Geometry, geochemistry and manner of emplacement of the Eau Jaune Complex, Chibougamau region, Quebec

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INTRODUCTION

The Eau Jaune complex (CEJ) is a polyphased intrusion located in the Chibougamau area, in northeastern Abitibi Subprovince. The CEJ rocks underwent ductile deformations and were subjected to high-grade metamorphism; thus, this complex could be one of the few examples of documented deep crust in the Abitibi. The depth of emplacement, the mechanism of the upward displacement, the age and relationship to Chibougamau regional stratigraphy of this little known complex remain undetermined.

Covering several hundred squares kilometres, the CEJ is in fact one of the most important intrusions of the Metal Earth project 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 Chibougamau 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 (2009–2017) located in the northeastern part of the complex, close to the contact between the two magmatic phases (Figure 1). At present, it is one of two Mo showings documented in the Chibougamau area, the first one being the Au-Cu-Mo MOP-II showing located northwest of Chibougamau (Lépine, 2009).

Mapping was done in the CEJ during summer 2018 to gather new data for the Chibougamau seismic transect mapping project. The aim of this work was to document the different phases of the CEJ, their relations to deformation and metamorphism, and the timing of their emplacement. The second goal was to determine the relationship between the Mo showing and the geological history of the complex. This report presents preliminary mapping results for the CEJ and the strippings of the Moly-Desgagné showing.

REGIONAL GEOLOGY

The Archean Abitibi Subprovince consists of an assemblage of volcanic and sedimentary rocks cut by intrusions. Little is known about the large plutonic masses of the Abitibi Subprovince as they are considered sterile compared to the volcanic rocks. The CEJ is no exception to the rule. The synthesis of available information on the CEJ and its relation to regional stratigraphy is presented below. It is an illustration of the problems raised by the interpretation of the Metal Earth project seismic transect in the Chibougamau area.

The CEJ is located at the eastern end of the Lapparent massif (Figure 1), a pre-tectonic 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). This is particularly important in regard to the Metal Earth project since exhumation of deep parts of the crust is typical of post-Archean orogens and ancient crust might not be sufficiently rigid to allow development of such a process (Zibra et al. 2017). Documenting the exhumation process in Abitibi might inform Neoarchean transition between the ancient and modern tectonic processes. The massif has not been dated and is cut by syn- to post-tectonic polyphased tonalite plutons, of which the CEJ is potentially part (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 Gait (1992), the CEJ consists of a minor, early 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, whereas phases II, III and IV would be syntectonic. This differs from the interpretation of Chown et al. (2002), which states that the whole CEJ is synvolcanic. The absolute age of none of the CEJ magmatic phases has been determined and geochemical data available is insufficient to determine conclusively whether the different phases of the CEJ are synvolcanic or syntectonic.

The CEJ polyphased 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. Il is also in contact with 2798.7 ±0.7 Ma (Mueller et al.1989; Davis et al., 2014) mafic and felsic volcanic rocks (Leclerc et al., 2010; David et al. 2011) originally designated under the name of Des Vents Member by Potvin (1991) but renamed 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 that would have fed volcanic activity in the Des Vents Formation, which would therefore be regarded as comagmatic with the CEJ. Hence, the CEJ would be the same age or older than the Des Vents Formation. However, the CEJ has not been dated, the Chrissie and Des Vents formations seldom outcrop and their relations with the CEJ intrusion are poorly documented.

LITHOLOGICAL UNITS OF THE CEJ AND METAMORPHISM

The main lithological units observed in the CEJ are felsic–intermediate intrusive rocks. The borders between the different CEJ ‘phases’, as defined on the map drawn by the Ministère de l’Énergie et des Ressources naturelles du Québec (SIGÉOM, 2016; Figure 1), will be used to present and situate the preliminary results. Thus, the central phase (CEJ3) is characterized by a coarse-grained (1–3 mm on average) tonalite, which seems homogeneous from one outcrop to the next (Figure 2a). The intermediate phase (CEJ2) is homogeneous in the west-southwestern part of the complex, where it is still coarse-grained tonalite. However, this tonalite is different from the tonalite observed in phase CEJ3 as it is more altered, paler and frequently contains rods of amphibole. The rest of CEJ2 is not homogeneous as it contains other lithological units associated to the previously mentioned tonalite: coarse-grained diorite, fine-grained diorite, felsic injections as well as mafic rocks (typically amphibole). Although it may appear to be the most representative lithological unit in the CEJ2 phase , the diorite is older than the tonalite as it is systematically crosscut by it or found as an enclave (Figure 2 b). Breccia dikes crosscut all of these units. They consist of aplite fragments surrounded by bands of greyish quartz (Figure 2c). It should be noted that, on most of the outcrops visited, the least homogeneous part of the CEJ2 phase is banded. The CEJ1–CEJ (undetermined), located on the eastern and southeastern borders of the complex is represented by a diorite, very often banded and here also cut by tonalite injections, although these are less common than those observed in the CEJ2 phase.

Enclaves of amphibolite-facies metamorphosed volcanic rocks were noted across the eastern portion of the complex. Feldspar glomerocrysts, varying in size from 2 mm to 4 cm, indicate these are likely enclaves of the Obatogamau Formation (Figure 2d). The CEJ phases containing enclaves can therefore not be comagmatic with the Des Vents Formation.

The Moly-Desgagné showing is in the CEJ2 phase and its strippings highlight both the intrusion's complexity and the metamorphic grade of the rocks in this phase. It displays all the banded, folded, deformed and amphibolite-facies metamorphosed rock units of the CEJ2 phase. Locally, deformation corridors containing chlorite indicate that the rocks were subjected to retrograde metamorphism.

DEFORMATION, ALTERATION AND MINERALIZATION

The Moly-Desgagné strippings are the best-exposed outcrops to study the different deformation events, as well as the Mo mineralization. They show a weak (old), north–south oriented foliation gently dipping toward the east (N025°/20°), although it contains a stretching lineation shallowly plunging toward the east (20°). This foliation is locally folded, with centimetre-sized, open to asymmetric folds that parallel the stretching lineation. The dominant foliation strikes N110–130° and is marked by aligned amphiboles and feldspars (amphibolite-facies metamorphic grade). It also has east–west-striking subvertical deformation corridors (anastomosing mylonites). The east–west-striking breccia dikes are probably associated to the deformation event as quartz bands are typical in mylonite. No direct crosscutting relation was observed between the two rock fabrics. It is therefore possible that there was a shortening of the north–south foliation resulting in a reorientation to an east–west direction. Many other CEJ outcrops also have a strongly foliated, nearly gneissic, texture striking N110–130°. They are in an extension of the Moly-Desgagné showing deformation zone, which suggests the presence of a larger-scale deformation zone. Finally, some east–west-striking deformation corridors have been completely reworked by retrograde chlorite alteration. The older foliation is always weakly present on the borders. This chloritization implies circulation of retrograde alteration hydrothermal fluids. The east–west schistosity is therefore confined to the deformation corridors affected by retrograde alteration caused by hydrothermal fluids.

In addition to chloritization, hydrothermal activity manifests itself as different generations of tourmaline, quartz-tourmaline and quartz veins in brittle fault networks. The presence of pyrite in some quartz and aplite veins is due to thermal conditions reaching an equilibrium stage with greenschist-facies metamorphic grade. The hydrothermal system can therefore only be apparent from the last deformation event. Five families of veins have been individualized and crosscutting relationships suggest the following timing for their emplacement:

1. A first generation of massive white quartz veins striking N110–130° is confined to shear zones affected by retrograde chlorite alteration; the veins are gently dipping, contain pyrite cubes et locally display a saccharoidal texture.

2. Quartz veins striking N020–045°, usually secant to the foliation of the host rocks; in addition, a similarly striking (N090°) aplite dike crosscuts this foliation.

3. A first generation of black tourmaline veins, roughly oriented ~N130°

4. Black tourmaline veins striking N020° locally reoccur in quartz veins.

5. A late generation of black tourmaline veins striking N175° crosscuts all the veins from the previous events; Figure 3 presents an example of the different generations of quartz, quartz-

tourmaline and tourmaline veins observed on one of the strippings of the Moly-Desgagné showing.

Molybdenum mineralization is mainly located in the walls of the quartz veins within the east–west shear zones affected by retrograde chlorite alteration. The most striking example is a pocket of massive Mo on the border of a quartz vein, which is in fact the outcrop where the Moly-Desgagné showing was discovered in the 1970s (Figure 2e). However, Mo flakes are also visible in more recent black tourmaline veins. The hydrothermal system having remained active, Mo mineralization can be the result of repeated pulses.

Finally, carbonate alteration (ankerite) is observed around the east–west oriented quartz veins. Alteration is also associated with black tourmaline veins and presents itself as a change in host rock colouring and by the appearance of small pyrite cubes (1–2 mm; Figure 2f). This alteration destroys older fabrics.

DISCUSSION AND CONCLUSION

Mapping done during summer 2018 highlights both the lithological and metamorphic complexity of the intrusion. The different lithological units and their crosscutting relationships show that the diorite phase is older. In the CEJ2 phase, it is often found as enclaves or slices within the tonalite, which is however the least represented unit. On the other hand, the CEJ3 phase tonalite is homogeneous, contains no diorite enclaves and the rock is weakly deformed, suggesting that this phase is more recent.

The high metamorphic grade of the rocks in phase CEJ2, and more specifically the lithological units of the outcrops and Moly-Desgagné showing that share similar features (banding), points to deep crust level involvement. These amphibolite-facies metamorphic grade rocks are dehydrated. It is therefore unlikely that retrograde metamorphic fluids originated from these deeper levels. The presence of a recent intrusive system is therefore the preferred hypothesis; this system would have brought the hydrothermal fluids that caused the chlorite, molybdenite and ankerite retrograde mineralization. A good candidate would be a K-feldspar dike located 1 km north of the Moly-Desgagné showing. This dike, striking N050°, is secant to the foliation, which indicates it was emplaced after the last-mentioned deformation event. It could be related to the central phase (CJE3), which also seems to have been a more recent event than the deformation, thus constraining the timing at which mineralization occurred.

FUTURE WORK

Future work will include petrological and geochemical analyses of the various lithological units identified in the CEJ to confirm rock classifications made in the field. These analyses will make it possible to check phase affinities and whether they belong to the TTG suite, as well as to test whether the different phases are comagmatic. The link between the late K-feldspar dike and the central phase of the CEJ can also be verified. The metamorphic grade of certain rocks will be measured in amphibole samples. The goal is to estimate prevailing conditions at the time the CEJ intrusion was formed. Finally, the determination of a U-Pb absolute age of zircons from the tonalitic phase of the Moly-Desgagné showing will help constrain the timing of the intrusion’s emplacement. Using the rhenium-osmium method to date the molybdenite pocket would also help constrain the timing of deformation events.

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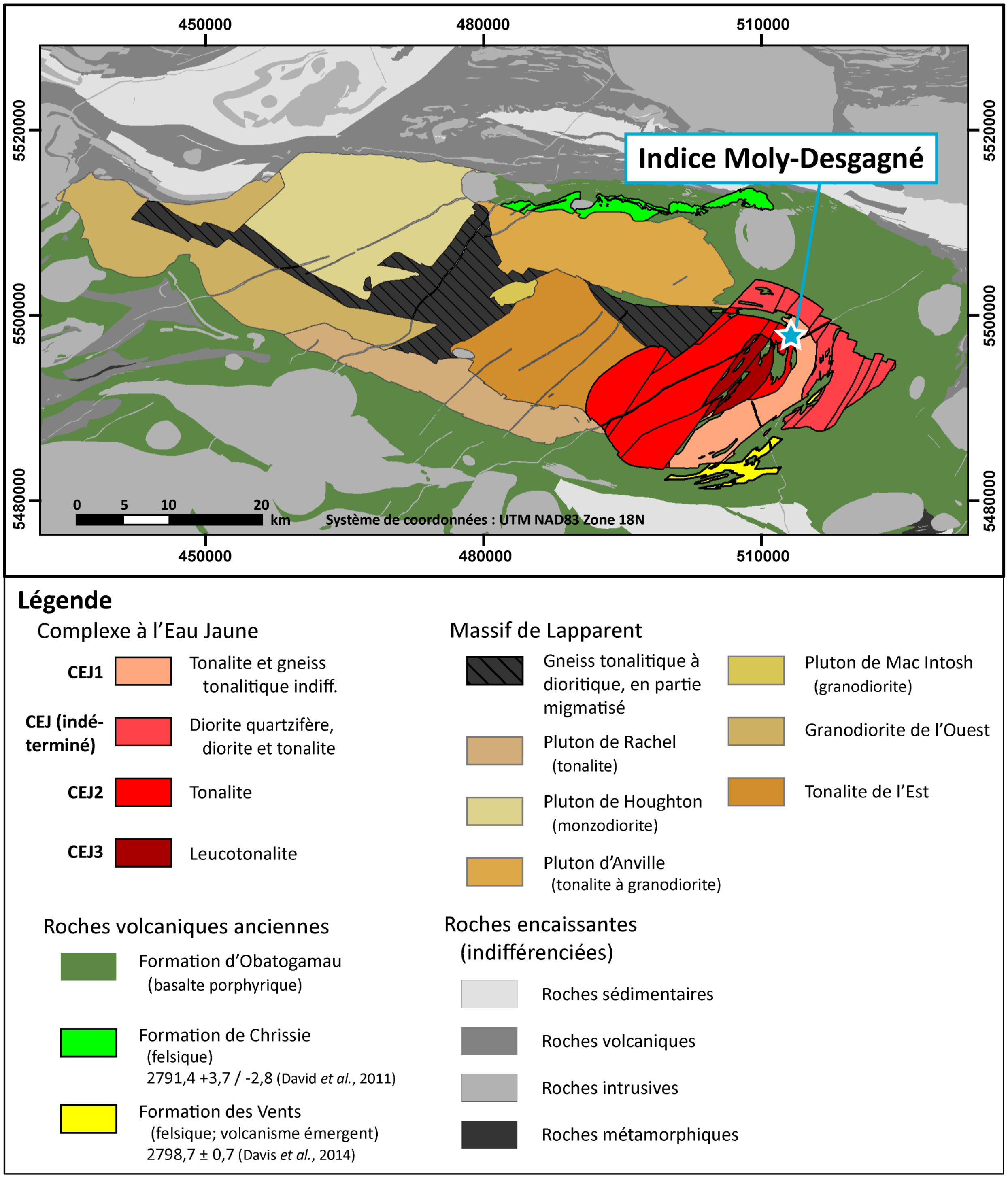

Figure 1. Simplified geology of the Eau Jaune Complex, compiled from Ministère de l'Énergie et des Ressources naturelles du Québec data (SIGÉOM, 2016); legends after Racicot et al. (1984), Mueller et al. (1989), Midra et al. (1991), Leclerc et al. (2010) and SIGÉOM (2016). Abbreviation: indiff., undifferentiated.

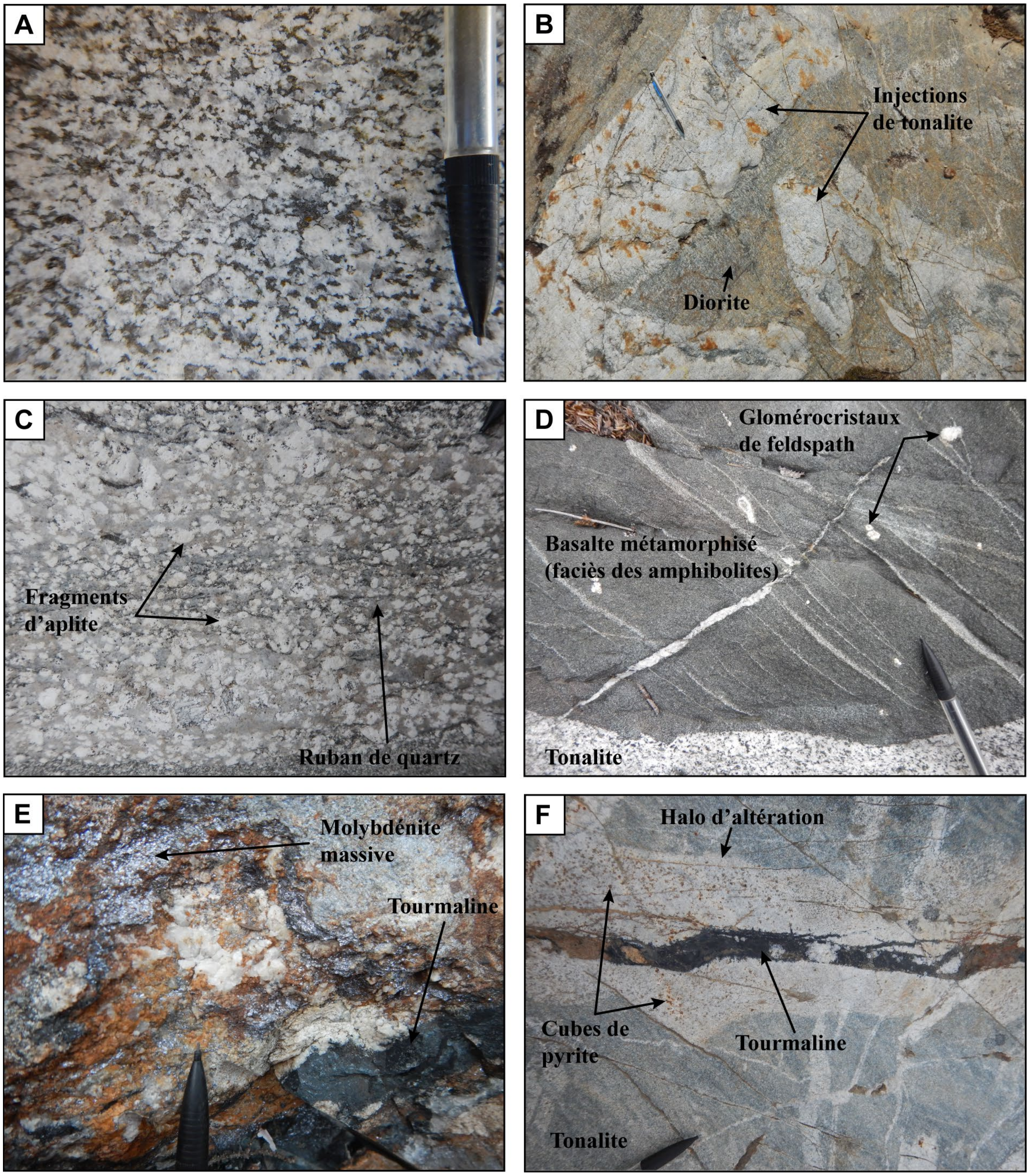

Figure 2. Photographs from the Eau Jaune Complex (CEJ; pencil tip indicates north) showing: a) tonalite within CEJ3 phase; b) tonalite (light shade) intruded into diorite; c) breccia dike: autobrecciated aplite fragments surrounded by a quartz band; d) metamorphic amphibolite-facies basalt enclave with feldspar glomerocrysts (Obatogamau Formation) in a CEJ3 phase tonalite; e) black tourmaline vein in tonalite, with alteration halo (leaching) containing pyrite cubes (Moly-Desgagné showing); f) massive molybdenum pocket on the outcrop where the Moly-Desgagné showing was discovered.

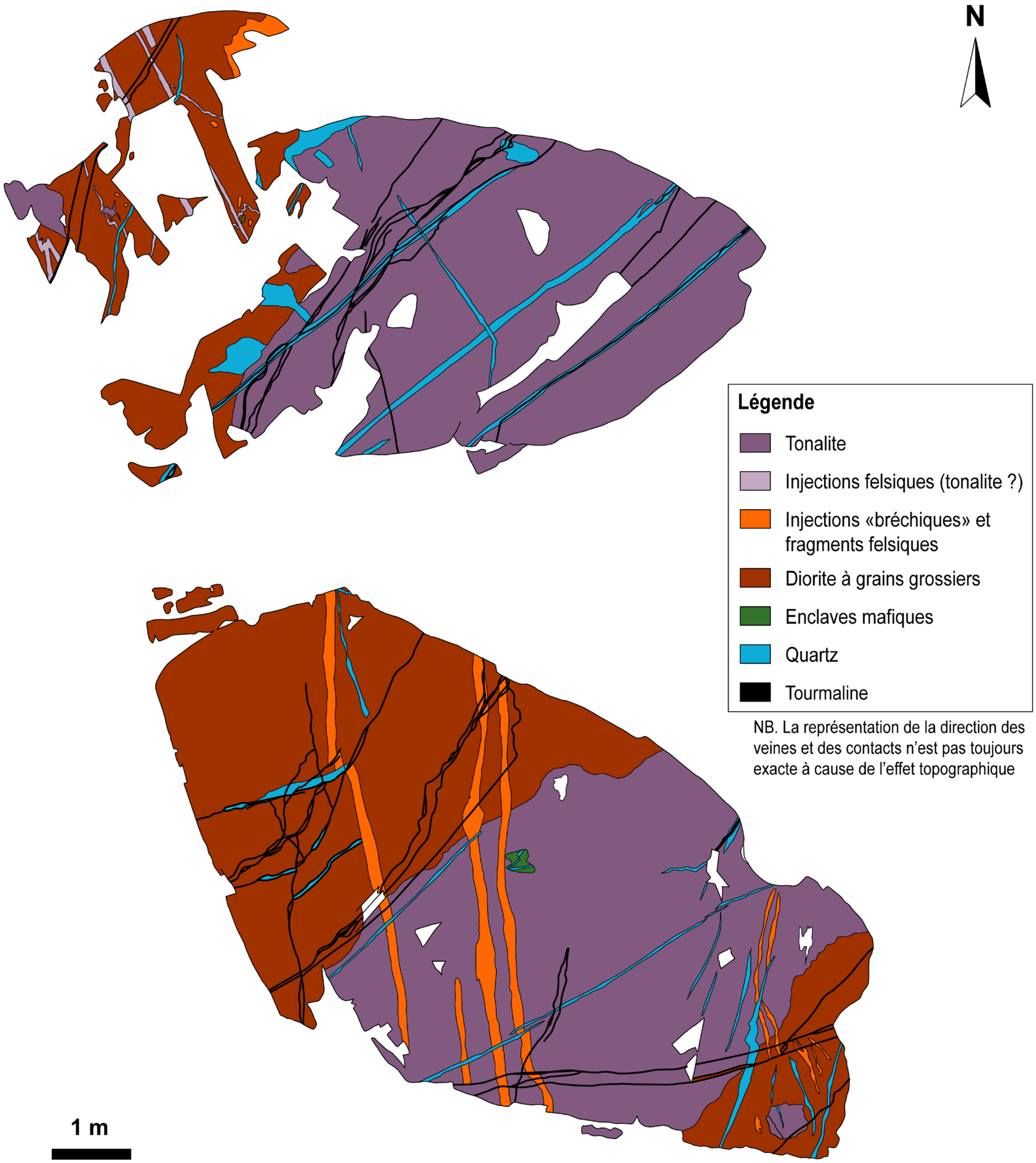

Figure 3. Preliminary mapping of one of the Moly-Desgagné strippings, showing the main lithological units found in the Eau Jaune Complex, as well as the various generations of quartz, quartz-tourmaline and tourmaline veins.