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Targeted Geoscience Initiative 4: Contributions to the Understanding of Precambrian Lode Gold Deposits and Implications for Exploration

The Archean Westwood Au deposit, southern Abitibi: Telescoped Au-rich VMS and intrusion-related Au systems

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TABLE OF CONTENTS

Figures

Table

The Archean Westwood Au deposit, southern Abitibi: Telescoped Au-rich VMS and intrusion-related Au systems

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ABSTRACT

The Westwood deposit (3.74 Moz Au) is part of the Doyon-Bousquet-LaRonde mining camp. The deposit is hosted in the 2699–2996 Ma Bousquet Formation that forms a moderately to highly-strained, steeply south-dipping and east-west-trending, upper greenschist/lower amphibolite facies, homoclinal volcano-plutonic sequence that faces south.

The Westwood deposit consists of three east-west-trending and steeply south-dipping mineralized corridors that are stacked from north to south: the Zone 2 Extension, the North Corridor, and the Westwood Corridor. The Zone 2 Extension consists of transposed centimetre- to decimetre-wide pyrite ± chalcopyrite-sphalerite-rich quartz veins and disseminations whereas the North Corridor consists of centimetre- to decimetre-wide quartz-pyrite-chalcopyrite ± sphalerite-galena-pyrrhotite veins and disseminations as well as thin, semi-massive to massive sulphide veins. The Westwood Corridor consists of discontinuous stratabound polymetallic semi-massive to massive sulphide lenses, veins and disseminations.

The Westwood and North corridors are associated with a large, semi-conformable to discordant Mn-rich garnet and biotite distal alteration halo that hosts a zone of more proximal sericite-dominated alteration. The Zone 2 Extension is characterized by a 2–10-m wide zone of intense biotite and sericite (± gypsum) alteration and local alteration zones composed of an assemblage of quartz-andalusite-kyanite-pyrophyllite. Mapping and 3-D modeling of the alteration zones strongly suggests that the Zone 2 Extension alteration overprints that of the North and Westwood corridors.

The Westwood and North corridors are considered to be subseafloor to seafloor (VMS-type) mineralization, whereas the Zone 2 Extension vein system is proposed to represent the eastward extension of the intrusion-associated Doyon Au deposit located less than 1.5 km west of Westwood. The Doyon system is rooted in, and possibly genetically related to, the polyphase Mooshla synvolcanic intrusive complex. The three mineralized corridors at Westwood were probably formed in a ≤2 Ma time span, as indicated by U-Pb zircon geochronology. By analogy with telescoped porphyry-epithermal systems, the three mineralized corridors of the Westwood deposit may represent various components of a submarine Archean auriferous synvolcanic magmatic-hydrothermal system, providing a unique opportunity to improve and expand metallogenic and exploration models for Archean greenstone belts.

INTRODUCTION

The Doyon-Bousquet-LaRonde (DBL) mining camp represents one of the largest Canadian gold and volcanogenic massive sulphide (VMS) districts and was the subject of numerous studies in the last few decades (Mercier-Langevin et al., 2007b). Two major types of Au systems are present in the Doyon-Bousquet-LaRonde (DBL) mining camp: Au-rich VMS deposits (i.e. Bousquet 1, Bousquet 2-Dumagami, LaRonde Penna, and possibly Mouska) and intrusion-related Au ± Cu deposits (i.e. Doyon) (Fig. 1; Mercier-Langevin et al., 2007b). Due to major deformation and conflicting characteristics, the timing of Au introduction in the DBL deposits has been debated for many years, and various models were proposed (Mercier-Langevin et al., 2007b and references therein). Recent models favour a synvolcanic/syngenetic origin for the bulk of the Au in the district (e.g. Dubé et al., 2007, 2014;

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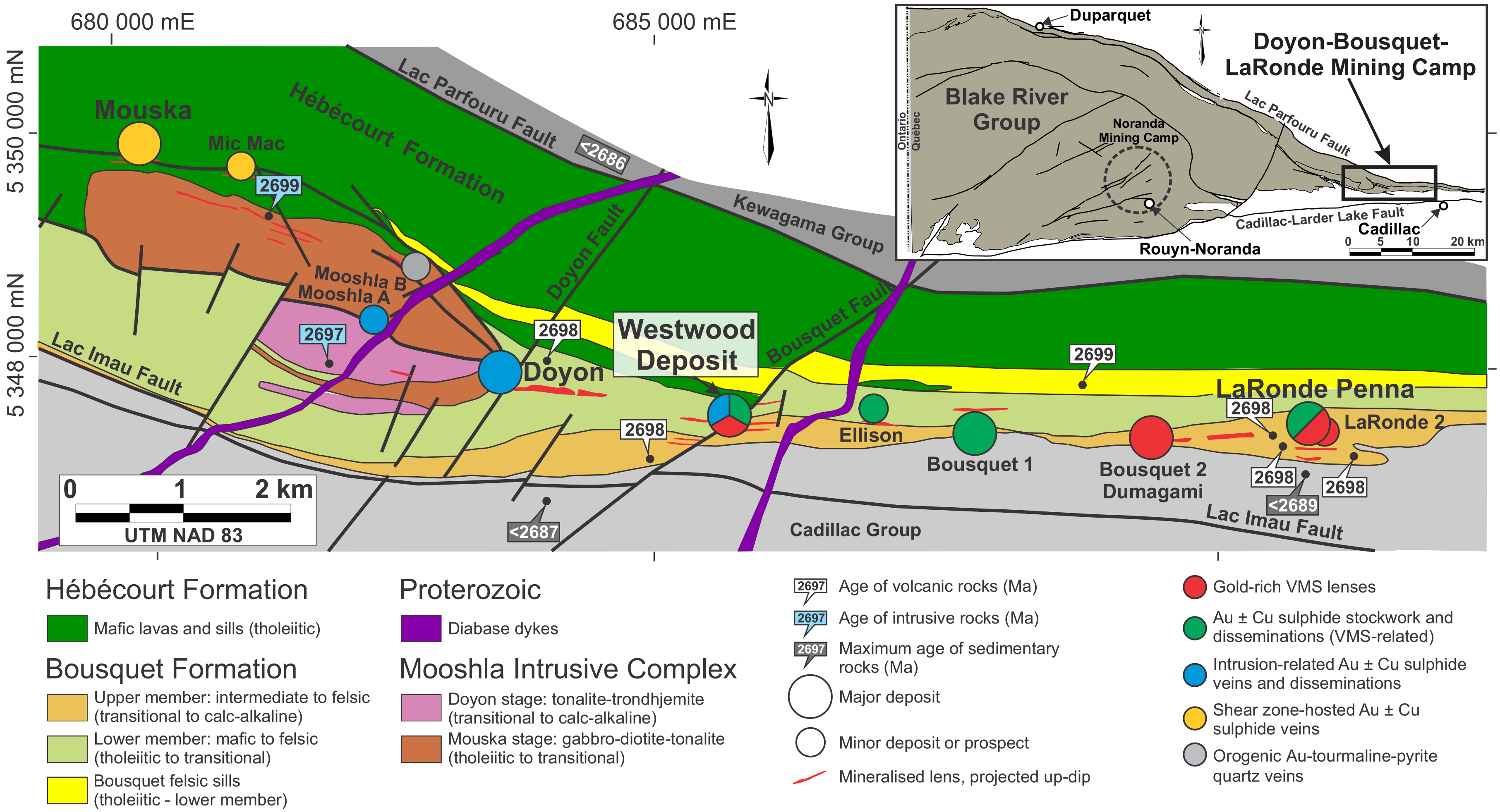


Figure 1. Simplified geological map of the Doyon-Bousquet-LaRonde (DBL) mining camp showing the types of deposits, the age of the rocks, and the location of the Westwood deposit. The inset shows the location of the DBL camp in the Blake River Group of the Abitibi greenstone belt. Modified from Mercier-Langevin et al. (2007a). U/Pb ages from Davis (2002), Lafrance et al. (2003, 2005), Mercier-Langevin et al. (2007a), and McNicoll et al. (2014).

Mercier-Langevin et al., 2007b; Wright-Holfeld, 2011; Galley and Lafrance, 2014), with extensive syntectonic reworking.

A genetic link between the intrusion-associated veins and the VMS-type deposits in the district has been proposed in the past, but this hypothesis has never been properly tested because of a lack of close spatial relationships between the different systems. The discovery, extensive drilling, and underground development of the Westwood deposit in the last decade has provided this opportunity, as both styles of mineralization are present and exposed in that area (Mercier-Langevin et al., 2009; Wright-Holfeld, 2011 and references therein). The reconstruction of the paleo-volcanic architecture and an exhaustive study of the ore zones and alteration halos, combined with a structural and metamorphic characterization of the Westwood deposit, were conducted through an M.Sc. project (Wright-Holfeld, 2011) and a Ph.D. project (Yergeau, 2015) as part of the Geological Survey of Canada TGI-4 Lode Gold project. A summary of our work at Westwood is presented here. Readers are referred to Yergeau (2015) and Wright-Holfeld (2011) for more details and complete referencing.

GEOLOGY AND LITHOGEOCHEMISTRY OF THE WESTWOOD AREA

The base of the host volcanic succession at Westwood consists of a kilometre-thick sequence of pillowed to massive tholeiitic basaltic flows and gabbro sills (map unit 1.0: Hébécourt Formation; Figs. 1 to 4). The Hébécourt Formation is in structural contact with the underlying sedimentary rocks of the ≤2686 Ma Kewagama Group (Davis, 2002).

Lower Member of the Bousquet Formation

The Hébécourt Formation is stratigraphically overlain by the lower member of the Bousquet Formation. The base of the lower member is composed of basaltic to andesitic porphyritic lapilli and block tuffs intercalated with andesitic to dacitic aphanitic lobes and sills (unit 3.0). This unit is tholeiitic (Figs. 3 and 4) and locally strongly altered with epidote- and quartz-filled amygdules (Fig. 5a).

The upper part of the Hébécourt Formation, as well as the base of unit 3.0, are injected by a series of metre-thick quartz- and feldspar-phyric massive tholeiitic rhyolitic sills (unit 2.0; 2698.6±1.5 Ma; Lafrance et al., 2003).

Unit 3.0 is overlain by the Bousquet heterogeneous unit (unit 4.4), which is composed mainly of pillowed to massive basaltic to andesitic lavas of tholeiitic to transitional affinity (Fig. 3). This unit becomes thinner and seems to be locally absent in the eastern part of the deposit. Unit 4.4 is more evolved than unit 3.0, with a significant depletion in heavy rare earth elements (HREE) ($[La/Yb]_N = 7.75$) combined with a strong Nb-Ta negative anomaly and a weak Zr-Hf negative anomaly (Fig. 4).

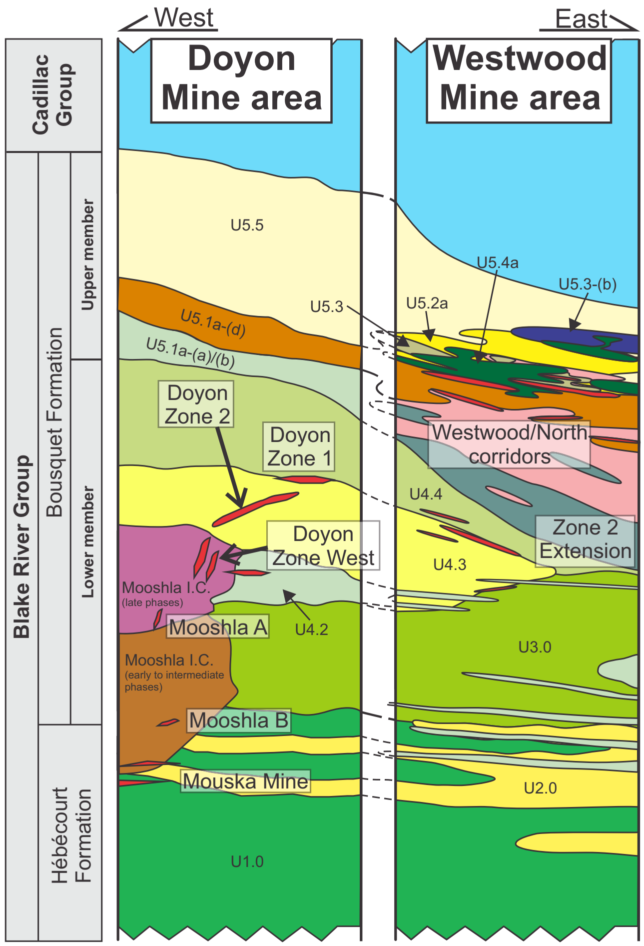


Figure 2. Schematic stratigraphic sections of the Westwood Mine and Doyon Mine areas. The Zone 2 Extension ore zone sits at the same level as the Doyon Mine zones 1 and 2. The North and Westwood corridors are hosted in the upper member of the Bousquet Formation. Modified from Mercier-Langevin et al. (2007a) and references therein.

Units 3.0 and 4.4 are cut by a series of intermediate to felsic massive sills and transposed dykes (units 4.2 and 4.3), with the most prominent ones located near or directly at the contact between the two mafic units. Unit 4.2 (2698.3±0.9 Ma; Lafrance et al., 2005) is characterized by metre-thick feldspar-phyric andesitic-dacitic sills and dykes, whereas unit 4.3 is characterized by aphanitic rhyodacitic sills and dykes, with both units being of transitional affinity (Fig. 3). The largest sill of unit 4.3 is up to 200 metres thick and gradually thins and disappears in the eastern part of the Westwood deposit. The composition of these two intrusive units contrasts with the composition of the other units of the Bousquet Formation lower member, but is very similar to that of the Bousquet Formation upper volcanic member units (see below).

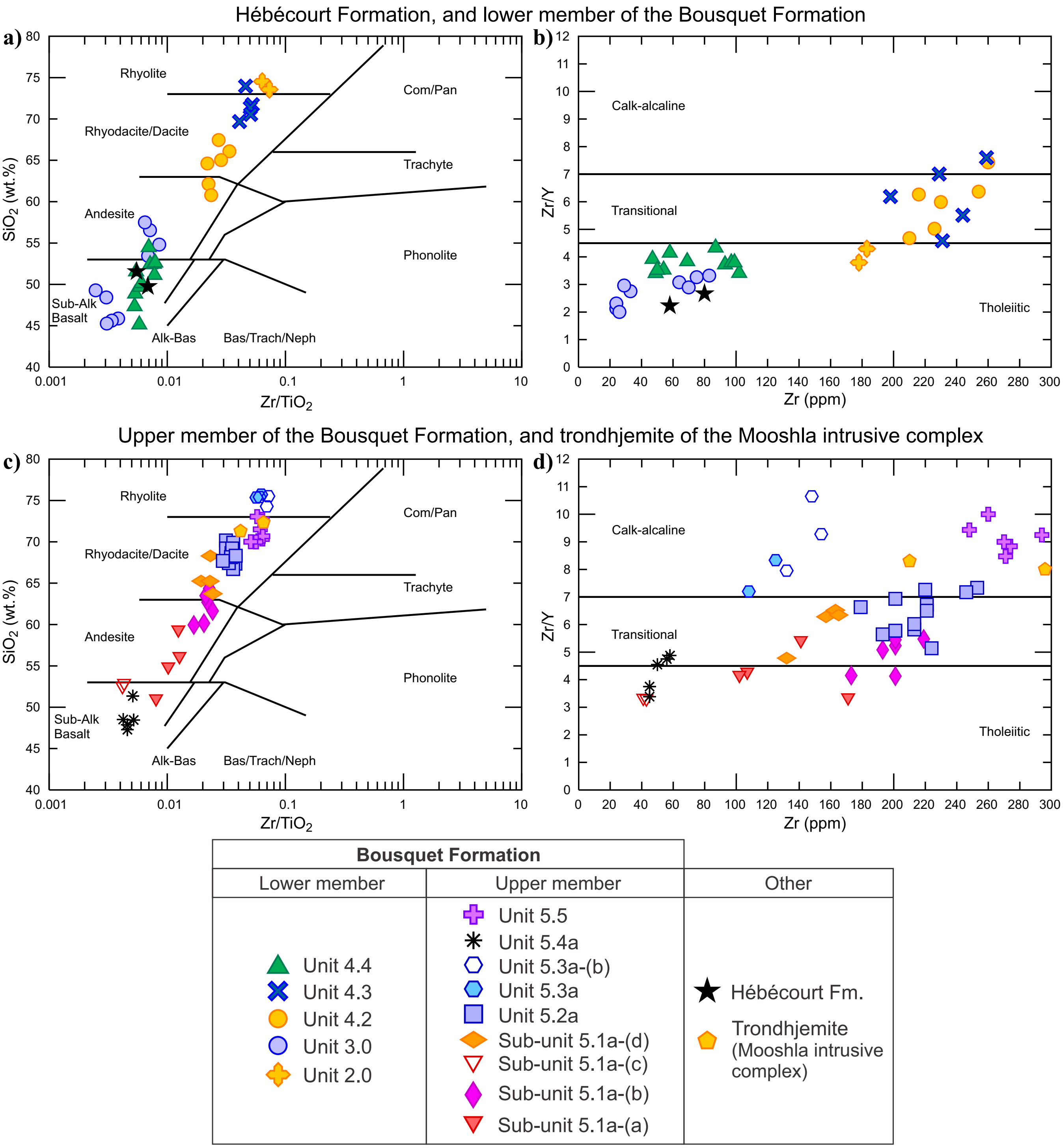
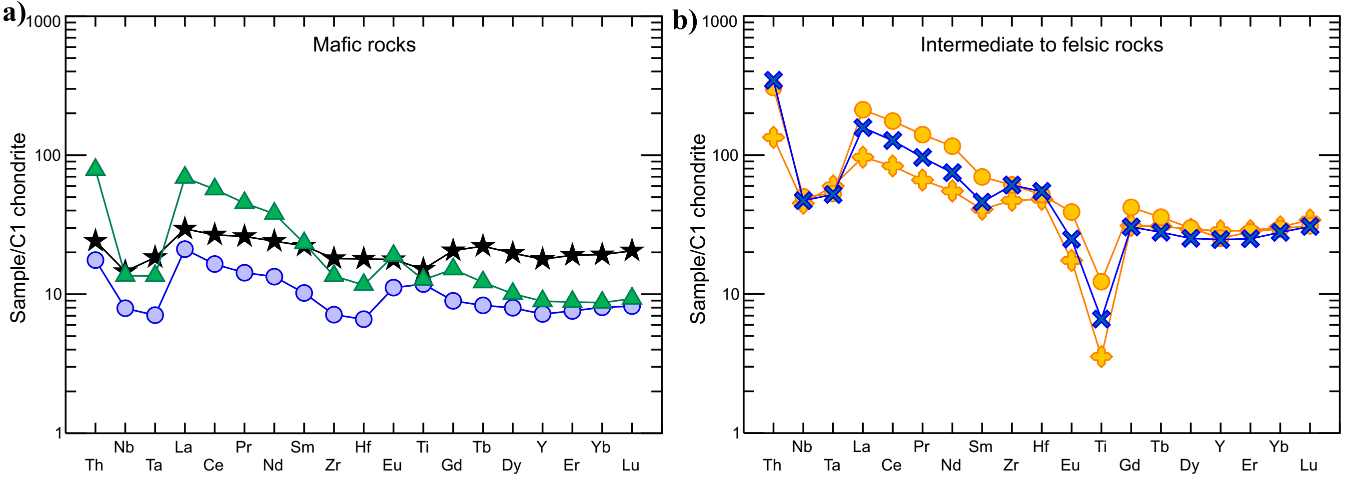


Figure 3. Major and trace element classification diagrams for the least-altered samples of the Westwood deposit host units. The Zr/TiO_2 vs SiO_2 (wt%) diagrams are from Winchester and Floyd (1977); the Zr (ppm) vs Zr/Y diagrams are from MacLean and Barrett (1993).

Upper Member of the Bousquet Formation

The upper member of the Bousquet Formation lies on top of units 4.4 or 3.0. The base of the upper member is composed of basaltic to andesitic (subunit 5.1a-(a)) and andesitic to dacitic (subunit 5.1a-(b)) volcanic rocks. Those two intercalated subunits consist mostly of amygdular and feldspar-phyric massive to brecciated flows. Both subunits are tholeiitic to transitional (Fig. 3), and characterized by a moderate to strong HREE depletion and Nb-Ta and Ti negative anomalies (Fig. 4).

The upper part of unit 5.1a contains spatially restricted dacitic domes and lobes (subunit 5.1a-(d)) intercalated with, or overlying, the two other subunits.


Hébécourt Formation, and lower member of the Bousquet Formation

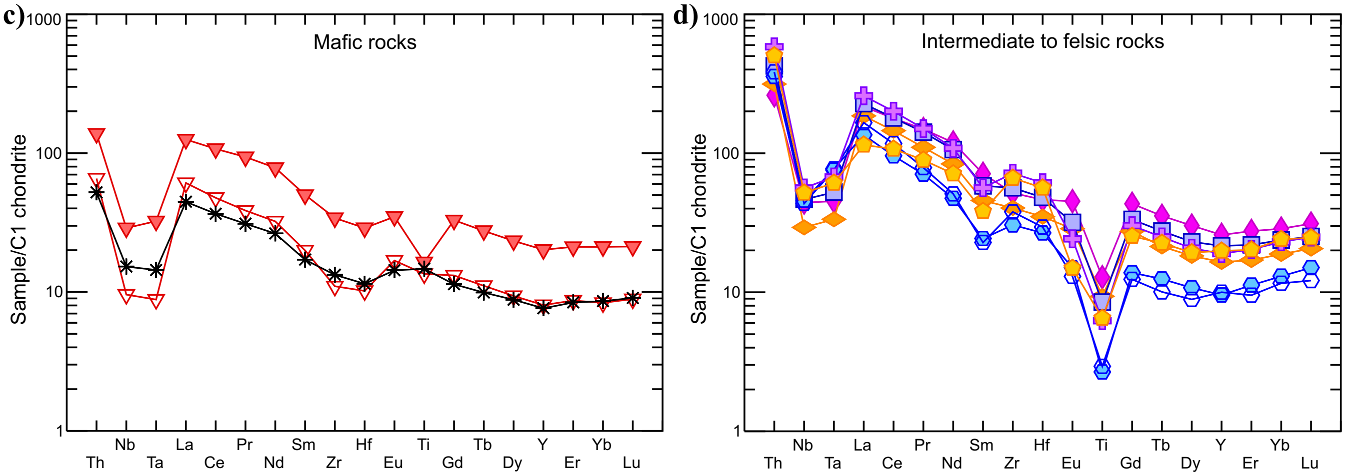

Upper member of the Bousquet Formation, and trondhjemite of the Mooshla intrusive complex

Figure 4. Chondrite-normalized trace and rare earth element diagrams for the Westwood deposit host units. C1 chondrite normalizing values from McDonough and Sun (1995). Unit symbols as in Figure 3.

It is mainly composed of aphanitic to feldspar-phyric volcaniclastic dacitic-rhyodacitic rocks (Fig. 5b) with local coherent facies. This transitional unit (Fig. 3) is significantly depleted in HREE ($[La/Yb]_N$ = 9.85) and has strong Nb-Ta and Ti negative anomalies (Fig. 4).

Unit 5.2a (2698.3±0.8 Ma; Mercier-Langevin et al., 2007a) overlies unit 5.1a and consists of a volcaniclastic and locally coherent volcanic feldspar-phyric dacitic-rhyodacitic rock sequence that is thicker in the central part of the deposit. Unit 5.2a is visually and geochemically similar to subunit 5.1a-(d) (Figs. 3 and 4) but it is slightly more felsic and generally much less altered (i.e. in the hanging wall of the VMS-type ore zones).

The uppermost effusive unit of the Bousquet Formation (unit 5.5; 2697.5±1.1 Ma; McNicoll et al., 2014) consists of rhyodacitic volcaniclastic rocks and locally massive lobes rich in feldspar phenocrysts and biotite microporphyroblasts. This unit is calc-alkaline (Fig. 3) and the rare earth element-high field strength elements (REE-HFSE) diagram shows depletion in HREE, strong negative Nb-Ta and Ti anomalies, and a positive Zr-Hf anomaly (Fig. 4).

Calc-alkaline, blue quartz- and feldspar-phyric rhyolitic dykes and sills (Fig. 3; 2697.8±1.0 Ma; Mercier-Langevin et al., 2007a), which are characterized by a pronounced negative Ti anomaly (unit 5.3a: Fig. 4), cut the felsic volcanic units (5.2a and 5.5) of the upper Bousquet Formation. All units of the upper member are subsequently cut by a series of synvolcanic, tholeiitic, basaltic to andesitic dykes and sills (Fig. 3 and 5c: subunit 5.1a-(c) and unit 5.4) that are geochemically similar to unit 4.4 (Figs. 3 and 4). A feldspar-phyric rhyolitic cryptodome (subunit 5.3a-(b)) is present within unit 5.5 in the eastern and upper part of the deposit. This unit has a similar geochemical signature to the unit 5.3a, but it does not contain blue quartz phenocrysts.

At least two centimetre- to decimetre-thick horizons of argillite are present in the upper Bousquet Formation. One of these horizons is located at the contact between

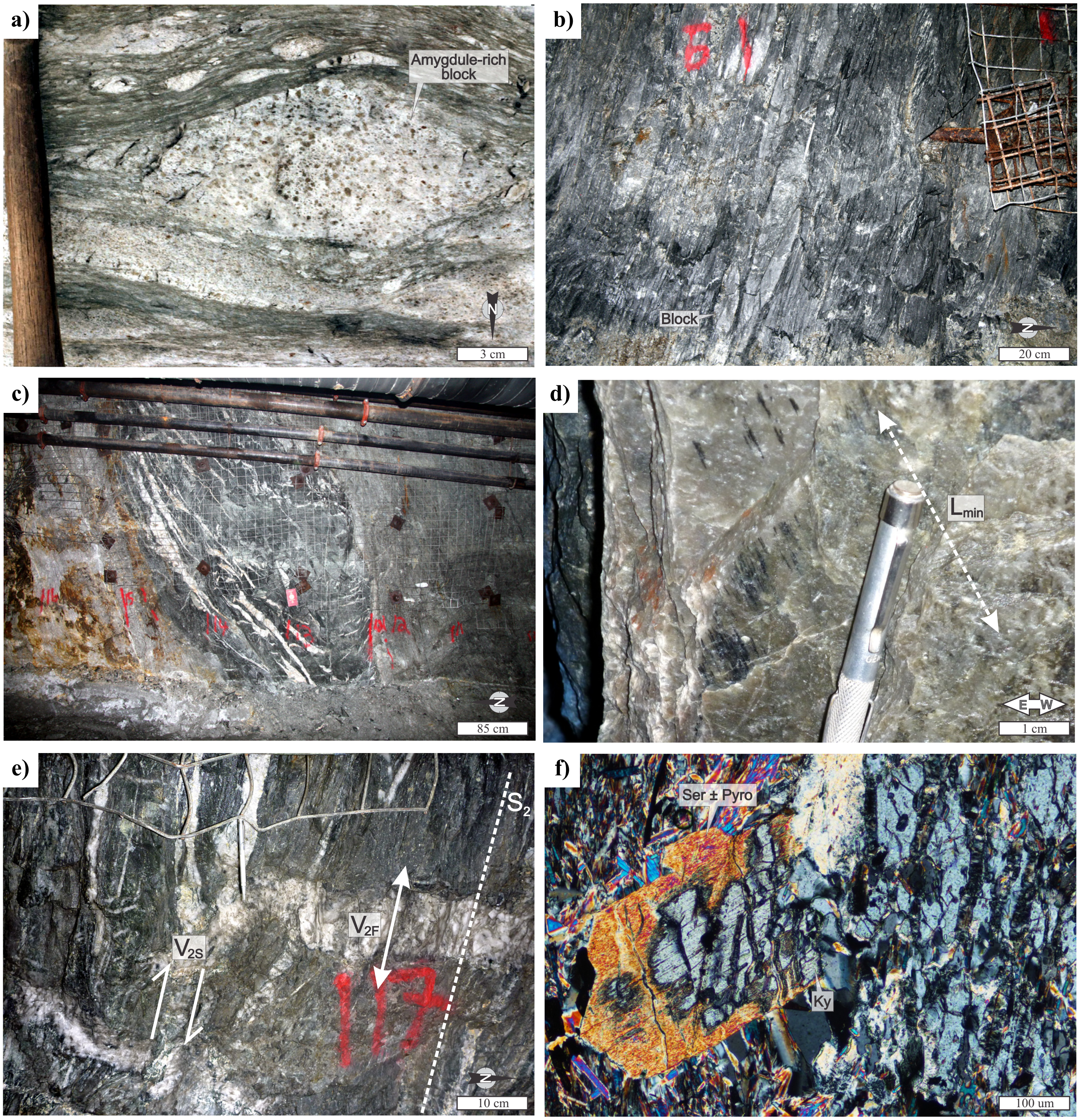


Figure 5. a) Mafic lapilli and block tuff of the Bousquet scoriaceous tuff (unit 3.0). The block shown contains 20% of epidote-quartz-filled amygdules. **b)** Felsic lapilli and block tuff of subunit 5.1a-(d) in the footwall of the Westwood Corridor. The matrix is altered in magnesian chlorite and sericite, whereas the fragments are weakly altered. **c)** Slightly altered mafic dyke of subunit 5.1a-(c) that crosscuts the intermediate volcanic rocks of subunit 5.1a-(b). **d)** Steeply west-dipping stretching lineation (L_{min}) on the S_2 plane characterized by the preferential orientation of chlorite. **e)** Extension flat quartz veins and S_2-parallel quartz veins (V_{2S}) generated during D_2 deformation. **f)** Kyanite crystal partially retrograded to sericite and pyrophyllite during the retrograde M_2 event. Abbreviations: Pyro = pyrophyllite, Ser = sericite.

unit 5.2a and the overlying unit 5.5, whereas a more spatially restricted horizon is located directly within unit 5.5 in the eastern part of the deposit. This argillite has a geochemical signature comparable to that of the upper member of the Bousquet Formation, and possibly represents sedimentation in local depressions during short volcanic hiatuses.

Less than 1 m-thick microcrystalline quartz-feldspar trondhjemite dykes of the Mooshla synvolcanic intrusive complex (Galley and Lafrance, 2014) crosscut unit

3.0 in the western, deep part of the Westwood deposit. The geochemistry of this unit is similar to that of felsic volcanic units 5.2a and 5.5 (Figs. 3 and 4).

The contact between the upper part of the Bousquet Formation and the overlying ≤2685 Ma Cadillac Group turbiditic sequence is characterized by a ≤1 m-thick horizon of massive pyrrhotite locally overlain by some argillite. The contact itself is traditionally interpreted as being structural or depositional (Mercier-Langevin et al., 2007b and references therein).

DEFORMATION AND METAMORPHISM OF THE WESTWOOD AREA

Deformation and related metamorphism are responsible for the modification of the primary geometry and mineralogy of the volcanic rocks, alteration zones, and ore zones. The first and most penetrative deformation event recognized (regional D_2 deformation) is characterized mainly by a penetrative east-west subvertical S_2 schistosity, a west-plunging stretching lineation (L_{min}; Fig. 5d), and local subhorizontal isoclinals folds (F_2). Those features are interpreted to be related to the major north-south shortening episode that characterizes the southern Abitibi greenstone belt (Dimroth et al., 1983). Two conjugate sets of quartz veins (flat subhorizontal veins (V_{2F}) and steeply dipping and boudinaged veins parallel to S_2 (V_{2S}); Fig. 5e) are also associated with D_2 deformation. Syn-D_2 stretching is responsible for the elongation of the ore zones and the development of perpendicular subhorizontal ore shoots. When the quartz veins cross-cut the ore zones, some of the most mobile elements (i.e. mostly Cu, Au, Ag, Pb, and Te) are remobilized in the quartz veins that are otherwise barren in the area. Free gold has also been found directly coating the S_2 plane within highly sericitized and schistose rocks adjacent to ore zones. Various structural elements that were discordant to the bedding (S_0) during D_2 deformation are highly transposed and folded, whereas those subparallel to S_0 are flattened and stretched (boudinaged). Although no specific fabric is attributed to the D_1 deformation in the Westwood area, it is interpreted as being responsible for the tilting of the volcanic sequence to the south (Yergeau, 2015).

Subsequent deformation events have had much less influence on the ore zones and the host rocks. The D_3 deformation is responsible for the development of a subvertical northeast-southwest cleavage in sericitized rocks that could have locally remobilized some metals. The D_4 deformation is associated with the development of three conjugated sinistral/dextral sets of discrete subvertical faults (northeast-southwest, northwest-southeast, and north-south) that locally displace ore zones over less than 3 m. The Bousquet Fault, a northeast-southwest brittle structure that divides the Westwood deposit in half with a ~250 m sinistral displacement is also associated with D_4. The final D_5 deformation event is associated with three sets of conjugate joints (subhorizontal, north-south/east-west subvertical) that locally remobilize some base and precious metals.

The M_1 prograde metamorphic event is syn- to late-D_2 deformation. Peak metamorphic conditions are estimated at 450–550ºC (upper greenschist), based on the presence of chlorite-epidote-actinolite-biotite ± hornblende in mafic volcanic rocks and biotite-sericite-chloritoid ± staurolite in sedimentary rocks in the upper part of the deposit. In the deeper part of the mine (>1500 m) on the eastern side of the Bousquet fault, the pressure-temperature (P-T) conditions are slightly more elevated, at 500–600ºC (lower amphibolite), with hornblende-biotite-garnet-epidote ± chlorite-actinolite-staurolite in mafic rocks and biotite-sericite-staurolite-garnet in sedimentary rocks. This gradual increase of the P-T conditions with increasing depth affects the mineralogy of the metamorphosed alteration assemblages. For example, aluminosilicate minerals (i.e. andalusite, kyanite, and Zn-staurolite) are present, along with sericite, in the argillic-style alteration (or phyllic) at depth, whereas the same alteration closer to surface consists exclusively of quartz and sericite. The coating by M_1 magnetite of S_2-flattened pyrite and pyrrhotite in the deeper part of the Westwood Corridor indicates that oxidation and desulphurization processes occurred at depth during metamorphism.

The M_1 prograde metamorphism is followed by a greenschist-facies retrograde metamorphism (M_2). This is indicated by the partial replacement of hornblende and biotite by chlorite, of Mn-garnet by chlorite and carbonate, and aluminosilicates (i.e. andalusite and kyanite) by sericite and pyrophyllite (Fig. 5f).

MINERALIZATION AND ALTERATION ZONES OF THE WESTWOOD DEPOSIT

This section presents a brief description of each mineralized corridor. The main features of each corridor are summarized in Table 1. A very detailed description of the ore and alteration zones at Westwood can be found in Yergeau (2015).

Zone 2 Extension

The Zone 2 Extension ore zones are spatially associated with the felsic to intermediate dykes and sills of units 4.2 and 4.3, which crosscut the mafic volcanic rocks of the lower member of the Bousquet Formation. The ore zones consist of sulphide-rich quartz veins, and zones/bands of sulphide dissemination that can locally form semi-massive sulphides. The veins and sulphide bands are deformed, boudinaged, and transposed within the main S_2 schistosity and locally seem to be overprinted by quartz veins that are themselves

Table 1. The main features of the Zone 2 Extension, North Corridor, and Westwood Corridor of the Westwood deposit.

	Zone 2 Extension	North Corridor	Westwood Corridor
Types of ore zones	Disseminated to semi-massive sulphides and sulphide-quartz veins	Massive to semi-massive sulphide veins/veinlets and disseminated sulphides	Massive to semi-massive sulphide veins/veinlets, disseminated sulphides, and massive sulphide lenses
Major host units	4.2, 4.3, and 4.4	5.1a-(a), and 5.1a-(b)	5.1a-(b), 5.1a-(d), 5.2a, 5.3a, and 5.4a
Thickness	0.1 m to <5 m	0.1 m to <1 m	0.1 m to 14 m (massive sulphide lenses)
Extent of ore zones	<500 m^2 to >200 m X 1 km	<500 m^2 to >200 m X 800 m	<500 m^2 to 300 m X 1.5 km
Major sulphide phases	Pyrite-Chalcopyrite	Pyrite-Sphalerite-Chalcopyrite	Pyrite-Sphalerite-Chalcopyrite± Galena
Accessory minerals	Sphalerite-Pyrrhotite	Pyrrhotite-Galena-Arsenopyrite	Pyrrhotite-Arsenopyrite-Stannite-Magnetite ± Gahnite-Cassiterite
Trace minerals	Galena-Gold-Melonite-Tellurobismuthite-Tetradymite	Gold-Electrum-Melonite-Tellurobismuthite-Tetradymite-Petzite-Sylvanite	Gold-Electrum-Melonite-Tellurobismithite-Tetradymite-Petzite-Sylvanite-Volynskite
Trace elements suite	B-Cd-Mo-Sb-Sn-W-As-Bi-In-Co-Hg-Se-Te	Sn-Bi-Sb-Mo-As-In-Cd-Hg-Se-Te	Bi-W-Sn-In-As-Cd-Sb-Hg-Se-Te
Metals associated with gold	Ag-Bi-Sb-W-Sn-Co-B-Mo-Te	Sb-Cd-Zn-Pb-Mo-Te	Cu-Bi-Ag-Te
Au/Ag ratio	2	1.95	0.26

deformed by D_2 (Fig. 6a). Sulphide-rich veins are thought in some cases to represent remobilization of disseminated sulphides during D_2 deformation. Replacement and breccia textures are commonly present and the vein contacts with the host rocks are usually gradational. At deposit scale, some of the ore zones seem to merge, forming a flattened, anastomosed pattern. The sulphides consist mainly of pyrite and/or chalcopyrite, although sphalerite and galena can constitute as much as 80% of the ore zones very locally. The sulphide-quartz veins/bands and disseminated sulphide zones are up to a metre wide but are laterally and vertically extensive, being transposed within the S_2 schistosity and subvertical stretching lineation. Native Au, electrum, and tellurides are common as microscopic trace minerals in association with the sulphides. Early pyrite grains, preserved from recrystallization, are enriched in Au, suggesting that Au was mainly within the pyrite lattice prior to the D_2 metamorphism (laser-ablation ICP-MS analysis). Gold-rich early pyrite is present in all three mineralized corridors (Yergeau, 2015). The most laterally extensive and richest veins are hosted in the main sill of unit 4.3, and close to, or at the contact with, the overlying unit 4.4. Several Zone 2 Extension ore zones are also associated with smaller satellite felsic dykes and sills located on both sides of the main unit 4.3 intrusion. The presence of these felsic dykes and sills seems to be an important element in the development of the Zone 2 Extension veins, as most of the veins are spatially associated with the dykes. A preliminary U/Pb ID-TIMS zircon crystallization age of 2699 Ma, obtained from an unaltered but strongly foliated mafic dyke that cuts the proximal alteration associated with the Z2-31 zone (Zone 2 Extension), suggests that the Zone 2 Extension mineralization is pre-D_2 deformation.

The Zone 2 Extension ore zones are accompanied by a sericite-quartz-pyrite ± gypsum-albite halo that can be up to a few tens of metres thick. Mass balance calculations indicate K-Ba-S-Fe gains and Ca-Na-Mn-Mg losses in that alteration halo. This assemblage is interpreted as a metamorphosed argillic- or phyllic-style alteration. This alteration overprints a much larger chlorite-carbonate-biotite-garnet alteration assemblage that is commonly associated with all the Doyon-Bousquet-LaRonde VMS-type ore zones (Fig. 6b; Mercier-Langevin et al., 2007b). Locally, some intensely leached zones (i.e. advanced argillic-style alteration) are present in the hanging wall of the ore zones and are characterized by a metamorphic assemblage of quartz-andalusite-kyanite-pyrophyllite ± sericite-gypsum where all mobile elements were leached.

North Corridor

North Corridor ore zones are preferentially hosted in the mafic to intermediate volcanic rocks of subunits 5.1a-(a) and 5.1a-(b) at the base of the upper member of the Bousquet Formation. This mineralized corridor is composed of semi-massive to massive sulphide veins and dissemination zones that can be up to a few metres wide, and characterized by pyrite and sphalerite with lesser amounts of quartz, chalcopyrite, and pyrrhotite with local traces of galena. Some veins are also exceptionally rich in chalcopyrite (i.e. >30%) or sphalerite. Gold is present as free Au, electrum, and tellurides. The North Corridor ore zones have strongly recorded the D_2 deformation, and consequently tight to isoclinal

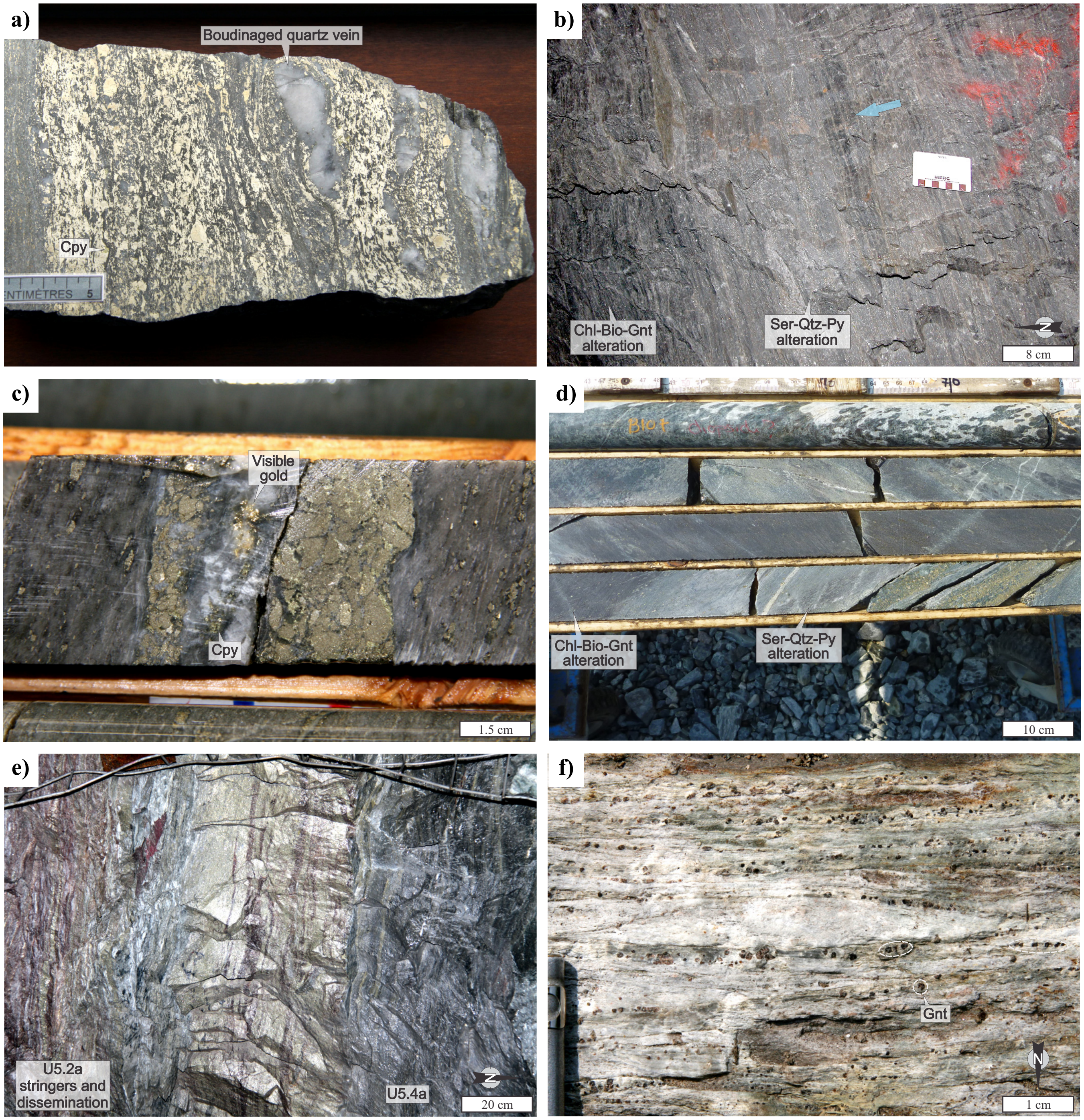


Figure 6. a) The Z2-30 (Zone 2 Extension) vein, composed mainly of pyrite with minor chalcopyrite, is strongly affected by the D$_2$ deformation event. Boudinaged orogenic quartz veins cut the Z2-30 in this sample. **b)** Sericite-quartz-pyrite alteration associated with the Zone 2 Extension overprinting the background chlorite-biotite-garnet alteration related to the North and Westwood corridors. A zone of background alteration is preserved in the sericite-dominated alteration (blue arrow). **c)** Deformed massive pyrite ± chalcopyrite vein of the North Corridor hosted within a sericitized andesite of subunit 5.1a-(b). A quartz vein crosscuts the sulphide vein and contains remobilized Au. **d)** Sericite-quartz-pyrite alteration halo surrounding a North Corridor ore zone. **e)** Banded pyrite-sphalerite massive sulphide lens of the Westwood Corridor overlain by a pyrite-sphalerite ± chalcopyrite stringer zone hosted in unit 5.2a. The footwall is composed of a mafic sill of unit 5.4a. **f)**. Manganiferous garnet alteration in a lapilli and block tuff of subunit 5.1a-(b) in the footwall of the Westwood Corridor. Abbreviations: Bio = biotite; Chl = chlorite; Cpy = chalcopyrite; Gnt = garnet; Py = pyrite; Qtz = quartz; Ser = sericite.

folding (shortening/transposition) of the veins and veinlets is common. Replacement and breccia textures are typical and sulphide-filling of volcanic vesicles is common in the vein selvages. The ore zones are preferentially developed within high-permeability rocks (i.e. mostly volcaniclastic rocks and vesicle-rich rocks) that are overlain by low-permeability cap rocks (i.e. massive lavas and intrusions). Syntectonic quartz veins that cut the ore zones are usually rich in Au and base metals as they caused, or are the locus of, some local metal remobilization in the three mineralized corridors (e.g. Fig. 6c). The North Corridor ore zones are spatially associated with the overlying mineralization of the Westwood Corridor that is less than 100 m higher in the stratigraphic sequence. The North Corridor mineralization is thought to represent a failed VMS-type system or a footwall replacement zone associated with the Westwood Corridor, which consists of more classic subseafloor to seafloor VMS-type mineralization, as described below.

The metamorphosed hydrothermal alteration surrounding the North Corridor ore zones consist of a few metres- to a few tens of metres-thick alteration halo characterized by a sericite-quartz-pyrite ± albite-biotite-carbonate-chlorite-Mn-garnet assemblage (Fig. 6d). Mass balance calculations indicate that this proximal alteration is marked by gains in K-Ba-Si-S-Fe-Mn-CO_2 and losses in Na-Ca-Mg.

Westwood Corridor

The Westwood Corridor is located at the same stratigraphic position as the massive sulphide lenses of the LaRonde Penna and Bousquet 2-Dumagami mines, which are located in the eastern part of the mining camp (Mercier-Langevin et al., 2009). The Westwood Corridor ore zones are mainly hosted in, or at the contact between, the volcanic intermediate to felsic units 5.1a-(b), 5.1a-(d) and 5.2a and the lower contact of, and locally within, the felsic and mafic dykes and sills of units 5.3a and 5.4a. The ore zones consist of sulphide-rich veins, disseminated sulphide zones, and stratabound semi-massive to massive sulphide lenses (Fig. 6e). Dissemination zones can be up to 10 m wide, whereas the veins are usually less than a metre thick. The massive sulphide lenses are up to 14 m thick. The veins, disseminated sulphide zones, and semi-massive sulphides can be laterally very extensive (i.e. > 800 m), whereas the massive sulphide lenses are spatially restricted and associated with felsic domes of subunit 5.1a-(d). Felsic breccia, rich in auriferous massive sulphide fragments, is also locally present. All ore zones are strongly affected by deformation; transposition, boudinage, and stretching, as well as piercement structures associated with D_2 deformation are common within the massive sulphide lenses. The massive sulphide lenses are elongated parallel to the stretching lineation, with subhorizontal Au-Ag-Cu-rich ore shoots which are perpendicular to the L_{min} lineations that are present within the lenses. Pyrite and sphalerite are the most abundant sulphides; chalcopyrite, galena, and pyrrhotite usually form less than 10% of the mineralized material, although some ore zones are locally quite rich in chalcopyrite and/or galena (i.e. >15%). Replacement of permeable volcanic rocks seems to be the main mineralizing process for the vein and disseminated sulphide zones. Free Au, electrum, tellurides, and primary pyrite are the main hosts for Au. Traces of stannite, arsenopyrite, gahnite, Zn-rich staurolite, and magnetite are locally present.

The metamorphosed hydrothermal alteration halo associated with the Westwood Corridor consists of a very extensive (<1 km), semi-conformable footwall chlorite-biotite-carbonate-Mn-rich garnet ± albite-tourmaline alteration assemblage. This alteration assemblage seems to be linked in time and space with the footwall alteration associated with the other VMS lenses of the district. Sodium leaching and gains in K, Ba, Mn, S, Fe, and CO_2 characterize this footwall alteration zone. The abundance of Mn-garnet generally increases toward the ore zones and can locally represent as much as 30 vol.% of the rock (Fig. 6f). The ore zones are wrapped in a plurimetric, proximal quartz-sericite-pyrite ± garnet-albite-tourmaline alteration envelope that overprints the distal alteration. Mass loss of Ca, Na, and Mg and gains of K, Ba, S, Fe, and Mn are associated with this alteration. At depth in the deposit (>1500 m), Zn-rich staurolite, kyanite, andalusite, gahnite, and magnetite are present in the alteration halos of the Westwood and North corridors ore zones. The development of aluminosilicate porphyroblasts is interpreted as being the result of a slight increase in the metamorphic grade at depth, combined with perhaps subtly more acidic hydrothermal alteration conditions in this part of the deposit. The presence of late-M_1 magnetite grains that partially replace pyrite and pyrrhotite is possibly related to the desulphurization and oxidation of sulphides during lower amphibolite-facies metamorphism.

SIMPLIFIED GENETIC MODEL

The Westwood deposit is characterized by different styles of Au ± base metals ore zones, which are stacked in the host stratigraphic succession. The lowermost ore zones consist of sulphide-rich quartz veins and disseminations that are thought to be an extension of the Doyon Mine intrusion-associated Au deposit to the west; whereas the uppermost ore zones are similar to the Au-rich VMS deposits of the Bousquet 2-Dumagami and LaRonde Penna mines to the east (Fig. 1). The intensity of the deformation in the Westwood

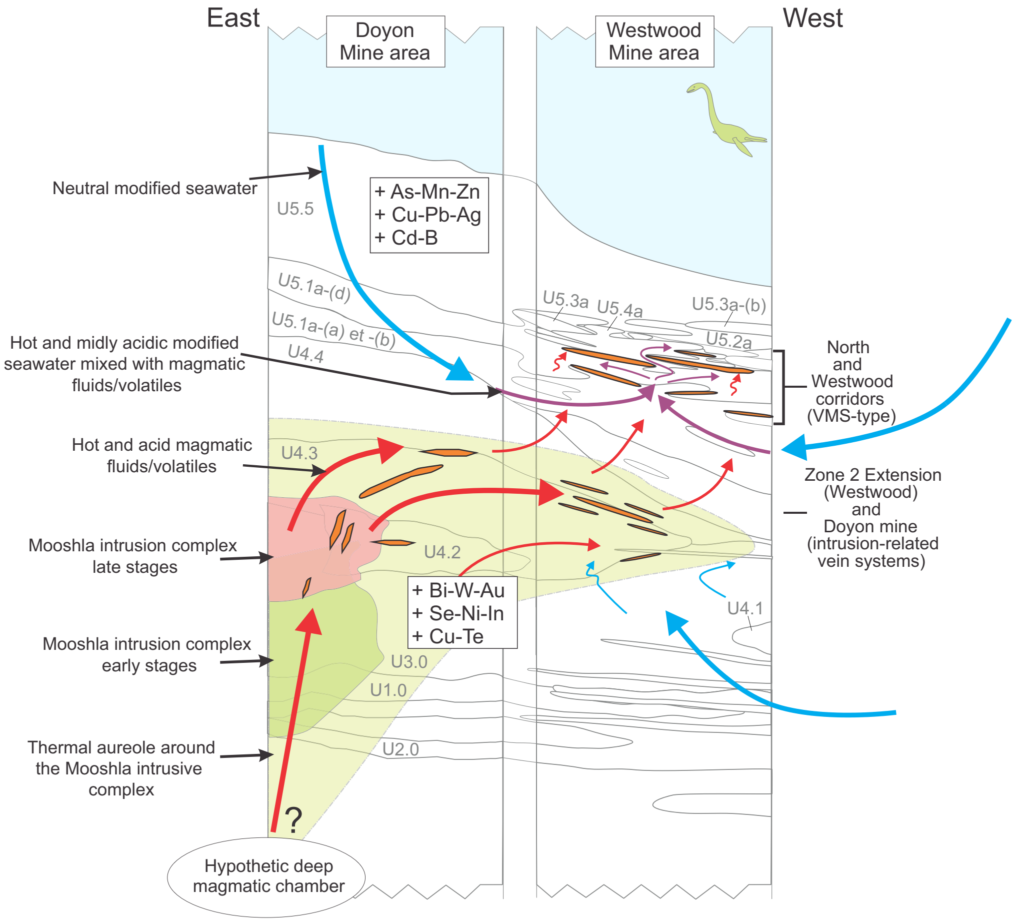


Figure 7. Schematic longitudinal section showing the origin of hydrothermal fluids that generated the Zone 2 Extension, Doyon mine ore zones, and North and Westwood corridors. The Zone 2 Extension represents the distal expression of the intrusion-related magmatic-hydrothermal system centred on the upper part of the Mooshla intrusive complex (i.e. Doyon Mine ore zones). The magmatic fluids/volatiles that were involved in the genesis of these ore zones were possibly exsolved from the crystallizing felsic late phases of the Mooshla intrusive complex. A deep magmatic chamber could also be the source of the fluids. The North and Westwood corridors result from the circulation of modified seawater within the volcanic edifice, in which a magmatic input from the Mooshla intrusion or from the passive degassing of the volcanic rocks might explain the anomalous Au enrichment of the fluids.

area is such that we can only speculate on the primary architecture of the system. Previous studies and our current work at Westwood, however, provide a number of geological, geochemical, and geochronological constraints that can be used to better understand the system prior to deformation.

The Zone 2 Extension ore zones (and those of the Doyon Mine) are spatially and interpreted as genetically associated with the Mooshla synvolcanic intrusive complex that generated (or channelled) magmatic volatiles/fluids during the crystallization of its late felsic calc-alkaline phases (e.g. Galley and Lafrance, 2014; Fig. 7). These magmatic volatiles, which possibly carried Au and Cu, escaped the intrusion and were transported into the overlying volcanic rocks of the lower Bousquet Formation, preferentially along the felsic sills and dykes of units 4.2 and 4.3. The seafloor and subseafloor-style mineralized zones of the Westwood and North corridors are associated with the development of a large hydrothermal cell comprising a dominant modified seawater component. This seawater-dominated hydrothermal system was fuelled by a temperature gradient associated with the hot volcanic and intrusive rocks of the Bousquet Formation. The presence of impermeable cap rocks (i.e. massive lavas and sills) is essential to the subseafloor maturation of the hydrothermal systems. The presence of felsic volcanic or talus breccias containing auriferous massive sulphide fragments suggests that at least some of the ore was potentially formed by exhalative activity on the seafloor. The presence of stacked semi-massive to massive sulphide lenses and disseminated sulphide zones at different stratigraphic levels suggests that the seafloor hydrothermal system was capped and became a subseafloor hydrothermal system during the evolution of the Bousquet Formation (e.g. replacement ore zones in the hanging wall of the seafloor massive sulphide lenses and laterally; Fig. 6e). By analogy with the neighbouring Bousquet 2-Dumagami and LaRonde Penna Au-rich VMS deposits (e.g. Dubé et al., 2007, 2014; Mercier-Langevin et al., 2007b), the Au enrichment of the VMS-type ore zones at Westwood is interpreted to be due to magmatic input into the circulating modified seawater. Geochronology indicates that the volcanic and intrusive rocks of the Bousquet Formation were emplaced in less than two million years, and crosscutting relationships and relative timing regarding deformation and metamorphism suggest that the intrusion-related and VMS-type hydrothermal systems are more or less coeval with volcanism. The mixing of fertile magmatic fluids/volatiles with modified seawater is, in this context, a viable hypothesis to explain the Au-rich VMS deposition (e.g. Dubé et al., 2014). In light of what has been summarized here, previous work in the district, and an in-depth discussion on the nature of the Westwood deposit in Yergeau (2015), the Westwood deposit is interpreted as part of an Archean subaqueous, telescoped magmatic-hydrothermal system that shares some similarities with subaerial porphyry-epithermal systems that are generated in younger volcanic arcs (e.g. Hedenquist et al., 1998).

IMPLICATIONS FOR EXPLORATION

Transitional to calc-alkaline, basalt-andesite-dacite-rhyodacite-rhyolite volcanic and intrusive suites (i.e. more oxidized and fluid-rich "arc" magmas) represent good targets for synvolcanic gold deposits. At the district scale, the upper part of multiphase synvolcanic calc-alkaline intrusive complexes may represent favourable targets for Archean intrusion-related Au and Au-Cu deposits, especially if Au-rich VMS-style mineralization is present nearby. Manganiferous and potassic alteration halos combined with sodium depletion are good indicators of modified seawater circulation in the volcanic edifice, whereas combined positive barium and potassium anomalies are more commonly associated with intrusion-related ore zones. The presence of permeable volcaniclastic rocks facilitates fluid infiltration and efficient precipitation of sulphides in the subseafloor environment through replacement of the host rocks, whereas the presence of impermeable sills and dykes is key for the channelling of Au-enriched magmatic fluids.

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