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Reconstruction and evolution of Archean intracaldera facies: the Rouyn-Pelletier Caldera Complex of the Blake River Group, Abitibi greenstone belt, Canada

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Abstract

Sub-vertically- to vertically-dipping Archean strata provide an excellent opportunity to study synvolcanic structures and internal organization of subaqueous volcanic complexes. The Abitibi greenstone belt in Quebec, Canada, hosts a number of these volcanic complexes and specifically the unique Blake River megacaldera complex (BRMCC). The BRMCC is composed of 1) an initial shield phase known as the Misema caldera and 2) two graben-type calderas known as the New Senator and Noranda calderas. The southern portion of the New Senator caldera (SNSC), the focus of this study, is of particular interest as the structure hosts the 54 Mt Horne Au-rich VMS deposit.

Detailed facies mapping, coupled with geochemical and geochronological analysis at multiple outcrop localities throughout the city of Rouyn-Noranda, Quebec, show that the stratigraphy of the SNSC is dominated by subaqueous effusive mafic volcanic facies with local felsic effusive and intrusive deposits. With the incorporation of structural data, we have used synvolcanic faults and dyke complexes to divide these facies into specific blocks within this region, here renamed the Rouyn-Pelletier sector. This study focuses on the facies and characteristics of the Pelletier, Senator and Glenwood blocks and identifies the Évain, Stadacona and Chadbourne blocks.

Geochronological analysis reveals that facies of the Glenwood block are approximately the same age as those of the felsic flows of the previously identified Horne block. Together, all extrusive and intrusive volcanic facies from the Stadacona unit north to the Horne Creek Fault compose a large caldera complex known as the Rouyn-Pelletier caldera complex.

Key words: Archean, subaqueous, caldera, volcanic architecture, facies

23 **1.0 Introduction**

24 The Abitibi greenstone belt is the world's largest greenstone belt and has been explored and
25 studied for over 100 years for orogenic gold and VMS deposits. For the latter, much focus has
26 been placed upon the belt's vast mineral wealth, such as the world class Horne (Dimroth et al.,
27 1982; Gibson and Watkinson, 1990; Kerr and Gibson, 1993), LaRonde-Penna (Mercier-
28 Langevin et al., 2007 a, b) and Kidd Creek (Hannington et al., 1999) deposits. However, sub-
29 vertically- to vertically-dipping strata in a terrain dominated by volcanic units provide a wealth
30 of information regarding the internal architecture of the volcanic edifices hosting these deposits.

31 Pearson and Daigneault (2009) brought renewed interest to the volcanic evolution of the Blake
32 River Group in the Abitibi greenstone belt when they proposed the presence of a large
33 megacaldera complex known as the Blake River Megacaldera Complex (BRMCC) (Fig. 1). The
34 complex consists of the large 40 x 80 km Misema Caldera with two smaller interior nested
35 caldera structures known as the New Senator Caldera (14 x 35 km) and the Noranda Caldera (15
36 x 20 km). These dimensions represent the present dimensions of the complexes and do not take
37 into account the shortening effect associated with the regional deformation. The Noranda
38 Caldera (or Noranda "cauldron") has been recognized for decades (Gibson, 1989; Kerr and
39 Gibson, 1993) but the proposition of an older nested caldera structure (New Senator Caldera) and
40 a host megacaldera (Misema Caldera) have implications for mineralization outside the central
41 camp (Mueller et al., 2008; Pearson and Daigneault, 2009).

42 The volcanic stratigraphy south of the Noranda camp is of particular interest because of the 54
43 Mt gold-rich volcanogenic massive sulfide (VMS) Horne deposit located just south of the Horne
44 Creek Fault. To date, the stratigraphy of the Horne block has not been confidently correlated

across the Horne Creek Fault and into the Noranda camp (Gibson et al., 2000; Monecke et al., 2008); leaving the question of the stratigraphic and structural relationship between the Horne deposit and the central camp. Compilations of previous radiometric dating and new geochronological analysis of the Blake River Group by McNicoll et al. (2014), show that several VMS deposits (e.g. Quemont, Horne, Fabie and Hébécourt) correlate with a cycle of eruptive events at approximately 2702 Ma that pre-date the central Noranda camp by almost four million years. Given the lack of correlation with the stratigraphy of the central camp and an age difference of approximately four million years (even considering age uncertainties), it is plausible that the Horne deposit formed in relation to a different volcanic complex.

Detailed mapping conducted by Moore et al. (2012; 2014) on successions south of the Horne deposit shows that the stratigraphy of the southern Rouyn-Noranda area is dominated by effusive mafic sequences with ponded lavas (Fig. 2; Moore et al., 2012) interspersed with infrequent felsic volcanic deposits (e.g. the Glenwood Felsic Flow Complex; Moore et al., 2014). These individual events within the southern sector of the New Senator Caldera (NSC) structure as defined by Pearson and Daigneault (2009), suggest the presence of a dominantly effusive subaqueous volcanic complex. The focus of this study is to formulate a complete stratigraphic model of the volcanic and intrusive facies within this sector of the NSC, determine their relationship with the host volcanic environment and determine if facies of the Horne block are associated with these facies directly south of it. Detailed facies analysis, in conjunction with geochemical and geochronological studies, is employed to identify distinct eruptive events.

In the first segment of this paper we present detailed facies, petrographic and geochemical analysis of numerous outcrops located across a region from south of the Horne Creek Fault to the northern shore of Lac Pelletier (Fig. 2). These analyses are divided into mafic and felsic

volcanic deposits to emphasize 1) the typical initial mafic basal stratigraphy characteristic of seamounts in arc environments and 2) the evolution to a more bimodal system. Following this, a comprehensive volcanic model integrating all of these eruptive events in the context of a single volcanic complex within the BRMCC will be proposed.

2.0 General Geology

2.1 Abitibi Greenstone Belt

The Abitibi greenstone belt, located in the Superior Province of Canada, is an east-trending volcanic-sedimentary belt intruded by numerous plutonic suites. The 300 x 700 km belt straddles the modern day Ontario and Quebec geopolitical boundary and is divided into northern and southern domains (Northern and Southern Volcanic Zones – NVZ and SVZ respectively) by the Destor-Porcupine-Manneville Fault Zone (see inset; Fig. 1) (Dimroth et al., 1982; Ludden et al., 1982; Chown et al., 1992). Thurston et al. (2008) interpret that this subdivision does not exist due to the similar ages of individual lithostratigraphic units in both domains (Thurston et al., 2008).

The SVZ is further divided into stratigraphic groups, of which the Blake River Group is a part. The stratigraphy of the BRG was traditionally divided into the Misema and Noranda sub-groups by Goodwin (1977) but was then divided into the Lower and Upper Blake River Groups (Ayer et al., 2002; Goutier et al., 2009). This division remains in Ontario but within Quebec, the BRG is further divided into the Reneault-Dufresnoy, Rouyn-Pelletier, Duprat-Montbray, Hébécourt, Horne, Camac, Dupuis, Bousquet and Noranda Formations by Goutier et al. (2009) and McNicoll et al. (2014).

Subaqueous volcanism formed the BRG over an interval extending from 2704 to 2695 Ma (Goutier et al., 2009; McNicoll et al., 2014). The composition of lavas and related volcaniclastic products ranges from basaltic to rhyolitic with affinities ranging from tholeiitic to calc-alkaline (Sterckx et al. 2013; 2014). Early volcanism (Lower Blake River Group) began with the eruption of mostly high Fe to high Mg tholeiitic basalts interspersed with minor felsic lavas that later transitioned into bimodal volcanism (Peloquin, 2008; Thurston et al., 2008; Goutier et al., 2009). Repeated intrusive activity is represented by numerous plutons and mafic to intermediate dykes and sills.

2.2 Blake River Megacaldera Complex

The BRMCC has been described in terms of three caldera structures by Pearson and Daigneault (2009): the large, host Misema Megacaldera and two nested and overlapping caldera structures known as the New Senator and Noranda Calderas (Fig. 1; Pearson and Daigneault, 2009, Mueller et al., 2012). The three structures are identified and defined by the distribution and geometry of synvolcanic faults and dyke complexes and the organization of intrusive and volcanic facies. The New Senator caldera is a northwest-trending structure divided into three sectors: the northwest, central and southeast (Mueller et al., 2012; Fig. 1). Tholeiitic to calc-alkaline extrusive and intrusive facies were emplaced between approximately 2702 – 2700 Ma (Mueller et al., 2012; McNicoll et al., 2012).

2.3 The Rouyn-Pelletier Sector

The study area focuses upon a 4 x 8 km area of the southeast sector of the New Senator caldera; an area delimited by faults and major dyke complexes and hereby identified as the Rouyn-Pelletier sector (RPS, Figs. 1, 2). The RPS is bounded to the north by the Horne Creek fault and

111 to the south by the Stadacona unit (described below). Bounding the western margin of the sector
112 is the NW-trending McPhee dyke complex (also known as the Seguin gabbro); interpreted as a
113 synvolcanic fault by Mueller et al. (2012) and separating the sector from the Évain felsic
114 complex to the west. The eastern limit is less defined due to the effects of deformation and
115 folding but the Glenwood synvolcanic fault (described below; Mueller et al. 2012) will be
116 considered as an internal limit near a principal one further east that is obscured by deformation.

117 In addition to being fault-bounded, the RPS is also cross-cut by several ENE-trending faults,
118 such as the Andesite Fault, that are interpreted by many authors as synvolcanic in origin (Wilson
119 1941; Gibson and Galley 2007; Moore et al., 2014). The Perreault Fault (informally named)
120 bounding the southern limit of the Glenwood Felsic Flow Complex is one such fault, with
121 associated hydrothermal alteration and hosting a fault-filling mafic dyke. Several NE- and N-S-
122 trending fault sets are also recognized as synvolcanic. The NE-trending Glenwood Fault is
123 located at the eastern margin of the Glenwood Complex and is defined by hydrothermal
124 alteration, a series of NE-trending gabbroic dykes, and has variable orientation of volcanic facies
125 along its strike; features characteristic of synvolcanic faults (Mueller et al., 2012). Additionally,
126 both the Osisko and Iberville N-trending dyke complexes are also believed to be hosted within
127 primary synvolcanic fractures (Moore et al., 2014). The Osisko dyke complex is N to NE-
128 trending along its western extent and then extends eastward, forming a T-shaped intrusion and
129 bounding the upper contact of the Glenwood Complex. The N-trending Iberville dyke complex
130 cross-cuts the centre of the Glenwood Complex and is an example of dyke-in-dyke injection with
131 both Archean- and Proterozoic-aged phases (Moore et al., 2014). It is important to note at this
132 time that the amount of displacement and/or subsidence along these faults is often masked by
133 later movement associated with later deformation.

Stratigraphy of the RPS is primarily organized as a north-facing homoclinal sequence with a few rotated or folded panels. In this study, attention will be paid to successions extending from the northern limit of the Stadacona unit (Ross et al., 2008), a 1 x 7 km east-trending mafic to intermediate volcanoclastic unit (Fig. 2). From this contact to the southern limit of the Horne block (Fig. 2), the stratigraphy of this mostly homoclinal sequence is dominated, in no particular abundance, by basaltic sills and pillowed and massive flows with mainly tholeiitic to transitional magmatic affinities.

Volcanic facies north of the Stadacona volcanoclastic unit consist of mafic lavas and intrusions until the Glenwood Felsic Flow Complex (Moore et al., 2014). North, west and east of the Glenwood Complex, volcanic facies are typically mafic to intermediate until just south of the Andesite Fault (Monecke et al., 2008; Moore et al., 2012; Moore et al., 2014). Volcanic facies north of the Andesite Fault are bimodal but dominated by felsic volcanic and volcanoclastic facies of the Horne Block (Fig. 2). Mafic to intermediate intrusions are also a significant facies, with several large intrusions marking major synvolcanic faults such as the McPhee, Osisko and Glenwood dyke complexes (Pearson and Daigneault, 2009; Mueller et al., 2012; Moore et al., 2014). All volcanic deposits south of the Horne block have undergone sub-greenschist to greenschist metamorphism (Powell et al., 1995) and weak to moderate alteration such as silicification, carbonatization, chloritization and epidotization (Genna et al., 2011; Moore et al., 2012).

2.4 Deformation of the Rouyn-Pelletier sector

Regional deformation within the Rouyn-Pelletier sector and the Blake River Group in general is largely attributed to a N-S horizontal shortening event (Daigneault et al., 2004; Mueller et al.,

2012). The area is characterized by a heterogeneous distribution of ductile deformation. The shortening event primarily manifests as a sub-vertical foliation expressed as a slaty cleavage preferentially developed around synvolcanic faults due to softening facilitated by hydrothermal alteration. This fabric is globally E- to ENE-trending and contains a sub-vertical stretching lineation (Fig. 3a). Overprinting and masking of some primary volcanic textures occurs in relation to this lineation but its sub-vertical attitude allows for the preservation of primary textures and organization in plan view (Y-Z section; Moore et al., 2014).

The region between the Perreault Fault and the Stadacona unit (Fig. 2) is considered as a specific structural domain; distinguished from the rest of the north-facing homoclinal sequence. Present within the domain are two distinct, east-trending fold axial traces directly south of the Glenwood Felsic Complex (Fig. 2) (Mueller et al., 2012). These folds are moderately open in their western extent but become more closed further to the east, exhibiting an overall Z asymmetry. This folding is particularly well expressed at Locality A (Fig. 4). Measured values of S_0 taken at brecciated flow margins of massive mafic lava flows and plotted on a stereonet. When plotted on a great circle, the poles of these measurements delineate the closing of a syncline, with poles indicating a fold axis plunging 45 degrees to the east (Figs. 3b, c). The observation of molar tooth structures within pillow lavas in this area is compatible with the presence of a hinge zone.

The orientation of major faults and dyke patterns within the RPS is a product of from ductile deformation during the regional horizontal shortening. The impact of this deformation is more developed in the eastern part of the study area. The overall Z-shaped fold pattern in the RPS can be attributed to a clockwise rotation of all elements during a dextral shearing event. This dextral component is compatible with offsets observed along marker horizon such as the McPhee dyke

and shear sense indicators observed in the reactivated E-trending synvolcanic faults (Fig. 5a). By removing this ductile deformation, a reconstruction of pre-folded strata at Locality A can be interpreted with as a dominant NW-trending attitude (Fig. 5b). Mueller et al. (2012) interpreted this domain as a tilted and rotated block prior to regional shortening and related to a caldera collapse event.

3.0 Volcanic Facies and Facies Assemblages

3.0.1 Field Methodology

In this study, a series of key outcrops (Fig. 4) were mapped, sampled for geochemical analysis and/or photographed. Mapping was conducted at scales ranging from 1:100 to 1:400 with five to ten metre grid spacing and the assistance of a sub-metric differential GPS. Samples collected for geochemical analysis are representative of the distribution of volcanic facies and selected from areas that exhibit the least amount of surficial and visible alteration. All GPS co-ordinates given for outcrop and sample localities are in the UTM UPS co-ordinate system with NAD83 grid in zone 17 U.

Volcanic and intrusive facies in RPS are identified as facies of the Rouyn-Pelletier Formation (Goutier et al., 2009; McNicoll et al., 2014). Tilting of the strata exposes a vertical cross-section, allowing internal architecture to be viewed. This study divides these facies into geographically referenced blocks with boundaries defined by a) facies distribution and organization and b) by synvolcanic faults, fractures and dyke complexes (Fig. 4). These blocks are divided into external and internal domains based on their location relative to the McPhee and Glenwood dyke complexes (Figs. 2, 4). Those blocks located between the two dyke complexes are defined as “internal”, whereas those located outside of these complexes are defined as “external”. General

descriptions will be given for facies in both internal and external blocks, with more detailed descriptions given for the Pelletier, Senator and Glenwood blocks (the focus of this study). Mafic pillowed lavas found within all facies associations indicate all deposits erupted into a subaqueous environment. The facies mapped, sampled and/or photographed within the scope of this study are presented and summarized in Table 1 and schematic stratigraphic sections of each block are provided in figure 6.

3.1 External Blocks

3.1.1 Stadacona Block

The Stadacona block is bounded to the north by the Stadacona volcanoclastic unit described by Ross et al. (2008) and to the south by the CLLFZ (Figs. 2, 4). Facies of the block are dominated by voluminous mafic to intermediate lavas and their associated volcanoclastic products. Fine to medium grained, mafic to intermediate sills and dykes compose the intrusive facies within this region. The majority of lava flows south of the Stadacona unit have a tholeiitic magmatic affinity, whereas several intrusions have tholeiitic to transitional magmatic affinities (Ross et al., 2008).

3.1.2 Evain block facies

The Evain block is located west of the McPhee Dyke (Figs. 2, 4). The block consists of felsic lavas and associated volcanoclastic deposits of the Évain felsic volcanic centre (Fig. 2). The Évain centre is a 10 x 1.6 km complex composed of E-W-trending massive and brecciated felsic flows. Massive flows are quartz- and feldspar-phyric and exhibit columnar jointing (McNicoll et al., 2014).

3.2. Internal Blocks

3.2.1 Pelletier Block

The Pelletier block is bounded to the south by the Stadacona volcanoclastic unit and to the north by the Perreault Fault (Figs. 2, 4). Facies of the assemblage (Table 1) are dominantly mafic in composition and consist of massive and pillowed lava flows, sills and rare dykes and felsic volcanoclastic deposits (Fig. 6). Most facies are east-west to east-southeast-trending (Figs. 2, 4) except where two axial fold traces are present just south of the Perreault Fault (Fig. 2).

Pillowed and massive mafic lava flows are the most dominant facies of the assemblage (Localities 1 and 2; Fig. 4). Pillowed lavas are closely packed (Figs. 7, 8, 9a) and morphology shows a consistent younging direction to the north. Grain size in the field ranges from aphanitic to fine grained and pillows are often vesiculated or amygdular. Surficial weathering is common and hyaloclastite-rich rims are weathered orange.

Mafic massive flows have a maximum thickness of seven metres and a minimum thickness of <10 cm (Fig. 8). Most flows are entirely massive but thicker ones transition laterally into lobate and pillowed flows (Fig. 8). The flows are commonly internally brecciated with mm-scale fractures filled with sub-mm-scale hyaloclastite fragments (Fig. 9b). Columnar jointing is rare but where present is cm- to m-scale (Fig. 9c). Lobate and pillowed forms are bordered by mm-scale hyaloclastite fragments that are weathered orange similarly to those present in the brecciated margin facies.

Brecciated facies bound the margins of most massive flows and vary in thickness from < 10 cm to approximately 5 m. All facies have a hyaloclastite-rich matrix containing mm- to cm-scale hyaloclastite fragments that are altered by iron-rich fluids and have weathered bright orange in

the field (Fig. 9d). Fragments of fractured pillows and pillow rinds are also present within this facies and have weathered black and white respectively (Fig. 9e).

Mafic sills have an apparent thickness ranging from < 5 m to approximately 35 m. Primary magmatic layering is present in the largest of the sills and consists of 5 – 10 cm-thick alternating orange and black bands composed of varying percentages of feldspar and amphibole respectively (Fig. 9f). Feldspar-rich bands are typically fine-grained, whereas mafic-rich bands range from fine- to medium-grained. All sills have well developed chilled margins and the central sill has been intruded but another series of mafic dykes characteristic of re-injection.

Felsic volcanoclastic deposits are the least abundant facies ($< 1\%$ overall) within the block and occur in isolated exposures near its southern limit (Fig. 4). These units appear conformably interbedded with pillowed units and consist of normally graded beds with clast sizes ranging from < 0.5 mm to 8 cm. The fresh surfaces of exposed units are nearly entirely white, making the units easily differentiated from the surrounding mafic units (Fig. 9g).

Mafic dykes are both discordant to pillowed and sill facies and intrude mafic sills. Within a large central sill, mafic dykes are centimetre- to metre-scale and taper and anastomose laterally (Fig. 9h). Wispy terminations and dismembered morphology are also present in several dykes, consistent with intrusion into a cooling, viscoelastic medium (i.e. Moore et al., 2014). Overall, most dykes are fine-grained with aphanitic chilled margins and are altered (Table 1).

3.2.2 Senator Block

The Senator block (Table 1) is characterized by ponded mafic lavas, mafic intrusions and minor massive and pillowed lavas. The block is bounded to the west and east by the McPhee and Osisko dyke complexes respectively. The northern limit of the block extends up to the Horne

Creek Fault and southern limit is bounded by the Perreault Fault (Fig. 2). Ponded lavas with minor hyaloclastite horizons and mafic sills and dykes are the dominant extrusive facies (Moore et al., 2012) [Localities 3, 4 and 5; Fig. 4], with massive and pillowed flows found at the extreme eastern margin of the block (Locality 6; Fig. 4).

Ponded lava successions are well documented at three localities within the Senator block (Fig. 4) and it is believed that all three localities represent individual ponded lava sequences (Moore et al., 2012). Massive ponded lavas are typically bounded by hyaloclastite horizons and range in thickness from $< 2.5 - 30$ m, with most units less than five metres thick. Thinner units are aphanitic, whereas those that are thicker are medium grained (Fig. 10a) and exhibit sub-ophitic to ophitic textures. Massive units, where in contact with hyaloclastite horizons, have a variolitic texture present for several tens of centimetres proximal to the contact (Fig. 10b).

Hyaloclastite horizons vary from poorly to well developed both laterally and vertically with well developed hyaloclastite horizons exhibiting several prominent primary volcanic structures: v-shaped structures, cigar structures and pillowed forms (Moore et al., 2012). The v-shaped structures are filled with mm- to cm-scale hyaloclastite fragments that entrain elongated blebs of lava resembling cigars (cigar structures; Fig. 10c). Pillowed forms can form independently or can grade laterally outward from v-shaped structures. These forms are predominantly ovoid (Fig. 10d) and can be up to several metres in diameter. Hyaloclastite fragments weather orange in the field, have angular and polycuspate forms and mm- to cm-scale in size.

Mafic dykes and sills are the dominant intrusions within the Senator block. Mafic sills are often found concordant to massive ponded lavas and mafic dykes are found at most localities. Most dykes range in thickness from < 20 cm to approximately 7 metres wide and have an aphanitic to

sub-ophitic texture. Mafic sills are up to 30 metres thick, with these thicker sills having an aphanitic texture at their margins and a sub-ophitic to ophitic texture in their interiors.

At the eastern margin of the block, ponded lava facies and well developed hyaloclastite horizons are absent. Exposed facies consist of alternating massive and pillowed flows that show the greatest degree of deformation within mapped facies of the SNSC (Fig. 11). Exposed thickness of massive flows ranges from approximately five metres to < 20 metres. The contacts between the massive flows and bounding pillowed flows are largely transitional with an absence of developed chilled margins, brecciated fragments or hyaloclastite. Lobate structures are present within the massive flow facies (Fig. 10e). Jointing and fractures within these forms are consistent with flow banding and indicate forms are primary volcanic structures.

Pillowed flows are the dominant flow facies at the eastern margin of the block. The gradational nature of the contacts with the massive flows makes it difficult to discern the exact thickness of the pillowed flows but one flow ranges from 10 – 12 metres thick. Pillow morphology varies from rounded and ovoid to elongated and flattened (Fig. 10f). In the latter, this pillow morphology is interpreted as a modification by late ductile deformation localized near the Perreault Fault.

3.2.3 Glenwood Block

Facies of the Glenwood block (Fig. 4, Table 1) predominantly consist of felsic lavas and synvolcanic intrusions associated with the Glenwood Felsic Flow Complex and the Osisko dyke complex, respectively (Fig. 2). The assemblage is bounded to the west and north by intrusive facies of the eastern arm of the Osisko dyke complex and to the east and south by the Glenwood and Perreault Faults, respectively. The felsic flow facies of the Glenwood Felsic Flow Complex

(Locality 7; Fig. 4) are the dominant facies and are divided into two types: 1) exogenous facies extruded during the building of the complex and 2) late endogenous facies intruding and inflating the host exogenous deposits. All felsic facies are later cross-cut by several mafic dyke complexes (Moore et al., 2014).

Exogenous deposits are characterized by four main facies: massive, in situ brecciated, flow breccia and flow-front breccia. The facies become increasingly brecciated from west to east. The massive facies is located on the far western margin of the complex and is represented by m-scale flows. The overall texture of the facies is aphanitic and several synvolcanic structures and textures are present including lobes, detached lobes, locally developed columnar jointing and well developed flow banding (Fig 12a). Detached lobes are also present within the in situ brecciated facies but only where proximal to the massive flow facies as it became gradually more glass-rich and fragment-rich distally (Fig. 12b).

The flow breccia and flow-front breccia facies are the dominant facies of the central and eastern exposures of the assemblage. Both facies are characterized by aphanitic to fine-grained fragments entrained in a formerly glassy matrix (Fig. 12c). Fragments of the flow-front breccia facies are similarly aphanitic to fine-grained but are sub-rounded to rounded due to increased transportation and increased abrasion. The amount of matrix between fragments is greatly reduced in comparison to the flow breccia facies and is evidenced by the near “jigsaw-fit” of fragments (Fig. 12d; Moore et al., 2014).

The flow breccia and flow-front breccia facies are intruded by quartz- and feldspar-phyric endogenous lobes at the eastern margin of the block. Margins of the lobes are aphyric and locally brecciated where they intrude into the older and cooler deposits of the flow breccia facies.

Where these lobes breach the surface of the flow complex, they begin to brecciate and flow as lava (Fig. 12e). Two radiometric ages were obtained from this facies using U-Pb geochronological analysis; one from a quartz- and feldspar-phyrlic area in the central complex and one from the brecciated region in the northern sector of the complex. Both ages are very similar at 2702.9 ± 1.4 Ma and 2702.2 ± 3.0 Ma respectively (Mueller et al., 2012).

Synvolcanic intrusions compose a significant amount of this block. Three prominent gabbroic dyke complexes are recognized; the Glenwood, the Iberville and the Osisko dyke complexes (Fig. 2). The Lac Noranda intrusion (formerly known as the “Kiwanis pluton”; Mueller et al., 2012) is an intermediate to felsic intrusion hosted within the Osisko Dyke Complex (Fig. 2) near the northwest margin of the Glenwood Complex (Locality 8; Fig. 4). The composition of the intrusion is mainly quartz diorite to tonalite and is in turn cross-cut by several (predominantly west-east-trending mafic and felsic dyke systems (Fig. 13). The principal plutonic facies is phaneritic and fine- to medium-grained overall (Fig. 12f). Several m-scale zones of chloritization and epidotization also trend west-east across the outcrop. A sample was selected from the main intrusion for U-Pb age determination just to the southwest of the mapped area and has an approximate age of 2702.0 ± 1.6 Ma (Mueller et al., 2012). This intrusive event is relatively contemporaneous with the emplacement of the Glenwood Felsic Flow Complex stratigraphically below it (Mueller et al., 2012; Moore et al., 2014).

Several mafic and felsic dykes cross-cut intrusions associated with the Osisko dyke complex (Fig. 13). All felsic dykes are aphanitic to fine grained and appear silicified in the field. Felsic dykes are difficult to discern from the finer-grained dioritic to tonalitic host and could be mingling with felsic volcanic deposits near the margin of the intrusion. Most mafic dykes cross-cut the host intrusive rocks in a west-east direction with the exception of a few east-southeast-

trending dykes with pronounced jointing (Fig. 12g). Small, often podiform-like, mafic-rich phases are found within the intrusion. One such pod-like intrusion was sampled for U-Pb age analysis and yielded an age of 2696.6 $\pm$ 0.7 Ma (Mueller et al., 2012).

The three large mafic dyke complexes that intrude and border the Glenwood Block delineate large synvolcanic fault and are conduits for the majority of dykes that intrude the assemblage and feed mafic flows to the north of the complex (unpublished data, CONSOREM; Moore et al., 2014). The width of mafic dykes cross-cutting the assemblage ranges from cm- to m-scale, whereas length varies from tens of centimetres to hundreds of metres. Numerous dykes have wispy terminations suggesting intrusion into a cooling and plastic medium (Fig. 12h; Moore et al., 2014). Dykes propagate in two main directions: east-west and north-south. A number of dykes strike northwest-southeast and northeast-southwest but these are usually small branches of larger dykes striking in the two principal directions. Most dykes are aphanitic to fine-grained and vesiculation is visible both in the field and in thin section (Moore et al., 2014).

3.2.4 Chadbourne Block

The Chadbourne block was not mapped in detail in this study. This block corresponds to the region located immediately to the north of the Glenwood block. Facies of the Chadbourne block are bounded to the north by the Andesite Fault and to the south by the eastern arm of the Osisko dyke complex (Fig. 4). The assemblage is characterized by voluminous mafic to intermediate flows and gabbroic to dioritic intrusions (Fig. 6; Dimroth et al., 1974).

3.2.5 Horne Block

The Horne Block is bounded to the north and west by the Horne Creek Fault and to the south by the Andesite Fault. The eastern limit is cross-cut by a large north-south-trending intrusion but it

is interpreted that the mafic to intermediate flow facies that are to the east of this intrusion are conformable and contemporaneous with facies of the western Horne block (i.e. Monecke et al., 2008). The two dominant facies of the assemblage are aphyric to quartz-phyric rhyolite flows and associated felsic volcanoclastic deposits that are interpreted to be products of small-volume effusive and explosive eruptive processes (Fig. 6; Monecke et al., 2008; Laurin, 2009).

4.0 Geochemical Analysis

All volcanic and intrusive facies were sampled for geochemical analysis according to lateral and vertical facies transitions. Samples are considered “least altered” based on relatively fresh appearance in the field with minimal surface and hydrothermal alteration such as sericitization, chloritization and carbonatization. Preparation of samples for analysis was conducted at the Université du Québec à Chicoutimi where alteration rinds were removed and samples were crushed and then pulverized in an aluminum ring mill.

Analysis of elemental concentrations in samples was completed at the Geoscience Laboratories (GEOLABS) facility at the Ontario Geological Survey in Sudbury, Ontario, Canada. Fused disk X-ray fluorescence (XRF) was employed for determining concentrations of major oxides (0.01% detection limit), whereas trace and rare earth element (REE) concentrations were analyzed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). A closed vessel multi-acid digestion was used for ICP-MS analysis and detection limits for element concentrations range from 0.002 to 26 ppm. To verify precision in the laboratory, duplicate analysis was conducted every tenth sample for both XRF and ICP-MS techniques. For accuracy, GEOLABS’ internal certified reference materials were used for one blank and one standard every ten samples. Values for geochemical analysis of collected samples from the Pelletier and Senator blocks are presented in

Appendix A. Values from samples collected from the facies of the Glenwood block are presented in Moore et al., 2014 and values for the ponded lava facies of the Senator block are reported in Moore et al., 2012.

To better present analyses and illustrate the evolution of the edifice, analyses will be grouped and presented according to composition: mafic extrusive facies, mafic intrusive facies and felsic extrusive and intrusive facies.

4.1 Mafic Extrusive Volcanic Facies

Pillowed and massive flows of the RPS plot predominantly within the subalkaline basalt field on the trace element classification diagram but range up to andesitic basalt. Samples plot within two distinct groups: tightly clustered within the centre of the field and in a second cluster extending into the andesitic basalt field (Fig. 14a). All lavas either plot near the base of the tholeiitic field or along the boundary between the tholeiitic and transitional fields of the binary Y vs. Zr magmatic affinity diagram (Fig. 14b).

Several distinct REE profiles are present when data is plotted normalized to primitive mantle values on REE diagrams: 1) a tholeiitic profile with slight LREE enrichment; 2) a primitive and relatively flat signature with a slight positive Eu anomaly and 3) a more transitional profile with a moderate LREE concentration (Fig. 15a) (Sun and McDonough, 1989). The transitional affinity and elevated LREE concentrations are potentially an expression of hydrothermal alteration as these samples were notably altered in the field.

4.2 Mafic Intrusive Facies

419 Mafic intrusions of the RPS are typically fine- to medium-grained mafic dykes and sills and
420 show a wider range in composition than mafic extrusive facies. On the trace element
421 compositional diagram, samples from the Pelletier block are typically plot within the subalkaline
422 basalt field, whereas those from the Senator block range from subalkaline basalt to andesite in
423 composition (Fig. 14c). Mafic sills and dykes of the BIFA plot within the tholeiitic field of the
424 binary magmatic affinity diagram of Barrett and MacLean (1999), with the exception of one
425 sample that plots within the transitional field. Samples from mafic intrusive facies of the
426 Glenwood block plot in all three fields; with the majority of samples plotting within the calc-
427 alkaline field (Fig. 14d).

428 Many of the intrusive facies of the Pelletier and Senator blocks exhibit REE profiles similar to
429 those of mafic extrusive facies with an elevated LREE profile, slight positive Eu anomaly and
430 overall negative slope (Fig. 15b). Mafic intrusive facies of the Glenwood block have more
431 variable REE profiles reflecting their calc-alkaline, transitional and tholeiitic magmatic affinities
432 with LREE profiles with significant negative slopes, marginally negative slopes and relatively
433 flat HREE profiles respectively (Fig. 15b) (Moore et al., 2014).

434 4.3 Felsic Extrusive and Intrusive Facies

435 Felsic extrusive and intrusive facies are dominated by the felsic flows of the Glenwood Felsic
436 Volcanic Complex (Locality 7; Fig. 4) within the Glenwood block. These flows have a
437 dacitic/rhyodacitic composition when plotted on the trace element diagram of Winchester and
438 Floyd (1977) (Fig. 14e). All samples have a transitional magmatic affinity (Fig. 14f), further
439 supported by primitive mantle-normalized REE profiles that have elevated LREE concentrations
440 (Fig. 15c) (Sun and McDonough, 1989). All profiles exhibit a variable negative Eu anomaly and

flat HREE trends relative to primitive mantle (Fig. 15c) (Sun and McDonough, 1989; Moore et al., 2014). Elemental concentrations reported by Laurin (2009) for massive rhyolite flows of the Horne block are plotted along with those from the Glenwood block and have a similar rhyodacitic composition (Fig. 14e) but a more calc-alkaline magmatic affinity (14f). Rare earth element profiles for the Horne block felsic flows are similar to felsic flows from the Glenwood block (Fig. 15c). However, this appearance could also be caused by significant hydrothermal alteration. Samples of quartz diorite and tonalite collected from intrusive facies of the Osisko dyke complex (Figs. 2, 4) have similar REE profiles to those of the Horne Mine sequence and the Glenwood block and are characteristic of felsic facies with a transitional magmatic affinity using the criteria of Sun and McDonough) (1989).

5.0 Interpretation and Discussion

Through the use of detailed facies, geochemical and geochronological analysis, the volcanic evolution of the Rouyn-Pelletier sector can be reconstructed. With the aid of previous studies conducted within the immediate area (i.e. Kerr and Gibson, 1993; Gibson and Galley, 2007; Ross et al., 2008; Monecke et al., 2008 and Ross et al., 2011 a, b) and comparisons to modern subaqueous to emergent volcanic complexes such as those present in the Kermadec (Wright and Gamble, 1999; Wright et al., 2002; Wright et al., 2006), Izu Bonin (Fiske et al., 2001; Tani et al., 2008; Allen et al., 2010) and South Sandwich (Lachlan-Cope et al., 2001; Leat et al., 2010; Leat et al., 2013) arcs, we can reconstruct the complete evolution of the RPS and hypothesize a possible relationship with facies of the Horne block. .

462 The above described blocks of the RPS are composed of subaqueous volcanic and intrusive facies
463 emplaced during the development of a bimodal subaqueous volcanic complex. following
464 development within a bimodal subaqueous complex. This complex is hereby identified as the
465 Rouyn-Pelletier caldera complex (RPCC). The Glenwood and McPhee dyke complexes are
466 hosted within the bounding faults of the complex's subsidence structure and the distance
467 between these faults (caldera diameter) is what necessitates the classification of the complex as a
468 caldera. As described by Lipman (2000), calderas are volcanic-tectonic depressions, ranging in
469 diameter from 2 to 100 km, resulting from the subsidence and collapse of volcanic complexes in
470 relation to the draining of high-level magma chambers.

471 Evidence of subsidence is present within the Pelletier, Senator and Glenwood blocks. As
472 previously described, rotated and folded basaltic flows of the Pelletier block are believed to have
473 been displaced during an initial collapse event. Within the Senator block, massive ponded lavas
474 at Locality 4 have a north-westerly-south-easterly orientation consistent with subsidence along
475 the McPhee complex (Moore et al., 2014). The Glenwood block is hosted within a graben-type
476 structure and is fault-bounded to the north, east, south and west. Subsidence of the Senator block
477 was necessary to allow for the extrusion of felsic facies within the Glenwood block and
478 continued subsidence is indicated by the offset of several mafic dykes cross-cutting felsic facies
479 (Moore et al., 2014). These collapse and subsidence events are discussed in the following
480 paragraphs in the context of the evolution of the RPCC.

481 Initial mafic to intermediate eruptive phases have a predominantly tholeiitic magmatic affinity
482 that evolve to a more transitional bimodal edifice with the emplacement of the Glenwood Felsic
483 Complex. Mafic tholeiitic volcanism continues throughout the development of the caldera with
484 prolonged extrusion of ponded mafic lavas and mafic intrusions along the western margin of the

complex. Several intermediate to felsic facies selected for U-Pb geochronological analysis reveal the approximate age of the edifice to be 2702 Ma.

5.1 Facies and Geochemical Analysis

5.1.1 Pre-caldera Stage

Facies of the pre-caldera stage are found within the Stadacona block (Fig. 4) and represent the extrusive and intrusive facies characteristic of the initial constructional stages of mafic subaqueous seamounts (Cas, 1992; Corcoran, 2000). There is insufficient mapping in the area to determine whether the base of the RPCC is fed by one point source or a series of vents. Constructional activity typically begins as a series of mounds of pillowed lavas and massive flows, which coalesce and build upon the plateau of the edifice (Corcoran, 2000) (Fig. 16a). Mafic to intermediate dykes and sills feed upper level flows and endogenously inflate the complex. Lavas can originate from a single point of origin or they can feed from a series of vents along a fissure or fracture (Cas, 1992). In the instance of multiple feeder systems, the base of the complex builds as a series of amalgamated mounds as opposed to one increasingly larger complex (Cas, 1992). The dimensions and geometry of the underlying chamber is unknown as it is not exposed. There is evidence that caldera magma chambers can have simple single chamber geometries or can be a series of interconnected and/or stacked melt lenses (Cashman and Giordano, 2014). For the purpose of this study, we model the chamber as a simple single chamber.

5.1.2 Stage One: Basal Caldera Construction

During initial caldera development, inflation of the magma chamber structure leads to the development of a localized extensional regime and initial ring faulting (Lipman, 1997). As

magma is evacuated from the underlying chambers or melt lenses, a void is created beneath the complex (i.e. Lipman, 1997; Geist et al., 2005; Cashman and Giordano, 2014). The weight of the overlying roof structure and lavas begins to depress the upper stratigraphy of the initial seamount and subsidence commences, forming the bounding caldera faults (Fig. 16b) (Walker, 1988). Within the study area, these large bounding synvolcanic faults are represented by the McPhee and Glenwood dyke complexes (Fig. 2). The lava flows constructing the upper stratigraphy of this initial mafic edifice subside and then become the first caldera floor. These initial seamount facies and deposits erupted on the first caldera floor are represented in the study area by the mafic flows and sills of the Pelletier block found between the Stadacona volcanoclastic unit and the Perreault Fault (Figs. 2, 4). This large scale collapse and subsidence is evidenced by the rotated and folded structures in mafic lava flows observed at Locality A (Figs. 2, 3b, c) and by the orientation of volcanic units bordering the McPhee dyke complex. The pre-folding north-south orientation of lavas (Fig. 5) suggests that faulting of the caldera floor was significant and several blocks rotated during collapse. This faulting would have subsequently enabled extrusion of lava, feeding small volume eruptions stratigraphically above these structures.

Geochemical analysis of intrusive and extrusive facies of pre-caldera facies and the Pelletier block supports the interpretation of an initial mafic volcanism (Moore et al., 2012). Mafic flows, sills and dykes of the pre-caldera facies south of the Stadacona volcanoclastic unit are predominantly basaltic with minor basaltic andesitic and andesitic compositions (Ross et al., 2008). These volcanic facies, along with the basaltic to basaltic andesitic flows and intrusions of the Pelletier block, are present in early constructional phases such as those exposed at the Sturgeon Lake caldera (Morton et al., 1991), those found in the Point Lake and Beaulieu River

belts of the Slave province (Corcoran, 2000), the Bay Volcanic Group in Fiji (McPhie, 1995) and the Waiatarua Formation at Maori Bay, New Zealand (Bear and Cas, 2007).

5.1.3 Stage Two: Trap-door Collapse

Asymmetrical emplacement of small volume eruptions in the western sector of the Senator block, coupled with the lateral extrusion of magma along dykes and sills and differential evacuation from the underlying magma chamber or lenses culminates in incremental collapse and faulting of the caldera floor. For the RPCC, differential evacuation of the magma chamber resulted in a trapdoor collapse on the western margin of the caldera structure (Fig. 16c) (Lipman, 1997). In trapdoor geometries, one side of the caldera floor subsides significantly in comparison to the other. The bounding fault of the significantly subsided floor is preferentially more prominent than the opposite bounding fault. A significant collapse is demonstrated by the NW-NNW orientation of volcanic deposits bordering the eastern limit of the McPhee dyke (Fig. 4; Pearson and Daigneault, 2009). This characteristic is observed when comparing the geometries of the intrusive facies of the McPhee dyke and the Glenwood Fault/dyke complex (Fig. 2) in that the intrusion hosted within the McPhee complex is more coherent than the dismembered dykes of the Glenwood complex. This trapdoor geometry facilitated the extrusion of magma allowing the extrusion and accumulation of massive ponded lavas and forming some of the initial deposits of the Senator block (Fig. 16d).

Ponded lavas accumulate in synvolcanic depressions such as large collapse structures or in smaller craters and pit craters (Cas, 1992; Gregg et al., 2000; Geist et al., 2005). Multiple localities host ponded lavas on the western margin of the study area between the McPhee and Osisko dykes (Figs. 2, 4), implying there was a significant depression hosting prolonged lava

accumulation (Moore et al., 2012). Pillowed and massive flow facies at the eastern margin of the Senator block (Locality 6, Fig. 4) represent the edge of ponded lava sequences where lavas break and flow along the caldera floor.

The orientation of ponded lavas of the Senator block is consistent with continued subsidence along the western margin of the caldera complex (Fig. 4). The overlying weight of ponded lavas, along with continued faulting and seismic activity, caused fracturing of the downward-sloping caldera floor and a more piecemeal-type fault system developed and facilitated the emplacement of the Osisko and Iberville dyke complexes.

Massive ponded lavas and intrusions of the Senator block emplaced after faulting and collapse of the first caldera floor range in composition from basaltic to andesitic with tholeiitic to transitional magmatic affinity and represent continuing discharge and emplacement of mafic to intermediate lavas along the McPhee dyke complex. The presence of extrusive and intrusive facies with basaltic to andesitic composition and a more transitional magmatic affinity suggests a more evolved magmatic phase than those of the predominantly tholeiitic Pelletier and pre-caldera Stadacona blocks.

5.1.4 Stage Three: Piecemeal Faulting and Bimodal Volcanism

Extrusive and intrusive facies of the Glenwood block are consistent with the transition to bimodal activity and development of a second and third caldera floor. The establishment of the fault hosting the Osisko dyke (Fig. 1) provided a significant conduit for the extrusion of magma. This conduit allowed the extrusion of the Glenwood Felsic Flow Complex (Locality 7, Fig. 4) as the first significant phase of felsic extrusive volcanism. The felsic flows of the Glenwood Complex were emplaced as a series of easterly-flowing stacked lobes extruded from an eruptive

centre at or very proximal to the Osisko dyke (Moore et al., 2014) (Fig. 16e). Due to the absence of Glenwood deposits to the west of the Osisko dyke, it is evident that the block of caldera floor immediately to the east of the dyke was tilted and subsided enough to limit the emplacement of flows to the east of the dyke. The complex flowed eastward until it abutted against the uplifted eastern margin of the caldera wall (marked by the Glenwood Fault). As a result, the waning stages of felsic volcanism were then confined endogenously to the eastern margin of the flow complex (Moore et al., 2014).

Dacitic to rhyodacitic lavas of the Glenwood Felsic Flow Complex compose the bulk of the Glenwood block and are the first deposits in the RPCC with a) a felsic composition and b) a significantly transitional magmatic affinity (Moore et al., 2014). The appearance of felsic lavas represents the shift to bimodal activity similar to other oceanic arc volcanoes and calderas such as those found in the Kermadec (Wright and Gamble, 1999; Wright et al., 2006), Izu Bonin (Fiske et al., 2001; Allen et al., 2010) and South Sandwich (Leat et al., 2010; Leat et al., 2013) arcs. Intrusions associated with the Osisko dyke complex, such as certain phases of the Lac Noranda pluton, similarly have a more felsic composition and transitional affinity indicating the presence of more evolved lavas and intrusions higher in the volcanic stratigraphy of the RPCC.

Mafic to intermediate eruptive and intrusive activity resumed almost immediately along the Iberville, Glenwood and Osisko dyke complexes and is represented by a complex network of dykes with poorly developed, irregular and wispy margins intruding the felsic deposits of the Glenwood block (Moore et al., 2014). As these intrusions breached the surface, the complex fed extensive overlying mafic to intermediate lavas directly above and to the east and west of the Glenwood block and formed a third caldera floor (Fig. 16f). In the case of the Glenwood dyke complex, it not only fed lavas within the caldera, but also along the flank of the host complex.

The majority of dykes are basaltic but range in composition from basaltic to andesitic. They also exhibit the greatest variation in magmatic affinity; ranging from tholeiitic to calc-alkaline. Several calc-alkaline mafic dykes intruding the facies of the Glenwood block are notably altered by chloritization, carbonatization and epidotization (Moore et al., 2014) and their calc-alkaline magmatic affinity could be a function of alteration. Another possibility is that these dykes are associated with a younger calc-alkaline event higher in the stratigraphy.

The Osisko dyke complex was a key conduit throughout the eruptive history of the RPCC, as is evidenced by the polyphase nature of the Lac Noranda pluton, and was again activated during the younger Noranda event (Mueller et al., 2012). The eastern extension of the Osisko dyke complex is associated with the presence of an east-west-trending fault between the northern limit of the Glenwood block and the overlying mafic lavas of the Chadbourne block (Fig. 2). In addition to being a conduit for intermediate to felsic intrusive facies, it also marks the boundary between the second and third floors of the caldera. Cross-cutting relationships show that intrusion occurred following the emplacement of the overlying mafic lavas and is chronologically associated with mafic to intermediate facies forming the upper stratigraphy of the edifice. A quartz-dioritic sample dated at 2702.0 ± 1.6 Ma suggests its emplacement is relatively contemporaneous but younger than the lavas of the Glenwood block dated at 2702.9 ± 1.4 Ma and 2702.2 ± 3.0 Ma (Mueller et al., 2012). A second date obtained from a mafic-rich enclave within the Lac Noranda pluton indicates the dyke complex was re-activated during the younger Noranda event (Pearson and Daigneault, 2009; Mueller et al., 2012).

5.1.5 Stage Four: Continued Intracaldera Activity and Summital Events

Volcanic extrusive and intrusive facies located to the north of the Osisko dyke complex and south of the Andesite Fault represent a tertiary caldera floor and infilling event following emplacement of the volcanic and intrusive facies of the Glenwood block (Fig. 16f). These extensive mafic to intermediate lavas and intrusions (SIGEOM, 2012) were fed by the Osisko, Iberville and Glenwood dykes and now comprise the volcanic and intrusive facies of the Chadbourne block (Fig. 2). Monecke et al. (2008) report that deposits similar to facies found within the Horne block are found in the Chadbourne block. Therefore, it is inferred that felsic volcanic activity resumed just before the emplacement of the volcanic and intrusive facies of the Horne block and that these facies are in conformable contact with those of the Horne block (Fig. 4) and therefore part of the RPCC.

Volcanic and intrusive facies of the Horne block comprise the summital facies of the RPCC. Following the extrusion of the mafic to intermediate lavas of the Chadbourne block, several small felsic dome-flow complexes erupted onto a fourth caldera floor and are now exposed as the volcanic and intrusive facies of the Horne block (Fig. 16g). Small-scale pyroclastic eruptions were either associated with these dome-flow complexes or were erupted from parasitic cones along the rim of the complex (Fig. 16h). Localized pyroclastic and parasitic cones are common in the uppermost stratigraphy of several subaqueous calderas as shallowing of the edifice favours increasing explosive activity (Fiske et al., 2001; Geist et al., 2005; Leat et al., 2013).

Facies of the Horne block (Fig. 4) are bounded to the north by the Horne Creek Fault (Fig. 1), also separating the assemblage from the Noranda camp. The lack of correlation between the Horne block with the rest of the Noranda camp has been well documented and persists today (Kerr and Gibson, 1993; Gibson et al., 2000; Monecke et al., 2008) and the model presented here sufficiently explains this lack of correlation. The volcanic and intrusive facies of the Noranda

camp are spatially and chronologically different from those to the south of the Horne Creek Fault, which can now be attributed to the existence of two separate caldera complexes.

5.1.6 Caldera Flank Activity

Throughout the aforementioned stages of caldera development, volcanic and intrusive activity both internal to the caldera and along its margins have continuously built the flanks of the RPCC. The volcanic facies of the Evain block are representative of this activity and comprise the western flank of the RPCC. A quartz- and feldspar-phyric massive rhyolite flow sampled by McNicoll et al. (2014) dated using U-Pb geochronological analysis has a reported age of 2700.6 $\pm$ 0.9 Ma and could be one of the latest eruptive phases of the RPCC. The extent, geometry and organization of facies of the eastern flank is less clear. Deformation is more developed in the eastern portion of the SNSC, as evidenced by the presence of fold axial traces (Fig. 2). This deformation limits the interpretation of events but a significant accumulation of volcanic facies is present (Figs. 2, 4) and it can be inferred that the eastern flank was of a similar extent to that of the western flank.

5.2 Depositional Environment of the Rouyn-Pelletier Caldera Complex

The protracted history of deformation and associated shortening events within the Abitibi greenstone belt (i.e. Daigneault et al., 2002; Daigneault et al., 2004) prohibits determination of the exact thickness of the volcanic pile that constructed the RPCC. If we use the Stadacona volcanoclastic unit as an approximate marker for the base of the complex, the thickness of the RPCC is a minimum of five kilometres. Accepting that the McPhee and Glenwood dyke complexes represent the bounding faults of the caldera structure, at an average distance of

approximately six kilometres east-west from each other, the base of the RPCC is likely several tens of kilometres in diameter.

The continuous presence of pillow lavas indicates facies of the RPCC were emplaced in a submarine setting. With a potential volcanic pile thickness of five kilometres, most facies of the RPCC were emplaced in a deep marine setting. Kerr and Gibson (1993) estimate that deposits of the Horne Mine sequence were emplaced in a submarine setting at a depth of 100 – 500 m but could not conclusively estimate water depth. This shallow level emplacement is consistent with pyroclastic activity at caldera complexes in modern arc settings (Fiske et al., 2001; Geist et al., 2005; Leat et al., 2013).

Subaqueous to emergent volcanoes and calderas in arc settings, along spreading centres and at hotspots are known to cluster and form larger, complex volcanic centres with nested and overlapping structures such as those of the South Sandwich arc (Leat et al., 2013), the Kermadec arc (Wright et al., 2006), the Galapagos archipelago (Geist et al., 2005), the island of Hawaii (i.e. Walker, 1988) and Tamu Massif (Sager et al., 2013). In the context of the Blake River Group, if we assume that exposed plutons represent the eroded cores of ancient volcanic complexes, it is more than plausible that a series of clustered seamounts, volcanoes and calderas existed along the Archean seafloor (Fig. 17). We therefore propose that the volcanic and intrusive facies of the RPCC form a single subaqueous caldera clustered with the Noranda complex inside the host structure of the New Senator Caldera (Fig. 17).

6.0 Conclusions

Subaqueous volcanic and intrusive facies south of the Horne mine sequence in Rouyn-Noranda, Quebec, are characteristic of facies ranging from early seamount construction to those of a well-

684 established bimodal subaqueous caldera, known as the Rouyn-Pelletier caldera complex.
685 Voluminous lavas and intrusions south and north of the Stadacona volcanoclastic unit are
686 characteristic of pre-caldera and initial caldera-forming volcanic activity. Subsequent faulting
687 and subsidence resulted in a trapdoor-style collapse along the western margin, allowing for the
688 emplacement of ponded lavas. Piecemeal-style faulting continued after ponded lava
689 emplacement, breaking up the caldera floor and establishing pathways for the lavas and
690 intrusions composing the facies of the central and upper facies assemblages. Facies of the Horne
691 block represent some of the final stages of eruptive activity for the RPCC, as the edifice
692 shallowed and volcanic activity transitioned from effusive to explosive phases. The overall
693 thickness of the volcanic pile is a minimum of five kilometres, with a base of up to several tens
694 of kilometres in diameter. The RPCC was one of several seamounts, volcanoes and calderas
695 clustered along the approximately 2702 – 2700 Ma Archean seafloor.

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9.0 Table 1

Block Name	Facies	Volcanic Textures and Features	Petrography	Process and Setting
Pelletier Block	Pillowed Lava Flows	Flows range in thickness from < 0.5 m to 18 m. Individual pillows have horizontal and vertical axes ranging from cm- to m-scale. Forms are rounded to elongated and keel structures show younging direction to the north.	Aphanitic groundmass with occasional porphyritic texture with relict plagioclase and chlorite; amygdules rimmed/filled with quartz, carbonate, zeolite and/or epidote	Low-energy effusive mafic lava flows typical of seamount construction
	Massive Lava Flows	Flows range in thickness from < 10 cm to 7 metres. Most flows are massive but transition laterally into lobate and pillowed flows. Internally brecciated and brecciated at margins. Brecciated margins are < 10 cm to 5 m thick and contain hyaloclastite, rip-ups and pillow rinds; weathered bright orange in the field.	Dominantly aphanitic groundmass; epidote, carbonate, chlorite, actinolite and relict feldspar present; some amygdules present filled with quartz and/or carbonate, minor epidote present.	Low to moderate energy mafic lava flows typical of initial seamount construction
	Mafic Sills	5 - 35 m thick, fine to medium grained, massive to layered (5-10 cm thick feldspar- and mafic-rich layers), well developed chilled margins.	Dominantly epidote, albite, chlorite, actinolite and muscovite; accessory carbonate, quartz, titanite and oxides	Mafic intrusions characteristic of inflation of mafic volcanic edifices
	Mafic Dykes	Cm- to m-scale, taper and anastomose laterally, wispy terminations with dismembered morphology.	Aphanitic to fine grained with unidentifiable mafic minerals and feldspar; glomerocrystic plagioclase texture with epidote replacement; epidote, chlorite, actinolite, albite and carbonate present in groundmass; quartz and epidote visible as patchy alteration.	Synvolcanic intrusions discordant to volcanic facies; intrude along fractures during inflation events and feed upper level flows when surface breached

Block Name	Facies	Volcanic Textures and Features	Petrography	Process and Setting
Senator Block	Ponded massive lavas	Range in thickness from 2.5 to 30 m with most being <5 m thick Mostly aphanitic to fine grained with thickest units up to sub-ophitic. Bounded by hyaloclastite-rich horizons. Variolitic texture visible along contacts with hyaloclastite horizons	Relict pyroxene and feldspars present but rare; dominantly actinolite and chlorite phases present with minor quartz, carbonate, oxide phases and epidote present. Variolites are individual and clustered	Voluminous low-energy effusive events; lava collects in synvolcanic depressions or sag structures
	Hyaloclastite Horizons	Aphanitic. Fragments are mm- to cm-scale with angular and polycusate forms that weather orange-beige in the field. Pillowed forms, cigar structures and v-shaped structures found entrained within the horizons. cm-scale blocky tabular jointing found internal to pillowed forms.	Micro-crystalline to aphanitic in thin section. Individual mineral phases in groundmass not identifiable in thin section. Individual and clustered variolites contain relict feldspar and chlorite. Perlitic fractures are visible in larger fragments.	Small-scale in situ fragmentation within ponded lavas. Occurs as water/steam propagates along fractures.
	Mafic Dykes and Sills	Dykes are aphanitic to fine grained, whereas sills can be medium grained with ophitic texture. Dykes have sharp but irregular chilled margins. Visibly altered and vesiculated in the field.	Chlorite is the dominant mineral phase in all thin sections, with actinolite, carbonate, sericite, epidote, quartz and feldspar also visible. Both feldspar and pyroxene present as relict phases. Minor oxides and sulfides in most samples.	Synvolcanic intrusions associated with inflation of the edifice; intrude along discordant fractures and concordant stratigraphic boundaries.
	Pillowed Lava Flows	Exact thickness unknown; one unit ranges from 10 to 12 m thick. Pillows are undeformed (rounded to ovoid) to deformed (molar tooth and boomerang forms) and can be up to a metre in diameter. Flows are vesiculated and vesicle morphology reflects level of deformation – from rounded/elongated to flattened. Hyaloclastite fragments occur at pillow margins and in cavities between pillows.	Chlorite is the dominant mineral phase with actinolite, feldspar, quartz, epidote and minor oxides comprising the groundmass. Vesicles visible as voids or filled with phyllosilicate and/or alteration phases. Individual and clustered variolites present.	Low-energy flows breaching along margins of massive ponded lavas and beginning to flow floor.
	Massive Lava Flows	Thickness of flows ranges from <5 to 20 m. Flows are aphanitic to fine grained and vesiculated. cm- to m-scale lobate structures present along southern margins.	Chlorite is the dominant mineral phase with actinolite, feldspar, quartz, epidote and minor oxides comprising the groundmass. Vesicles visible as voids or filled with phyllosilicate and/or alteration phases.	Flows breaching along margins of massive ponded lavas and flowing along the caldera floor. Massive flows are higher volume and velocity in comparison to pillowed flows.

Block Name	Facies	Volcanic Textures and Features	Petrography	Process and Setting
Glenwood Block	Exogenous Lava Flows	Exposed thickness of facies ranges from <50 m to ~ 200 m. Stacked flows transition laterally from massive to flow and flow-front breccia. Lobes, detached lobes, columnar joints and flow banding present. Brecciated fragments are sub-rounded to angular and exhibit jigsaw textures locally.	All facies are aphanitic; groundmass (where visible) dominated by quartz and feldspar phenocrysts with minor chlorite and biotite. Chlorite present as alteration phase, as is sericite and quartz. Perlitic fractures present in massive facies and in breccia fragments	Structurally-controlled low-energy felsic lava flows; flow west to east along caldera floor. Effusive eruption with associated autoclastic brecciation.
	Endogenous Lobes	Mostly massive quartz- and feldspar-phyric lobes confined to brecciated exogenous facies. Some brecciation at upper levels and along margins.	Aphanitic to fine grained groundmass with large, porphyritic feldspar and quartz phenocrysts. Weak to moderate sericitization with weak chloritization.	Structurally controlled; intrude exogenous flows but breach surface and begin to brecciate; last stage of felsic volcanism
	Mafic Dykes	cm- to m-scale, vary from well defined chilled margins to irregular, wispy margins; some vesiculated; concordant to discordant	Aphanitic to sub-ophitic textured; dominantly chlorite, actinolite, epidote, feldspar and quartz with oxide phases; alteration phases present as epidote, chlorite, carbonate and quartz; vesicles visible in thin section and filled with carbonate, epidote and/or quartz	Dykes fed by larger dyke complexes (the Glenwood, Osisko and Iberville Dyke Complexes), concordant dykes intruded along stratigraphic contacts; discordant dykes intruded along synvolcanic fractures; associated with inflation and subsidence events.

10.0 Figure Captions

Figure 1. Blake River Megacaldera Complex. Synvolcanic faults and distribution of volcanic and intrusive facies delineate the host Misema caldera and nested New Senator (in purple) and Noranda calderas. The New Senator Caldera is further divided into three sectors (northwest, central and southeast) by the Hunter Creek Fault (HuCF) and the Horne Creek Fault (HoCF) respectively. (MDF = McDougall-Depsina Fault; TSF = T.S. Fault; PF = Pink Fault; ABCF = ABC Fault; BF = Beauchastel Fault; EFVC = Évain Felsic Volcanic Complex). Inset shows the regional map of the Abitibi greenstone belt within the province of Quebec, Canada with domain and stratigraphic divisions (NVZ = Northern Volcanic Zone; SVZ = Southern Volcanic Zone; BRG = Blake River Group; PP = Pontiac Sub-province; GP = Grenville Province; DPMFZ = Destor Porcupine-Manneville Fault Zone; CLLFZ = Cadillac-Larder Lake Fault Zone) (modified from Pearson and Daigneault, 2009; Moore et al., 2014).

Figure 2. General geology, synvolcanic structures, distribution of volcanic facies and notable features of the southern Rouyn-Noranda region (modified from Moore et al., 2012).

Figure 3. Measured values of the regional schistosity (black) showing a global E-W trend with a sub-vertical stretching lineation (red) (plotted on an equal area stereonet using Stereonet 8; Allmendinger et al., 2012; Cardozo and Allmendinger, 2013. B) S_0 values measured at Locality A showing dispersion along a great circle defining a fold axis plunging 45 degrees to the east (pole indicated in red) (plotted on an equal area stereonet using Stereonet 8; Allmendinger et al., 2012; Cardozo and Allmendinger, 2013). C) Folded massive and pillowed mafic lava flows of Locality A showing a fold axial trace consistent with a synclinal structure.

Figure 4. Facies assemblages of the Rouyn-Pelletier Caldera Complex. Distribution and boundaries of facies assemblages are shown in relation to the geology of the southern Rouyn-Noranda region, along with outcrops and other locations within the study area (modified from Moore et al., 2012; Moore et al., 2014).

Figure 5. Post- and –pre-ductile deformation model of the Rouyn-Pelletier sector (RPS). A) Post-ductile deformation organization of major structural elements (faults and dykes) within the RPS. B) Interpretive reconstruction of pre-ductile deformation geometry depicting an accumulation of strain in the eastern region of the RPS.

Figure 6. Schematic stratigraphic sections depicting dominant facies of each block of the Rouyn-Pelletier sector. Information for facies of the Évain, Stadacona, Chadbourne and Horne blocks obtained from: SIGEOM, 2012; McNicoll et al., 2014; Ross et al., 2008; Monecke et al., 2008; Laurin, 2009.

Figure 7. Locality 1. Mafic flows and sills and felsic volcanoclastic deposits of the Pelletier block with relevant photo positions represented by red boxes (modified from Aird, 2008).

Figure 8. Locality 2. Massive, pillowed and lobate mafic flows with brecciated margins of the Pelletier block with relevant photo positions shown with white and black boxes.

Figure 9. Mafic extrusive and intrusive facies of the Pelletier block. A) Closely packed pillows at Locality 1 (grid is approximately 1 metre wide by 1.5 metres long). B) In situ brecciated (Ib) massive flow at Locality 2 with mm-scale hyaloclastite fragments hosted within fractures (hammer is approximately 35 cm long). C) Columnar jointing (Cj) in a massive mafic flow at Locality 2 (scale card is 8 cm long). D) Brecciated flow margin of massive mafic flow with iron-stained, hyaloclastite-rich (Hy) matrix (grid markers at left margin of photo are spaced 20

cm apart; Locality 2). E) Pillow fragments (Pf) and pillow rinds (Pr) in a hyaloclastite-rich matrix at the margin of a massive mafic flow (grid markers are spaced 20 cm apart; Locality 2). F) Alternating felsic-rich (Fb) and mafic-rich (Mb) bands in a massive mafic sill at Locality 1 (hammer is 30 cm long). G) Felsic volcanoclastic deposits (Fv) within pillowed flows (Pl) at Locality 1 (hammer is 33 cm long). H) Mafic dyke (Md) with wispy terminations intruding mafic sill (Ms) at Locality 1 (pencil is 14 cm long).

Figure 10. Mafic extrusive and intrusive facies of the Senator block. A) Sub-ophitic texture in thick massive ponded lava unit at Locality 3 (hammer is 30 cm long). B) Variolites (Va) at margin of massive ponded lava near a contact with a hyaloclastite horizon at Locality 3. C) Cigar structures (Cs) hosted within a hyaloclastite horizon at Locality 4 (notebook is 17 cm long). D) Rounded to ovoid pillowed forms (Pf) in within a hyaloclastite horizon at Locality 4 (notebook is 17 cm long). E) Lobate forms (Lf) in massive mafic flows exposed at Locality 6 (scale card is 14 cm long). F) Stretched and elongated deformed pillows in a mafic flow exposed at Locality 6 (scale card is 14 cm long).

Figure 11. Alternating mafic pillowed and massive flows at the margin of Senator block (Locality 6). Elongated pillow lavas and lobate forms in massive lava flows exemplify increasing deformation approaching the CLLFZ at the southern margin of the study area. Magnified areas 1 to 7 show varying pillow lava morphology throughout the mapped area.

Figure 12. Felsic extrusive and intrusive facies of the Glenwood block. A) Detached lobes (Dl) and mm- to cm-scale flow banding in the massive lobate facies at Locality 7 (notebook is 17 cm long). B) Well-developed, cm-scale flow banding (black outline) and sparse fragments (white outline) in the in situ brecciated facies at Locality 7 (scale card is 8 cm long). C) Millimetre to

centimetre-scale, sub-angular to angular fragments in glassy matrix, characteristic of the flow breccia facies exposed at Locality 7 (scale card is 8 cm long). D) Sub-rounded to rounded fragments with near jigsaw-fit texture found within the flow front breccia facies at Locality 7 (lens cap is 7.2 cm in diameter). E) Locally brecciated margin (yellow outline) of the quartz- and feldspar-phyric endogenous lobe facies exposed at Locality 7 (scale card is 8 cm long). F) Phaneritic texture in the quartz dioritic to tonalitic Lac Noranda pluton (scale card is 8 cm long; Locality 8). G) Well-developed jointing in an east-west-trending mafic dyke cross-cutting the Lac Noranda pluton (scale card is 8 cm long; Locality 8). Jointing is both parallel to the dyke margins and the regional schistosity. H) Dismembered mafic dyke with wispy terminations intruding the felsic flow breccia facies at Locality 7 (pencil is 14 cm long).

Figure 13. Lac Noranda pluton (Locality 8) of the Osisko dyke complex. Pluton composition ranges from quartz diorite to tonalite and has an overall phaneritic texture. Several mafic and felsic dykes cross-cut the pluton and trend ESE-WNW. A number of hydrothermally altered zones also cross-cut the pluton and are near-parallel to the orientation of the dykes.

Figure 14. Discrimination and magmatic affinity diagrams for analyzed samples from mafic to felsic extrusive and intrusive volcanic facies of the RPCC. A) Trace element discrimination diagram (Winchester and Floyd, 1977) for extrusive mafic volcanic facies. B) Binary Y vs. Zr magmatic affinity diagram (Barrett and MacLean, 1999) for extrusive mafic volcanic facies. C) Intrusive mafic facies plotted on the trace element discrimination diagram of Winchester and Floyd (1977). D) Extrusive mafic facies of the RPCC plotted on the Y vs. Zr magmatic affinity diagram of Barrett and MacLean (1999). E) Samples from extrusive felsic facies of the RPCC and the Horne Mine (Laurin, 2009) plotted on the trace element discrimination diagram of Winchester and Floyd (1977). F) Binary Yb vs. Th magmatic affinity diagram (Barrett and

MacLean, 1999) with plotted samples from the extrusive felsic facies of the RPCC and Horne Mine (Laurin, 2009).

Figure 15. Rare earth element plots for analyzed samples from extrusive and intrusive volcanic facies of the RPCC. A) Primitive mantle-normalized REE diagram of mafic extrusive facies with normalization values from Sun and McDonough (1989). B) Samples of mafic intrusive facies of the RPCC plotted with primitive mantle-normalized REE values. C) Primitive mantle-normalized REE profiles of samples from extrusive and intrusive facies of the RPCC.

Figure 16. Evolution of the Rouyn-Pelletier caldera complex. A) Initial mafic seamount development dominated by eruption of pillowed and massive mafic flows (pre-caldera stage; Stadacona block). B) Continued growth of edifice coupled with localized extension beneath it results in the beginning of subsidence, formation of first crater floor and deposition of initial Pelletier block facies and development of bounding faults (marked by McPhee and Glenwood dyke complexes). Mafic lavas begin to fill the crater and construct the floor, completing the formation of the Pelletier block facies (Stage 1). C) Continued asymmetric subsidence and evacuation of magma from underlying chamber causes the formation of a trapdoor caldera geometry and extension of the McPhee fault. D) Elongation of the McPhee fault forms an efficient pathway for lava to travel along the fault and fill in the trapdoor structure with ponded lavas, massive flows and pillowed flows, forming the facies of the Senator block (Stage 2). E) Further faulting of caldera floor results in destruction of original trapdoor geometry and formation of a near-piecemeal geometry, establishing the Glenwood fault. F) The first episode of felsic volcanism is represented by the Glenwood felsic flow complex. Mafic volcanism resumes directly following felsic activity, forming several mafic dyke complexes and intruding the Glenwood complex (Stage 3). Synvolcanic faults allow the mafic lavas to breach the felsic

deposits, forming the next caldera floor and the deposits of the Chadbourne block (beginning of Stage 4). G) Small intermediate to felsic dome-flow complexes begin to form within crater following the cessation of mafic volcanism, forming the initial facies of the Horne block. H) Intermediate to felsic activity continues and the caldera has evolved to the point where activity becomes more explosive with pyroclastic material begins to accumulate within the crater (end of Stage 4).

Figure 17. Schematic block diagram positioning the RPCC in relation to other volcanic centres of the Blake River Group. The RPCC was clustered on the Archean seafloor with several calderas, volcanoes and seamounts, the cores of which are now exposed as synvolcanic plutons. These clustered volcanic centres formed the majority of the Blake River Group.

Legend

Undifferentiated Sedimentary Facies	Endogenous Felsic Facies	Massive Flow Facies	Lobate Facies
Extrusive Mafic Volcanic Facies	Felsic Intrusive Facies	Pillowed Flow Facies	Bedded Volcaniclastic Facies
Extrusive Mafic to Intermediate Volcanic Facies	Extrusive and Intrusive Mafic Volcanic Facies	Volcaniclastic Facies	Faulted Contact
Extrusive Felsic Volcanic Facies	Mafic to Intermediate Intrusive Facies	Ponded Lava with Hyaloclastite Facies	

- Pelletier Block Pillowed Lavas (Locality 1)
- Pelletier Block Pillowed and Massive Lavas (Locality 2)
- Senator Block Ponded Lavas (Locality 3)
- Senator Block Ponded Lavas (Locality 4)
- Senator Block Pillowed and Massive Lavas (Locality 6)

- Pelletier Block Mafic Dykes (Locality 1)
- Pelletier Block Mafic Sills (Locality 1)
- Senator Block Mafic to Intermediate Intrusions (Locality 3)
- Glenwood Block Mafic to Intermediate Dykes (Locality 8)

- Glenwood Block Exogenous Flows (Locality 8)
- Glenwood Block Endogenous Lobes (Locality 8)
- Glenwood Block Intrusive Facies (Locality 7)
- Horne Block Massive Rhyolite Facies

- Pelletier Block Pillowed Lavas (Locality 1)
- ▲ Pelletier Block Pillowed and Massive Lavas (Locality 2)
- ▲ Senator Block Ponded Lavas (Locality 3)
- ▲ Senator Block Ponded Lavas (Locality 4)
- Senator Block Pillowed and Massive Lavas (Locality 6)

- Pelletier Block Mafic Dykes (Locality 1)
- Pelletier Block Mafic Sills (Locality 1)
- ▲ Senator Block Mafic to Intermediate Intrusions (Locality 3)
- ▲ Glenwood Block Mafic to Intermediate Dykes (Locality 8)

- Glenwood Block Exogenous Flows (Locality 8)
- Glenwood Block Endogenous Lobes (Locality 8)
- Glenwood Block Intrusive Facies (Locality 7)
- Horne Block Massive Rhyolite Facies

Blake River Group: Post 2696 Ma