Geometry, Geochemistry and Manner of Emplacement of the d'Eau Jaune Complex, Northeastern Abitibi Subprovince, Quebec

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PREAMBLE

This field report is part of the M.Sc. research project undertaken by M. Kieffer and builds on the 2018 fieldwork. The results of the 2019 fieldwork are presented in this report.

INTRODUCTION

The d'Eau Jaune Complex (CEJ) is a multiphase intrusion located in the Chibougamau area, in northeastern Abitibi Subprovince. Covering several hundred squares kilometres, the CEJ is in fact one of the most important intrusions of the Metal Earth seismic transect in the Chibougamau area. However, little work has been done in the CEJ area and available results are insufficient to lead to a decision on either the nature (geochemistry) and geometry of the complex, or its structure and depth of emplacement. Consequently, it is difficult to place the CEJ in its proper stratigraphic setting, although such a determination is critical to the interpretation of the Metal Earth transect. In addition, a molybdenum (Mo) showing, known since the 1970s, was rediscovered in a phase of the CEJ in 2009. This showing, called the Moly-Desgagné (or Lac Sébastien) showing, corresponds to a series of six recent strippings (2009–2019) located in the northeastern part of the complex, near the contact between two magmatic phases (Figure 1). Currently, it is one of two Mo occurrences documented in the Chibougamau area, the first one being the Au-Cu-Mo MOP-II showing. The latter is located northwest of Chibougamau and is well documented, along with its relationship with the hostrocks (Lépine, 2009).

Mapping was done in the CEJ during summer 2018 and 2019 to gather new data for the Chibougamau seismic transect mapping project. The CEJ is located less than 5 km west of the transect but cannot be seen from there. The main aim of this work was to document the different phases of the CEJ, their relationship to deformation and metamorphism, and the timing of their emplacement. The second goal was to determine the relationship between magmatism and Mo mineralization. The various magmatic phases identified are presented in this report, as well as the evidence of deformation observed at the CEJ.

LOCAL GEOLOGY

The Archean Abitibi Subprovince consists of an assemblage of volcanic and sedimentary rocks crosscut by intrusions. The large plutonic masses of the Abitibi Subprovince have seen little development as they are considered barren compared to the volcanic rocks. The CEJ is no exception to the rule. The synthesis of available information on the CEJ and its relationship to regional stratigraphy is presented below. It is an illustration of the problems it raises related to the interpretation of the Metal Earth seismic transect in the Chibougamau area.

The CEJ is located at the eastern end of the Lapparent massif (Figure 1), a pretectonic tonalite–diorite gneiss body belonging to the tonalite-trondhjemite-granodiorite (TTG) suite and corresponding to deep crustal layers exhumed by still undocumented mechanisms (Mueller et al. 1989; Chown and Mueller 1992; Chown et al., 2002). The massif has not been dated and is crosscut by syn- to post-tectonic multiphase tonalite plutons, of which the CEJ could be one (Racicot et al. 1984; Midra et al.1991).

The CEJ is interpreted as an intrusion related to the TTG suite emplaced at the transition between the synvolcanic and the syntectonic periods (Legault 2003; Faure 2012). According to Tait (1992), the CEJ consists of an early, minor diorite to quartz-diorite phase (I), followed by three successive late tonalite phases (II, III and IV) that contain volcanic rock enclaves. Phase I is considered as being possibly synvolcanic and related to the des Vents Formation volcanic rocks (Mueller et al. 1989; *see* below), whereas phases II, III and IV would be syntectonic. This interpretation differs from that of Chown et al. (2002), which recognized the whole CEJ as synvolcanic. Absolute ages have not been determined for any of the CEJ magmatic phases and available geochemical data are insufficient to determine conclusively whether the different phases of the CEJ are synvolcanic or syntectonic.

The CEJ multiphase intrusion is therefore in contact with rocks of the Lapparent massif to the west. It is also in contact with the Obatogamau Formation basalts to the east, and mainly with the oldest lavas of the Abitibi Subprovince to the northeast and south (Figure 1). Indeed, the CEJ is in contact with 2791.4 +3.7/-2.8 Ma intermediate volcanic rocks (Leclerc et al., 2010; David et al. 2011) that are part of the Chrissie Formation. It is also in contact with 2798.7 ±0.7 Ma (Mueller et al.1989; Davis et al., 2014) mafic and felsic volcanic rocks originally referred to as the des Vents Member by Potvin (1991) but later assigned to the des Vents Formation by Leclerc et al. (2017). These are the oldest rocks in the Chibougamau and Abitibi Subprovince area. Mueller et al. (1989) and Tait (1992) proposed that the CEJ was a subvolcanic complex fueling the volcanic activity of the des Vents Formation, which would therefore be considered comagmatic with the CEJ. Hence, the CEJ would be the same age or older than the des Vents Formation; however, the CEJ has never been dated. The Chrissie and des Vents formations seldom outcrop and their relationship with the CEJ intrusion is poorly documented.

CHARACTERIZATION OF THE CEJ PHASES

Field observations made during the summer 2018 and 2019 mapping campaigns (155 stations), combined with petrographic analysis of thin sections, have revealed 11 distinct rock types in the CEJ sector. Outcrops were examined in the Anville pluton and Rachel pluton sectors located on the northwestern and southwestern margins of the CEJ, respectively, to better constrain the western border of the CEJ. These observations have shown that the CEJ comprises at least six main felsic to intermediate intrusive phases (Figure 1). These phases are accompanied by dykes consisting of aplite, pegmatites and mylonitized pegmatites, and late felsic dykes. These rock type groupings were done during summer 2018 and winter 2019 based on summer 2018 fieldwork data, petrographic analysis of thin sections and lithogeochemical analyses. They were finalized during summer 2019 mapping and the phase names used here correspond to the names they were given in the field. The crosscutting relationships between phases, as observed on the strippings of the Moly-Desgagné showing and across the CEJ, made it possible to establish a relative timeline. Consequently, from the earliest to the most recent, the rock units observed are:

1. Enclaves of mafic rocks, which are found in all six CEJ intrusive phases. They are usually equigranular but the grain size varies from one enclave to another (<1–5 mm). They consist of metamorphic amphiboles wrapped in feldspars. Their ‘salt-and-pepper’ appearance is a typical feature of amphibolite-facies metamorphosed basalt (and gabbro). In addition, the presence of feldspar macrocrystals in some enclaves indicates that they were likely related to the

Obatogamau Formation, in which microcrystals of this type have been documented. Hence, the six intrusive phases are not comagmatic with the des Vents Formation.

2. Diorite 1, which has only been observed on strippings of the Moly-Desgagné showing and one other outcrop located east of the CEJ. The coarse-grained (0.5–2 mm) diorite of this phase consists of 30–40% quartz and 30–50% feldspars (Figure 2a). The felspars are sericitized and chlorite is the main alteration product (<15%), with some carbonates (<10%).

3. Diorite 2, which appears as fine-grained facies on strippings of the Moly-Desgagné showing (0.3–0.7 mm). This rock type is found in the eastern part of the CEJ, where the grain size is coarser (1–3 mm; Figure 2b). It consists of <32% quartz and of 35–50% feldspars, also sericitized. The amphibole (10%) is a green hornblende and intergrowths between this mineral and feldspars attest to its magmatic origin.

4. Tonalites 1 and 2, which are mainly observed in the western sector of the CEJ. These facies appear to extend beyond the limits of the CEJ, as defined on the geological maps of the Quebec Ministère de l'Énergie et des Ressources naturelles (MERN). Indeed, they also show up in the eastern part of the Lapparent massif, up to 15 km west of the western limit of the CEJ, as mapped by the MERN. A few tonalite outcrops have also been identified in the eastern part of the CEJ, between diorite 1 and phase CEJ 3 (Figure 1). The chronological relations between the two tonalites have not been determined. Tonalite 1 is medium grained (0.7–3 mm) and consists of 30–50% quartz, 30–40% microcline, 5–20% unspecified alkali feldspars, and minor biotite and amphiboles (<5%). Fresh tonalite 1a differs from weathered tonalite 1b by its colour: tonalite 1a is beige, whereas the pinkish green hue of tonalite 1b is the product of alteration and hematization. As for tonalite 2, it is coarser grained (1–5 mm) and has less quartz (20–30 %), and more biotite (10–15%) than tonalite 1 (Figure 2d). It contains 7–30% alkali feldspars and microcline, and up to 40% plagioclase.

5. Central phases 1 and 2, which correspond to phase CEJ 3 as defined by the MERN. Here again, no crosscutting relationship was observed between these two phases. Central phase 1 (Figure 2e) is located on the margin of phase CEJ 3, as defined by the MERN. It consists of 30–40% quartz, 25% plagioclase and 25% alkali feldspars (5% microcline). It also contains 10–15% biotite and rare green hornblende crystals. Central phase 2 (Figure 2f), located at the centre of phase CEJ 3, differs from central phase 1 in that it has a lesser amount of quartz (5–10%) and biotite as well as a greater amount of amphiboles (30–35%) and plagioclase (30–40%). The grain size of both rock types is homogeneous and coarse, ranging roughly from 0.5 to 4 mm.

6. Dykes consisting of aplite, pegmatites and mylonitized pegmatites, and felsic dykes crosscut all the foregoing rock types. The chronological relations between the dykes have not been determined.

CEJ DEFORMATION

Observations made during summer 2018 and 2019 fieldwork have revealed that structural history of the CEJ is closely linked to the metamorphic grade of the rocks. Overall, the CEJ shows little deformation. The deformation is strongest generally at the contacts between the main intrusive phases described above. All the measurements made in the CEJ indicate that foliation tends to follow the contours of the intrusive phases. In addition, strong deformation can be found within and on the margin of mafic rock enclaves. Also, a major, ductile deformation zone has been identified in the eastern part of the CEJ. This corridor is oriented N110–N130° and includes the strippings of the Moly-Desgagné showing (Figure 3). Overall, foliation on the outcrops in this deformation corridor is intense (oriented N110–N130°) and shows alignment of associated minerals (feldspars, quartz, at times amphiboles). Detailed work at the strippings of the Moly-Desgagné showing, as well as at other key CEJ outcrops, made it possible to determine the timing of deformation events. The CEJ has been subjected to at least two deformation events characterized by: 1) early north–south-oriented foliation (S_1); and 2) main foliation that trends east–west (S_2) and northwest–southeast in the deformation corridor. In the corridor, the intrusive phases and enclaves show evidence of ductile deformation, such as banding. The S_1 foliation is folded and forms asymmetrical folds. The S_1 axial plane foliation usually shows east-trending, weakly dipping (<20°) stretching lineations. In addition, chlorite-rich zones (>60%) in some sections of the deformation corridor suggest retrograde alteration caused by hydrothermal-fluid flow, which is consistent with the greenschist metamorphic facies observed on the strippings of the Moly-Desgagné showing.

DISCUSSION AND CONCLUSION

Mapping done during summer 2018 and 2019 revealed the lithological diversity of the CEJ. They also allowed the complex relationship between magmatism, deformation and metamorphism to be defined. Amphibolite-facies basalt enclaves observed in the six main intrusive phases of the CEJ belong to the Obatogamau Formation. Consequently, the CEJ phases are not comagmatic with the des Vents Formation, which is older than the Obatogamau Formation. This conclusion was confirmed by ages obtained from diorite 2, published by David (2018), and preliminary ages obtained by M. Hamilton (unpub. data, 2019) from tonalite 2 and central phase 1. The ages yielded were 2718.6 ±5,4 Ma, 2727 ±1 Ma and 2725–2728 Ma, respectively. The crosscutting relationships indicate that diorite 1 is the earliest phase, followed by diorite 2, tonalite phases 1 and 2, and finally central phases 1 and 2. The chronological relations between tonalites 1 and 2 as well as between central phases 1 and 2 have not been determined.

Although the CEJ shows little deformation overall, a strongly deformed corridor oriented N110–N130° crosscuts the eastern part of the CEJ. This ductile deformation is consistent with amphibolite-facies metamorphism. This observation agrees with laboratory results, which have shown that the main intrusive phases were emplaced at a deep crustal level. The rocks were subsequently affected by local hydrothermal-fluid flow leading to retrograde alteration under P-T conditions that are consistent with greenschist-facies metamorphism. These fluids were channelled in the deformation corridor.

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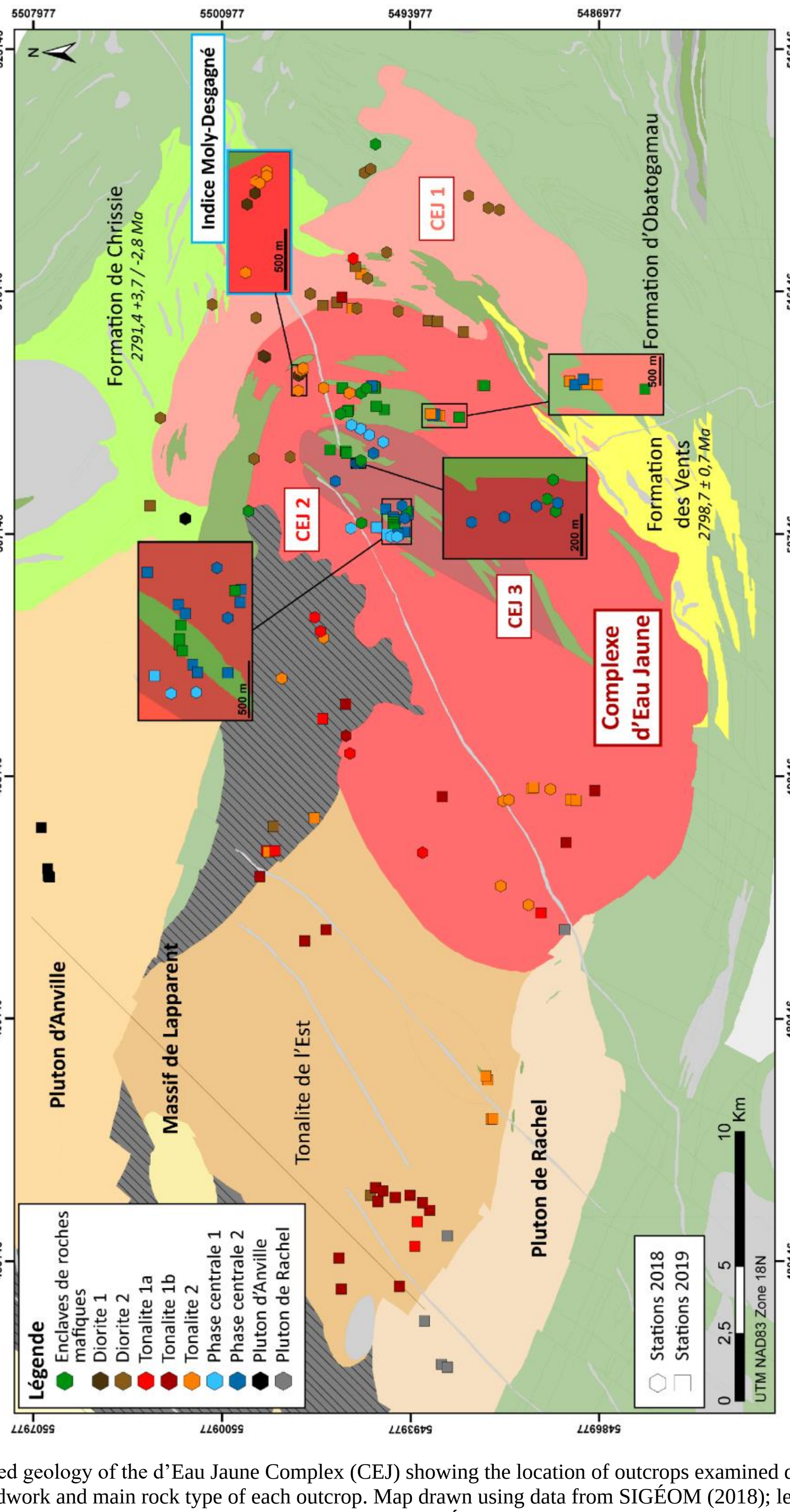

Figure 1. Simplified geology of the d'Eau Jaune Complex (CEJ) showing the location of outcrops examined during summer 2018 and 2019 fieldwork and main rock type of each outcrop. Map drawn using data from SIGÉOM (2018); legends *modified from* Leclerc et al. (2010); David et al. (2011); Davis et al. (2014); SIGÉOM (2018).

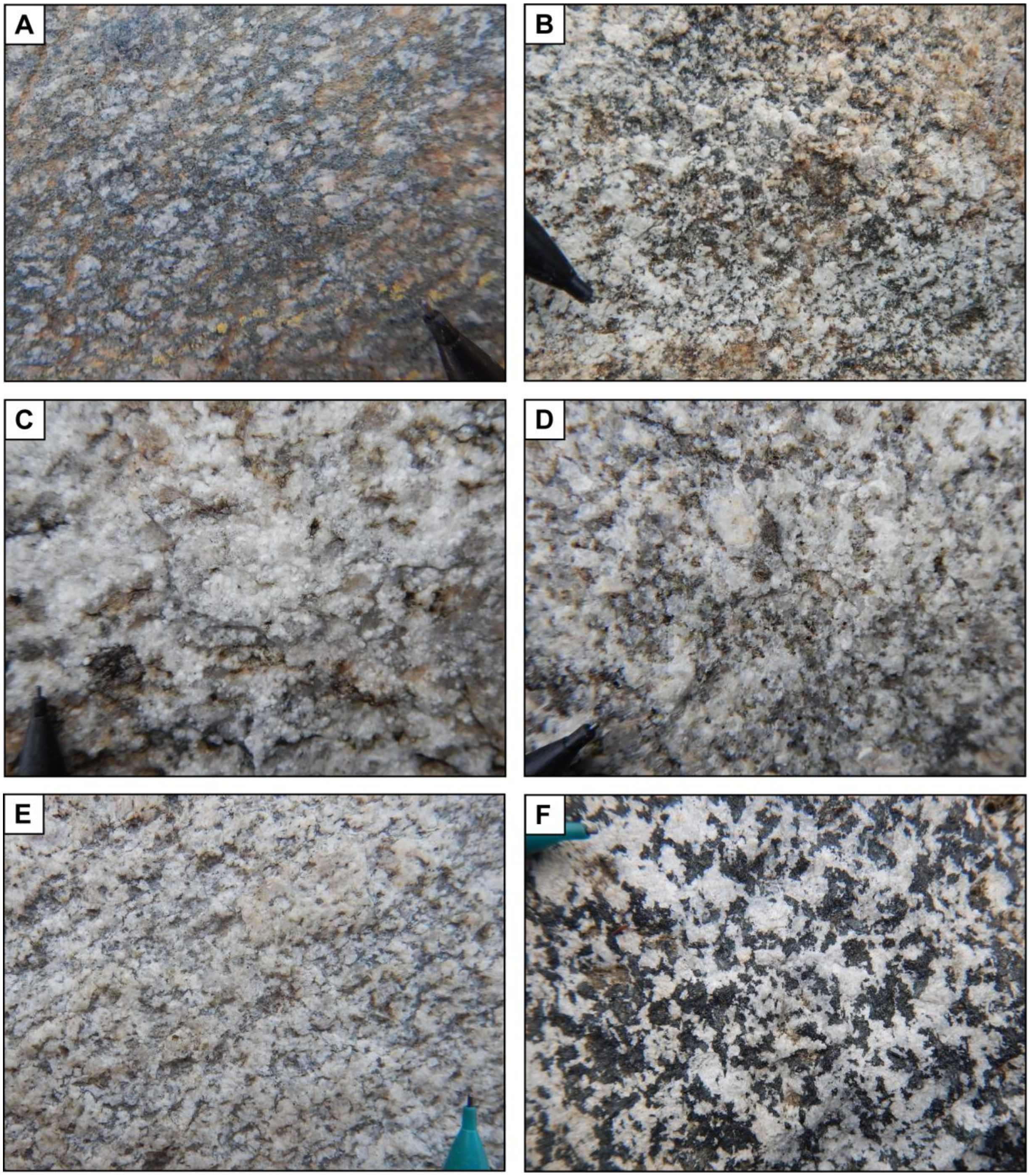

Figure 2. Photographs from the d'Eau Jaune Complex (pencil tip measures 0.7 mm and indicates north) showing the textures of the six main intrusive phases that constitute it: **a)** diorite 1; **b)** diorite 2; **c)** fresh tonalite 1a ; **d)** tonalite 2; **e)** central phase 1; **f)** central phase 2.

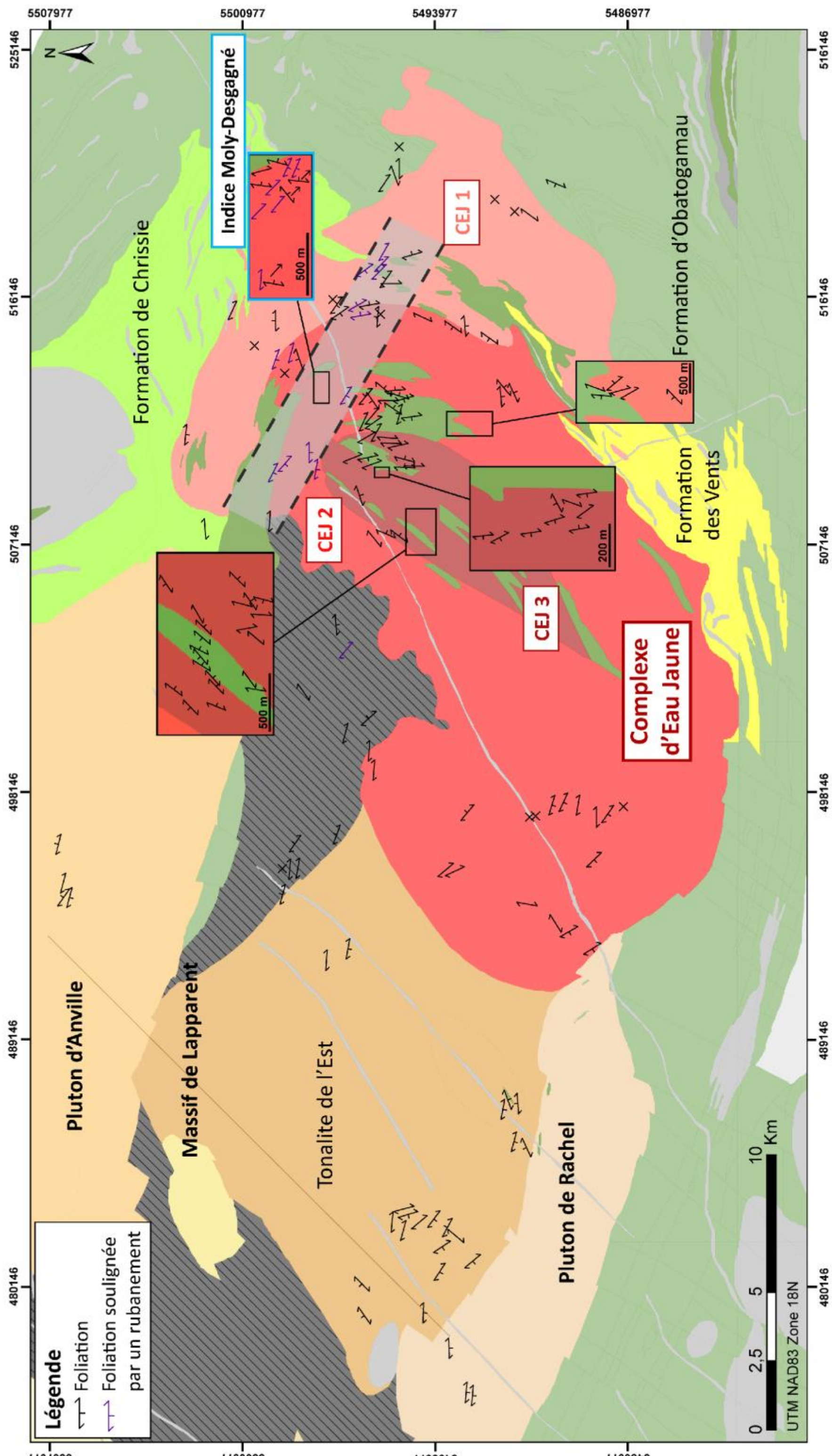

Figure 3. Simplified geology of the d'Eau Jaune (CEJ) Complex showing foliation measurements from each outcrop examined during the summer 2018 and 2019 fieldwork. Map drawn using data from SIGÉOM (2018); legends *modified from* Leclerc et al. (2010); SIGÉOM (2018).