Mineralogical and chemical characterization of the Chevrillon pluton and relationship with its sedimentary host, Chibougamau area, Quebec

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INTRODUCTION

This study was carried out north of the Town of Chibougamau as part of the Metal Earth project. The Chevrillon Pluton, in the northeastern part of the Abitibi greenstone belt (Superior Province), is located 5 km east of the northern end of the Metal Earth seismic transect that extends through the Chibougamau area. The small-volume granodioritic intrusion was formed at the end of the Archean in the syntectonic Waconichi syncline. This fault-bounded depositional basin contains conglomerate deposits of the Chebistuan Formation (Opemisca Group). The pluton and its sedimentary host could be compared to the Kirkland Lake area, in the southern part of Abitibi. Indeed, that area displays a spatial and temporal association between conglomerate units of the Timiskaming Group emplaced in syntectonic basins, faults, and late syenite and granodiorite intrusions.

However, the Timiskaming setting contains several gold deposits, whereas there is no known mineralization in the Waconichi syncline. This study has two main goals: 1) chemical characterization of the Chevrillon Pluton and its source to determine whether it is alkaline; 2) establishing the relationship between the Chevrillon Pluton and its sedimentary host, as well as the timing of its emplacement and its relationship to deformation events. The aim of the summer 2018 fieldwork was to collect data and samples for laboratory analysis to provide answers to those goals.

REGIONAL SETTING AND DEFORMATION (PREVIOUS WORK)

The Abitibi greenstone belt consists of an assemblage of Neoarchean volcanic and sedimentary rocks crosscut by many intrusive bodies. The Chibougamau area is bounded to the east by a northeast–southwest-striking deformation zone, which separates it from the Grenville Subprovince, and to the north by the Barlow Pluton, which separates it from the Opatica Subprovince (Daigneault, 1991; Leclerc et al., 2011, 2017). The rocks in the Chibougamau area are generally of greenschist facies metamorphic grade, and are also folded and faulted. However, the areas surrounding the intrusive bodies, such as the Barlow or Chevrillon plutons, show indications of amphibolite facies metamorphism and deformation (Boudreault, 1977).

The stratigraphy of the Chibougamau area can be divided into two groups: Roy Group and Opémisca Group. The first corresponds to an assemblage of volcanic rocks divided into two cycles. The first cycle consists of the Obatogamau, and Waconichi formations, whereas the second cycle consists of the Bruneau, Blondeau and Bordeleau formations. The Opémisca Group, mainly composed of sedimentary rocks, unconformably lies on top of the Roy Group (Daigneault and Allard, 1990). The mostly sedimentary Opémisca Group deposits lie within the core of the east–west-striking Chapais and Waconichi synclines (Leclerc et al., 2017). Within the synclines, the Opémisca Group consists of the Stella and Haüy formations, and the Chebistuan Formation, respectively (Allard and Gobeil, 1984).

Finally, the numerous intrusive bodies in the Chibougamau area can be divided into two categories: the first corresponds to the tonalite-tronjdhemite-granodiorite (TTG) suite of the synvolcanic period, whereas the second one corresponds to intrusive bodies of the syn- to post-tectonic period (e.g., the Chevrillon Pluton granodiorite).

Three deformation events marked the Chibougamau area. The first deformation phase, of lesser importance (D_1, synvolcanic period), is expressed by north–south oriented folds associated with the emplacement of large-volume intrusions coeval with the Roy Group (e.g., the Chibougamau Pluton; Daigneault and Allard, 1983). The second deformation phase (D_2, north–south shortening) formed east–west regional folds associated to the regional foliation. Moving from the south to the north, this deformation formed the Chapais, Chibougamau and Waconichi synclines, as well as the Waconichi, Chibougamau and La Dauversière anticlines. The third deformation phase (D_3) manifests itself as a strike-slip motion along east–west oriented structures (Daigneault and Allard, 1984; Dimroth et al., 1986; Daigneault et al., 1990; Leclerc et al., 2017). Deformation events D_2 and D_3 occurred during the syntectonic period, which throughout the Abitibi Subprovince lasted from 2700 to 2670 Ma (Chown et al., 1992, 2002). However, in the Chibougamau area, the time interval associated with this event begins learlier and extends from 2707 to 2692 Ma (Dimroth et al., 1986; Daigneault et Allard, 1990).

Lithological units in the study area

The Chevrillon Pluton is described as a small (11 by 8 km^2), massive and homogeneous granodiorite-phyric microcline phenocryst pluton emplaced between the end of the syntectonic period and the syntectonic period (Duquette, 1982), It is characterized by a quartz-microcline-plagioclase assemblage, with rare chloritized biotite and amphibolite grains. It contains, in variable proportions, titanite crystals and crystals of the apatite series, zircon, ilmenite and magnetite (Sabourin, 1956). The intrusion is bounded to the north, northwest and west by three small homogeneous intrusive bodies of similar composition. Their relationship to the Chevrillon Pluton remains undefined. A 1.6 km amphibolite-facies metamorphic halo surrounds the Chevrillon Pluton in the Chebistuan Formation sedimentary rocks (Sabourin, 1956). Mapping done in the area surrounding the Chevrillon Pluton shows that it is surrounded to the north, northeast and northwest by Chebistuan Formation sedimentary rocks but that it crosscuts the Bordeleau and Bruneau formations in the south (Daigneault and Allard, 1990).

The Chebistuan Formation is the stratigraphic equivalent of the Stella and Haüy formations, which have been defined in the Chapais syncline, south of the Town of Chibougamau (Allard et al., 1979). The Chebistuan Formation consists of polygenetic conglomerate, arkosic sandstone and argillite similar to those of the Stella Formation, and also contain andesitic lava similar to that of the Haüy Formation. The Stella Formation consists of polymictic conglomerate, arkosic sandstone and argillite. This formation has been dated at 2704 ±2 Ma, which corresponds to the maximum age of conglomerate deposition based on a U-Pb zircon age obtained by isotope dilution-thermal ionization mass spectrometry analysis (ID-TIMS; Leclerc et al, 2012). The conglomeratic Haüy Formation yielded a maximum depositional age of 2691 ±2.9 Ma (ID-TIMS U-Pb on detritic zircons; David et al., 2007). Additional geochronological measurements will be done on these two formations and the available data reveal deposition occurred ~2690 Ma. The Chevrillon Pluton has been preliminarily dated at 2693 ±1.7 Ma (M. Hamilton, unpublished data, 2018). Thus, the relationship of the Chevrillon Pluton to deformation is particularly significant since determining the age of the pluton will aid in closing the tectonic window associated with deformation in the Chibougamau area.

WORK COMPLETED

The aim of the three-month summer 2018 fieldwork was to start mapping along the 172 km seismic transect that passes through Chibougamau. During this fieldwork, 18 days were devoted to mapping the Chevrillon Pluton and the surrounding area to address the research project goals. The mineral percentages from field macroscopic descriptions in the following sections are provided for reference purposes only.

Chevrillon pluton

A total of 45 stations (outcrop areas) were examined in the Chevrillon Pluton and its satellites. They are unevenly distributed, the majority being in the northwestern area, which was the only one accessible by vehicle. Figure 1 shows the distribution of stations on a SIGÉOM (SIGÉOM, 2018) geological base.

Macroscopic descriptions show that the borders of the Chevrillon Pluton consist on average of 20% zoned porphyritic euhedral feldspar phenocrysts measuring up to 3 cm. The medium-grained matrix consists of approximately 45% milky euhedral feldspar, 15% anhedral interstitial quartz on average 2 mm in size and 15% euhedral amphibole and biotite crystals (Figure 2a, b). In the central part of the pluton, the porphyritic feldspath phenocrysts are smaller (on average 1–1.5 cm) and make up only 10% of the rock. The matrix is composed of 55% euhedral feldspar measuring approximately 3 mm, 25% ovoid quartz grains measuring up to 4 mm, and 10% amphibole and biotite (Figure 2c).

Different types (4) of enclaves were observed in the Chevrillon Pluton: grey, black, non-layered green and layered green. The rounded grey enclaves (30%) can be metric in size but generally measure 20 cm (Figure 2d). The borders of these enclaves are more micro-crystallized than the centre and sometimes contain porphyritic feldspar crystals similar to those observed in the Chevrillon pluton granodiorite. The medium-grained matrix consists of millimetre-sized feldspar crystals, stocky amphibole crystals and chlorite crystals. The size of the black enclaves, which account for most of the observed enclaves (65%), varies between 0.5 and 40 cm, measuring on average 3 cm. The border of these always angular enclaves is sometimes darker and micro-crystallized. Matrix size is <1 mm. It mostly consists of thin rods of amphibole, feldspar (5%) and chlorite. The two green types of enclaves are the least represented (<5%). They are angular in shaped and <10 cm in size, and consist of chlorite (50%), feldspar (40%) and amphibole (10%). Crystal size in these enclaves does not exceed 1 mm. Some display thin layering. Locally, black and green enclaves are observed within the grey enclaves.

The grey enclaves correspond to a gabbro that intruded the Chevrillon Pluton soon after its emplacement. This interpretation is based on the rounded shape of the enclaves as well as on the presence in the gabbro enclaves of porphyritic feldspar crystals from the Chevrillon Pluton granodiorite. The black enclaves are amphibolite enclaves broken off in solid state and incorporated into the Chevrillon Pluton during its upward displacement. The green enclaves are probably fragments of sedimentary or volcano-sedimentary rocks. Overall, the distribution of enclaves within the pluton appears homogeneous (5%), except in the northwestern zone, where the enclaves are more abundant (5–20%).

In the northern and northwestern part of the Chevrillon Pluton, the overall east–west direction values vary between 260 and 290°, with an average dip of 75°. In the northwestern part (4 stations), amphibole crystals are aligned between 300 and 320°, with a dip value of 80°. In the southern part (4 stations), the overall east–west foliation shows the same direction and dip values as those observed in the northern part. The central part of the pluton (5 stations) consists of massive rock with no preferential alignment of amphibole crystals.

Northern Satellite

The Northern satellite is composed of homogeneous rocks related to those on the border of the Chevrillon Pluton. There is also a small proportion (5%) of gabbro and amphibolite enclaves resembling the ones previously described. The alignment of the amphibole crystals reflects an overall east–west-striking foliation, with direction values ~285° and dipping ~75°. At one station, the contact between the Northern satellite and the sedimentary rocks of the Chebistuan Formation was observed. Deformation caused by the emplacement of the satellite is visible in the sediments less than 1 m from the linear and very sharp contact. No enclave of sedimentary rocks of the Chebistuan Formation is visible on the outcrop.

Western Satellite

Information relative to this satellite is drawn from observations on its northern and eastern borders. Rock in this intrusive body consists of an assemblage of feldspar (65%), quartz (20%), amphibole and biotite (15%) and would correspond to a diorite. However, unlike the Chevrillon Pluton and the Northern satellite, the Western satellite contains no porphyritic feldspar crystals greater than 1 cm in size. The longest ones observed have complex shapes (Figure 2e) and measure <8 mm. The amphibole crystals in the rock are overall oriented east–west, with direction values varying between 270 and 280° and dipping steeply around 75°. The contact between the sedimentary rocks of the Chebistuan Formation and the intrusive body corresponds to a deformation zone <2 m thick surrounding the pluton. Several dikes similar in composition to the intrusive body are observed on the perimeter of the pluton. They are metric in size and crosscut other gabbro dikes, also metric in size, which are parallel with the main foliation. A few angular, metric amphibolite enclaves (3%) are also found in this pluton. A small, silty sedimentary rock enclave approximately 2 by 3 cm in size was found 2 cm from the border of a diorite dike. It represents the only sedimentary rock enclave of the Chebistuan Formation observed in this satellite or the others. Many quartz, tourmaline and ankerite veins approximately1 cm thick were observed on the border of this intrusive body (Figure 2f).

CHEBISTUAN FORMATION

The sedimentary rocks of the Chebistuan formation, located in the Waconichi syncline, can be divided into two families, the first consisting of jointive polymictic conglomerate and sandstone, and the second of argillite, silt and sandstone. Structural measurements reveal that the sediments are affected by an east–west foliation. However, around the northern part of the Chevrillon pluton, structural measurements reveal that deformation is deflected around the borders of the pluton. Thus, in the northwest, the average foliation direction is 72°, with dip values around 70°. Northwest, measurements give a foliation direction around 310° and a dip value of 75°. According to the literature (Daigneault and Allard, 1990) and data gathered during the fieldwork, this deformation halo could extend up to 4 km beyond the Chevrillon Pluton. This estimate is based on the attitude of the foliation in the Chebistuan Formation deposits. However, on the western side, this deformation zone seems to extend over <1 km. The sedimentary rocks surrounding the Chevrillon Pluton and its satellites are metamorphosed to amphibolite facies grade unlike those located further south and east along the route du Nord, which are of greenschist facies grade.

SYNTHESIS

The mapping carried out during summer 2018 allows to demonstrate that the Chevrillon Pluton, although relatively homogeneous, reveals greater differentiation within its central part, which contains

slightly more quartz crystals than its borders. With respect to the three satellites, mapping has determined that, unlike the Western satellite, the Northern Satellite is similar to the Chevrillon Pluton in terms of its mineralogical composition and mineral proportions. The Western satellite contains no porphyritic feldspath phenocrysts although its matrix is comparable. No information was collected on the Northwestern satellite because of a lack of outcrops due to a thick cover of Quaternary sediments.

The study of amphibole alignment at the Chevrillon Pluton scale allows to show that, although its borders have been affected by east–west-striking deformation, such is not the case for the rocks within its central part. This suggests late-tectonic emplacement that laboratory petrographic analyses could confirm. The age of the Chevrillon Pluton would correspond to the end of the tectonic period in the area. Foliation measurements of sedimentary rocks from the Chebistuan Formation seem to parallel the northern part of the Chevrillon Pluton. Both the Northern and Western satellite intrusive bodies also display east–west amphibole crystal alignment, which is coherent with regional deformation patterns in the area. In addition, their shape (stretched along the east–west axis) suggests that emplacement occurred during the deformation period (Figure 1).

FUTURE WORK

Thin section and whole-rock geochemical analyses as well as in situ measurements using a scanning electron microscope (MEB) or laser ablation inductively-coupled plasma mass spectrometer (LA-ICP-MS) will help determine the chemical characteristics of the Chevrillon Pluton and its satellites. Analysis of the chemical composition of zoning in porphyritic feldspar crystals will help define the evolution of the magma. Two methods are possible: MEB semi-quantitative chemical analyses could be enough if the contrast in chemical density between zoned areas is sufficiently significant. Otherwise, the second possibility would be to use the LA-ICP-MS, which will provide quantitative data associated with a geochemical profile starting at the core of a feldspar crystal and moving toward its border. Another mineral of interest when dealing with the chemical characterization of magma is apatite; this mineral also has the advantage of being resistant to metamorphism and rich in incompatible elements. This work will help determine the impact of potential contamination caused by the incorporation of xenoliths on the chemistry of the Chevrillon Pluton. To this end, lithogeochemical analysis will be used to determine the chemical characteristics of the gabbro and amphibolite enclaves.

The foliation data gathered during the 2018 field season will be compiled with pre-existing data on the area from the SIGÉOM database (SIGÉOM, 2018). The data will then be transferred onto the geological map to show the foliation pattern at the edge of the pluton and more distally. The sedimentary rocks of the Chebistuan Formation will be compared to those of the Timiskaming Group to determine if these two formations are similar.

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REFERENCES

Allard, G. O. and Gobeil, A. 1984. General geology of the Chibougamau region; in Chibougamau–Stratigraphy and Mineralization, J. Guha et E. H. Chown (éd,), Canadian Institute of Mining and Metallurgy, Special Volume 34, p. 5–20.

Allard, G.O., Caty, J.L., Chown, E.H., Cimon, J., Gobeil, A. and Baker, D. 1979. Stratigraphie et métallogénie de la région de Chibougamau; Association Géologique du Canada et Association minéralogique du Canada, Réunion annuelle, Québec, livret-guide de l'excursion B-l, 95 p.

Boudreault, A.P 1977. Géologie de la demie est du canton de Blaiklock (comté d'Abitibi-Est): Rapport préliminaire ; Ministère des Richesses naturelles du Québec, DPV-541, 10 p., 1 plan.

Chown, E. H., Daigneault, R., Mueller, W. and Mortensen, J. K. 1992. Tectonic evolution of the Northern Volcanic Zone, Abitibi belt, Quebec; Canadian Journal of Earth Sciences, v. 29, p. 2211–2225.

Chown, E. H., Harrap, R. and Moukhsil, A. 2002. The role of granitic intrusions in the evolution of the Abitibi belt, Canada; Precambrian Research, v. 115, p. 291–310.

Corfu, F., Jackson, S.L. and Sutcliffe, R. H. 1991. U-Pb ages and tectonic significance of late Archean alkalic magmatism and nonmarine sedimentation: Timiskaming Group, southern Abitibi belt, Ontario; Canadian Journal of Earth Sciences, v. 28, n. 4, p. 489–503.

Daigneault, R. 1991. Évolution structurale du segment de roches vertes de Chibougamau, Sous-province archéenne de l'Abitibi, Québec ; thèse de doctorat, Université Laval, Québec, Québec 352 p.

Daigneault, R. and Allard, G.O. 1983. Stratigraphie et structure de la région de Chibougamau; *in* Stratigraphie des ensembles volcanosédimentaires archéens de l'Abitibi: état des connaissances; Ministère de l'Énergie et des Ressources du Québec, séminaire d'information 1983, DV 83-11, p. 1–17.

Daigneault, R. and Allard, G.O. 1984. Nouvelle interprétation de la structure et de la stratigraphie du canton de Haüy; Ministère de l'Énergie et des Ressources du Québec; DP 84-34, 12 p., 1 plan.

Daigneault, R. and Allard, G.O. 1990. Le Complexe du lac Doré et son environnement géologique (région de Chibougamau-sous-province de l'Abitibi); Ministère de l'Énergie et des Ressources du Québec, rapport MM 89-03, 275 p.

Daigneault, R., St-Julien, P. and Allard, G.O. 1990. Tectonic evolution of the northeast portion of the Archean Abitibi greenstone belt, Chibougamau area, Quebec; Canadian Journal of Earth Sciences, v. 27, p. 1714–1736.

David, J., Davis, D. W., Dion, C., Goutier, J., Legault, M. and Roy, P. 2007. U-Pb age dating in the Abitibi Subprovince in 2005-2006. Ministère des Ressources naturelles du Québec, RP 2007-01(A), 17 p.

Dimroth, E., Mueller, W., Daigneault, R., Brisson, H., Poitras, A. and Rocheleau, M. 1986. Diapirism during regional compression: The structural pattern in the Chibougamau region of the archaean Abitibi belt, Quebec; Geologische Rundschau, v. 75, p. 715–736.

Duquette, G. 1982. Demie nord des cantons de McKenzie et de Roy et quart nord-ouest du canton de McCorkill; Ministère de l'Énergie et des Ressources du Québec, DPV-837, 80 p., 4 plans.

Leclerc, F., Bédard, J.H., Harris, L.B., McNicoll, V., Goulet, N., Ray, P. and Houle, P. 2011. Tholeiitic to calc-alkaline cyclic volcanism in the Roy Group, Chibougamau area, Abitibi Greenstone Belt–Revised stratigraphy and implications for VHMS exploration; Canadian Journal of Earth Sciences, v. 48, p. 661–694.

Leclerc, F., Harris, L.B., Bédard, J.H., Van Breemen, O. and Goulet, N. 2012. Structural and stratigraphic controls on magmatic, volcanogenic and syn-tectonic mineralization in the Chapais-Chibougamau mining camp, northeastern Abitibi, Canada; Economic Geology, v. 107, p. 963–989.

Leclerc, F., Roy, P., Houle, P., Pilote, P., Bédard, J. H., Harris, L. B., McNicoll, V. J., Van Breemen, O., David, J. and Goulet, N. 2017. Géologie de la région de Chibougamau; Ministère des Ressources naturelles et de la Faune du Québec, Rapport RG 2015-03, 97 p.

Sabourin, R.J.E. 1956. Blaicklock area (Abitibi territory and Abitibi-East county)–Final report; Ministère des Mines du Québec, DP-484, 44 p., 1 plan.

SIGÉOM, 2018. SIGÉOM (online resource): Système d'Information Géominière à référence spatiale. Regroupement des données géoscientifiques aux échelles 1 : 20 000 et 1 : 50 000, Ministère des Ressources naturelles et de la Faune du Québec, URL http://sigeom.mines.gouv.qc.ca.

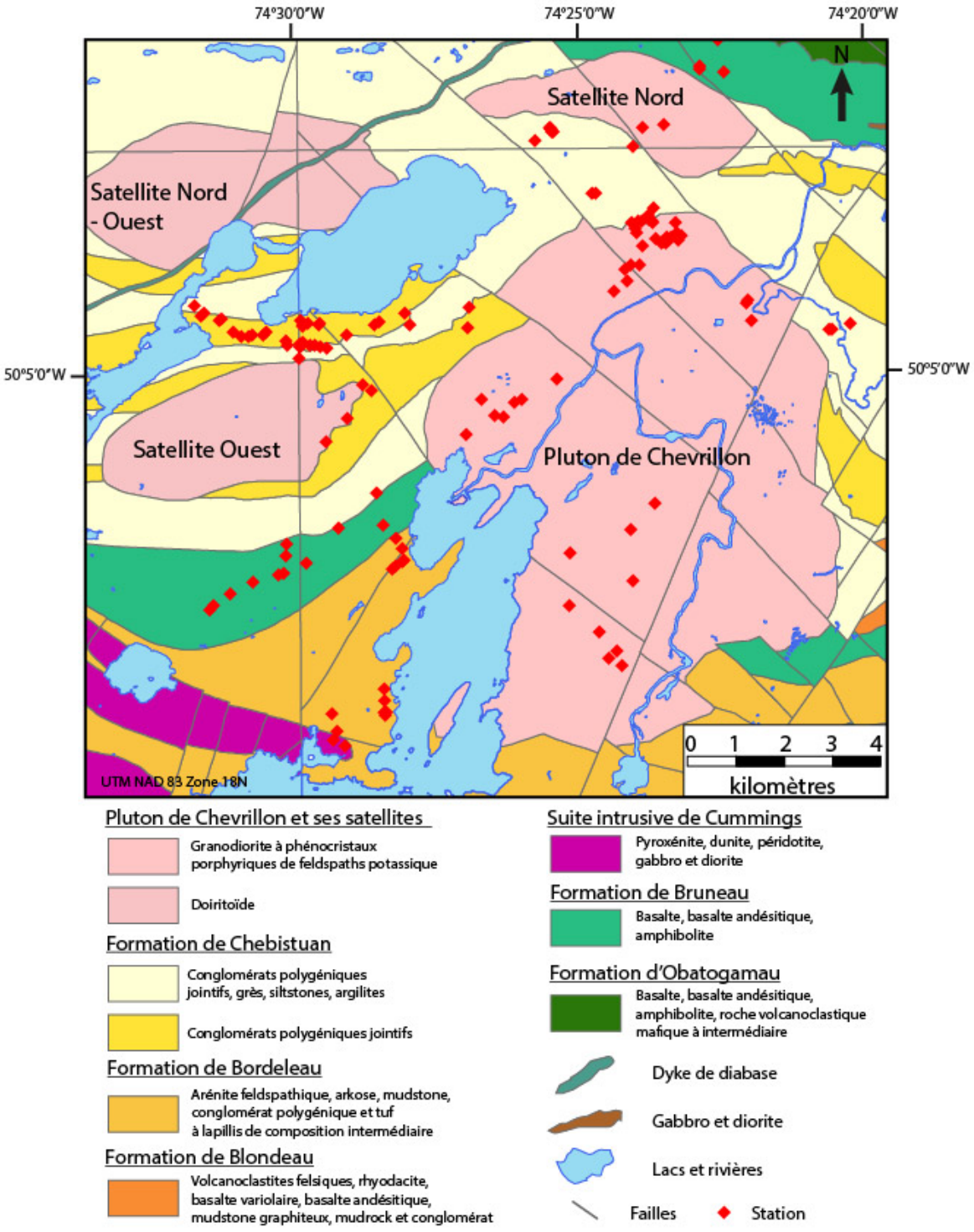

Figure 1. Geology of the Chevrillon Pluton area drawn from a SIGÉOM base (SIGÉOM, 2018), showing the location of the stations studied during the summer 2018 mapping campaign.

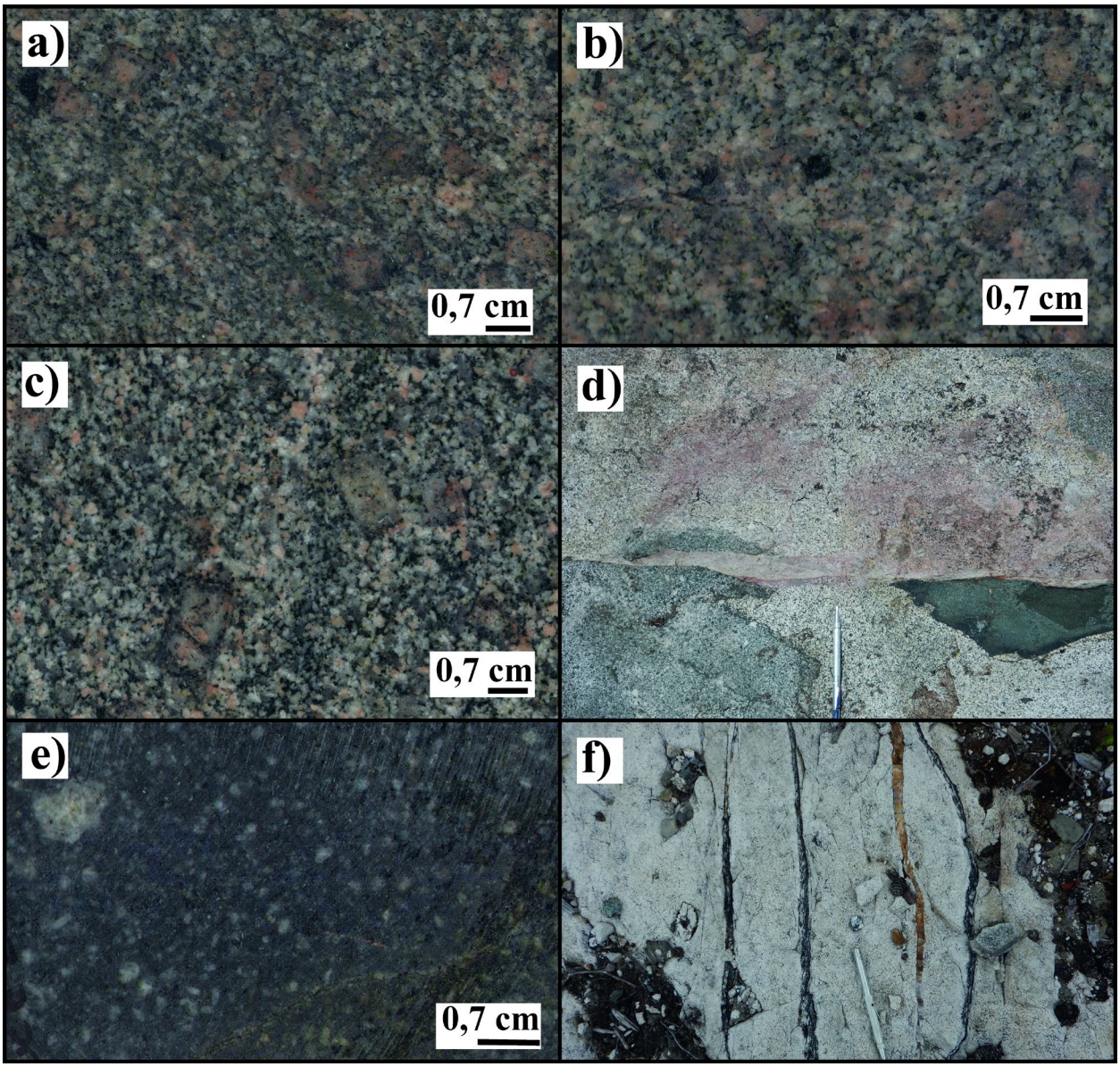

Figure 2. Selected photographs of lithological units in the Chevrillon Pluton area: **a)**, **b)** and **c)** Chevrillon Pluton granodiorite, with samples from the northern (c) , central (d) and southern (e) parts, respectively; **d)** black amphibolite (right) and grey gabbro (left) enclaves in the Chevrillon Pluton granodiorite; porphyritic feldspar belonging to the hostrock in the gabbro enclave as well as the small, pinkish aplite intrusion, which cuts both types of enclaves, should be noted; **e)** diorite from the Western satellite; **f)** quartz, tourmaline and ankerite veins and veinlets on the northern border of the Western satellite