New volcanological and geochemical observations from the Blake River Group, Abitibi Greenstone Belt, Quebec: the D’Alembert tuff, the Stadacona unit, and surrounding lavas

P.-S. Ross, J. Goutier, J.A. Percival, P. Mercier-Langevin and B. Dubé
New volcanological and geochemical observations from the Blake River Group, Abitibi Greenstone Belt, Quebec: the D’Alembert tuff, the Stadacona unit, and surrounding lavas

P.-S. Ross, J. Goutier, J.A. Percival, P. Mercier-Langevin and B. Dubé
Critical reviewer
J.H. Bedard

Recommended citation

Authors
P.-S. Ross (rossps@ete.inrs.ca) INRS-ETE, 490 rue de la Couronne, Québec (QC), G1K 9A9
J. Goutier (jean.goutier@mrnf.gouv.qc.ca) Ministère des Ressources naturelles et de la Faune (Québec), 70 avenue Québec, Rouyn-Noranda (QC), J9X 6R1
J.A. Percival (joperciv@nrcan.gc.ca) Geological Survey of Canada, 601 Booth Street, Ottawa (ON), K1A 0E8
P. Mercier-Langevin (pmercier@nrcan.gc.ca) Geological Survey of Canada, 490 rue de la Couronne, Québec (QC), G1K 9A9
B. Dubé (bdube@nrcan.gc.ca) Geological Survey of Canada, 601 Booth Street, Ottawa (ON), K1A 0E8

Correction date:
New volcanological and geochemical observations from the Blake River Group, Abitibi Greenstone Belt, Quebec: the D’Alembert tuff, the Stadacona unit, and surrounding lavas

P.-S. Ross, J. Goutier, J.A. Percival, P. Mercier-Langevin and B. Dubé


Abstract: The Archean Blake River Group hosts a number of volcanogenic massive-sulphide deposits, several of which are world-class. A better understanding of the stratigraphy and volcanic architecture would help exploration for additional mineralization in the area, including the lesser-known areas of the group. To contribute to this objective, the authors present a comparison of two mafic to intermediate volcaniclastic units on the periphery of the Blake River Group: the D’Alembert tuff in the north, and the Stadacona unit in the south. Both are bedded sequences, several hundred metres in stratigraphic thickness, that were likely emplaced by successions of submarine, water-supported density currents. New findings were that a) explosive basaltic to andesitic eruptions were episodic and separated by pauses long enough to allow the formation of silicic domes and mafic lava lenses in between the volcaniclastic layers; and b) several chemical subgroups can be identified in both the volcaniclastic rocks and the surrounding lavas.

Volcaniclastic units from the periphery of the Blake River Group, including the two discussed here, have been inferred by some previous workers to be correlative and to belong to a caldera-margin setting, with the implication that they were erupted simultaneously or in close succession from a common magma chamber. It is shown that the D’Alembert tuff and the Stadacona unit are geochemically distinct and that they likely have different ages. The authors conclude that these two volcaniclastic units were generated by different eruptive phases, most likely from distinct magma chambers, in different parts of the Blake River Group.

Résumé : Le Groupe de Blake River est l’hôte de nombreux gisements de sulfures massifs volcanogènes, dont plusieurs sont de classe mondiale. Une meilleure compréhension de la stratigraphie et de l’architecture volcanique du groupe faciliterait l’exploration pour d’autres minéralisations de ce type, notamment dans les régions moins connues du Groupe de Blake River. Afin de contribuer à la réalisation de ces objectifs, cet article compare deux unités volcanoclastiques intermédiaires à mafiques de la périphérie du groupe : le tuf de D’Alembert, au nord, et l’unité de Stadacona, au sud. Les deux unités représentent des séquences clastiques litées de plusieurs centaines de mètres d’épaisseur, qui furent mises en place par des successions de courants de densité sous-marins. Nous proposons que a) les éruptions explosives de magmas basaltiques à andésitiques furent épidodiques et séparées par des pauses suffisantes pour permettre la mise en place de dômes felsiques et de lentilles de laves maﬁques entre certains niveaux volcanoclastiques et b) plusieurs sous-groupes peuvent être identifiés dans les roches volcanoclastiques et les laves adjacentes sur le plan chimique.

Des auteurs précédents ont suggéré que les unités volcanoclastiques de la périphérie du Groupe de Blake River, dont les deux décrites ici, étaient corrélables et s’étaient mises en place dans un contexte de marge de caldeira, l’implication étant que les éruptions responsables de leur dépôt s’étaient produites simultanément ou en succession rapide, à partir d’une chambre magmatique commune. Le présent article montre que le tuf de D’Alembert et l’unité de Stadacona possèdent des signatures géochimiques distinctes et ont probablement des âges différents. Nous concluons que ces deux unités volcanoclastiques ont été produites par des phases éruptives différentes, très probablement à partir de chambres magmatiques distinctes, dans des secteurs différents du Groupe de Blake River.
INTRODUCTION

The Blake River Group in Quebec and Ontario is one of the most prospective Archean stratigraphic packages for volcanogenic-massive sulphide (VMS) exploration, especially for gold-rich VMS (e.g. Dubé et al., 2007a, 2007b; Gibson and Galley, 2007; Goutier et al., 2007; Mercier-Langevin et al., 2007a, 2007b, 2007c). As part of Phase 3 of the Geological Survey of Canada’s Targeted Geoscience Initiative (TGI) program, a multidisciplinary, integrated study of the Blake River Group (Abitibi Greenstone Belt) has been initiated, in collaboration with the two provinces, the private sector, and several universities. This includes regional mapping, geochronology, alteration and mineral deposit studies, volcanology, geochemistry, structure, isotope geochemistry, geophysics, and 3D modelling (e.g. Ayer et al., 2006, 2007; Legault and Rabeau, 2007; Monecke et al., 2008).

One aim of this integrated study is to improve our understanding of the stratigraphy and volcanic architecture of the Blake River Group as a whole, to help exploration for VMS deposits. Research on mafic to intermediate volcaniclastic rocks is an important contribution, as these units represent marker horizons and provide indications on the depositional environments. Intriguingly, the map pattern of some of these mafic to intermediate volcaniclastic units define a rough ellipse on the periphery of the Blake River Group, and it has been suggested by other workers that this postdeformation arrangement reflects emplacement in a caldera-margin setting (Pearson, 2005; Daigneault and Pearson, 2006). It was further proposed that the peripheral volcaniclastic units were correlatable ‘andesitic ignimbrites and outflow sheets’ (Mueller, 2006), i.e. subaqueous pyroclastic flow deposits, with the implication that the units were erupted from the same magma chamber at more or less the same time, during the collapse of a giant submarine caldera. A project was initiated in 2006 to re-evaluate the nature and mode of emplacement of the peripheral volcaniclastic units, as well as their supposed Blake River–wide correlation, since this has implications for exploration models.

Ross et al. (2007) described two volcaniclastic units, the D’Alembert tuff (Dimroth and Demarcke, 1978; Tassé et al., 1978) and the Stadacona unit (Dimroth and Rocheleau, 1979; Gilbert, 1986) (Fig. 1), and inferred that they were deposited mostly by water-supported density currents, following submarine explosive eruptions of plagioclase-phryic magmas. Preliminary data showed that the D’Alembert tuff and the Stadacona unit were located in different stratigraphic settings within the Blake River Group, and that the volcaniclastic units were chemically distinct from each other. Ross et al. (2007) also mentioned two additional intermediate to mafic volcaniclastic units, the Bousquet scoriaceous tuff (Stone, 1990; Lafrance et al., 2003; Mercier-Langevin et al., 2008) and the Jévis Sud unit (Trudel, 1978; Pilote et al., 2007), which have, at least in part, similar characteristics and origins.

The Monsabrais area in the northern Blake River Group (Fig. 1) also contains mafic to intermediate volcaniclastic rocks that were implicitly correlated with other peripheral units by Pearson (2005), and were suggested to have been emplaced by pyroclastic density currents. Nevertheless, reinvestigation of these rocks by Ross et al. (2008) returned evidence that the rocks are dominantly flow breccias and hyaloclastites, rather than the products of submarine explosive eruptions. Ross et al. (2008), in agreement with some of the previous workers (e.g. Dimroth et al. 1982, 1985), interpreted the Monsabrais area as a distinct volcanic centre. Identifying volcanic centres has important consequences for mineral exploration, as they can be important loci for VMS-style hydrothermal circulation (e.g. Gibson et al., 1999).

In this report, the authors present new work, including geochemical data, on the D’Alembert tuff, the Stadacona volcaniclastic unit, and the enclosing and interbedded lavas, based on their 2007 field season.

REGIONAL GEOLOGY AND USE OF GEOCHEMICAL TERMS

The Blake River Group is the youngest (~2702–2696 Ma) dominantly volcanic package in the Abitibi Greenstone Belt; it consists largely of submarine, basaltic to rhyolitic, tholeiitic to calc-alkaline volcanic rocks, that are intruded by several generations of plutons as well as by mafic to intermediate dykes and sills. Readers are referred to Ross et al. (2007) (and references therein) for an overview of the geological and stratigraphic setting of the whole Blake River Group, and a discussion of the terminology employed to describe fragmental volcanic rocks.

The latest division of the group into formations is that of Goutier et al. (2007) who recently proposed a revised stratigraphic scheme based on field relationships, a geochemical compilation, and newly available geochronology (V. McNicoll, pers. comm., 2008). In this working model, the Stadacona volcaniclastic unit is thought to belong to one of the oldest volcanic packages of the Blake River Group, the Rouyn-Pelletier formation, whereas the D’Alembert tuff is located near the top of the youngest volcanic package, the Reneault-Dufresnoy Formation. If indeed the Stadacona unit and the D’Alembert tuff belong to volcanic packages with non-overlapping ages, this precludes their direct correlation. We show here that both of these volcaniclastic units have chemical signatures similar enough to their respective enclosing lavas to fit petrogenetically within their host sequences, but that these sequences — including the volcaniclastic units — are geochemically distinct from one another.

In this paper, FeO\textsuperscript{T} is total iron expressed as FeO. For Archean rocks that have experienced metamorphism, and in many cases hydrothermal alteration, magmatic affinities cannot be consistently determined using major elements.
Figure 1. Simplified geological map of a portion of the southern Abitibi Greenstone Belt showing selected VMS mines and the distribution of mafic to intermediate volcaniclastic rocks in the Blake River Group. Grid on all maps is UTM NAD 83, zone 17.
Therefore we use ratios of immobile trace elements such as Zr/Y or La/Yb to assign magmatic affinities (Barrett and MacLean, 1999). ‘Transitional’ is employed to describe rocks which plot between tholeiitic and calc-alkaline fields.

### D’ALEMBERT TUFF AND SURROUNDING LAVAS

The D’Alembert tuff is an intermediate to mafic, approximately 15 km long, bedded volcaniclastic unit composed predominantly of lapilli tuff, with lesser amounts of tuff and tuff-breccia (Fig. 2). Details on the host volcanic sequence, economic geology, stratigraphic thickness, geochemistry, structural geology and mode of emplacement of the D’Alembert tuff were given by Ross et al. (2007), along with the volcanological description of the ‘proximal’ and some ‘distal’ volcaniclastic facies. Here the authors focus on the intercalated lava lenses in the D’Alembert tuff, the lavas surrounding the tuff, and the geochemistry of the volcaniclastic rocks and lavas.

### Lavas: field and petrographic observations

The lavas discussed here fall into four geographical groupings: a) lavas north of the D’Alembert tuff; b) lavas southwest of the tuff; c) a pillowed lens within the tuff, south of area A2 (Fig. 2); d) a rhyolite breccia lens overlying the pillowed lens, also enclosed within the tuff. No lava samples from the area southeast of the tuff (i.e. east of 637 000 m E) were analyzed for geochemistry since no fresh-looking, sulphide-free or sulphide-poor samples were obtained from this area. Because a synclinal axis crosses the D’Alembert tuff (Fig. 2), lava groupings a) and b) are considered older that the tuff, whereas the intercalated lenses c) and d) are contemporaneous. Overall, lavas north and south of the tuff (groupings a and b) range from massive to pillowed and they have a variety of macroscopic and microscopic textures, depending on cooling rates, etc. Field stations and samples mentioned in the text or figures are listed in Table 1.

### Lavas north of the tuff

Generally these lavas lack large plagioclase phenocrysts, in sharp contrast with the D’Alembert tuff, where such crystals — either free-standing or as phenocrysts within fragments — are ubiquitous. The northern lavas are quite pale in weathered surface and were called ‘dacites’ by Tassé et al. (1978), but our geochemical data demonstrate that they are tholeiitic basalts and basaltic andesites (details below). Thin sections show 1–5% amygdales (containing one or more of: quartz, epidote, chlorite, carbonate, and/or pyrite), traces to 25% of epidote-altered plagioclase macrophenocrysts, in a groundmass of former glass with or without plagioclase microlites. The former glass has the same aspect as in the northern lavas. None of the southwestern lavas examined contain recognizable clinopyroxene. In summary, the apparent restriction of clinopyroxene to some northern lavas is compatible with a stratigraphic distinction between the northern and southwestern lavas, but otherwise the field and petrographic differences are not consistent.

### Lens of pillow lava

This lava unit intercalated in the D’Alembert tuff clearly youngs northward based on the pillow shapes. The pillows are up to 1.5 m in exposed long axis on a subhorizontal surface, with glassy rinds up to 4 cm thick. Two thin sections are available for this unit, including one from a silicified sample (BR-157) and the other from a fresher sample. The latter contains ~1% fully epidote-replaced plagioclase phenocrysts (≤1 mm) in a groundmass consisting of approximately 30% epidote-altered plagioclase microphenocrysts and microlites surrounded by probable former glass. The former glass is now replaced by epidote, leucoxene, opaque minerals, and optically irresolvable fine-grained components. The rock is crosscut by veinlets of quartz-epidote-opaque minerals. The geochemistry of this unit differs from that of the other mafic to intermediate lavas in this area (see below).

### Rhyolite breccia lens

This rhyolite lens is 2.8 km in length and 400 m in surface width, based on regional considerations it faces north and dips steeply. The rhyolite was sampled for U-Pb geochronology in June 2007 (zircon is present in the sample; final results pending). On the southwest side, the footwall of the rhyolite is the pillow-lava lens just described; the footwall is the D’Alembert tuff elsewhere. In outcrop, the rhyolite is a monomictic, clast-supported breccia throughout (Fig. 3a). Clasts visible on outcrop have rounded corners but linear sides, indicating brittle fracturing and very limited transport. Jigsaw-fit textures are locally observed, confirming in situ
Figure 2. Simplified geology of the D’Alembert tuff area, showing the distribution of the senior author’s field stations (only one station of out two shown in area A2). Mafic to intermediate intrusions and felsic volcanic rocks have been omitted from the Kinojévís Group for clarity. Geology modified from 1:20 000 maps (National Topographic System sheets 32D/06, 32D/07, 32D/11) by Ministère des Ressources naturelles et de la Faune (MRNF) (Québec). Mineralized occurrences are from the MRNF’s Sgeom database, supplemented by the compilation of Legault et al. (2006). Gold occurrences (including former mines) in the northern part of the figure are associated with the Porcupine-Destor Fault and lesser-order structures. Letters a, b, and c correspond to the locations of high-Ti samples in the D’Alembert tuff (samples BR-007a, BR-078a and BR-241, respectively; see Table 1 for UTM co-ordinates).
The rhyolite clasts, which range in size from 0.5 cm to about 30 cm, are very fine grained, devoid of flow banding, and contain approximately one quartz phenocryst per square metre (visual estimate). Feldspar phenocrysts make up 3 to 5% of rhyolite clasts and reach 1 mm in size (Fig. 3b). The groundmass of the clasts is dominated by quartzofeldspathic material which is accompanied by small fractions of epidote, chlorite, and opaque minerals, either disseminated or in veinlet form (Fig. 3c, left side). The breccia is well sorted if only the clasts greater than 0.5 cm across are included in the assessment of sorting; this will be justified below. The monomict rhyolite breccia is of volcanic origin, resulting from auto-fragmentation of magma and perhaps non-explosive interaction with seawater (e.g. McPhie et al., 1993).

The matrix of the breccia consists of much smaller rhyolite clasts (~0.05–0.5 mm) and disaggregated feldspar crystals, in a cement of chlorite, epidote, opaque minerals, and optically irresolvable material (Fig. 3c, 3d). In detail, the cement appears to have corroded the clast margins, creating rounded to wavy outlines, and the proportion of matrix versus cement is highly variable (compare Fig. 3c to 3d). Some — or all — of the clasts in the matrix may have been fragmented by hydrothermal processes (by the same fluids that deposited the cement and formed the veinlets). Therefore the rock was likely a well sorted breccia before the introduction of the cement and the accompanying hydrothermal re-fracturing.

The rhyolite breccia is interpreted overall as the carapace of a dome or a fragmental lava flow. No coherent (unfragmented) core is currently known.

**Geochemistry**

Including the analyses cited by Ross et al. (2007), the authors now have a geochemical database of 24 lavas and 22 volcaniclastic rocks from the D’Alembert tuff and vicinity (including our surface samples only). Most of these analyses are from the same laboratory and include a full suite of trace elements, allowing a comparison between the volcaniclastic rocks and lavas from this area. The rocks are addressed in stratigraphic order.

**Lavas north of the tuff and southwest of the tuff**

On Figure 4, most of the northern lavas plot separately from the southwestern lavas. Specifically, the analyzed northern lavas are tholeiitic basalts and basaltic andesites, with TiO₂ contents of 1.25% or more, whereas the southwestern lavas are transitional to calc-alkaline andesites and basaltic andesites with TiO₂ abundances below 0.8% (magnmatic affinities assigned from the Zr/Y ratio; based on the La/Yb ratio the northern lavas are transitional whereas the southern lavas are transitional to calc-alkaline). The only exception is BR-018, a sample from the northern lavas which plots with the southwestern lavas on Figures 4a, 4b, 4d and on a La-Yb plot (not shown). The multi-element patterns are also distinct (Fig. 5a, 5b): all the southwestern lavas have steep overall profiles, steep light rare-earth element (REE) slopes, prominent Zr-Hf plateaus, and deep negative Nb-Ta anomalies; whereas all the northern lavas except BR-018 have gentler overall slopes, gentler light REE slopes, little evidence for a Zr-Hf plateau, and small Nb-Ta anomalies.

At a slightly more regional scale, integration of new data with a compilation from the Ministère des Ressources naturelles et de la Faune’s (MRNF) Sigeom database reveals that the mafic to intermediate lavas between the D’Alembert tuff and the Hébécourt Formation (Fig. 2) vary in TiO₂ concentration from 0.62 to 2.15%. Lenses of low-Ti (presumably transitional to calc-alkaline) and high-Ti (presumably tholeiitic to transitional) lavas appear to be intercalated in this area, which would be consistent with the BR-018 ‘anomaly’ mentioned above. The same observation of alternating affinities in mafic to intermediate lavas (tholeiitic vs. calc-alkaline) was made in the Blake River Group further east in the Cléricy area by Lafleche et al. (1992) and Goutier (1997). Based on the Sigeom data, lavas immediately southeast of the D’Alembert tuff are characterized by high TiO₂ values.

**Table 1. Field station and sample location**

<table>
<thead>
<tr>
<th>Station</th>
<th>Sample</th>
<th>Easting*</th>
<th>Northing*</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-PSR-025</td>
<td>BR-007a</td>
<td>641 458</td>
<td>5 368 165</td>
</tr>
<tr>
<td>06-PSR-065</td>
<td>BR-018</td>
<td>637 331</td>
<td>5 370 205</td>
</tr>
<tr>
<td>06-PSR-162</td>
<td>BR-078a</td>
<td>641 442</td>
<td>5 368 301</td>
</tr>
<tr>
<td>07-PSR-001</td>
<td>n. m.</td>
<td>649 074</td>
<td>5 342 085</td>
</tr>
<tr>
<td>07-PSR-002</td>
<td>n. m.</td>
<td>649 073</td>
<td>5 342 037</td>
</tr>
<tr>
<td>07-PSR-003</td>
<td>n. m.</td>
<td>649 079</td>
<td>5 342 132</td>
</tr>
<tr>
<td>07-PSR-009</td>
<td>n. m.</td>
<td>636 397</td>
<td>5 367 469</td>
</tr>
<tr>
<td>07-PSR-010</td>
<td>BR-148</td>
<td>636 312</td>
<td>5 367 450</td>
</tr>
<tr>
<td>07-PSR-012</td>
<td>BR-146</td>
<td>636 356</td>
<td>5 367 382</td>
</tr>
<tr>
<td>07-PSR-029</td>
<td>BR-157</td>
<td>635 490</td>
<td>5 367 697</td>
</tr>
<tr>
<td>07-PSR-034</td>
<td>BR-161</td>
<td>644 257</td>
<td>5 341 323</td>
</tr>
<tr>
<td>07-PSR-038</td>
<td>BR-165</td>
<td>645 080</td>
<td>5 341 122</td>
</tr>
<tr>
<td>07-PSR-039</td>
<td>BR-204</td>
<td>646 877</td>
<td>5 342 417</td>
</tr>
<tr>
<td>07-PSR-040</td>
<td>BR-205</td>
<td>646 900</td>
<td>5 342 461</td>
</tr>
<tr>
<td>07-PSR-042</td>
<td>BR-210</td>
<td>645 427</td>
<td>5 341 236</td>
</tr>
<tr>
<td>07-PSR-047</td>
<td>BR-211</td>
<td>645 589</td>
<td>5 341 256</td>
</tr>
<tr>
<td>07-PSR-055</td>
<td>BR-216</td>
<td>645 936</td>
<td>5 342 473</td>
</tr>
<tr>
<td>07-PSR-057</td>
<td>n. m.</td>
<td>645 903</td>
<td>5 342 443</td>
</tr>
<tr>
<td>07-PSR-111</td>
<td>BR-241</td>
<td>633 067</td>
<td>5 369 468</td>
</tr>
<tr>
<td>Section, Stadacona</td>
<td>BR-199</td>
<td>649 073</td>
<td>5 342 091</td>
</tr>
<tr>
<td>Section, Stadacona</td>
<td>BR-237</td>
<td>649 097</td>
<td>5 342 130</td>
</tr>
<tr>
<td>P-385</td>
<td>n. m.</td>
<td>647 191</td>
<td>5 342 431</td>
</tr>
</tbody>
</table>

* UTM Nad 83, Zone 17 (measured by GPS)
  n. m.: if a sample exists, it is not mentioned in the text or the figures
Volcaniclastic rocks

The D’Alembert tuff samples analyzed were mostly lapilli tuffs and coarse tuffs (whole rocks, ~1.5–2.5 kg) to avoid incorporating very large clasts. The samples range in composition from basalt to andesite (Fig. 4a, 4b) and fall in two types (Fig. 4c and 4d): a common low-Ti variety (19 samples) and a rarer high-Ti variety (3 samples, marked a, b and c on Fig. 2). Both types have overlapping Ti/Zr (or Zr/TiO₂) ratios and SiO₂ values. High-Ti samples have both higher TiO₂ (1.15–1.30%) and FeO° (7.7–10.1%); they also have lower Zr/Y ratios (3.9–4.2). Low-Ti samples have lower FeO° (2.4–7.5%) and TiO₂ (0.47–0.83%) abundances, but higher Zr/Y ratios (5.5–12.6). When the La/Yb and Th/Yb ratios are also considered (e.g. Ross et al., 2007 and see below) it appears that the high-Ti samples are tholeiitic to transitional, whereas the low-Ti samples are transitional to calc-alkaline.

On multi-element plots (Fig. 5c, 5d), the high-Ti samples have gentler overall slopes (e.g. mantle-normalized Th/Yb), gentler light REE slopes, less prominent Zr-Hf plateaus, and smaller negative Nb-Ta anomalies. The heavy REE and Y abundances are also higher in the high-Ti samples. This indicates that the two volcaniclastic types sampled so far represent petrogenetically distinct batches of magma.

Nevertheless, the authors observed no consistent field or petrographic differences between the two geochemical types in the D’Alembert tuff. For example, both the low-Ti and the high-Ti localities range from tuffs to tuff-breccias, so
Figure 4. Geochemistry of the D’Alembert tuff, nearby lavas, and the two lava lenses in the tuff; only the surface samples are plotted. a), b) Classification diagrams from Winchester and Floyd (1977). c) Magmatic affinity diagram from Barrett and MacLean (1999). d) TiO$_2$-Zr binary diagram. e) SiO$_2$-Zr binary diagram, showing only the lava lenses for clarity. All plots except b) include unpublished X-ray fluorescence (XRF) data from Xstrata Copper (9 samples of the lava lenses and 6 volcaniclastic rocks near the rhyolite lens). All other geochemical analyses shown in this paper are from Actlabs (Ancaster, Ontario): major elements by XRF, trace elements by fusion inductively coupled mass spectrometry (ICP-MS).
Figure 5. Multi-element profiles for the D’Alembert tuff, nearby lavas, and the two lava lenses in the tuff. See text for explanation (normalization values from Sun and McDonough, 1989). Sample BR-018 from the northern lavas is omitted from d) for clarity; its profile looks similar to those of the southwestern lavas.
grain size is not a factor. The texture of volcanic fragments varies widely within the two geochemical types, as does the proportion of free plagioclase crystals.

So far, high-Ti samples are only present in area A3 and west of the road leading to the Baie D’Alembert showing, near the synclinal axis (Fig. 2). There is no consistent relationship between inferred stratigraphic position (e.g. distance from the synclinal axis) and the occurrence of high-Ti volcaniclastic samples. Further sampling is planned in order to establish the chemo-stratigraphy of the D’Alembert tuff.

An interesting observation is that the southwestern lavas are chemically very similar to the low-Ti volcaniclastic samples from the D’Alembert tuff (see in particular Fig. 4d and Fig. 5a, 5c). Conversely, the northern lavas resemble high-Ti volcaniclastic samples (see Fig. 4d and Fig. 5b, 5d). The stratigraphic and genetic implications of these findings are not currently clear, but an intercalation of different geochemical types of mafic to intermediate products seems to be present in both the D’Alembert tuff and the surrounding lavas.

**Lens of pillow lava in the D’Alembert tuff**

This unit has the lowest Zr/Y ratio of the rocks analyzed in the D’Alembert tuff area, showing a clear tholeiitic affinity (Fig. 4c). The composition of most samples ranges from basalt to andesite (Fig. 4a, 4b). One sample (BR-157) plots in the dacite/rhyodacite field on Figure 4a, but it lies more or less on a vertical line with the other samples from this unit, suggesting that the high silica content is a result of hydrothermal alteration rather than magmatic differentiation. This is confirmed by the visual and petrographic aspect of the specimen, and its position in Figure 4e, where it plots well away from the fractionation trend for this unit.

The lens of pillow lava has the highest TiO₂ contents of the rocks analyzed in the D’Alembert tuff area (1.22–1.71%, Fig. 4d). The FeO values range up to 11.5%, with MgO mostly in the 4 to 7% range, demonstrating the iron-rich nature of this unit. The trends displayed by this unit on a TiO₂-Zr plot (Fig. 4d) and on a SiO₂-Zr plot (Fig. 4e) suggest that it behaves somewhat like a ferroandesite (Barrett and MacLean, 1999). The multi-element profiles for the pillow lava lens (Fig. 5e, filled dots) are comparatively flat, but the elemental concentrations are elevated considering the relatively mafic nature of this unit (all mantle-normalized elements above 10 except Ti).

**Rhyolite breccia lens**

This rhyolite (Fig. 4a, 4b) has exceptionally low TiO₂ values (0.05 to 0.11%). Its Zr/Y ratios are near the tholeiitic to transitional boundary (Fig. 4c). The Zr variations in this unit are likely due to different levels of alteration of a single precursor — this is confirmed by field and petrographic observations (see above). Elements such as Zr and Ti were immobile but gains and losses in other elements caused the samples to plot on an alteration line crossing the origin (Fig. 4d).

**STADACONA VOLCANICLASTIC UNIT AND SURROUNDING LAVAS**

The Stadacona unit is a basaltic, ~10 km-long, bedded volcaniclastic unit in the southern part of the Blake River Group in Quebec (Fig. 1, 6). Comments on the host volcanic sequence, stratigraphic thickness, structural geology and preliminary volcanological observations are given by Ross et al. (2007). Younging is to the north in this area, within a homoclinal sequence. Here the authors focus on observations on a new stratigraphic section in the lower part of the Stadacona unit; field and petrographic observations on the upper contact of the unit; and new geochemical data from volcaniclastic rocks and surrounding lavas.

**Stratigraphic section in the lower part of the Stadacona volcaniclastic unit**

In order to obtain more information on the internal make-up of, temporal variations within, and origin of, the Stadacona unit, a 118 m long section was measured on a series of flat-lying outcrops exposing steeply dipping strata some 3.7 km east of Lake Pelletier (Fig. 6, 7). This corresponds to stop III-9 from Dimroth and Rocheleau (1979, p. 147), who measured less than 20 m of volcaniclastic beds from the top part of this study’s main section (old paint marks were found on the outcrops).

The main section only reaches slightly above 100 m, so a secondary section to the east is utilized to cover the last few metres; similarly, the 14 m to 33.5 m interval on the main section is poorly exposed, so a secondary section to the west is used to illustrate a lava intercalation. Overall, the volcaniclastic sequence is diluted by at least 34 m of gabbroic to dioritic intrusions of transitional magmatic affinity (Fig. 8). These are mostly sills or low-angle sheets, some containing coarse-grained disseminated pyrite. The section includes at least 10 m of basaltic lava (pillow lava to pillow breccia; Fig. 9a). The lava intercalation is laterally discontinuous over a few tens of metres and therefore is lenticular in nature.

The volcaniclastic beds are laterally continuous over at least a few tens of metres — further tracing of beds is exposure-limited. The layers range in apparent thickness from a few centimetres to over 12 m (top unexposed for the thickest bed, at the base of the main section) and the largest clast is 82 cm across (long axis on a horizontal outcrop). Reverse grading is observed at the base of the thickest bed, and at the base of a few beds higher up (Fig. 7). Normal grading is more frequent and characterizes whole beds or their upper parts only. Finer-grained, generally thinner beds feature planar
Figure 6. Simplified geology of the Rouyn-Noranda area, including the Stadacona unit in the Blake River Group. Geology modified from 1:20 000 maps (NTS sheets 32 D/02, 32 D/03, 32 D/06, 32 D/07) by Ministère des Ressources naturelles et de la Faune (MRNF) (Québec). Mineralized occurrences are from the MRNF’s Sigeom database, supplemented by the compilation of Legault and Rabeau (2007).
**Figure 7.** Stratigraphic section in the lower (southern) part of the Stadacona unit, southeast of Rouyn-Noranda (location on Fig. 6). Beds dip 70 to 80° to the north but no thickness corrections have been made on the section which was measured horizontally, perpendicular to bedding strike. Station 07-PSR-001 (see Table 1 for GPS co-ordinates) corresponds to 75 m on the main section. Station 07-PSR-002 is near 30 m on the secondary section to the west. Station 07-PSR-003 is within the secondary section to the east. All units on the section are volcanioclastic rocks belonging to the Stadacona unit, except if noted. See text for geological explanation.
Figure 8. Composite section condensed from Figure 7, showing selected geochemical ratios. No thickness corrections have been made, as explained in Figure 7. All the volcaniclastic rocks analyzed from this section have the same geochemical signature (tholeiitic basalts, Ti/Zr between 149 and 162, Zr/Y between 2.5 and 3.4), except the porphyritic clast at 5 m which is richer in Ti. The hyaloclastite matrix from the pillow breccia in the lava intercalation is geochemically similar to the volcaniclastic samples from the section. The intrusions are very distinct chemically; other intrusions crosscutting the Stadacona tuff are tholeiitic, but these have a transitional affinity.
lamination, except for one bed displaying cross-lamination in the upper part of the secondary section to the east (near 116 m).

Sorting appears poor overall (visual assessment), especially in beds containing large fragments. Volcanic clasts of lapilli and block/bomb size are all mafic to intermediate in composition (visual assessment) and do not show heat-retention features or chilled margins. Some have curvilinear shapes (e.g. Fig. 9b) and others are almost round (i.e. they are bombs; Fig. 9c); clast vesicularity ranges from nil to 30% (vesicles ≤2 mm). In thin section the proportion of plagioclase (as free crystals and as phenocrysts in mafic clasts) can reach 40% in some volcaniclastic beds (Fig. 9d) but is much less in other beds. Secondary minerals such as carbonate, chlorite, and epidote are abundant. Carbonate can reach 15% of the rock and invades the matrix (Fig. 9e, 9f). Some samples have a weak planar fabric due to tectonic deformation, especially near the base of the section. Due to their poor state of preservation in general, the authors cannot comment on the microtextures of clasts.

Many of the poorly sorted, graded, relatively coarse-grained beds likely represent subaerial, eruption-fed density current deposits as suggested for the D’Alembert tuff (Ross et al., 2007). Fragments in the Stadacona unit lack chilled margins, as opposed to the large fragments in the pillow breccia from the lava intercalation. The authors envisage no genetic relationship, in terms of fragmentation processes, between the lava intercalation and the volcaniclastic beds, although the geochemistry is comparable (Fig. 8). However, the lava intercalation is an example of a distinct break in the explosive activity responsible for generating the material found in the volcaniclastic deposits of the Stadacona unit. No felsic clasts or quartz crystals were noticed within the volcaniclastic rocks of the section.

**Observations on the upper contact of the Stadacona unit and the overlying felsic unit**

At the very top of the Stadacona volcaniclastic unit, the proportion of felsic fragments increases significantly. In several places, the upper contact of the Stadacona unit is with a thin felsic unit that is not currently shown on the map. This felsic unit occurs, from west to east:

- **a)** on the east shore of Lake Pelletier (Fig. 6), where it consists of a poorly exposed, clast-supported breccia with sub-angular to sub-rounded fragments mostly smaller than 20 cm (station 07-PSR-055) and of a tuff that contains about 20% quartz crystals smaller than 2 mm (station 07-PSR-057); the tuff is crosscut by sericite veinlets [these two nearby outcrops are separated by a thin band of pillow lavas];
- **b)** on the Granada road (see below); and
- **c)** behind the cement plant in the Rouyn-Noranda industrial park, where it consists of mostly coherent rocks which are often quartz-phyric and locally flow-banded (station P-385).

Geochemical analyses from all these localities confirm a common trace-element signature (see below). No site clearly exposes both the lower and upper contacts of the felsic unit; the maximum exposed thickness is about 10 m at site (c). Two attempts have been made at this site, from different samples, to obtain a crystallization age for this felsic unit based on the U-Pb method, but no magmatic age was obtained (V. McNicoll, pers. comm., 2008).

On the east side of the Granada road, just south of Boulevard Industriel, two outcrops illustrate the transition zone from the Stadacona unit to the overlying felsic unit (site b). The southern outcrop (station 07-PSR-039) shows a single mafic to intermediate, lapilli tuff to tuff breccia bed, at least 6 m thick (base and top not exposed), from the Stadacona unit. The diversity of mafic to intermediate volcanic fragments is obvious, with clast textures ranging from aphryic to porphyritic and from dense to vesicular (Fig. 10a). The tuffaceous matrix contains plagioclase crystals but no quartz. Felsic clasts are present in trace amounts. No clear grading is observed, although the bed could be graded on a scale larger than that exposed. No geochemical analysis of that particular outcrop is available, but a stratigraphically equivalent sample is a tholeiitic basalt.

A short distance to the north, the other freshly stripped outcrop (station 07-PSR-040) displays strongly deformed, finer-grained Stadacona rocks (lapilli-tuff to coarse tuff). They still contain free plagioclase crystals and plagioclase-aphyric volcanic fragments indicating a mafic provenance, but they display a greater proportion of felsic clasts. Both these uppermost Stadacona beds and the immediately overlying felsic unit (Fig. 10b) have been intensely stretched sub-vertically by tectonic deformation. In the Stadacona unit, the...
Figure 10. Photographs a) and microphotographs c) to e) from the very top of the Stadacona volcaniclastic unit and the overlying felsic unit near the Granada road/boulevard Industriel intersection. a) A thick Stadacona bed showing a range of textures in its volcanic fragments (sub-horizontal outcrop viewed from above, station 07-PSR-039). b) Contact between the Stadacona unit (medium grey rock, bottom of photo) and the overlying felsic lobe (sub-horizontal outcrop viewed from above, station 07-PSR-040). c) XPL view of the coherent, flow-banded felsic lobe showing quartz phenocrysts (QZ) broken apart by tectonic deformation in a fine-grained quartzofeldspathic groundmass (sample BR-204). Carbonate (CB) and chlorite (CL) are among the secondary minerals. d), e) PPL-XPL pair from the Stadacona tuff near the contact, showing a deformed rock in which rhyolite-derived quartz crystals (QZ) have fared well, but in which volcanic clasts (V) have been stretched (sample BR-205). PPL = plane-polarized light; XPL = cross-polarized light.
A proportion of quartz crystals reaches 1 to 2% just below, i.e., south of, the contact (Fig. 10c-10d). This indicates that felsic material was available on the seafloor where the last currents responsible for deposition of the Stadacona unit — dominated by mafic clasts and generated by explosive eruptions of mafic plagioclase-phyric magmas — picked up felsic clasts and quartz grains. Alternatively, the felsic components were derived from the walls of the volcanic conduit during explosions involving mafic magmas. In either case, felsic magmatism had to occur contemporaneously with the last phases of the Stadacona explosive (mafic) volcanism to provide a felsic contaminant.

The felsic unit overlying the Stadacona unit is a flow-banded coherent lava containing 5 to 7% quartz phenocrysts; this unit has an undulating contact with the Stadacona beds and also includes brecciated parts. A small felsic lobe (a few decimetres across) intruded the Stadacona unit just below the contact, indicating that at least a fraction of the felsic magmatism was intrusive. Overall, it appears that felsic magmatism started before the end of explosive mafic activity (to provide a contaminant for the uppermost Stadacona beds) and continued slightly after (to create the overlying felsic unit and the intrusive lobe in the Stadacona unit). Other thin felsic units are also exposed higher up in the sequence, intercalated with pillow lavas and gabbroic sills.

**Geochemistry**

The authors have analyzed 21 volcaniclastic rocks from the Stadacona volcaniclastic unit, two interbedded lavas, and a few dozen lava samples from the surrounding Rouyn-Pelletier formation. A detailed discussion of the full Rouyn-Pelletier lava stratigraphy is beyond the scope of this paper and we only plot general fields for lavas south of the Stadacona unit (based on eight samples) and lavas north of the unit (11 samples). These fields reveal that excluding felsic rocks, the Rouyn-Pelletier lavas north and south of the Stadacona unit are mainly tholeiitic basalts, with minor basaltic andesites (Fig. 11). Lavas south of the Stadacona unit have higher Ti/Zr ratios, on average, than those found north of the Stadacona unit.

The only lavas discussed in more detail here — and plotted as individual data points on Figure 11 — are (a) two samples from Lake Pelletier, immediately south of the Stadacona unit; (b) the felsic unit immediately north of the Stadacona unit in certain areas (five samples); (c) the mafic lavas just north of, or interbedded with, the aforementioned felsic unit (four samples). We deal with the volcaniclastic rocks first and then discuss these lavas, not necessarily in stratigraphic order. All volcaniclastic samples were whole rocks except for a porphyritic clast from the stratigraphic section (labelled on Fig. 8).

**Mafic volcaniclastic rocks: main group**

The great bulk of the Stadacona volcaniclastic rocks plot as tholeiitic basalts on Figures 11b and 11c, confirming that the Stadacona unit fits petrogenetically within the Rouyn-Pelletier formation. SiO₂ contents are consistent with a basaltic composition as well (Fig. 11a). Analyzed rocks include samples from most parts of the Stadacona unit, laterally and stratigraphically. This ‘main group’ of Stadacona volcaniclastic samples excludes three analyses (BR-161, BR-205 and BR-211) discussed separately below.

Multi-element plots for the main group (Fig. 12a, 12b) show relatively flat patterns overall; small to moderate Nb-Ta anomalies; gently dipping light REE; essentially flat heavy REE; no prominent Zr-Hf plateau (as opposed to the D’Alembert tuff signature), and, in some cases, small positive Eu anomalies. Overall, these profiles resemble those of arc tholeiites. Some samples from the main group fall on the tholeiitic-transitional boundary on the La-Yb plot (Fig. 13e), and this is reflected in REE slopes somewhat greater than that expected for true tholeiites on Figure 12.

On Figure 11d, the main group of volcaniclastic samples defines a fan pattern with Ti/Zr ratios between 276 and 134. An arbitrary division was established within the fan using a Ti/Zr limit of 180 (long-dashed line on Fig. 11d) and multi-element patterns for volcaniclastic samples were plotted separately. Samples with Ti/Zr >180 have large positive Ti anomalies (Fig. 12b); this subgroup includes all the samples from the eastern tip of the Stadacona unit, one sample from Lake Pelletier, and a porphyritic clast from the stratigraphic section. Volcaniclastic samples with Ti/Zr <180 have a smaller or no positive Ti anomaly on multi-element plots (Fig. 12a); this subgroup includes all the whole-rock volcaniclastic samples from the stratigraphic section, and most volcaniclastic samples from Lake Pelletier and the industrial park area (just south of Rouyn-Noranda, Fig. 6). If titanium is excluded, the elemental concentrations are lower, on average, in Stadacona samples with Ti/Zr >180.

The stratigraphic significance of the Ti/Zr subgroup in the main group of volcaniclastic rocks is not clear at this stage: the high Ti/Zr volcaniclastic samples are not found in a specific stratigraphic position. Hand specimen and petrographic examination of samples from the two subgroups yields no consistent difference.

**Mafic lavas interbedded in the Stadacona unit**

Multi-element profiles for these two samples, including the intercalated lava from the section (Fig. 12c), strongly resemble the low Ti/Zr volcaniclastic rocks from the Stadacona unit (Fig. 12a) and plot with the main group (with Ti/Zr <180) on Figure 11.
Figure 11. Geochemistry of the Stadacona volcaniclastic unit and nearby lavas (intrusive rocks not shown). Samples of mafic volcaniclastic rocks range from base to top of the Stadacona unit, and the bulk of them plot as tholeiitic basalts on these diagrams. All the felsic rocks (one tuff, four lavas including breccias) are from a thin unit just above (north of) the Stadacona unit. Labelled samples are discussed in the text. The fields for the Rouyn-Pelletier formation mafic to intermediate lavas north of the Stadacona unit (dashed outline, turquoise-green fill) and south of the Stadacona unit (continuous outline, apple-green fill) are from newly obtained data only. The fields for the northern lavas include samples shown on Figure 12d but exclude two outlier samples which have lower Ti/Zr and higher Zr/Y ratios. a), b) Classification diagrams from Winchester and Floyd (1977). c) Magmatic affinity diagram from Barrett and MacLean (1999). d) TiO$_2$-Zr binary diagram. The short-dashed line on d) is an alteration trend (MacLean and Barrett, 1993), whereas the long-dashed line (Ti / Zr = 180) separates the “main group” of volcaniclastic samples into two sub-groups.
Figure 12. Multi-element profiles for the Stadacona volcaniclastic unit and nearby lavas (normalization values from Sun and McDonough, 1989). See text for discussion.
Figure 13. Geochemical comparison of the main group of volcaniclastic samples from the Stadacona unit with the low-Ti volcaniclastic rocks from the D’Alembert tuff. a), b) Classification diagrams from Winchester and Floyd (1977). c) and e) Magmatic affinity diagrams from Barrett and MacLean (1999). d) TiO₂-Zr binary diagram. f) Multi-element profiles (normalization values from Sun and McDonough, 1989). Data points used to create the envelopes shown here are from Figures 4, 5c, 11 and 12a, b.
Mafic lavas just north of the felsic unit or the Stadacona unit

These four samples plot with the main group on Figure 11 (with Ti/Zr > 180) and their multi-element plots (Fig. 12d) have some similarities with the high Ti/Zr volcaniclastic samples (Fig. 12b), although the patterns are flatter.

Mafic lavas from southern Lake Pelletier

These two samples (BR-165, BR-210; grey dots with green outlines on Figures 11 and 12e) have distinctly lower Ti/Zr ratios (82 to 74) than those of the main group, and transitional affinities based on their Zr/Y ratios. By contrast, the other mafic to intermediate lava samples south of the Stadacona unit are clearly tholeiitic.

Mafic volcaniclastic rocks: others

BR-211 is a highly deformed and severely altered rock, not typical of the Stadacona unit, from southeast Lake Pelletier. Petrography suggests a polymictic character, including the presence of felsic clasts. Light contamination by felsic material possibly explains why BR-211 plots slightly outside the main group on most diagrams.

BR-161 is a coarse tuff from south-central Lake Pelletier, showing an abundance of plagioclase in a chloritized matrix, and is petrographically much more typical of the Stadacona unit. There is no physical evidence of contamination in this sample.

Felsic rocks and contaminated Stadacona rocks

The silicic unit located just north of the Stadacona unit was sampled everywhere it was found (see above). These felsic samples have Zr/Y ratios near the tholeiitic-transitional boundary (Fig. 11c) and La/Yb ratios in the transitional range (not shown). Multi-element plots display gently sloping REE profiles, and small negative Nb-Ta anomalies (Fig. 12e). A sample of felsic breccia from northeastern Lake Pelletier (BR-216) has a similarly shaped profile but with lower element abundances, including Ti. This is the result of the significant addition of silica and carbonates as secondary minerals, as observed petrographically and also on Figure 11a where this sample is enriched in SiO2 compared to other felsic samples. Figure 11d shows the same process: BR-216 lies on an alteration line, closer to the origin than other felsic samples, due to dilution of immobile components during hydrothermal alteration (mass gain). By contrast, BR-216 plots with the other felsic samples on Figure 11b, which uses ratios of immobile elements.

Summary and comparison with the remainder of the Rouyn-Pelletier formation

In summary, the Stadacona volcaniclastic unit consists largely of tholeiitic basalts (based on Zr/Y ratios). The bulk of the lavas in the Rouyn-Pelletier formation south and north of the tuff (fields on Fig. 11) also consist of tholeiitic products, ranging in composition from basalt to basaltic andesite. So at a regional scale, the Stadacona volcaniclastic unit fits within the overall trend of the mafic to intermediate lavas from the Rouyn-Pelletier formation, but at the mafic end of this trend (i.e. low Zr and SiO2 values). At a more local scale (individual data points on Fig. 11), the Stadacona unit is immediately overlain by a thin tholeiitic to transitional felsic unit from eastern Lake Pelletier to the industrial park area; this felsic unit is itself overlain by, and locally interbedded with, a tholeiitic basalt which has some resemblance to high Ti/Zr volcaniclastic samples in the Stadacona unit. Southern Lake Pelletier contains lavas and volcaniclastic rocks that are more evolved than both those of the ‘main group’ in the Stadacona unit and the bulk of the Rouyn-Pelletier formation.

DISCUSSION

Enough geochemical data are now available to confidently compare the D’Alembert tuff with the Stadacona volcaniclastic unit. Specifically, the volumetrically dominant low-Ti type from the D’Alembert tuff, on one hand, and the main group of samples from the Stadacona unit, on the other hand, plot in non-overlapping fields (Fig. 13 a-c; see also Fig. 5c, 12a, and 12b). In summary, the main group of Stadacona volcaniclastic samples consists overwhelmingly of tholeiitic basalts with relatively flat multi-element plots (whole pattern); moderate negative Nb-Ta anomalies; gentle light REE slopes; small positive Eu anomalies; no Zr-Hf plateau; small to moderate positive Ti anomalies; and flat heavy REE. In sharp contrast, low-Ti volcaniclastic rocks from the D’Alembert tuff are transitional to calc-alkaline basaltic andesites or andesites. Their multi-element patterns are much steeper overall; negative Nb-Ta anomalies are more pronounced; the light REE slopes are steeper; Zr-Hf plateaus are prominent; Ti shows a negative anomaly rather than a positive one; and heavy REE slopes are gentle, but not flat.
This geochemical comparison indicates that although the D’Alember tuff and the Stadacona unit share some physical characteristics, they were derived from very different magmas. Further, there are strong suggestions from recent and historical U-Pb geochronology that the host sequences for these volcaniclastic units have distinct ages. Specifically, all the U-Pb dates for volcanic rocks between the Larder Lake–Cadillac fault and the Horne mine — the sequence which contains the Stadacona unit — fall in the 2702 to 2700 Ma range (V. McNicoll, pers. comm., 2008); these are among the oldest volcanic rocks in the Blake River Group. In contrast, the U-Pb dates from volcanic rocks in the northern part of the Blake River Group in Quebec (the Reneaul-Dufresnay Formation of Goutier et al., 2007, which contains the D’Alember tuff) are between 2698 and 2696 Ma; these are among the youngest rocks the Blake River Group.

Considering the geochemical and geochronological evidence presented above, the authors conclude that the D’Alember tuff and the Stadacona unit cannot be correlated and were generated from different eruptions. These eruptions most likely originated from distinct magma chambers in different parts of the Blake River Group, at different times in its evolution. The common physical characteristics of the two volcaniclastic units can be explained by similar processes affecting the respective magma chambers, i.e. crystal and gas enrichment leading to explosive eruptions, and then by similar submarine transport and deposition processes.

SUMMARY AND CONCLUSIONS

This report deals with some mafic to intermediate volcaniclastic rocks, enclosing lavas, and associated felsic rocks in the Blake River Group, based on summer 2007 field work and subsequent investigations. Some of the highlights for the D’Alember tuff (DT) and the Stadacona unit (SU) are as follows:

1. Submarine explosive eruptions of mafic to intermediate, plagioclase-phryic magmas are thought to be the source of the bulk of the material found in the bedded tuffaceous sequences, which were deposited in large part by high-concentration density currents, likely of the eruption-fed type (DT, SU) (see also Ross et al., 2007).

2. These explosive basaltic to andesitic eruptions were episodic and separated by pauses long enough to allow the formation of silicic domes (DT) and mafic lava lenses (DT, SU) in between the volcaniclastic layers.

3. Broadly contemporaneous, comparatively small-volume felsic magmatism is demonstrated by an intercalated felsic dome (DT), the local presence of a silicic clasts and quartz crystals in the volcaniclastic deposits (SU), contamination of volcaniclastic rocks (SU), and rare invasive felsic lobes (SU).

4. Several geochemical sub-groups are present in the volcaniclastic units and the surrounding lavas (DT, SU).

5. Additional geochemical analyses shown here, as well as recently obtained U-Pb geochronology (V. McNicoll, pers. comm., 2008), support Ross et al.’s (2007) contention that the DT and the SU have a different chemical signature and occur in different stratigraphic settings, so they cannot be correlated. The most obvious way to interpret these results is that the DT and the SU were generated by different eruptions, probably from geographically and petrogenetically distinct magma chambers, at times separated by a few million years. Thus, these volcaniclastic units were probably not produced by eruption(s) from a common magma chamber in association with a large-scale caldera collapse event.

ACKNOWLEDGMENTS

This study was funded by the Targeted Geoscience Initiative (TGI-3) program of the Geological Survey of Canada, including a NSERC Visiting Fellowship in Canadian Government Laboratories to Pierre-Simon Ross during the period May 2006 – September 2007. Pierre-Simon Ross also received support from the Chief Scientist’s Office (Earth Sciences Sector, Natural Resources Canada) during that time. The authors thank Xstrata Copper Canada for the use of some of their geochemical data. J. Ayer, C. Dion, H. Gibson, E. Grunsky, M. Hannington, V. McNicoll, M. Masson, T. Monecke, L. Moore, W.U. Mueller, V. Pearson, C. Pilote, P. Pilote, H. Poulsen, P. Riopel, B. Taylor, P. Thurston, J.D.L. White, and B. Wing are acknowledged for helpful discussions. A. Jean was an enthusiastic field assistant during field season 2007 and contributed to the drafting of the Stadacona section. K. Lauzière helped with the preparation of geological maps. J. Bédard is thanked for a detailed and very useful review of the manuscript.

REFERENCES


Geological Survey of Canada Project X92