Preliminary Description of the Volcanic-Intrusive Setting of the Duprat–Montbray Formation, Lower Blake River Group, Rouyn-Noranda, Quebec

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INTRODUCTION

Metal Earth is a world-leading geoscience project funded by the Canada First Research Excellence Fund, Laurentian University and partners from academia, government and industry that is managed by the Mineral Exploration Research Centre at the Harquail School of Earth Sciences. The preliminary results presented herein are part of a two-year M.Sc. research project undertaken as part of the Metal Earth initiative and represent new observations from the 2018 field season.

Field work was conducted in the upper part of the ca. 2701 Ma Duprat–Montbray formation (DMF; McNicoll et al., 2014) located 35 km northwest of the central Noranda mining camp (Figure 1). In this area, the DMF is part of the lower Blake River group (BRG) and hosts volcanogenic massive sulphide (VMS) deposits of the same age as more prolific deposits in the central mining camp (e.g., Horne and Quemont Au-rich VMS deposits; McNicoll et al., 2014). The DMF comprises bimodal intermediate and felsic lava flows intruded by synvolcanic plutons and stocks of similar composition. The DMF is in fault contact with the ca. 2702–2696 Ma Renault–Dufresnoy formation (RDF; McNicoll et al., 2014). The fault is an east-trending shear zone known as the Baie Fabie shear zone (BFSZ); its orientation is parallel to synclinal and anticlinal fold axes located to the north and south (Powell et al., 1995). The RDF, on the northern side of the fault, consists of alternating intermediate volcanic flows and volcaniclastic units (Figure 2; Ross et al., 2008).

The DMF is host to the Fabie and Magusi VMS deposits, which produced 0.89 Mt at 2.59 wt. % Cu, 0.90 g/t Au and 20.57 g/t Ag, and 3.73 Mt at 1.2 wt. % Cu, 3.55 wt.% Zn, 1.10 g/t Au and 31.20 g/t Ag, respectively (Gibson and Galley, 2007). The VMS deposits occur stratigraphically above and proximal to the Fabie pluton, a composite synvolcanic intrusion dated at ca. 2700 Ma (McNicoll et al., 2014). Regional bedrock mapping at the 1:5000 scale was conducted around the periphery of the Fabie pluton and more detailed mapping at the 1:2500 scale in an area proximal to the VMS deposits to reconstruct the volcanic stratigraphy and structural setting of the VMS deposits; gain a better understanding of the volcanic–intrusive contact relationships; and identify key outcrops likely to aid in the interpretation of the paleoenvironement in which the DMF was emplaced (i.e., deep versus shallow marine versus subaerial).

GEOLOGICAL SETTING

Volcanic Stratigraphy

The DMF consists of mafic to intermediate massive and pillowed flows that dominate exposures and two main felsic units that are located southeast and northeast of the Fabie pluton; these are referred to as the 'lower' and 'upper' rhyolites (Figure 2; Sutton et al., 2017). The mineralogy, composition, textures and contact relationships were documented for multiple volcanic units.

Basaltic Andesite Volcanic Units

Pillowed basaltic andesite flows with well-preserved spherulites and hyaloclastite constitute the lowermost sequence of the DMF and are located east-southeast of the Fabie pluton (Figure 2). Common characteristics include hyaloclastite within pillow selvages and spherulites along pillow margins (Figure 3a). Amygdules, ranging in size from 0.1 to 5 cm, are filled with quartz and epidote.

From oldest to youngest, the following are observed:

- a basaltic andesite flow with 5–15% amygdules and 10–20% plagioclase phenocrysts;
- an overlying massive and pillowed vesicular basaltic andesite flow that contains 20–40% amygdules and up to 10% fine-grained plagioclase phenocrysts; at the observed lower contact, subangular to subrounded clasts of the underlying basaltic andesite are incorporated in the vesicular basaltic andesite flow (Figure 3b); and
- a porphyritic basaltic andesite flow overlying the vesicular basaltic andesite; the contact is interpreted based on the location of outcrops that host porphyritic flows with minor vesicle content.

The porphyritic basaltic andesites consist of pillowed flows with 20–40% fine- to medium-grained plagioclase phenocrysts and a relatively low concentration of vesicles (10–15%; Figure 3c). The basaltic andesite succession is overlain by a series of andesite units, followed by a pillowed vesicular (>20%) basaltic andesite flow located northwest of the Fabie pluton (Figure 2).

Andesite Volcanic Units

The andesite succession consists of pillowed to massive flows with a variable abundance of plagioclase phenocrysts and amygdules. These flows are texturally indistinguishable from the basaltic andesites but their immobile trace-element geochemistry indicates an andesitic composition. From oldest to youngest the following units are recognized:

- a pillowed porphyritic andesite flow with 20–40% fine- to coarse-grained plagioclase phenocrysts and 10–15% amygdules;
- a distinct pillowed vesicular porphyritic andesite flow with 20–50% plagioclase phenocrysts that often have a glomeroporphyritic texture (Figure 3d) and 20–45% quartz-epidote-carbonate amygdules, which are ~2 mm in diameter and are locally observed to have amalgamated, forming large open cavities up to 10 cm in diameter, with the minerals partially or fully weathered out (Figure 3e);
- a vesicular andesite flow that lacks phenocrysts and contains 20–50% quartz-epidote±chlorite-calcite amygdules (Figure 3f); and
- a bedded volcaniclastic andesite unit consisting of alternating tuff-breccias, lapillistones, and lapilli-tuffs, in turn overlain by a bedded tuff unit 2 m thick that marks a volcanic hiatus at the top of the andesite sequence (Figure 4). The monomictic scoria and pumice clasts contain a high vesicle content of 35–70%, with amygdules ranging in size up to 3 cm, and are filled by quartz and minor epidote. Hyaloclastite is observed where the matrix shows signs of silicification and silica alteration.

Felsic Volcanic Units

The lower rhyolite is massive and flow banded, containing fragments of similar composition (Figure 3g). It is aphanitic and aphyric, but locally contains 3 mm quartz phenocrysts as well as minor to moderate amounts of pyrite associated with pervasive chlorite alteration. Preliminary U-Pb zircon dating of this rhyolite yielded an age of 2700.4 ±1.3 Ma (M. Hamilton, pers. comm., 2018).

The upper rhyolite is a massive, aphanitic, aphyric, rhyolitic flow that is variably spherulitic (Meyers and MacLean, 1983). However, a few quartz-phyric bodies were observed in the lower part of the flow, which contains disseminated and vein-style Py+Ccp mineralization associated with pervasive chlorite-sericite alteration (Figure 3h; Liaghat and MacLean, 1995). The rhyolite has an age of 2701.9 ±0.9 Ma (McNicoll et al., 2014), which is statistically indistinguishable from the age of the underlying lower rhyolite. Small, fine-grained porphyritic rhyolite units and dikes that contain microphenocrysts of quartz and plagioclase were observed in the northwestern part of the area.

Intrusions

The oldest intrusions are the composite Fabie pluton and numerous diorite intrusions, all of which present features suggesting a synvolcanic origin. Late intrusive units include Matachewan diabase and gabbroic dikes that crosscut the volcanic and synvolcanic intrusions (Figure 2).

Fabie Pluton

The oldest intrusion is the 2700.6 ±1.0 Ma synvolcanic Fabie pluton (McNicoll et al., 2014). The pluton has an elliptical shape (~2.2 by ~4.5 km in lateral extension; Figure 2) and comprises a quartz-feldspar porphyritic tonalite with a very fine- to fine-grained groundmass (Figure 5a). Epidote and magnetite are more common in the northeastern part of the intrusion, where they are associated with hydrothermal breccia within the tonalite.

Equigranular diorite and porphyritic quartz diorite xenoliths occur within the intrusion (Figure 5b, c). Fine-grained and subrounded equigranular diorite xenoliths ~1–6 cm in size occur along the southwestern and northeastern edges of the pluton. Porphyritic quartz diorite xenoliths are observed only in the northeastern part of the intrusion, where they occur within a small apophysis of the main intrusion (Figure 2). These xenoliths vary in shape from subangular to angular and range in size from 5 to 30 cm. Their mineralogy consists of medium-grained amphibole and pink feldspar phenocrysts in a light blue, fine-grained, quartz-rich groundmass. The quartz-diorite xenoliths have a higher percentage of pink feldspar than the main tonalite phase. Smaller (~3 cm), rounded andesite xenoliths containing amphibole-filled amygdules ~3 mm in size also occur in the Fabie pluton (Figure 5d).

Diorite Intrusions

Diorite intrusions occur as stocks and dikes. They are fine- to medium-grained and consist mainly of plagioclase (50–70%), lesser quartz (20–30%) and minor amphiboles (5–10%). The diorite stock located northeast of the Fabie pluton (Figure 2) contains a leucocratic plagioclase+quartz pegmatite phase (Figure 5e). The diorite intrusions have sharp, chilled contacts with volcanic units and display variable degrees of quartz-epidote alteration. Locally, the contacts are irregular and some volcanic units host diorite xenoliths, suggesting that at least some of the intrusions are of synvolcanic origin (Figure 5f).

Structural Geology

Multiple younging directions in the DMF are defined by pillow morphology and graded bedding (Figure 2). Strata east of the Fabie pluton young toward the north-northeast (330–360°) and are overturned as they dip steeply toward the south (Meyers and MacLean, 1983). West of the Fabie pluton, bedded tuffs are facing and shallowly dipping toward the west. The regional foliation strikes at 240° and 060°, with a steep dip toward the northwest and southeast, respectively. Stretching lineations, defined by amygdules and phenocrysts, trend at 240–270° and plunge at ~40° toward the west.

Bedding, cleavage orientations and facing directions define an open, steeply inclined, moderately plunging anticline, with a fold axis plunging to the southwest, subparallel to the stretching lineation. The axial plane of the fold is near vertical and subparallel to the regional foliation. The regional cleavage is oriented in a clockwise fashion relative to bedding younging toward the west (Figure 6a), which suggests that most of the map area is located along the northern limb of an anticline with a hinge zone located to the south. The regional foliation is axial planar to a previously mapped anticline in the southeast that could potentially represent the hinge of the same fold (Figure 2).

The BFSZ that marks the contact between the RDF and DMF was not observed in the field. Foliations recorded near the fault strike ~080° with a moderate dip toward the south, which is slightly different to the regional foliation. Mineral stretching lineations have a moderate plunge toward the southeast.

DISCUSSION

The bedded andesitic volcaniclastic rocks west of the Fabie pluton are the first occurrence of andesitic volcaniclastic rocks recognized in the DMF. Fragmentation is attributed to pyroclastic processes and the unit is interpreted to have been emplaced in a shallow marine setting in the same manner as similar units to the north (Ross et al., 2011). The high primary vesicularity of the clasts and the bomb- and cauliflower-like shape of some clasts with aerodynamic tails suggest ballistic emplacement and subsequent redeposition by mass flows (Figures 6b, c). The fine-grained, hyaloclastite-like shards in the matrix are consistent with passive quench and/or explosive hydrovolcanic fragmentation.

Massive andesite flows, located in the southwestern area and next to the Fabie pluton, host amoeboid-shaped andesitic clasts in the upper surface of the flow that are molded to each other and are therefore interpreted as primary volcanic-spatter deposits (Figure 6d). The clasts are subrounded to rounded, with an equant, elongated or amoeboid morphology (Figure 6e). Many of the clasts have a distinct aerodynamic shape and all have chilled margins. The andesite matrix is hyaloclastite and contains plagioclase phenocrysts, which are also observed in the amoeboid clasts.

The porphyritic quartz-diorite xenoliths and tonalite hostrocks seem to be coeval based on their similar textures, mineralogy and contact relationships. The irregular boundaries between the xenoliths and hostrocks suggest that the xenoliths were not completely solidified at the time of their inclusion in the tonalite (Figure 6f).

Comparision with the Renault-Dufresnoy Formation

The RDF consists mainly of alternating intermediate volcanic flows and volcaniclastic units that young toward the south, with bedding steeply to moderately south dipping (Ross et al., 2008). The bottom of the RDF stratigraphy is located further north, where it is in conformable contact with the Hébécourt formation. (Figure 1). This contact is marked by the 2702 ±1.0 Ma Hébécourt rhyolite (McNicoll et al., 2014), which is overlain by volcanic flows of the RDF (Rogers et al., 2014). Volcanic units in the RDF range in composition from basalt to andesite and are characteristically highly vesicular (Ross et al., 2008). The textures and composition of the andesitic volcaniclastic units described by Ross et al. (2008) in the RDF are identical to those mapped in the DMF, which suggests they are identical and that the RDF extends across the BFSZ.

The age of the RDF andesitic flows and volcaniclastic deposits is not known, but the timing of identical andesitic volcanism in the DMF is constrained by the 2700.6 ±1.0 Ma age of the Fabie pluton, which intrudes this volcanic package. Considering the age and the recognition of the continuity of the andesitic volcanic succession across the BFSZ, the movement along this structure is insignificant. The change of younging directions requires the presence of an east–west syncline along or near the BFSZ (Larsson, 1983). In this model, the entire volcanic sequence in the western portion of the RDF would be part of the lower BRG as the northern and southern contacts of the RDF are conformable.

CONCLUSION

The geochronology of the upper and lower rhyolites and the Fabie pluton suggests that volcanic and synvolcanic intrusive activity occurred within a time interval of 0.7 million years at ca. 2701 Ma. Contact relationships between quartz-diorite xenoliths and the Fabie tonalite suggest they were incorporated before becoming totally crystallized. The diorite xenoliths could potentially represent a slightly older phase that is not observed at surface.

The orientation and facing of the DMF strata suggest an open, steeply inclined anticline and indicate as well that the map area is located on the northern limb. Additionally, the andesite flows and volcaniclastic units in the DMF are similar to and continuous with those in the RDF. This implies that the BFSZ does not have a significant offset following DMF/RDF volcanism.

Finally, the andesitic volcanic units that constitute the hanging wall of the Fabie and Magusi VMS deposits continue along the fold and are located west of the Fabie pluton. In proximity to the VMS deposits, the andesitic strata are overturned and dip steeply toward the south, whereas west of the Fabie pluton, the andesitic strata dip shallowly to the west. If the VMS-hosting upper rhyolite footwall is laterally continuous, then the Magusi–Fabie ore interval is located beneath the andesite volcanic package west of the Fabie pluton and in the southern limb. Understanding the fold structure and continuation of the lithological units opens up new terrains for exploration in the DMF.

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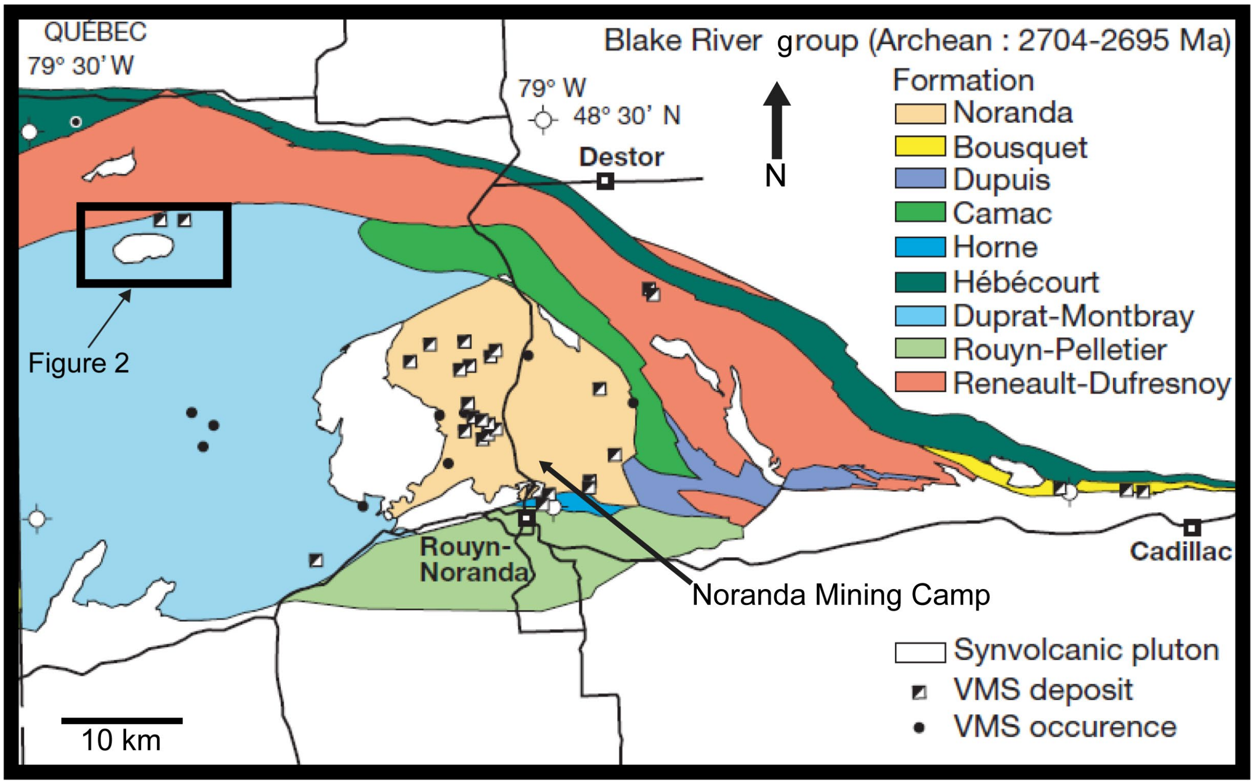

Figure 1. Stratigraphic subdivision of the Blake River group in Quebec. Area outlined in black indicates location of Figure 2. Figure *modified from* McNicoll et al. (2014). Abbreviation: VMS, volcanogenic massive sulphides.

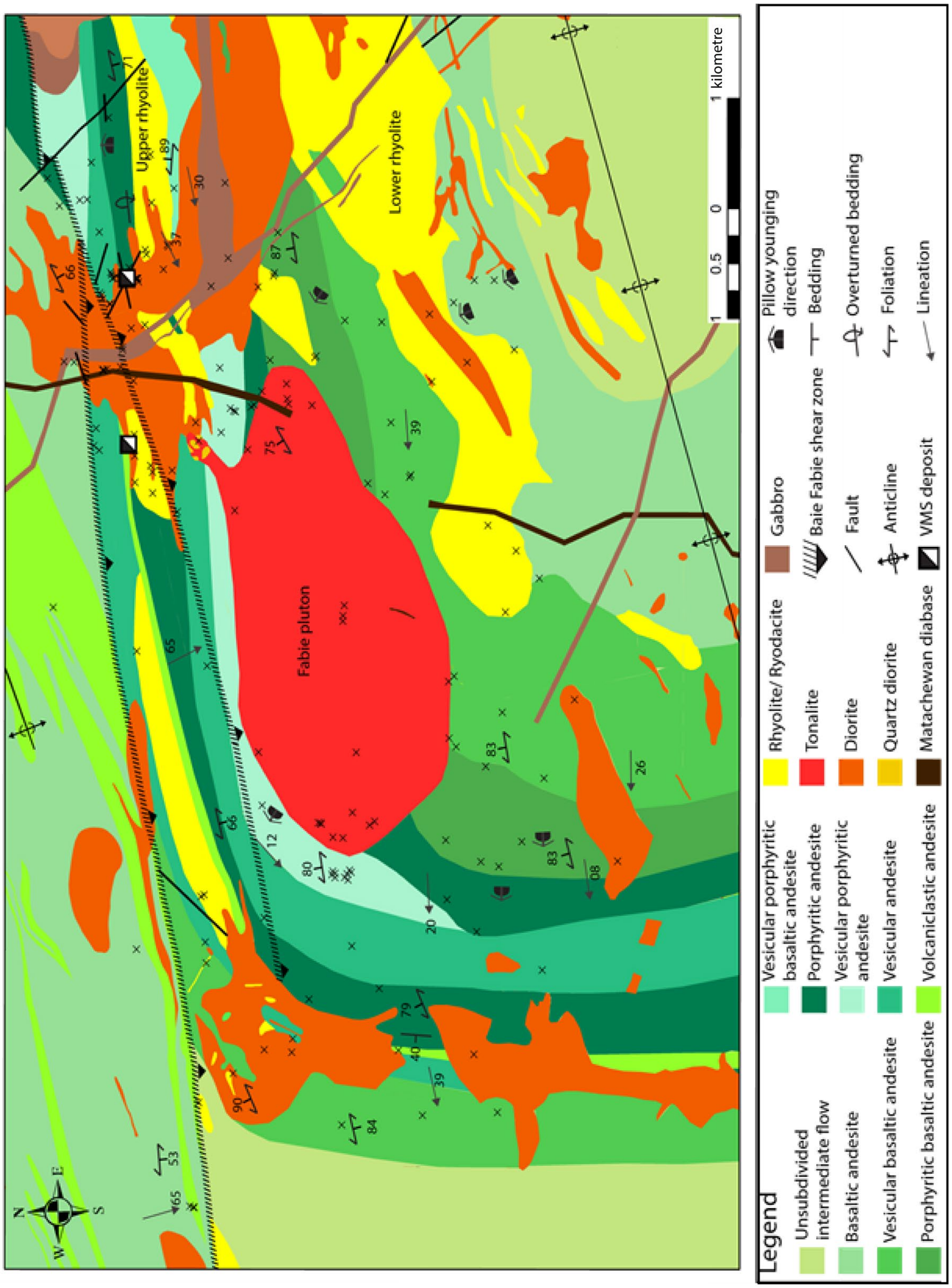

Figure 2. Geology of the Duprat–Montbray (south) and Renault–Dufresnoy (north) formations, and structural measurements taken during the 2017 and 2018 field seasons. Map *modified from* SIGÉOM (2018). Abbreviation: VMS, volcanogenic massive sulphide.

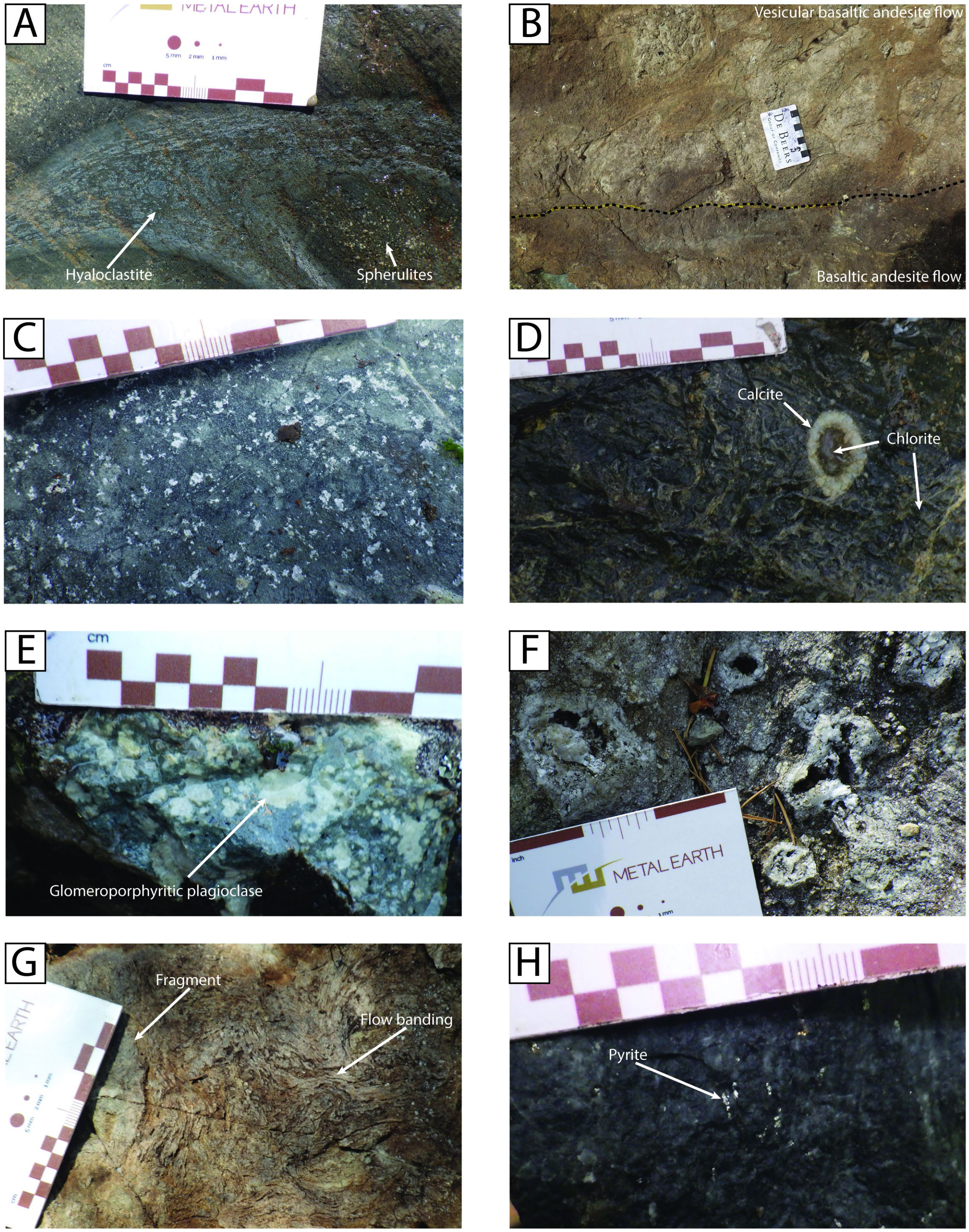

Figure 3. Features observed on volcanic bedrock exposures: **a)** hyaloclastite and spherulites within and along pillow selvages in a basaltic andesite flow; **b)** contact between basaltic andesite and vesicular basaltic andesite flows; clasts are located at the base of the vesicular flow and are similar in composition to the lower basaltic andesite; **c)** plagioclase phenocrysts in a porphyritic basaltic andesite flow; **d)** glomeroporphyritic plagioclase phenocrysts in a vesicular porphyritic andesite flow; **e)** amalgamated segregation amygdules in a vesicular porphyritic andesite flow; **f)** amygdules (0.2-3 cm) with chlorite cores rimmed by calcite in

a vesicular andesite flow; **g)** flow banding and fragments of similar composition in the lower rhyolite flow; **h)** trace amounts of pyrite in the chloritized upper rhyolite.

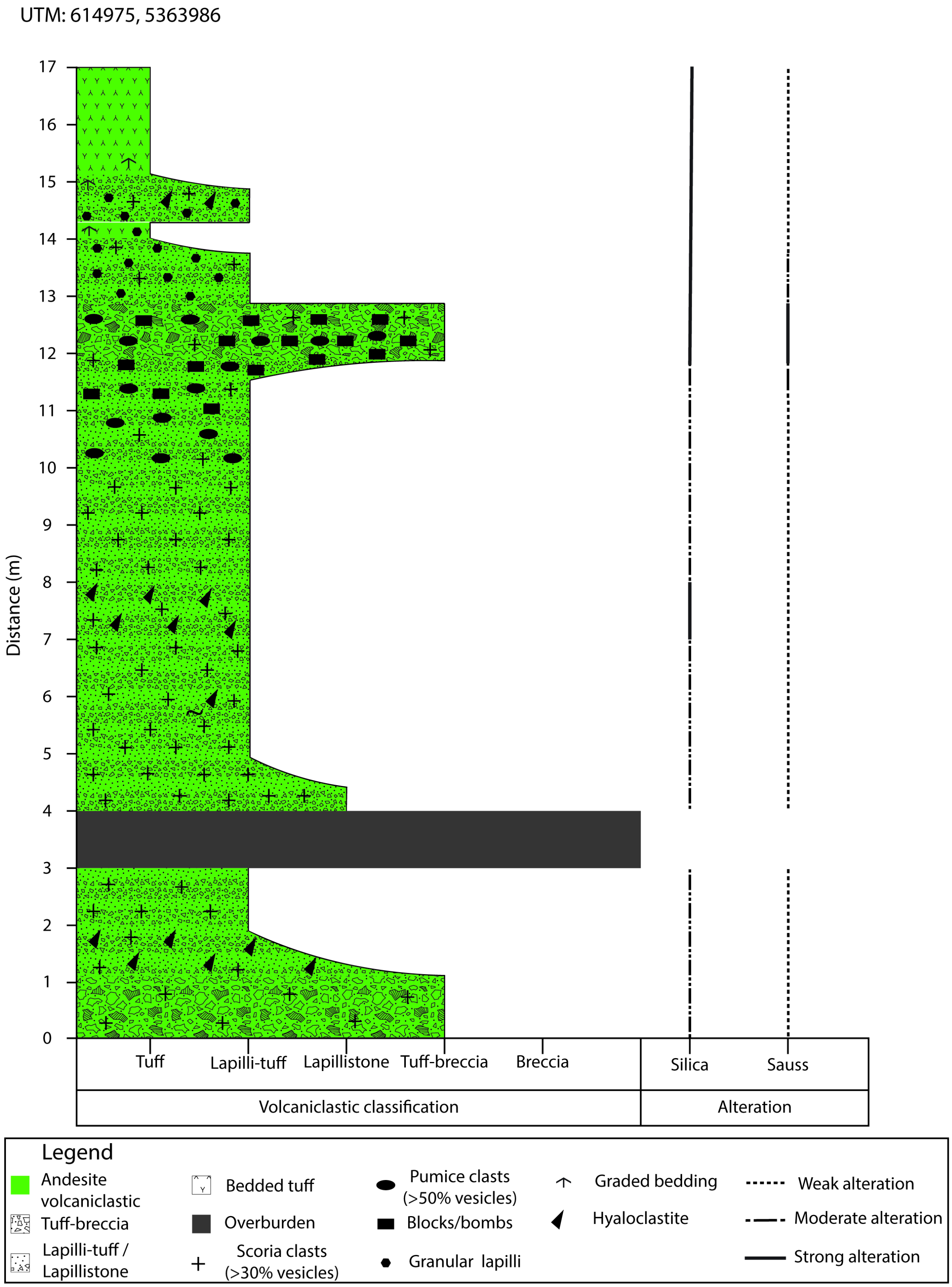

Figure 4. Stratigraphic column for the volcaniclastic andesite sequence of the Duprat–Montbray formation. Volcaniclastic rocks are classified using granulometric subdivisions proposed by Fisher and Schminke (1984). Alteration profile on the right indicates the degree of pervasive alteration and amygdule composition.

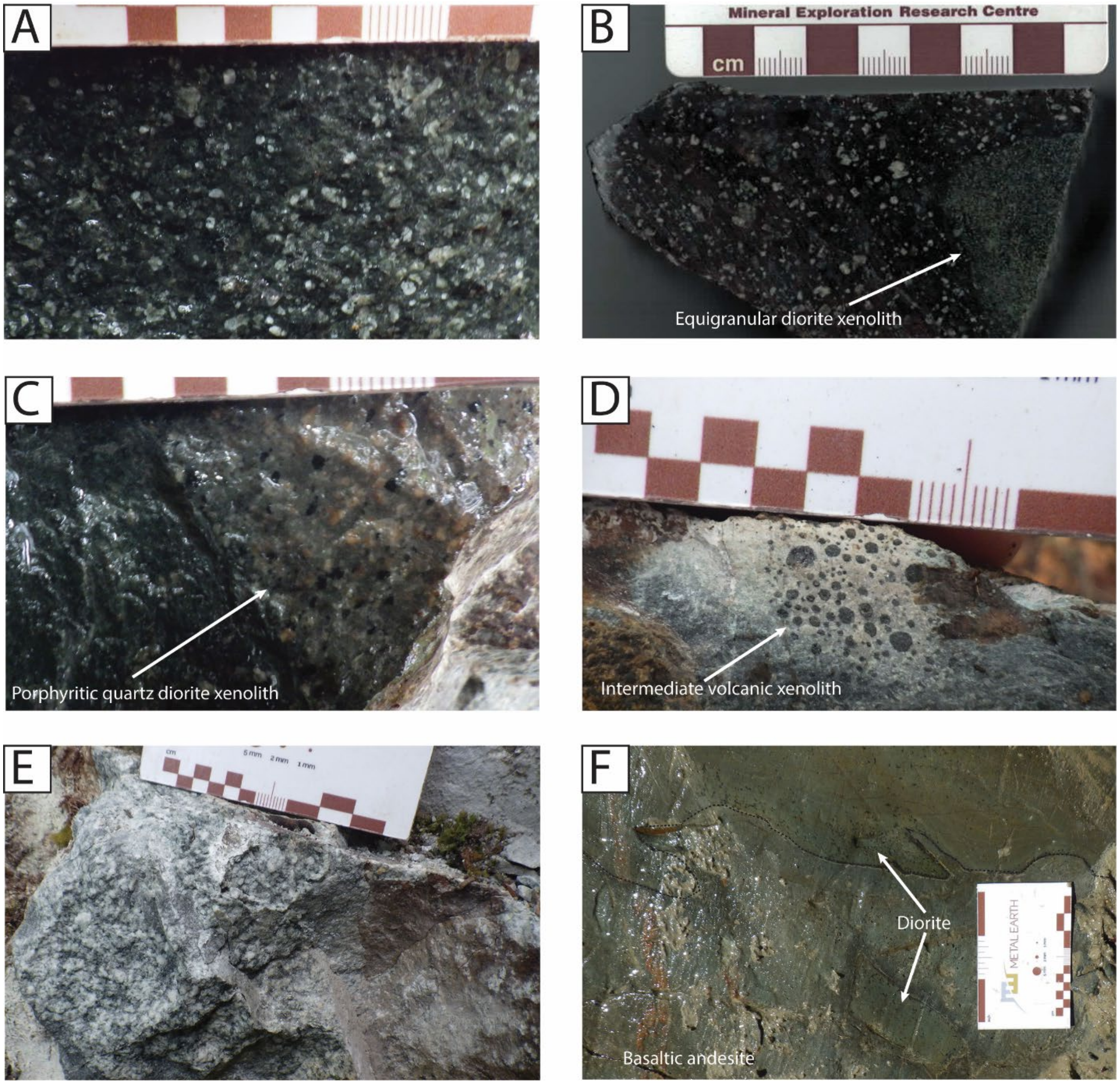

Figure 5. Features of intrusive units in the Duprat–Montbray formation: **a)** quartz-plagioclase phenocrysts in a fine-grained groundmass of similar composition, characteristic of the Fabie porphyritic tonalite; **b)** equigranular, fine-grained diorite xenolith in the Fabie tonalite; **c)** plagioclase and amphibole phenocrysts in a fine-grained groundmass; based on field observations this sample is classified as a quartz diorite and occurs as xenoliths within the Fabie tonalite; **d)** intermediate vesicular volcanic xenolith in the Fabie tonalite; amgydules are filled with amphibole; **e)** leucocratic, pegmatitic phase within a fine-grained diorite; **f)** intrusive contact between a basaltic andesite and a chilled diorite dike; a diorite xenolith is hosted in the basaltic andesite flow.

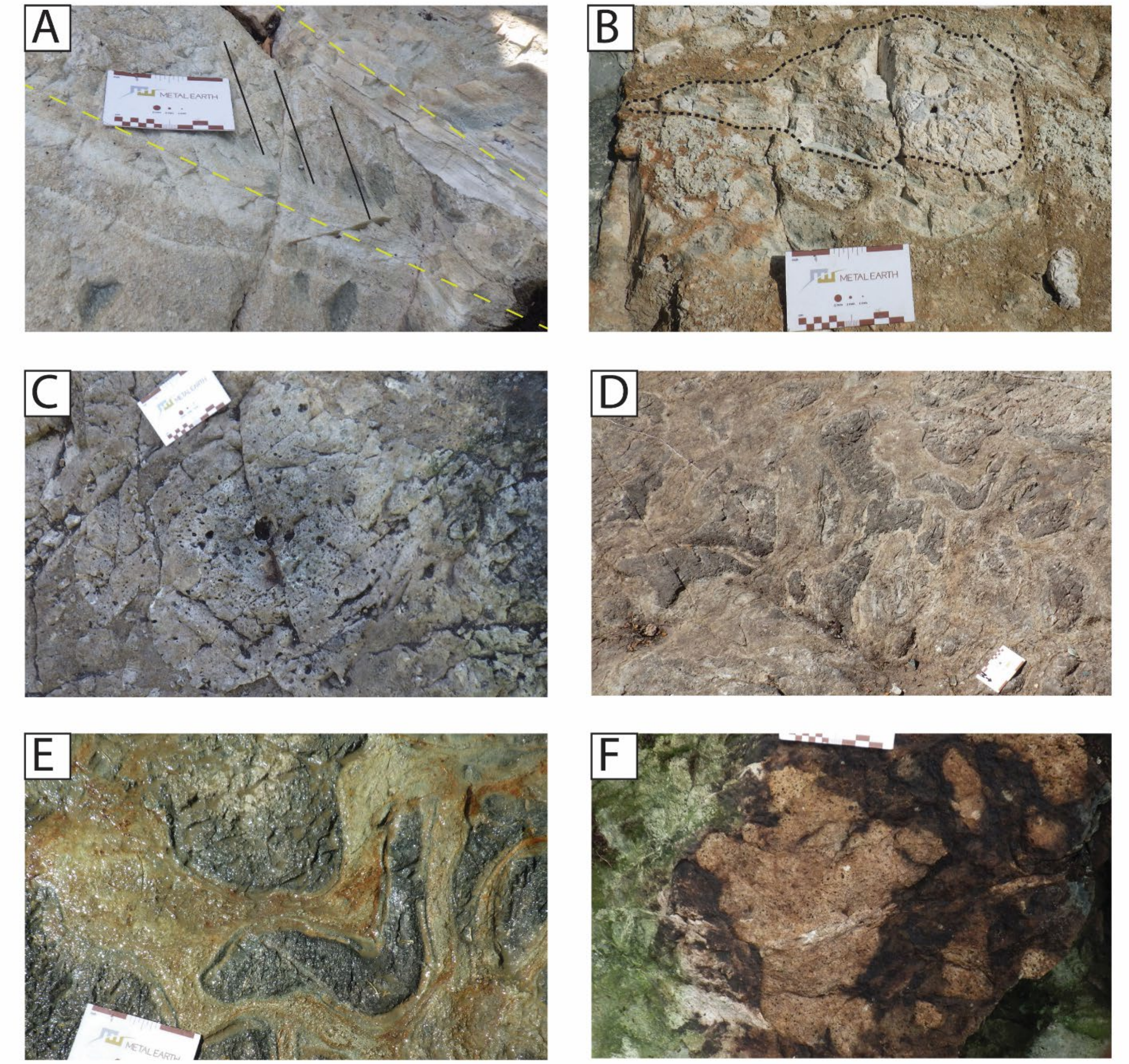

Figure 6. Structures and textures of the Duprat–Montbray formation: **a)** bedded, alternating andesitic lapilli-tuffs and tuff; bedding is striking at 180° (yellow lines), whereas the cleavage is at 240° (black lines), indicating clockwise rotation; **b)** fluidal bomb with a head and tail within the tuff-breccia sequence; **c)** block-sized bomb with a subrounded shape and chilled margins; vesicles are concentrated in the core of the bomb; **d)** amoeboid-shaped fluidal clasts within the flow-top breccia; elongated clasts tend to have a head-tail structure; **e)** elongated amoeboid clasts hosted in a hyaloclastite-rich flow-top breccia of porphyritic basaltic andesite; **f)** subangular porphyritic quartz-diorite xenoliths in the Fabie tonalite.