

The Colomb-Chaboullié greenstone belt and its polymetallic sulphides, James Bay: preliminary results

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Résumé

La Ceinture de roches vertes de Colomb-Chaboullié est localisée au contact entre les sous-provinces d'Opatica et de Nemiscau qui font toutes deux partie de la Province du Supérieur. Elle est constituée de roches métamorphiques et sédimentaires, de volcanites mafiques et felsiques, ainsi que d'intrusions mafiques-ultramafiques. Trois faciès volcaniques ont été identifiés dans cette ceinture : une unité dominante de basalte amphibolitisé, des andésites massives ou coussinées et des volcanoclastites felsiques à intermédiaires. Les indices polymétalliques, composés de sulfures massifs, semi-massifs, disséminés et en filonnets, sont observés uniquement dans certaines unités, particulièrement dans les basaltes.

Ce projet de maîtrise vise à améliorer le niveau de connaissance sur la volcanologie, la stratigraphie et la géochimie de la Ceinture de Colomb-Chaboullié, ainsi que sur les indices de sulfures polymétalliques du secteur. Cette étude devrait permettre d'en connaître davantage sur le contexte géologique des petites ceintures de roches vertes localisées au nord de la Ceinture de roches vertes de l'Abitibi et de fournir des guides pour l'exploration des sulfures massifs volcanogènes dans ce type d'environnement. Cette étude devrait également contribuer au débat touchant l'affectation de la Ceinture de Colomb-Chaboullié à la Sous-province d'Opatica ou à la Sous-province de Nemiscau.

Un levé géologique détaillé de la région à l'étude effectué en 2016 vient compléter les travaux effectués par le Ministère de l'Énergie et des Ressources naturelles du Québec en 2015. Soixante-treize échantillons ont été prélevés pour des analyses chimiques et pétrographiques en mettant l'accent sur les unités volcaniques. Les indices connus de substances métalliques ont été visités. L'indice d'or de Lac Marcaut a été cartographié en détail afin d'établir les liens de parenté entre les lentilles de sulfures massifs et les roches volcaniques encaissantes.

Les données de terrain montrent que les coussins reconnus dans les unités basaltiques et andésitiques sont allongés et déformés. Du matériel hyaloclastique contenant des sulfures disséminés est observé localement dans les espaces entre les coussins basaltiques. D'étroites zones d'altération en chlorite et en grenat sont également associées à ce matériel hyaloclastique. L'analyse pétrographique montre que les

lentilles de sulfures massifs sont composées essentiellement de pyrrhotite et de pyrite accessoire et renferment des clastes siliceux arrondis à subarrondis. Ces clastes sont composés essentiellement de quartz et, accessoirement, de biotite et d'augite. Les basaltes sont d'affinité tholéitique et se projettent dans le champ des îles en arc sur le diagramme d'Agrawal (2008).

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Summary

Geological Context. The Colomb-Chaboullié greenstone belt, situated in the contact region between the Opatica and Nemiscau subprovinces of the Superior Province, is made up of metamorphic and sedimentary rocks, mafic and felsic volcanics, and mafic/ultramafic intrusive bodies. The three volcanic facies identified in the Colomb-Chaboullié belt comprise: the predominant amphibolised basalt suite, porphyritic andesites which are subdivided into massive and pillowed facies, and felsic to intermediate volcanoclastic rocks. Polymetallic sulfide showings, which range from massive or semi-massive, to disseminated and stringer-type, are only present in certain units, particularly in the pillowed basalt facies.

Objectives. The current MSc project at INRS aims to improve our volcanological, stratigraphic and geochemical understanding of the Colomb-Chaboullié greenstone belt, and of its sulphide showings. This will help increase our knowledge of the smaller greenstone belts that are situated to the north of the world-renowned Abitibi Greenstone Belt, in order to facilitate VMS exploration. It will also contribute to assigning the Colomb-Chaboullié belt to either the Opatica Subprovince or the Nemiscau Subprovince.

Methods. Mapping was carried out in 2016 to combine with field data gathered by the *Ministère de l'Énergie et des Ressources naturelles du Québec* (MERN) in 2015 in that same area. 73 samples were collected for geochemical and petrographic analysis, with a focus on volcanic units. Known sulphide showings were examined and the Lac Marcaut gold showing was mapped in detail to establish the relationship between the sulphide lens and the surrounding host rock.

Preliminary Results. Field results show that the pillowed facies of the basalt and andesite units are elongate and deformed. A hyaloclastite material containing disseminated sulphides occurs locally in the interpillow areas in the basalt, and is associated with small chlorite and garnet alteration zones. Petrographic analysis shows that the massive sulphides are dominantly composed of pyrrhotite, with minor amounts of pyrite, and that the rounded to sub-rounded siliceous clasts embedded in these sulphides are dominantly composed of quartz, with biotite and augite also present. The basalts are tholeiitic and plot in the island arc field on the Agrawal (2008) diagram.

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1 Introduction

The Colomb-Chaboullié greenstone belt is a volcano-sedimentary belt that is orientated NE-SW to E-W, within the Archean Superior Province, in the James Bay area of Québec. It is located in the contact region between the Nemiscau and Opatica subprovinces (Fig. 1). The Colomb-Chaboullié belt is situated approximately 144 km north of the mining town of Matagami, and about 80 km east of Waskaganish. The MERN completed the mapping of NTS sheets 32K13, 32K14, 32N03, and 32N04 on a scale of 1:50,000, during the summer of 2015. Eight main geological units were identified in the Colomb-Chaboullié greenstone belt, including three volcanic units. Polymetallic (Au-Ag-Cu) sulphide showings were compiled and newly identified, suggesting a potential for volcanogenic massive sulphide (VMS) mineralization in the belt. There is also Ni-PGE potential in the mafic to ultramafic intrusive units (Tague et al. 2016), but this is not addressed here.

The present report summarizes the progress made so far on the senior author's MSc project at INRS, which is supervised by the second author and supported by the MERN. This project deals with the volcanology, stratigraphy and geochemistry of the Colomb-Chaboullié greenstone belt. The report will describe the problem statement and outline the objectives of this project. It will then define each of the volcanic, metamorphic and sedimentary type lithological units identified in the study area, and describe the massive to semi-massive, and disseminated sulphide mineralization identified. The main petrographic and geochemical observations to date are also detailed below.

2 Geological Context

The Superior Province is the most extensive Archean terrane on Earth (Benn and Moyen 2008). It forms a large part of the Canadian Shield. Our study area comprises two of the Superior subprovinces, the Opatica Subprovince and the Nemiscau Subprovince.

The Opatica is located to the south of the Colomb-Chaboullié, and is made up of five units of intrusive igneous rocks (Bandyayera and Daoudene in preparation). The Lac Rodayer pluton is the northernmost unit of the Opatica, and is located adjacent to the Colomb-Chaboullié belt. This

pluton is a large-scale complex that is composed of four different subunits: 1) *Arod1*-a quartz-diorite and diorite unit; 2) *Arod2*- a magnetic tonalite that is hematized and foliated. It also contains pegmatite injections that are granitic in nature; 3) *Arod3* is a quartz-diorite and tonalite complex that is foliated; and 4) *Arod4* is hematized and foliated tonalite with biotite + magnetite bearing granitoid injections (Fig. 2). U-Pb zircon ages around 2825 Ma for the Lac Rodayer pluton have been determined by Davis et al. (1992).

The Nemiscau Subprovince is a metasedimentary complex that is located to the north of the Colomb-Chaboullié belt (Bandyayera and Daoudene in preparation). This subprovince can be divided into two distinct areas, a metasedimentary sequence and a felsic-intermediate plutonic unit composed dominantly of granodiorite and monzonite (Hocq 1994). Bandyayera and Daoudene (in preparation) have also proposed a third group, the Rupert Group. This group is made up of five units: a paragneiss containing biotite + hornblende (Aru1), migmatized Aru1 (Aru2), metatexite (Aru3), diatexite (Aru4), and granitic pegmatite with biotite ± garnet ± muscovite (Aru5) (Fig. 2).

3 Problem statement

The Superior Province contains about 80% of the VMS tonnage hosted in Archean rocks in the world (Mercier-Langevin et al. 2014). The Abitibi Greenstone Belt within the Superior Province contains over 800 Mt of VMS deposits (Galley et al. 2007). These VMS deposits have been thoroughly studied in terms of the geochemistry, petrogenesis and stratigraphy of the associated host rocks, and are well understood (e.g., Laflèche et al. 1992a; Ayer et al. 2002; Mercier-Langevin et al. 2007). The smaller greenstone belts located in the subprovinces north of the Abitibi Subprovince are less well understood and are underexplored.

The Colomb-Chaboullié belt is situated between the Opatca and Nemiscau subprovinces. As a result, the origin of this greenstone belt is also unknown in terms of which of these subprovinces this greenstone belt belongs to.

The emplacement history of the polymetallic sulphide showings of the Colomb-Chaboullié belt is unclear, as to whether they are tectonic or volcanic in origin. This project therefore allows the opportunity to study these sulphide showings and their host rocks, and ascertain their origin.

4 Objectives

The objectives of this project are:

1. To increase the knowledge on the volcanic units of the Colomb-Chaboullié belt, in particular the geological, stratigraphic and geochemical information in order to establish the tectonic environment of this greenstone belt;
2. To provide information that will allow us to assign the Colomb-Chaboullié belt in either the Opatoca or the Nemiscau Subprovince, by comparing the physical geological features and geochemistry of the Colomb-Chaboullié and greenstone belts located in the Opatoca Subprovince such as the Frotet-Evans belt or smaller greenstone belts in the Nemiscau Subprovince;
3. To determine the origin of the polymetallic sulphide showings to establish whether they are volcanic or tectonic in origin.

Overall, this study may help future exploration endeavours that focus on the smaller, less understood greenstone belts located further north of the Abitibi Greenstone Belt.

5 Methodology

5.1 Field work

The study area is located in the central part of the Colomb-Chaboullié greenstone belt. The main north-south transect of the area of interest extends between 51°17'55.2"N, 77°22'42.4"W and 51°02'58.6"N, 77°34'11.5"W. This area was mapped by the first author on a scale of 1:20,000 over a two week period in August 2016. The *Route de la Baie-James* cuts through the study area in a north-south orientation (Fig. 2, blue line) which allowed extensive sampling to be carried out. These samples will help refine the stratigraphy of the Colomb-Chaboullié belt.

Detailed outcrop mapping was completed for outcrop 16-SG-3521 (Fig. 2), also known as the Lac Marcaut showing, located at E316632 and N5662111 UTM, in the western sector of the study region. The baseline used for this map was the massive sulphide lens which stretches east-west across the whole outcrop. This lens was the feature that was closest to representing S₀.

Due to the low density of outcrops in the study area as a result of the presence of swampy or forested land, the majority of mapping was conducted via helicopter, either by traverse or by helicopter visits to more dispersed outcrops. The locations for outcrops to be mapped were planned in advance using satellite and magnetic imagery for the traverse and helicopter “jump” mapping. This allowed a variety of different lithologies to be mapped while covering as much ground as possible due to the short timeframe for mapping. The helicopter “jumps” enabled full coverage of all lithological types within the 72x5 km greenstone belt, allowing the more distant lithologies such as the banded iron formation and the intrusive mafic rocks further west of the study area to be studied, in order to become familiar with all the rock types of the Colomb-Chaboullié belt.

5.2 Laboratory work

A total of 73 hand samples were collected in the field that covered all the volcanic lithologies, and some of the other lithologies, in the greenstone belt in order to obtain a suitable selection for petrographic and lithogeochemical analysis. These samples included massive and pillowed basalt, porphyritic andesite, intermediate to felsic volcanics, schist, gabbro, high-grade metasedimentary, and sedimentary types. From this total, 45 lithogeochemical and 34 thin section samples were prepared. The lithogeochemical samples were cut using a rock saw into fist sized “cubes” that contained as little weathered and fractured surfaces as the material would permit. These blocks were then labelled and sent off to Activation Laboratories in Ancaster, ON, where they were analysed with the standard MERN lithogeochemical package. Two different types of thin sections were prepared, 1) 31 regular sized, covered sections measuring 27x46 mm and 2) three large, polished thin sections measuring 51x76 mm of the massive sulphide samples. Three polished slabs of massive sulphides were also prepared.

6 Lithological Units Identified in the Study Area

The following section combines information from Bandyayera and Daoudene (in preparation) with new observations made in 2016. All of the rocks in the Colomb-Chaboullié belt have been metamorphosed to amphibolite grade (Sawyer and Benn 1992) but the prefix ‘meta’ is omitted from the name of volcanic and sedimentary rocks for simplicity.

6.1 Volcanic Assemblages

Massive to pillowed basalt flows (Acch1) make up approximately 80% of the Colomb-Chaboullié belt (Bandyayera and Daoudene in preparation) (Fig. 2). This is a fine-grained to recrystallized lithology which is dominated by pillowed flows that are variably tectonically deformed (Fig. 3a), ranging up to schists in high-strain zones. A dark-coloured, typically chloritised, hyaloclastite material is present between the pillows, making up the interpillow material (Fig. 3b).

A porphyritic intermediate facies is present in the northeastern side of the study area (Acch2 and 2a), which have been labelled andesites. These form thin, elongate bands within Acch1 (Fig. 2). Two types of andesites have been identified, the first being a massive, porphyritic unit that contains ~20% 1-2 mm tabular plagioclase phenocrysts (Acch2). The second andesite (Acch2a), located north of the Acch2 bands, at the contact between the Colomb-Chaboullié belt and the Nemiscau Subprovince, is a pillowed facies. The east-west orientated pillows in Acch2a, much like the pillows observed in Acch1, are elongate, and measure up to 1 m in length. These andesites are composed of a fine-grained groundmass which is grey to green on the fresh surface and contain phenocrysts of idiomorphic plagioclase crystals measuring 3-5 mm in size and 2-8 mm tabular hornblende crystals (Fig. 3c).

The final volcanic facies of the Colomb-Chaboullié belt is an intermediate to felsic unit composed of volcaniclastic rocks (Acch3). As with the Acch2 unit, Acch3 occurs as thin, elongate bodies within the basalts. In one of the best exposed locations, these rocks are aphyric and banded, where the bands are defined by a colour change from white to green (Fig. 3d). In another Acch3 outcrops, elongate lapilli are present.

6.2 Sedimentary Assemblages

The Colomb-Chaboullié belt includes three sedimentary to metamorphic units. Acch7 are fine-grained, foliated, biotite + hornblende bearing paragneiss rocks, with biotite making up to 30-60% of the composition. This unit is highly deformed and forms two small bands, one north of Lac Colomb (Fig. 2), and the other situated to the west of Lac Chaboullié. As seen in Figure 2, the Acch7 band located to the north of Lac Colomb is located at the contact between the Colomb-Chaboullié volcanic units to the south, and the metasedimentary rocks of the Nemiscau Subprovince to the north. There are individual garnet crystals measuring 2 mm in size within this

unit, suggesting that high metamorphic conditions were reached. Tonalitic veins and injections are also present within Acch7.

A polymict conglomerate sequence (Acch 8) forms a thin band in the eastern part of the belt (Fig. 2). It is located between the Acch1 and Acch2 volcanic units. Polarities observed during the 2015 mapping campaign indicate that this conglomerate is situated in the centre of a syncline (Bandyayera and Daoudene in preparation). Acch8 is defined by rounded to sub-rounded fragments in a deformed, schistose, biotite-bearing paragneiss-like matrix. The clasts are dominantly composed of granitoid fragments (50-80%), with lesser amounts of fine-grained mafic clasts (1-10%), and chert (1%). The conglomerate is generally deformed where the foliation moulds around the felsic clasts, while the mafic clasts are strongly flattened in the east-west foliation. The presence of these clasts suggests that the Acch8 unit is younger than the surrounding lithologies.

Beyond the study area is a banded quartzite/iron formation (Acch6) which marks a pause in volcanism in the region. Acch6 is composed of interbedded iron-rich and quartzite layers. Some pyrrhotite-rich sulphide patches also occur within this unit.

6.3 Massive Sulphides

The VMS-style mineralisation consists of northeast-southwest orientated, massive to semi-massive sulphide lenses that are dominantly composed of pyrrhotite and pyrite. Within these lenses, highly rounded lithic fragments, composed mostly of quartz and pyrite, are embedded in a matrix of pyrrhotite and pyrite (Fig. 3f). Mineralisation also occurs as disseminated sulphide grains in the interpillow material of the pillowed basalt facies, or between individual lava flows in the massive facies. Commonly surrounding the sulphide-bearing hyaloclastite material within the pillowed basalts is a zone of chlorite in which small garnet crystals are embedded (Fig. 3b). Within the massive flows, the sulphides occupy fractures (Fig. 3e), forming stringer-type mineralisation.

The Lac Marcaut gold showing (Fig. 2, outcrop 3521 and Fig. 3f) is the best known VMS-style mineralisation in the Colomb-Chaboullié belt, with 8.37 g/t Au over 3.9 m of drill core (Riopel 1994). Within the mafic host rock of this outcrop, mineralisation forms a rusty zone composed of massive to semi-massive sulphides (Bandyayera and Daoudene in preparation). These sulphides are composed of pyrrhotite (40-90%) and pyrite (40-50%), with lesser amounts

of chalcopyrite (1%), galena (1%) and arsenopyrite (trace).

7 Petrographic Results

7.1 Petrography of the Colomb-Chaboullié lithofacies

Acch1 rocks are very fine-grained (Fig. 4a) and dominantly composed of amphibole crystals (up to 50%) and plagioclase (40%), with lesser amounts of quartz, biotite and metamorphic derived pyroxene crystals. This rock does not represent the most schistose rocks observed in this unit.

The Acch2 unit is composed of quartz (40%), amphibole crystals (30%), plagioclase (15%), biotite (10%), and lesser amounts of epidote, zircon and iron oxides (Fig. 4b). In thin section, the porphyritic texture is clearly observed, where microphenocrysts of tabular, altered plagioclase crystals measuring ca. 0.2-0.4 mm in length and glomerophenocrysts composed of amphibole and biotite are embedded in a fine-grained, recrystallised groundmass of quartz and plagioclase. These phenocrysts and glomerophenocrysts make up about 20% of the rock composition and do not show any preferential orientation.

Acch3 (Fig. 4d) is composed of quartz (55%), chlorite (35%) and plagioclase (10%). The fabric here is subtle but is identified by the common orientation of the elongate chlorite crystals, with respect to the more equigranular quartz and plagioclase crystals. This rock displays a granoblastic texture.

Acch7 is mainly composed of quartz (40%) and plagioclase (30%) with variable concentrations of biotite (commonly 30%, but in some places up to 60%) (Fig. 4c). The biotite crystals mark only a weak orientation, but this sample is from the middle of the unit and therefore not as deformed as the other samples collected for Acch7. Elsewhere, this unit underwent high degrees of deformation due to the presence of localised shear zones.

7.2 Petrography of the massive sulfides

Within the massive sulfides are rounded to sub-rounded siliceous fragments that are embedded within the sulphide-rich matrix (Figs. 5a, 5b). These fragments range in size from ca. 100 μm to 2 cm, and make up approximately 25% of the composition. These rocks are mainly composed of pyrrhotite (65%) (Fig. 5c). Lesser amounts of pyrite are also present (10%) as individual grains

within the pyrrhotite (Fig. 5c). Trace amounts of chalcopyrite were also identified. Figure 5d shows the composition of the siliceous fragments. These are dominantly composed of variably sized quartz crystals (70%) with lesser amounts of very fine-grained biotite and augite. The biotite and augite crystals are concentrated around the edges of these clasts whereas quartz makes up the majority of the central parts of the fragments.

8 Preliminary Geochemistry

The geochemical analyses presented in figure 5 are derived from 45 samples that were taken by the first and second authors in 2016. Acch1 rocks plot in the basalt and andesite/basalt fields on the Winchester and Floyd (1977) diagrams (Fig. 6). Their magmatic affinity is mostly tholeiitic (Fig. 6c). Acch2 samples plot in the andesite/basalt to andesite fields on the classification diagram, and they have a calc-alkaline magmatic affinity. Finally, Acch3 rocks plot in the rhyodacite/dacite to andesite fields on the classification diagrams, and they have a calc-alkaline magmatic affinity as well.

The tectonic discrimination diagram from Agrawal et al. (2008) shows the general tectonic setting for these rocks and can distinguish four tectonic settings for basalts: island arc (IAB), oceanic island (OIB), mid-ocean ridge (MORB), and continental rift (CRB). The majority of these rocks are located in the IAB field.

The chondrite normalized spidergram (McDonough and Sun 1995) shows that there are two distinct groups in these samples. The first group, which consists of Acch1, Acch2 and Acch3, are plotted in the top half of this diagram, where they are more enriched in light rare earth elements (LREE). These samples also display a negative Eu anomaly. The second group, which is dominantly composed of Acch1, have lower LREE concentrations and have lines that plot horizontally, with a slight increase in heavy rare earth elements.

9 Preliminary Interpretations

The basalt and andesite flows were deposited in a submarine setting as shown by the presence of the pillowed facies in both these lithologies. There was no evidence found of shallow water

features such as ripple marks, which suggests that these rocks were emplaced in a relatively deep (sub-wave base) water environment.

The disseminated sulphides within the Colomb-Chaboullié belt were identified in both the massive and pillowed basalt facies. In the pillowed flows, these disseminated sulphides were dominantly present in the interpillow material, often associated with chlorite and garnet (<5 mm) in the pillow margins (Fig. 3b). This suggests that hydrothermal alteration and mineralisation occurred early on, in the primary porosity between the pillows, before diagenesis, and therefore is synvolcanic. The garnets are interpreted as the metamorphosed equivalent of more intense chlorite alteration, relative to rocks that lack garnet. In the massive flows, the disseminated sulphides are fracture-controlled and form a network of infilling fractures (Fig. 3e). This stockwork fracture pattern of sulphides with chloritisation is typical of VMS-type mineralisation which also indicates that these sulphides are syn-volcanic.

The geochemical data presented in this report confirms the data presented in Bandyayera and Daoudene (in preparation) as both sets of analyses show: 1) a large silica range from sub-alkaline basalts to rhyodacite/dacite, with some samples from Bandyayera and Daoudene (in preparation) plotting in the rhyolite field, 2) mafic basaltic rocks that have a tholeiitic to transitional affinity, 3) intermediate volcanic and intermediate to felsic volcanoclastic rocks with a calc-alkaline affinity, and 4) two distinct groups on REE plots with one group having a higher concentration of LREE with respect to HREE, which is less pronounced in the second group.

10 Future Work

The next steps of the project are to:

1. Integrate our geochemical results with those from the MERN 2015 campaign and prepare further diagrams. This will enable the current geological map (Fig. 2) to be revised should further volcanic divisions be identified based on chemostratigraphy;
2. Continue petrographic analysis of the thin sections in order to establish the mineralogy and textural information;
3. Use this geochemical and petrographic data in order to classify the Colomb-Chaboullié belt into either the Opatica or Nemiscau Subprovince, and also to establish tectonic and stratigraphic information for this greenstone belt.

11 Bibliography

- AGRAWAL S, GUEVARA M, VERMA PV (2008) Tectonic Discrimination of Basic and Ultrabasic Volcanic Rocks through Log-Transformed Ratios of Immobile Trace Elements. *International Geology Review* 50: 1057-1079
- AYER J, AMELIN Y, CORFU F, KAMO S, KETCHUM J, KWOK K, TROWELL N (2002) Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation. *Precambrian Research* 115:63-95
- BANDYAYERA D, DAOUDENE Y (in preparation) Géologie de la région du lac Nemiscau, secteur du lac Royayer (SNRC 32K13, 32K14, 32N03 et 32N04-SE). MERN report.
- BENN K, MOYEN JF (2008) The Late Archean Abitibi-Opatoca terrane, Superior Province; A modified oceanic plateau. *Geological Society of America, Special Paper* 440, p. 173-197
- DAVIS WJ, SAWYER E, MACHADO N, GARIÉPY C, BENN K (1992) U-Pb Geochronology of Plutonism and Metamorphism in the Opatoca Belt: Initial Results. *Lithoprobe report* 33:147-149
- GALLEY AG, HANNINGTON MD, JONASSON IR (2007) Volcanogenic Massive Sulphide Deposits, *in* Goodfellow, W.D., ed., *Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods*: Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5.141-161
- HOCQ M (1994) La Province du Supérieur. In: Dubé C (ed) *Géologie du Québec*, Les publications du Québec, p. 7-20
- LAFLÈCHE MR, DUPUY C, BOURGAULT H (1992) Geochemistry and petrogenesis of Archean mafic volcanic rocks of the southern Abitibi belt, Québec. *Precambrian Research* 57:207-241
- MCDONOUGH WF, SUN SS (1995) The composition of the Earth. *Chemical Geology* 120:223-253
- MERCIER-LANGEVIN P, DUBÉ B, LAFRANCE B, GALLEY AG, MOORHEAD J (2007) A group of papers devoted to the LaRonde Penna Au-rich volcanogenic massive sulfide deposit, eastern Blake River Group, Abitibi greenstone belt, Quebec. *Economic Geology* 102:577-583

- MERCIER-LANGEVIN P, GIBSON HL, HANNINGTON MD, GOUTIER J, MONECKE T, DUBÉ B, HOULÉ MG (2014) A Special Issue on Archean Magmatism, Volcanism, and Ore Deposits: Part 2. Volcanogenic Massive Sulfide Deposits. *Economic Geology* 109:1-9
- PEARCE JA (1996). A user's guide to basalt discrimination diagrams. In: Wyman DA (ed) Trace element geochemistry of volcanic rocks: applications for massive sulphide exploration, Short course notes. Geological Association of Canada, p. 79-113
- RIOPEL J (1994) Rapport technique des travaux, campagne 1994, propriété Lac Marcaut. Report submitted to Ministère des Ressources naturelles, Québec, p. 1-328
- ROSS P-S, BÉDARD JH (2009) Magmatic affinity of modern and ancient subalkaline volcanic rocks determined from trace-element discriminant diagrams. *Canadian Journal of Earth Sciences* 46:823-839
- ROSS P-S, MERCIER-LANGEVIN P (2014) Igneous Rock Associations 14. The Volcanic Setting of VMS and SMS Deposits: A Review. *Geoscience Canada* 41:365-377
- SAWYER EW, BENN K (1992) Geochemistry, Metamorphism and Structure of the Opatica Belt. Abitibi-Grenville Transect. Lithoprobe, p. 159-162
- TAGUE PD, PAGÉ P, BANDYAYERA D, BARNES S-J (2016) Caractérisation pétrologique et géochimique des intrusions de la Ceinture de Coulomb-Chaboullié, Baie-James. Poster session presented at Québec Mines, Québec
- WINCHESTER JA, FLOYD PA (1977) Geochemical Discrimination of Different Magma Series and their Differentiation Products using Immobile Elements. *Chemical Geology* 20:325-343

Figures

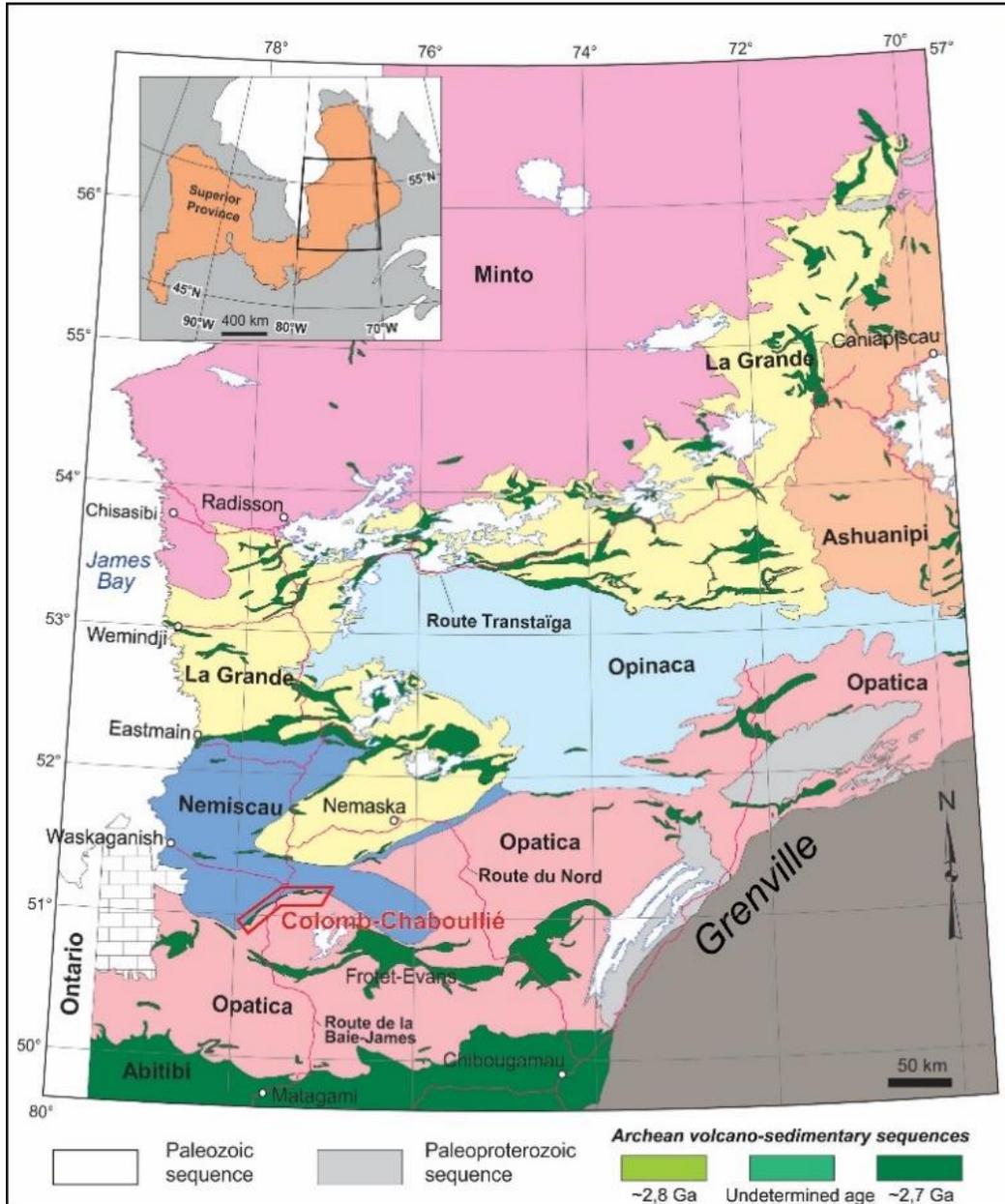


Figure 1. Location of the Colomb-Chaboullié greenstone belt in the James Bay area of Québec (Bandyayera and Daoudene in preparation). The Archean rocks belong to the Superior Province.

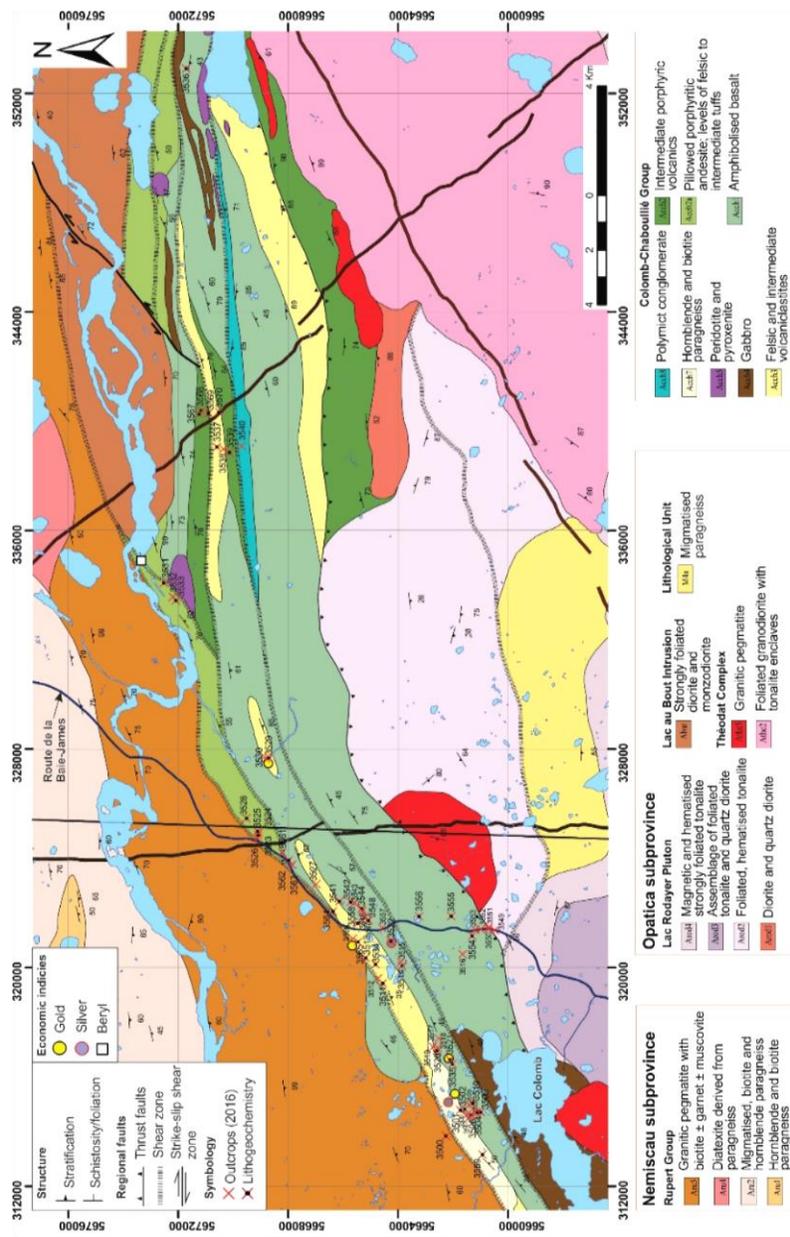


Figure 2. Geological map of the Colomb-Chaboullié greenstone belt (after Bandyayera and Daoudene in preparation) showing the location of the outcrops mapped in 2016 by the author, the locations of the 2016 lithochemical samples, and the location of previously recorded mineralisation in the study area.

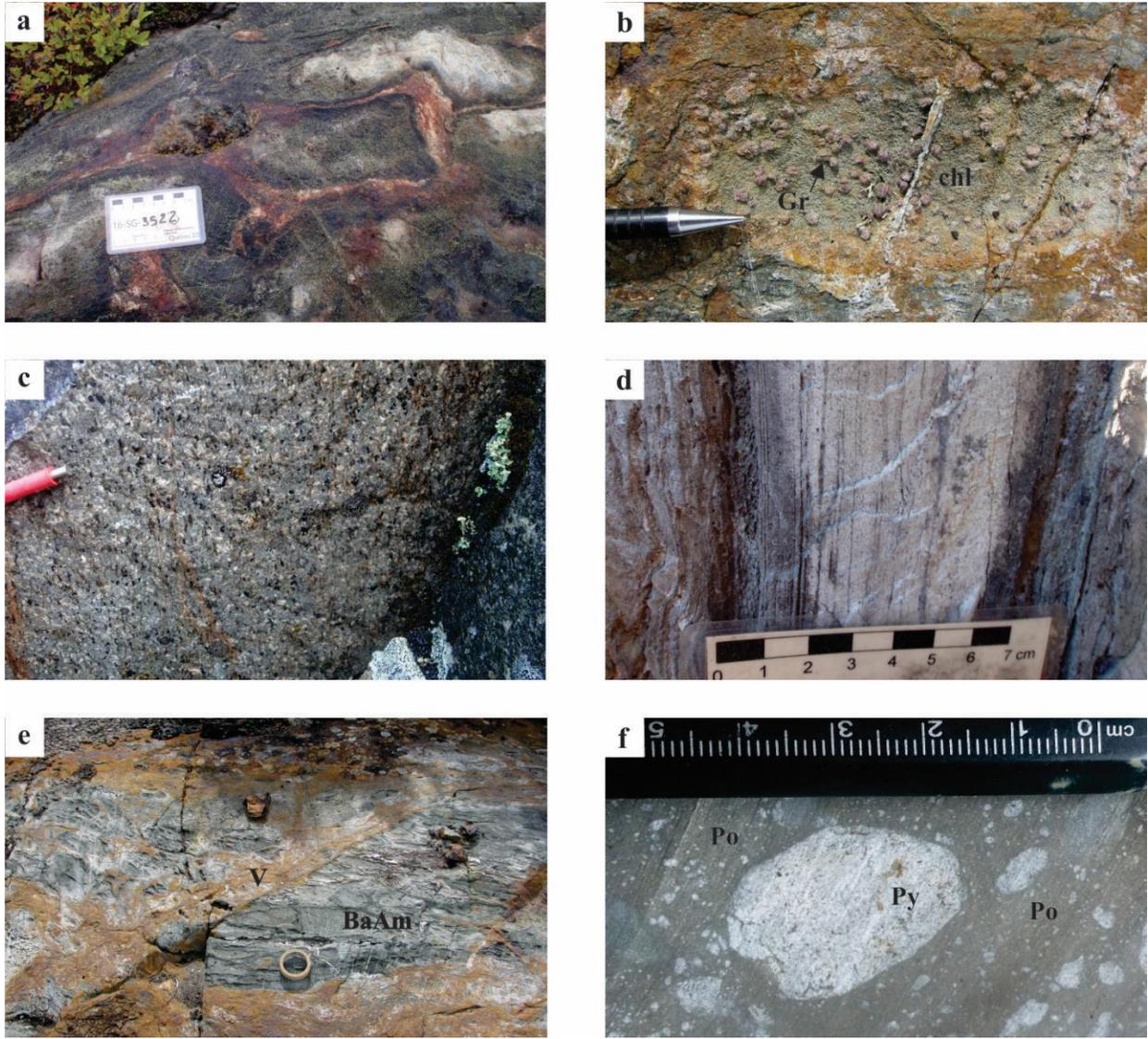


Figure 3. **a.** Deformed pillowed basalt with rusty interpillow material which suggests the early circulation of hydrothermal fluids. **b.** Basalt showing synvolcanic alteration of recrystallised chlorite (chl) and garnet (Gr) in the pillow margins. **c.** Porphyritic andesite showing phenocrysts of plagioclase and hornblende (fresh surface). **d.** Acch3 volcanic rock showing aphyric green and white banding. **e.** Veins of sulphides (V) in the amphibolised basalt (BaAm) showing stockwork pattern. **f.** Sample from the Lac Marcaut outcrop, containing gold values. Rounded siliceous fragments containing pyrite (Py) are embedded in a matrix of pyrrhotite (Po).

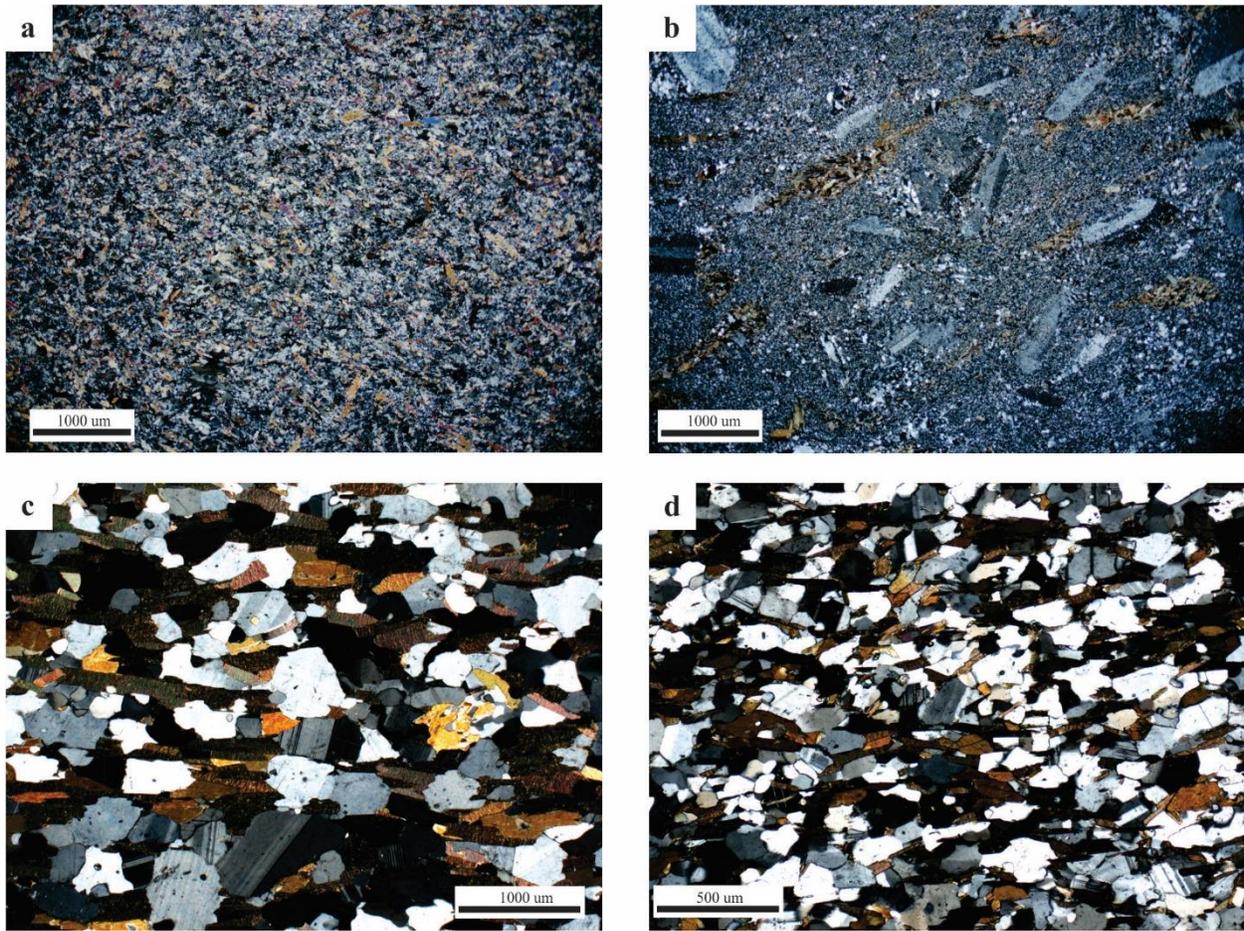


Figure 4. **a.** General overview of Acch1 showing the fine-grained nature of this rock. **b.** Acch2 general overview showing plagioclase phenocrysts and biotite + hornblende glomerophenocrysts in a fine-grained groundmass. **c.** Acch7 comprising quartz, plagioclase and biotite. **d.** Mineralogy of Acch3 consisting quartz, chlorite and plagioclase. All photos are in crossed-polar transmitted light.

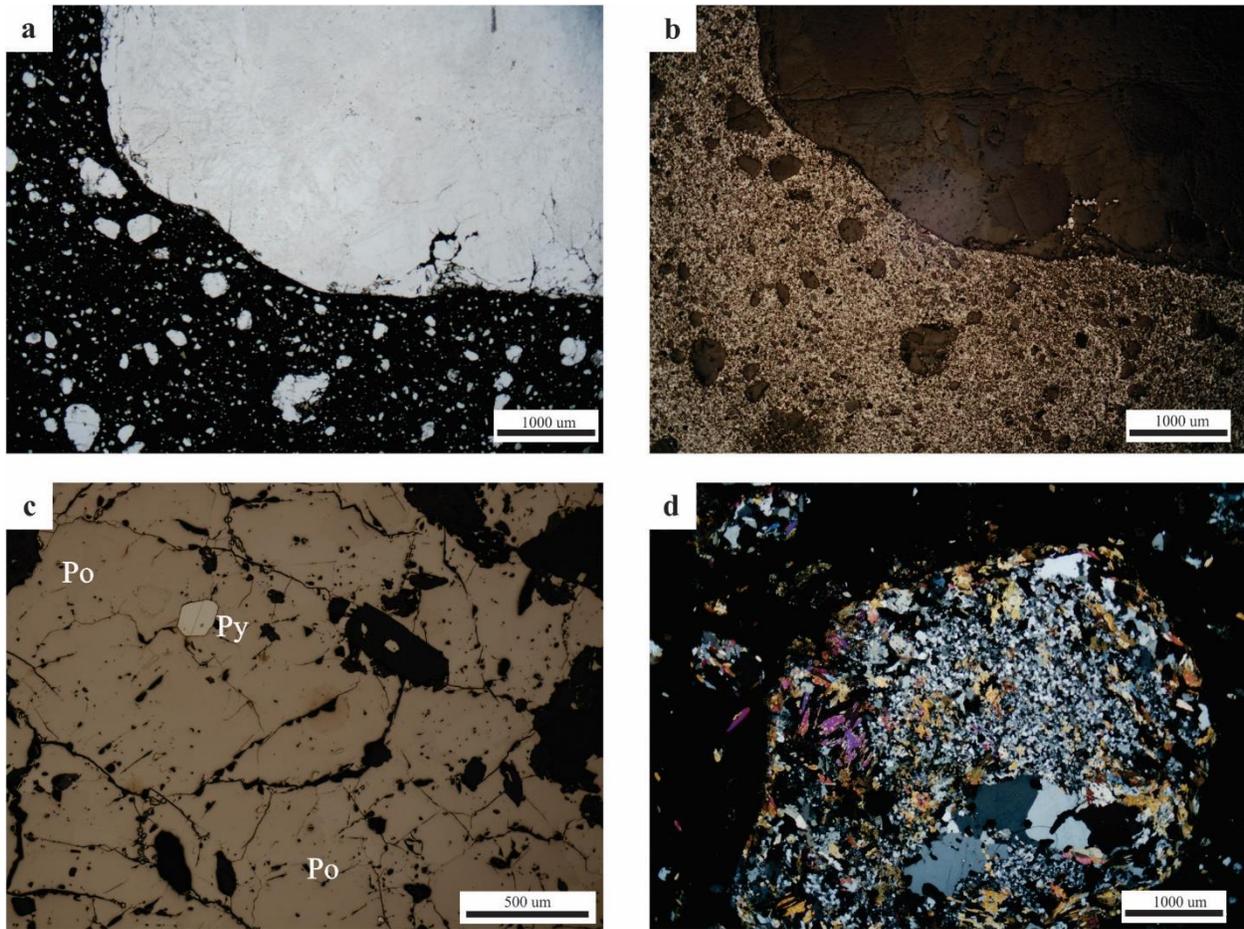


Figure 5. a-b. Massive sulphide at Lac Marcaut, showing the size and proportion of siliceous clasts (a. plane-polarised transmitted light; b. reflected light). **c.** Reflected light image of the massive sulphide which is dominantly composed of pyrrhotite (Po) and minor amounts of pyrite (Py). **d.** Cross-polarised image of a siliceous clast, containing quartz, biotite and pyroxene.

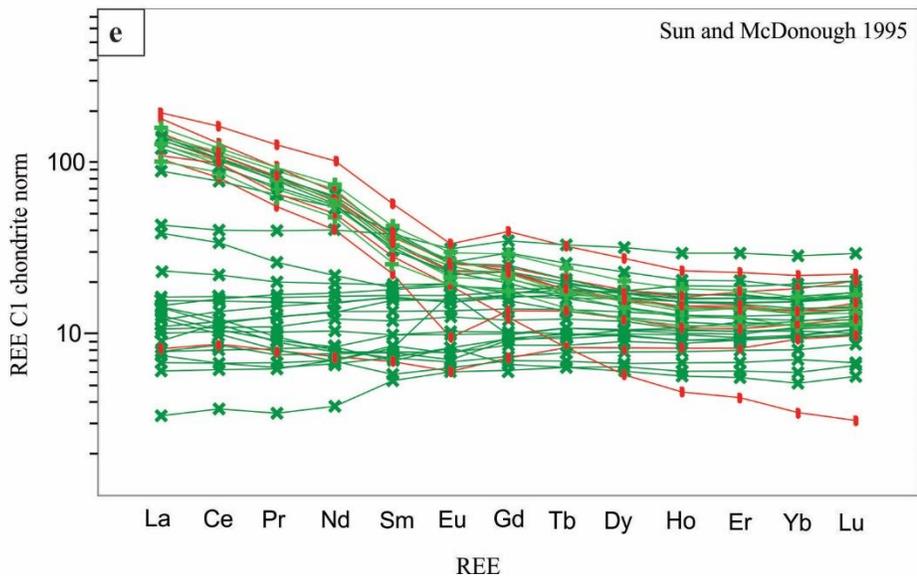
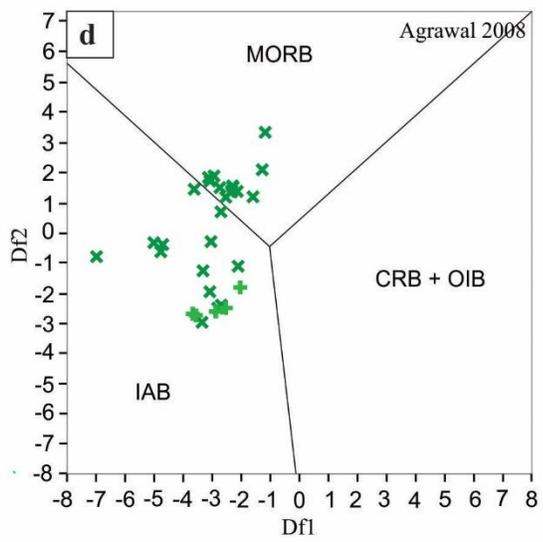
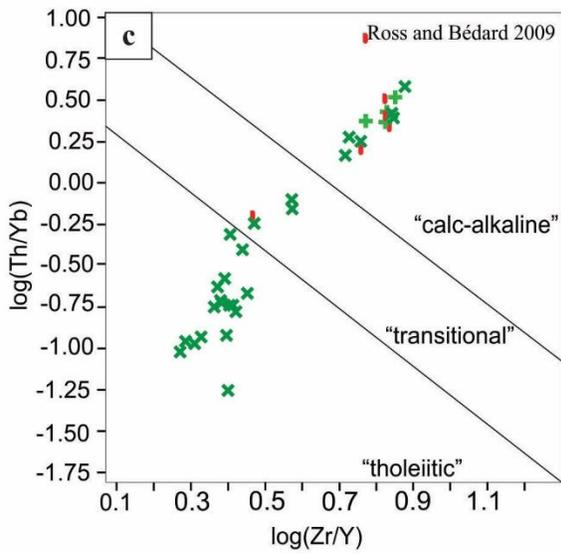
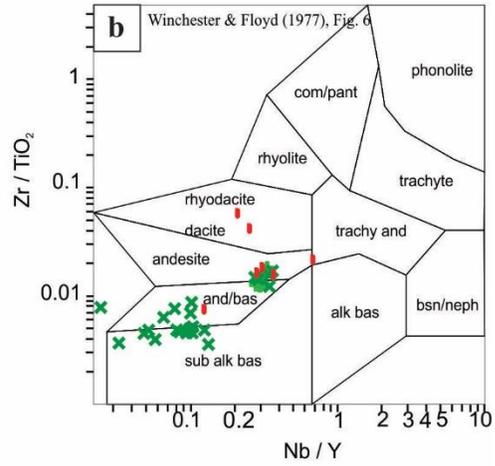
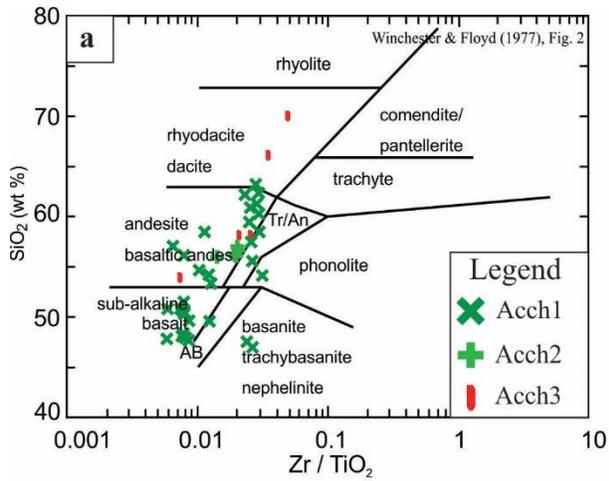


Figure 6. Geochemical diagrams of the samples taken in 2016. **a-b.** Classification diagrams from Winchester and Floyd (1977). **c.** Magmatic affinity diagram from Ross and Bédard (2009). **d.** Tectonic discrimination diagram from Agrawal et al. (2008). **e.** Rare earth elements normalised to chondrites (McDonough and Sun 1995).