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Critical review

A. Galley

Authors

A. Wright-Holfeld
(Abhidheya.wright_holfeld@ete.inrs.ca),
INRS-ETE,
490, rue de la Couronne
Québec, Quebec
G1K 9A9

P. Mercier-Langevin
(Patrick.Mercier-Langevin@RNCan-NRCan.gc.ca),
B. Dubé
(Benoit.Dube@RNCan-NRCan.gc.ca)
Geological Survey of Canada
490, rue de la Couronne
P.O. Box 7500
Québec, Quebec
G1K 9A9

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Contrasting alteration mineral assemblages associated with the Westwood deposit ore zones, Doyon-Bousquet-LaRonde mining camp, Abitibi, Quebec

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Abstract: The Westwood deposit is located in the prolific Doyon-Bousquet-LaRonde mining camp of the Abitibi greenstone belt. The gold-rich polymetallic ore zones of the Westwood deposit are located in three stacked corridors from north to south: zone 2 extension, north corridor, and Westwood-Warrenmac corridor.

The mineralized zones at the Westwood deposit are associated with contrasting alteration assemblages and ore styles described in this report. The study presented here is focused on a selection of closely spaced drill-holes that are aligned on a vertical cross-section cutting through the three mineralized corridors in the central part of the deposit. Widespread quartz-chlorite-sericite alteration and proximal Mn-garnet alteration suggest a volcanogenic massive-sulphide–style alteration halo for the Westwood-Warrenmac and north corridors. Intense deformation and stacking or telescoping of alteration halos hinders a definitive interpretation for the origin of the zone 2 extension veins and dissemination-style mineralization and sericite-quartz alteration assemblage, but a synvolcanic origin cannot be ruled out. Observations made at Westwood suggest that primary permeability of volcanic rocks played a major role in controlling the ore and alteration distribution. Based on these observations, the north and Westwood-Warrenmac corridors are thought to be Au-rich volcanogenic massive-sulphide lenses. The north corridor polymetallic veins may also represent feeders to the ore lenses found higher in the stratigraphy. The zone 2 extension shares characteristics with Au-rich sulphide veins and disseminations typical of the neighbouring Doyon intrusion-related deposit, yet has some alteration traits similar to those of the north corridor and Westwood-Warrenmac ore zones.

Résumé : Le gisement de Westwood est situé dans le prolifique camp minier Doyon-Bousquet-LaRonde, dans la ceinture de roches vertes de l'Abitibi. Les zones minéralisées polymétalliques riches en or de ce gisement sont contenues dans trois corridors qui se superposent du nord vers le sud : zone 2 extension, corridor nord et corridor Westwood-Warrenmac.

Les zones minéralisées du gisement de Westwood sont associées à des assemblages contrastants de minéraux d'altération et à différents styles de minéralisation, qui sont décrits dans le présent rapport. Cette étude porte principalement sur une sélection de sondages rapprochés s'alignant le long d'une coupe transversale verticale qui recoupe les trois corridors minéralisés dans la partie centrale du gisement. Dans les corridors nord et Westwood-Warrenmac, l'altération étendue en quartz-chlorite-séricite et l'altération proximale en grenat manganésifère suggèrent la présence d'une auréole d'altération de style SMV (sulfures massifs volcanogènes). À cause de la déformation intense et de l'empilement ou du télescopage des auréoles d'altération, il est difficile de fournir une interprétation définitive de l'origine des filons de la zone 2 extension, de la minéralisation disséminée, et de l'assemblage d'altération séricite-quartz, mais on ne peut écarter la possibilité d'une origine synvolcanique. Certaines observations du gisement de Westwood indiquent que la perméabilité primaire des roches volcaniques a eu un effet déterminant sur la répartition des zones minéralisées et des zones d'altération. Ces observations laissent supposer que les corridors nord et Westwood-Warrenmac sont des lentilles de sulfures massifs volcanogènes riches en or. En outre, les filons polymétalliques du corridor nord représenteraient des filons nourriciers pour les lentilles minéralisées de position stratigraphique supérieure. Dans la zone 2 extension, les minéralisations en filons et en disséminations de sulfures riches en or ressemblent aux minéralisations typiques du gisement de Doyon voisin, qui est associé à une intrusion, alors que certains aspects de l'altération rappellent les zones minéralisées des corridors nord et Westwood-Warrenmac.

INTRODUCTION

Documenting the geological characteristics and understanding the genesis of the newly discovered Westwood deposit (resources of 9.48 Mt at 11.45 g/t Au: 3.46 Moz (108.6 t) of Au; Iamgold Corp. press release, June 22, 2009), located in the Doyon-Bousquet-LaRonde mining camp in the Abitibi Subprovince of northwestern Quebec (Fig. 1), is an opportunity to further increase the understanding of auriferous synvolcanic mineralizing systems. The study of the Westwood deposit ore zones is also key to the characterization and classification of contrasting styles of ore found in volcanic environments. There are four types of mineralization known in the Doyon-Bousquet-LaRonde mining camp: 1) Au-rich volcanogenic massive-sulphide deposits; 2) Au-rich sulphide veins, stockworks, and disseminations; 3) epizonal 'intrusion-related' sulphide-rich Au-Cu vein systems; and 4) orogenic ((?)remobilized) sulphide-rich Au-Cu vein systems (Mercier-Langevin et al., 2008a). The ore zones of the Westwood deposit collectively share some similarities with these four mineralization types (Mercier-Langevin et al., 2009). Therefore, there is a need for a detailed description and characterization of the Westwood deposit before any attempt is made at classifying the deposit and discussing its genesis; however, the Doyon-Bousquet-LaRonde mining camp area, and especially the Westwood deposit area, is characterized by high-strain zones that in many places hinders recognition of primary features such as volcanic textures and facies, and original crosscutting relationships, adding a level of complexity to the study of these deposits.

The Westwood deposit is characterized by three mineralized zones that are stacked from north to south in the Bousquet Formation: the zone 2 extension, the north corridor, and the Westwood-Warrenmac corridor (Fig. 2). Each of these zones is associated with alteration, the geochemical and mineralogical signatures of which extend over several tens of metres to hundreds of metres (Fig. 3). Because of stacking of mineralized horizons, and superimposed host rocks that represent repeated volcanic activity, difficulty arises in accurately defining the temporal and spatial relationships between unique hydrothermal alteration footprints and distinct mineralizing events. Stacking of synvolcanic ore lenses implies sequential emplacement of mineralization, and may indicate that some overprinting of older alteration signatures by younger events occurred. It is equally possible that the alteration assemblages observed is the result of a single long-lived hydrothermal event that has been subsequently metamorphosed.

Study of the Westwood deposit geology and mineralization was undertaken by the Geological Survey of Canada, Iamgold Corp., and the Ministère des Ressources Naturelles et de la Faune du Québec (MRNF) as part of a metallogenic synthesis of the Doyon-Bousquet-LaRonde mining camp that includes a Master's thesis at the INRS-ETE that is presented in part by this interim report.

The main aspect of research undertaken for this study was diamond-drill core logging of six drillholes on the Iamgold Corporation property adjacent to the Doyon mine during the summers of 2007 and 2008 to document the alteration assemblages in order to gain an understanding of the hydrothermal signatures associated with the ore zones. In the following description and discussion, the focus is on data gathered from and observations made in two drillholes, R14070-06 and R14286-07, but data and key observations from all six studied drillholes are incorporated. Like the other drillholes in this study, these two drillholes crosscut the volcanic stratigraphy approximately perpendicularly, and are relatively close together (50–250 m vertically and horizontally) which allows for correlation of host units, volcanic textures, ore horizons, alteration assemblages, as well as large-scale structures like the Bousquet fault zone (Fig. 2).

Major-element and precious-metal geochemical profiles were constructed to detect and illustrate variations in host-rock composition and hydrothermal alteration footprints. Some deposit-scale geochemical trends can be identified and correlated with mineralized horizons, and may serve as ore vectors, despite the complex geometry of the lithological units in the study area, and the complex geochemical characteristics of each of these units. For this report, alteration minerals associated with the three corridors of mineralization and their distribution in drillholes R14070-06 and R14286-07 were studied in detail to define more specifically the alteration assemblages associated with each mineralized corridor and therefore better understand the nature of the hydrothermal event or events that were responsible for the formation of the mineralized horizons at the Westwood deposit. This better understanding will also increase exploration effectiveness in the continued evaluation for other Au-rich deposits in the Doyon-Bousquet-LaRonde mining camp and elsewhere.

REGIONAL GEOLOGICAL SETTING

The Westwood deposit is located in the eastern extremity of the Blake River Group in the Archean Abitibi greenstone belt in northwestern Quebec (Fig. 1a). The 2704–2695 Ma Blake River Group (Péloquin et al., 1990; Mortensen, 1993; Barrie et al., 1993; Ayer et al., 2002; Lafrance et al., 2005; McNicoll et al., 2009) consists predominantly of submarine mafic to intermediate volcanic rocks, with lesser amounts of felsic volcanic rocks, as well as several significant synvolcanic intrusive bodies (Lafrance et al., 2003, and references therein).

Four types of mineral deposits are recognized in the Doyon-Bousquet-LaRonde mining camp: Au-rich volcanogenic massive-sulphide deposits (e.g. LaRonde Penna and Bousquet 2-Dumagami; Au-rich sulphide veins, stockworks and disseminations (e.g. Bousquet 1 and Doyon zone 1); epizonal 'intrusion-related' sulphide-rich Au-Cu vein systems (e.g. Doyon Zone 2 and west zone); and orogenic ((?)remobilized) sulphide-rich Au-Cu vein systems (e.g. Mouska;

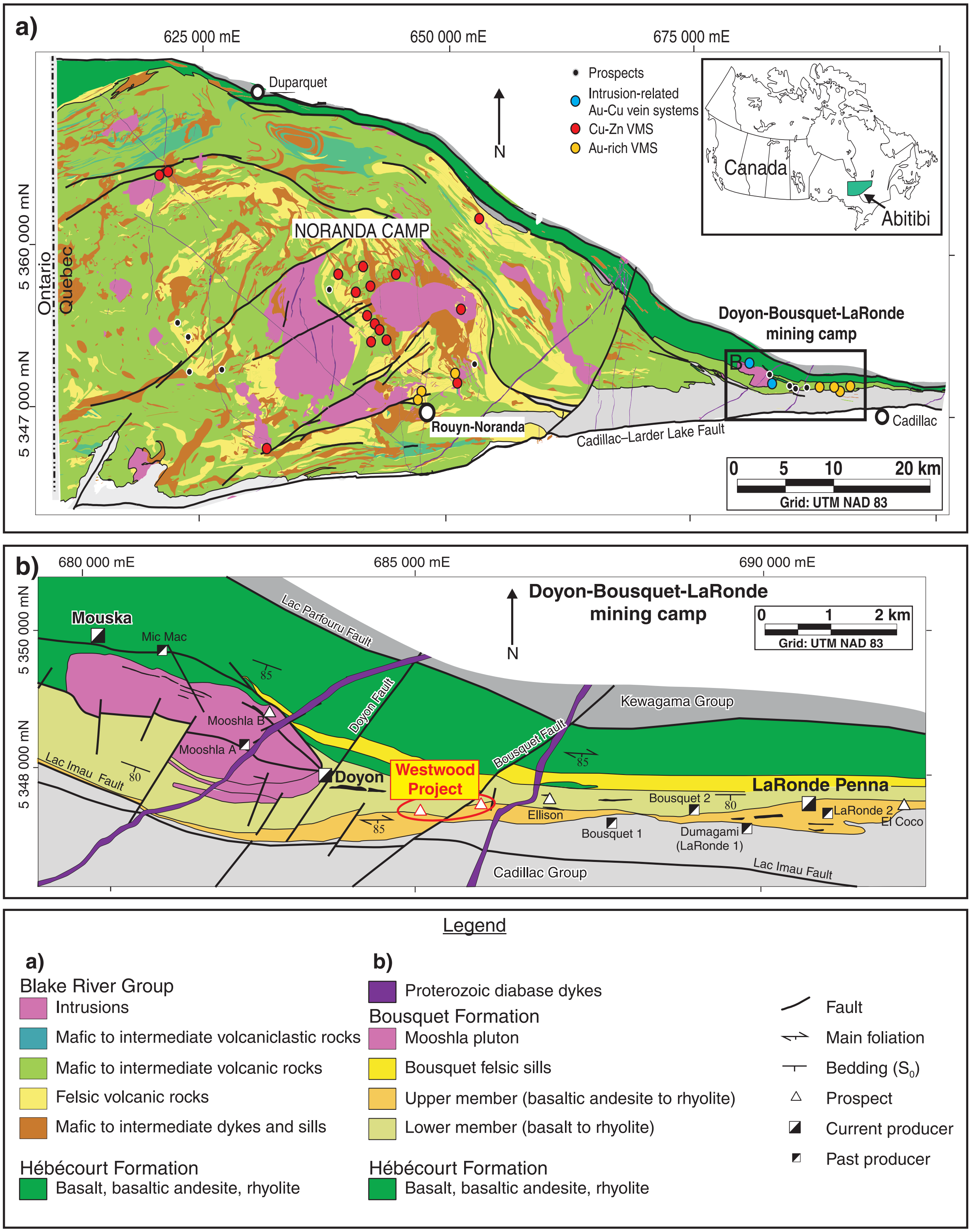

Figure 1. a) Regional setting of the Doyon-Bousquet-LaRonde mining camp in the Blake River Group, northwestern Quebec. **b)** The Doyon-Bousquet-LaRonde mining camp showing current and past-producing mines, as well as prospects, and the location of the Westwood deposit (*modified from* Lafrance et al., 2003; Mercier-Langevin et al., 2007a). VMS = volcanogeni massive sulphide

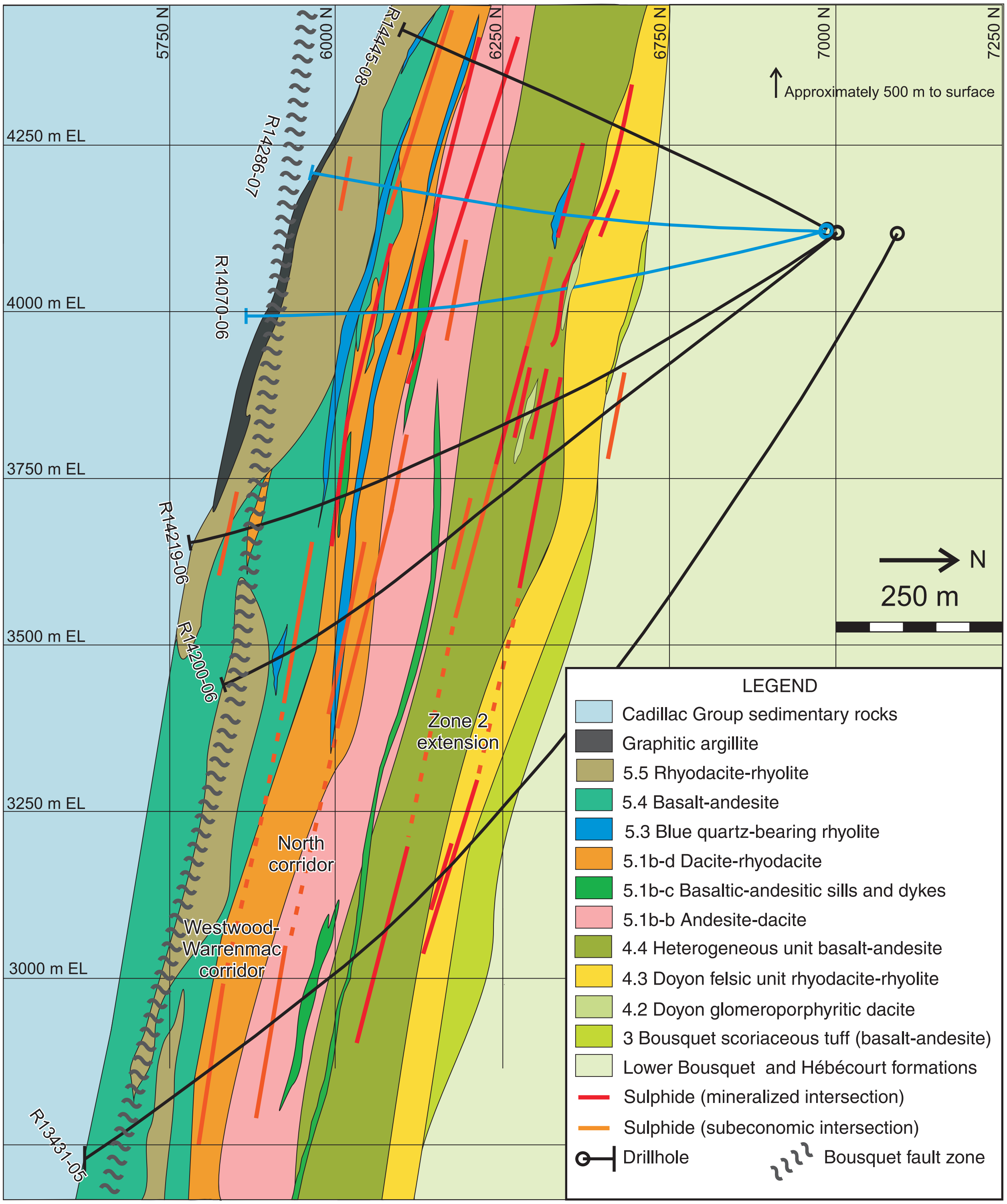

Figure 2. West-facing composite cross-section of Westwood deposit lithological units, showing drillholes studied for the project, and intersected mineralized horizons in red. Highlighted in blue are drillholes R14070-06 and R14286-07, the description of which is the focus of this paper. Ore zones (red) and subeconomic intersections (orange) are schematic, showing location, but not true thickness.

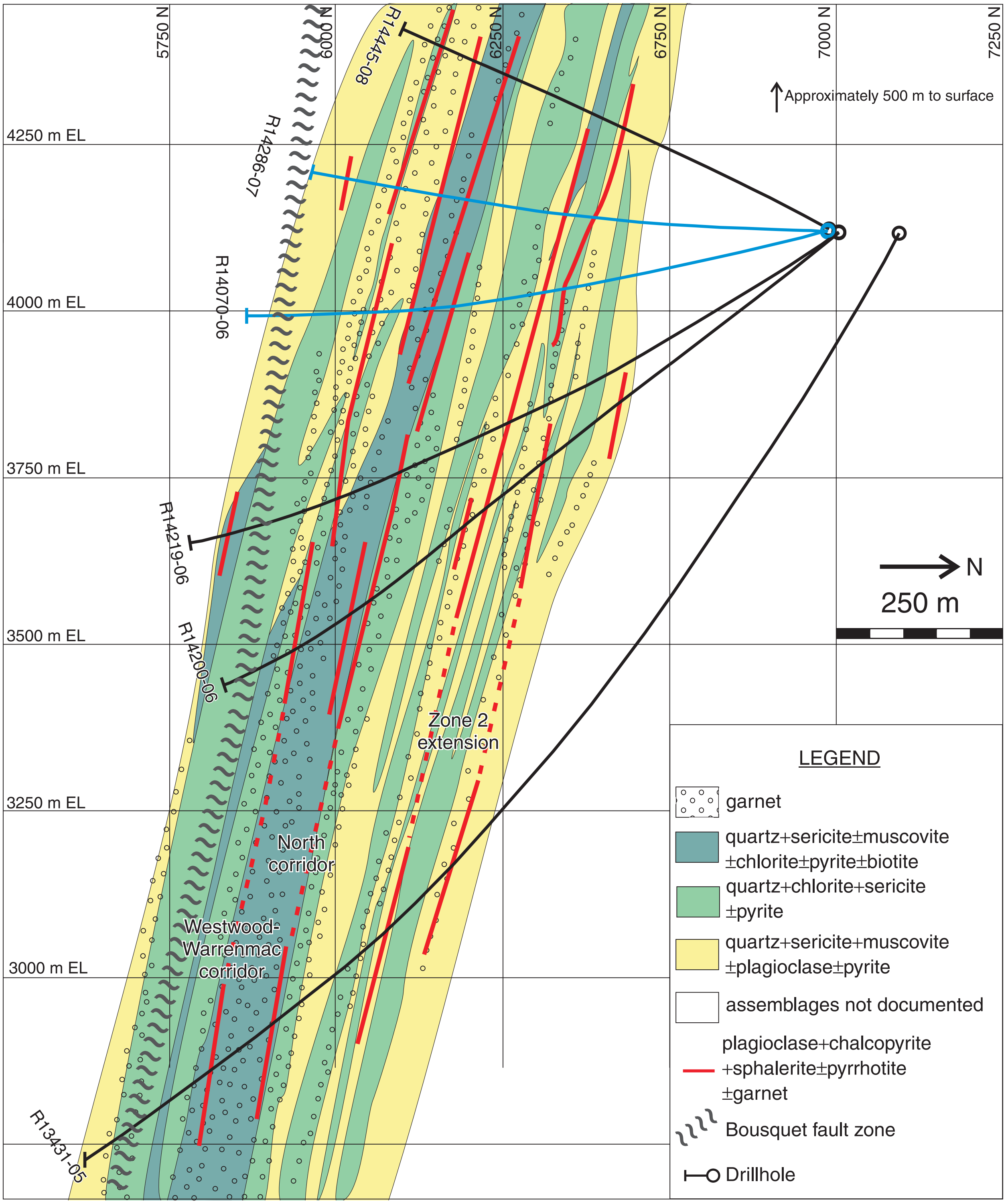

Figure 3. West-facing composite cross-section showing the main alteration assemblages associated with the three mineralized corridors in the Westwood deposit: chlorite, sericite, and lesser biotite and garnet are found in the base of the stratigraphy associated with the zone 2 extension and footwall of the north corridor mineralized zones; sericite, chlorite, biotite, and garnet alteration are associated with the Westwood-Warrenmac corridor ore zones. Not shown is the distribution of proximal minerals such as epidote, clinozoisite, talc, and anhydrite. Highlighted in blue are drillholes R14070-06 and R14286-07, the description of which is the focus of this paper.

Mercier-Langevin et al. (2007c)). The recently discovered mineralization of the Westwood deposit shares similarities with vein-style systems typical of the Doyon deposit as well as with volcanogenic massive-sulphide–style systems typical of the LaRonde Penna deposit (Mercier-Langevin et al., 2009). The Bousquet Formation volcanic rocks are host rocks to these deposits, and form an east-trending, steeply south-dipping homoclinal sequence. Fault-bounded on the north and the south by the 2686 Ma and younger Kewagama Group and 2687 Ma and younger Cadillac Group sedimentary rocks, respectively (Davis, 2002), the Blake River Group, composed of the Hébécourt and Bousquet formations, forms a continuous volcanic sequence that youngs toward the south (Lafrance et al., 2005; Mercier-Langevin et al., 2007c). Multiple episodes of deformation and metamorphism have resulted in highly strained greenschist to amphibolite grade rocks, with metamorphic grade increasing to the north (Tourigny et al., 1989; Marquis et al., 1990; Savoie et al., 1990; Mercier-Langevin et al., 2007c). Two late northeast-trending large-scale faults are found in the area around the Westwood deposit ore zones; the Doyon Fault to the west, and the Bousquet Fault to the east (Fig. 1b).

The geology of the Doyon-Bousquet-LaRonde camp, highlighted in Figure 1b, is composed of the 2703–2702 Ma (McNicoll et al., 2009) predominantly tholeiitic Hébécourt Formation basalt, and of the 2701–2696 Ma tholeiitic to calc-alkaline Bousquet Formation volcanic, volcaniclastic, and intrusive units (Lafrance et al., 2005; Mercier-Langevin et al., 2007c). The lowermost unit in the stratigraphy of the study area is the Hébécourt Formation, which consists of tholeiitic, quartz-amygdaloidal, feldspar-bearing basaltic flows and sills with minor felsic volcanic units near its top (Lafrance et al., 2003; Goutier et al., 2007). The Mouska deposit is hosted in part by the Hébécourt Formation, and the Mic Mac deposit is also located in the Hébécourt Formation, along the north margin of the Mooshla synvolcanic pluton (Galley and Lafrance, 2007).

The Bousquet Formation has been informally subdivided into the mafic to intermediate locally felsic lower member and the predominantly intermediate to felsic upper member (Lafrance et al., 2003), both of which are host to the ore zones of the Westwood deposit. At Westwood, basalt and andesite are the most common rocks found in the lower member, and are partially hosting zone 2 extension mineralization; however, there are felsic units present in the lower member as well. The upper member is composed of thick andesite, dacite, rhyodacite and rhyolite flows, volcaniclastic units, and possibly domes or cryptodomes (Mercier-Langevin et al., 2007a), as well as minor amounts of thin (5–20 m thick) basaltic and andesitic sills or dykes. These intermediate to felsic volcanic units are host to the north corridor and the Westwood-Warrenmac corridor mineralization.

The unit 2 Bousquet felsic sill complex straddles the contact between the Hébécourt and Bousquet formations. Adjacent to the Westwood deposit is the kilometre-scale multiphase gabbroic to granitic synvolcanic Mooshla pluton (Galley and Lafrance, 2007), with which the Doyon, and Mooshla A and B gold deposits are associated (Lafrance et al., 2003; Mercier-Langevin et al., 2007c).

SUMMARY OF THE WESTWOOD DEPOSIT HOST ROCKS

The rock units at the Westwood deposit can be correlated, on the basis of core logging observations and geochemical composition, with units of the Doyon-Bousquet-LaRonde camp previously identified and characterized (e.g. Lafrance et al., 2003; Mercier-Langevin et al., 2007a). Hydrothermal alteration, metamorphism, and deformation require protolith identification to be made by geochemical comparison with known units in the camp, using the major elements as well as least mobile elements in the system, determined by bivariate plots (e.g. MacLean and Barrett, 1993). For the purpose of direct comparison with data from other studies (e.g. Lafrance et al., 2003; Mercier-Langevin, 2005), elements focused on in this paper are Si, Al, Ti, and trace elements Y and Zr. A summary of characteristics of units intersected in drillholes, and probable corresponding Doyon-Bousquet-LaRonde camp unit names are given in Table 1.

On a classification diagram comparing the values of SiO_2 to Zr/TiO_2 (Fig. 4a; Winchester and Floyd (1977)), the average values for units sampled show a progression from basaltic and andesitic rocks lower in the stratigraphy, to more felsic rhyodacite and rhyolitic samples in the upper portions of the stratigraphy, although there are exceptions. For example, basaltic andesite units occur in the upper member. Individual units in the lower member shown in Figure 4b display alteration (silicification) trends, whereas upper member units show effects of fractionation, as well as some alteration effects (Fig. 4c).

Bousquet Formation, lower member

The host rocks of the zone 2 extension vein system are basaltic, andesitic, and rhyodacitic units that resemble geochemically units 3, 4.3, 4.4, and possibly 4.2 of the Doyon and Bousquet mines, based on Ti, Zr, and Y values (Lafrance et al., 2003). These units display primary textures such as breccia, lapilli, fragments, and amygdales, all of which occur to varying degrees throughout. These units are predominantly transitional to tholeiitic in magmatic affinity, based on Zr, Ti, and Y values (Fig. 4d; MacLean and Barrett (1993); Lentz (1998)).

Relatively few samples were taken from the Bousquet scoriaceous tuff units (3.2 and 3.3), and their geochemical signature is ambiguous, showing similarities to units 4.2 and 4.4 (Table 2; e.g. Mercier-Langevin et al. (2007b, 2009)).

Table 1. Lithological characteristics and Doyon-Bousquet-LaRonde mining camp unit names.

		Lithology	Magmatic affinity	Doyon-Bousquet-LaRonde unit	Characteristics
Blake River Group	Bousquet Formation upper member	Ryodacite-dacite	Calc-alkaline	5.5	Quartz-phyric and relatively fresh feldspar-glomeroporphyritic in sericite-altered fine-grained quartz and feldspar matrix, lapilli tuff
Blake River Group	Bousquet Formation upper member	Basaltic andesite	Transitional	5.4	Sericite-altered, locally garnet- and biotite-altered, feldspar-phyric, quartz-sericite matrix, intrusion with variable thickness, calcite-quartz amygdaloidal
Blake River Group	Bousquet Formation upper member	Rhyolite	Calc-alkaline	5.3	Coarse blue quartz–phyric and feldspar in microcrystalline quartz and muscovite-sericite matrix, with coarse granoblastic pyrite
Blake River Group	Bousquet Formation upper member	Dacite-rhyodacite	Transitional to calc-alkaline	5.1b-d	Main Westwood-Warrenmac corridor ore-zone host, locally quartz-calcite-garnet amygdaloidal, fragments of very fine-grained quartz with lesser sericite, coarse recrystallized quartz-phyric
Blake River Group	Bousquet Formation upper member	Basaltic andesite	Transitional	5.1b-c	Locally fragmental, locally quartz-calcite-garnet-sulphide, amygdaloidal, locally blue quartz–bearing
Blake River Group	Bousquet Formation upper member	Andesite	Tholeiitic to tansitional	5.1b-b	North corridor ore-zone host, epidote-, biotite-, chlorite-, sericite-, clinozoisite-altered amygdaloidal matrix, possibly locally fragmental
Blake River Group	Bousquet Formation lower member	Basalt-andesite	Tholeiitic to tansitional	4.4	Partial zone 2 extension host, 200 m thick, locally quartz-epidote-chlorite-sulphide amygdaloidal, garnet-bearing, feldspar-phyric, possibly lapilli-bearing
Blake River Group	Bousquet Formation lower member	Rhyodacite-dacite	Transitional to calc-alkaline	4.3	Partial zone 2 extension host, quartz- and feldspar-phyric, locally fragmental, commonly forming highly sheared, light grey bleached quartz, sericite, and muscovite schist
Blake River Group	Bousquet Formation lower member	Dacite	Transitional to calc-alkaline	4.2	Doyon glomeroporphyritic dacite, sericite- and muscovite-altered, locally garnet-bearing, minor clinozoisite alteration, calcite-veining
Blake River Group	Bousquet Formation lower member	Basaltic andesite	Tholeiitic to transitional	3.3 or 3.2	Fine-grained basaltic andesite tuff, commonly schistose and epidote-, sericite-, chlorite-, and biotite-altered

Table 2. Geochemical averages of samples from each Doyon-Bousquet-LaRonde mining camp unit. Data compiled from all studied drillholes.

	Bousquet scoriaceous tuff		Doyon glomeroporphyritic dacite		Doyon felsic schist		Heterogeneous unit		Andesite-dacite		Basaltic-andesite sills		Dacite-rhyodacite		Blue quartz–bearing rhyolite		Basaltic-andesite		Upper felsic unit	
	Unit 3		Unit 4.2		Unit 4.3		Unit 4.4		Subunit 5.1b-b		Subunit 5.1b-c		Subunit 5.1b-d		Unit 5.3		Unit 5.4		Unit 5.5	
	n = 8		n = 3		n= 17		n = 28		n = 11		n = 7		n = 17		n = 3		n = 13		n = 13	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
SiO_2	53.58	6.31	65.53	2.83	71.22	7.55	53.09	6.71	61.79	4.23	52.91	2.76	68.34	5.12	75.11	4.37	51.35	2.32	66.91	9.85
TiO_2	0.90	0.13	0.81	0.18	0.59	0.21	1.08	0.23	1.07	0.12	1.17	0.25	0.61	0.15	0.32	0.21	1.25	0.39	0.52	0.23
Al_2O_3	17.06	1.32	15.19	1.14	13.53	1.15	17.15	4.68	15.66	1.30	15.33	3.64	14.03	1.65	12.51	1.36	20.77	3.80	14.75	3.93
Fe_2O_3(t)	10.74	4.77	10.11	4.99	7.16	7.36	12.81	8.28	8.83	3.25	14.67	8.94	8.92	7.41	4.81	3.02	9.81	2.64	7.74	14.03
MnO	0.18	0.08	0.06	0.04	0.05	0.05	0.16	0.16	0.22	0.13	0.29	0.17	0.18	0.19	0.10	0.13	0.19	0.17	0.05	0.03
MgO	5.72	3.29	1.59	0.87	1.39	1.22	4.02	1.68	2.93	1.22	4.69	2.03	1.35	1.00	1.12	1.08	2.91	1.68	0.89	0.47
CaO	8.02	4.79	2.29	1.46	2.42	1.89	6.64	3.04	5.18	2.55	7.24	3.64	2.38	1.92	1.91	1.68	9.27	5.68	2.07	1.43
Na_2O	0.75	0.48	0.78	0.21	1.07	0.81	1.39	0.88	1.10	0.85	0.99	0.66	0.92	1.15	0.71	0.51	1.74	1.16	4.23	2.54
K_2O	1.85	1.59	3.42	1.03	2.45	1.03	2.37	1.40	2.43	1.02	2.26	0.75	3.07	1.00	2.79	0.46	2.76	2.88	2.66	1.33
P_2O_5	0.23	0.08	0.22	0.12	0.11	0.10	0.25	0.13	0.37	0.07	0.28	0.09	0.15	0.07	0.07	0.05	0.18	0.03	0.16	0.10
LOI	6.67	3.61	6.66	0.65	4.73	3.15	10.16	3.62	5.12	1.60	6.20	4.30	5.05	2.70	3.39	0.91	5.25	1.61	3.69	5.65
Total	99.54	1.31	99.94	0.99	99.36	2.14	98.84	2.68	99.60	0.85	99.89	1.06	99.28	1.79	98.77	0.20	99.50	0.85	100.11	0.75
CO_2	1.68	3.42	0.10	0.06	0.29	0.39	0.70	1.25	1.21	1.91	2.33	2.29	0.91	1.13	0.62	0.83	2.36	2.15	0.86	0.67
FeO	5.89	1.67	3.66	1.91	2.93	1.89	5.65	1.71	5.55	2.38	8.37	0.69	3.90	2.42	3.09	1.86	5.18	1.65	2.80	2.61
Y	23.06	11.17	42.30	10.87	42.71	12.96	22.31	13.54	54.43	11.50	18.96	8.28	32.71	9.30	20.30	7.55	15.29	4.00	26.91	11.23
Zr	86.38	46.62	207.00	65.11	227.18	41.55	83.89	42.66	208.82	45.29	78.57	35.43	187.76	28.04	132.33	6.81	62.54	21.08	211.46	77.37
Ba	620.75	539.19	1039.67	235.26	730.53	627.96	592.57	502.19	637.27	355.21	417.71	169.33	634.47	198.92	582.67	98.33	480.92	389.17	558.46	315.77
V	212.38	63.14	85.33	45.17	30.88	34.24	219.39	64.68	80.36	65.37	246.00	71.14	44.06	24.03	48.00	59.77	299.85	64.62	47.31	23.44
Sc	28.25	3.85	18.33	3.06	13.06	5.86	25.39	6.96	20.91	4.11	26.57	6.19	12.41	1.94	7.00	7.81	33.15	7.16	9.38	4.57
Be	1.60	0.55	1.00	0.00	1.11	0.35	1.45	0.51	1.18	0.40	1.67	0.52	1.22	0.44	1.00	0	1.82	0.60	1.67	0.90
Cr	144.88	99.74	46.00	60.65	13.82	7.07	42.98	42.94	15.36	16.05	75.86	116.41	14.82	12.14	21.50	16.53	187.92	32.06	17.00	9.87
Co	24.93	11.45	18.05	10.86	21.82	34.00	29.20	22.47	11.61	7.23	27.57	11.73	8.88	10.54	4.47	2.42	42.44	15.07	8.09	10.21
Ni	58.31	40.02	13.33	18.77	5.76	6.00	26.59	32.31	5.55	6.71	32.29	38.12	6.29	5.91	7.17	7.29	98.58	42.74	8.19	10.97
K*	15317.92	13182.43	28385.24	8580.87	21641.33	8523.96	19647.17	11594.98	20156.25	8485.78	18767.61	6188.88	25518.86	8281.61	23166.11	3799.63	22909.00	23940.49	22120.09	11081.48
Ti*	5366.95	799.26	4845.25	1086.03	3521.87	1274.70	6451.28	1394.72	6440.88	714.12	7009.81	1493.47	3685.90	869.47	1916.43	1257.05	7522.73	2318.65	3132.27	1401.14
Sr	143.63	120.18	80.67	36.00	113.76	102.12	163.00	72.05	124.45	65.72	90.57	29.22	67.24	76.80	60.00	41.73	184.69	102.33	123.62	52.48

Table 2. continued.

	Bousquet scoriaceous tuff		Doyon glomeroporphyritic dacite		Doyon felsic schist		Heterogeneous unit		Andesite-dacite		Basaltic-andesite sills		Dacite-rhyodacite		Blue quartz–bearing rhyolite		Basaltic-andesite		Upper felsic unit	
	Unit 3		Unit 4.2		Unit 4.3		Unit 4.4		Subunit 5.1b-b		Subunit 5.1b-c		Subunit 5.1b-d		Unit 5.3		Unit 5.4		Unit 5.5	
	n = 8		n = 3		n= 17		n = 28		n = 11		n = 7		n = 17		n = 3		n = 13		n = 13	
	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation	Average	Standard deviation
Cd	b.d.	-	b.d.	-	0.20	-	0.44	0.43	2.00	3.06	0.33	0.06	7.51	19.06	b.d.	-	8.00	15.21	0.40	0.18
Rb	46.88	28.21	83.33	29.91	59.06	23.41	57.89	27.75	70.00	25.73	69.57	31.46	87.00	28.16	79.00	15.13	89.38	88.13	76.69	35.60
Nb	5.31	2.82	13.20	2.70	12.64	3.08	5.90	2.30	12.44	1.44	5.69	1.29	11.28	3.11	9.67	4.35	4.95	1.26	13.36	5.68
Cs	1.13	0.34	1.57	0.86	1.33	0.56	2.01	0.87	2.44	1.14	3.91	2.22	1.99	0.79	2.23	0.72	4.52	5.17	2.43	1.16
Hf	2.28	1.15	5.07	1.26	5.78	0.92	2.13	0.96	5.38	1.01	1.97	0.98	4.78	0.83	3.30	0.20	1.66	0.47	5.12	1.89
Ta	0.26	0.17	0.62	0.18	0.61	0.10	0.27	0.10	0.52	0.08	0.24	0.09	0.52	0.12	0.71	0.35	0.21	0.07	0.67	0.28
Pb	7.25	3.85	14.00	7.21	7.71	5.75	10.00	8.75	8.73	9.45	25.29	29.28	124.38	307.25	24.17	12.33	39.50	75.18	23.62	41.23
Th	2.60	1.38	7.83	2.63	6.65	1.62	2.67	1.09	5.25	1.21	2.51	0.98	8.33	1.74	8.87	3.82	1.75	0.35	11.48	5.16
U	0.72	0.33	2.12	0.68	1.65	0.38	0.77	0.34	1.34	0.25	0.65	0.26	2.19	0.48	2.17	0.88	0.50	0.10	2.89	1.23
La	14.24	14.02	47.43	23.78	35.37	9.29	20.50	13.19	42.21	5.08	17.64	6.32	38.56	11.95	5.97	10.16	12.45	2.54	49.33	21.43
Ce	31.29	30.66	100.40	45.88	77.65	21.57	49.82	24.88	95.95	12.07	39.73	13.89	81.91	24.93	39.50	n.d.	27.79	5.33	102.57	44.80
Pr	8.42	6.29	12.71	6.64	9.70	2.84	8.36	6.94	12.15	1.25	5.06	1.91	9.62	3.17	20.75	18.56	3.68	0.76	11.40	4.85
Nd	24.91	14.50	44.73	20.88	35.11	10.34	26.75	15.76	46.24	5.11	19.09	7.11	32.66	10.45	41.87	29.79	13.60	2.73	36.31	15.17
Sm	4.86	2.87	8.58	3.13	7.43	2.22	5.26	2.48	10.18	1.43	4.27	1.64	6.45	2.10	5.24	2.48	2.91	0.56	6.74	2.82
Eu	5.91	8.20	2.24	1.00	1.64	0.52	4.17	8.48	2.69	0.32	1.22	0.43	1.57	0.52	13.44	11.47	1.04	0.25	1.41	0.58
Gd	4.44	2.27	8.03	3.18	7.11	2.07	4.77	2.31	9.71	1.71	3.86	1.44	5.59	2.14	3.31	0.89	3.01	0.68	5.24	2.36
Tb	0.92	0.51	1.24	0.38	1.17	0.39	0.82	0.53	1.59	0.32	0.57	0.23	0.90	0.28	0.78	0.36	0.47	0.12	0.81	0.36
Dy	4.13	2.00	6.88	1.77	6.82	2.34	3.93	2.29	9.06	1.87	3.24	1.46	5.21	1.40	3.02	0.74	2.60	0.66	4.39	1.83
Ho	0.76	0.42	1.36	0.34	1.38	0.45	0.73	0.44	1.81	0.39	0.64	0.31	1.06	0.27	0.55	0.15	0.50	0.13	0.87	0.35
Er	2.72	1.27	4.17	1.04	4.25	1.34	2.40	1.51	5.49	1.19	1.95	1.01	3.30	0.86	2.91	1.52	1.49	0.37	2.75	1.11
Tm	0.46	0.24	0.65	0.16	0.66	0.20	0.38	0.27	0.83	0.17	0.30	0.16	0.52	0.13	0.58	0.35	0.23	0.05	0.44	0.18
Yb	2.32	1.21	4.34	1.11	4.40	1.16	2.11	1.24	5.38	1.09	1.89	1.06	3.46	0.84	2.20	0.73	1.44	0.33	3.01	1.18
Lu	0.36	0.18	0.69	0.18	0.70	0.16	0.32	0.19	0.85	0.18	0.30	0.17	0.56	0.13	0.37	0.11	0.23	0.06	0.50	0.19

* calculated from weight per cent oxide
b.d. = below detection limit
n.d. = not determined

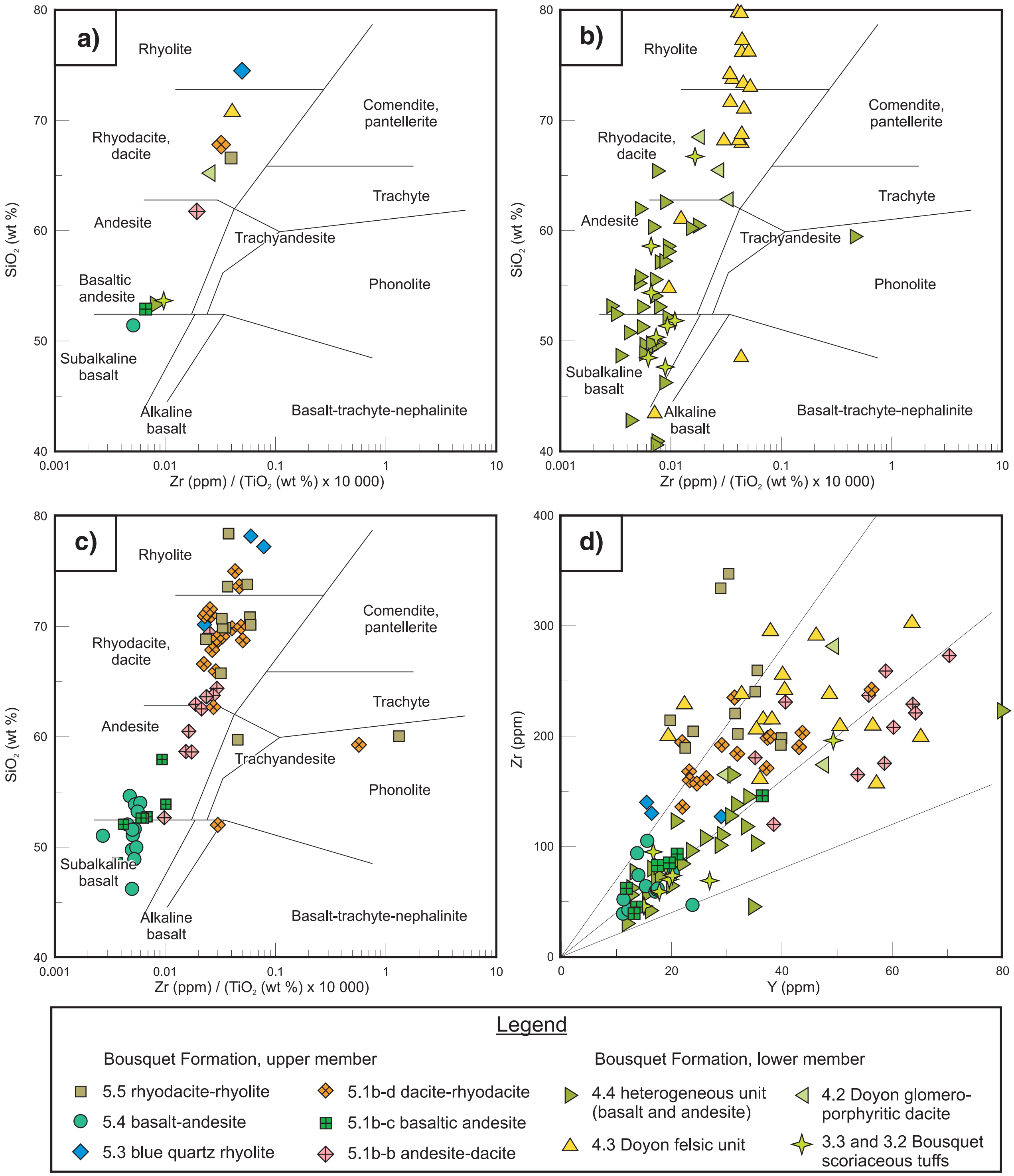

Figure 4. a) The averages of samples from each of the units studied are plotted on a rock classification diagram (Winchester and Floyd, 1977). **b)** Samples from the lower member of the Bousquet Formation. **c)** Samples from the upper member of the Bousquet Formation. **d)** Magmatic affinity of all samples (MacLean and Barrett, 1993).

Silica, alumina, and titanium dioxide values range from 47.5–66.7 weight per cent, 14.7–18.4 weight per cent, and 0.71–1.15 weight per cent, respectively, and Zr/Y values range from 2.6 to 5.7. Three samples were collected from unit 4.2 Doyon glomeroporphyritic dacite.

The Doyon mine felsic unit (4.3) is the host of the Doyon mine zones 1 and 2, and is a highly deformed sericite-altered schist, which generally prohibits recognition of primary volcanic features (Savoie et al., 1990; Lafrance et al., 2003). At the Westwood deposit this unit is quartz- and feldspar-phyric rhyolite and rhyodacite, and possibly is locally fragmental. Intensely bleached intervals in unit 4.3 are associated with quartz-carbonate veins, as well as with significant amounts of pyrite. This unit is partially hosting zone 2 extension mineralization. The Zr, Ti, and Y values from analyzed samples in this unit yield transitional to calc-alkaline magmatic affinity (Fig. 4d).

The heterogeneous unit (4.4) of the Doyon-Bousquet-LaRonde mining camp occurs throughout the camp, and is approximately 100 m thick in the Westwood deposit area. Geochemically, this unit bears similarity to units in both the upper and lower members of the Bousquet Formation. This unit appears to be one of the least evolved of the rock types studied, with samples from this interval ranging from basalt to andesite, although basalt is the most common, as reflected by their average composition (Fig. 4a). Magnetite and amphibole mineralogy in this unit may represent alteration associated with the Mooshla pluton or zone 1 and zone 2 mineralization at the Doyon mine, located to the west of the selected drillholes (Fig. 1b, 2). Based on core logging, this alteration shows an apparent lateral and stratigraphic zonation of magnetite and amphibole, with magnetite occurring as an alteration mineral proximal to the Mooshla pluton, and amphibole making a more distal, or less altered signature. Magmatic affinity varies between tholeiitic and transitional. Major and trace elements have a wide range of abundance in this unit, for example 12–80 ppm Y and 32–223 ppm Zr (Table 2). Data from a study by Lafrance et al. (2003) show a similar range. This spread of values most probably suggests mobilization of elements during hydrothermal alteration, or a truly heterolithological interval of volcanic rocks.

Bousquet Formation, upper member

The upper member of the Bousquet Formation is comparatively more felsic and has a more evolved magmatic affinity than the lower member. This portion of the Bousquet Formation is composed of lithological units numbered 5.1 and higher, according to the Doyon-Bousquet-LaRonde mining camp nomenclature (Lafrance et al., 2003). The majority of samples taken in the upper member have a transitional to calc-alkaline signature, although there are mafic samples with a tholeiitic magmatic affinity.

In the lower part of the upper member an approximately 75 m thick sequence of andesite with lesser amounts of dacite is the host to the north corridor ore zones, and comprises part of the altered stratigraphic footwall of the Westwood-Warrenmac corridor. This sequence is generally fine grained, locally amygdaloidal, and displays fragmental textures that are suggestive of volcaniclastic rocks (Fig. 5b, c), but the exact nature of which is unclear due to the intensity of deformation in this area. Geochemically, samples share similarities with subunit 5.1b-(b), an andesitic to dacitic volcanic rock, although some samples are more similar to subunit 5.1b-(d) dacite and rhyodacite (Mercier-Langevin et al., 2007b).

The host to the Westwood-Warrenmac corridor ore zones is a dacitic-rhyodacitic unit that is locally fragmental and locally amygdaloidal (Fig. 5d). This volcanic unit correlates with subunit 5.1b-(d), based on its geochemistry, stratigraphic location, and the presence of multiple thin (<10 m) basaltic and andesitic units that may be the western equivalent of subunit 5.1b-(c) found at the LaRonde Penna mine (Fig. 2; Mercier-Langevin et al., 2007b).

A blue quartz-bearing feldspar-phyric rhyolite (unit 5.3, Fig. 5e) occurs stratigraphically immediately above the mineralization. This unit is several metres thick, but is markedly thinner than its eastern equivalent found in the LaRonde deposit hanging-wall rocks (Mercier-Langevin et al., 2007b). Averages of samples in this unit have rhyolitic composition and a calc-alkaline magmatic affinity.

Stratigraphically above this rhyolite unit lies a rhyodacitic to rhyolitic, fine-grained recrystallized quartz- and fine- to coarse-grained (up to 3 mm) feldspar-phyric and glomeroporphyritic unit 5.5 (Fig. 5f) that makes up the hanging wall of the Westwood-Warrenmac corridor. Toward the top of the unit, there is an increase in amygdale abundance and locally fragmental textures. In thin section, feldspar crystals are undeformed, relatively fresh, twinned, and randomly orientated in a quartz-sericite groundmass. In the two drillholes, this unit is overlain by graphitic argillite (Fig. 2). At Westwood deposit, unit 5.5 is on average a calc-alkaline rhyodacite (Table 1). In the study area, this unit is crosscut by the northeast-trending, steeply dipping Bousquet fault zone responsible for quartz-veining, bleached rock, extensive fracturing, and fault gouge present over intervals on the order of several tens of metres.

A basaltic-andesitic unit displaying highly irregular geometry crosscuts these upper member felsic units, and is interpreted as unit 5.4 based on its chemistry and stratigraphic position (Fig. 2). In drillhole R14286-07 this unit has a thickness of 20–25 m and is the immediate hanging wall of the thickest Westwood-Warrenmac corridor ore lens, but in drillhole R14070-06 it has a thickness of approximately 10 m and is part of the more distal hanging-wall rocks. This suggests the unit was emplaced at a shallow angle to

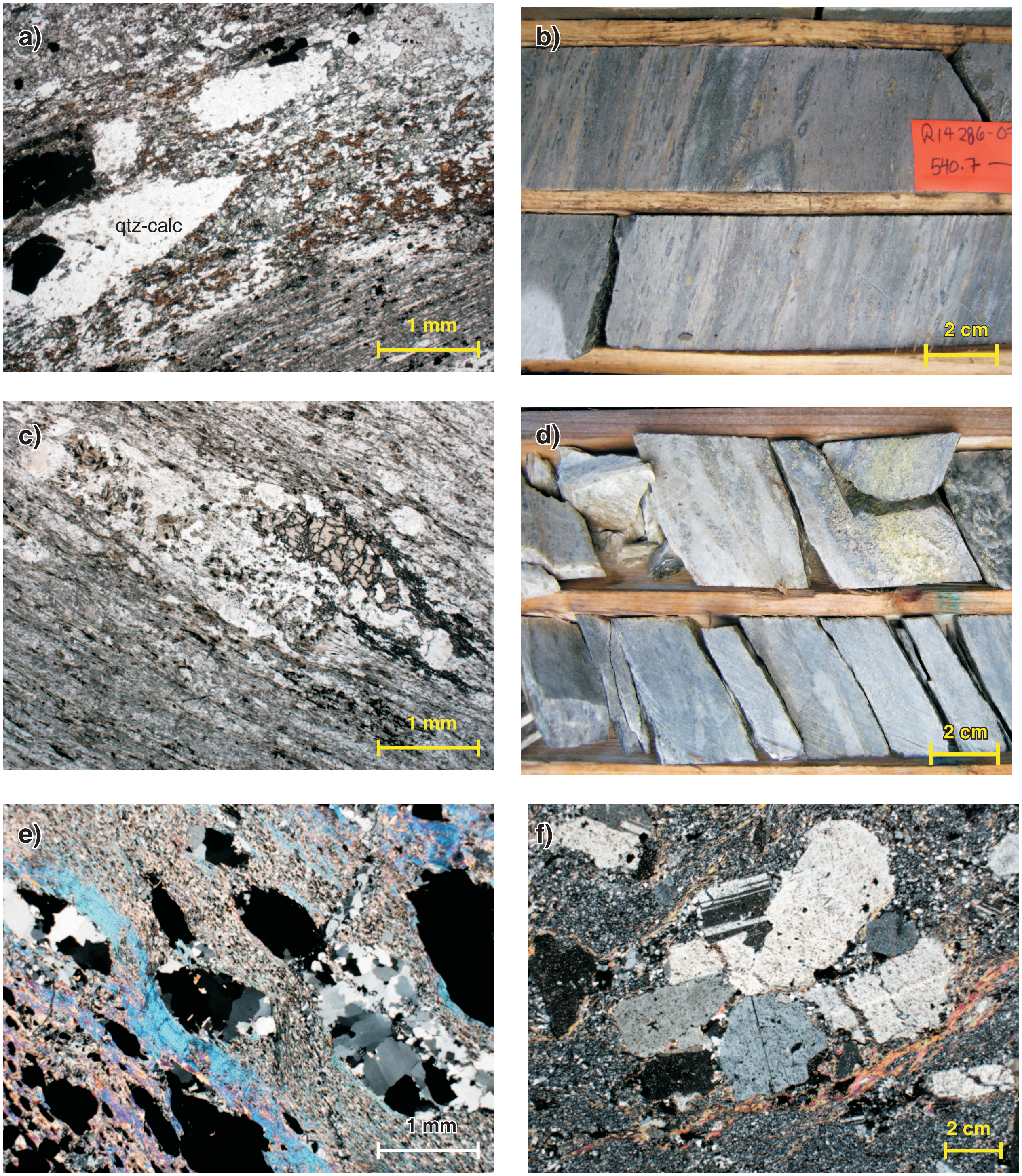

Figure 5. a) Garnet and biotite in quartz-calcite (qtz-calc), a commonly seen mineral association in the north corridor mineralized zones (XPL). 2010-258. **b)** Drill-core photograph (2010-253) and **c)** thin-section photograph (2010-255) (PPL) quartz-carbonate-chlorite altered amygdaloidal subunit 5.1b-(b) andesite-dacite, host to the north corridor mineralization. **d)** Felsic fragments in subunit 5.1b-(d) rhyodacite, main host to the Westwood-Warrenmac corridor ore zones. 2010-256. **e)** Blue quartz-bearing rhyolite of unit 5.3 in the Westwood-Warrenmac corridor hanging wall (XPL) 2010-260. **f)** Unit 5.5 glomeroporphyritic rhyodacite in the Westwood-Warrenmac corridor hanging wall in drillhole R14070-06 (XPL). 2010-252. All photographs by A. Wright-Holfeld. XPL =cross-polarized light, PPL = plane-polarized light.

stratigraphy as a sill. This unit is characterized by intensely sericite- and muscovite-altered feldspar, coarse biotite, and calcite amygdales. Unit 5.4 at the Westwood deposit is, on average, basaltic to andesitic (Fig. 4a) and of transitional magmatic affinity (Table 1).

MINERALIZATION

Mineralization in the Westwood deposit consists of multiple horizons grouped into three stratigraphically stacked corridors: the zone 2 extension, the north corridor, and the Westwood-Warrenmac corridor (Fig. 2). Gold mineralization is accompanied by the presence of sulphide minerals in each corridor: 1) pyrite with very minor amounts of chalcopyrite and sphalerite in zone 2 extension; 2) pyrite, sphalerite, and lesser chalcopyrite and pyrrhotite in the north corridor; and 3) pyrite, sphalerite, chalcopyrite, pyrrhotite, and rare galena in the Westwood-Warrenmac corridor (Mercier-Langevin et al., 2009).

Zone 2 extension

The zone 2 extension mineralization is the northernmost ore horizon of the Westwood deposit and is located near the base of the Bousquet Formation. Mineralization consists of centimetre- to decimetre-scale auriferous sulphide-rich quartz veins. Pyrite is by far the most abundant sulphide, and occurs as coarse grains in close association with quartz augen in a highly sheared and sericitized host. Pyrite grains are characterized by rounded to angular irregular boundaries and embayments, microfracturing, and Fe-titanium oxide fringes. Epidote, chlorite, and quartz grains often cap pyrite porphyroblasts, suggesting their recrystallization in pressure shadows. Gold and electrum occur as microscopic inclusions in pyrite, and native gold is also observed in drill core (Fig. 6a, b). Based on electron microprobe results, pyrite locally contains trace amounts of As, Co, and rarely Mn. Arsenic and manganese also occur in chalcopyrite and sphalerite.

North corridor

The north corridor mineralization consists of centimetre- to decimetre-scale quartz veins associated with varying amounts of sulphide mineralization as well as local semi-massive to massive sulphide veins. Sulphide minerals present are pyrite, pyrrhotite, chalcopyrite, and sphalerite, and are commonly associated with gold and electrum. In thin section, pyrite grains are very irregular and have rounded to angular boundaries. Grains are fractured and infilled with chalcopyrite, sphalerite, and electrum (Fig. 6c), and also contain inclusions of gangue, and sulphide minerals. Pyrite is recrystallized and electrum is found in triple junctions and subgrain boundaries. Electron microprobe analyses of pyrite show that it contains traces of arsenic and cobalt. Pyrrhotite and chalcopyrite occur in close association with pyrite, often rimming pyrite grains (Fig. 6d). In addition to infilling fractures in pyrite, sphalerite also occurs in fine disseminations in the silicate matrix, and contains traces of Fe, As, Co, and Mn.

Westwood-Warrenmac corridor

The ore zones of the Westwood-Warrenmac corridor are Au-rich Cu-Zn-Ag volcanogenic massive-sulphide lenses. Mineralized intervals are generally thicker than the north corridor and zone 2 extension vein systems, and reach thicknesses of up to 10 m. There are multiple mineralized lenses which consist of semimassive to massive pyrite, sphalerite, chalcopyrite, and pyrrhotite, with rare visible gold (Fig. 6e). Gold, electrum, and telluride minerals occur in or near these sulphide minerals and are microscopically visible in some samples (Fig. 6f). Pyrite is the most abundant sulphide, followed by sphalerite, chalcopyrite, and pyrrhotite with very minor amounts of galena. In thin section, pyrite displays variable morphology, but most often occurs as coarse irregular grains showing microfractures which are variably infilled by the other sulphide minerals and gangue minerals. Grains sometimes have many small inclusions of gangue minerals or other sulphide minerals. Sulphide inclusions tend to have rounded boundaries, whereas silicate minerals usually have irregular and angular boundaries. Electron microprobe analysis shows that pyrite grains have trace amounts of Ni, As, Co, and Mn, and although the amounts are not significant, grains sometimes show concentric compositional zoning reflecting changes in abundances of these elements.

Sphalerite most often occurs as coarse grains with highly irregular geometry, fringing and interstitial to pyrite grains, and somewhat less frequently as finer grains disseminated in the silicate matrix. Chalcopyrite inclusions are common in larger grains of sphalerite. Chalcopyrite also occurs as medium to coarse grains adjacent to or included in pyrite grains, irregular grains interstitial to pyrite, as well as disseminated in the matrix. When hosted in gangue minerals, chalcopyrite has very irregular grain boundaries. Pyrrhotite has a distribution and morphology similar to that of chalcopyrite, but does not occur as micro-inclusions in sphalerite. Very minor amounts of galena were logged in drill core.

Native gold in the Westwood-Warrenmac corridor is commonly visible in thin section, and its presence is confirmed by microprobe analysis. Two electrum grains from drillhole R14070-06 were probed and results show that the electrum contains approximately twice as much gold as silver. A gold-rich telluride with traces of silver was identified, and bismuth-telluride was also detected. Gold, electrum, and telluride minerals occur as small grains adjacent or interstitial to pyrite, and along fractures in pyrite.

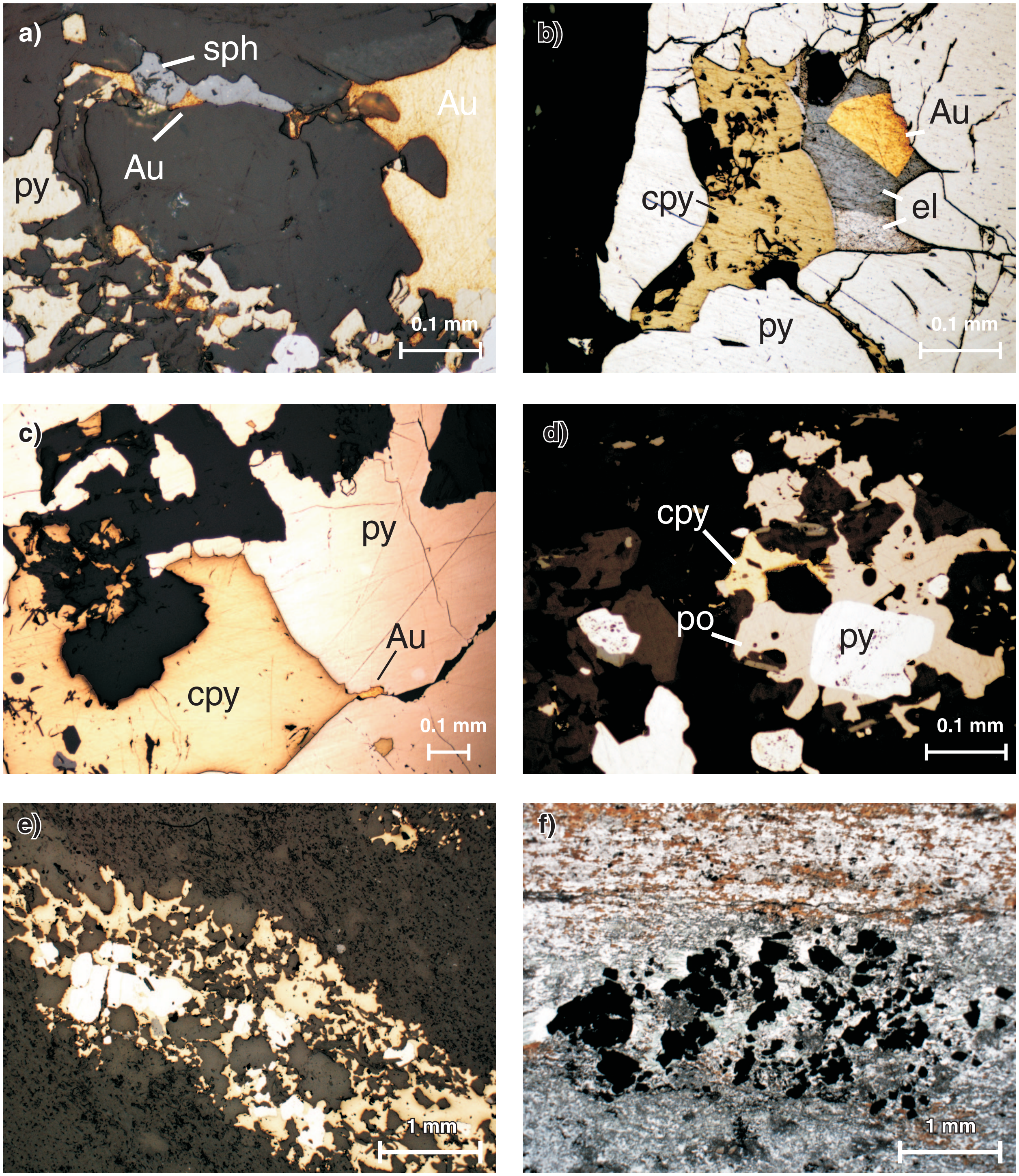

Figure 6. Sulphide and gold mineralization in the Westwood deposit area. **a)** Silicate minerals with gold (Au), pyrite (py), chalcopyrite, and sphalerite (sph) infill (RL). 2010-249. **b)** Pyrite (py) with gold (Au), electrum (el), and chalcopyrite (cpy) (RL). 2010-245. **c)** Gold (Au) infilling microfracture in chalcopyrite-pyrite (cpy-py) grain, a commonly seen mineralization style in the north corridor and Westwood-Warrenmac mineralized horizons (RL). 2010-254. **d)** Pyrrhotite (po) rimming pyrite (py) grain. Chalcopyrite (cpy) in close association with pyrrhotite (RL). 2010-257. **e)** Highly irregular chalcopyrite grains encasing pyrite, concentrated in a lensoid shape (possibly relict amygdale) (RL). 2010-246. **f)** Sulphide aggregate in relict (?)amygdale (XPL). 2010-259. All photographs by A. Wright-Holfeld. RL = reflected light, XPL = cross polarized light.

ALTERATION MINERAL ASSEMBLAGES

The three mineralized corridors at Westwood share similarities with each other in terms of alteration assemblages, such as the presence of sericite, chlorite, and garnet, although there are some differences in minerals present. These differences may be the result of: 1) the composition of host rock; 2) temporal or spatial changes in hydrothermal fluid characteristics; or 3) repeated, overprinting mineralizing phases resulting in stacking of lenses and alteration assemblages, or a combination of the above. The majority of the alteration minerals present in the Westwood deposit are the result of metamorphism of synvolcanic alteration. The distribution of alteration minerals was studied in detail in an attempt to define more specifically the assemblages associated with each mineralized corridor. Estimates of mineral abundances are based on petrographic analysis of thin sections.

Zone 2 extension alteration assemblages

The footwall rocks of zone 2 extension consist of the Doyon mine felsic unit (4.3) as well as mafic and intermediate rocks of units 3.2 and 4.4 (Fig. 2). The zone 2 extension has an alteration signature similar to that of a vein system: a relatively limited spatial distribution of alteration minerals is present, and especially focused in drillhole R14070-06 compared to drillhole R14286-07, where alteration minerals have a slightly wider distribution around the ore veins. Alteration is observed in the immediate few centimetres on either stratigraphic side of individual ore horizons, or tight groupings of veins.

Zone 2 extension alteration mineralogy

Minerals present in the footwall rocks of zone 2 extension ore horizons include approximately 40–50 volume per cent less than 1–2 mm (coarse) quartz; 10–30 volume per cent sericite, muscovite, and coarse plagioclase (Fig. 7a); 5–10 volume per cent less than 0.1 mm (fine-grained) chlorite replacing muscovite to varying degrees; coarse clinozoisite (5 volume per cent); 1 volume per cent or less allanite; and talc or other clay minerals. In andesitic rocks hosting the ore, alteration minerals include quartz, sericite, chlorite, clinozoisite, and allanite, with minor amount of titanite, garnet, and possibly anhydrite. Detailed core-logging and thin-section observations show that on a centimetre-scale, vein halos associated with peak gold values and sulphide minerals consist of the above minerals in addition to calcite, biotite, and epidote. Clinozoisite and allanite are fringing and forming pressure shadows next to pyrite grains.

Hanging-wall rocks of zone 2 extension consist of basalt from the heterogeneous unit 4.4 (Fig. 2). Alteration minerals present in immediate hanging-wall rocks of zone 2 extension mineralization (drillholes R14070-06 and R14286-07) are composed of 30 volume per cent fine-grained quartz, 30 volume per cent sericite-altered medium-grained plagioclase groundmass, 5–10 volume per cent fine-grained Mg-rich chlorite, muscovite, and sericite, 3–5 volume per cent medium to coarse disseminated pyrite, approximately 1 volume per cent coarse anhydrite, and less than 1% fine to coarse clinozoisite, epidote, and Ce-bearing allanite. Additional minerals with patchy distribution are present in the hanging-wall rocks and include titanite, calcite, and minor amounts of talc in drillhole R14286-07; and muscovite, sphalerite, and Mg-rich tourmaline in drillhole R14070-06.

Zone 2 extension geochemistry

In the zone 2 extension corridor Mn, Mg, and Ca show increased abundances in the hanging-wall rocks compared to footwall rocks (Fig. 8). Iron, sodium, and aluminum display moderately uniform abundances throughout the lower member, although Na values are low, reflecting the leaching of mobile elements. In addition, Ti and Zr have peaks representing increased content in ore zones compared to the immediate footwall and hanging wall. Barium has a large peak in the immediate footwall rocks of the zone 2 extension. Silicon and zirconium decrease in abundance in the hanging-wall rocks of zone 2 extension: this apparent depletion reflects the differences in rock type in the footwall and hanging wall. At the mineralized horizon, leaching of elements otherwise enriched in the ore zones is best illustrated by Mn, Mg, and Ca, which display a peak and trough pattern around the zone 2 extension.

North corridor alteration assemblages

The volcanic rocks associated with the north corridor ore zones consist of more intermediate and felsic rocks when compared with footwall, hanging-wall, and host rocks associated with the zone 2 extension ore zones (Fig. 2). The most abundant rock found in the north corridor is andesite-dacite (subunit 5.1b-(b)): all studied north corridor ore zones occur within this unit. Two main groupings of mineralized horizons are present in the north corridor in both drillholes, although there is a third intervening mineralized horizon (Fig. 3, 8). Background alteration in the north corridor is composed mainly of the banded biotite-chlorite alteration described below.

North corridor alteration mineralogy

An assemblage of metamorphic minerals that represents a distal alteration footprint is recognized several tens of metres on either side of the ore zones and is characterized by approximately equal proportions of fine- to medium-grained quartz and sericite (Fig. 7b), approximately 3 volume per cent coarse pyrite, and minor amounts (~1 volume per cent) of fine-grained Mg-rich chlorite (dark green on Fig. 3).

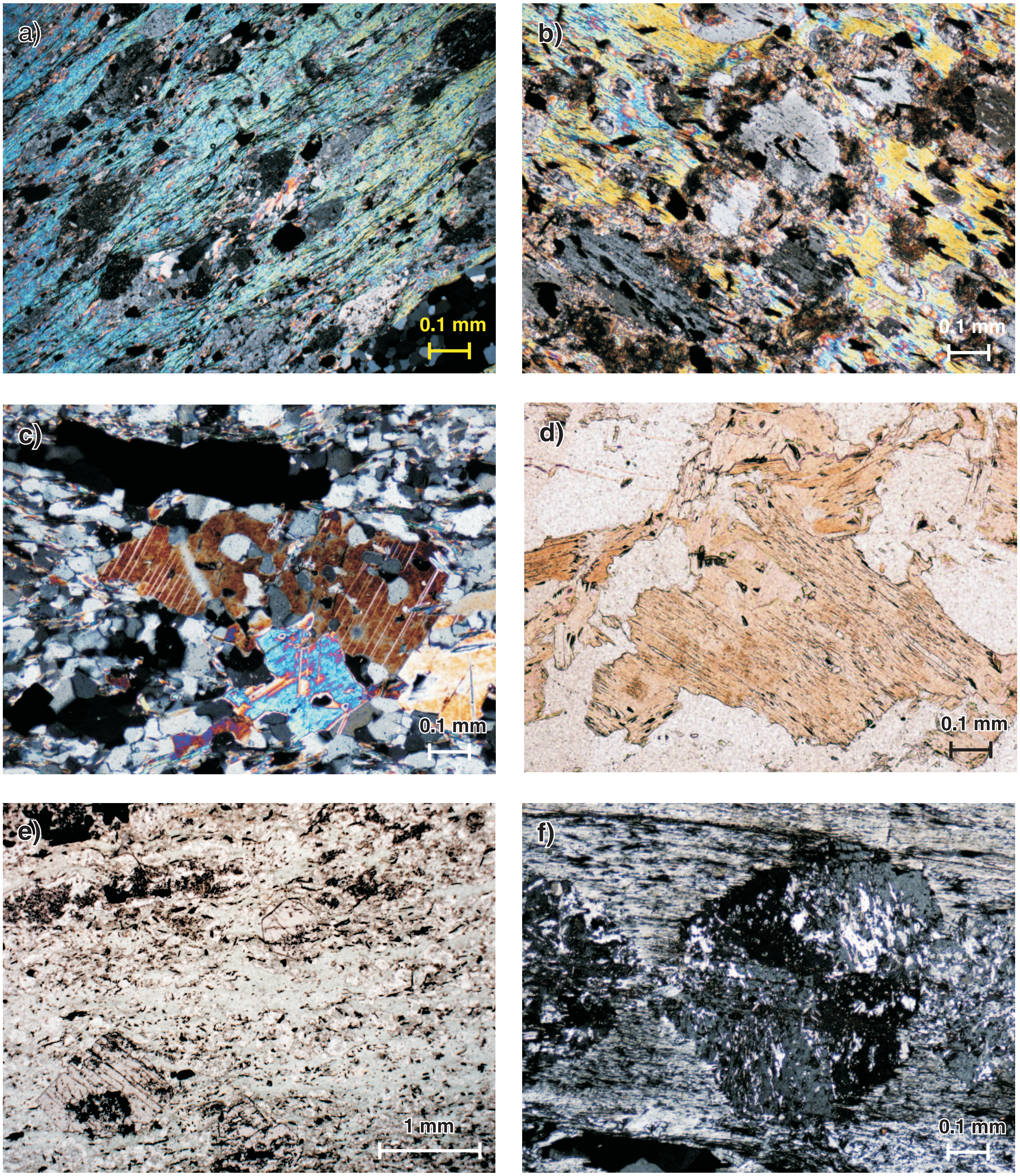

Figure 7. Alteration minerals associated with the Westwood deposit mineralized horizons. **a)** Intensely muscovite-altered feldspar-bearing rocks of unit 4.3, Doyon felsic unit. 2010-247. **b)** Sericite coronas on altered feldspar porphyroblasts in a muscovite-altered matrix. Dark patches and needle-like crystals of Ti-oxide minerals occur throughout (XPL). 2010-248. **c)** Coarse anhydrite grains associated with gold and sulphide mineralization in the zone 2 extension. Anhydrite occurs in the immediate footwall and the hanging wall of all three mineralized corridors in the Westwood deposit (XPL). 2010-251. **d)** Biotite porphyroblast in the north corridor associated with elevated gold values (PPL). 2010-244. **e)** Garnet internally foliated by titanite (PPL). 2010-250. **f)** Twinned and sheared feldspar aligned along main foliation, and displaying internal foliation defined by titanite (XPL). 2010-261. All photographs by A. Wright-Holfeld. XPL = crossed polarized light, PPL = plane polarized light.

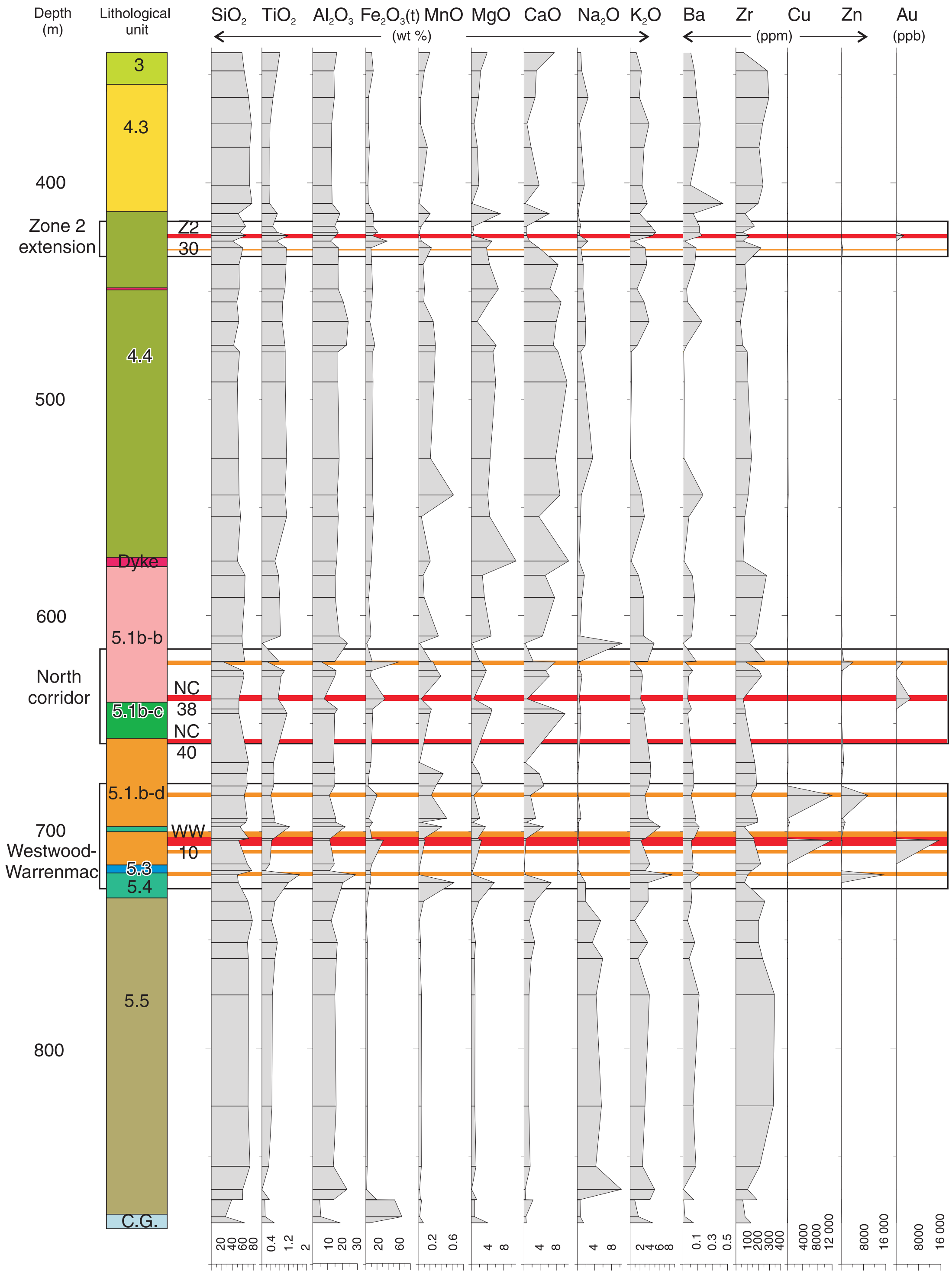

Figure 8. Geochemical profile along drillhole R14070-06 showing major element oxide (weight per cent) trends, and metals (Ba, Cu, and Zn in ppm, and Au in ppb) on the right marking the mineralized horizons. Largest peaks of metals occur in the Westwood-Warrenmac corridor, and are associated with the presence of semimassive to massive sulphide minerals. Also shown are lithological units intersected. C.G. = Cadillac Group, NC = north corridor, WW = Westwood-Warrenmac corridor.

Many other minerals are present in minor amounts (trace to 2 volume per cent), and they include medium to coarse biotite (restricted to hanging wall), fine-grained garnet in the footwall and ore zones, fine- to medium-grained muscovite, clinozoisite, epidote, Ce-rich allanite, very coarse-grained calcite, very fine-grained titanite; some anhydrite (Fig. 7c); and rare medium-grained tourmaline, Zn-spinel (gahnite), and Zn-rich chlorite. The footwall (unit 4.4) and hanging-wall basalt (subunit 5.1b-(c)) in the north corridor appear to be overprinted by thin alteration halo in which titanite, talc, clinozoisite, and epidote all occur to varying degrees (trace to 2 volume per cent) in 1–5 m wide bands on either side of ore zones. In the ore zones, the minerals present are quartz, sericite, calcite, titanite, and varying amounts of chlorite and epidote. Biotite and chlorite occur together in approximately centimetre-wide bands, giving the rocks a striped appearance in drill core. This pattern may represent the selective replacement of fragments by biotite in a chlorite-altered matrix, and could indicate a local control of rock type on the distribution of the original alteration mineral assemblage. Centimetre-wide K-feldspar bands occur in a metre-wide zone below the mineralized intervals. These bands of boudinaged orthoclase are predeformational and have been transposed parallel to foliation. Variable degrees of albitization of plagioclase occur throughout the north corridor mineralization.

North corridor geochemistry

Calcium content decreases gradually with depth in drillholes toward the north corridor, and shows a more pronounced depletion closer to the ore zone. Sodium has a large peak in the immediate footwall of the north corridor mineralization, although it occurs in very minor abundances in the ore zones and hanging wall. The content of K generally increases in both the footwall and the hanging wall of the north corridor, but does show depletion coinciding with increased Fe content coinciding with sulphide mineralization. An overall increase in Fe content in the distal footwall may reflect the presence of magnetite and amphibole in the host rocks. Titanium and zirconium have a saw-tooth pattern with depletion in ore zones, and greater abundance in host and surrounding rocks. Footwall rocks (subunit 5.1b-(b)) are enriched in Mg and Mn, and the immediate hanging-wall rocks (unit 5.1b-b(c)) are depleted in both. Magnesium and Mn are enriched toward the Westwood-Warrenmac corridor higher in the stratigraphy (subunit 5.1b-(d); Fig. 8). Aluminum and silicon concentrations remain relatively constant in hanging-wall and footwall rocks, but are slightly depleted in association with semimassive to massive sulphide deposits.

Westwood-Warrenmac corridor alteration assemblages

The ore zones of the Westwood-Warrenmac corridor have a relatively large hydrothermal footprint compared to the north corridor and zone 2 extension alteration halos. Possible effects of the hydrothermal system responsible for the formation of the Westwood-Warrenmac corridor lenses are present for several tens of metres stratigraphically below and above the ore zones; however, it is challenging to define the metamorphosed alteration assemblage in this stratigraphic interval due to the complex geometry of the lithological units and their potential control on the variation in mineral assemblages. Further complicating the distribution of the metamorphosed alteration mineral assemblages in this area is the overprinting by secondary alteration associated with the Bousquet fault zone, which can occur up to approximately 100 m away in the hanging-wall rocks.

Westwood-Warrenmac corridor alteration mineralogy

The stratigraphic footwall rocks of the Westwood-Warrenmac corridor ore zones consist of the uppermost portions of the north corridor hanging-wall basaltic andesite, subunit 5.1b-(c), and a dacite-rhyodacite subunit 5.1b-(d) (Fig. 1b, 2). Minerals that are pervasively present over distances on the order of tens of metres in footwall units in both drillholes make up the following generalized distal footwall metamorphosed alteration assemblage: quartz+sericite+muscovite+Mn-garnet+biotite+rutile+titanite.

Quartz is present throughout the drillholes, and therefore does not aid in identifying the margins of alteration footprints associated with ore zones. Muscovite, identified in thin section by its coarse grain size of up to 0.5 mm, is present everywhere in the Westwood-Warrenmac corridor in abundances of 10–30 volume per cent. Very fine-grained albite is present in the immediate footwall and hanging-wall rocks to the thickest ore lenses at abundances up to 10 volume per cent. Albitization of feldspars is extensive throughout the Westwood-Warrenmac corridor.

Biotite has a widespread, but very patchy distribution in the footwall rocks, and is most abundant in basaltic and andesitic footwall rocks along with intense chlorite alteration. It also occurs sporadically in the dacite-rhyodacite subunit 5.1b-(d) footwall rocks in close association with ore lenses. Biotite is associated most closely with garnet±quartz±calcite as grains that are up to 0.5 mm in diameter (Fig. 7d), in abundances of up to 10 volume per cent locally, and are randomly oriented. Biotite also occurs as fine grains in the groundmass, and is generally randomly oriented, but shows a small degree of preferred foliation parallel orientation. This behaviour of biotite suggests late-main deformation crystallization.

Manganese-rich garnet (Fe-spessartine) has a similar distribution to biotite, although it is most abundant in the dacite-rhyodacite unit 5.1b-(d), and is most commonly an immediate footwall alteration-zone mineral. It is most abundant in the first few metres stratigraphically below ore lenses, with a maximum abundance of approximately 5 volume per cent locally, and grain size of up to 2 cm (Fig. 7e). Garnet crystals display internal foliation defined by needles of titanite or rutile, or both, and are elongate parallel to foliation, indicating that they are syntectonic. Also occurring as small patches in garnet grains is a rare-earth element–bearing fluorine-rich carbonate mineral, probably synchysite.

Sericite is perhaps the best indicator of proximity to ore lenses on a local scale, due to the fact that it is present in the several metres stratigraphically below most ore lenses in the Westwood-Warrenmac corridor and is equally abundant in all rock types. This widespread occurrence of sericite, up to 15 volume per cent throughout the footwall rocks, and its correlation with ore zones suggests that its distribution may be a function of hydrothermal activity, and that the original chemistry of the rocks played a less significant role in the distribution of sericite.

Fine-grained rutile, titanite, and rarely ilmenite have a similar distribution pattern to sericite in that they occur in all altered rock types (basalt, andesite, and dacite-rhyodacite) in a 1–5 m interval immediately below ore zones, but are less abundant (less than 1%) than other alteration minerals.

In addition to the above minerals, other minerals present in one or both of the drillholes, and in varying amounts are calcite, Fe- and Mg-rich chlorite, epidote, clinozoisite, and allanite, which make up more proximal alteration assemblages (Table 3). For example, chlorite and clinozoisite are commonly found in the approximately 1–5 m interval stratigraphically below an individual lens or cluster of ore lenses. These minerals occur in both the basaltic and andesitic footwall rocks (units 4.4 and 5.1b-(b)), as well as in the dacite-rhyodacite unit (unit 5.1.b-d), however there may be a primary compositional control on the presence of these minerals. Aside from its presence in the banded biotite-chlorite alteration zone, chlorite also appears to be associated with amygdaloidal and possibly fragmental rocks of both mafic and felsic composition. Similarly, clinozoisite is predominantly associated with what is inferred to be fragmental dacite-rhyodacite. This also may reflect the control of rock type on the distribution of alteration minerals. Epidote is associated with basaltic rocks found in the immediate footwall in both drillholes, but is also found in the hanging-wall andesite in drillhole R14286-07. Calcite is present in the footwall rocks of both drillholes studied, although it is much more abundant (15%, up to 2 mm) in drillhole R14070-06, where it occurs pervasively in both mafic and felsic units in the footwall, as well as in the hanging wall. Like in the north corridor immediate footwall, foliation-parallel centimetre-scale K-feldspar bands occur in the immediate footwall of the Westwood-Warrenmac corridor ore zones.

The hanging-wall rocks of the Westwood-Warrenmac corridor are dominated by a comparatively simple background alteration assemblage, partly due to the relative simplicity of the hanging-wall rocks, which consist mostly of homogeneous felsic rocks of units 5.3 and 5.5 (*see* Fig. 2). Minerals present in the felsic units include 40 volume per cent quartz, approximately 40 volume per cent sericite and feldspar (Fig. 7f) and up to 20 volume calcite, with traces of muscovite.

Proximal to the ore zones is a more complex alteration pattern. Garnet has a generally limited distribution in the hanging wall than in footwall rocks, with garnet crystals above the ore zones smaller (<1 cm), are sparser, at an abundance of about 1–2 volume per cent and occur over a shorter interval. Calcite abundance and grain size in the hanging wall is similar to that of the footwall.

Other minerals present in the several metres above ore zones include, 10 volume per cent fine-grained chlorite-altered biotite, up to 5 volume per cent medium-grained rutile and titanite; trace fine- to coarse-grained tourmaline, aluminosilicate, and epidote minerals; and locally up to 30 volume per cent very fine-grained muscovite. There does not appear to be a primary lithological control on distribution of these minerals: garnet, rutile, and biotite are present in dacite-rhyodacite, rhyolite, and basalt-andesite. Abundant muscovite is associated with the thickest sulphide lenses observed. The tourmaline has a somewhat random distribution.

In drillhole R14286-07, the 5–20 m thick basaltic-andesitic unit (unit 5.4) makes up the immediate hanging wall of the largest ore lens. In addition to a pervasive quartz-sericite-feldspar-rutile hanging-wall mineral assemblage, other minerals associated with unit 5.4 are epidote and locally calcite, probably reflecting the more mafic nature of the andesitic body. This unit is present in two intervals in drillhole R14070-06 ranging from 5–10 m, and has similar alteration minerals, with the addition of biotite. Biotite is generally absent in this unit in drillhole R14286-07.

Westwood-Warrenmac corridor geochemistry

Chlorite minerals analyzed by electron microprobe show an increase in Mg content in proximity to the Westwood-Warrenmac corridor ore zones, and a decrease in Fe content. This pattern is reflected in whole-rock geochemical data for MgO and Fe_2O_3(total) in drillhole R14070-06, shown in Figure 8. Manganese and magnesium increase in the immediate footwall (5.1b-(d)). Calcium (CaO) values decrease with further depth toward the Westwood-Warrenmac corridor. In contrast, K displays a slight overall enrichment in the Westwood-Warrenmac corridor zones. Both Mn and Mg are present in uniformly very low abundances in the hanging-wall felsic rocks of the Westwood-Warrenmac corridor horizons. Sodium is leached in the Westwood-Warrenmac corridor, but is enriched in the hanging-wall rocks. Minor peaks in barium in the ore zone are associated with elevated values of Zn. Comparatively large peaks of Mn, Mg, and Ca occur in the immediate hanging wall of the Westwood-Warrenmac corridor, possibly reflecting the remobilization of these elements from the footwall to the hanging wall.

Table 3. Alteration assemblages associated with the three main mineralized corridors of the Westwood deposit.

Dominant alteration assemblage	Less abundant minerals
Zone 2 extension	
Footwall Quartz+sericite+plagioclase±chlorite±muscovite	Clinozoisite, allanite, talc, garnet
Hanging wall Quartz+sericite+plagioclase±chlorite±muscovite	Clinozoisite, epidote, allanite, anhydrite calcite, titanite, talc, tourmaline
North corridor	
Footwall Quartz+sericite+chlorite+garnet±biotite±calcite	Titanite, clinozoisite, epidote, plagioclase allanite, anhydrite, spinel, tourmaline, K-feldspar
Hanging wall Quartz+muscovite+biotite±chlorite	Sericite, titanite, clinozoisite, epidote
Westwood-Warrenmac corridor	
Footwall Quartz+muscovite+sericite+calcite+garnet	Plagioclase, rutile, titanite, biotite, chlorite, epidote, clinozoisite, allanite, K-feldspar
Hanging wall Quartz+sericite+plagioclase+titanite	Chlorite, garnet, rutile, biotite, tourmaline

DISCUSSION ON THE NATURE OF THE WESTWOOD DEPOSIT

Despite strong heterogeneous deformation in the entire Doyon-Bousquet-LaRonde camp, and particularly in the vicinity of ore deposits where rocks were more responsive to deformation due to intense hydrothermal alteration, it has been demonstrated that some primary features (alteration patterns, volcanic facies, and textures, etc.) can be recognized (e.g. Tourigny et al., 1993; Lafrance et al., 2003; Mercier-Langevin, 2005; Dubé et al., 2007; Mercier-Langevin et al., 2007c). Mercier-Langevin et al. (2009) have shown that different types of mineralization and contrasting styles of alteration are present in this area (Fig. 3). The spatially restricted alteration assemblage around the zone 2 extension quartz-sulphide vein–style mineralization and the inferred association with the Doyon mine Zone 2 vein system implies a component of vein-style ‘intrusion-related’ emplacement of the zone 2 extension at the Westwood deposit. Because of the stacked nature of ore horizons in this area, and the presence of the Mooshla synvolcanic pluton nearby, the alteration pattern may be partially obscured by the effects of a large-scale, long-lasting hydrothermal system associated with the synvolcanic intrusion (Lafrance et al., 2005; Galley and Lafrance, 2007); however, there are a few minerals that occur in a 5–10 m envelope around the zone 2 extension veins: talc, anhydrite, epidote, clinozoisite, allanite, garnet, and titanite. These alteration minerals are more suggestive of those associated with volcanogenic massive-sulphide–style mineralization seen higher in the stratigraphy. Deformation in the zone 2 extension corridor appears to have obliterated any primary volcanic textures that might aid in the classification of these ore zones, and a more definitive statement on this part of the Westwood deposit mineralization will require further investigation.

The ore zone and hanging-wall alteration of the north corridor provides important clues on its formation history, assuming that original stratigraphic relationships are intact. The north corridor has what appears at a first glance to be narrow vein-like polymetallic mineralization and alteration envelope. Close proximity to the north corridor mineralization of minerals similar to those found in the zone 2 extension raises the possibility of a similar emplacement and alteration style for both the corridors; however, unlike the zone 2 extension alteration, chlorite, sericite, and calcite make up a broad (approximately 100 m wide) alteration halo around the north corridor mineralized zones. Whether or not this pattern is truly a representation of hydrothermal activity associated with the formation of the north corridor is unclear, due to the fact that the lowest Westwood-Warrenmac corridor mineralized horizons are located a few tens of metres stratigraphically above the north corridor (Fig. 2). The footwall alteration of the Westwood-Warrenmac corridor ore zones may be overprinting north corridor hanging-wall alteration. Two of the three mineralized horizons in the north corridor intersected in drillhole R14070-06 are hosted in a continuous andesite, and the other in basalt at the andesite-basalt contact (Fig. 2). These host rock–ore zone relationships and alteration patterns may suggest subseafloor mineralizing processes (e.g. Doyle and Allen, 2003) rather than classical volcanogenic massive-sulphide–style exhalative mineralization. Although talc and anhydrite occur in the immediate footwall and hanging wall of the north corridor ore zones (Fig. 9), which is similar to some alteration zones associated with Noranda-type volcanogenic

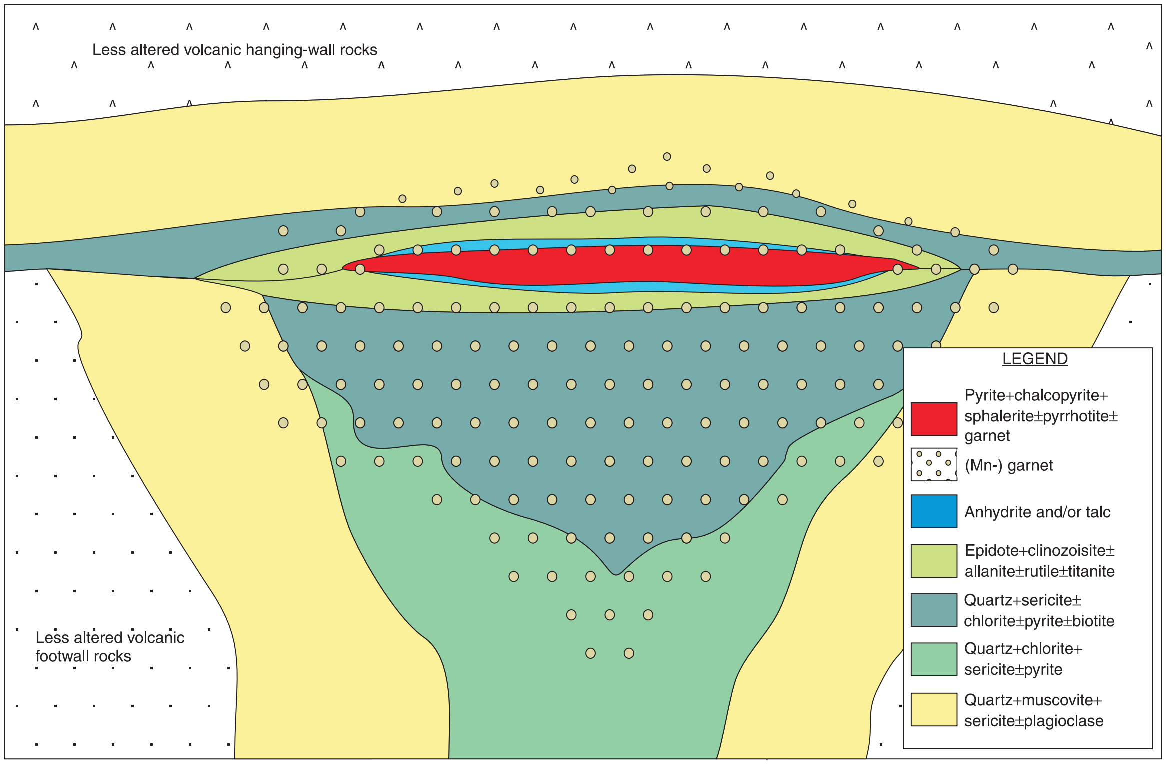

Figure 9. Schematic representation of alteration halos associated with Westwood-Warrenmac and north corridor mineralized zones in the Westwood deposit. Distal alteration is characterized by large-scale envelopes or halos of predominantly sericite and chlorite, with minor amounts of biotite and garnet, as well as variable amounts of feldspar minerals, rutile, and titanite. Proximal alteration is characterized by the presence of coarser and more abundant garnet, biotite, epidote-group minerals, anhydrite, rarely talc, as well as mica alteration, partially albitized feldspars, and rutile and titanite.

massive-sulphide deposits (Gibson and Galley, 2007), and is further support for a volcanogenic massive-sulphide–style origin for the north corridor.

Though not as abundant in the study area of the Westwood deposit compared to other deposits in the Doyon-Bousquet-LaRonde camp (e.g. LaRonde: Dubé et al., (2007); Bousquet 1: Valliant et al. (1982)), garnet distribution and morphology can provide some insights to the formation of the deposit. In the Westwood-Warrenmac corridor, and in the north corridor, garnet is often associated with amygdale-filling minerals and sulphide mineralization (Fig. 5e, 7d).

The altered host rocks of the north corridor are characterized by two distinct mineral assemblages present in foliation-parallel bands: microcrystalline quartz with varying degrees of muscovite and sericite anastomosing around coarser quartz grains; and an intensely sericite- and chlorite-altered, garnet, titanite, and plagioclase zone. Biotite is overprinting both assemblages, although it is much more prevalent in the sericite-chlorite alteration zone, and weak in the quartz-muscovite-sericite zone. Sulphide minerals and gold-bearing phases hosted in or adjacent to sulphide minerals occur as highly irregular to patchy aggregates close to and sometimes within garnet crystals present in the in the chlorite-sericite-altered zone (Fig. 6f). A possible explanation for the observed pattern involves the influx of Mn-rich mineralizing fluids into the north corridor host rocks, and preferential filling of more porous areas, or voids with Mn-bearing minerals and sulphide minerals. The presence of comparatively fewer sulphide minerals in the quartz-sericite-muscovite assemblage may be the result of somewhat limited infiltration of mineralizing fluids in to a more coherent portion of the protolith.

There is evidence (e.g. Dubé et al., 2007) that the syn-deformation metamorphic growth of garnet was due to the presence of volcanogenic massive-sulphide–related Mn-bearing alteration phases like carbonate minerals or chlorite. In the Westwood deposit area, garnet crystals are sometimes cored by rutile, suggesting that garnet crystals might be replacing Ti-oxide, as proposed by Stone (1988) for garnet crystals present elsewhere in the Doyon-Bousquet-LaRonde camp. As described above, garnet crystals can be sheared and are internally foliated by titanite and sometimes rutile and these minerals are observed in foliation-parallel bands in silicate matrix. Garnet commonly contains inclusions of quartz and sericite-muscovite-altered feldspar groundmass. This suggests that garnet is a metamorphic mineral developed on primary, hydrothermal alteration assemblages in the Westwood area. Sparser distribution of garnet in the hanging-wall rocks could suggest either a waning hydrothermal system, or inability of hydrothermal fluid to penetrate into overlying rocks, suggesting subseafloor replacement.

Stacking of lenses may be explained by repeated mineralization events and capping of the hydrothermal system by emplacement of units 5.3 and 5.4, implying subseafloor replacement mineralization, a situation that is very similar to that proposed for the LaRonde Penna deposit (Dubé et al., 2007); however, the capping units are relatively thinner in the Westwood deposit area. Narrow chalcopyrite- and sphalerite-dominant 'veins' in the base of the Westwood-Warrenmac corridor can be interpreted as the stringer zone to thicker (semi-) massive sulphides higher in the stratigraphy. These stringer veins are now transposed by deformation, and their original geometry relative to the volcanogenic massive-sulphide ore lenses is no longer preserved, as they are parallel to lithological contacts and ore lenses.

The ore zones of the Westwood-Warrenmac corridor have what is interpreted to be an alteration signature typical of volcanogenic massive-sulphide systems, although the original geometry is no longer recognizable due to intense deformation. Chlorite, quartz, calcite, and sericite or muscovite, or varying degrees of both, in the footwall, ore zones, and immediate hanging-wall rocks, shown schematically in Figure 9, are interpreted to be the product of a long-lived hydrothermal system. It is difficult to distinguish the original zonation of minerals with respect to the ore horizons, due to large amounts of shearing and subsequent shortening and stretching of lithological boundaries, alteration zones, ore lenses, and stringer zones, causing previously lateral features to be pseudo-stratigraphically superimposed. Despite these difficulties in defining original features, it can be speculated, based on the presence of aluminosilicates and reported occurrence of kyanite and andalusite (Mercier-Langevin et al., 2008b, 2009), as well as the presence of garnet, biotite, and epidote-group minerals in the Westwood-Warrenmac corridor, that the mineralization was emplaced in a submarine environment, perhaps somewhat analogous to subaqueous low-, intermediate-, and high-sulphidation-style epithermal regimes, at least locally (Sillitoe et al., 1996; Hannington et al., 1999; Dubé et al., 2007). This implies that alteration minerals present, though the original geometry of mineral assemblages may be sheared, are metamorphosed and recrystallized components of previous synvolcanic events.

Inferred synvolcanic porosity and permeability are favourable for the development of subseafloor aquifers, which in turn focused, trapped, and channelled rising hydrothermal or magmatic fluids to form the various types of ore zones in the Westwood deposit area. In the north corridor, host rocks and the underlying Bousquet scoriaceous tuff units are thought to have channelled mineralizing fluids (e.g. Stone, 1988). Volcaniclastic, amygdaloidal and fractured host rocks in the Westwood-Warrenmac corridor may have provided the ideal pathways for circulating hydrothermal fluids.

Because of the inferred conformable and stacked original geometry of the host volcanic stratigraphy, particular units having properties favourable for the development of shallow subseafloor ore zones have widespread distribution. These favourable properties include permeability of rocks creating fluid pathways, and impermeability of capping rocks. Circulation of hydrothermal and possibly magmatic-hydrothermal fluids through these units resulted in the development of geochemical and mineralogical gradients due to changes in fluid composition during continuous interaction with host rocks. These gradients are defined by the presence of alteration facies focused on the sulphide zones. Manganese and potassium both show an enrichment trend toward ore zones as evidenced by the presence of Mn-bearing garnet and sericite and biotite alteration. This is contrasted by Na depletion throughout the ore zones and host rocks with the exception of Na enrichment in the hanging-wall rocks of the Westwood-Warrenmac corridor. Magnesium shows repeated depletion in the footwall rocks of the north corridor and the Westwood-Warrenmac corridor. Potassium associated with sericite shows a gradual increase toward the zone 2 extension ore zone, and a gradual decrease away from it. Barium is enriched in zone 2 extension footwall rocks (Fig. 8).

CONCLUSIONS

The study of the Westwood deposit geology, mineralization and metamorphosed alteration assemblages has allowed for the following conclusions to be drawn.

- The zone 2 extension is difficult to classify in terms of deposit type due to high degrees of strain and intense alteration in the host and surrounding rocks. Vein-style intrusion-related emplacement is possible due to the close association and similarities with the Zone 2 ore body at the Doyon mine; however, based on the presence of alteration mineral assemblages characteristic of the volcanogenic massive-sulphide deposits of the Doyon-Bousquet-LaRonde camp, and seen in Westwood-Warrenmac corridor and north corridor ore zones higher in the stratigraphy, the zone 2 extension could be interpreted as a stringer zone associated with volcanogenic massive-sulphide–style mineralization higher in the stratigraphy.
- The north corridor is perhaps a smaller, earlier-formed volcanogenic massive-sulphide–associated vein system that was overprinted by the hydrothermal system responsible for the formation of the Westwood-Warrenmac corridor lenses higher in the stratigraphy.
- The Westwood-Warrenmac corridor has a large-scale volcanogenic massive-sulphide–style alteration halo, although it is significantly sheared and the original

mineral zonation is obscured. Sulphide minerals commonly associated with ore deposits further support a volcanogenic origin for the Westwood-Warrenmac corridor mineralized horizons.

- Because of the stacked nature of the ore zones, it is difficult to clearly distinguish between the hanging wall of an ore zone with the footwall of another. As such, the Westwood footwall halo may be obscuring the original alteration assemblages of the north corridor.
- The presence of Mn-garnet in the ore zones throughout the Westwood deposit area supports the hypothesis that the hydrothermal history of the deposits included the circulation of lower temperature, relatively oxidized, Mn-enriched seawater circulating on a large scale. Manganese-garnet formed in the north corridor and Westwood-Warrenmac corridor ore zones in areas of high permeability in a shallow subseafloor environment, as evidenced by its stratabound distribution, the presence of a cap rock in the form of an andesite sill, zonation, and its common association with altered amygdale-filling minerals like clinozoisite, epidote, calcite, quartz, and chlorite.
- The presence of Au mineralization associated with the amygdale-filling minerals in some units suggests a synvolcanic origin for the Au and sulphide deposition. Some degree of remobilization associated with deformation may have caused Au to become more concentrated in high-strain zones.

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