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A Group of Papers Devoted to the Laronde Penna Au-Rich Volcanogenic Massive Sulfide Deposit, Eastern Blake River Group, Abitibi Greenstone Belt, Quebec: Preface*

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Gold-rich volcanogenic massive sulfide (VMS) deposits are a subgroup of lode gold deposits, as defined by Poulsen et al. (2000). They are commonly defined by an average gold grade in grams per tonne greater than that of the combined base metals in weight percent (Au g/t > Cu + Zn + Pb wt percent: Poulsen et al., 2000). Five of the largest and best examples of Au-rich VMS deposits currently recognized in the world are located in the Blake River Group in the Abitibi greenstone belt, Quebec, Canada. The Horne (54.3 Mt at 6.1 g/t Au, 11.7 Moz Au) and Quemont (13.9 Mt at 4.7 g/t Au, 2.3 Moz Au) deposits occur in the Noranda camp (Fig. 1), and the LaRonde Penna (59 Mt at 4.3 g/t Au, 8.1 Moz Au), Bousquet 2-Dumagami (15.5 Mt at 7.2 g/t Au, 3.6 Moz Au) and Bousquet 1 (7.5 Mt at 5.3 g/t Au, 1.3 Moz Au) deposits occur in the Doyon-Bousquet-LaRonde mining camp (Table 1), 45 km east of Noranda (Fig. 1).

The LaRonde Penna Au-rich VMS deposit is a major Zn producer and one of the largest Canadian gold deposits, with 58.6 Mt of ore (production, reserves, and resources) at an average grade of 4.31 g/t Au, 45 g/t Ag, 0.33 percent Cu, and 2.17 percent Zn (Table 1). Its discovery and development into a mine allowed the Geological Survey of Canada and the Ministère des Ressources naturelles et de la Faune du Québec, along with the mining companies active in the area, to undertake a full geologic synthesis of the Doyon-Bousquet-LaRonde mining camp. The detailed study of the LaRonde Penna Au-rich VMS deposit was a major component of this project and was aimed at providing a field-based, thorough description of a major deposit of the Au-rich VMS class, as detailed documentation of such deposits is still limited. Results of the geologic synthesis were published in a series of government reports and maps (Lafrance et al., 2003a, b, c, 2005; Dubé et al., 2004; Mercier-Langevin et al., 2004; Galley and Lafrance, 2007) and some of the results from the LaRonde Penna deposit study are presented in a group of three papers in this issue of *Economic Geology*.

An objective of the study was to develop exploration guidelines applicable in the Blake River Group and elsewhere in Archean terrains by determining the critical factors in the formation of Au-rich VMS deposits. The remarkable concentration of Au-Cu ± Zn-Ag VMS deposits in the Blake River Group, more specifically in the Doyon-Bousquet-LaRonde mining camp, was also an opportunity to examine the factors responsible for the provinciality of Au-rich VMS deposits.

Geologic Context and History

The Doyon-Bousquet-LaRonde mining camp, located in the eastern part of the Blake River Group in the Abitibi greenstone belt (Fig. 1), is one of the world's major Archean gold districts, with more than 22 Moz of gold contained along a ~10 km-long east-west–trending succession of volcanic rocks. Three main deposit types are developed in the camp: (1) the Au-rich VMS deposits that comprise the LaRonde

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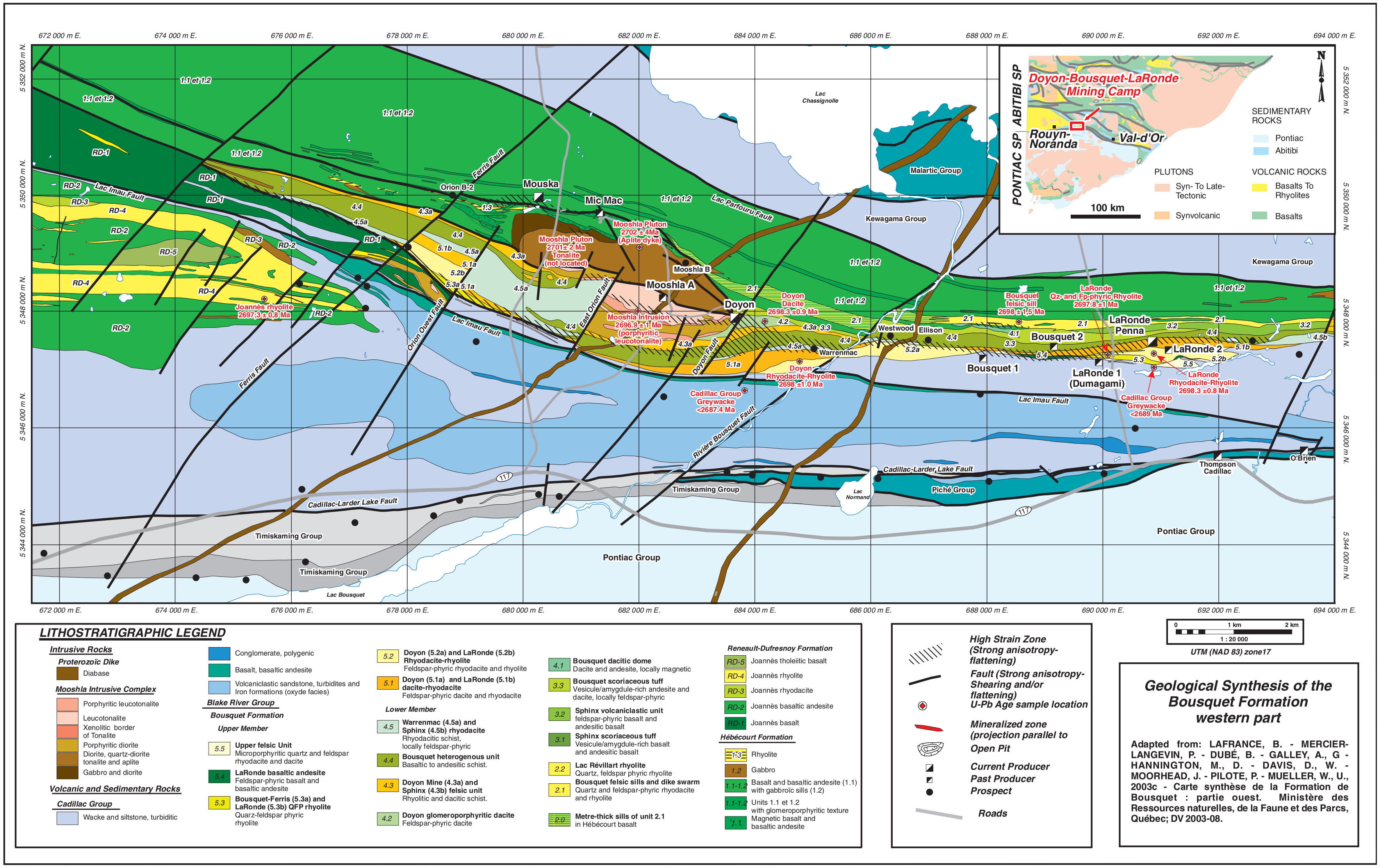


FIG. 1. Geologic map of the Bousquet Formation in the Doyon-Bousquet-LaRonde mining camp area. This map is a synthesis of the Doyon-Bousquet-LaRonde mining camp and shows the location of the Au-rich VMS deposits (current and past producers) and main occurrences and the location of the intrusion-related Au-Cu vein systems (current and past producers) and main occurrences at surface. Adapted from Lafrance et al. (2003a, b, c). U-Pb ages from Lafrance et al. (2003a; 2005) and from Mercier-Langevin et al. (2004; 2007a).

TABLE 1. Total Production, Reserves and Geologic Resources for the Doyon-Bousquet-LaRonde (DBL) Mining Camp

		Production						Reserves and geologic resources						Total for each deposit					
Deposit	Year	Mt	Au (g/t)	Au (tonnes)	Ag (g/t)	Cu (%)	Zn (%)	Mt	Au (g/t)	Au (tonnes)	Ag (g/t)	Cu (%)	Zn (%)	Mt	Au (g/t)	Au (tonnes)	Ag (g/t)	Cu (%)	Zn (%)
Au-rich volcanogenic massive sulfide deposits																			
Dumagami[1]	1988-1999	7.33	6.27	46.0	11.7	0.47	0.35							7.33	6.27	46.01	11.7	0.47	0.07
Bousquet 2[1]	1990-2002	8.14	8.14	66.25		0.56								8.14	8.14	66.25		0.56	
Bousquet 1	1978-1996	7.45	5.3	39.5				1.82	5.97	10.9				9.27	5.447	50.36			
LaRonde Penna[2,3]	2000-(2005)	12.3	3.53	43.44	53.7	0.28	2.66	46.46	4.51	209.5	42.7	0.34	2.04	58.76	4.31	252.97	45.0	0.33	2.17
Ellison								0.25	5.67	1.4				0.25	5.67	1.4			
Westwood								8.61	5.19	44.7				8.61	5.19	44.72			
	Total	35.22	5.54	195.19	38.0	0.41	1.69	57.14	4.66	266.5				92.36	5.00	461.71			
Intrusion-related and shear zone-hosted Au-Cu vein systems																			
Doyon[2]	1980-(2005)	29.78	5.55	165.14				7.92	5.17	41.0				37.7	5.47	206.09			
Mouska[2]	1989-(2005)	1.51	11.55	17.45				0.38	14.40	5.5				1.89	12.13	22.95			
Mic Mac	1942-1947	0.72	4.62	3.34										0.72	4.62	3.34			
Mooshla A	1939-1940	0.05	29.66	0.13										0.05	29.66	0.13			
	Total	32.02	5.81	186.06				8.30	5.60	46.5				40.32	5.77	232.51			
Total DBL mining camp		67.24	5.67	381.25				65.44	4.78	313.0				132.68	5.23	694.23			

Mt = million tonnes, g/t = grams per tonne
[1] The Bousquet 2-Dumagami deposit has been mined from the Bousquet 2 and the LaRonde 1 (Dumagami) mines
[2] Current producers
[3] Comprises the LaRonde II mine project reserves and geologic resources

Penna, Bousquet 2-Dumagami, and Bousquet 1 deposits, and the Westwood, Ellison, and Warrenmac ore zones; (2) the intrusion-related Au-Cu vein systems of the Doyon deposit; and (3) the greenstone-hosted quartz-carbonate Au-Cu veins that include the Mouska, Mic Mac, and Mooshla A and B deposits. Since the 1930s, mining has taken place at three of the Au-Cu ± Zn-Ag VMS deposits and four Au-Cu vein-hosted deposits for a cumulative production, at the end of 2005, of 67 Mt of ore at an average grade of 5.67 g/t Au (12.3 Moz Au or 381 t), including 35.2 Mt of ore at 5.54 g/t Au from VMS deposits (Table 1). The total past production added to the current reserves and resources for the mining camp amount to 132.7 Mt (22.3 Moz Au, Table 1), with two-thirds of the Au (14.8 Moz) hosted in Au-rich VMS deposits (Table 1).

The Au-rich VMS lenses are stacked at different stratigraphic intervals in the Bousquet Formation (Figs. 1, 2), the uppermost lenses being located in the eastern part of the camp (Fig. 2). All the VMS ore zones plunge steeply to the west (Fig. 3). This represents the combination of the primary elongation of the mineralization along inferred, regularly spaced synvolcanic faults, and stretching-flattening during the main stage of deformation (Mercier-Langevin, 2005). This attitude is mimicked at a smaller scale by the distribution of volcanic units, hydrothermal alteration, and metal zonation within the lenses at depth (Mercier-Langevin, 2005). The ore lenses are associated with discordant to subconcordant alteration zones that comprise variable amounts of aluminosilicates (andalusite, kyanite, pyrophyllite, staurolite), garnet (spessartine, almandine), biotite, carbonates, chlorite, epidote, phengite, quartz, rutile, sericite, and titanite. This alteration is described in the paper by Dubé et al. (2007) in this issue.

The intrusion-related Au-Cu vein systems of the Doyon mine (Table 1) and some parts of the Mouska mine are composed of sulfide-rich (75 to 80 vol %) veins and veinlets, sulfide disseminations, and quartz-sulfide veins (Savoie et al., 1990; Belkabir and Hubert, 1995; Gosselin, 1998; Galley and Lafrance, 2007) hosted by the Mooshla synvolcanic intrusion and by highly altered, schistose felsic ± mafic volcanic rocks in the upper part of the lower member of the Bousquet Formation. The mineralization forms slightly discordant orebodies and intensely transposed vein stockworks. The alteration assemblage is similar to the assemblage associated with the Au-rich VMS deposits, although there are significant variations in intensity and distribution patterns.

The greenstone-hosted quartz-carbonate Au-Cu vein systems of the camp include the Mic Mac, Mooshla A, and Mooshla B ore zones and parts of the Mouska deposit (Table 1). The Mouska deposit consists of a series of subvertical east-west to northwest-southeast–trending sulfide and quartz-sulfide vein systems and associated narrow, high angle-reverse ductile and brittle-ductile shear zones superimposed on the regional foliation (Belkabir and Hubert, 1995; Tourigny and

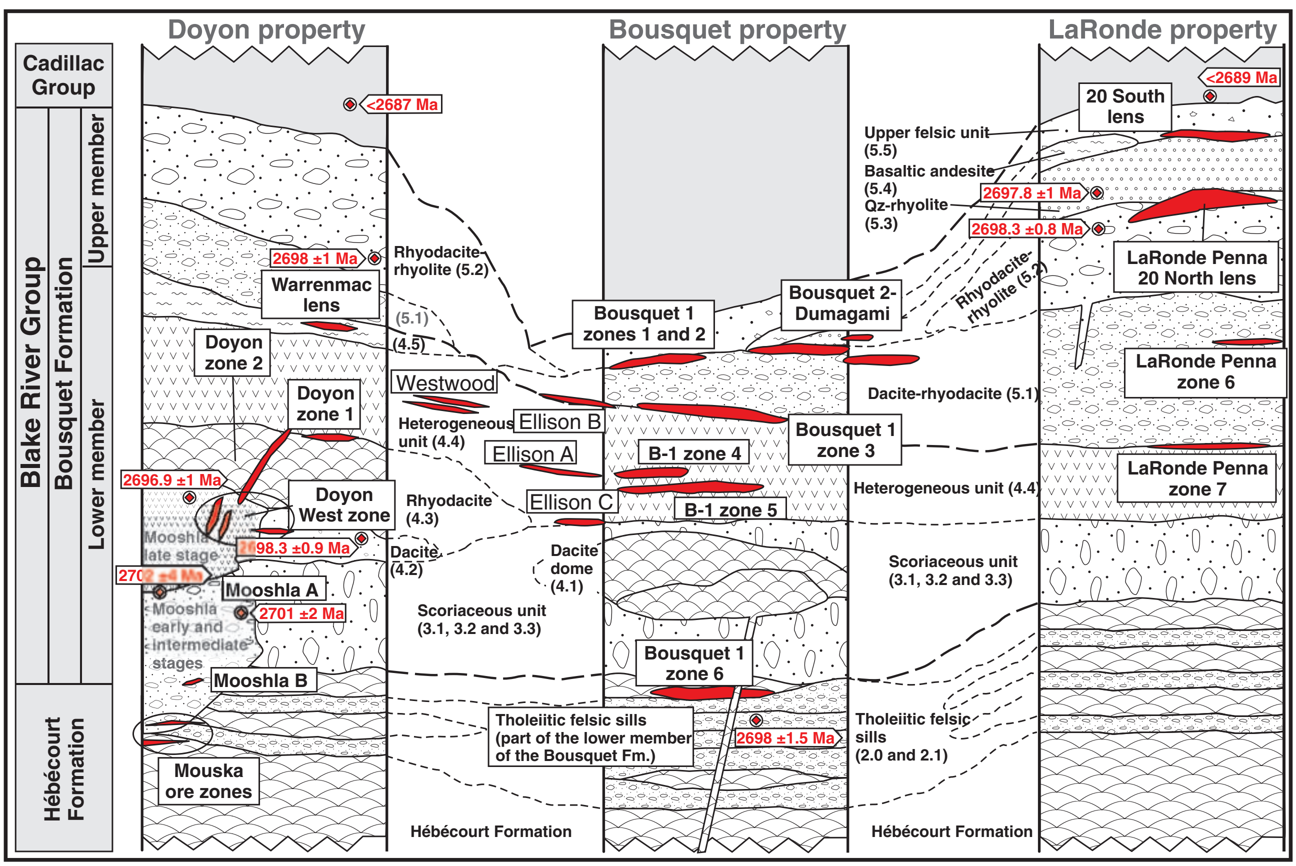
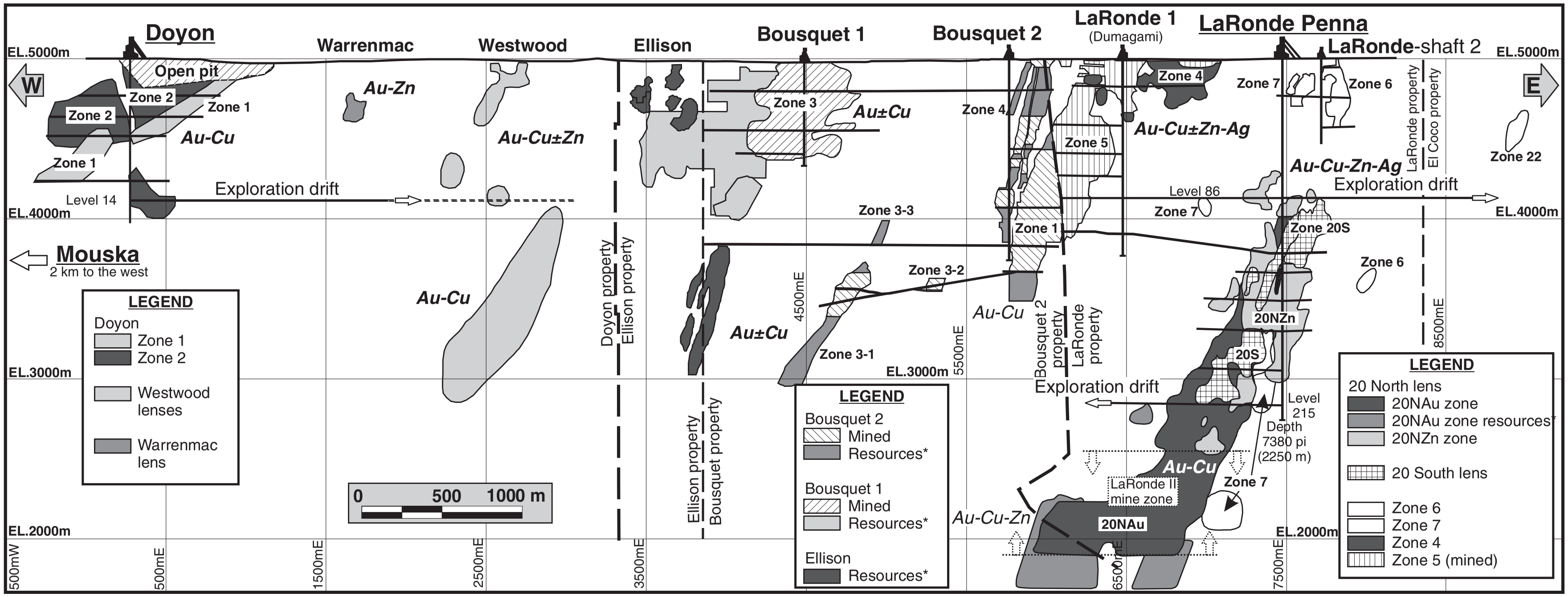


FIG. 2. Simplified stratigraphic setting of the Au-rich VMS lenses and intrusion-related Au-Cu vein systems of the Doyon-Bousquet-LaRonde mining camp. See Figure 1 for legend. Modified from Lafrance et al. (2003a) and Mercier-Langevin (2005).



*Geological resources

FIG. 3. Composite longitudinal view (looking north) of the Doyon-Bousquet-LaRonde mining camp for the Doyon mine (west)–LaRonde Penna mine (east) segment. This map excludes the Mouska deposit, which is located about 2 km west of the Doyon mine.

Tremblay, 1997; Belkabir et al., 1998). Zones 07, 08, and 22 at Mouska and the Mic Mac deposit are hosted in mafic to intermediate volcanic rocks of the Hébécourt Formation north of the Mooshla pluton, and zones 40, 50, 50 south, and 60 at Mouska and Mooshla A and B ore zones are hosted in the northern part of the intrusion (Fig. 2). However, these shear zone-hosted deposits share some characteristics with the first two ore types and, therefore, could consist, at least in part, of transposed and/or remobilized intrusion-related Au-Cu vein systems or Au-rich volcanogenic sulfides (Belkabir and Hubert, 1995; Galley and Lafrance, 2007).

An east-west–trending, steeply south dipping penetrative schistosity of variable intensity is developed everywhere in the camp and is responsible for localized flattening, stretching, folding, and shearing of the primary features in most of the ore deposits. This heterogeneous deformation is related to the main regional deformation episode that was accompanied by syn- to late-D_2 prograde upper greenschist-lower amphibolite facies metamorphism (Marquis et al., 1990a; Dubé et al., 2004; Mercier-Langevin, 2005). Previous studies in the camp were, in some cases, hindered by this regional deformation and its apparent control on mineralization.

A primary or synvolcanic origin for the gold in these deposits has been proposed by Fillion et al. (1977), Valliant and Barrett (1982), Valliant and Hutchinson (1982), Valliant et al. (1982, 1983), Stone (1990, 1991), Tourigny et al. (1993), Teasdale et al. (1996), Gosselin (1998), and Belkabir et al. (2004), whereas others (e.g., Guha et al., 1982; Savoie et al., 1986, 1990, 1991; Tourigny et al., 1988, 1989a, b; Hoy et al., 1990; Marquis et al., 1990a, b, c; Trudel et al., 1992) have proposed a multistage or a syn- to late-tectonic and metamorphic origin with an emphasis on a structural control on the distribution of the ore and of the gold within the ore zones. However, the discovery of the LaRonde Penna deposit in 1993 in a less deformed part of the volcanic sequence provided an opportunity to examine the primary features and the genesis of an Au-rich VMS deposit more closely. Preliminary detailed geologic and metallogenic studies of the LaRonde Penna deposit (Dubé et al., 2004; Mercier-Langevin et al., 2004; Mercier-Langevin, 2005) and of the Mooshla synvolcanic intrusion-related mineralization (Galley and Pilote, 2002; Galley and Lafrance, 2007), combined with mapping of the Bousquet Formation and U-Pb geochronology (Lafrance et al., 2003a, b, c, 2005), indicate that the gold was mainly introduced as a primary component of the orebodies along with the other metals. Some of the key evidence supporting this interpretation is presented in the three papers on the LaRonde Penna deposit in this issue.

The first paper (Mercier-Langevin et al., 2007a) provides the geologic and geochronologic context of the LaRonde Penna deposit and discusses the influence of the host volcanic units and their architecture on the different ore and alteration styles that characterize the deposit. The second paper (Mercier-Langevin et al., 2007b) examines the geochemistry of the volcanic units hosting the LaRonde Penna deposit and considers the possible relationship between the inferred geodynamic setting, the petrogenesis of calc-alkaline felsic volcanic rocks, and the elevated gold content of the volcanogenic massive sulfides of the Doyon-Bousquet-LaRonde mining camp. The paper by Dubé et al. (2007) describes in detail the various hydrothermal alteration styles and documents the diverse styles of Au-rich VMS mineralization that can coexist laterally within the same system. It also presents an exploration model based on the key alteration assemblages and their zonation, taking into account the superposition of deformation and metamorphism.

The current research, combined with the knowledge gained at LaRonde Penna and at camp scale contributes to a practical metallogenic and genetic model for Au-rich VMS deposits by further constraining the geologic and metallogenic relationships between the various ore zones and ore types (Au-rich VMS, intrusion-related, and greenstone-hosted quartz-carbonate Au-Cu veins) of the Doyon-Bousquet-LaRonde mining camp. This area represents a unique laboratory for understanding the relationships between synvolcanic intrusions, volcanic centers, and related ore sytems on which major, late-tectonic, and metamorphic disturbances were superimposed. The detailed work in the Doyon-Bousquet-LaRonde mining camp also illustrates the importance of basic geologic mapping and documentation in establishing key primary volcanic, stratigraphic, and hydrothermal features and crosscutting relationships for accurate descriptive, genetic, and exploration models. We hope that the group of papers presented in this issue of *Economic Geology* will contribute to the description and evolution of ideas about Au-rich VMS deposits and Archean metallogeny.

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