Natural Resources Canada · Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8789

Molybdenite Re-Os ages of a gold-rich vein, Porphyry zone, Upper Beaver deposit, Abitibi greenstone belt, Ontario

P. Mercier-Langevin, R.A. Creaser, B. Dubé, J. Dubé, D.J. Kontak, J. Sutton, and O. Côté-Mantha

2021

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8789

Molybdenite Re-Os ages of a gold-rich vein, Porphyry zone, Upper Beaver deposit, Abitibi greenstone belt, Ontario

P. Mercier-Langevin[1], R.A. Creaser[2], B. Dubé[1], J. Dubé[3], D.J. Kontak[4], J. Sutton[3,4], and O. Côté-Mantha[3]

[1]Geological Survey of Canada, 490, rue de la Couronne, Québec, Quebec
[2]University of Alberta, 116th Street and 85th Avenue, Edmonton, Alberta
[3]Agnico Eagle Mines Limited, 765 chemin de la mine Goldex, Val-d'Or, Quebec
[4]Harquail School of Earth Sciences, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario

2021

Permanent link: https://doi.org/10.4095/328239

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Mercier-Langevin, P., Creaser, R.A., Dubé, B., Dubé, J., Kontak, D.J., Sutton, J., and Côté-Mantha, O., 2021. Molybdenite Re-Os ages of a gold-rich vein, Porphyry zone, Upper Beaver deposit, Abitibi greenstone belt, Ontario; Geological Survey of Canada, Open File 8789, 13 p. https://doi.org/10.4095/328239

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

Molybdenite Re-Os ages of a gold-rich vein, Porphyry zone, Upper Beaver deposit, Abitibi greenstone belt, Ontario

Patrick Mercier-Langevin[1]*, Robert A. Creaser[2], Benoît Dubé[1], Julien Dubé[3], Daniel J. Kontak[4], Jonathan Sutton[3,4], and Olivier Côté-Mantha[3]

[1]Geological Survey of Canada, 490 rue de la Couronne, Québec, Quebec G1K 9A9
[2]University of Alberta, 116th Street and 85th Avenue, Edmonton, Alberta T6G 2R3
[3]Agnico Eagle Mines Limited, Exploration Division, 765 chemin de la mine Goldex, Val-d'Or, Quebec J9P 4N9
[4]Harquail School of Earth Sciences, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario P3E 2C6
*Corresponding author email: patrick.mercier-langevin@canada.ca

INTRODUCTION

The Upper Beaver Au-Cu (±Mo) deposit, located midway between the Kirkland Lake and Larder Lake gold camps, was intermittently exploited between 1913 and 1972 (Argonaut and then Upper Beaver mines) and produced a total of 0.53 Mt at 8.31 g/t Au and 1.03 wt.% Cu (140,708 troy ounces, or 4.38 metric tonnes of Au, and 11.9 M lbs Cu: Puritch et al., 2012). Probable mineral reserves are estimated (at the end of 2019) at 8 Mt at 5.43 g/t Au and 0.25 wt.% Cu (1.4 Moz, or 43.4 t Au), with an extra 0.4 Moz Au (~12.5 t) in indicated resources and 1.42 Moz Au (~44.1 t) in inferred resources (Agnico Eagle Mines Ltd., 2021). Contrary to most major quartz-carbonate vein-style orogenic gold deposits of the Larder Lake and Kirkland camps, Upper Beaver is located farther north relative to the Larder Lake-Cadillac fault zone and therefore sits in a different geological setting than other gold deposits of the area. It is also characterized by distinct alteration assemblages (e.g., magnetite, feldspar, epidote). Because of this, the origin and timing of the gold mineralization at the Upper Beaver deposit have remained key issues in the understanding of its genesis, which therefore impacts on exploration models.

The Geological Survey of Canada, as part of its review of gold metallogeny in the Abitibi (see Dubé and Mercier-Langevin, 2020, and Mercier-Langevin et al., 2020) had the opportunity to visit the Upper Beaver site with Agnico Eagle Mines limited Upper Beaver exploration team in early June 2019. This visit, and the observation of recent core from the mineralized zones exposing Au-rich quartz-carbonate veins containing molybdenite, led Agnico Eagle Mines limited and the Geological Survey of Canada to sample the Au-Mo veins for Re-Os geochronology on molybdenite. These Au-rich quartz-carbonate-molybdenite (± chalcopyrite-pyrite) veins represent a style of mineralization that differs from the bulk of the ore at Upper Beaver (Kontak et al., 2013). The objective of this study was therefore to improve the current knowledge of the deposit by providing age constraints on a style of gold mineralization that is distinct from the magnetite-chalcopyrite Au-rich and quartz-calcite ± chalcopyrite-magnetite-molybdenite-Au styles of mineralization. Analyses were undertaken in collaboration with the University of Alberta. The results are briefly reported and discussed here.

Geological Setting

Only a brief overview of the geological setting of the Upper Beaver deposit is provided here and readers are referred to Morris (1974), Roberts and Morris (1982), Kontak et al. (2008, 2011, 2013), Feick (2016), Monecke et al. (2017), Poulsen (2017), Dubé and Mercier-Langevin (2020) for more information about the deposit geology.

The Upper Beaver Au-Cu (± Mo) deposit is located in the southernmost part of the 2704–2695 Ma (McNicoll et al., 2014) western Blake River Group (formerly known as Kinojevis in that area; Roberts and Morris, 1982), approximately 5–6 km north of the Larder Lake-Cadillac fault zone and its panels of Timiskaming conglomerate and Larder Lake Group mafic-ultramafic rocks (Fig. 1). It is spatially associated and partly hosted in dykes and apophyses part of a small intrusive complex (the "Upper Beaver intrusive complex") in dominantly tholeiitic mafic volcanic rocks (Ayer et al., 2005) close to surface and volcaniclastic units at depth close to, or at the contact with the 2710–2704 Ma transitional to calc-alkaline, intermediate to felsic volcanic and volcaniclastic rocks of the Gauthier Group (Tisdale Group: Ayer et al., 2002; Fig. 1). The contact between the Blake River (north) and Gauthier Group (south) is marked by volcaniclastic rocks and locally identified as a deformation zone called the Victoria Creek deformation zone, even though deformation along that contact is locally very weak to absent. The currently known Upper Beaver mineralized zones are restricted to the hanging wall (north) of the contact.

The Upper Beaver intrusive complex hosting part of the mineralized zones consists of a sub-alkaline (calc-alkaline) to alkaline suite of monzodioritic, quartz-monzodioritic and granodioritic plugs and dykes (Kontak et al., 2008; Feick, 2016; Dubé and Mercier-Langevin, 2020). Numerous intrusive rock types have been defined (based on mineralogical, textural, geochemical, and cross-cutting criteria) by exploration teams to decipher the evolution of the intrusive complex and better understand controls on the mineralized zones. Three units are shown on figures 2 and 3: the "mafic syenite"; the "crowded porphyry"; and the "spotted porphyry". The crowded and spotted porphyry are part of what is sometimes referred to as the "felsic syenite". The mafic syenite (amphibolite-bearing diorite to monzodiorite) is the oldest and most voluminous phase of the complex. The crowded porphyry forms a large mass in the center of the mafic syenite and occurs as a series of SW-trending dykes and apophyses, especially on the SW side of the intrusive complex (Figs. 2, 3). The crowded porphyry dykes cut across the mafic syenite and are spatially closely associated with the mineralized replacement-style zones and veins in the volcanic rocks SW of the intrusive complex (Figs. 2, 3). Both the mafic syenite and crowded porphyry are mineralized and altered. The spotted porphyry consists of a WNW-ESE-oriented dyke that cuts the older intrusive phases and the mineralized zones and is therefore considered to be an intrusive phase younger than mineralization (Fig. 3). There is significant overlap between the mafic and felsic syenite phases in terms of composition (e.g., Dubé and Mercier-Langevin, 2020 and references therein).

Different styles of Au (± Cu-Mo) mineralization are present in the various ore zones (e.g., Porphyry, North Contact, South Contact, and Q-zone) of the Upper Beaver (Roberts and Morris, 1982; Kontak et al., 2008, 2013; Feick, 2016), including vein-style mineralization (e.g., quartz-carbonate-magnetite; chalcopyrite ± pyrite-molybdenite-free gold; calcite ± quartz with chalcopyrite-pyrite-free gold; quartz-calcite-molybdenite with free gold; Magnetite-hematite-chalcopyrite; and carbonate-anhydrite veins) and replacement, disseminated and fracture controlled-style mineralization (magnetite-epidote-feldspar-hematite-pyrite-chalcopyrite). Hydrothermal alteration associated with these different styles of mineralization is complex and heterogeneously distributed through the deposit; it also varies depending on host rocks (Kontak et al., 2008; Feick, 2016). The principal alteration assemblages consist of varying abundance of epidote, sericite, albite, K-feldspar, magnetite, carbonates, actinolite, tourmaline, magnetite, and hematite (Kontak et al., 2008, 2013).

Although strain intensity is relatively low in the Upper Beaver area, a foliation overprints the alteration and mineralized veins (Roberts and Morris, 1982; Kontak et al., 2008). This foliation is interpreted as the main regional foliation. This, plus the fact that alteration and mineralization overprint some of the early intrusive phases but are cut by the later phases indicates that mineralization was formed prior to the main regional deformation and coeval with the emplacement of the intrusive complex (Kontak et al., 2011, 2013).

The spotted porphyry, which is post-ore, has been dated at ca. 2679 Ma (Kontak et al., 2011, 2013; Dubé and Mercier-Langevin, 2020), which thus provides a minimum age for the mineralization, whereas a molybdenite Re-Os age of ca. 2685 Ma was obtained from a Au-rich sericite-altered zone associated in the intrusive complex (Kontak et al., 2013). These ages correspond to the age of the early- to syn-Timiskaming intrusive rocks that are common along the major E-W fault zones of the southern Abitibi and makes the deposit part of the syn-Timiskaming intrusion-associated stockwork-disseminated, veinlet and replacement-style deposits according to the new classification of Dubé and Mercier-Langevin (2020). Because of its distinct styles of mineralization and alteration, and a very close association with the different intrusive phases of the host complex, the Upper Beaver deposit is interpreted as a magmatic-hydrothermal system that shares analogies with the magnetite subgroup of iron-oxide copper-gold (IOCG) systems and also with skarn and alkalic copper-gold systems (Kontak et al., 2008, 2011, 2013; Dubé and Mercier-Langevin, 2020).

RESULTS

Samples Selection

Three 10 cm-long NQ-sized (47.6 mm diameter) half drill core samples were collected from drill holes KLUB19-496 and KLUB19-489. The drill holes intersect mafic volcanic rocks, porphyry dyke rocks, and numerous Au- (± Mo-Cu)-bearing intervals of the shallow, mafic volcanic-hosted North Contact, Porphyry, and South Contact zones of the deposit (Fig. 3). The sampled mineralized intervals of the Porphyry zone consist of zones of disseminated sulfides (pyrite ± molybdenite-chalcopyrite) and quartz-calcite veins and veinlets containing variable amounts of chalcopyrite, molybdenite, pyrite and a few occurrences of visible gold. The mineralized intervals are associated with pervasive to heterogeneous (patchy) calcite, epidote, chlorite, magnetite and hematite ± K-feldspar alteration of moderate intensity that is mostly developed in the basalts, in some cases in proximity to mafic syenite intervals and porphyry dykes.

Two samples (PLBD-2019-001 and -002) were taken between 120 and 122 m-depth along drill hole KLUB19-496 (Figs. 2, 3). A third sample (PLBD-2019-003) was taken in drill hole KLUB19-489 at a downhole depth of 227 m. These three samples were selected based on the presence of well-mineralized molybdenite-rich quartz-calcite veins, high grade Mo and S values (determined on site using a portable x-ray fluorescence analyzer), and the presence of visible gold with traces of chalcopyrite in Au-rich intervals.

Sample PLBD-2019-001 (ddh KLUB19-496, 120 m): This sample is from a 1–3 cm-thick quartz-calcite vein (Fig. 4A) with abundant molybdenite forming mm-thick slivers (Fig. 4B, C). The vein is in sharp contact with strongly calcite-chlorite-magnetite ± epidote-altered basalt. The sample comes from a 13.7 g/t Au over 0.5 m interval and contain traces of free gold directly associated with the fine-grained molybdenite (Fig. 4D).

Sample PLBD-2019-002 (ddh KLUB19-496, 121.8 m): This sample, taken less than 2 m farther downhole from samples PLBD-2019-001 consists of a 4–5 cm-thick, laminated quartz ± carbonate vein (Fig. 5A, B) containing heterogeneously distributed, fine-grained molybdenite with traces of pyrite (Fig. 5C, D). The vein is hosted in calcite-chlorite-magnetite ± epidote-altered and foliated basalt. The contacts are irregular. The sample comes from a 22.3 g/t Au over 0.5 m interval and contain minute traces of gold directly associated with the fine-grained molybdenite (Fig. 5D).

Sample PLBD-2019-003 (ddh KLUB19-489, 227 m): This sample comes from a very rich interval grading at 22.9 g/t Au and 720 ppm Cu over 1.1 m. The sample consist of a <1 cm-thick quartz ±

carbonate vein with very fine-grained molybdenite and chalcopyrite that cuts calcite, chlorite and magnetite-altered basalts (Fig. 6A–C). The vein contains fine-grained visible Au (Fig. 6D) that is associated with the molybdenite.

Re-Os Analytical Methods

Sample PLBD-2019-002 was prioritized for Re-Os analyses because of its slightly coarser-grained molybdenite and lesser abundance of other sulfides. The other two samples (PLBD-2019-001 and -003) were kept as backup samples. Methods used for molybdenite analysis are described in detail in Selby and Creaser (2004). Areas of the sample PLBD-2019-002 with visible molybdenite were removed, and preparation of a molybdenite mineral separate was made by metal-free crushing and sieving followed by magnetic and gravity concentration methods. The ^{187}Re and ^{187}Os concentrations in molybdenite were determined by isotope dilution mass spectrometry using Carius-tube, solvent extraction, anion chromatography and negative thermal ionization mass spectrometry (N-TIMS) techniques at the University of Alberta. For this work, a mixed double spike containing known amounts of isotopically enriched ^{185}Re, ^{190}Os, and ^{188}Os analysis was used (Markey et al., 2007). Isotopic measurements used a ThermoScientific Triton mass spectrometer with static faraday collectors. Total procedural blanks for Re and Os are less than <3 picograms and 2 picograms, respectively, which are insignificant in comparison to the Re and Os concentrations in molybdenite. The Reference Material 8599 Henderson molybdenite (Markey et al., 2007) is routinely analyzed as a standard, and during the past 5 years returned an average Re-Os date of 27.78 ± 0.06 Ma (n= 18), indistinguishable from the Reference Age Value of 27.66 ± 0.1 Ma (Wise and Watters, 2011). The ^{187}Re decay constant (λ^{187}Re) used for age calculation is $1.666 \pm 0.005 \times 10^{-11}\ a^{-1}$ (Smoliar et al, 1996), a value which is cross-calibrated to the U-Pb system (^{238}U and ^{235}U) to better than ~ ± 0.31% (Selby et al., 2007).

Re-Os Analytical Results

The results of the Re-Os age determinations are presented in Table 1. The age uncertainty is quoted at 2σ level, and includes all known analytical uncertainty, including a ~0.31% uncertainty in the decay constant of ^{187}Re. The initial analysis (9 mg) yielded an age of 2688.7 ± 5.9 (11.9) Ma after re-analysis of weak Re and Os mass spectrometer runs. Two replicates of the same molybdenite mineral separate of double the sample size (19 mg) yielded ages of 2680.4 ± 5.9 (11.9) Ma and 2680.5 ± 5.9 (11.9) Ma, which are regarded as the most reliable analyses.

CONSTRAINTS ON THE TIMING OF GOLD MINERALIZATION AT UPPER BEAVER

The sample dated in this study, taken from a representative drill hole in the Porphyry zone of the Upper Beaver deposit and in very Au-rich intervals, consist of quartz-carbonate vein that clearly shows the direct association between gold and molybdenite (Figs. 4–6). The age obtained, 2680.5 ± 5.9 Ma on two replicate analyses is interpreted as dating the time of the Au mineralization.

This age is in agreement with the minimum age provided by the ca. 2679 Ma post-ore phase (spotted porphyry) of the multiphase intrusive monzodioritic to granodioritic ("syenite") complex that hosts part of the mineralized zones at Upper Beaver (Kontak et al., 2011, 2013; Dubé and Mercier-Langevin, 2020). It is also in agreement with a previously reported 2685 Ma Re-Os ages obtained from molybdenite from a phyllic alteration zone proximal to the Au zones (Kontak et al., 2013).

The 2680.5 ± 5.9 Ma age for the Au mineralization of the Porphyry zone reported herein, which is associated with the crowded porphyry dykes, confirms that Au, or at least part of the Au mineralization at Upper Beaver, is synmagmatic as indicated by cross-cutting relationships between the various phases of the host multiphase intrusive monzodioritic to granodioritic ("syenite") complex and the ore zones (e.g., Figs. 2, 3), as discussed in Kontak et al. (2008, 2011, 2013) and in Dubé and Mercier-Langevin (2020). It also confirms that the Upper Beaver magmatic-hydrothermal deposit is part of the early- to syn-Timiskaming group of deposits, which are common in the southern part of the Abitibi and associated with sub-alkaline to alkaline intrusive centers close to major deformation zones (Dubé and Mercier-Langevin, 2020).

ACKNOWLEDGMENTS

This study results from the Abitibi (2005-2010), and Gold (2015-2020) projects of the Targeted Geoscience Initiative Program of the Geological Survey of Canada. The authors are most grateful to Agnico Eagle Mines limited for access to samples and data and for scientific support. Thanks to S. Villeneuve, P. Barbe, M. Masson and O. Grondin (Agnico Eagle Mines limited), V. McNicoll and W. Bleeker (Geological Survey of Canada), H. Poulsen (consultant), and Agnico Eagle Mines and Queenston Mining geological staff for insightful discussions on the geology of the Upper Beaver gold deposit. M. Boutin helped prepare some of the figures. Thanks to J.-L. Pilote for his constructive review of an earlier version of the manuscript.

REFERENCES

Agnico Eagle Mines Limited, 2021, Agnico Eagle reports fourth quarter and full year 2020 results: Press release, 130 p. <https://s21.q4cdn.com/374334112/files/doc_financials/quarterly/2021/Q4-2020_AEM-Results-February-11-2021-Final.pdf> [accessed March 3, 2021]

Ayer, J.A., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K., and Trowell, N., 2002, Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: Authochtonous volcanic construction followed by plutonism, regional deformation and sedimentation: Precambrian Research, v. 115, p. 63–95.

Ayer, J.A., Thurston, P.C., Bateman, R., Dubé, B., Gibson, H.L., Hamilton, M.A., Hathway, B., Hocker, S.M., Houlé, M.G., Hudak, G., Ispolatov, V.O., Lafrance, B., Lesher, C.M., MacDonald, P.J., Péloquin, A.S., Piercey, S.J., Reed, L.E. and Thompson, P.H., 2005, Overview of results from the Greenstone Architecture Project: Discover Abitibi Initiative: Ontario Geological Survey, Open File Report 6154, 146 p.

Dubé, B., and Mercier-Langevin, P., 2020, Gold deposits of the Archean Abitibi greenstone belt, Canada: Society of Economic Geologists, Special Publication 23, p. 669–708.

Kontak, D., Dubé, B., and Benham, W., 2008, The Upper Beaver project, Kirkland Lake area: Investigation of a syenite-associated copper-gold deposit with magnetite-epidote-feldspar alteration in Summary of Field Work and Other Activities 2008, Ontario Geological Survey, Open File Report 6226, p. 12-1 to 12-12.

Kontak, D., Dubé, B., Kyser, T. K., 2011, Geological, petrological and geochemical observations of an Archean syenite-associated Au-Cu deposit, Kirkland Lake, Ontario: A temporal or genetic relationship:

[abs.]: Geological Association of Canada-Mineralogical Association of Canada (GAC-MAC-SEG-SGA) Annual Joint Meeting, Ottawa, May 25-27, 2011, Abstract Volume 34, p. 111.

Kontak, D., Dubé, B., McNicoll, V., Creaser, R., and Kyser, K., 2013, The Upper Beaver Au-Cu deposit, Kirkland Lake, Ontario, Canada: An Archean IOCG analogue or just an intrusion-related iron oxide copper-gold deposit? [abs.]: Geological Association of Canada-Mineralogical Association of Canada (GAC-MAC) Annual Joint Meeting, Winnipeg, May 22–24, 2013, Abstract Volume 36, p. 122.

Feick, K.E., 2016, An evaluation of the lithologies and geochemistry of the Upper Beaver deposit of the Kirkland Lake area: Unpublished M.Sc. thesis, University of Western Ontario, Kinston, Ontario, Canada, 247 p.

Markey, R., Stein, H.J., Hannah, J.L., Selby, D., and Creaser, R.A., 2007, Standardizing Re-Os geochronology: A new molybdenite Reference Material (Henderson, USA) and the stoichiometry of Os salts: Chemical Geology, v. 244, p. 74–87.

McNicoll, V., Goutier, J., Dubé, B., Mercier-Langevin, P., Ross, P.-S., Dion, C., Monecke, T., Legault, M., Percival, J., and Gibson, H., 2014. U-Pb geochronology of the Blake River Group, Abitibi greenstone belt, Quebec, and implications for base metal exploration; Economic Geology, v. 109, p. 27–59.

Mercier-Langevin, P., Lawley, C.J.M., Castonguay, S., Dubé, B., Bleeker, W., Pinet, N., Bécu, V., Pilote, J.-L., Jackson, S.E., Wodicka, N., Honsberger, I.W., Davis, W.J., Petts, D.C., Yang, Z., Jautzy, J., et Lauzière, K., 2020, Targeted Geoscience Initiative 5, Gold Project: A summary of contributions to the understanding of Canadian gold systems : Geological Survey of Canada, Open File 8712, p. 1–30.

Monecke, T., Mercier-Langevin, P., Dubé, B., and Frieman, B.M., 2017. Geology of the Abitibi greenstone belt; *in* Archean Base and Precious Metal Deposits, Southern Abitibi Greenstone Belt, Canada, (ed.) T. Monecke, P. Mercier-Langevin, and B. Dubé; Society of Economic Geologists, Reviews in Economic Geology, v. 19, p. 7–49.

Morris, J.H., 1974, The geology of the Upper Beaver mine, Gauthier Township, Ontario: Unpublished M.Sc. thesis, University Waterloo, Waterloo, Ontario, Canada, 117 p.

Poulsen, K.H., 2017, The Larder Lake-Cadillac break and its gold districts: Reviews in Economic Geoology, v. 19, p. 133–167.

Puritch, E., Rodgers, K., Pearson, J.L., Burga, D., Oraya, D., and Hayden, A., 2012, Technical report and preliminary economic assessment of the Upper Beaver gold-copper deposit, Kirkland Lake, Ontario, Canada: Internal report prepared for Queenston Mining Inc. by P&E Mining Consultants, 178 p. [https://www.miningnewsfeed.com/reports/UpperBeaver_PEA_03302012.pdf] (consulted February 15, 2021)

Roberts, R.G., and Morris, J.H., 1982, The geological setting of the Upper Beaver mine, Kirkland Lake district, Ontario: A copper-gold deposit in mafic volcanic rocks: Canadian Institute of Mining and Metallurgy, Special Volume 24, p. 73–82.

Selby, D., and Creaser, R.A., 2004, Macroscale NTIMS and microscale LA-MC-ICP-MS Re-Os isotopic analysis of molybdenite: Testing spatial restrictions for reliable Re-Os age determinations, and implications for the decoupling of Re and Os within molybdenite: Geochimica et Cosmochimica Acta, v. 68, p. 3897–3908.

Selby, D., Creaser, R.A., Stein, H.J., Markey, R.J., and Hannah, J.L., 2007, Assessment of the ^{187}Re decay constant by cross calibration of Re–Os molybdenite and U–Pb zircon chronometers in magmatic ore systems: Geochimica et Cosmochimica Acta, v. 71, p. 1999–2013.

Smoliar, M.I., Walker, R.J., and Morgan, J.W., 1996, Re-Os ages of group IIA, IIIA, IVA, IVB iron meteorites: Science, v. 271, p. 1099–1102.

Wise, S.A., and Watters, R.L., 2011, Reference Material 8599 Henderson Molybdenite: National Institute of Standards and Technology Report of Investigation, 30 March 2011.

Table 1. Re-Os isotopic results, mixed double ^{185}Re+^{190}Os+^{188}Os spike

Sample	**Fraction**	**Weight**	**Re ppm**	**2σ**	**^{187}Re ppm**	**2σ**	**^{187}Os ppb**	**2σ**	**Model age (Ma)**	**2σ**	**2σ with λ**
PLBD-2019-002	run 1	9 mg	155	0.5	97.2	0.3	4455	3.4	2689	5.9	11.9
	repeat 1	19 mg	166	0.5	104.3	0.3	4762	3.8	2680	5.9	11.9
	repeat 2	19 mg	161	0.5	101.3	0.3	4628	4.5	2681	6.0	12.0

ppb = parts per billion
ppm = parts per million
All uncertainties quoted at 2σ
Age uncertainty includes ^{187}Re decay constant uncertainty

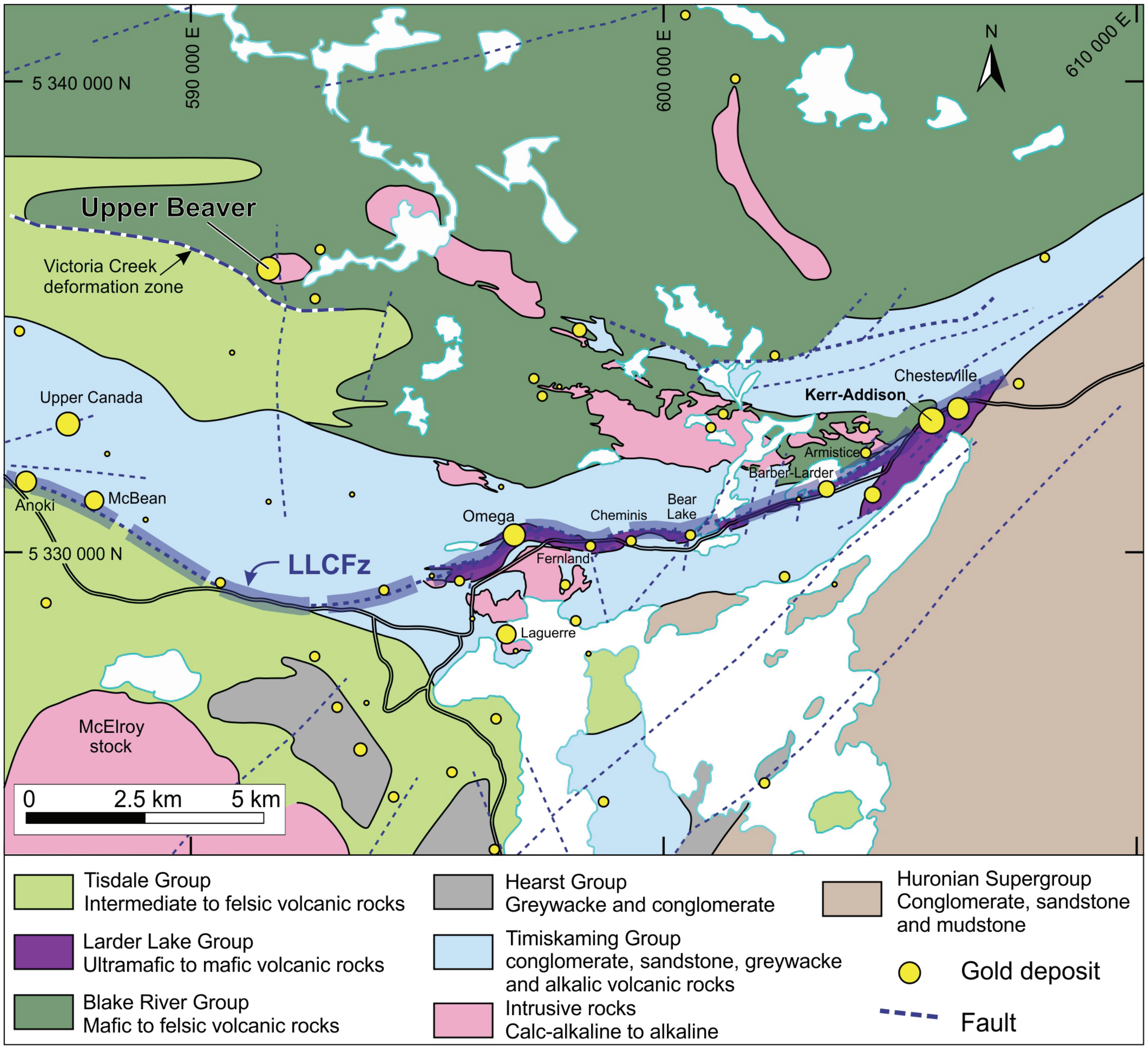

Figure 1. Geologic map of the Larder Lake district showing the location of the Upper Beaver deposit in the northwestern part of the district. LLCFz = Larder Lake-Cadillac fault zone. From Poulsen (2017).

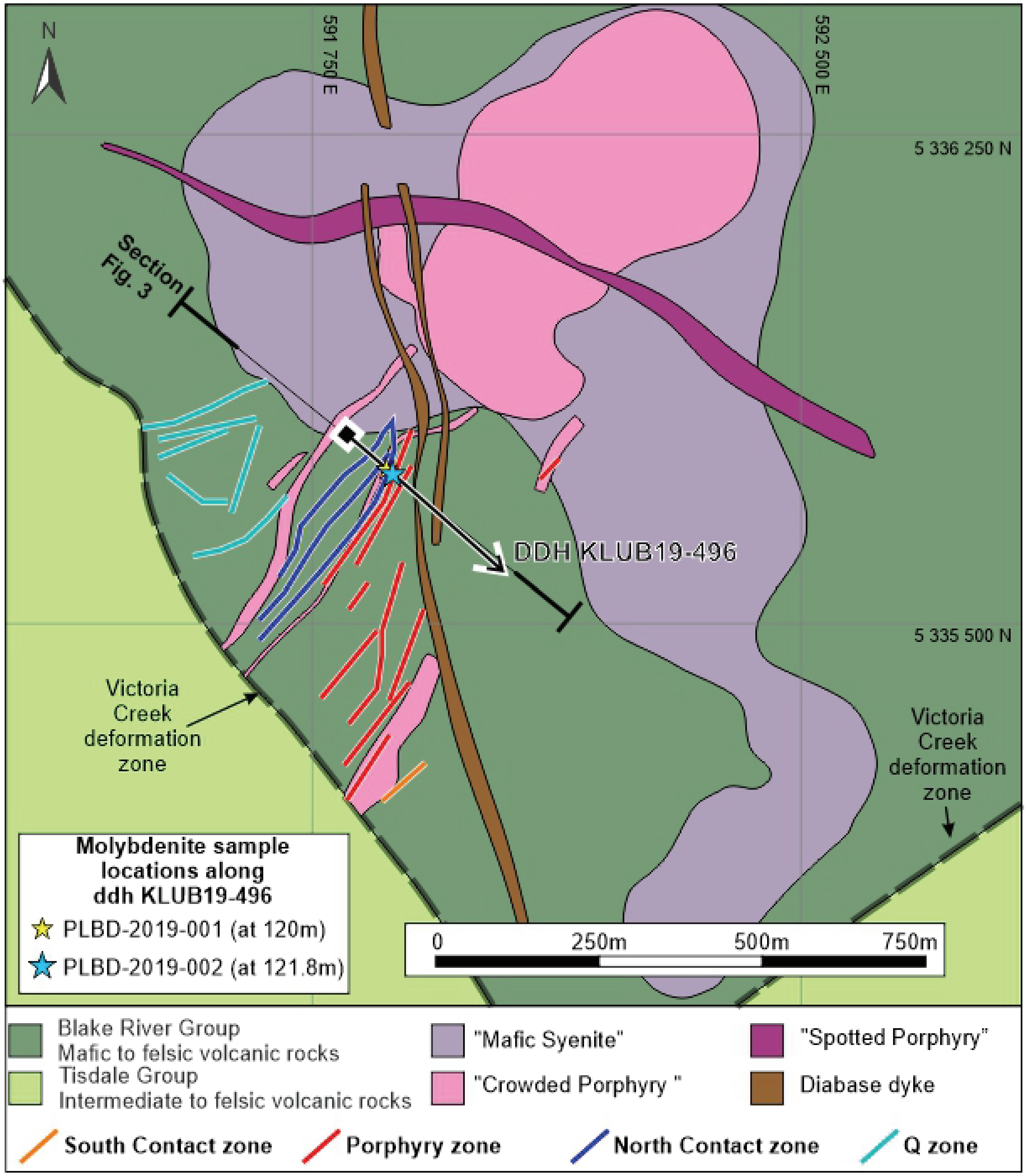

Figure 2. Simplified surface geologic map of the Upper Beaver deposit. The map illustrates the trace of the mineralized zones at surface (bedrock). The trace of drillhole KLUB19-496 (projected to surface), the location of the sampled molybdenite-bearing Au-rich veins, and the trace of the section shown in figure 3 are also shown. From Agnico Eagle Mines limited.

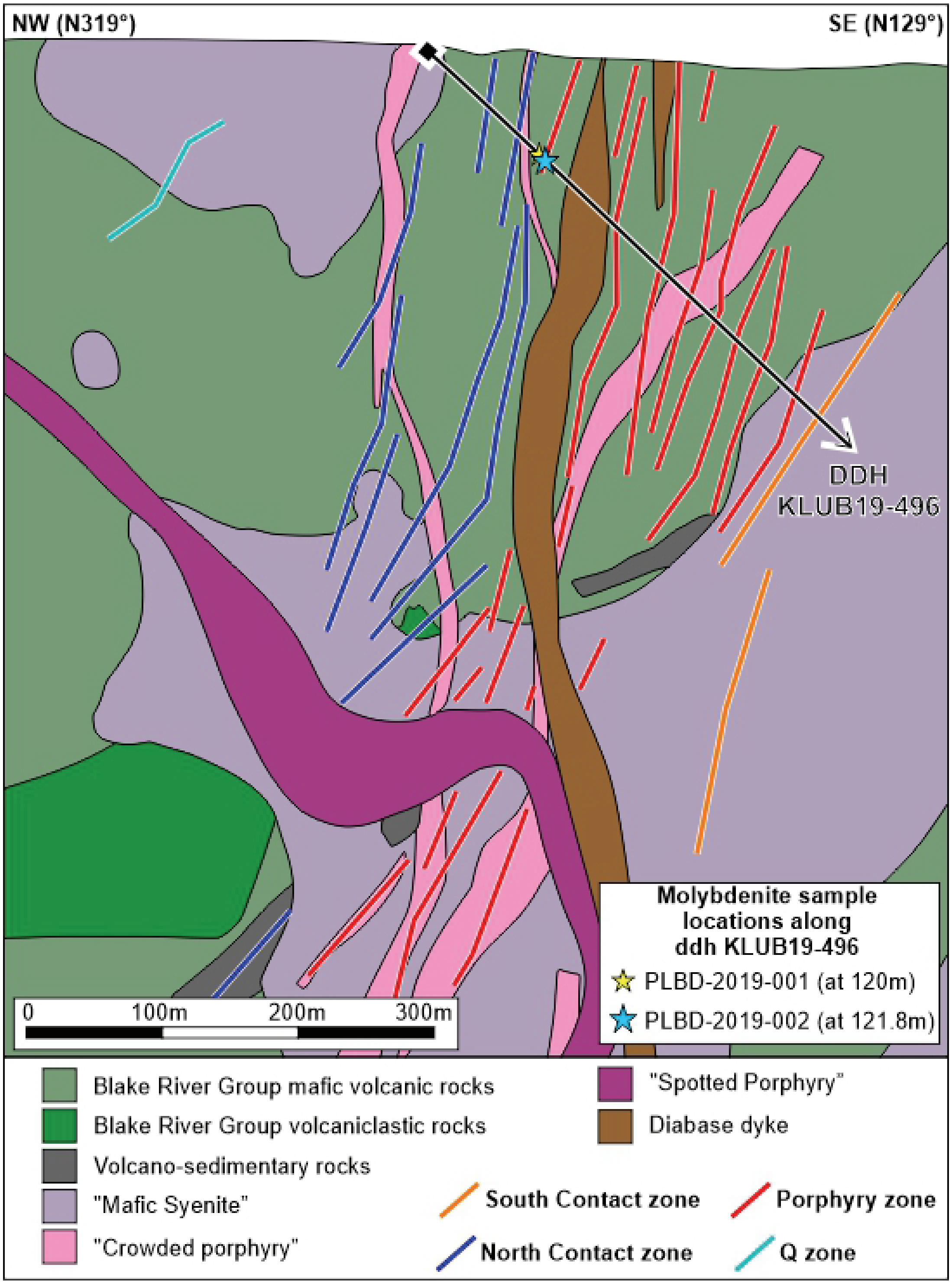

Figure 3. Simplified geologic section looking northeast of the central northeastern part of the Upper Beaver deposit showing the trace of drillhole KLUB19-496 and the location of the sampled molybdenite-bearing Au-rich veins. The section also shows the distribution of the veins systems within the different mineralized zones. From Agnico Eagle Mines limited.

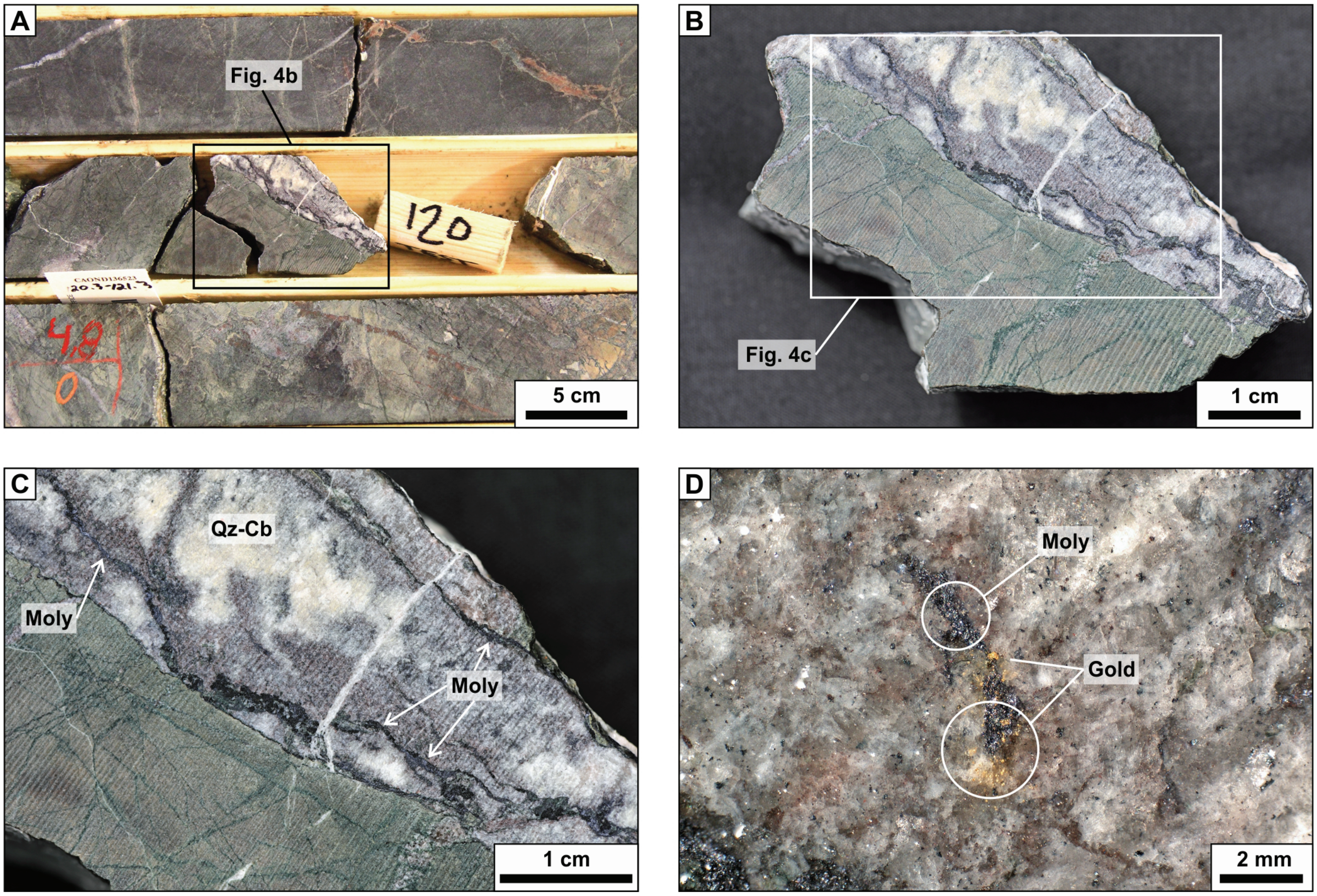

Figure 4. Photographs of sample PLBD-2019-001, located at a depth of 120 m along drillhole KLUB19-496. The sample comes from an interval at 13.7 g/t Au over 0.5 m. a) Sample PLBD-2019-001 consisting of a 1-3 cm-thick quartz and carbonate vein with molybdenite crosscutting calcite, chlorite and magnetite-altered basalts. Photograph by P. Mercier-Langevin, NRCan photo 2021-015. b) Closer view of the sampled vein and altered selvages. Photograph by P. Mercier-Langevin, NRCan photo 2021-016. c) Millimeter-thick molybdenite slivers and disseminated molybdenite in a narrow quartz-carbonate vein cut by later calcite veinlets. Photograph by P. Mercier-Langevin, NRCan photo 2021-017. d) Close-up view of a molybdenite sliver with abundant native gold in the quartz-carbonate vein, showing the close association between gold and molybdenite. Photograph by P. Mercier-Langevin, NRCan photo 2021-018.

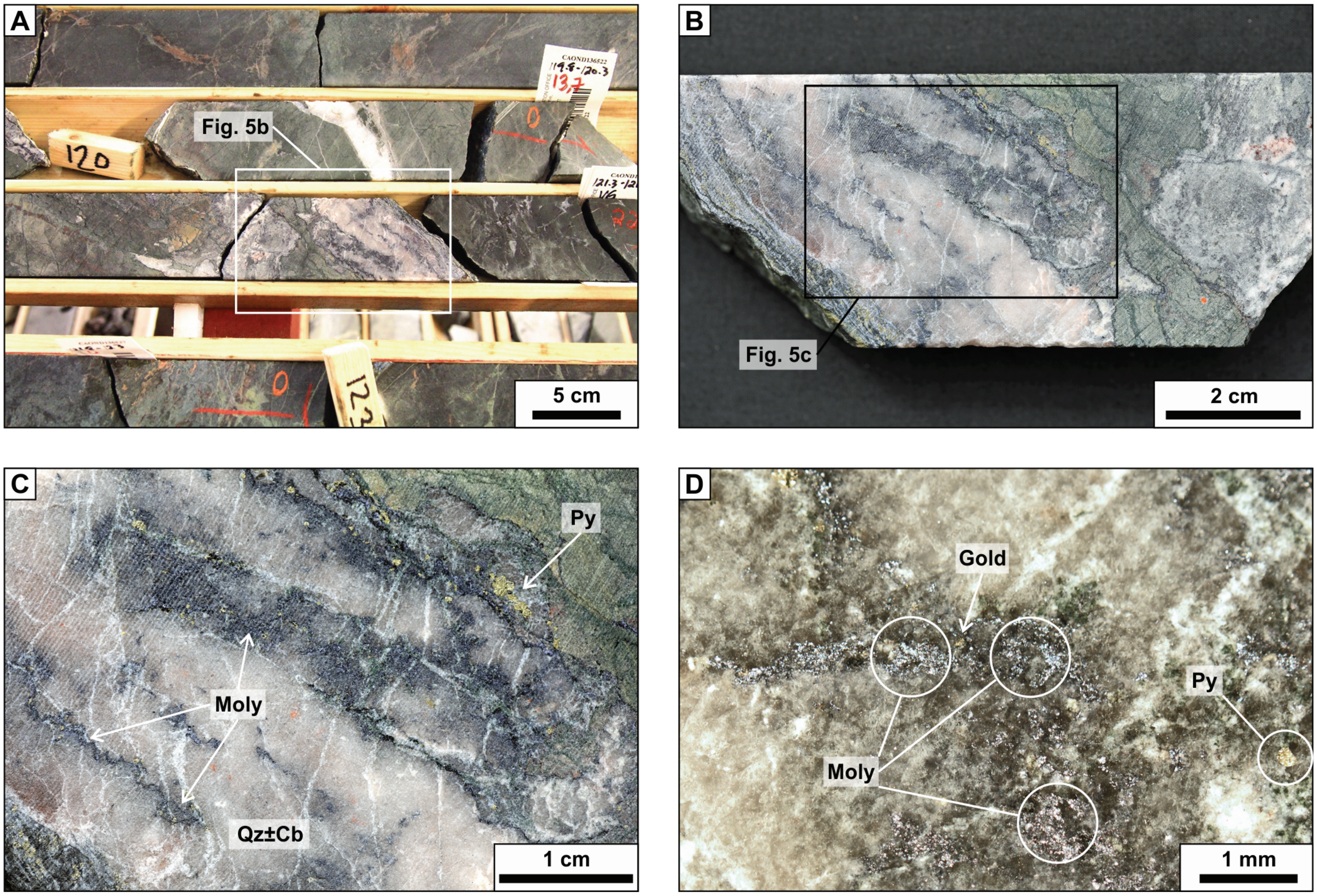

Figure 5. Photographs of sample PLBD-2019-002, located at a depth of 121.8 m along drillhole KLUB19-496. The sample comes from an interval at 22.3 g/t Au over 0.5 m. a) Sample PLBD-2019-002 consisting of a 4-5 cm-thick laminated quartz ± carbonate vein with molybdenite and trace pyrite crosscutting calcite, chlorite, epidote and magnetite-altered and foliated basalts. Photograph by P. Mercier-Langevin, NRCan photo 2021-019. b) Closer view of the sampled vein and altered selvages. Photograph by P. Mercier-Langevin, NRCan photo 2021-020. c) Millimeter-thick molybdenite slivers, bands and patches cut by later calcite-filled fractures. Photograph by P. Mercier-Langevin, NRCan photo 2021-021. d) Close-up view of a molybdenite patch with traces of native gold in the quartz ± carbonate vein, showing the close association between gold and molybdenite. Photograph by P. Mercier-Langevin, NRCan photo 2021-022.

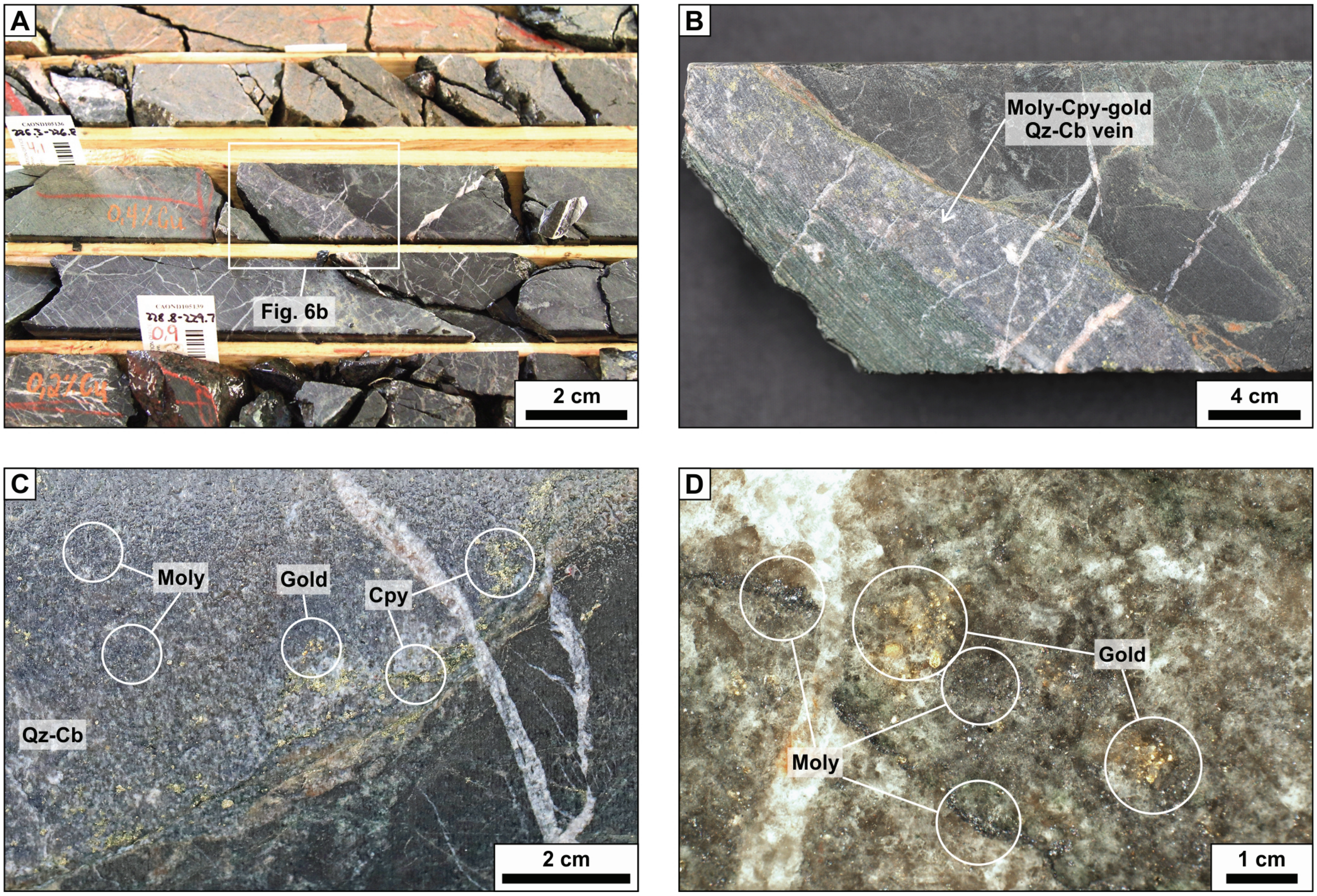

Figure 6. Photographs of sample PLBD-2019-003, located at a depth of 227 m along drillhole KLUB19-489. The sample comes from an interval at 22.9 g/t Au and 720 ppm Cu over 1.1 m. a) Sample PLBD-2019-003 consisting of a <1 cm-thick quartz-carbonate vein with abundant fine-grained molybdenite and chalcopyrite crosscutting calcite, chlorite and magnetite-altered and foliated basalts in proximity to a hematite-altered dyke ("mafic syenite"). Photograph by P. Mercier-Langevin, NRCan photo 2021-023. b) Closer view of the sampled vein and altered selvages. Photograph by P. Mercier-Langevin, NRCan photo 2021-024. c) Millimeter-thick molybdenite- and chalcopyrite-rich vein with native gold, cut by later calcite veinlets. Photograph by P. Mercier-Langevin, NRCan photo 2021-025. d) Close-up view of finely disseminated molybdenite and native gold in the quartz-carbonate vein. Photograph by P. Mercier-Langevin, NRCan photo 2021-026.