of 1:200 and completed in the SW segment with a SX Blue II Bluetooth GPS system. Volcanic facies mapping was done at a 1:400 scale and in some areas at a greater detail (1:200 to 1:100). Representative samples were collected for petrographic, geochronological and geochemical analyses in accordance with field observations. U-Pb geochronological analyses were performed by Dr. R.Friedman at the Pacific Centre for Isotope and Geochemical Research at the University of British Columbia using thermal ion mass spectrometry (TIMS). Major and trace element geochemical analyses were completed at the GEOLABS facility of the Ontario Geological Survey in Sudbury using X-ray fluorescence (XRF) for major elements and induced coupled plasma mass spectrometry (ICP-MS) for trace and rare Earth elements.

Table 1: Volcanic and sedimentary cycles in the Northern and Southern Volcanic Zones

Sedimentary cycles (remnant sedimentary basins)

SC-4) NVZ-SVZ: molasse (strike-slip) basins (phase I: 2680-2690 & phase II: 2670-2680 Ma) along major E-trending fault zones
SC-3) NVZ-SVZ: synorogenic interarc flysch basins (2686-2705 Ma) due to arc–arc collision-shortening
SC-2) NVZ: synorogenic arc unroofing basins with shoshonitic volcanism (2692-2720 Ma) and clastic deep-basin turbidite successions
SC-1) NVZ: intra-arc flysch basins with mafic-felsic volcanism (2692-2735 Ma) during incipient arc evolution

Volcanic cycles (volcanic arc-ocean floor)

VC-4) NVZ-SVZ: calc-alkaline - alkaline volcanism in molasse basins (2670-2690 Ma): Arc fragmentation
VC-3) SVZ: komatiitic - tholeiitic - calc-alkaline volcanism (2696-2706 Ma): Arc formation and ocean floor volcanism

BLAKE RIVER MEGACALDERA COMPLEX

VC-2) NVZ-SVZ: komatiitic - tholeiitic - calc-alkaline - shoshonitic volcanism (2705-2720 Ma): Arc formation and ocean floor volcanism
VC-1) NVZ: komatiitic - tholeiitic - calc-alkaline volcanism (2720-2735 Ma): Arc formation and ocean floor volcanism with large subaqueous shield volcanoes

2. INTRODUCTION AND ROLE OF PARTICIPANTS

Our multi-disciplinary Divex study focuses on the renewed economic potential and interest of the Noranda mining camp in the Abitibi greenstone belt by assessing the various caldera-forming stages, and their link to volcanogenic massive sulfide (VMS) deposits. Apart from a detailed geochemical programme and systematic sampling for U-Pb age determinations, special emphasis is placed on the interpreted summit calderas of the Misema caldera, especially the Montsabrais volcanic complex (Figure 2b), because of the VMS potential (subproject Wulf Mueller). The ring dyke complexes, the magmatic roots of the summit calderas are new exploration loci, as mafic summit calderas favour extensive hydrothermal venting. The best documented example is Axial Seamount (Figure 3) along the Juan de Fuca Ridge with the Ashes hydrothermal field. The subaqueous summit calderas are ponded magmas characterized by channelled, sheet, pillowed, and pahoehoe flows as well as related inflation structures (Applegate and Embley, 1992). Some of the ponded magmas in ancient sequences may have erroneously been interpreted as thick sills (see Moore and Mueller, 2008). The economic potential of these magma ponds should not be dismissed, because modern seafloor analogies are favourable sites (Schmincke, 2004). Associated with the volcanic flow facies of the Montsabrais volcanic complex are 20-30 m-thick volcaniclastic deposits that show an explosive origin and subsequent shallow-water reworking (mapping supplement to BSc-thesis by Levin Castillo-Guimond).

The PhD study of Lyndsay Moore constrains the evolution of the New Senator caldera in the basal part of the volcanic sequence where there is ample exposure to identify ponded subaqueous mafic magmas and felsic dome-flow complexes. At the detailed volcanic facies scale 1-2 km large felsic dome-flow centres are important loci for VMS deposits. Identification of proximal and distal volcanic facies is an important exploration tool, as it helps locate the synvolcanic faults. The novel volcanic facies studies of PhD candidate Lyndsay Moore, shows the importance of locating vents and major conduits. The associated volcaniclastic sedimentary gravity flow deposits of felsic composition was mapped in detail by Levin Castillo-Guimond (BSc-thesis). Subaqueous volcanic centres associated with VMS deposits display abundant hydrothermal alteration and carbonate-sericite-chlorite assemblage is common: The MSc-thesis by Dominique Genna focused primarily on the alteration assemblage, structure and mineralization in the Glenwood rhyolite (Cap d'Ours).

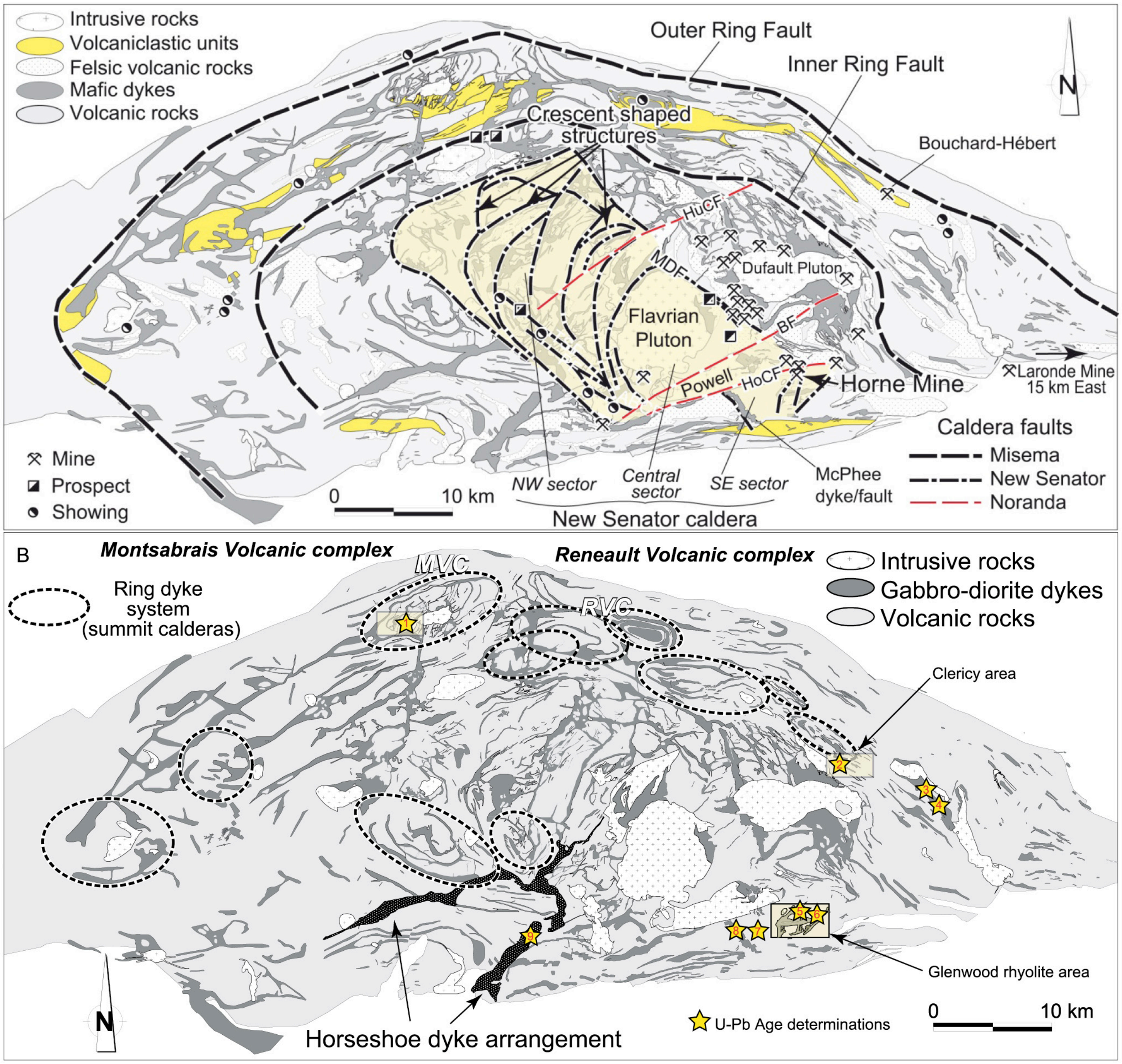

Figure 2: A) Geometry of the Blake River caldera complex. Major faults constrain the subaqueous E-W Misema, NW-SE New Senator and NE-SW Noranda calderas (from Pearson and Daigneault, 2009). MDF McDougall fault; HuCF, Hunter Creek fault; BF, Beauchastel fault, and HoCF, Horne Creek fault. Showings and mines are closely related to caldera margin faults. B) Ring dyke complexes interpreted as the roots of summit calderas and triple junction rift zone dykes (e.g. Horseshoe dyke geometry). U-Pb ages of mafic and fleisc volcanic rocks: 1-2701.5 ± 1.4 Ma; 2-2701.3 ± 3.4 Ma; 3-2702.9 ± 4.1 Ma; 4-2704.3 ± 2.0 Ma; 5-2702.3 ± 5.6 Ma; 6-2703.2 ±1.5 Ma; 7- 2701.9 +/- 1.7 Ma; Ma; 8-2698.5 ± 1.6 Ma; 9-2695.8 ± 1.5 Ma. U-Pb ages of plutonic rocks not indicated in figure.

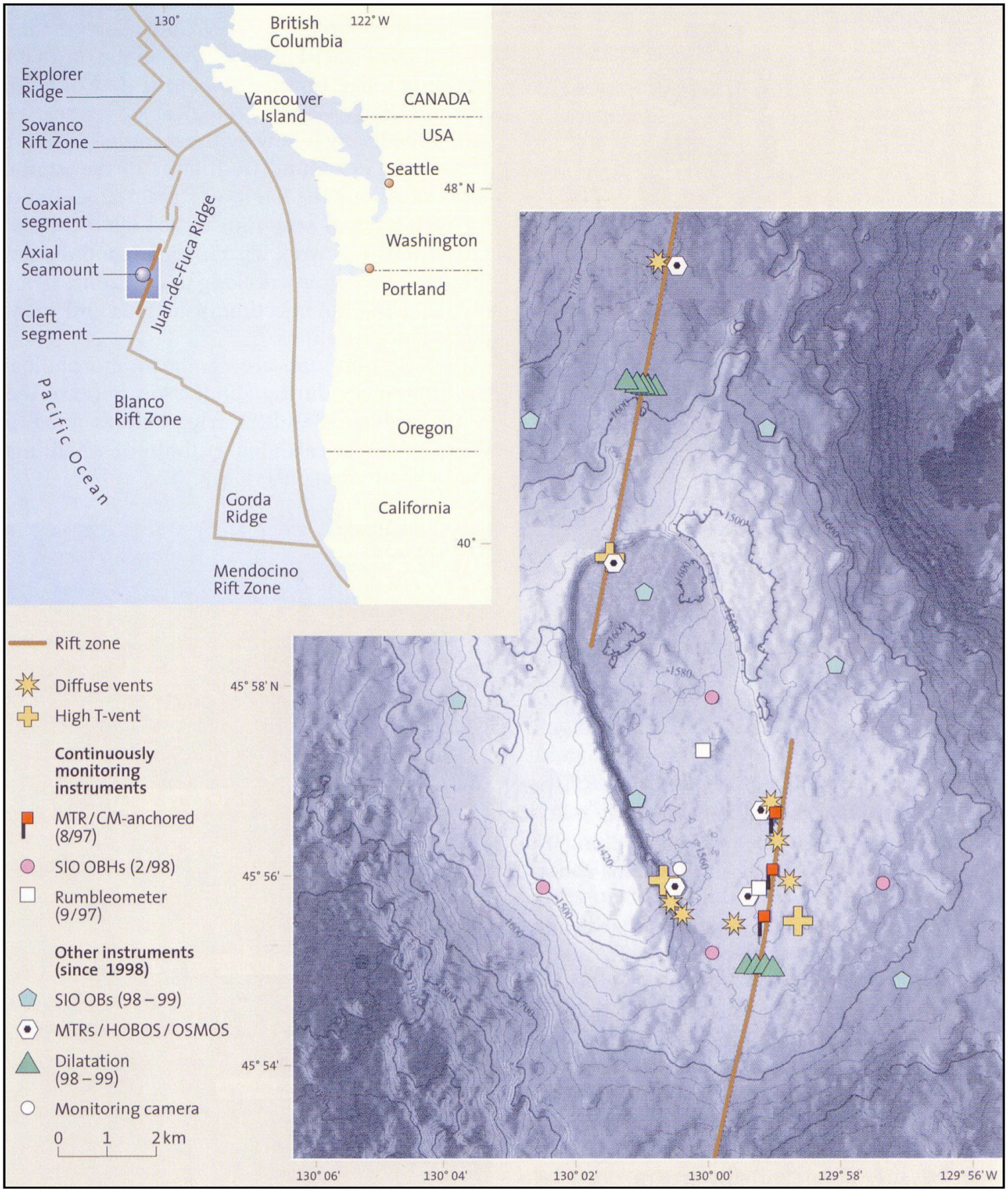

Figure 3: Location of hydrothermal vents at the caldera margin. Axial Seamount is a ca. 3x8 km mafic summit caldera located along the Juan de Fuca Ridge (from Schmincke, 2004).

3. RESULTS OF 2008

3.1. Ages determinations (Wulf Mueller, Lyndsay Moore, Richard Freidman)

U-Pb age determinations of zircons in mafic and felsic volcanic rocks provide a rigorous manner in which to test the evolution of the Blake River megacaldera complex. The primary focus is to discern the evolution of the Blake River megacaldera complex from early volcanic shield volcano-building to the evolved felsic dominated caldera stage. The presented volcanic ages give the maximum spread of Blake River evolution. The synvolcanic plutonic ages are not considered in this report but are an integral part of evolutionary history (e.g. Mueller et al., 2008a).

A rigorous approach was used, and at every site mafic and felsic, or plutonic rocks were sampled. The basal New Senator caldera, the Montsabrais volcanic complex, and the Clericy area, at intersection Noranda and Misema calderas, were emphasized (Figure 2a, b). Numerous samples did not yield any zircons, and often a chemical abrasion method was required. This was especially true for the mafic dykes and sills. The mafic dykes and sills were primarily sampled to chronicle the evolution of the Misema caldera and to evaluate the Blake River synvolcanic fault system.

3.1.1. U-Pb ages (locations in Figure 2b) and Brief Description

***1**-2701.5 ± 1.4 Ma, Misema caldera (UTM-17U Nad 83- 0659091/5355241):* Montsabrais volcanic complex with ring dykes. The medium-to fine-grained gabbros and diorites (m- to 100m-thick; Figure 4a, b) intrude the pillowed flows and the volcaniclastic deposits. They are considered the magmatic roots of the subaqueous summit calderas that are associated with the Misema caldera. The summit caldera may be somewhat latter is the history of the Misema shield to caldera stage.

***2**-2701.3 ± 3.4, Ma Misema caldera, Clericy region (UTM-17U Nad 83- 0651021/5358334):* The several 100 m-thick gabbro dyke has locally been subjected to hydrothermal alteration processes. The linear dyke-sill, traceable laterally for several kilometres along strike, intruded high in the volcanic sequences as it cross-cuts the subaqueous pyroclastic rocks and massive to pillowed flows of the Clericy-Mobrun area (see DIVEX report 2007). The pyroclastic sequence is considered to be part of the older explosive Misema event and possibly correlative with the Montsabrais volcaniclastic and explosive event (Mueller et al., 2009).

***3**-2702.9 ± 4.1 Ma, Misema caldera, Clericy region (UTM-17U Nad 83- 0659091/5355241):* The Clericy gabbro is generally medium-grained and an up to 1 km-thick mafic intrusion. It is intruded by the Clericy tonalite pluton (2696 Ma), and displays a pervasive N60 to N70 hydrothermal alteration and fracturing pattern, consistent with the influence of the Noranda graben caldera.

***4**-2704.3 ± 2.0 Ma, Misema caldera, Clericy region (UTM-17U Nad 83- 0659514/5355061):* This is another sample from the Clericy gabbro, but from the most evolved phase (Figure 5a, b). It is thusfar the oldest age for a mafic rock in the Blake River megacaldera complex, and shows that the mafic plumbing system was already well established during the Misema caldera event.

***5**-2702.3 ± 5.6 Ma, New Senator caldera, Glenwood rhyolite, Rouyn-Noranda (UTM-17U Nad 83- 0648375/5344279):* The felsic rocks of the Glenwood rhyolite have a aphyric and quartz-feldspar phyric phase (Figure 6), of which only the later yielded zircons suitable for reliable age determinations. The sample area adjacent to the once principal mining shaft is an endogenous lobe highly altered and locally mineralized. The m-scale endogenous lobe shows excellent flow-banding and columnar jointing, and displays *in-situ* brecciation.

***6**-2703.2 ± 1.5 Ma; New Senator caldera; Glenwood rhyolite, Rouyn-Noranda (UTM-17U Nad 83- 0648177/5344256):* The quartz-feldspar phyric dyke to lobate intrusion has a sharp contact with the aphyric flow breccia (Figure 6). Alteration and deformation is low in this segment of the Glenwood rhyolite, as the surrounding breccias have taken up these attributes. This is the oldest age yet obtained in the central mining camp of Rouyn-Noranda, and supports the notion of a pre- Noranda caldera-forming event.

7-2701.9 ± 1.7 Ma, New Senator caldera, Hydro-Quebec, Rouyn-Noranda, (UTM-17U Nad 83- 0644509/5345183): Quartz-feldspar and aphyric fragments or rafts are entrained in mafic flows and ponded magmas. The mafic sequence must therefore be older and is consistent with a New Senator event.

***8**-2698.5 ± 1.6 Ma, New Senator caldera, McPhee dyke (UTM-17U Nad 83- 0642691/5343393):* The mafic dyke is a quartz-rich gabbro known for its mineralized zone. The several 100 m-thick mafic dyke system is inferred to intrude the New Senator caldera wall (Figure 2a). It is possible that this is the

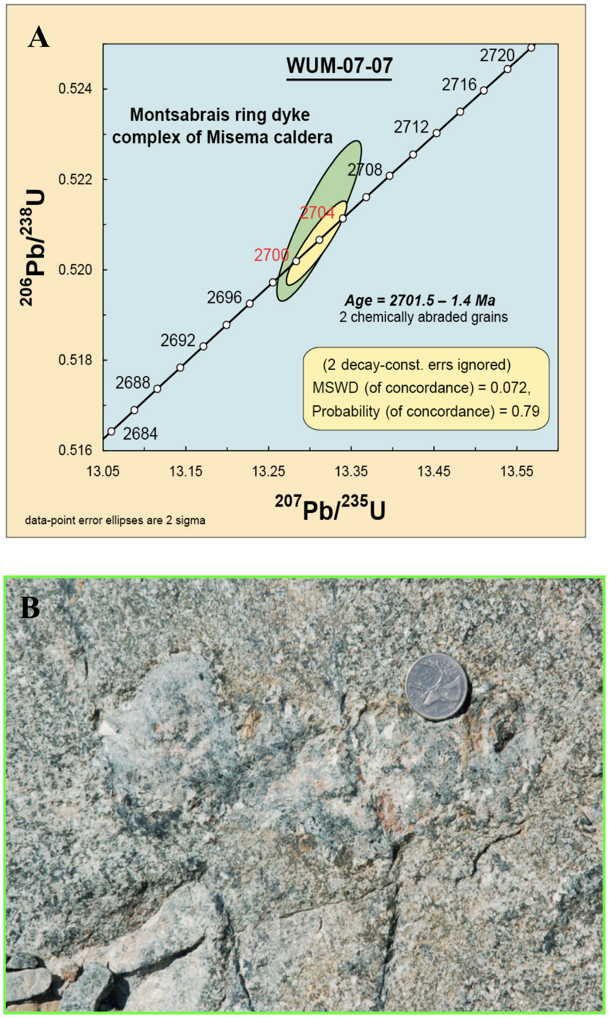

Figure 4: A) Concordia age determination of 2 chemically abraded zircons from a gabbro in the ring dyke complex of the Montsabrais volcanic centre. B) Medium-grained gabbro with small pockets of quartz-amphibole, commonly enriched in zircons. The pockets represent the last magmatic (exsolution-explusion) events in the development of dyke-sills.

last and most evolved dyke phase, and therefore show a younger than presumed age of 2700-2700 Ma. The dyke intruded a synvolcanic fault system, in which hydrothermal fluids percolated.

9-*2695.8 ± 1.5 Ma, Misema caldera, Evain, Horseshoe dyke system (UTM-17U Nad 83- 0627599/5345001):* The complex volcanic rift zone is composed of a km-thick dyke system, and numerous samples from all rift arms were taken but only one sample yield an age. The sample was taken from the most evolved segment of the dyke in the volcanic rift, as large pockets of quartz-amphibole were present. The young age possibly suggests the long evolution of the rift system, or alternatively indicates a late mafic intrusive event, unrelated to the caldera phase. The former is favoured due to complex emplacement history of rift dykes.

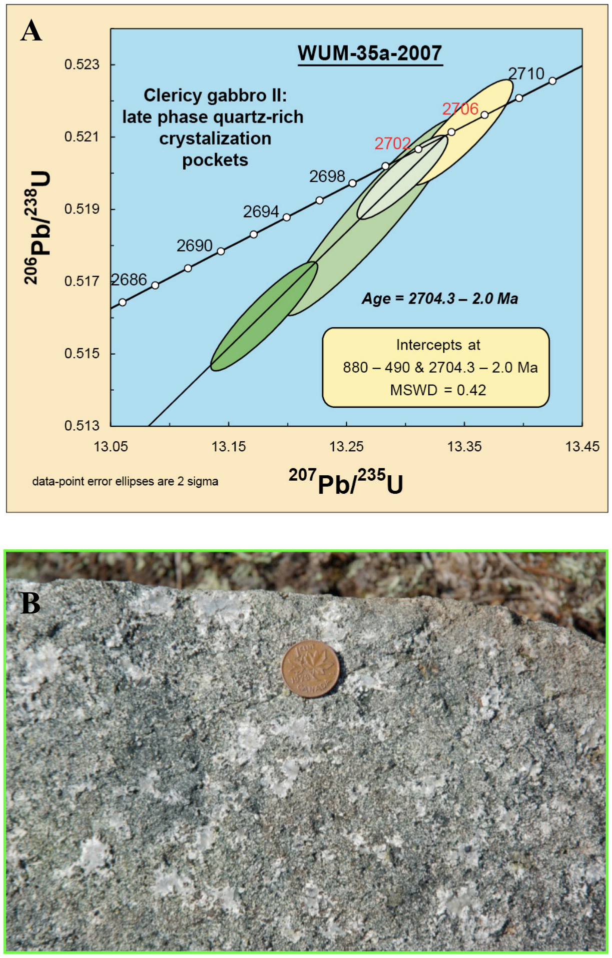

Figure 5: A) Concordia diagramme of Clericy gabbro with the most evolved quartz-rich gabbro phase. The regression line has an upper intercept of 2704.3 ± 2.0, which is considered the age of crystallization. B) Medium-grained quartz gabbro with cm-to mm-scale quartz rich quartz patches.

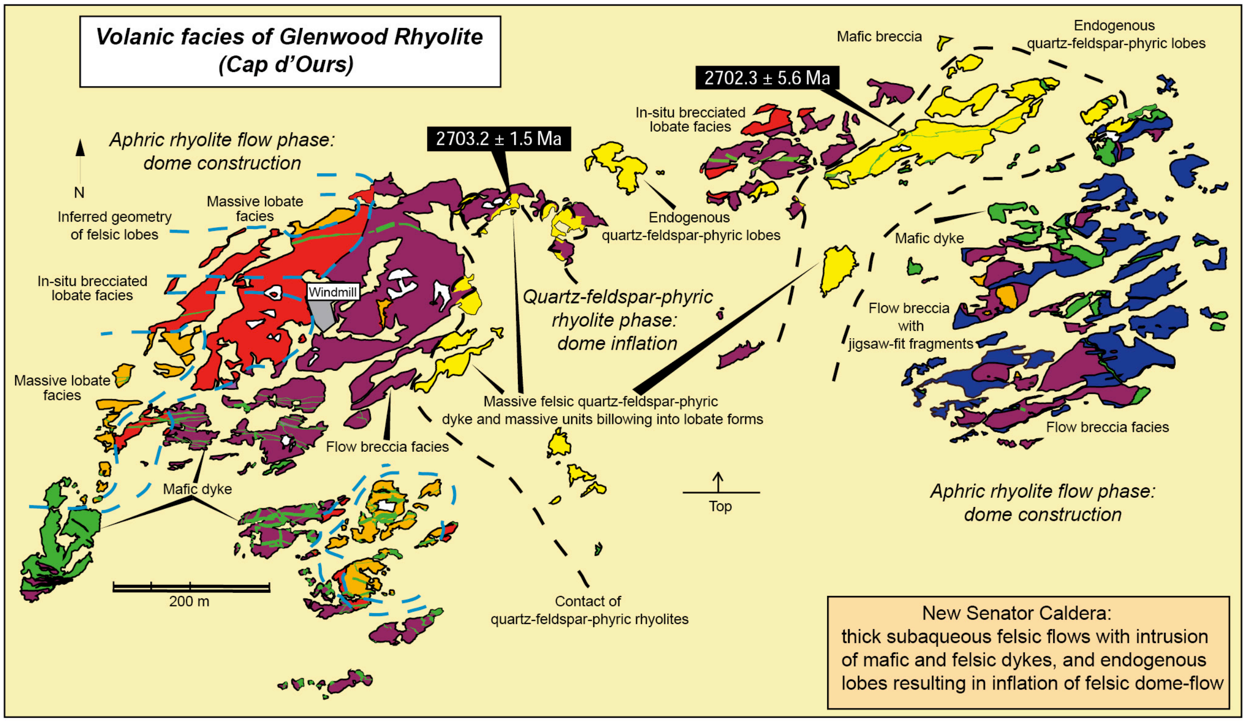

Figure 6: Volcanic facies of the Glenwood rhyolite (Cap d'Ours). Note the aphyric volcanic construction phase and the quartz-feldspar-phyric inflation stage. U-Pb ages shows that the Glenwood rhyolite is part of the New Senator caldera event (Mapped by Moore, Genna, Mueller, 2008).

3.1.2. Interpretation of Data

The U-Pb age determinations show that the Blake River megacaldera complex evolved over roughly 10-12m.y., from 2706- 2696-94 Ma (if errors are included). The evolution of a single caldera is rarely more than 1-2 m.y., but if one considers caldera multiple events and includes the basal shield volcano phase then time scales of 6-13 m.y. for a complete evolutionary development are common, shown for the continental Valles caldera, and especially for the oceanic island, Tenerife with the Las Cañadas caldera. The study shows that there are numerous ages for the mafic volcanic rocks with the oldest documented event at ca. 2704-2706 Ma. The development of a mafic basalt plain and numerous overlapping shield volcanoes is therefore real and represents the base for subsequent complex caldera evolution. The ring dykes may be somewhat younger at 2701-2702 Ma, but are certainly related to the mafic constructional phase, possibly occurring at the same time as the New Senator caldera between 2703-2700 Ma. A possible scenario is that while a central felsic volcano and caldera system developed in the central Blake River, the mafic dominated rim represented by the Misema caldera, showed the formation of numerous summit calderas along major rift zones. This would be analogous to the modern and active rift zone on Hawaii (Mueller et al., 2009). Felsic volcanism of 2703 Ma, represented by the Glenwood rhyolite, re-enforces the interpretation by Pearson and Daigneault (2009) of the older New Senator caldera.

Calderas occur in clusters and are overlapping events (Mueller et al., 2008b). The Blake River megacaldera complex is no exception, and shows a complex history that can only be resolved with detailed facies mapping and geochemistry in conjunction with U-Pb age determinations. As stratigraphic concepts are of little use, volcanic facies must identify intrusive and extrusive volcanic phases, and only then do the ages make any sense. Our major contribution is understanding and documenting the evolution of the mafic rocks in the scheme of caldera formation. The ages of extrusive and intrusive felsic rocks constrain local felsic edifice construction (e.g. Glenwood rhyolite).

3.1.3. Continuation of Misema-New Senator Project: Age determinations

This subproject is now in the evaluation phase as additional samples for 2009 are not foreseen. A manuscript with the results will commence shortly once all data has been finalized. Some data sets had required additional sampling and these are now forthcoming (summer 2009). A total of 33 samples were taken for geochronological studies, but many samples did not yield sufficient zircons. Somewhat disappointing only half of the samples (13-16) yielded high quality results suitable for publication.

3.2. **Glenwood Rhyolite** (Lyndsay Moore, PhD, Dominque Genna, MSc)

Two aspects were considered in 2008: (1) the physical volcanology and geochemistry (Lyndsay Moore) and (2) the alteration, mineralization and deformation (Dominque Genna) of the Glenwood rhyolite. The former is briefly presented in this report. The Glenwood rhyolite is a 800-1000 m-thick felsic succession located in the town of Rouyn-Noranda proper (Figure 6). The rhyolite is intruded by numerous dyke generations and conformably overlain by pillowed and brecciated mafic volcanic rocks. The felsic and mafic volcanic facies are indicative of a subaqueous setting. The felsic Glenwood rocks at Cap d'Ours are divided into aphyric (aphanitic) and quartz-feldspar-phyric rhyolites. The 100-400m-thick aphyric rhyolites are lava flows construct a subaqueous dome, and contain several volcanic flow facies, which include: (1) massive lobate facies, (2) *in-situ* brecciated lobate facies, and (3) flow breccia facies. Sericitization, chloritization, and silicification indicate the hydrothermal alteration processes, and this is readily identified in the volcanic matrix. The 5-50m-thick, quartz-feldspar-phyric flow forms (Figure 6) are divided into a (2) massive to dyke facies and (2) an endogenic lobate facies. Alteration assemblages are pronounced in the lobate facie for thes. This volcanic facies is responsible for the inflation of the dome-flow edifice. The mafic dykes post-date the felsic event and feed the overlying mafic pillowed flows that cap the Glenwood rhyolite.

3.2-1. Aphyric flow units (Figure 6)

Massive lobate facies: The 20-200 m-thick lobate facies is prominent west side of the Cap d'Ours and is local in the east. Internally, the lobes are nearly massive and in some areas appear brecciated. Smaller lobate structures (<5 m) are common within the large lobes, and display the complex propagation of flows. Locally columnar jointing (5-15 cm; Figure 7) is developed. Flow banding is prevalent throughout the flow facies and accentuated by sericitic and silicic alteration. The buff white to yellowish weathering colour is characteristic, and distinguishes this facies from the others.

Figure 7: Columnar-joints of the massive lobate facies with pervasive silicification. Scale: pen 13 cm.

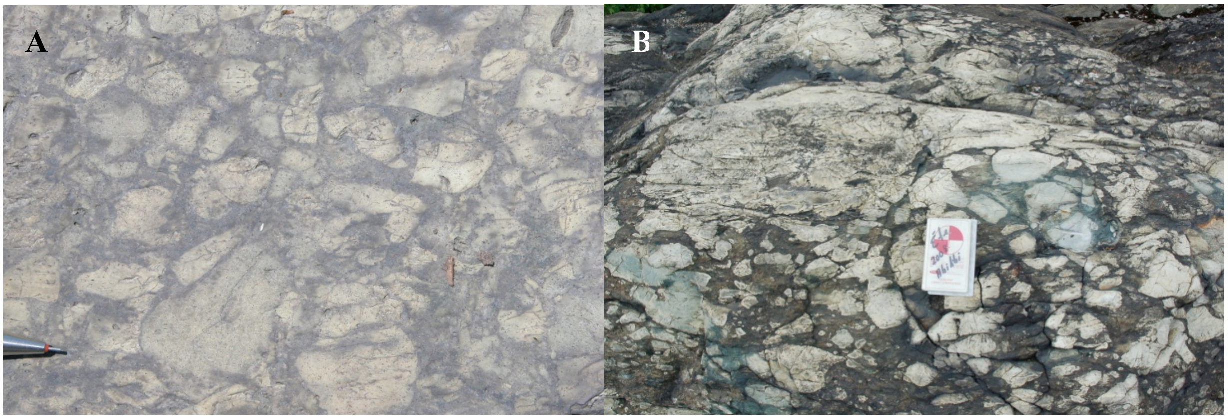

Figure 8: Characteristics of the Glenwood breccias, Cap d'Ours. A) Felsic flow breccia facies with rounded to angular clasts in an altered volcanic matrix. Scale, pen tip, 2 cm. B) Felsic flow breccia with a jigsaw fit of flow fragments. The angular to amoeboid clast are silicified and the matrix shows a chlorite and sericite alteration. Scale, fieldbook, 20 cm.

In-situ brecciated lobate facies: The massive lobate facies grades abruptly into the 5-130 m-thick, in-situ brecciated lobate facies. Small, m-scale, flow-banded lobate structures are dispersed in a breccia, in which cm-scale clasts are rigidly connected to the flow. Clasts are angular, and indicate the changing flow conditions.

Flow breccia facies: The felsic flow breccia facies dominates the volcanic stratigraphy of the Cap d'Ours and has two subfacies with (i) *felsic flow breccia* (Figure 8a) and (ii) *felsic flow breccia with jigsaw-fit fragments* (Figure 8b). There is a gradual transition between these two subfacies. The 2-80 cm (average 5 to 30 cm) subangular to angular felsic fragments of the felsic flow breccia are angular, but local amoeboid fragments (< 10%) are also present. Columnar-jointed clasts detached from massive lobate segments are rare, but show how the flow evolves, as it incorporates and cannibalizes its own lobes during flow advancement. Larger fragments exhibit *in-situ* brecciation and are polycuspate. The clasts display straight to cuspate fractures, perlitic cracks, and can be flow-banded. Vesicularity (amygdules: filled vesicles) of fragments is highly variable from 0 – 35% and is to be expected in such viscous volcanic flows. The felsic flow breccia with jigsaw-fit fragments is characteristic of autoclastic breccias. The clasts split along thermal fracture planes during flow. This subfacies, in the scheme of breccia formation, occurs prior to the formation of the felsic flow breccia because of the texture. Silicification is pronounced, and the matrix displays a sericite-chlorite alteration.

3.2.2. **Quartz-feldspar-phyric units** (Figure 9)

The central segment of the Glenwood rhyolite displays dome inflation, whereby dykes and correlative endogenous domes intrude the aphyric rhyolites. Phenocryst composition is 2-5% quartz (0.5-3 mm) and 20-40% feldspar (0.2-4 mm). *Massive and dyke facies*: The massive units, due to the sharp intrusive contact with the brecciated flows and different phenocryst composition, are considered massive units and dykes, if both margins are observed. Flow-banding as common at the dyke margins, as is a change in phenocryst size. The contact is locally highly irregular suggesting intrusion into a non-consolidated volcanic flow. A direct transition into the endogenic lobate facies was not observed, but outcrop-scale mapping suggests a direct relationship.

Endogenic lobate facies: The endogenic lobate facies is complex unit and has the physical flow attributes of the aphyric rhyolite phase. This lobate facies intrudes the aphyric rocks, and helps constrain the mineralization events. The 10's of metre endogenous dome is columnar-jointed, has m-scale, flow-banded lobate structures, and displays in-situ brecciation. The 5-20 cm large columnar joints are associated with the lobate structure. The volcanic unit is highly altered and appears linked to the mineralization event, as the observed sulfides occurs at the dome margin or within the unit.

Figure 9: Metre-scale flow-banded lobe in endogenic lobate facies of quartz-feldspar-phyric units. Note alteration and sulfide stains, as lobes are adjacent to principal mining shaft. Scale, fieldbook, 20 cm.

3.2.3. Continuation of New Senator Project

The New Senator caldera volcanic facies mapping project by Lyndsay Moore (PhD) started in 2007 and summer 2009 is the last mapping season. Emphasis will be placed on completely selected areas of the New Senator caldera (e.g. Lake Noranda). Larger-scale mapping of the area will be conducted to place the detailed work into an overall New Senator caldera setting. The field portion of the MSc-thesis of D. Genna is terminated and a first draught of the thesis should occur summer 2009. Levin Castillo-Guimond will submit the final version of his BSc-honor's thesis also in summer 2009.

3.3. Montsabrais volcaniclastic sequence

(Levin Castillo-Guimond, Wulf Mueller)

The volcanic-volcaniclastic deposits of the Montsabrais volcanic complex are the first evidence of a shallow-water depositional setting associated within central ring dykes of the Misema caldera (Figure 10). Dimroth et al. (1985) interpreted the massive and stratified lapilli tuff breccias in the Montsabrais region as pyroclastic pillow breccias, but the here described cross-bedded units had not yet been identified. In the innovative paleographic model of the Blake River Group, Dimroth et al. (1982) advocated a shoaling volcanic centre at Montsabrais that has abundant explosive volcanism. It is possible and logical that the volcaniclastic sequence at Montsabrais is time-correlative with the Dalembert tuff (Tasse et al., 1978), the Jevis and Kino pyroclastic deposits of the Clericy-Bouchard–Hebert area (Pilote et al., 2007, 2008) and the Stadacona breccia of Noranda (Mueller et al., 2009), as these units are compositionally similar (e.g. basaltic to basaltic andesite) and are contain massive to stratified beds with abundant pumice, euhedral and broken crystal and lithic volcanic fragments (see Figure 2a and location of volcaniclastic deposits). The abundant mafic explosive volcanism is constrained between the inner and outer ring faults of the Misema caldera, and this is also where most of mafic summit calderas are located.

Figure 10: Altered m-scale mafic pillow flow units conformably overlain by cross-bedded and planar stratified tuff and lapilli tuffs. Note thin-tuff beds indicating suspension deposits. Scale blue pen: 14 cm.

3.3.1. Primary mafic volcanic flows

The massive, pillowed (Figures 10, 11) and pillow breccia basalt flows are highly vesicular and amydule-rich in the study area. The silica- and chlorite-filled vesicles are mm to cm-scale. The metre-thick massive flows have sharp upper depositional contact with the volcaniclastic sequence and erode the volcaniclastic deposits at the base (Figures 12a). Locally peperites, a magma-wet sediment interaction, form. The pillows are metre-scale and closely packed (Figures 10) with little hyaloclastite material.

3.3.2. Reworked volcaniclastic deposits

The up to 2-30 m-thick volcaniclastic deposits are primary composed of massive, graded and stratified lapilli tuff and lapilli tuff breccias that occur in 0.20-2.0 m-thick beds. The beds have sharp upper contacts and erosional bases. The units were deposited by laminar to turbulent sediment gravity flows, but local stratification suggests unsteady conditions with bedload transport (Lowe, 1982). The clasts are highly vesicular-amydaloidal (Figures 12b), and may be formed via explosive disintegration or autoclastic fragmentation. The preferred interpretation is an explosive origin with subsequent reworking due to the presence of interstratified cross-bedded units.

The cross-bedded tuffs and lapilli tuff beds, 1-30 cm-thick are important as they are indicative of the transport process and hence depositional setting (see Corcoran and Moore, 2008). The cross-beds have erosive basal contacts and some display tangential foresets. Overall each bed fines upward and is capped by a 0.5-2cm-thick fine-to coarse-grained tuff that indicates a pause in energy transport condition: suspension sedimentation is prevalent (e.g. Mueller, 2003). The cross-beds are indicative of traction current deposits, and although deep-water turbidite sequences may generate such structures, the volcanic facies association would favour a shallow-water setting, in which waves reworked the autoclastic-pyroclastic debris. Water depths of metres to tens of metres are envisaged. As suggested by Dimroth et al. (1982, 1985), shoaling of a mafic volcanic edifice is the best explanation for such sedimentary structures.

Figure 11: Mafic pillow flow units overlain by tangential cross-beds and planar beds that have thin tuff pause (suspension) plane deposits at the top of each depositional event. Note irregular contact with pillows Scale, pen: 14 cm.

3.3.3. Continuation of Montsabrais Project

This investigation was part of the BSc-thesis, but merits considerable attention (new PhD or MSc-thesis), as the area of Montsabrais has a strong economic potential, even though a shallow-water setting may not be considered favourable. Additional detailed volcanic facies mapping (e.g. Corcoran, 2000) is required to understand these ring dyke complexes as they seem to be associated with explosive volcanism and lava flows. Interestingly, effusive dominated summit calderas of Hawaii display are associated with explosive mafic volcanism.

Figure 12: A) Erosive contact at base of amydule-rich massive basalt flow with stratified lapilli tuffs. Scale, fieldbook, 20 cm. B) Highly vesicular pyroclast in lapilli tuff breccia. Scale, pen tip: 3 cm.

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