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2021

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Permanent link: https://doi.org/10.4095/328274

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Recommended citation
Sappin, A.-A., and Perreault, S., 2021. Drill core pictures and description of samples collected from the REE Kwyjibo deposit (SOQUEM warehouse, Val d'Or, Quebec—October 2015); Geological Survey of Canada, Open File 8794, 14 p. https://doi.org/10.4095/328274

Publications in this series have not been edited; they are released as submitted by the author.

1- Introduction

The Kwyjibo property, located in the northeastern part of the Grenville Province, hosts iron oxide-copper-gold (IOCG) mineralization (Perry and Raymond, 1996) and the Josette rare earth element (REE) iron oxide-apatite (IOA) deposit (Perreault, 2015). The property comprises several Mesoproterozoic Fe-Cu-REE-(Au) mineralized zones (e.g., Gabriel, Gabruge, Andradite, Fluorine, Malachite, and Josette), occurring semi-continuously over a ~4 km-long NE-SW strike length area (Fig. 1). In the years following the discovery of the Kwyjibo mineralization, the main mineralized zones, especially the Josette horizon, have been extensively diamond drilled (Fig. 1), culminating in the current resources calculations of 6.92 Mt at 2.72% total rare earth oxide (TREO) and 53% Fe_2O_3 (measured + indicated) and 1.33 Mt at 3.64% TREO and 48% Fe_2O_3 (inferred; Gagnon et al., 2018). As part of a research project in collaboration with the Université Laval (Québec) and the Ministère de l'Énergie et des Ressources naturelles du Québec (MERN), aiming to characterize the Sm-Nd isotopic signatures of the main REE deposits of the Quebec Province, a visit was carried out in 2015 at the Soquem's warehouse in Val d'Or (Quebec) to collect some drill core samples from the main areas with high-grade REE mineralization of the Kwyjibo property.

This report under the TGI-6 sub-activity "Mineral systems with IOCG and affiliated critical metal deposits" document the context of the representative samples collected from four boreholes, which intersected the Josette deposit and the Fluorine prospect of the Kwyjibo property, as well as the drill core pictures of the main rock types and the field relationships between each of the units. The geological context is of high importance as IOA deposits that form within iron oxide and alkali-calcic mineral systems can have heavy REE/light REE ratios significantly greater than those of IOCG deposits (Corriveau et al., 2016). The development of their high-grade REE mineralization is conditional to significant remobilization of the primary REE endowment of the host IOA deposit through renewed fluid circulation related to subsequent alteration facies in the most mineral system development or to subsequent intrusive or orogenic activities as observed at the Josette deposit (Perreault, 2015) and in the Pea Ridge deposit of the Southeast Missouri district (Harlov et al., 2016; Corriveau et al., in press a, b).

2- Regional and local geology

Studies by Gauthier et al. (2004), Clark et al. (2005, 2010), Magrina et al. (2005), Perreault (2015), Perreault and Lafrance (2015), and Gagnon et al. (2018) described in detail the geology of the Kwyjibo property. In the following paragraphs, we outline the most relevant features of the regional and local geology. Readers are referred to these past publications for additional information and to Gobeil et al. (2003) and Corriveau et al. (2007, 2010) for the regional framework of the Grenville Province context for the property.

The Kwyjibo property occurs along the southeast margin of the Canatiche Complex, near the contact with the supracrustal rocks of the Manitou Complex (Fig. 1). The Canatiche Complex (1181-1165 Ma: Clark et al., 2005; David, 2014, unpublished data, see Perreault and Lafrance, 2015) contains mainly granitic rocks (Figs. 2A-2B) and hosts most of the mineralized zones of the Kwyjibo deposit, as well as some dikes of gabbro (Figs. 2C-2F) and pegmatite (Perreault and Lafrance, 2015). All these units were metamorphosed to amphibolite facies (Perreault and Lafrance, 2015). Nevertheless, metasomatic textures and iron oxide breccia of the mineralized system as well as potential fragmental volcanic host rocks are locally very well preserved (Clark et al., 2010; Jébrak, 2010; Perreault, 2015). Both the Canatiche and Manitou complexes, and at least one iron-oxide breccia, were intruded by a dike swarm with diagnostic mafic-felsic magma mingling textures at 1.17 Ga, then affected by thrusting related to the Ottawan phase of the Grenville Orogeny (Gobeil et al., 2003; Wodicka et al., 2003; Clark et al., 2005, 2010) and subsequently injected by late-orogenic granite and pegmatite including little recrystallized mafic-felsic dyke swarm with magma mingling textures (Figs. 5F, 6A-6B) associated with the Rigolet phase of the Grenville Orogeny (Gauthier et al., 2004; Clark et al., 2005; Corriveau et al., 2007, 2010). Intrusive relationships place the development of the metasomatic system at 1.17 Ga, nearly coevally with the intrusive rocks of the Canatiche complex, while remobilization is extensive and leads to the most mineralized veins (e.g., Clark et al., 2010; Corriveau et al., 2010).

The mineralized zones of the Kwyjibo property occur in three en-echelon zones that are concordant with the local structural grain (Perry and Roy, 1997). They include: 1) massive magnetitite and brecciated magnetitite (1-30 m thick); 2) magnetite-rich breccias and pseudobreccias; 3) stockworks of magnetite and calcsilicate veins; and/or 4) networks of anastomosing, centimeter- to decimeter-scale magnetite veins and veinlets, commonly containing apatite and allanite-bearing calcsilicate veins, cross-cutting the leucogranite (Perreault and Lafrance, 2015).

The formation of the mineralization involves at least two main stages: 1) an extensive alteration with albitization, massive zones of hydrothermal iron-oxide replacement (namely the hydrothermal iron formation of Perreault (2015)), foliated biotite-hornblende zones with gneissic textures, and many other metasomatites, with one iron oxide breccia cut by the 1.17 Ga dyke swarm and numerous features implying potential syntectonic hydrothermal activity during the shortening related to the Grenville orogeny and 2) the remobilization and deposition of REE and Fe-Cu sulphide minerals during the later extensional stages (Gauthier et al., 2004; Clark et al., 2005, 2010). Among the different mineralized zones of the Kwyjibo property, the Josette deposit shows the highest grade in REE and Cu. The REE enrichment of this mineralized zone appears to be late Grenvillian (983-972 Ma: Gauthier et al., 2004; David, 2014, unpublished data, see Perreault and Lafrance, 2015). Such remobilization is typical of metasomatic iron oxide and alkali calcic mineral systems with IOCG and REE-endowed IOA deposits (Corriveau et al., 2010, in press a, b).

The Josette REE-Fe±Cu deposit contains massive and brecciated magnetitite, breccias and stockworks of magnetite, and calcsilicate veins hosted by a gneissic leucogranite, which are all the host rocks of the REE and Cu mineralization (Perreault and Lafrance, 2015). Three main zones are recognized in the Josette horizon (Perreault, 2015; Perreault and Lafrance, 2015): 1) the upper breccia zone (1–10 m thick) composed of magnetite veins and fluorite veinlets, with commonly very low grades in REE; 2) the magnetitite zone (1 m to >40 m thick; Figs. 3, 4A–4C, 5A-5E), an hydrothermal 'iron formation' with magnetitite, stockworks of magnetite, REE-bearing calcsilicate veins, and high grade in REE, Cu, P, and F; and 3) the lower breccia zone (1 m to >40 m thick; Figs. 4D–4F, 6C–6F) composed of magnetite veins and boudins and late REE-bearing calcsilicate stockworks and veins, with variable grades in REE. In the Josette deposit, the main REE-bearing minerals are allanite, apatite, britholite, and kainosite (Perreault and Lafrance, 2015). The best REE mineralized intervals are located in the northeastern part of the Josette horizon with, for example, an weighted average interval of 2.12% TREO over 60 m, including 12% TREO over 3 m, in the deeper lower breccia zone (Fig. 7, Perreault and Lafrance, 2015).

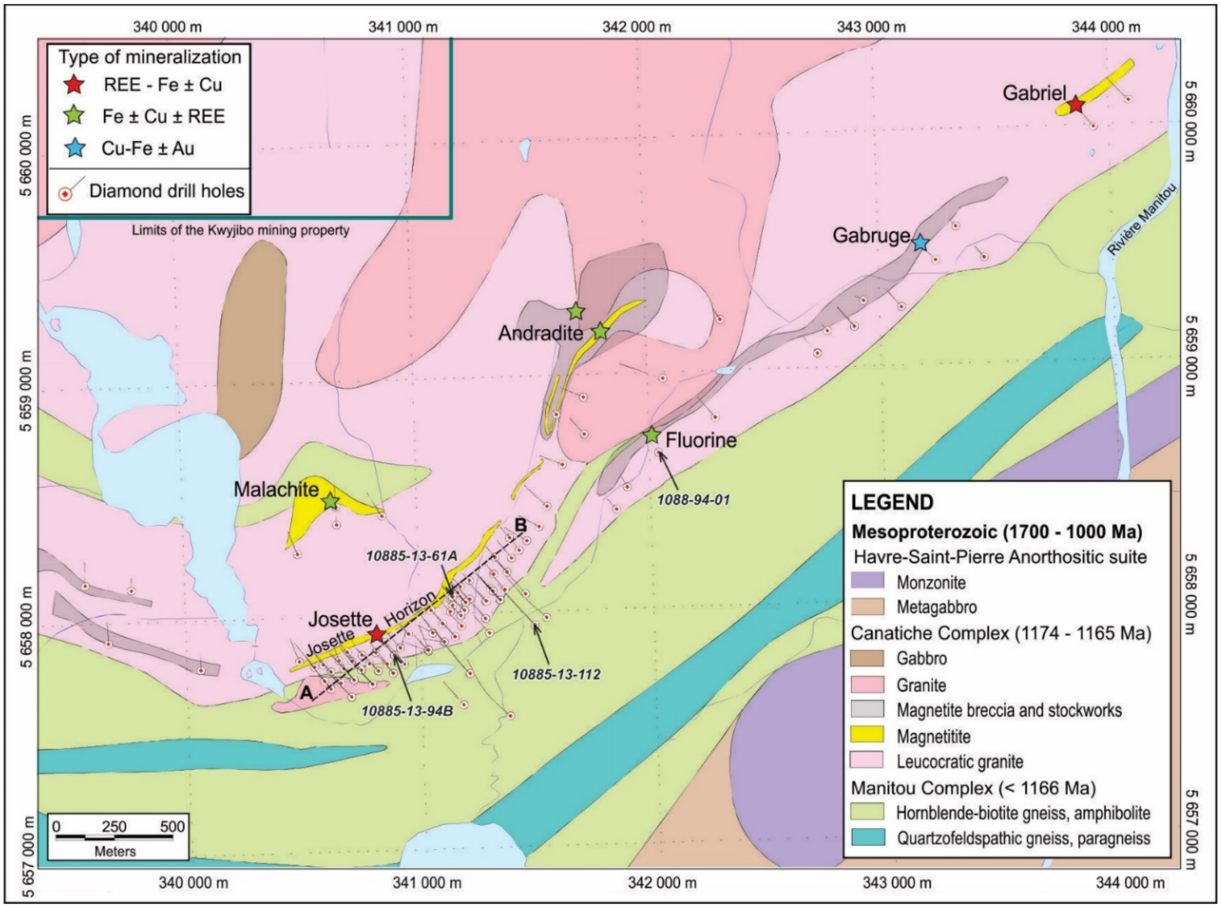

Figure 1. Geological map of the Kwyjibo deposit showing the locations of the main mineralized zones and the diamond drill holes (modified after Perreault and Lafrance, 2015). Coordinates in UTM NAD83, Zone 20.

The Fluorine Fe±Cu±REE mineralized zone consists of a layer of massive magnetitite and banded calcsilicate rocks (Fig. 8) with fluorite (up to 30%; Gauthier et al., 2004), apatite (up to 60%; Clark et al., 2005), andradite, pyrite, and locally chalcopyrite (Perreault, 2015). Mineralization precipitated near the contacts between quartzofeldspathic gneiss and calcsilicate rocks or hornblende-biotite gneiss, some of which were interpreted as metamorphosed hydrothermal alteration zones (Perreault, 2015) in line with what is to be expected of deformed high-temperature Na-Ca-Fe (amphibole-albite) with K-feldspar overprints such as those modeled in Corriveau et al. (2018) and of high-temperature Ca-K-Fe biotite-amphibole alteration such as those of the Au-Co-Bi-Cu NICO deposit (Corriveau, pers. comm, 2021). Like the Josette mineralized zone, the fluorine zone shows a high concentration in REE, Y, U, Th, and P (Gauthier et al., 2004; Clark et al., 2005, 2010). However, the Fluorine prospect differs from other mineralized zones of the Kwyjibo property by its high concentration in apatite and fluorite (Figs. 8D-8E) and its relatively low magnetite content (<25%; Clark et al., 2005).

3- Sample description

Nearly one hundred and fifty diamond-drill holes (DDHs) have been drilled on the Kwyjibo property by Soquem Inc. between 1994 and 2013. The present report focuses only on four of these

DDHs. Three DDHs drilled in 2013 intersected the northeastern part (10885-13-112 and 10885-13-61A) and the southwestern part (10885-13-94B) of the Josette deposit (Fig. 1). One DDH drilled in 1994 intersected the Fluorine mineralized zone (1088-94-01; Fig. 1). Nine representative samples were selected from the 10885-13-61A DDH, five from the 10885-13-94B DDH, and one from the 1088-94-01 DDH for future petrographic and mineralogical works (Table 1).

Table 1. Location of the representative samples collected from the Josette deposit and the Fluorine prospect of the Kwyjibo property

Sample ID	Drill hole ID	Depth (m)		Collar		Elevation (m)	Azimuth	Dip	Length (m)
		From	To	UTM East (m)	UTM North (m)				
10885-13-61A-4.7	10885-13-61A	4.70	4.90	341142	5658071	475	318°	-45°	90
10885-13-61A-7.5	10885-13-61A	7.50	7.60	341142	5658071	475	318°	-45°	90
10885-13-61A-33.25	10885-13-61A	33.25	33.37	341142	5658071	475	318°	-45°	90
10885-13-61A-42.88	10885-13-61A	42.88	43.05	341142	5658071	475	318°	-45°	90
10885-13-61A-51.8	10885-13-61A	51.80	51.95	341142	5658071	475	318°	-45°	90
10885-13-61A-58.65A	10885-13-61A	58.65	58.80	341142	5658071	475	318°	-45°	90
10885-13-61A-58.65B	10885-13-61A	58.65	58.80	341142	5658071	475	318°	-45°	90
10885-13-61A-60.75	10885-13-61A	60.75	60.95	341142	5658071	475	318°	-45°	90
10885-13-61A-71.85	10885-13-61A	71.85	72.00	341142	5658071	475	318°	-45°	90
10885-13-94B-80.65A	10885-13-94B	80.65	80.75	340887	5657830	469	320°	-52°	114
10885-13-94B-80.65B	10885-13-94B	80.65	80.75	340887	5657830	469	320°	-52°	114
10885-13-94B-87.00	10885-13-94B	87.00	87.25	340887	5657830	469	320°	-52°	114
10885-13-94B-97.55A	10885-13-94B	97.55		340887	5657830	469	320°	-52°	114
10885-13-94B-97.55B	10885-13-94B	97.55		340887	5657830	469	320°	-52°	114
1088-94-01-37.08	1088-94-01	37.08		342049	5658705	335	320°	-50°	93.57

Table 1. Location of the representative samples collected from the Josette deposit and the Fluorine prospect of the Kwyjibo property (continued)

Sample ID	Location	Sample type	Lithology
10885-13-61A-4.7	Josette NE area	Drill core	Leucocratic granite
10885-13-61A-7.5	Josette NE area	Drill core	Gabbroic dike
10885-13-61A-33.25	Josette NE area	Drill core	Massive magnetite with apatite, britholite, and fluorite veins. Second-generation magnetite
10885-13-61A-42.88	Josette NE area	Drill core	Massive magnetite with apatite and britholite veins. First-generation magnetite.
10885-13-61A-51.8	Josette NE area	Drill core	Massive magnetite with andradite and britholite grains. Second-generation magnetite.
10885-13-61A-58.65A	Josette NE area	Drill core	Breccia with calcsilicate veins including andradite and fluorite
10885-13-61A-58.65B	Josette NE area	Drill core	Breccia with calcsilicate veins including andradite
10885-13-61A-60.75	Josette NE area	Drill core	Gabbroic dike
10885-13-61A-71.85	Josette NE area	Drill core	Leucocratic granite
10885-13-94B-80.65A	Josette SW area	Drill core	Massive magnetite with andradite and apatite grains First-generation magnetite.
10885-13-94B-80.65B	Josette SW area	Drill core	Massive magnetite with andradite, apatite, and pyrite grains First-generation magnetite.
10885-13-94B-87.00	Josette SW area	Drill core	Pegmatite dike
10885-13-94B-97.55A	Josette SW area	Drill core	Calcsilicate veins including apatite ± britholite, fluorite, and pyrite
10885-13-94B-97.55B	Josette SW area	Drill core	Calcsilicate veins including apatite ± britholite
1088-94-01-37.08	Fluorine mineralized zone	Drill core	Calcsilicate rocks including apatite, fluorite, and pyrite

Note: All the coordinates are in UTM NAD83, Zone 20.

4- Drill core pictures

In this section, we present a selection of pictures of the main units identified in the Josette deposit and the Fluorine prospect and some field relationships between the different rock types (Figs. 2–8).

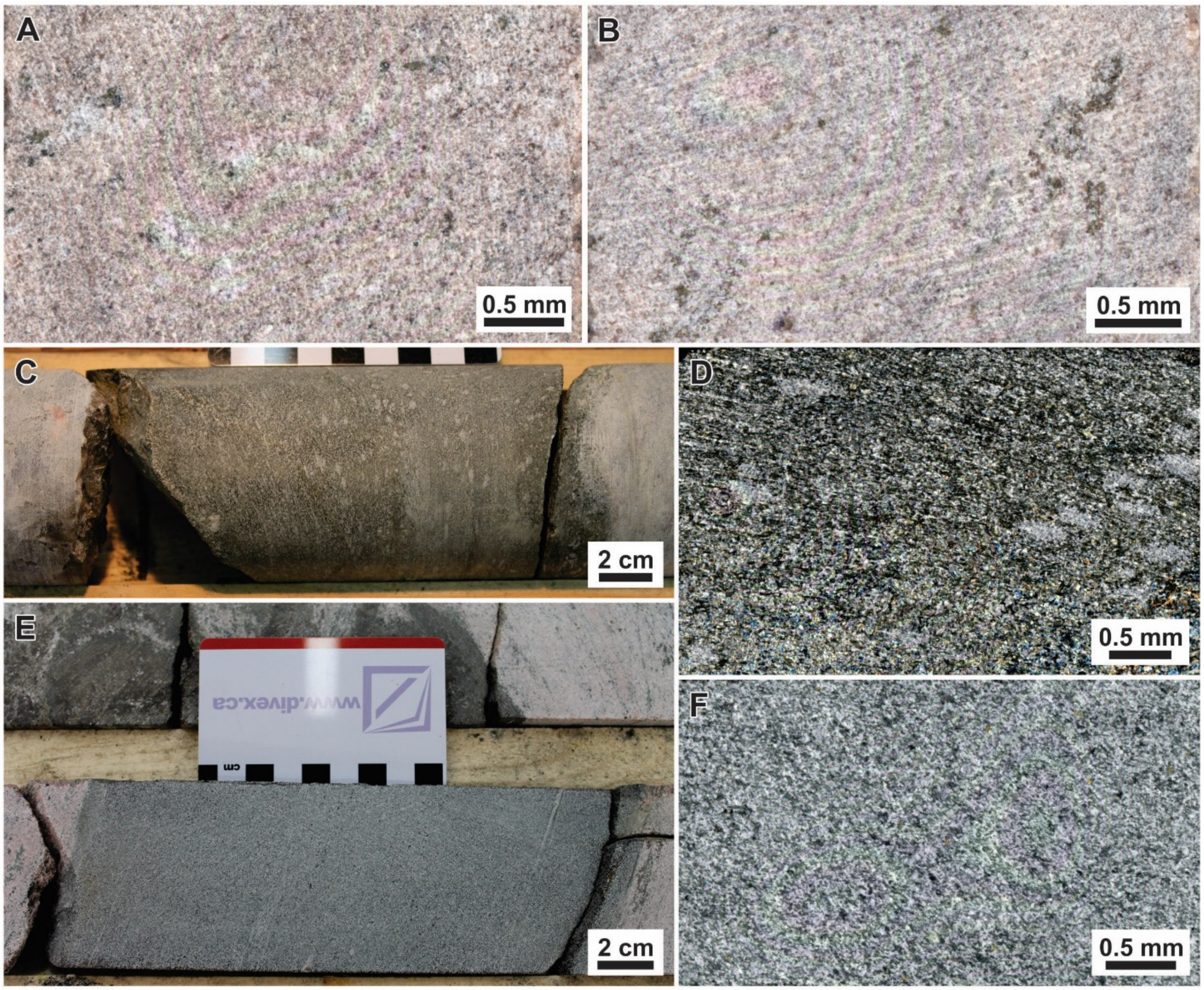

Figure 2: Photographs of the host rocks of the Josette mineralized zone and a few gabbroic dikes in the northeastern part of the Josette area. A) Leucocratic granite of the Canatiche complex located above the mineralized zone (10885-13-61A/4.70-4.90 m). NRCan photo 2021-077. B) Leucocratic granite of the Canatiche complex located below the mineralized zone (10885-13-61A/71.85-72.00 m). NRCan photo 2021-078. C) to F) Gabbroic dikes cross-cutting the leucocratic granite of the Canatiche complex (10885-13-61A/7.50-7.60 m in (C) and (D) and 10885-13-61A/60.75-60.95 in (E) and (F)). NRCan photos 2021-079 to 2021-082. All photographs by A.-A. Sappin.

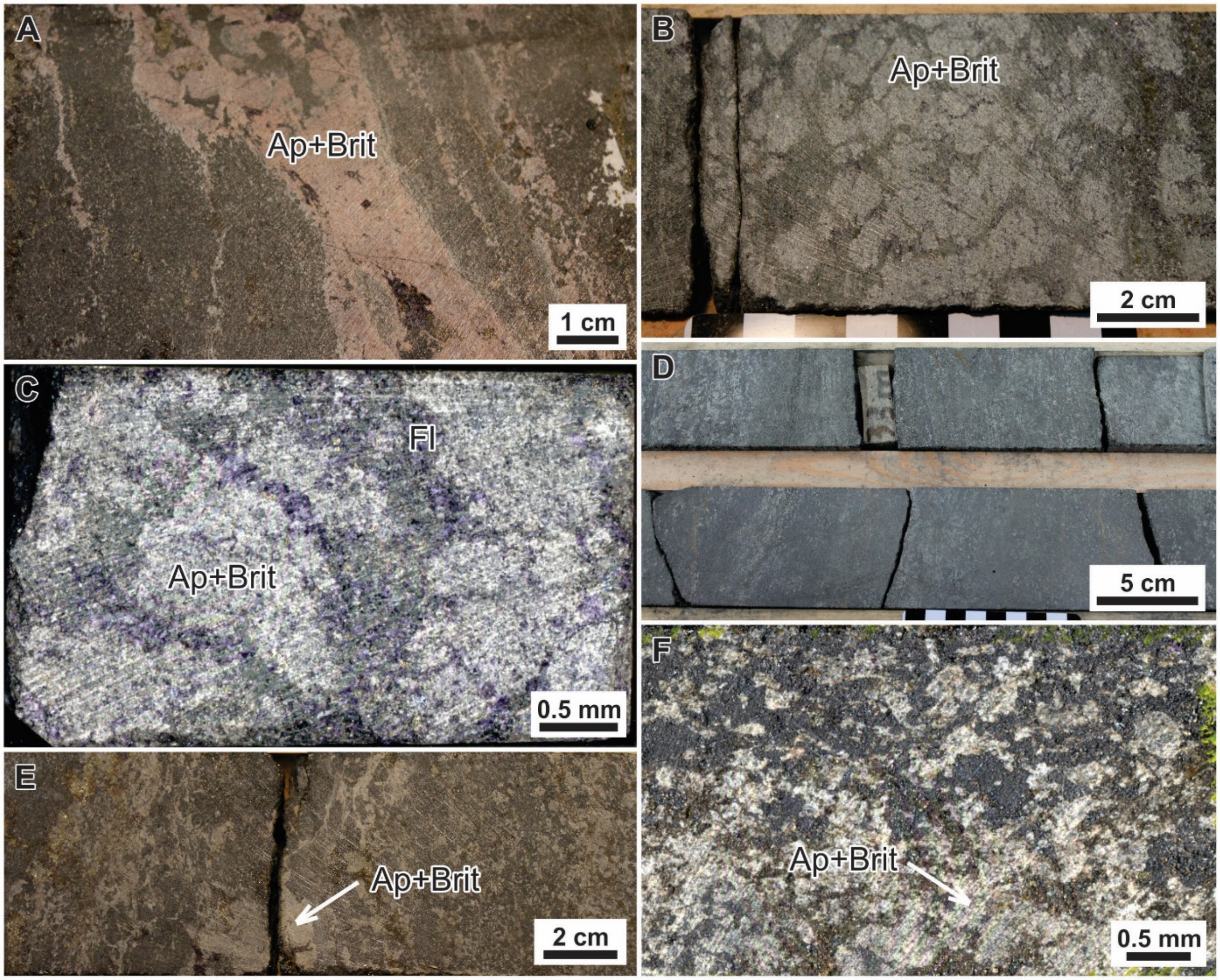

Figure 3: Photographs of samples from the magnetitite zone of the Josette REE-Fe±Cu mineralized zone, in the northeastern part of the Josette area. A) Massive magnetite brecciated by apatite (Ap) and britholite (Brit) veins. First-generation fine-grained magnetite (10885-13-61A/4.35-4.45 m). NRCan photo 2021-083. B) and C) Massive magnetite brecciated by apatite, britholite, and fluorite (Fl) veins. Second-generation magnetite with coarser grains (10885-13-61A/33.25-33.37 m). NRCan photos 2021-084 to 2021-085. D) Massive magnetite. First-generation fine-grained magnetite (10885-13-61A/~34.00 m). NRCan photo 2021-086. E) and F) Massive magnetite brecciated by apatite and britholite veins. First-generation fine-grained magnetite (10885-13-61A/42.88-43.05 m). NRCan photos 2021-087 to 2021-088. All photographs by A.-A. Sappin.

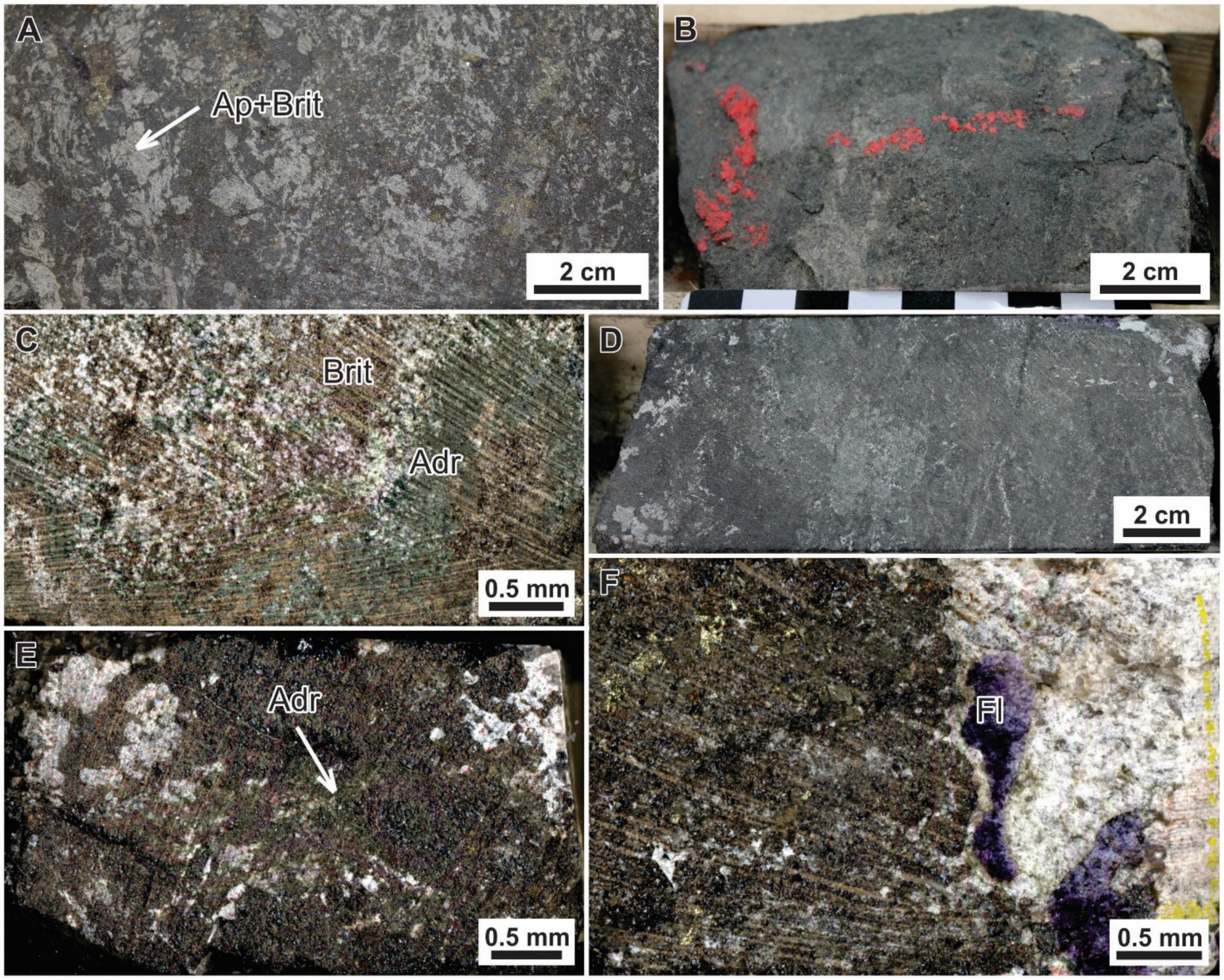

Figure 4: Photographs of samples from the Josette REE-Fe±Cu mineralized zone in the northeastern part of the Josette area. A) Massive magnetite brecciated by apatite (Ap) and britholite (Brit) veins in the magnetitite zone. Second-generation magnetite with coarser grains (10885-13-61A/~43.00 m). NRCan photo 2021-089. B) and C) Massive magnetite with andradite (Adr) and britholite grains in the magnetitite zone. Second-generation magnetite with coarser grains (10885-13-61A/51.80-51.95 m). NRCan photos 2021-090 to 2021-091. D) to F) Breccia with calcsilicate veins, including andradite and fluorite (Fl), in the lower breccia zone (10885-13-61A/58.65-58.80 m). NRCan photos 2021-092 to 2021-094. All photographs by A.-A. Sappin.

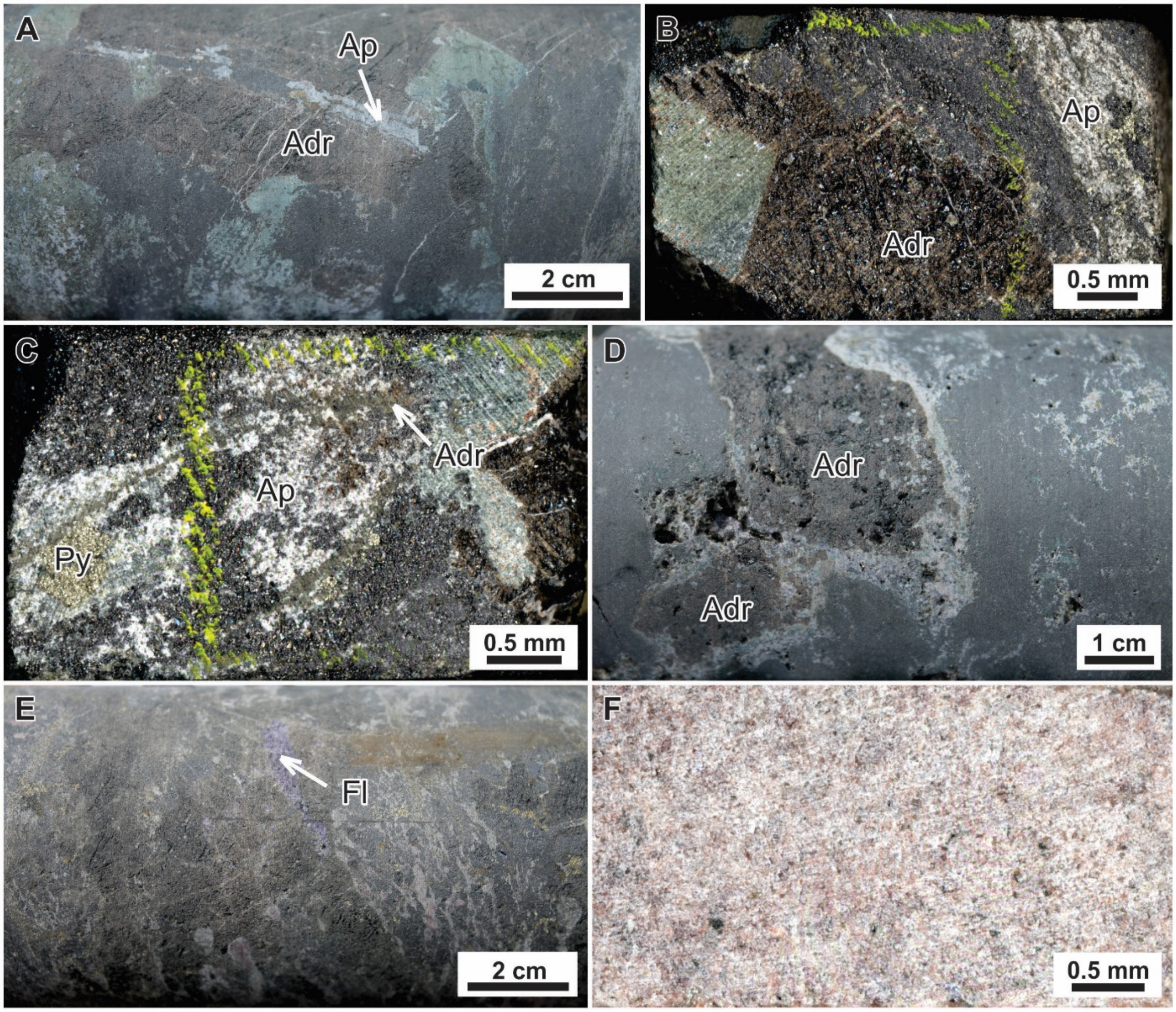

Figure 5: Photographs of the different rock types located down-dip of the Josette horizon in the southwestern part of the Josette area. A) to C) Massive magnetite with andradite (Adr), apatite (Ap), and locally pyrite (Py) grains in the magnetitite zone. First-generation fine-grained magnetite (10885-13-94B/80.65-80.75 m). NRCan photos 2021-095 to 2021-097. D) Andradite grains in a matrix of first-generation fine-grained magnetite in the magnetitite zone (10885-13-94B/~80.00 m). NRCan photo 2021-098. E) Fluorite (Fl) grain in a matrix of first-generation fine-grained magnetite in the magnetitite zone (10885-13-94B/~90.60 m). NRCan photo 2021-099. F) Pegmatite dike, dated at 947±4 Ma (U-Pb age on zircon, see reference in Perreault and Lafrance, 2015), cross-cutting the mineralized rocks (10885-13-94B/87.00-87.25 m). NRCan photo 2021-100. All photographs by A.-A. Sappin.

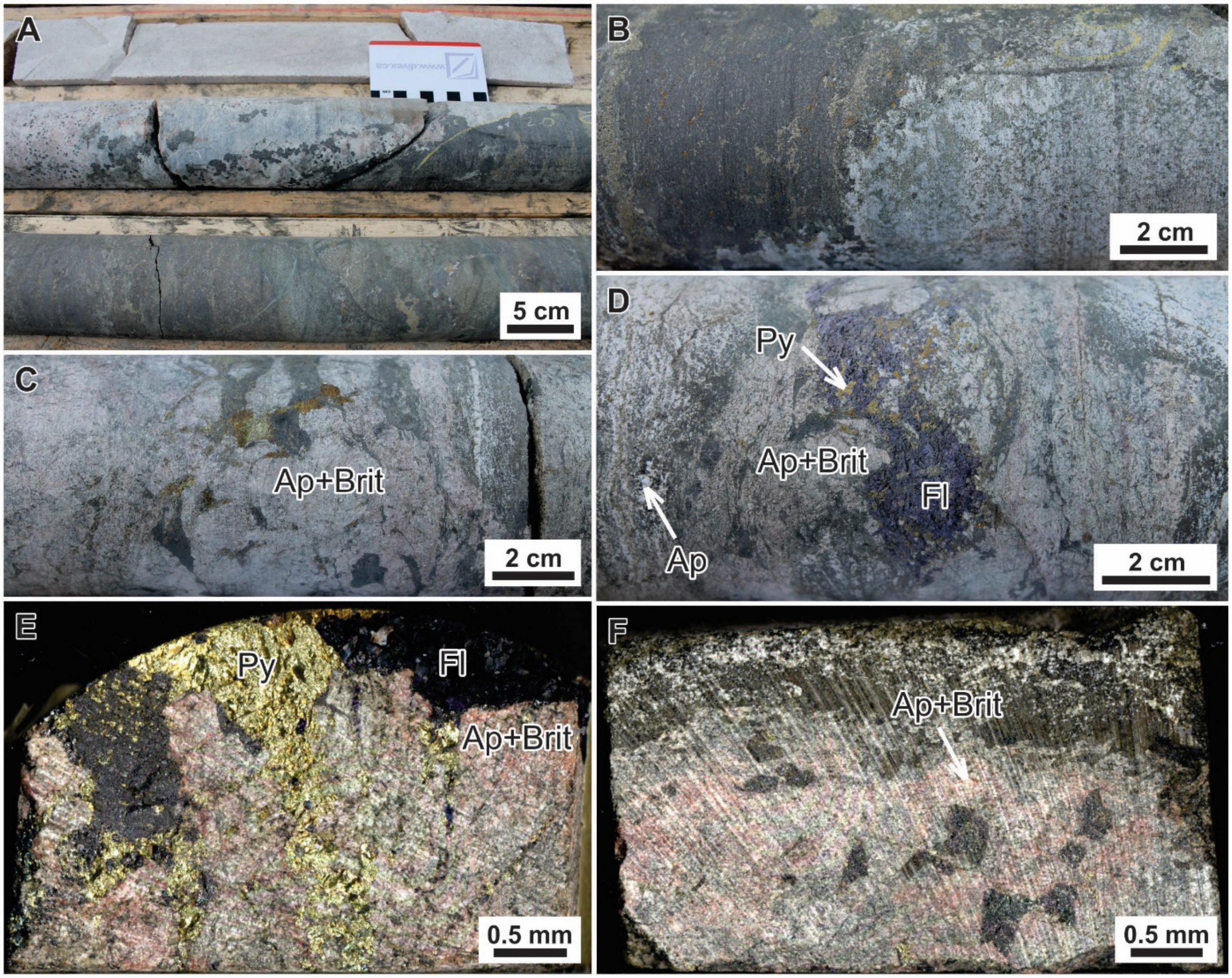

Figure 6: Photographs of the different rock types located down-dip of the Josette horizon in the southwestern part of the Josette area. A) Sharp lower contact zone with secondary-generation coarse-grained magnetite between the pegmatite dike and the mineralized rocks (10885-13-94B/88.15 m). NRCan photo 2021-101. B) Diffuse upper contact zone with secondary-generation coarse-grained magnetite between the pegmatite dike and the mineralized rocks (10885-13-94B/81.40 m). NRCan photo 2021-102. C) to F) Calcsilicate vein with apatite (Ap) ± britholite (Brit), fluorite (Fl), and pyrite (Py), injected into the granitic rocks of the Canatiche complex, in the lower breccia zone (10885-13-94B/97.55-98.00 m). NRCan photos 2021-103 to 2021-106. All photographs by A.-A. Sappin.

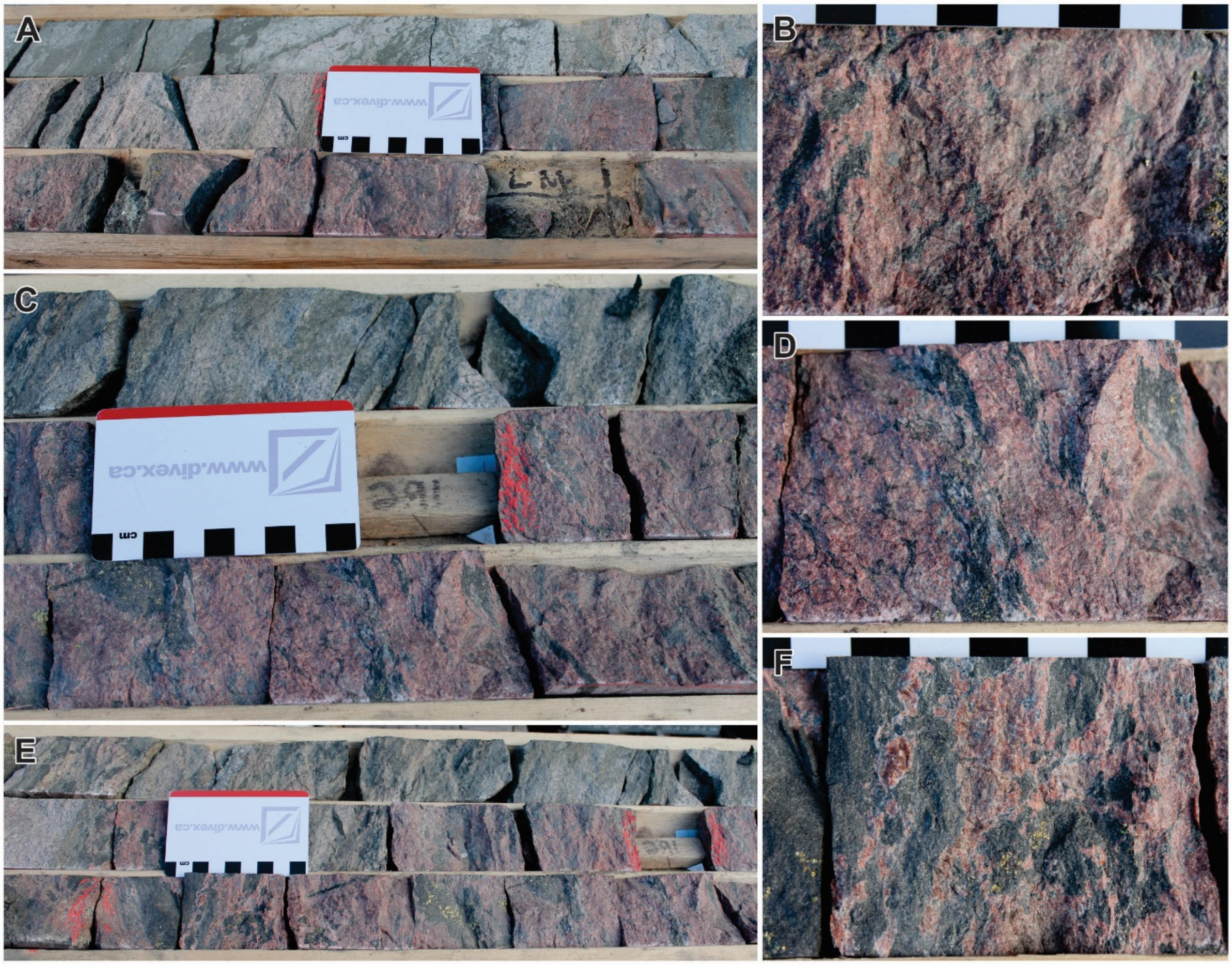

Figure 7: High-grade REE mineralization (~12% TREO over 3 m) hosted by veins of apatite with intergrown britholite (red minerals), which brecciated a biotite-hornblende gneiss in the lower breccia zone of the Josette REE-Fe±Cu mineralized zone (10885-13-112/291.00-294.00 m). NRCan photos 2021-107 to 2021-112. All photographs by A.-A. Sappin.

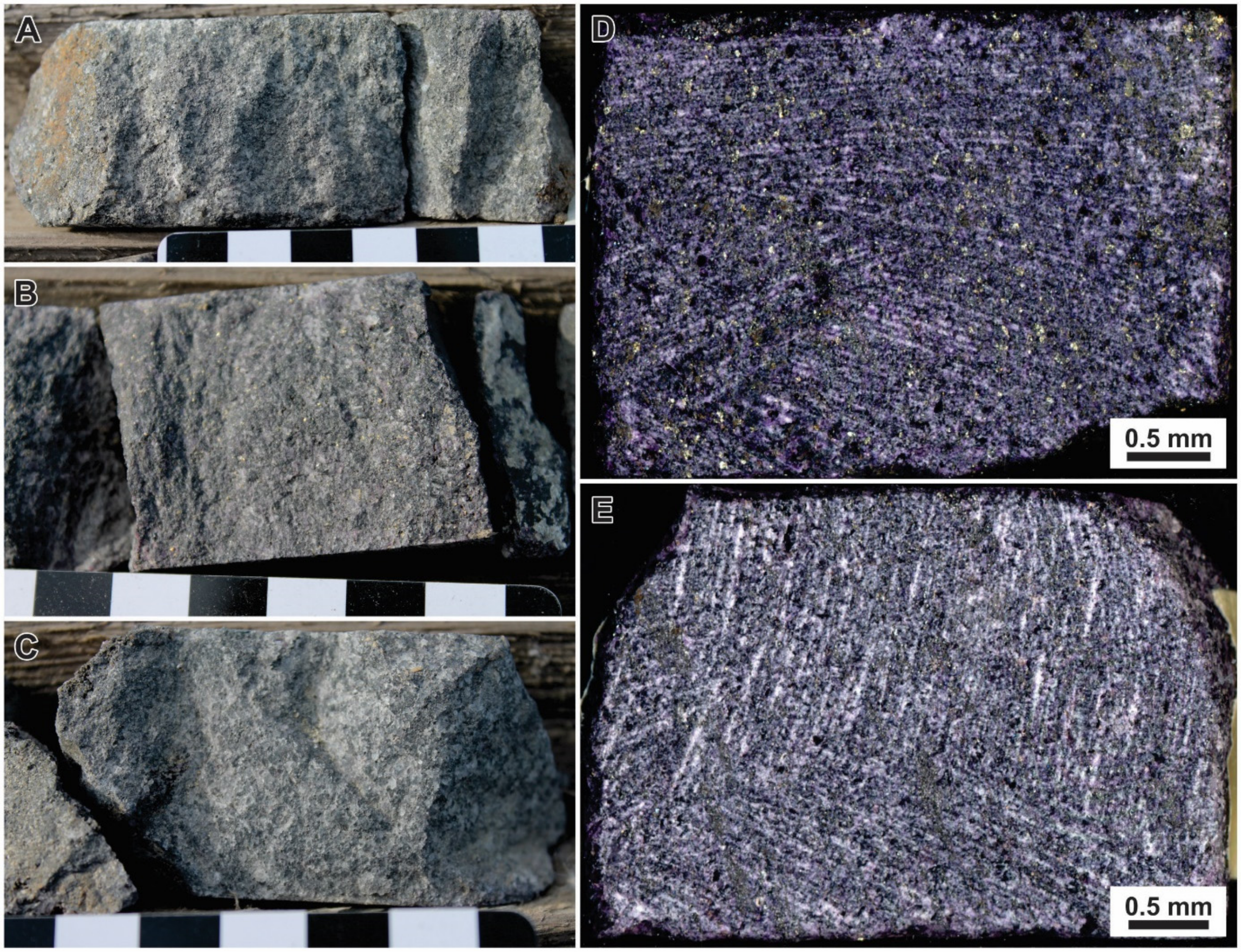

Figure 8: Fluorine Fe±Cu±REE mineralized zone (1088-94-01/37.08-37.88 m). A) to C) Calcsilicate rocks. NRCan photos 2021-113 to 2021-115. D) and E) Apatite (white minerals), fluorite (purple minerals), and pyrite (yellow minerals) grains in the calcsilicate rocks. NRCan photos 2021-116 to 2021-117. All photographs by A.-A. Sappin.

5- Future work

Future work on the representative samples from the Josette deposit and the Fluorine mineralized zone will include the identification and characterization of both textures and REE-bearing minerals using µ-X-ray fluorescence spectroscopy (µ-XRF). Cathodoluminescence study of apatite crystals will also help to recognize the different generations of this mineral. The composition of the main REE-bearing minerals will be determined by electron probe micro-analyzer (EPMA), while their Sm-Nd isotopic signatures will be investigated by isotope dilution – thermal ionization mass spectrometry (ID-TIMS) or by laser ablation multi-collector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS). Together, these petrographic and geochemical works will help to better understand the geochemical source and the metallogenic processes involved in the formation of the REE mineralization in the Kwyjibo property.

6- Acknowledgment

This report is a contribution to NRCan's Targeted Geoscience Initiative Program (TGI-6). Support for this study was provided through the Ore Systems Project's 'Sub-Activity: Mineral systems with metasomatic iron oxide-copper-gold±uranium (IOCG) and critical metal deposit types' and a collaborative research and development grant to George Beaudoin (UL) from the Diversification de l'Exploration Minérale au Québec (DIVEX) network and the MERN. We would like to thank SOQUEM Inc. for providing representative samples. Thanks are also extended to Louise Corriveau (GSC) for reviews that helped improve the final version of this contribution.

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