

MINERALOGY AND METAL ZONING OF THE CAMBRIAN Zn-Pb-Cu-Ag-Au LEMARCHANT VOLCANOGENIC MASSIVE SULFIDE (VMS) DEPOSIT, NEWFOUNDLAND

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ABSTRACT

The Lemarchant deposit is a Cambrian bimodal felsic Zn-Pb-Cu-Ag-Au volcanogenic massive sulfide (VMS) deposit located in the Central Mobile Belt, Newfoundland, Canada. Despite regional greenschist metamorphism and faulting, primary mineralogy and mineral textures are well preserved. The deposit is a type example of a precious metal-enriched VMS deposit in the Appalachians. Mineralization consists of a stratiform massive sulfide zone that lies at the contact between a rhyolitic footwall and a basaltic hanging wall. A stringer sulfide zone that is hosted in footwall rhyolite breccia underlies the massive sulfide lens. The stratiform sulfide zone contains massive baryte that is heterogeneously replaced by sphalerite and pyrite, lesser galena, and trace chalcopyrite. The stringer zone contains chalcopyrite, pyrite, and lesser sphalerite and galena. Sphalerite ranges in color from white (low-Fe) to red (high-Fe). The palest sphalerite (<1 mol.% FeS) occurs in the baryte-rich stratiform zone and is associated with early stage exhalative mineralization, intermediate sulfidation epithermal suite minerals (tetrahedrite, bornite, colusite, Ag-bearing gold, covellite) and sulfide minerals enriched in the epithermal trace element suite (Au, Ag, As, Bi, Co, Cr, In, Mo, Ni, Sb, Sn, Te). Darker sphalerite (4.7–13.6 mol.% FeS) in the stratiform zone overprints early stage mineralization and occurs with chalcopyrite; high-Fe sphalerite is also present in the stringer zone.

Early exhalative/epithermal-type VMS mineralization was deposited from low temperature (150–250 °C), oxidized, acidic to near-neutral hydrothermal fluids with high sulfur activity. Early mineralization was likely deposited in relatively shallow water (<1500 mbsl) that intermittently boiled and precipitated Au in the stratiform zone. Late-stage polymetallic, Cu-rich VMS mineralization was deposited from higher temperature (>300 °C), less oxidized, near-neutral hydrothermal fluids, likely in deeper water (>1500 mbsl). Abundant epithermal suite minerals and epithermal trace element suite-enriched sulfides at Lemarchant suggest a direct magmatic contribution to the hydrothermal fluid.

Keywords: massive sulphide, sulphide mineralogy, petrography, electron microprobe, laser ablation ICP-MS, Newfoundland VMS, Cambrian VMS, gold in VMS, rifted arc.

INTRODUCTION

Precious metal-bearing volcanogenic massive sulfide (VMS) deposits are a sub-type of VMS deposit (Sillitoe *et al.* 1996, Hannington *et al.* 1999, Huston 2000, Dubé *et al.* 2007a, Mercier-Langevin *et al.*

2011). However, the distribution of precious metals within VMS deposits, and the processes of precious metal enrichment, have not been adequately described and are not clearly understood. Many precious metal-enriched VMS deposits also display enrichments in epithermal suite elements (e.g., As, Sb, Sn, In, Hg,

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Mo; Sillitoe *et al.* 1996, Hannington *et al.* 1999, Cooke & Simmons 2000), have anomalous aluminous alteration (*e.g.*, Mount Lyell, Tasmania, Huston & Kamprad 2001; LaRonde Penna, Canada, Mercier-Langevin *et al.* 2007), and show evidence for deposition in shallow water volcanic environments (*e.g.*, Nurukawa, Japan, Yamada *et al.* 1988; LaRonde-Penna and Bousquet 2, Canada, Dubé *et al.* 2007b). This sub-type of VMS deposit commonly occurs in bimodal felsic lithostratigraphic sequences associated with rifted arc/back-arc basin environments (Franklin *et al.* 2005, Hannington *et al.* 2005, Hannington & Monecke 2009). Modern precious metal-enriched seafloor massive sulfide (SMS) deposits generally possess the above features, but are also characterized by sulfur and helium isotope signatures that provide strong evidence for magmatic fluid involvement during their genesis (de Ronde *et al.* 2001, de Ronde *et al.* 2005). Magmatic fluid involvement is also considered important in the enrichment of Au, Ag, and epithermal suite elements in ancient precious metal-rich VMS deposits (Herzig *et al.* 1993, Sillitoe *et al.* 1996, Hannington *et al.* 1999, Scotney *et al.* 2005, Hannington *et al.* 2005, Dubé *et al.* 2007a).

Previous studies have suggested that the formation of precious metal-enriched VMS deposits is due to a unique combination of fluid chemical conditions and geological setting. Hannington & Scott (1989) and Hannington & Monecke (2009) showed that low temperature (<250 °C) oxidized hydrothermal fluids with high sulfur content (fS_2) are ideal for the transport of substantial gold in the VMS environment. Similarly, Huston & Large (1989) demonstrated that near-neutral, oxidized, low salinity, 150–275 °C fluids with high fS_2 are highly efficient for transporting significant gold in solution. Huston & Large (1989) also defined two element associations with Au in VMS deposits: (1) Cu-Au and (2) Zn-Pb-Ag-Au, which are interpreted to reflect gold transport in fluids by $AuCl_2^-$ and by $Au(HS)_2^-$, respectively (Seward 1973). Deposition of Au in the modern SMS and ancient VMS environments is strongly controlled by boiling and the depth-to-boiling curve for seawater (Bischoff & Rosenbauer 1983, Bischoff & Rosenbauer 1984, Butterfield *et al.* 1990). Boiling of the hydrothermal fluid in shallow seafloor environments (<1500 mbsl) is especially effective at inducing Au precipitation from solution (Huston 2000, Hannington & Monecke 2009).

Despite the general understanding of precious metal enrichment processes in modern SMS and some ancient VMS deposits, precious metal enrichment in Appalachian VMS deposits is not well understood, with some exceptions (*e.g.*, Bathurst, New Brunswick, McClenaghan *et al.* 2006, 2009; Ming Mine, New-

foundland, Brueckner *et al.* 2014). In particular, the styles of mineralization, mineralogy, precious metal associations, mineral chemistry, and physicochemical conditions of deposit formation are poorly understood. Although the Lemarchant deposit has a combined geological resource of 2.58 Mt grading 54.62 g/t Ag and 1.00 g/t Au, it is located in the same volcanic belt as the precious metal-poor Duck Pond and Boundary deposits (Fraser *et al.* 2012). Gold- and Ag-bearing massive sulfides at Lemarchant are characterized by Zn-Pb-Ba-rich mineralization with abundant sulfosalts and epithermal-suite element enrichment. The Lemarchant deposit represents a type example of precious metal-enriched Zn-Pb-Cu VMS mineralization within the Appalachians that has similarities with other precious metal-rich VMS deposits globally (*e.g.*, Wetar, Indonesia, Scotney *et al.* 2005; La Plata, Ecuador, Chiaradia *et al.* 2008).

Herein, a documentation of the mineralization styles and mineralogy of the Lemarchant deposit is provided through drill core analysis, petrography, and scanning electron microscopy (SEM). The sulfide mineral assemblages, precious metal associations, and their compositional variations are described using scanning electron microscopy (SEM), electron microprobe analysis (EMPA), and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). These data provide detailed documentation of the Lemarchant VMS deposit and insights into the styles and setting of mineralization, physicochemical conditions of formation, and genesis of the deposit. The results have implications for precious metal-enriched VMS deposits in the Appalachians and globally.

REGIONAL GEOLOGY

The Lemarchant deposit is located in the Dunnage Zone of the Newfoundland Appalachians, which is host to the majority of volcanogenic massive sulfide occurrences in Newfoundland (Swinden *et al.* 1988, Piercey 2007, Piercey & Hinchey 2012). The Exploits subzone comprises the southeastern section of the Dunnage Zone, and is composed of volcanic arc, back-arc, and sedimentary rocks (Kean & Evans 1988, Swinden 1991, Rogers *et al.* 2006, McNicoll *et al.* 2010). The oldest sequence in the Exploits subzone is composed of a succession of Cambrian to Pre-Caradocian volcanic arc, back-arc, and nascent to rifted arc rocks termed the Victoria Lake supergroup (Fig. 1; Swinden 1991, Dunning *et al.* 1991, Evans & Kean 2002, Rogers *et al.* 2006, McNicoll *et al.* 2010). The Cambrian Tally Pond group, host to the Lemarchant deposit, forms the base of the Victoria Lake supergroup and is overlain by younger succes-

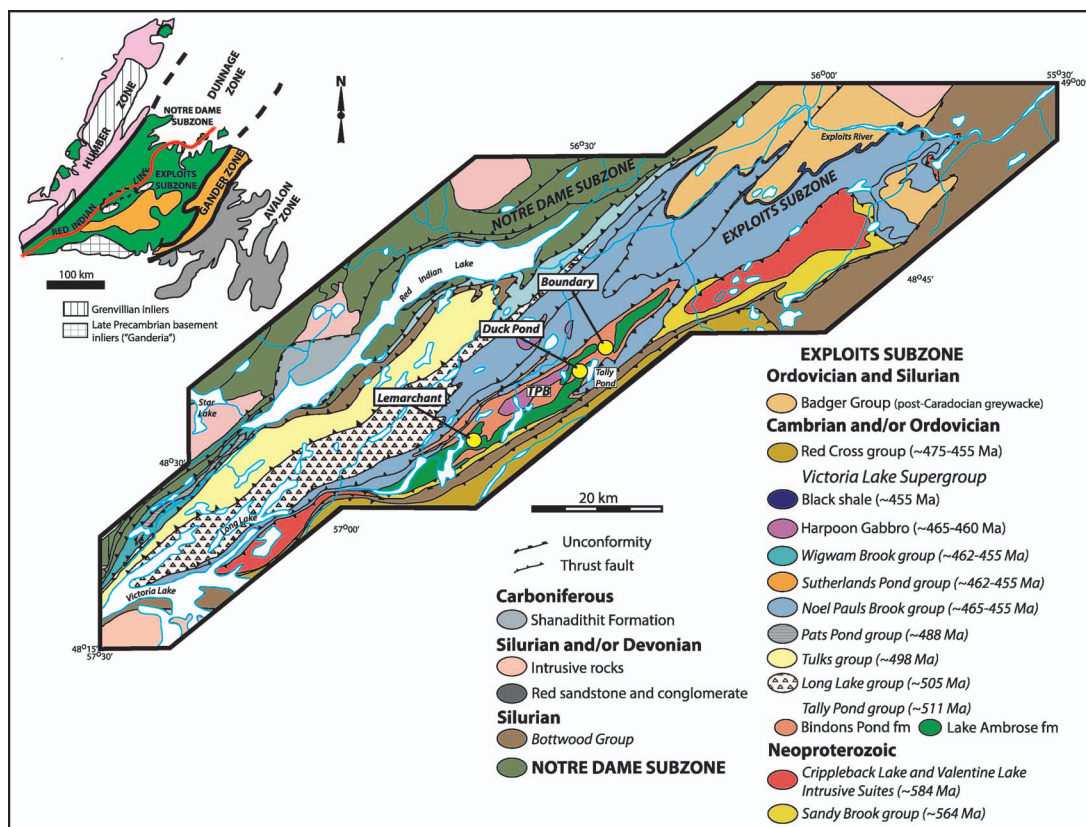


FIG. 1. Geological map highlighting the Tally Pond Belt (TPB) in the Victoria Lake supergroup in the Newfoundland Central Mobile Belt (Dunnage Zone, inset; modified after Rogers *et al.* 2006, McNicoll *et al.* 2010, Piercey & Hinchey 2012).

sions, including the Long Lake and Tulks volcanic groups (Fig. 1).

The Tally Pond group is a bimodal succession of ~513–509 Ma (Pollock 2004, McNicoll *et al.* 2010) tholeiitic mafic and mostly calc-alkaline felsic rocks, respectively called the Lake Ambrose and Bindons Pond formations (Lake Ambrose basalts and Boundary Brook formation of Dunning *et al.* 1991, Evans & Kean 2002). Mineralization is concentrated in the felsic volcanic-dominated Bindons Pond formation (McNicoll *et al.* 2010). The Tally Pond group is crosscut by Ordovician diabase to gabbroic intrusions, sourced from the Harpoon Hill Gabbro intrusion to the northeast, and by the proximal Lemarchant microgranite that outcrops ~400 m northwest of the Lemarchant deposit (Fig. 2; Squires & Moore 2004, McNicoll *et al.* 2010, Fraser *et al.* 2012). Moore (2003) and Squires & Moore (2004) interpreted the latter intrusion as the potential source of heat and fluids that drove the observed alteration and mineralization at Lemarchant, due to its lithogeochemical similarity to the outcropping felsic porphyritic rocks of

the Bindons Pond formation dated to 513 ± 2 Ma by Dunning *et al.* (1991). Neoproterozoic volcanic (Sandy Brook group) and intrusive (Crippleback Lake Suite) rocks occur below the Victoria Lake supergroup and form the basement through which the Tally Pond volcanic rocks were erupted (Rogers *et al.* 2006, McNicoll *et al.* 2010, Piercey & Hinchey 2012). The Tally Pond group is interpreted to have formed as a peri-Gondwanan nascent to rifted arc (Evans & Kean 2002, Rogers *et al.* 2006, van Staal & Barr 2012, Piercey *et al.* 2014).

DEPOSIT GEOLOGY

The Lemarchant deposit consists of a stratiform massive to semi-massive sulfide zone and a thin, possibly truncated, underlying stringer sulfide zone. The uppermost massive sulfide zone strikes north-northwest for 350 m and is ~20 m thick (Figs. 2 and 3A). Massive to semi-massive mineralization is hosted at the contact between hanging wall mafic volcanic rocks and footwall felsic volcanic rocks of the Lake

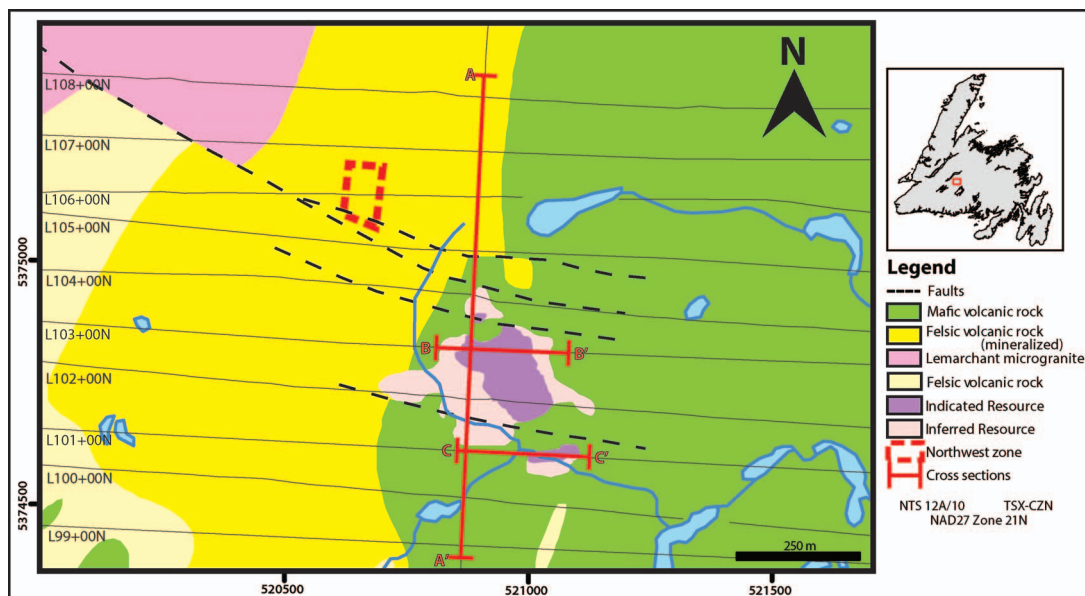


FIG. 2. Schematic geological map of the Lemarchant deposit in the Tally Pond volcanic belt (modified from Fraser *et al.* 2012). Resource estimates (Fraser *et al.* 2012) and Northwest Zone projected to surface. Figure 3 cross-sections (Long section A–A', L10300N B–B', and L10100N C–C') are highlighted in red.

Ambrose and Bindons Pond formations, respectively (Fig. 3A–C). The hanging wall-footwall contact and upper massive sulfide contact are marked by a thin, pyrite-rich mudstone layer that is laterally extensive and locally present in the hanging-wall basalts overlying mineralization (Figs. 3 and 4A–B).

The felsic volcanic footwall rocks consist of calc-alkaline, aphyric rhyolite breccia and rhyolite flows that contain devitrified glass fragments and are interbedded with rhyolite lapilli tuff, tuff breccia, and poly lithic lapilli tuffs (Squires & Moore 2004, Copeland *et al.* 2008a, Copeland *et al.* 2008b, Gill & Piercey 2014). Massive granular and locally bladed baryte immediately overlies the felsic footwall in the stratiform zone, and is intergrown with and replaced by sulfide mineralization. Baryte and sulfide minerals in the lower stratiform zone occur interstitial to rhyolite breccia and lapilli tuff breccia, and variably replace the felsic lapilli tuff. The stringer zone crosscuts the felsic footwall below the stratiform zone, and is devoid of baryte mineralization. A fine-grained variably graphitic mudstone layer conformably overlies the deposit and is interpreted to be an exhalative, chemical sedimentary unit (Copeland *et al.* 2008b, Lode *et al.* 2015). Minor base and precious metal sulfides (*i.e.*, chalcopyrite, sphalerite, galena), Ag-bearing gold, and baryte crosscut the pyrite-pyrrhotite-bearing mudstone, indicating deposition of the ex-

halative unit began prior to massive and semi-massive sulfide mineralization (Lode *et al.* 2015). However, hanging-wall mafic flows up to 50 m above the massive to semi-massive sulfide zone are intercalated and locally peperitic with the mineralized mudstone, are weakly hydrothermally altered, and are rarely crosscut by sulfides (*i.e.*, pyrrhotite-arsenopyrite $\pm$ chalcopyrite) (Copeland *et al.* 2008a, Copeland *et al.* 2008b, Lode *et al.* 2015). These characteristics indicate initial eruption of the hanging-wall mafic rocks into an unconsolidated mudstone, and suggest that volcanism occurred during exhalite sedimentation while the area was still hydrothermally active (Lode *et al.* 2015, Lode *et al.* in press). The mafic hanging wall is composed of dark green, variably magnetite-bearing, pillowed and lesser peperitic, vesicular to massive, transitional to calc-alkaline, basalt and basaltic andesite flows (Copeland *et al.* 2008a, Copeland *et al.* 2008b, Piercey & Hinchey 2012, Gill & Piercey 2014).

Light brown, pyroxene-phyric mafic dikes crosscut mineralization and the hanging wall and footwall rocks. The dikes have wispy, peperitic contacts with variable amygdule content and, based on these characteristics, are likely synvolcanic (*e.g.*, Gibson *et al.* 1999). Greenish-brown, medium-grained gabbro to diabase dikes and pink to white, aphyric to quartz-phyric felsic intrusions are less abundant; they have

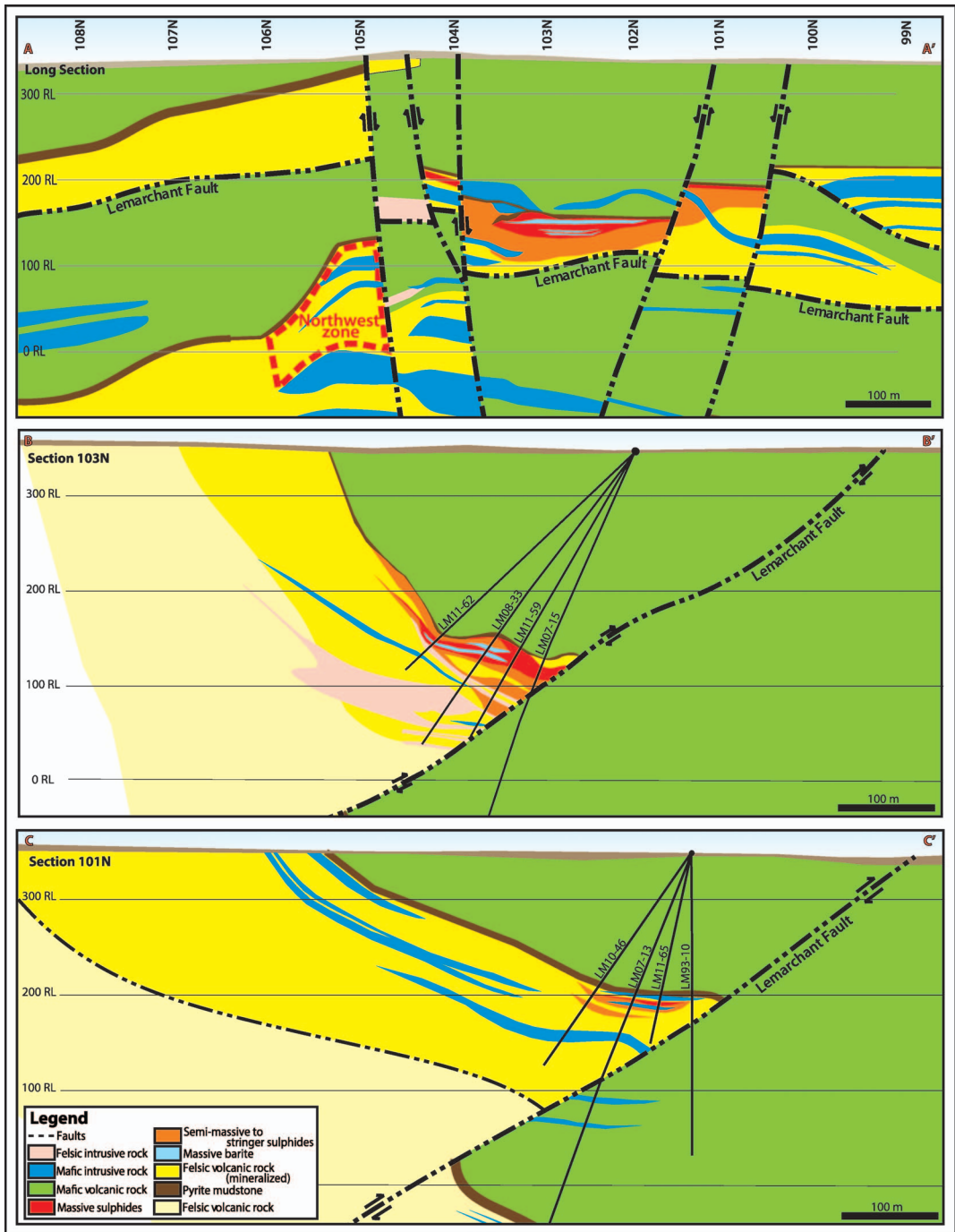


FIG. 3. Section diagrams of the Lemarchant deposit (modified from Fraser *et al.* 2012). (A) Long section A–A', looking east, bisecting the main mineralized zone; the Northwest Zone is projected onto section. (B) Cross section B–B' of L10300N, looking north, highlighting the center portion of the main mineralized zone. (C) Cross section C–C' of L10100N, looking north, highlighting the outer portion of the main mineralized zone.

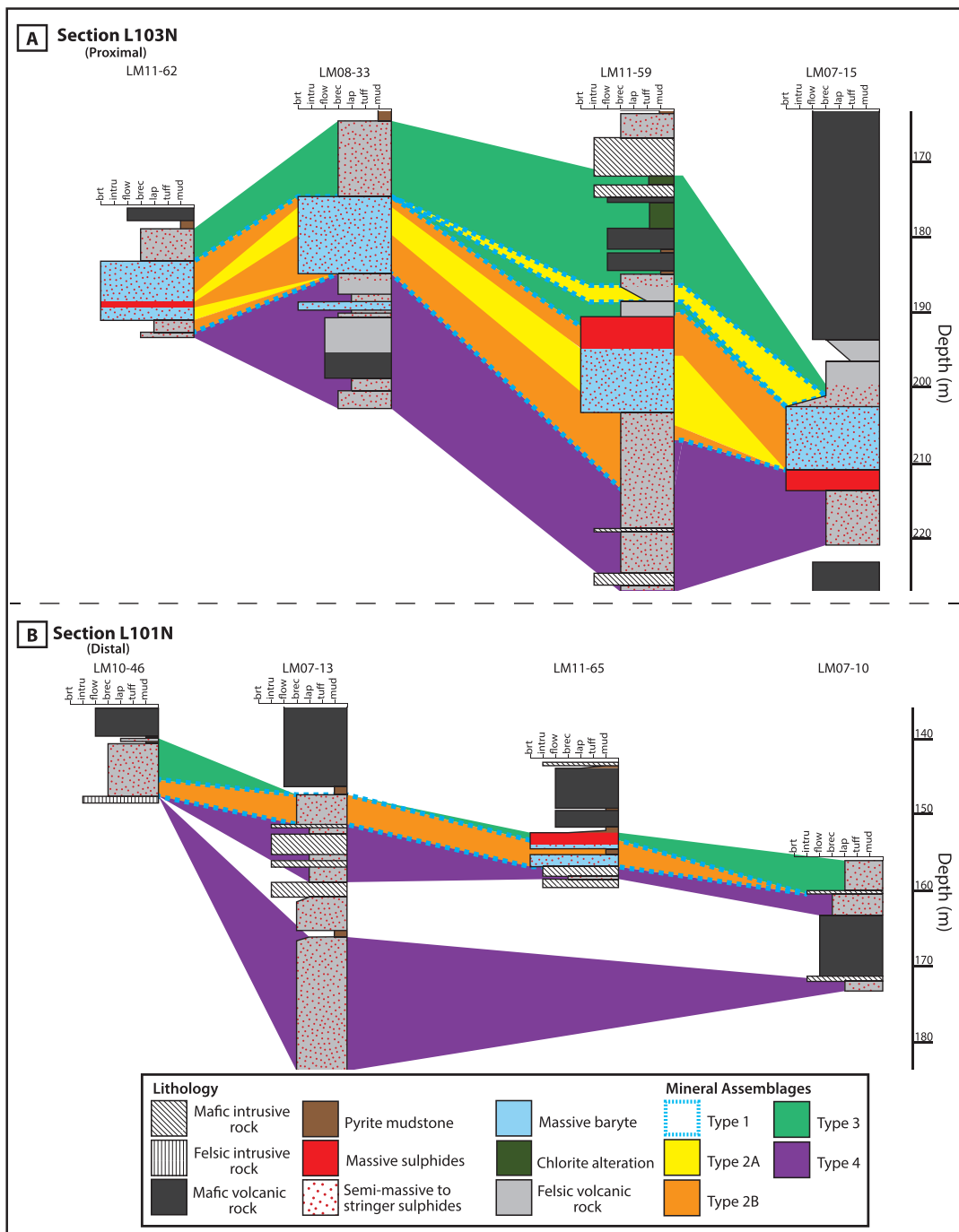


FIG. 4. Fence diagrams of mineralized sections within the Lemarchant deposit. (A) Proximal section L10300N contains a complete set of (5) assemblage types. (B) Distal section L10100N with the type 1, 2B, 3, and 4 assemblages. Section locations are represented in Figures 2 and 3.

sharp contacts and crosscut both mineralized footwall rocks and pyroxene-phyric synvolcanic dikes (Pollock 2004, Squires & Moore 2004, Copeland *et al.* 2008a).

Alteration in the felsic footwall is dominated by quartz and sericite, with minor chlorite and albite (Squires & Moore 2004, Copeland *et al.* 2008a, Copeland *et al.* 2008b, Gill & Piercey 2014). However, chlorite alteration is locally pervasive in the footwall rhyolite and felsic volcanoclastic rock, and intensely chlorite-altered fragments (relict volcanic glass?) do occur in the rhyolite breccia and lapilli tuffs. Mafic flows proximal to the footwall have weak silica-chlorite-epidote alteration (Squires & Moore 2004, Copeland *et al.* 2008a, Copeland *et al.* 2008b). Post-depositional carbonate alteration is present in all lithologies and includes disseminated rhombic calcite and ankerite, and crosscutting quartz-carbonate veinlets. Deformed synvolcanic dikes show carbonate bleaching and are variably fuchsite-bearing.

The Lemarchant deposit and other VMS occurrences within the Tally Pond group are thrust imbricated and experienced lower greenschist-grade regional metamorphism during Silurian-Devonian tectonism (Dunning *et al.* 1991, Squires & Moore 2004, Rogers *et al.* 2006). Post-mineralization deformation created or reactivated a number of east-west-trending, upright faults that offset portions of the Lemarchant deposit vertically and horizontally (Fig. 3A) and created a north-trending, gently west-dipping thrust fault (the Lemarchant fault; Squires & Moore 2004, Copeland *et al.* 2008a, Fraser *et al.* 2012). Section L10600N occurs down-dip of the main Lemarchant deposit, 200 m north-northwest of the Main Zone, and contains the "Northwest Zone" (Figs. 2 and 3A; Fraser *et al.* 2012). Sulfide mineralization observed in L10600N is texturally and chemically similar to the single mineralized horizon in the Main Zone, and suggests that thrust stacking of the stratigraphy may be related to movement along the Lemarchant fault.

ANALYTICAL METHODS

Samples were taken from stratigraphic sections of 44 diamond drill holes and subjected to petrographic examination to document the mineralized zones at the Lemarchant deposit. Mineral phases not identifiable using standard petrography were recoded as backscattered electron images by scanning electron microscopy (SEM) using a FEI™ MLA 650F SEM at the CREAT MAF-IIC facility, Memorial University of Newfoundland. A subset of samples was analyzed by electron microprobe analysis (EMPA) at the Queen's Facility for Isotope Research (QFIR), Queen's University, to obtain major and minor element compositions of mineral phases. This was done using wavelength dispersive

spectrometry (WDS) with a JEOL™ JXA-8230 instrument operating with an accelerating voltage of 20 kV, a beam diameter of 1 µm, and a beam current of 50 nA for galena and pyrite, 30 nA for sphalerite and baryte, and 20 nA for all other sulfide and sulfosalt minerals. The X-ray takeoff angle was 40°. Count times varied from 10–120 s depending on the relative abundance of the element in the mineral phase (e.g., S and Au in pyrite, respectively); off-peak (background) count times were set equal to the peak count times. Natural and synthetic mineral phases and pure elements were used as internal standards for instrument calibration. Standard and unknown intensities were corrected for dead time. Major element precision in analyses of unknowns was generally better than 1% (1σ), with reduced precision for minor (<1 wt.%) elements. Lower detection limits for minor elements were better than 100–500 ppm (3σ). Analyses with totals outside of 100 ± 1.5 wt.%, and quantities below calculated detection limits (3σ), were discarded.

Trace element (Ag, As, Au, Bi, Cd, Co, Cr, In, Ge, Mn, Mo, Ni, Sb, Se, Sn, Ti, Tl, V) contents were obtained by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at QFIR from a subset of the samples analyzed by EMPA. Ablation techniques and data reduction methods used in this study are outlined in Longerich *et al.* (1996) and Eggins *et al.* (1998). An ESI™ NWR-193nm Excimer laser coupled to a ThermoFisher™ X-Series 2 Quadrupole ICP-MS was used to ablate 50 µm-diameter spots, using 70% total power and a pulse rate of 10 Hz to minimize elemental fractionation, with a gas blank of 30 s. Daily setup of the LA-ICP-MS was conducted using a USGS glass standard (GSD) to optimize He and Ar flow through the ablation cell and the plasma torch to yield >300 kCPS on ²³⁸U, <0.5% doubly charged species, and <0.5% oxides. Sets of 20 spots were bracketed by calibrations using the USGS glass standards (GSC-1G, GSD-1G, and GSE-1G) and an external standard (BHVO-2G) to monitor instrument drift and correct for changes in element ionization. Trace-element contents in mineral phases were quantified by comparison to a sulfide matrix standard (MASS-1). Minor elements measured by EMPA were used as internal standards to correct for variability in the laser yield, and included Cd for sphalerite, Zn for tetrahedrite, and Ag for bornite. Major element abundances for Fe, Cu, Pb, and Zn in pyrite, galena, and chalcopyrite were either beyond the calibration curves for the GS-series glasses or not constrained by microprobe data (below detection), and not suitable for laser yield correction. Trace-element data for Lemarchant mineral phases is herein quantitative for sphalerite, tetrahedrite, and bornite, and semi-quantitative for pyrite, galena, and chalcopyrite.

TABLE 1. SULFIDE MINERALS IDENTIFIED FROM THE LEMARCHANT DEPOSIT ALONG STRIKE (PROXIMAL TO DISTAL STRATIFORM STRINGER ZONE) AND WITH DEPTH (STRATIFORM TO STRINGER SULFIDE ZONES)

Mineral phase	Formula	Stratiform sulfide zone	Proximal	Distal	Stringer sulfide zone
Identified phases					
Baryte	BaSO ₄	xxx	xxx	x	—
White to honey sphalerite	(Zn,Fe)S	xxx	xxx	xx	—
Honey brown to red sphalerite	(Zn,Fe)S	xx	xx	x	x
Colloform to reniform pyrite	FeS ₂	x	x	x	—
Recrystallized subhedral pyrite	FeS ₂	xx	xx	xx	xx
Euhedral pyrite	FeS ₂	x	x	x	xxx
Galena	PbS	xx	xx	xx	x
Tetrahedrite	(Cu,Ag) ₁₀ (Fe,Zn) ₂ (As,Sb) ₄ S ₁₃	xx	x	xx	—
Tennantite	(Cu,Ag) ₁₀ (Fe,Zn) ₂ (As,Sb) ₄ S ₁₃	xx	xx	x	—
Silver-tetrahedrite	(Cu,Ag) ₁₀ (Fe,Zn) ₂ (As,Sb) ₄ S ₁₃	x	—	xx	—
Chalcopyrite	CuFeS ₂	x	x	x	xxx
Bornite	Cu ₅ FeS ₄	xx	xx	—	—
As-rich colusite	Cu ₂₆ V ₂ (As,Ge,Sb,Sn) ₆ S ₃₂	x	x	x	—
Intermediate colusite	Cu ₂₆ V ₂ (As,Ge,Sb,Sn) ₆ S ₃₂	x	x	—	—
Germanium-rich colusite	Cu ₂₆ V ₂ (As,Ge,Sb,Sn) ₆ S ₃₂	x	x	—	—
Sulvanite	Cu ₃ (V,Fe)S ₄	x	x	—	—
Renierite	(Cu ¹⁺ ,Zn) ₁₁ Fe ₄ (Ge ⁴⁺ ,As ⁵⁺) ₂ S ₁₆	x	x	—	—
Stromeyerite	AgCuS	x	x	—	—
Bourbonite	PbCuSbS ₃	x	—	x	—
Polybasite	[(Ag,Cu) ₆ (Sb,As) ₂ S ₇][Ag ₉ CuS ₄]	x	—	x	—
Miargyrite	AgSbS ₂	x	—	x	—
Ag-poor gold	(Au,Ag)	x	x	—	—
Ag-rich gold	(Au,Ag)	x	—	x	—
Marcasite	FeS ₂	x	x	x	x
Pyrrhotite	Fe _{1-x} S	x	x	x	—
Arsenopyrite	FeAsS	x	x	x	—
Covellite	CuS	x	x	x	—
Unidentified phases					
Silver telluride		x	—	x	—
Nickel sulfide		x	x	—	—
Cu-Ag sulfosalts		x	x	x	—
Cu-V-Ge sulfosalts		x	x	—	—

Note: Relative abundance indicated from high (xxx) to low (x), and absent (—).

Supplementary methods are included in Appendix 1. Mineral phases identified by petrography, SEM, and EMPA are included in Table 1. Averages for analytical results for major and minor elements by EMPA are presented in Table 2 and for trace elements by LA-ICP-MS in Table 3.

RESULTS

Mineralization

The Lemarchant deposit displays five distinct styles of mineralization; four mineral assemblages compose the stratiform zone, and one mineral assemblage makes up the underlying stringer zone (Fig. 4A–B).

Type 1 consists of granular baryte and semi-massive sulfides that include white to honey sphalerite, subordinate fine-grained pyrite, galena, and minor chalcopyrite and tetrahedrite-tennantite (Fig. 5A). The type 2 mineral assemblages crosscut the type 1 mineral assemblage (Fig. 5B–D) and can be intergrown. Type 2A consists of bornite, galena, and minor chalcopyrite stringers, with lesser stromeyerite, covellite, unidentified Cu-Ag phases, and trace Ni-S phases (Fig. 5B–C), and type 2B consists of tetrahedrite-tennantite, galena, bladed baryte, and pyrite, with lesser white sphalerite and minor chalcopyrite, and trace marcasite, colusite-germanocolusite, visible Ag-bearing gold, bourbonite, polybasite, miargyrite, and unidentified V-Ge-Cu and

Baryte – BaSO ₄									
	Type	Mineralogy	N of						
			Type 1	Samples					
	Average	StDev	56						
BaO (oxide wt.%)	65.71	0.86							
SO ₃	34.19	0.42							
SrO (ppm)	5397	3283							
CaO	587	422							
FeO	1028	736							
PbO	240	98							
Total	100.50	0.59							
BaO (apfu)	1.00	0.02							
SO ₃	1.00	0.00							
SrO	0.01	0.01							
CaO	0.00	0.00							
FeO	0.00	0.00							
PbO	0.00	0.00							
Total	2.01	0.01							

Galena – PbS									
	Type	Mineralogy	N of						
			Type 1	Samples					
	Average	StDev	12						
Pb (wt.%)	86.86	0.48							
S	13.47	0.12							
Zn (ppm)	4540	6842							
Fe	BDL								
Cu	BDL								
Ag	250	122							
Sb	BDL								
Hg	BDL								
As	BDL								
Total	100.53	0.85							

TABLE 2. CONTINUED.

Galena – PbS										
	Type Mineralogy Type 1 Average	N of Samples 12 StDev	Type Mineralogy Type 2A Average	N of Samples 20 StDev	Type Mineralogy Type 2B Average	N of Samples 35 StDev	Type Mineralogy Type 3 Average	N of Samples 15 StDev	Type Mineralogy Type 4 Average	N of Samples 4 StDev
Pb (apfu)	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01	1.00	0.01
S	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Zn	0.01	0.02	0.00	0.00	0.00	0.01	0.01	0.01	0.05	0.02
Fe	BDL	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.01
Cu	BDL	0.00	0.01	0.01	0.00	0.00	0.00	0.00	BDL	0.00
Ag	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sb	BDL	0.00	BDL	0.00	0.00	0.00	0.00	0.00	BDL	0.00
Hg	BDL	0.00	BDL	0.00	0.00	0.00	BDL	0.00	BDL	0.00
As	BDL	0.00	BDL	0.00	BDL	0.00	BDL	0.00	BDL	0.00
Total	2.00	0.02	2.01	0.02	2.01	0.01	2.02	0.01	2.06	0.03

Chalcopyrite – CuFeS ₂										
	Type Mineralogy Type 1 Average	N of Samples 8 StDev	Type Mineralogy Type 2A Average	N of Samples 24 StDev	Type Mineralogy Type 2B Average	N of Samples 25 StDev	Type Mineralogy Type 3 Average	N of Samples 19 StDev	Type Mineralogy Type 4 Average	N of Samples 12 StDev
S (wt.%)	35.12	0.12	34.85	0.14	34.93	0.23	35.13	0.23	34.85	0.26
Cu	34.10	0.34	34.70	0.34	34.62	0.48	34.43	0.40	34.47	0.33
Fe	30.15	0.22	30.00	0.42	30.03	0.33	30.42	0.20	30.23	0.14
Zn (ppm)	1140	1318	1276	1168	2472	3785	1667	1941	1174	1075
Pb	BDL		1417	308	1370	124	1415	172	1370	137
Ag	BDL		807	319	784	389	325	125	BDL	
Bi	BDL		BDL		1657	163	BDL		BDL	
Total	99.46	0.64	99.80	0.63	99.92	0.80	100.26	0.69	99.75	0.80
S (apfu)	2.00	0.00	2.00	0.00	2.00	0.01	2.00	0.00	2.00	0.00
Cu	0.98	0.01	1.00	0.01	1.00	0.01	0.99	0.01	1.00	0.00
Fe	0.99	0.01	0.99	0.01	0.99	0.01	0.99	0.01	1.00	0.01
Zn	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Pb	BDL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ag	BDL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	BDL	0.00
Bi	BDL	0.00	BDL	0.00	0.00	0.00	BDL	0.00	BDL	0.00
Total	3.97	0.02	4.00	0.01	3.99	0.02	3.99	0.02	4.00	0.01

TABLE 2. CONTINUED.

Sphalerite – (Zn,Fe)S									
	Type Mineralogy Type 1 Average	N of Samples 78 StDev	Type Mineralogy Type 2B Average	N of Samples 12 StDev	Type Mineralogy Type 3 Average	N of Samples 27 StDev	Type Mineralogy Type 4 Average	N of Samples 6 StDev	
Zn (wt.%)	65.59	0.84	66.20	0.25	59.98	2.17	63.44	0.30	
S	32.79	0.21	32.73	0.24	33.15	0.29	32.80	0.18	
Cd (ppm)	2828	428	3251	687	2902	652	2763	149	
Fe	6511	6188	820	663	58791	20041	27853	766	
Cu	2651	3319	907	635	1190	540	360	NULL	
Mn	366	134	260	NULL	403	153	244	50	
Total	99.42	0.47	99.39	0.35	99.33	0.47	99.33	0.45	
Zn (apfu)	0.98	0.01	0.99	0.01	0.89	0.03	0.95	0.00	
S	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	
Cd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Fe	0.01	0.01	0.00	0.00	0.10	0.03	0.05	0.00	
Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	BDL	
Mn	0.00	0.00	0.00	BDL	0.00	0.00	0.00	0.00	
Total	2.00	0.01	2.00	0.01	1.99	0.02	2.00	0.00	
Pyrite – FeS ₂									
	Texture Colloform Average	N of Samples 6 StDev	Texture Subhedral Average	N of Samples 67 StDev	Texture Euhedral Average	N of Samples 29 StDev			
S (wt.%)	52.91	0.75	53.61	0.51	53.82	0.17			
Fe	45.18	1.20	45.86	0.68	46.17	0.25			
As (ppm)	13265	16041	5931	8423	1307	1278			
Cu	BDL		1369	1917	405	304			
Zn	743	85	1047	1246	1896	2096			
Sb	1583	2286	2626	4524	214	81			
Ag	560	127	2822	3725	BDL				
Hg	BDL		BDL		BDL				
Au	BDL		BDL		BDL				
Pb	BDL		BDL		BDL				
Total	99.67	0.43	99.95	0.55	100.13	0.35			

TABLE 2. CONTINUED.

Pyrite – FeS ₂						
Texture Colloform	N of Samples	Texture Subhedral Average	N of Samples	Texture Euhedral Average	N of Samples	StDev
	6		67		29	
Average	StDev	Average	StDev	Average	StDev	Average
S (<i>apfu</i>)	2.00	2.00	0.00	2.00	0.00	0.00
Fe	0.98	0.98	0.01	0.99	0.01	0.01
As	0.02	0.00	0.03	0.00	0.01	0.00
Cu	BDL	0.00	0.00	0.00	0.00	0.00
Zn	0.00	0.00	0.00	0.00	0.00	0.00
Sb	0.00	0.00	0.00	0.00	0.00	0.00
Ag	0.00	0.00	0.00	BDL	0.00	
Hg	BDL	BDL	0.00	BDL		
Au	BDL	BDL	0.00	BDL		
Pb	BDL	BDL	0.00	BDL		
Total	3.01	2.99	0.02	2.99	0.01	0.01
Tetrahedrite – [(Cu ₄ Ag] ₁₀ (Fe,Zn) ₂] _{Σ=12} (As,Sb) ₄ S ₁₃						
Mineralogy Type 1	N of Samples	Mineralogy Type 2B (prox.) Average	N of Samples	Mineralogy Type 2B (distal) Average	N of Samples	StDev
	2		33		61	
Average	StDev	Average	StDev	Average	StDev	Average
Cu (wt.%)	24.47	41.82	0.88	35.66	7.53	
S	23.72	26.85	0.44	25.70	2.04	
Sb	26.25	9.80	3.91	14.33	9.21	
As	0.82	12.83	2.81	9.65	6.89	
Zn	6.47	7.56	1.08	4.64	1.53	
Fe	1.09	0.53	0.99	3.11	1.43	
Ag	17.93	0.15	0.12	6.88	8.07	
Te (ppm)	BDL	10864	8592	683	523	
Pb	1225	931	138	1016	429	
Total	100.91	100.21	0.75	100.09	0.57	
Cu (<i>apfu</i>)	6.77	10.22	0.17	9.01	1.34	
S	13.00	13.00	0.00	13.00	0.00	
Sb	3.79	1.26	0.52	2.02	1.40	
As	0.19	2.65	0.55	1.99	1.36	

TABLE 2. CONTINUED.

Tetrahedrite – [(Cu,Ag] ₁₀ (Fe,Zn) ₂] _{Σ=12} (As,Sb) ₄ S ₁₃						
Type Mineralogy Type 1 Average	N of Samples 2 StDev	Type Mineralogy Type 2B (prox.) Average	N of Samples 33 StDev	Type Mineralogy Type 2B (distal) Average	N of Samples 61 StDev	
Zn	1.74	1.80	0.26	1.14	0.38	
Fe	0.34	0.14	0.27	0.92	0.47	
Pb	0.01	0.00	0.00	0.01	0.00	
Ag	2.92	0.01	0.02	1.14	1.39	
Te	BDL	0.00	0.10	0.00	0.00	
Total	28.76	0.09	0.23	29.22	0.35	
Colusite – Cu ₂₆ V ₂ (As,Ge) ₆ S ₃₂						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
Ag	7210	49114	37998			
Pb	949	14325	12002			
Total	100.23	29904	26840			
Cu (apfu)	4.91	2629	3195			
S	4.00	7462	4314			
Fe	1.02	768	417			
Zn	0.02	99.52	0.65			
Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
Total	9.98	2.01	0.03			
Bornite – Cu ₅ FeS ₄						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
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Zn (ppm)	2237	7.40	3.60			
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Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
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S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
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Zn	0.02	99.52	0.65			
Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
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Colusite – Cu ₂₆ V ₂ (As,Ge) ₆ S ₃₂						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
Ag	7210	49114	37998			
Pb	949	14325	12002			
Total	100.23	29904	26840			
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S	4.00	7462	4314			
Fe	1.02	768	417			
Zn	0.02	99.52	0.65			
Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
Total	9.98	2.01	0.03			
Colusite – Cu ₂₆ V ₂ (As,Ge) ₆ S ₃₂						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
Ag	7210	49114	37998			
Pb	949	14325	12002			
Total	100.23	29904	26840			
Cu (apfu)	4.91	2629	3195			
S	4.00	7462	4314			
Fe	1.02	768	417			
Zn	0.02	99.52	0.65			
Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
Total	9.98	2.01	0.03			
Colusite – Cu ₂₆ V ₂ (As,Ge) ₆ S ₃₂						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
Ag	7210	49114	37998			
Pb	949	14325	12002			
Total	100.23	29904	26840			
Cu (apfu)	4.91	2629	3195			
S	4.00	7462	4314			
Fe	1.02	768	417			
Zn	0.02	99.52	0.65			
Ag	0.03	23.85	1.77			
Pb	0.00	32.00	0.00			
Total	9.98	2.01	0.03			
Colusite – Cu ₂₆ V ₂ (As,Ge) ₆ S ₃₂						
Type Mineralogy Type 2A Average	N of Samples 23 StDev	Type Mineralogy Type 2B Average	N of Samples 29 StDev			
Cu (wt.%)	62.27	47.04	3.42			
S	25.60	31.86	0.23			
Fe	11.32	3.18	0.05			
Zn (ppm)	2237	7.40	3.60			
Ag	7210	49114	37998			
Pb	949	14325	12002			
Total	100.23	29904	26840			
Cu (apfu)	4.91	2629	3195			
S	4.00	7462				

TABLE 2. CONTINUED.

Sulvanite – Cu ₃ VS ₄				Renierite – (Cu ¹⁺ ,Zn) ₁₁ Fe ₄ (Ge ⁴⁺ ,As ⁵⁺) ₂ S ₁₆			
Cu (wt.%)	Type	N of	StDev	Type	Mineralogy	Type 2B	N of
	Mineralogy	Samples					
S	45.23	0.06		45.23			1
V	34.85	0.06		31.01			
	13.72	0.11		12.73			
Fe (ppm)	12158	3647		8.29			
Zn	5638	4579		5428			
Ag	606	142		1052			
Total	100.79	0.09		97.9226			
Cu (<i>apfu</i>)	2.92	0.01		11.78			
S	4.00	0.00		16.00			
V	0.99	0.01		3.77			
Fe	0.08	0.02		1.89			
Zn	0.03	0.03		0.14			
Ag	0.00	0.00		0.02			
Total	8.02	0.01		33.60			
Ag-bearing gold – (Au,Ag)				Stromeyerite – AgCuS			
Au (wt.%)	Type	N of	StDev	Type	Mineralogy	Type 2A	N of
	Mineralogy	Samples					
Ag	74.32	12.11		31.14			11
S (ppm)	22.89	13.04		16.60			
Hg	3050	4844		50.77			
As	2306	607		3645			
Sb	426	105		611			
Fe	340	35		6832			
Cu	1929	2077		1105			
Zn	5496	4331		1945			
Total	12430	834		99.77			
	98.52	1.71		0.95			
Bourmonite – CuPbSbS ₃				Type 2B			
Au (wt.%)	Type	N of	StDev	Type	Mineralogy	Type 2B	N of
	Mineralogy	Samples					
Ag	42.74	4.90		42.74			7
S (ppm)	24.37	1.69		24.37			
Hg	19.60	5.64		19.60			
As	13.50	3998		13.50			
Sb	1428	309		1428			
Fe	2472	4684		2472			
Cu	100.63	203		100.63			
Zn	1.01	120		1.01			
Total	0.98	1.21		0.98			
	3.00	0.15		3.00			

TABLE 2. CONTINUED.

Ag-bearing gold – (Au,Ag)				Stromeyerite – AgCuS				Bourmonite – CuPbSbS ₃			
Type		N of Samples		Type		N of Samples		Type		N of Samples	
Mineralogy		14		Mineralogy		11		Mineralogy		7	
Type 2B		StDev		Type 2A		StDev		Type 2B		StDev	
Average				Average				Average			
Au/(Au+Ag)				S	1.00	0.00	Cu	1.04	0.01		
				Ag	0.92	0.18	Zn	0.01	0.01		
				Fe	0.01	0.01	As	0.01	0.01		
				Zn	0.00	0.00	Total	6.06	0.03		
				Pb	0.01	0.00					
				Te	0.00	0.00					
				Bi	0.00	0.00					
				Total	2.90	0.23					
Polybasite – [(Ag,Cu) ₆ (Sb,As) ₂ S ₇][Ag ₉ CuS ₄]											
Type		N of Samples		Type		N of Samples		Type		N of Samples	
Mineralogy		1		Mineralogy		2		Mineralogy		2	
Type 2B		StDev		Type 2B		StDev		Type 2B		StDev	
Average				Average				Average			
Cu (wt.%)				Sb (wt.%)	41.03	0.08					
Ag				Ag	35.28	0.20					
S				S	21.56	0.15					
Fe (ppm)				Cu (ppm)	600	0					
Zn				Fe	1450	636					
Pb				Zn	BDL						
Te				Pb	8300	7071					
As				As	850	212					
Sb				Te	600	0					
Hg				Hg	BDL						
Bi				Bi	BDL						
Total				Ni	BDL						
Cu (<i>apfu</i>)				Total	99.04	0.57					
Ag				Sb (<i>apfu</i>)	1.00	0.01					
S				Ag	0.97	0.01					
Fe				S	2.00	0.00					
Zn				Cu	0.00	0.00					

TABLE 2. CONTINUED.

Polybasite – [(Ag,Cu) ₆ (Sb,As) ₂ S ₇][Ag ₉ CuS ₄]			Margarite – AgSbS ₂		
Type Mineralogy Type 2B Average	N of Samples 1		Type Mineralogy Type 2B Average	N of Samples 2	StDev
Pb	0.01	Fe	0.01	0.00	
Te	0.03	Zn	BDL	0.00	
As	0.73	Pb	0.01	0.01	
Sb	1.19	As	0.00	0.00	
Hg	0.00	Te	0.00	0.00	
Bi	0.00	Hg	BDL	0.00	
Total	28.84	Bi	BDL	0.00	
		Ni	BDL	0.00	
		Total	4.00	0.01	

Note: All values below detection limit (BDL) are indicated.

Ag-Te phases (Fig. 5B, D–E). Type 2A is situated in the center of the stratiform zone (proximal), whereas the type 1 and type 2B assemblages extend from the proximal to the distal regions of the stratiform zone (Fig. 4A and 4B, respectively). Type 3 partially replaces the type 1 assemblage in the upper portion of the stratiform sulfide zone and is composed of massive to stringer, honey brown to red sphalerite, with lesser pyrite, galena, and chalcopyrite (Fig. 5F). Type 4 mineralization occurs in the stringer zone and consists of chalcopyrite, disseminated to coarse-grained pyrite, honey brown to orange sphalerite, and minor galena stringers (Figs. 5G–H). Sphalerite and galena content in type 4 stringers decreases with increasing depth below the stratiform zone (Fig. 5H). A well-developed stockwork zone has not been documented beneath the Lemarchant deposit. The base of the stringer zone is abrupt, and it is possible that a stockwork/discordant alteration zone was removed by the Lemarchant thrust fault.

Sulfide mineralogy

Despite local faulting and regional metamorphism, the Lemarchant deposit contains exceptionally well-preserved primary textures in most sulfides, with only local structural remobilization. The Lemarchant deposit is dominated by sphalerite, pyrite, chalcopyrite, and galena, as well as numerous other sulfide and sulfosalt minerals that occur in five assemblages (Table 1).

Type 1 mineral assemblage. Sphalerite is semi-massive, anhedral, honey- to white-colored and contains microscopic blebs of chalcopyrite (Table 1; Fig. 6A and inset). Pyrite occurs in various forms reflecting multiple stages of growth. Fine-grained, colloform to reniform pyrite (Fig. 6B) is partly to completely recrystallized and forms annealed, fine-grained clusters. Euhedral pyrite is present but rare. Medium-grained subhedral to euhedral atoll pyrite contains minor inclusions of sphalerite and galena; zoned pyrite crystals are inclusion-rich (Fig. 6C). Galena generally occurs as medium- to coarse-grained anhedral grains in type 1 sphalerite and pyrite; discrete, subhedral tetrahedrite grains are commonly present with the galena. Fine- to medium-grained chalcopyrite blebs occur at sphalerite-pyrite and sphalerite-galena grain boundaries.

Type 2A mineral assemblage. Bornite grains are blebby to sheeted and occur in sphalerite and baryte gangue (Fig. 6D–F). Anhedral galena is abundant in type 2A sulfides (Fig. 6D–E). Chalcopyrite occurs at the grain boundaries of type 2A bornite and galena within type 1 sphalerite, pyrite, and gangue (Fig. 6D–F). Minor, irregular to acicular stromeyerite occurs at

bornite, galena, sphalerite, and chalcopyrite grain boundaries (Fig. 6D), and bright blue covellite overprints bornite, stromeyerite, and chalcopyrite (Fig. 6D–E). Type 2A bornite, galena, and chalcopyrite may also have filamentous texture in thin section (not pictured). Unknown Cu-Ag phases and trace Ni-S are only visible *via* SEM, occurring with stromeyerite and bornite, respectively (Table 1).

Type 2B mineral assemblage. Galena is angular to anhedral, medium- to coarse-grained, and intergrown with sphalerite, tetrahedrite, baryte (Fig. 6G–M), and trace bournonite as well as other sulfosalt minerals (Fig. 6H–K). Tetrahedrite–tennantite (hereafter referred to as tetrahedrite) occurs with galena and sphalerite, and is variably associated with Ab-bearing gold, colusite, and chalcopyrite (Fig. 6G, K–L). Compositionally zoned tetrahedrite occurs toward the outer edges of the deposit (Fig. 6L). Ag-bearing gold occurs in contact with galena and is spatially associated with sphalerite, pyrite, and tetrahedrite in a baryte-rich matrix (Fig. 6K–M). Sulfosalts of the colusite–germanocolusite (hereafter referred to as colusite), sylvanite, and renierite group of minerals form anhedral, <50 μm light brown-pink grains and occur in the central portion of the deposit, intergrown with the type 2A assemblage (Table 1; Fig. 6E–F; symplectitic galena-colusite, Fig. 6H). Pyrite and marcasite associated with the type 2B assemblage are recrystallized and form irregular, subhedral, and lesser euhedral atolls (Fig. 6H and M). Polybasite, miargyrite, and unidentified V-Ge-Cu and Ag-Te phases primarily occur with tetrahedrite and galena.

Type 3 mineral assemblage. Type 3 honey-brown to red sphalerite is generally free of inclusions and replaces type 1 white to honey sphalerite, galena, and baryte (Fig. 6N and inset). Pyrite from the type 3 mineral assemblage consists of fine- to coarse-grained euhedral crystals, but relict colloform to recrystallized subhedral pyrite of the type 1 and type 2B assemblages is also present. Galena occurs with recrystallized pyrite, at sulfide grain boundaries, or as wiry strands in type 3 sphalerite. Amorphous chalcopyrite is present at sulfide grain boundaries. Blebbly pyrrhotite and rhombic arsenopyrite are locally present with type 3 chalcopyrite near the stratiform zone-pyritic mudstone contact.

Type 4 mineral assemblage. Chalcopyrite is blebbly and crosscuts gangue, sphalerite, and galena, and is associated with rare dendritic marcasite (Fig. 6O–P). Type 4 sphalerite is honey-brown to orange and contains microscopic acicular chalcopyrite inclusions (Fig. 6O). Pyrite forms rounded to euhedral coarse-grained atolls that host anhedral grains of galena, sphalerite, and chalcopyrite (Fig. 6O–P). Fine- to

medium-grained euhedral pyrite is also disseminated throughout the footwall gangue.

Major and minor element mineral chemistry

The complete set of electron microprobe data for the 15 analyzed mineral and unknown phases outlined below are included in Appendix 2 (available from the MAC Depository of Unpublished Data, document CM54-5_10.3749/canmin.1500069).

Compositions of galena, chalcopyrite, and baryte are generally stoichiometric and show little variation in major and minor element compositions (Table 2). Lead and S in galena range from 84.57–87.98 wt.% and 13.11–13.67 wt.%, respectively. Minor Zn and Fe (<10.00 wt.%) and trace Ag and Sb (<0.10 wt.%) are present in some of the galena crystals. Sulfur, Cu, and Fe in chalcopyrite range from 34.43 to 35.53 wt.%, 33.43 to 35.4 wt.%, and 28.91 to 30.69 wt.%, respectively. Zinc in chalcopyrite ranges as high as 12780 ppm, whereas Ag is <1500 ppm. Near-stoichiometric chalcopyrite has higher contents of minor and trace elements (Table 2). Barium and S in baryte range from 63.56 to 67.23 wt.% and 33.44 to 35.28 wt.%, respectively. Minor Sr (<15700 ppm) and trace Ca (<1703 ppm) are common.

Sphalerite. Sphalerite is stoichiometric but contains variable Zn and Fe and trace element contents (Table 2). Major elements Zn and S range from 57.03 to 67.00 wt.% and 32.10 to 33.69 wt.%, respectively. Sphalerite commonly contains minor Cd (1950–4890 ppm; avg. 2882 ppm). Iron content ranges up to 8.41 wt.% (13.65 mol.% FeS), and Fe contents are antipathetic with Zn, consistent with Fe substitution at the Zn site in sphalerite (Wright 2009). Type 1 sphalerite is white-to honey-colored and contains a maximum of 2.60 wt.% Fe (4.54 mol.% FeS), with most grains having <1.87 wt.% Fe (3.27 mol.% FeS; Fig. 7A). White type 2B sphalerite contains <0.18 wt.% Fe (0.32 mol.% FeS). Type 3 and 4 honey-brown to red sphalerite contains >2.72 wt.% Fe (4.72 mol.% FeS), with Fe in type 3 sphalerite >2.84 wt.% (5.06 mol.% FeS). The sphalerite Fe content is lowest in the stratigraphic middle portion of the deposit, whereas the highest Fe contents occur at the top and bottom (Fig. 8).

Pyrite. Pyrite is stoichiometric to near-stoichiometric with varying As content (Table 2). Sulfur and Fe range from 51.56 to 54.38 wt.% and 43.43 to 46.66 wt.%, respectively. Arsenic substitution at the expense of S can be up to 3.60 wt.% (Fig. 7B), which is consistent with the incorporation of As as AsS dianion groups within the pyrite crystal lattice (Reich & Becker 2006, Blanchard *et al.* 2007). Zoned pyrite is common, with As ranging from below detection limit (BDL) to $\sim$ 3 wt.% within a single grain (*i.e.*, Fig. 6C).

TABLE 3. AVERAGE TRACE ELEMENT CONTENTS AND STANDARD DEVIATION (3 σ) OF SULFIDE PHASES IN TYPE ASSEMBLAGES FROM THE LEMARCHANT DEPOSIT

Type Mineralogy	Phase	n		Ti (ppm)	V (ppm)	Cr (ppm)	Mn (ppm)	Co (ppm)	Ni (ppm)	Ge (ppm)	As (ppm)
Type 1	Sphalerite	24	Avg	BDL	BDL	BDL	267	BDL	BDL	5	131
			StDev	0	1	0	268	4	34	5	458
	Pyrite	8	Avg	BDL	49	BDL	491	27	1609	6	20347
			StDev	119	49	1	360	24	1116	1	19830
Type 2A	Galena	7	Avg	578	BDL	28	BDL	18	1682	34	BDL
			StDev	99	0	5	16	3	327	8	79
	Chalcopyrite	9	Avg	BDL	BDL	BDL	BDL	BDL	30	22	BDL
			StDev	0	6	3	25	2	36	21	0
	Bornite	13	Avg	183	12	6	40	7	181	25	BDL
			StDev	159	15	5	50	10	348	14	12
Type 2B	Sphalerite	8	Avg	BDL	97	BDL	205	BDL	BDL	102	7384
			StDev	0	118	4	55	0	14	259	20238
	Pyrite	24	Avg	1182	58	7	208	13	635	8	6421
			StDev	5336	166	23	442	15	749	13	12736
	Galena	25	Avg	373	BDL	18	44	13	892	27	111
			StDev	163	14	10	40	5	683	43	377
	Chalcopyrite	12	Avg	BDL	BDL	BDL	146	BDL	BDL	11	BDL
			StDev	114	4	2	429	4	17	12	0
	Tetrahedrite	25	Avg	BDL	BDL	BDL	281	BDL	25	10	113279
			StDev	57	4	1	247	2	32	5	37131
Type 3	Sphalerite	4	Avg	BDL	38	4	278	BDL	BDL	5	BDL
			StDev	0	60	8	158	0	0	1	0
	Pyrite	4	Avg	BDL	7	BDL	BDL	BDL	2627	4	302
			StDev	93	9	0	17	3	1005	1	136
	Chalcopyrite	2	Avg	BDL	7	BDL	BDL	BDL	BDL	BDL	BDL
			StDev	0	10	4	0	0	22	4	0
Type 4	Chalcopyrite	2	Avg	BDL	BDL	BDL	BDL	BDL	BDL	4	BDL
			StDev	0	0	0	0	0	0	0	0

Note: All values below detection limit (BDL) are indicated.

The highest As values occur in recrystallized colloform and subhedral atoll pyrite in the middle section of the deposit, and proximal to the center of the deposit along strike (Fig. 9).

Tetrahedrite. The tetrahedrite group has a range of stoichiometric and non-stoichiometric compositions between endmember tetrahedrite [1.0 Sb/(Sb + As)] and endmember tennantite [0.97 As/(Sb + As)] (Table 2). Major elements Cu and S range from 17.44 to 42.01 wt.% and 21.42 to 28.32 wt.%, respectively. Minor elements Sb, As, Zn, and Fe range from 1.03 to 27.24 wt.%, 0.06 to 19.35 wt.%, 0.09 to 8.77 wt.%, and up to 7.87 wt.%, respectively. Silver contents range up to 27.78 wt.% and correlate positively with Sb contents (Fig. 7C). Substitution of Ag and Sb at Cu and As sites, respectively, increases along strike in type 2B tetrahedrite distal to the central portion of the deposit (Fig. 9). This is consistent with the fractional crystallization model of Hackbarth & Petersen (1984) and Huston *et al.* (1996), in which Cu and As are

preferentially incorporated into the tetrahedrite crystal lattice over Ag and Sb, until Cu and As contents in the mineralizing fluid are sufficiently depleted and Ag-Sb-bearing tetrahedrite can be precipitated. Silver-rich tetrahedrite contains Ag > 15.00 wt.%. Tellurium contents are up to 2.70 wt.% in Zn-rich (>6.00 wt.% Zn) tennantite (Fig. 7E), and increase along strike toward the center of the deposit.

Bornite. Bornite is near-stoichiometric and has a major element composition of 60.85–63.70 wt.% Cu, 25.23–25.99 wt.% S, and 11.00–11.57 wt.% Fe. Silver in bornite ranges from 1720 to 14720 ppm; minor Zn is present and ranges up to 13220 ppm in bornite (Table 2).

Colusite. Colusite and other V-bearing phases are stoichiometric to non-stoichiometric but with varying trace element contents (Table 2). Major elements in the colusite group of minerals include Cu, S, V, and Ge, which range from 41.80 to 51.11 wt.%, 31.47 to 33.20 wt.%, 3.05 to 3.28 wt.%, and up to 11.63 wt.%,

TABLE 3. CONTINUED.

Type Mineralogy	Se (ppm)	Mo (ppm)	Ag (ppm)	Cd (ppm)	In (ppm)	Sn (ppm)	Sb (ppm)	Au (ppb)	Tl (ppm)	Pb (ppm)	Bi (ppm)
Type 1	BDL	65	20	2680	BDL	10	52	BDL	19	121	BDL
	17	88	36	645	0	5	180	189	87	338	0
	7660	1170	715	118	BDL	BDL	1616	9230	1355	19951	8
Type 2A	8384	1031	420	211	0	2	1171	5223	860	15063	9
	2532	24	372	70	BDL	48	409	2746	8	1220788	61
	4329	9	837	36	3	15	952	589	2	147987	17
	BDL	230	132	4	8	10	3	BDL	2	4928	BDL
	0	524	228	2	5	8	5	0	4	14481	3
	BDL	331	4818	12	6	27	12	833	3	80078	9
	100	455	1931	14	5	20	21	1337	3	200968	12
Type 2B	BDL	39	65	3032	14	33	2283	BDL	2	177	BDL
	46	43	65	728	15	50	6401	0	1	419	0
	BDL	121	57	12	BDL	BDL	981	15439	211	1428	BDL
	115	275	89	47	1	2	2075	36488	524	4654	6
	219	71	1442	143	BDL	19	6986	1909	35	769021	39
	510	109	1431	433	4	10	27817	1785	64	451672	26
	BDL	23	214	58	BDL	28	15	BDL	0	516	BDL
	16	73	324	191	2	38	45	0	0	1188	0
	86	159	10216	2128	BDL	8	81495	BDL	1	2199	BDL
	105	630	23683	1629	7	7	64086	441	2	9767	2
Type 3	BDL	112	52	3463	BDL	18	43	BDL	0	534	BDL
	0	148	37	481	4	7	48	0	0	407	0
	BDL	711	19	4	BDL	BDL	37	BDL	BDL	4287	BDL
	0	1337	38	7	0	2	72	0	0	8496	3
	BDL	60	234	9	BDL	59	13	BDL	0	443	BDL
	0	85	15	1	0	5	15	0	0	619	0
Type 4	95	BDL	170	4	17	21	0	BDL	0	BDL	BDL
	16	0	11	1	2	2	0	0	0	0	0

respectively. Zinc ranges from 330 to 72680 ppm. Minor elements As, Fe, Sb, and Sn range up to 92180, 38810, 12500, and 19500 ppm, respectively. Coupled substitution of As and Sb with Ge and Sn is consistent with the presence of Ge-bearing colusite according to Wagner & Monecke (2005) and Spry *et al.* (1994) (Fig. 7F); however, more complex substitution mechanisms may contribute to the composition of colusite at Lemarchant. Three distinct compositions of colusite are recognized: (1) As-rich colusite with Ge + Sn < 5.00 wt.%, As + Sb > 8.00 wt.%, Cu > 49.00 wt.%, and Zn < 1.50 wt.%; (2) Ge-rich colusite with Ge + Sn > 11.00 wt.%, As + Sb < 1.00 wt.%, Cu < 43.00 wt.%, and Zn > 5.50 wt.%; and (3) intermediate colusite with Ge + Sn, As + Sb, Cu, and Zn ranging from 8.00 to 11.00 wt.%, 2.00 to 5.00 wt.%, 44.00 to 47.00 wt.%, and 3.00 to 5.50 wt.%, respectively (Fig. 7F–H). Arsenic-rich colusite occurs along strike at the edges and central portions of the deposit with type 2B mineralization, whereas Ge-rich and intermediate colusite occur only in the center of the deposit with

type 2B mineralization. Minor sulvanite and renierite also occur with type 2B mineralization in the center of the deposit (Table 1). Sulvanite is stoichiometric and contains 50.30–50.43 wt.% Cu, 34.80–34.93 wt.% S, and 13.55–13.78 wt.% V (Table 2). An unknown Cu–V–Ge–S phase rims germanium-rich colusite in the central portion of the deposit (Gill & Piercey 2014).

Ag-bearing gold. Gold at Lemarchant contains variable amounts of silver (Table 2). The composition ranges from 57.26 to 86.36 wt.% Au and 10.97 to 41.19 wt.% Ag. Trace Cu, Fe, and Zn are locally present, but comprise <0.50 wt.%. The highest ratios of Au:Ag (>0.70) occur in gold at the center of the deposit, whereas these ratios drop to 0.4–0.7 along the north and south edges of the deposit (Fig. 9). Five of the 14 accepted analyses are below the lower total cutoff (>95%); this error is attributed to small grain size effects.

Stromeyerite, polybasite, and miargyrite. In general, these phases are near stoichiometric to non-stoichiometric; miargyrite is stoichiometric (Table 2).

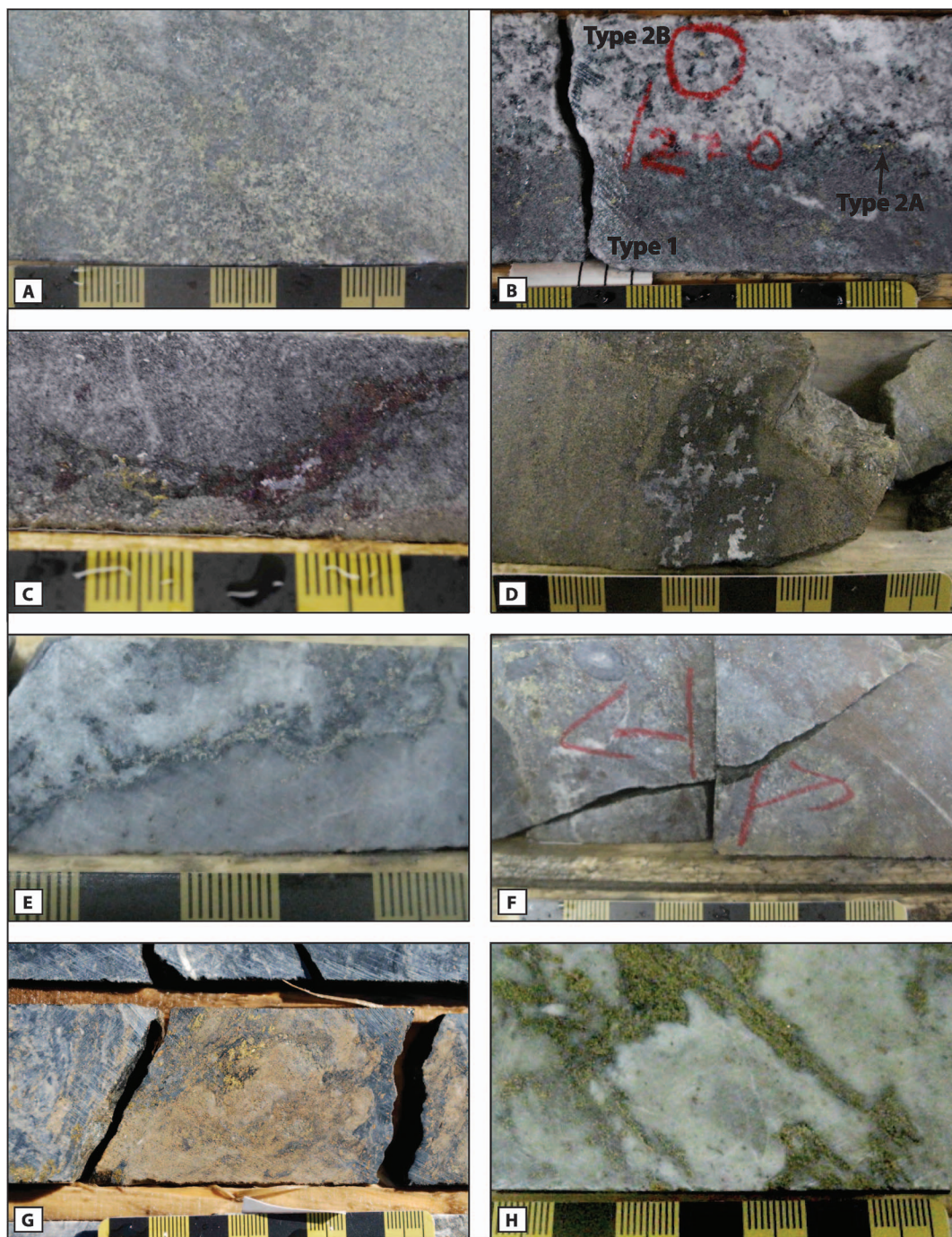


FIG. 5. Drill core photographs of the five types of mineralization at Lemarchant. Black scale bars = 1 cm. (A) Type 1 pale honey sphalerite-pyrite-galena-minor chalcopyrite in massive baryte (drill hole LM11-64 at 218.85 m depth). (B) Visible gold in type 2B massive/bladed baryte-tetrahedrite-sphalerite-galena, with type 2A bornite-chalcopyrite stringers and type 1 pale honey sphalerite-galena-pyrite (LM10-43 at 220.05 m). (C) Type 2A bornite-tetrahedrite-galena and late chalcopyrite stringers cross-cut type 1 baryte-sphalerite-pyrite-galena (LM11-62 at 259.6 m). (D) Type 2B baryte-tetrahedrite-lesser

Stromeyerite contains 42.99–58.55 wt.% Ag, 26.05–38.00 wt.% Cu, 14.17–18.53 wt.% S, and 810–1540 ppm Te. Polybasite contains 6.05 wt.% Cu, 66.05 wt.% Ag, 16.40 wt.% S, 2.50 wt.% As, 6.70 wt.% Sb, and 1910 ppm Te. Miargyrite contains 40.97–41.90 wt.% Sb, 35.14–35.42 wt.% Ag, and 12.45–21.66 wt.% S, with up to 1.30 wt.% Pb. All Ag-bearing minor phases display variable trace Fe, Zn, Pb, and Cu, which is likely due to their small grain size and contamination by proximal major phases (*i.e.*, pyrite, sphalerite, galena, and chalcopyrite).

Bournonite. Bournonite is near-stoichiometric and only occurs as rims on type 2B galena at the outer edges of the Lemarchant deposit (Fig. 6J). Lead, Sb, S, and Cu range from 42.46 to 43.11 wt.%, 23.92 to 24.69 wt.%, 19.23 to 19.88 wt.%, and 13.42 to 13.57 wt.%, respectively (Table 2). Bournonite contains trace As up to 3460 ppm and Zn up to 2720 ppm (Table 2).

Trace element mineral chemistry

The complete set of laser ablation ICP-MS data for the five mineral phases highlighted below are included in Appendix 3 provided in the data repository.

Type 1 mineral assemblage. The type 1 assemblage is enriched in Mn, Mo, Tl, and As relative to the type 2A, 2B, 3, and 4 assemblages (Fig. 10; Table 3). All five assemblages have similar Cd, Sn, and Ge content in sphalerite and pyrite. The cobalt contents of pyrite in the type 1 and type 2B mineral assemblages are comparable (Fig. 10). The type 1 assemblage has lower Cr, In, Ti, Sb, and Ni relative to the other mineral assemblages.

Type 1 sphalerite contains Mn, Cd, Sn, and Ge up to 806, 2306–3450, <24, and <16 ppm, respectively (Table 3). Colloform to reniform type 1 pyrite contains Mn, Mo, Tl, As, Ge, and Co <1189, 4–2610, <2566, 744–45600, <7, and 6–69 ppm, respectively (Table 3). Nickel and Au in pyrite range from 151 to 2961 ppm and 1540 to 15250 ppm, respectively; however, colloform pyrite has lower Ni and Au relative to type 3 pyrite and type 2B pyrite, respectively (Fig. 10). Type 1 pyrite contains atypically high Se (up to 17740 ppm) relative to all other phases in the deposit (Fig. 10).

Type 2A mineral assemblage. The type 2A mineral assemblage has higher Ge, Ag, and Sn contents

relative to the others (Fig. 10). Titanium, Bi, In, Co, Ni, and Cr contents are also higher in the type 2A and 2B mineral assemblages (Fig. 10).

Galena in the type 2A assemblage contains Ge, Sn, Ti, Bi, In, Co, Ni, and Cr in the ranges 22–42, 26–72, 428–681, 40–82, <8, 13–22, 1292–2032, and 20–35 ppm, respectively (Table 3); Se contents are erratic and range up to 9192 ppm (Fig. 10). Significant Ag enrichment occurs only in bornite (1867–7012 ppm), which also contains Ge, Sn, Ti, Bi, In, Mo, Co, Ni, and Cr in the ranges 6–54, 8–75, <380, <45, <13, <1385, <37, <1050, and <19 ppm, respectively (Table 3). Chalcopyrite in the type 2A assemblage contains Ge, In, and Mo in the ranges 8–62, <14, and <1604 ppm, respectively (Table 3).

Type 2B mineral assemblage. The type 2B assemblage has higher V, In, Au, and Sb relative to the other assemblages (Fig. 10; Table 3). Chromium, Co, Bi, Ti, Ge, and Ni contents are similar to the type 2A assemblage, whereas Mo, Ag, Tl, and As are lower than in the other mineral assemblages (Fig. 10). Silver, As, and Sb are elevated in type 2B tetrahedrite relative to the other assemblages (Fig. 7C–D and 9).

White sphalerite in the type 2B assemblage contains V, In, Mn, Sn, and Cd up to 274, <30, 156–333, <156, and 2297–3892 ppm, respectively (Table 3). Type 2B recrystallized to subhedral atoll pyrite contains V, Au, Sb, Cr, Mn, Co, and Ti up to 762, <133000, <6804, <110, <1390, and <56 ppm, respectively (Table 3). Thallium, Ni, and As contents in pyrite are up to 1781, <2341, and <37160 ppm, respectively (Table 3); however, Tl, Ni, and As are lower in subhedral pyrite relative to pyrite in the other assemblages (Fig. 10). Type 2B galena contains In, Au, Sb, Cr, Co, Ge, Se, Bi, Ni, and Ti up to 10, 773–8552, 56–3735, 8–46, 7–26, 7–225, <1955, 12–105, 159–2563, and 174–782 ppm, respectively (Table 3). The Ag content of galena at Lemarchant is highest in the type 2B assemblage (52–6549 ppm) and is associated with high Sb and Bi contents, which is consistent with the coupled substitution of Ag with Sb or Bi in galena (Fig. 10; Amcoff 1984, Huston *et al.* 1996). Tin in type 2B galena ranges from 5 to 45 ppm, but is lower than in type 2A galena (Fig. 10). Chalcopyrite in the type 2B assemblage contains In, Ge, Ti, and Sn up to 5, 3–40, <260, and 5–111 ppm, respectively (Table 3). Type 2B tetrahedrite contains

galena-white sphalerite cross-cut type 1 honey sphalerite-pyrite-galena (LM11-52 at 212.3 m). (E) Type 2B baryte-tetrahedrite-lesser white sphalerite-galena-chalcopyrite in rhyolite breccia (LM11-61 at 237.4 m). (F) Type 3 red sphalerite-pyrite-chalcopyrite replaces type 1 honey sphalerite-pyrite-galena and type 2B bladed baryte-white sphalerite-tetrahedrite-galena (LM11-64 at 218.2 m). (G) Type 4 orange sphalerite-chalcopyrite-pyrite stringers cross-cut chlorite-altered matrix (LM11-59 at 251.22 m). (H) Type 4 chalcopyrite-pyrite stringers in concentrically altered rhyolite breccia (LM11-52 at 228.54 m).

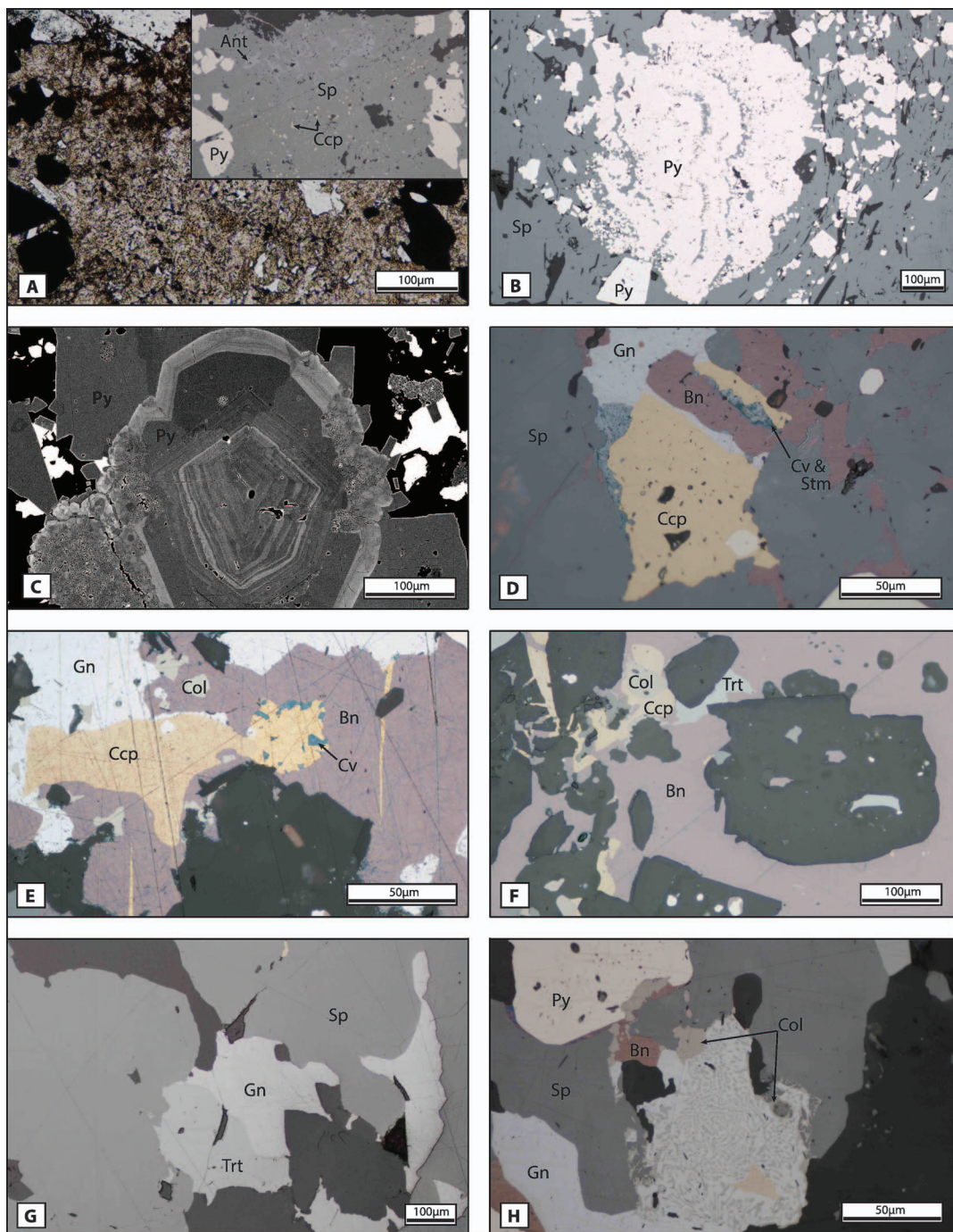


FIG. 6. Thin section and backscattered electron (BSE) images of the Lemarchant mineralogy. (A) Transmitted-light image of type 1 sphalerite; the inset reflected light image shows chalcopyrite disease in sphalerite, anatase, and subhedral pyrite (sample CNF29959 in drill hole LM11-59 at 207.72 m depth). (B) Reflected-light image of colloform and minor euhedral pyrite in sphalerite (CNF29960 in LM11-59 at 216.0 m). (C) BSE image of colloform, subhedral, and minor euhedral pyrite with arsenic zonation; light and dark banding depict As-rich and As-poor regions, respectively (CNF25134 in LM11-56 at

Mn, Ge, Se, and Cd up to 857, <23, <382, and 375–6088 ppm, respectively (Table 3).

Type 3 mineral assemblage. Pyrite and chalcopyrite from the type 3 mineral assemblage contain lower trace-element contents than pyrite and chalcopyrite in the type 1 and 2 assemblages (Table 3). However, Ni is higher in the type 3 assemblage relative to the other mineral assemblages (Fig. 10; Table 3). Cadmium and Sn contents in type 3 sphalerite are similar to those in type 1 and in type 2B white sphalerite (Fig. 10). Molybdenum contents in pyrite and high Sn in chalcopyrite from the type 3 mineral assemblage are similar to type 1 pyrite and type 2B chalcopyrite, respectively (Fig. 10). The type 3 assemblage has lower In, V, Mn, Ge, and Ti relative to the other mineral assemblages.

Type 3 sphalerite contains Cd and Sn from 3047 to 3880 ppm and 8 to 25 ppm, respectively (Table 3). Euhedral atoll pyrite in the type 3 assemblage contains Ni and Mo from 1258 to 3429 ppm and <2714 ppm, respectively (Table 3); however, extreme variability in Mo is likely due to the presence of inclusions (Fig. 10). Type 3 chalcopyrite contains 55–62 ppm Sn (Table 3).

Type 4 mineral assemblage. Type 4 chalcopyrite has very low trace-element contents relative to the other mineral assemblages (Fig. 10). Trace Se, In, and Sn in chalcopyrite range from 84 to 107, 16 to 18, and 19 to 20 ppm, respectively (Table 3).

DISCUSSION

Sulfide mineral paragenesis

The mineral textures, assemblages, contained metals, and crosscutting relationships of sulfides and sulfosalts in the Lemarchant deposit indicate a complex history involving an early subaqueous VMS-epithermal event (stages 1 and 2) that was overprinted by a later VMS event (stage 3; Fig. 11).

During stage 1 the polymetallic Kuroko-style VMS type 1 baryte-honey to white sphalerite-colloform pyrite-galena $\pm$ chalcopyrite-tetrahedrite-tennantite assemblage was deposited at or near the seafloor (Fig. 5A; Eldridge *et al.* 1983, Ohmoto 1996). This Zn-Pb-Ba $\pm$ Cu-(As-Sb) dominated assemblage is consistent with deposition from generally low-temperature (100–275 °C) fluids (*e.g.*, Lydon 1988, Large

1992). Stage 1 mineralization is overprinted by sulfosalt-rich stage 2 mineralization, dominated by bornite-galena-chalcopyrite-stromeyerite $\pm$ Ni-sulfide stringers (type 2A, Fig. 5C) and bladed baryte-tetrahedrite-galena-pyrite $\pm$ colusite-Ag-bearing gold-bournonite-miargyrite-polybasite-Ag-telluride (type 2B, Fig. 5D). The enrichment of this sulfide and sulfosalt suite in epithermal suite elements (Ag-Sb-As-Te), in addition to base metals and sulfosalt-rich mineralogy, is strongly supportive of a significant epithermal component in this stage of mineralization (*e.g.*, Sillitoe *et al.* 1996, Hannington *et al.* 1999, de Ronde *et al.* 2011). Based on thermodynamic data and analogies with modern seafloor vents, it is likely that the stage 2 mineralization was deposited at ~150–275 °C. The final stages of mineralization are Cu-rich, composed of honey-brown to red sphalerite-pyrite-chalcopyrite $\pm$ galena that crosscut stage 1 and 2 mineralization in the stratiform zone (type 3, Figs. 5F, 6E, L, and N) and chalcopyrite-pyrite $\pm$ orange sphalerite-galena stringers (type 4, Fig. 5G) in the underlying felsic footwall, and are more typical of high temperature (>300 °C) VMS mineralization (*e.g.*, Lydon 1988, Large 1992, Ohmoto 1996).

Physicochemical conditions of metal transport

The paragenesis and change in mineralogy, mineral assemblage, and metal associations outlined above reflect the changing physicochemistry of an evolving subaqueous VMS-epithermal system. Outlined below is an evaluation of the potential physicochemical conditions of formation for each stage (and type) of mineralization based on assemblages, mineral compositions, and comparisons to the literature.

Stage 1. The textures of the dominant phases in the type 1 mineral assemblage (*i.e.*, granular baryte, fine-grained, colloform-reniform pyrite) are indicative of rapid precipitation of sulfide minerals by mixing of the hydrothermal fluid with colder seawater at or near the seafloor (Barton & Skinner 1979, Ohmoto 1996). Additionally, the low abundance of chalcopyrite mineralization relative to type 3 and 4 assemblages suggests that initial deposition occurred at lower temperatures because Cu solubility is very low at temperatures less than 300 °C (Pisutha-Arnond &

158.7 m). (D) Type 3 chalcopyrite replaces type 2A bornite-galena-sphalerite-rounded pyrite; covellite replaces irregular stromeyerite (CNF29967 in LM07-17 at 247.63 m). (E) Type 3 chalcopyrite infills cracks in type 2A bornite-galena and type 2B colusite; covellite overprints chalcopyrite (CNF14279 in LM08-33 at 230.75 m). (F) Type 2B colusite-tetrahedrite and chalcopyrite replace type 2A bornite (CNF14299 in LM13-73 at 327.95 m). (G) Type 2B galena-tetrahedrite; pale honey sphalerite resorbs galena (CNF25146 in LM10-46 at 182.56 m). (H) Myrmekitic growth of type 2B galena-colusite-sphalerite with type 3 chalcopyrite replacement, and type 2A bornite at the pyrite-sphalerite interface (CNF14279 in LM08-33 at 230.75 m).

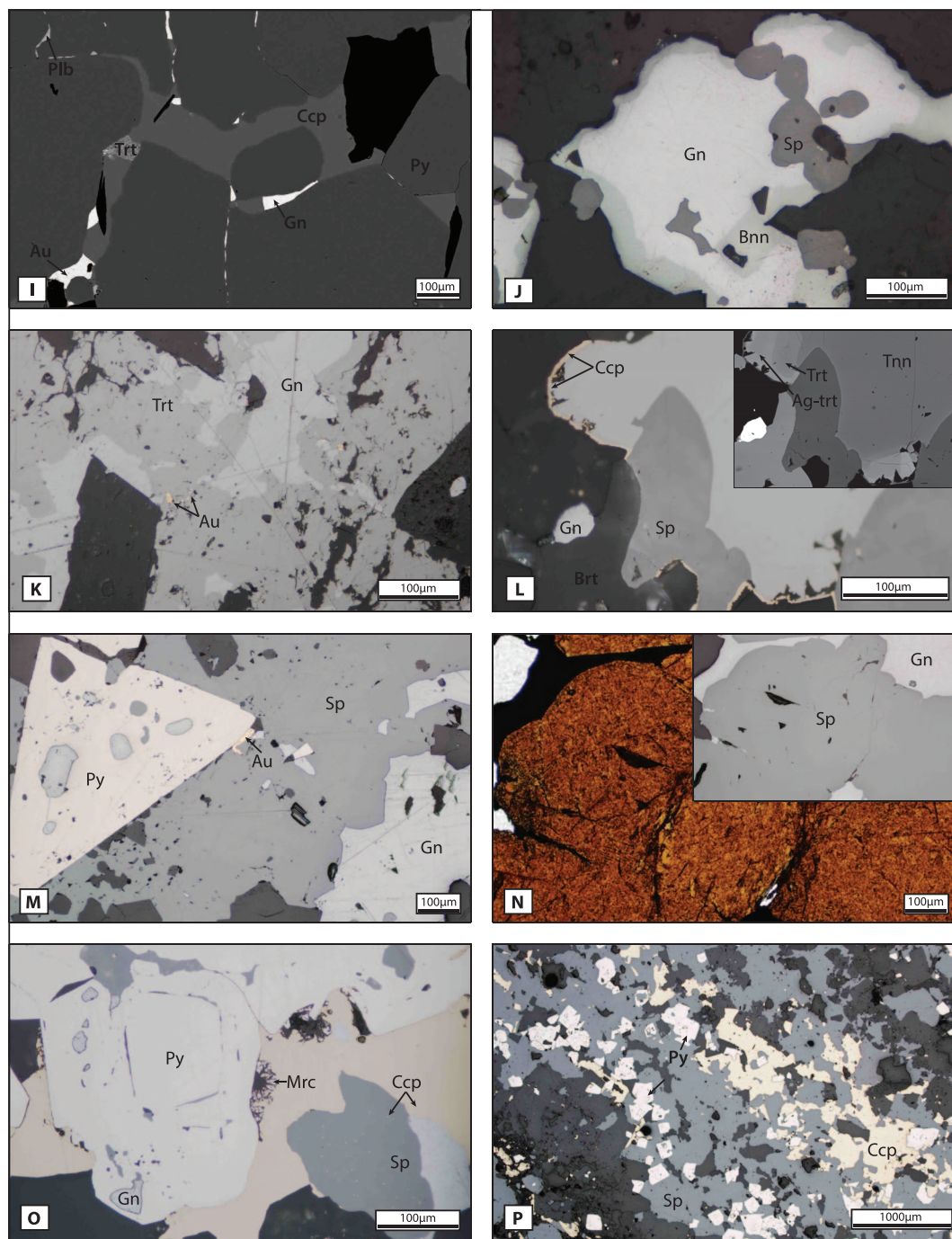


FIG. 6. (continued) (I) BSE image of type 2B rounded pyrite-galena-tetrahedrite-gold-polybasite and type 3 chalcopyrite (CNF29986 in LM08-19 at 97.63 m). (J) Reflected-light image of type 2B bournonite rimming galena-sphalerite (CNF14291 in LM11-65 at 159.3 m). (K) Type 2B galena-Ag-bearing gold in tetrahedrite (CNF25121 in LM11-52 at 212.3 m). (L) Type 2B tetrahedrite-galena-sphalerite-rounded pyrite with type 3 chalcopyrite rims; inset BSE Ag-content map of Ag-zonation in tetrahedrite (CNF14293 in LM11-65 at 161.75 m). (M) Type 2B galena-Ag-bearing gold at euhedral pyrite-

Ohmoto 1983, Ohmoto *et al.* 1983). Low temperature (~ 100 – 275 °C) deposition is also supported by the presence of Fe-poor (<4.5 mol.% FeS), honey to white sphalerite in this assemblage (Fig. 12; Scott & Barnes 1971, Czamanske 1974, Hannington & Scott 1989, Huston & Large 1989) and the high Mn, Tl, and As contents in colloform pyrite (Fleischer 1955, Ballantyne & Moore 1988, Hannington *et al.* 1995). Sulfate (baryte)-Zn-Pb-rich mineralization and associated low-Fe contents of type 1 sphalerite indicate lower Fe solubility in relatively oxidized, acidic to near-neutral pH hydrothermal fluids (Large 1977, Ohmoto *et al.* 1983, Hannington & Scott 1989, Huston & Large 1989, Seyfried & Ding 1995).

Stage 2. The complex textural intergrowth of type 2A and type 2B sulfides and sulfosalts (Fig. 6D–M) implies synchronous deposition of these two assemblages. The very low Fe-contents in type 2B sphalerite (<0.3 mol.% FeS) and associated Zn-Pb-Ag, baryterich, and Ag-Au-bearing mineralogy indicate that stage 2 hydrothermal fluid temperatures were also likely low (150 – 275 °C; Scott & Barnes 1971, Czamanske 1974, Hannington & Scott 1989, Huston & Large 1989). Silver-enrichment of tetrahedrite relative to galena and chalcopyrite and coupled substitution of Bi and Sb with Ag in galena also suggest hydrothermal fluid temperatures below 275 °C (Amcoff 1984, Huston *et al.* 1996). The low-Fe sphalerite and associated Au enrichment, baryte- and bornite-pyrite-chalcopyrite mineral assemblages, and Ag-rich tetrahedrite further suggest that the type 2A and type 2B assemblages were deposited from relatively oxidized (high fO_2) and high fS_2 hydrothermal fluids (Fig. 12; Barton & Skinner 1979, Pisutha-Arnond & Ohmoto 1983, Hannington & Scott 1989, Huston & Large 1989, Ohmoto 1996, Hannington *et al.* 1999, Lusk & Calder 2004). High fS_2 - fO_2 conditions are also consistent with the pentavalent As and V, and tetravalent Ge, present in colusite and renierite, which require highly oxidized conditions for transportation and deposition (Kase *et al.* 1994, Spry *et al.* 1994, Wagner & Monecke 2005). The mineralogy of the type 2 assemblages is indicative of acidic to near-neutral fluid conditions during stage 2 mineralization (pH ~ 5 ; Ohmoto *et al.* 1983, Hannington &

Scott 1989, Hannington *et al.* 1999, Wagner & Monecke 2005).

Stage 3. The type 3 and type 4 mineral assemblages were deposited under typical VMS conditions. The abundance of chalcopyrite and euhedral pyrite, relatively coarse-grained sulfides, and chalcopyrite disease in type 1 sphalerite suggest that hydrothermal fluid temperatures were greater than 300 °C and that previously deposited ores were partially recrystallized *via* zone refining (Pisutha-Arnond & Ohmoto 1983, Eldridge *et al.* 1983, Ohmoto 1996). Type 3 and type 4 orange to red-colored sphalerite contain the highest Fe by weight of the sphalerite at Lemarchant (<8.4 wt.%), consistent with higher-temperature fluids during stage 3 mineralization (>300 °C; Scott & Barnes 1971, Barton & Skinner 1979, Hannington & Scott 1989). The absence of sulfur-rich phases with type 3 and 4 pyrite (*i.e.*, bornite; Scott & Barnes 1971, Barton & Skinner 1979) associated with high-temperature, high-Fe sphalerite in the type 3 and type 4 assemblages further suggests a change to lower fS_2 (and likely lower fO_2) conditions (Fig. 12).

Magmatic contribution to the hydrothermal fluid

The stage 1 polymetallic sulfide mineralization at Lemarchant likely precipitated entirely from evolved seawater containing metals (*i.e.*, Zn, Pb, Cu, Ge) leached from the felsic host rocks and from the greater mass of surrounding volcano-sedimentary basement rocks (Lydon 1988, Kase *et al.* 1994, James *et al.* 2003, Franklin *et al.* 2005). In contrast, the type 2A and type 2B assemblages contain mineral phases and elemental enrichments that cannot be derived solely from evolved seawater (*e.g.*, Lydon 1996). High fS_2 , highly oxidized mineralizing fluids, as indicated by the Cu-rich bornite-, tetrahedrite-, colusite-, covellite-, and gold-bearing assemblages (Fig. 12; Barton & Skinner 1979, Hannington & Scott 1989, Huston & Large 1989), are characteristic of magmatic fluid contributions to VMS hydrothermal systems (Poulsen & Hannington 1995, Sillitoe *et al.* 1996, Hannington *et al.* 1999, Dubé *et al.* 2007a). Furthermore, the presence of very Ag-rich tetrahedrite, minor Ag-rich tennantite (>15 wt.% Ag), and high-Ag gold (<40 wt.% Ag) in the type 2B assemblage, and Ag-bearing

sphalerite interface (CNF14291 in LM11-65 at 159.3 m). (N) Transmitted-light image of type 3 red sphalerite; inset reflected-light image of sphalerite replacing type 1 galena (CNF29959 in LM11-59 at 207.72 m). (O) Type 3 sphalerite-galena in pyrite atoll, dendritic marcasite, and galena in chalcopyrite-diseased sphalerite (CNF14257 in LM11-62 at 266.84 m). (P) Type 3 subhedral to euhedral pyrite-chalcopyrite-honey brown sphalerite (CNF29971 in LM11-63 at 224.7 m). Abbreviations: Ant = anatase; Py = subhedral pyrite; Ccp = chalcopyrite; Sp = sphalerite; Gn = galena; Stm = stromeyerite; Bn = bornite; Cv = covellite; Col = colusite; Trt = tetrahedrite; Plb = polybasite; Au = Ag-bearing gold; Bnn = bournonite; Tnn = tennantite; Ag-trt = silver-rich tetrahedrite; Mrc = marcasite.

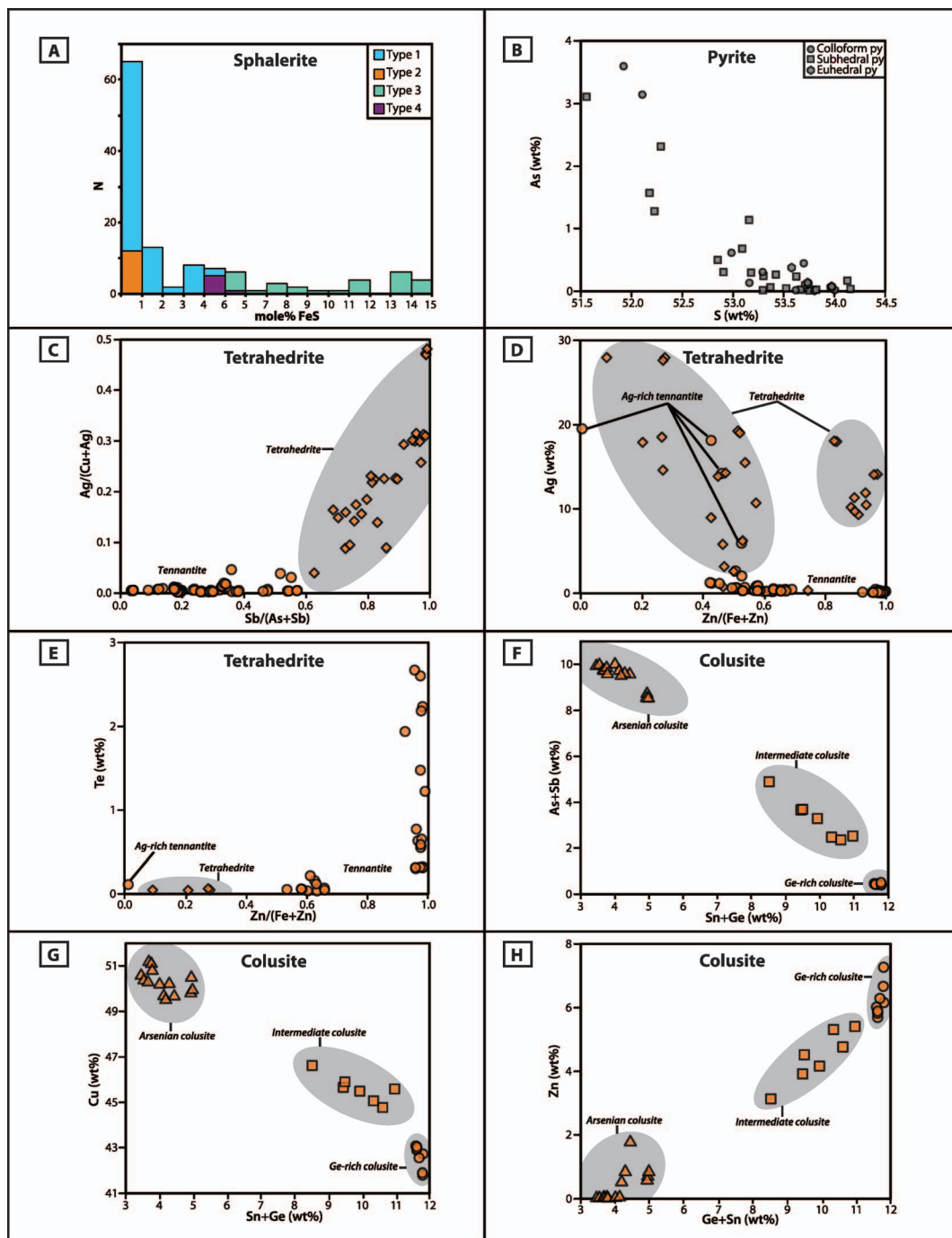


FIG. 7. Compositional variation in the Lemarchant mineralogy. (A) Iron content (mol.% FeS) in sphalerite. (B) Arsenic (wt.%) versus S (wt.%) contents in pyrite. (C) Normalized Ag [Ag/(Ag + Cu)] versus As [Sb/(As + Sb)] ratios in tetrahedrite; shaded area indicates Sb/(As + Sb) > 0.6. (D) Silver (wt.%) versus Zn/(Fe + Zn) in tetrahedrite; shaded area indicates Ag > 5 wt.%. (E) Tellurium (wt.%) versus Zn/(Fe + Zn) in tetrahedrite; shaded area indicate Ag > 5 wt.%. (F) Sums As + Sb (wt.%) versus Sn + Ge (wt.%) in colusite; shaded areas indicate distinct As-Ge compositions. (G) Copper (wt.%) versus Sn + Ge (wt.%) in colusite; shaded areas as above. (H) Zinc (ppm) versus Sn + Ge in colusite; shaded areas as above.

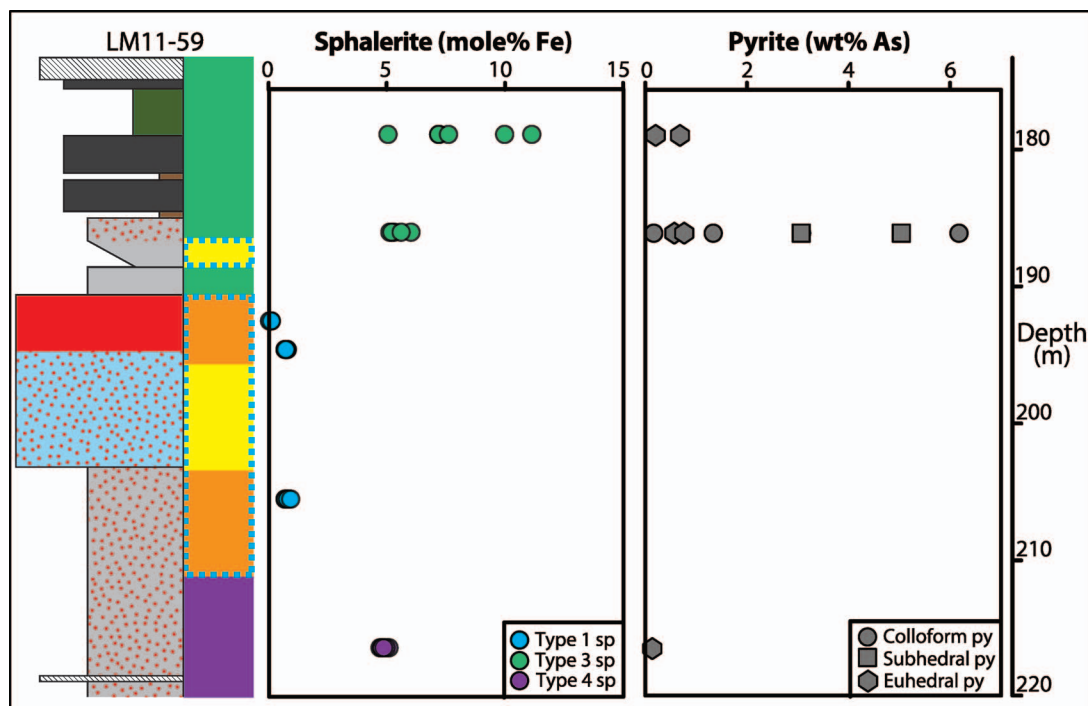


FIG. 8. Down-hole variation in Fe and As content in sphalerite and pyrite, respectively, in the central Lemarchant deposit (drill hole LM11-59 with values from adjacent LM11-61 at section L10300N). Legend as in Figure 4. Drill hole and sample depths corrected to true depth.

bornite (<0.7 wt.% Ag) in the type 2A assemblage, suggest that Ag was significantly enriched in the hydrothermal fluid relative to normal polymetallic VMS-forming fluids (Hackbarth & Petersen 1984, Petersen *et al.* 1990). There is enrichment of many trace elements in the type 2A and 2B ore mineral phases (*i.e.*, Au, Ag, As, Bi, Co, Cr, In, Mo, Ni, Sb, Sn, Te) that are likely not present in sufficient quantity in the volcanic host rock to contribute to the composition of the hydrothermal fluid solely by leaching (Poulsen & Hannington 1995, Lydon 1996, Franklin *et al.* 2005). However, these elements could be episodically transferred to the hydrothermal fluid from a contemporaneous magma *via* magmatic fluids or volatiles (Hedenquist & Lowenstern 1994, White & Hedenquist 1995, Sillitoe *et al.* 1996, Hannington *et al.* 1999). Evidence for pulsed magmatic fluid contributions is also suggested by the zoned, subhedral pyrite associated with the type 2 assemblages that contains As-rich bands and As-poor bands (Fig. 6C), indicating significant periodic As addition to the hydrothermal fluid during deposit formation (Rye 1993, Hedenquist & Lowenstern 1994, Cathles *et al.* 1997).

Precipitation of precious metals

Precious metal enrichment of the Lemarchant deposit occurred almost entirely during stage 2 paragenesis. Although deposition of Ag and Au were contemporaneous at Lemarchant, the mechanisms of Au and Ag precipitation were distinct. Silver occurs mostly in tetrahedrite, with subordinate enrichment in gold, galena, bornite, and trace Ag-Sb-sulfosalt minerals (Table 1; Figs. 7C–D and 10). The dominance of tetrahedrite as a Ag host, and the close association of tetrahedrite with baryte in the type 2B assemblage, suggests that fractional crystallization of tetrahedrite from the hydrothermal fluid was the main mechanism for Ag enrichment in the Lemarchant deposit (Hackbarth & Petersen 1984, Huston *et al.* 1996). This is reflected by the distribution of Cu-As- and Ag-Sb-tetrahedrite compositions along the strike length of the Lemarchant deposit (Fig. 9); near-endmember tennantite ($\text{Cu-As} > \text{Ag-Sb}$) occurs primarily in the center of the deposit, whereas endmember tetrahedrite [$\text{Sb}/(\text{As} + \text{Sb}) > 0.6$] occurs in the more distal parts of the deposit. Given that the assemblages were deposited from fluids with temperatures <275 °C (Fig. 12), it is likely that the Ag was

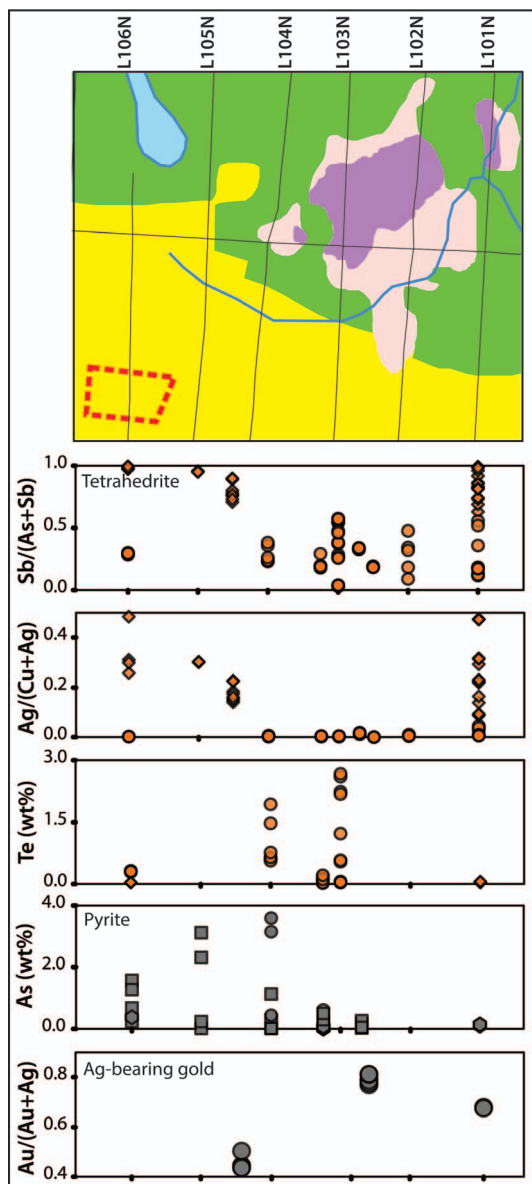


FIG. 9. Along-strike compositional variation in tetrahedrite (circles = tennantite; diamonds = tetrahedrite), pyrite (circles = colloform pyrite; squares = subhedral pyrite; hexagons = euhedral pyrite), and gold. Legend as in Figures 4 and 7.

transported as AgCl_2 (Seward 1976, Huston *et al.* 1996).

Although gold appears in laser ablation analyses of type 1 and 2B pyrite (Table 3, Fig. 10) and might be considered refractory, the abundance of gold in microprobe analyses of these phases is negligible

(Table 2) and suggests that the gold occurs in the type 1, 2A, and 2B assemblages primarily as Ag-bearing gold and possibly submicroscopic gold entrained in pyrite. These gold-bearing, lower temperature assemblages indicate that Au was transported as $\text{Au}(\text{HS})_2^-$, likely at high $f\text{S}_2$ and $f\text{O}_2$ (Fig. 12; Seward 1973, Hannington & Scott 1989, Huston & Large 1989, Williams-Jones *et al.* 2009). The association of Au-phases (*i.e.*, Ag-bearing gold) with Ag-bearing phases, bladed baryte, and euhedral feldspar (albite) within the ore (Gill & Piercey 2014) suggests that hydrothermal fluid boiling was important during stage 2 mineralization for the precipitation of Au and crystalline gangue minerals (Drummond & Ohmoto 1985, Hannington & Scott 1989, Huston & Large 1989, Sillitoe *et al.* 1996, Roth *et al.* 1999, Huston 2000, Dubé *et al.* 2007a, Hannington & Monecke 2009). Furthermore, the observation of fluid boiling imparts limitations on the depth of emplacement of the massive sulfide deposit in seawater. In particular, the depth to boiling curve for seawater (Bischoff & Rosenbauer 1984, Butterfield *et al.* 1990) requires relatively shallow emplacement of the deposit (<1500 mbsl at <275 °C) to permit boiling of the hydrothermal solution at or near the seafloor (Sillitoe *et al.* 1996, Hannington *et al.* 1999, Hannington & Monecke 2009). Although many polymetallic black smoker deposits at mid-ocean ridges form at depths >2000 mbsl (Hannington *et al.* 1995, 1999, Hannington & Monecke 2009), precious metal-enriched black and white smokers venting fluids with a magmatic fluid component (in addition to modified seawater) are common in shallow back-arc basins (*e.g.*, Lau Basin, Herzig *et al.* 1993; Okinawa Trough, Glasby & Notsu 2003), calderas in submarine arcs (*e.g.*, Brothers volcano, de Ronde *et al.* 2001, 2005), and ancient analogues in back-arc (*e.g.*, Eskay Creek, Roth *et al.* 1999, Sherlock *et al.* 1999) to rifted arc (*e.g.*, Kuroko-type deposits, Cathles *et al.* 1983; Louvincourt deposit, McClenaghan *et al.* 2006; Boundary deposit, Piercey *et al.* 2014) settings, with the rifted arc environment most closely resembling that of the Lemarchant deposit.

Changes in seafloor depth

The abrupt transition from stage 2 to stage 3 in the paragenetic sequence is accompanied by notable Fe enrichment in sphalerite, an abundance of chalcopyrite, and a coarsening of sulfide mineral textures, which collectively indicate an increase in the temperature of the system to greater than 300 °C. A prolonged temperature increase is not likely in this case because sustained heating would likely have produced massive chalcopyrite within the sulfide ore body and well-developed alteration in the overlying (insulating)

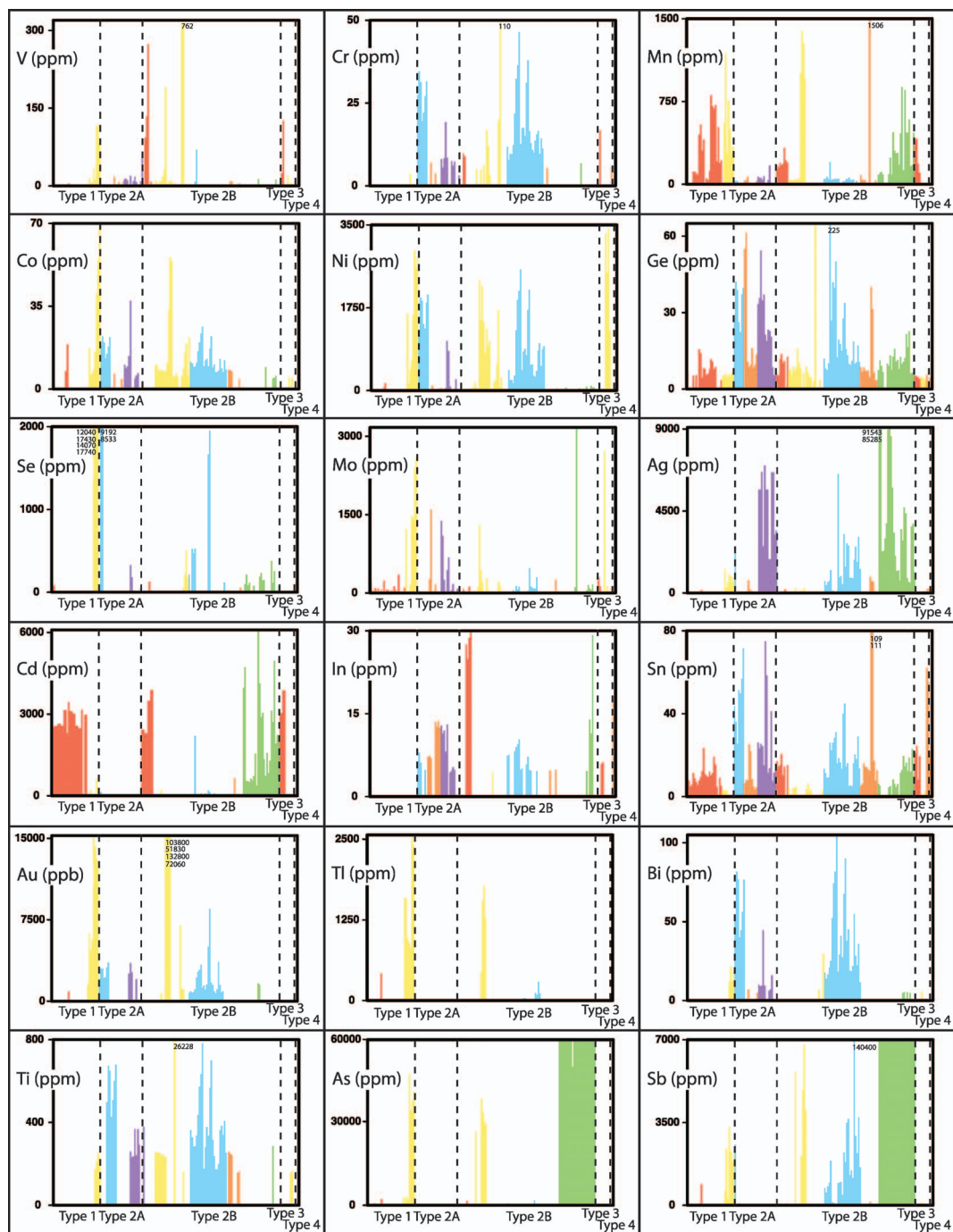


FIG. 10. Trace-element variation in sphalerite (red), pyrite (yellow), chalcopyrite (orange), galena (blue), tetrahedrite (green), and bornite (purple). Elements highlighted: Ag, As, Au, Bi, Cd, Co, Cr, In, Ge, Mn, Mo, Ni, Sb, Se, Sn, Ti, Tl, V.

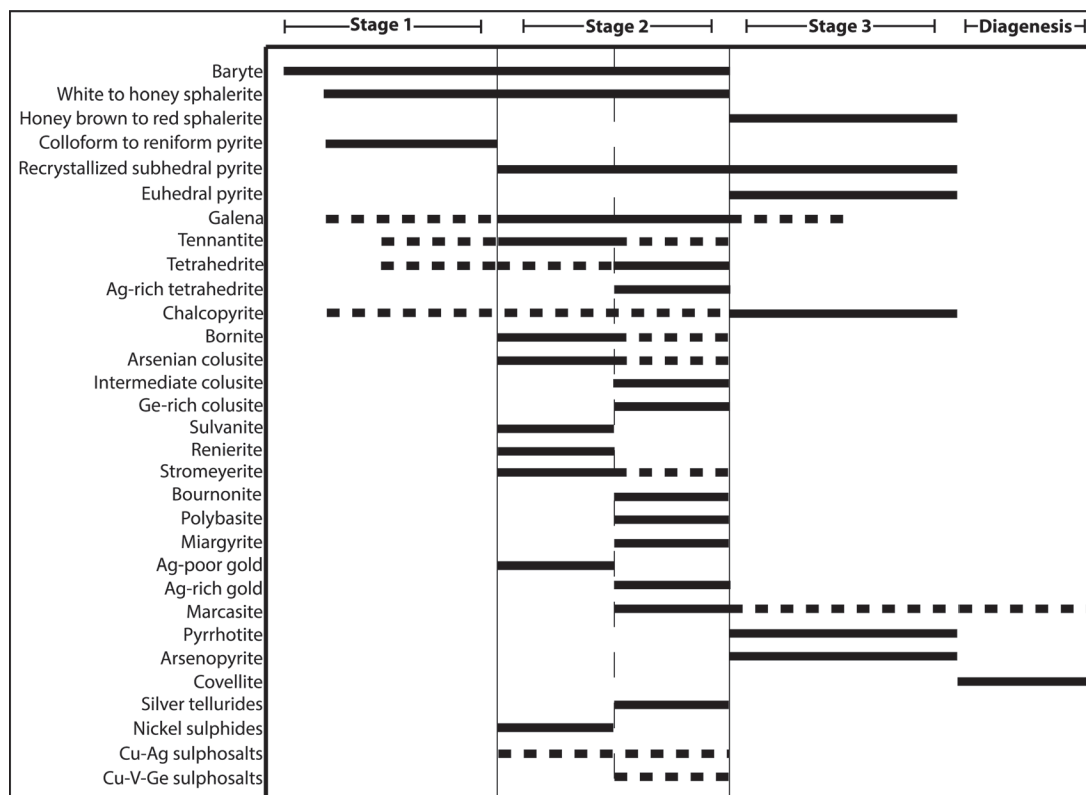


FIG. 11. Paragenetic sequence of all mineral phases that compose the Lemarchant stratiform and stringer sulfide zones. Solid lines and dashed lines represent major and ancillary phases, respectively.

hanging wall (Franklin *et al.* 2005, and references therein); such features are not manifested in the weakly altered and mineralized hanging wall interbedded basalts at Lemarchant (*e.g.*, Copeland *et al.* 2008a, Copeland *et al.* 2008b, Fraser *et al.* 2012, Lode *et al.* in press). Furthermore, the zone-refinement of the stratiform zone is not well developed and there is no typical ‘stockwork’ sulfide and chlorite alteration zone like in many VMS deposits (Fig. 3A–C; Riverin & Hodgson 1980, Eldridge *et al.* 1983, Lydon 1984, Large 1992, Ohmoto 1996). In the stratiform zone, early deposited mineralization (*i.e.*, type 1 white to honey sphalerite and colloform-reniform pyrite, Fig. 6A–C) is moderately chalcopyrite diseased (*i.e.*, formed at a reaction front; Eldridge *et al.* 1983, Barton & Bethke 1987) and is only partially replaced by the type 3 mineral assemblage. The type 4 mineral assemblage is mostly chalcopyrite-dominated and does not extend far below the stratiform zone (<50 m; Figs. 3 and 4). The incomplete zone refining of the stratiform zone and absence of “siliceous pyrite ore” (SPO; Eldridge *et al.* 1983) in type 4 sulfides suggests

that this stage of mineralization was relatively short-lived.

Although the Lemarchant Fault may have truncated part of the stockwork zone, thus removing possible evidence of long-lived stage 3 mineralization, it is more likely that another stage of low-temperature hydrothermal activity persisted after the stockwork zone was formed. This latter possibility is supported by the presence of weakly altered, locally peperitic basalt flows intercalated with mineralized mudstone in the hanging-wall basalt flows (up to 50 m above the massive sulfides), which indicates that hydrothermal activity at Lemarchant persisted after the main mineralizing events (Copeland *et al.* 2008a, b, Lode *et al.* 2015, Lode *et al.* in press).

Any increase in temperature above 250 °C in a shallow-water system (<1500 m) would necessitate an increase in confining pressure of the system (Bischoff & Rosenbauer 1984, Butterfield *et al.* 1990, Hannington *et al.* 1995, Hannington *et al.* 2005), suggesting that the increase in temperature at Lemarchant to >300 °C during stage 3 mineralization

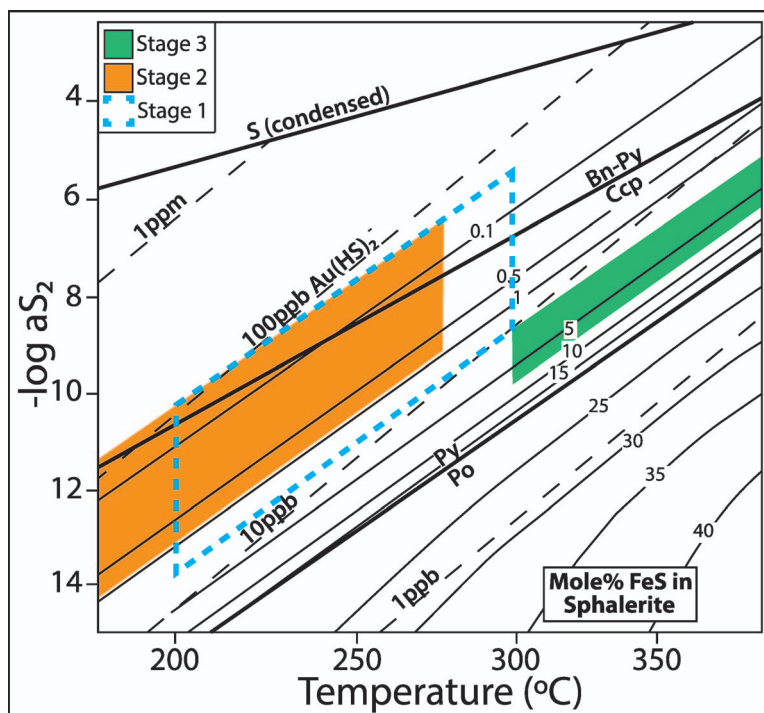


FIG. 12. Log a_{S_2} versus temperature with contours for mol.% FeS in sphalerite and gold solubility as $Au(HS)_2^-$ at pH 5 (Fig. 3; Hannington & Scott 1989). Shaded areas projected onto the diagram represent physicochemical conditions at each stage of the Lemarchant paragenesis.

was accompanied by an increase in seawater depth of the deposit (to >1500 mbsl) to prevent boiling. Variation in mineralization styles between the Lemarchant, Duck Pond, and Boundary deposits provides evidence for an increase in water depth accompanying the increase in temperature of the hydrothermal fluid and deposition of high temperature (Cu-rich) mineralization. Although the structural setting of mineralization in the Tally Pond group is complex, the Upper Block that unconformably overlies the Mineralized Block at Duck Pond has a well-constrained bimodal felsic-mudstone cap sequence with a U-Pb age of 513 ± 2 Ma (Dunning *et al.* 1991, McNicoll *et al.* 2010), similar to the stratigraphy and loosely correlated U-Pb age of the Lemarchant deposit (513 ± 2 Ma; Dunning *et al.* 1991). The Duck Pond and Boundary deposits in the Mineralized Block contain normal polymetallic VMS mineralization (deep water VMS; Hannington *et al.* 2005, Hannington & Monecke 2009) and are relatively younger (509 ± 3 Ma; McNicoll *et al.* 2010) than the Lemarchant deposit, but are hosted in a stratigraphic sequence with rifted-arc geochemical signatures similar to those of the Upper Block and Lemarchant host rocks (Squires & Moore 2004,

Copeland *et al.* 2008a, McNicoll *et al.* 2010, Piercey *et al.* 2014, Lode *et al.* in press). This suggests that formation of the Lemarchant deposit began during arc rifting around ~1500 m seawater depth, but deposition continued at an increased water depth during the final stages of mineralization, perhaps due to basin subsidence in an extensional arc-rift environment.

Deposit type

In many respects, the Lemarchant deposit resembles a typical polymetallic volcanogenic massive sulfide deposit (*i.e.*, Kuroko- or bimodal felsic-type; Eldridge *et al.* 1983, Large 1992, Poulsen & Hannington 1995, Franklin *et al.* 2005, Galley *et al.* 2007). The stratiform sulfide zone at Lemarchant (~concordant massive sulfide zone; after Lydon 1984, Gibson *et al.* 2007) is baryte-rich with $Zn + Pb > Cu$ and is underlain by a discordant Cu-rich stringer zone (*e.g.*, Riverin & Hodgson 1980, Lydon 1984, Large 1992, Franklin *et al.* 2005, Galley *et al.* 2007). The felsic volcanic host rocks contain mostly quartz-sericite alteration with localized chlorite-rich alteration proximal to mineralization (*e.g.*, Eldridge *et al.* 1983, Large 1992, Ohmoto 1996).

Mineralogical and metal zoning features atypical of VMS deposits are also present in the Lemarchant deposit. For example, the type 2A and type 2B assemblages contain sulfide and sulfosalt minerals (e.g., tetrahedrite, bornite, Ag-bearing gold, covellite, and tellurides) that are more characteristic of epithermal gold deposits (White & Hedenquist 1995, Cooke & Simmons 2000, Taylor 2007). The type 2 assemblages also contain epithermal-suite elements (e.g., Au, Ag, As, Sb, Bi, Te, Sn, and Mo; White & Hedenquist 1995, Sillitoe *et al.* 1996, Cooke & Simmons 2000). Gold contents at Lemarchant are elevated relative to typical polymetallic (Kuroko-style) VMS deposits, and both free gold (Ag-rich), Ag-bearing phases, and an epithermal trace element suite occur with granular to bladed baryte, which together are rare in Kuroko-style VMS deposits (Eldridge *et al.* 1983, Sillitoe *et al.* 1996). Collectively, the above features suggest that a hybrid epithermal-VMS system operated during the genesis of the Lemarchant deposit (e.g., Sillitoe *et al.* 1996, Hannington *et al.* 1999, Dubé *et al.* 2007a, Mercier-Langevin *et al.* 2011).

Although sulfide mineral associations in the type 2A and type 2B assemblages (*i.e.*, bornite + pyrite-chalcopyrite, low-Fe sphalerite) indicate an elevated sulfidation state for low-temperature stage 2 hydrothermal fluids (Fig. 12), the Lemarchant deposit lacks the acidic, advanced argillic alteration assemblage (e.g., vuggy silica, alunite-dickite) that is typically a diagnostic feature of high sulfidation epithermal-style mineralization (Rye 1993, Hedenquist & Lowenstern 1994, White & Hedenquist 1995, Poulsen & Hannington 1995, Sillitoe *et al.* 1996). Rather, the quartz-sericite $\pm$ chlorite-albite alteration assemblage present at Lemarchant (Copeland *et al.* 2008a, Copeland *et al.* 2008b, Fraser *et al.* 2012) suggests that the stage 2 fluids were near neutral (Hedenquist *et al.* 2000, Franklin *et al.* 2005). Similarly, despite convincing evidence for a magmatic contribution to the hydrothermal fluid during deposit genesis, alteration at the Eskay Creek deposit consists of sericite $\pm$ K-feldspar (Roth *et al.* 1999) and the Ming deposit has quartz- and sericite-dominant alteration (Brueckner *et al.* 2014). Hedenquist *et al.* (2000) and Sillitoe & Hedenquist (2003) define deposits such as these, with low-sulfidation alteration and low- to high-sulfidation sulfide mineral assemblages, as “intermediate sulfidation” epithermal-style deposits. The absence of low-pH, highly aluminous alteration at Lemarchant can be attributed either to the contribution of magmatic liquid-phase fluids (Hedenquist & Lowenstern 1994, Einaudi *et al.* 2003) or to the prolonged mixing of seawater-dominated hydrothermal fluids with magmatic fluids (vapor or liquid) prior to sulfide precipitation. Both mechanisms of magmatic fluid

contribution, contemporaneous with the shallow seafloor setting (<1500 mbsl) and the presence of the proximal, potentially synvolcanic Lemarchant microgranite intrusion, are compatible with the precious metal enrichment of the stage 2 hydrothermal fluids and precipitation of intermediate sulfidation epithermal-style mineralization (Sillitoe & Hedenquist 2003, Taylor 2007).

CONCLUSIONS

The well-preserved mineralization at Lemarchant exhibits two styles of massive sulfide deposition: (1) bimodal felsic (Kuroko)-style polymetallic VMS mineralization and (2) intermediate sulfidation epithermal-style mineralization. Distinctly different mineral assemblages and crosscutting relationships define three stages of deposition at Lemarchant (Fig. 13). Stage 1 was initially submarine exhalative, with deposition of massive baryte and precipitation of semi-massive low-Fe sphalerite and fine-grained colloform pyrite at or near the seafloor due to a relatively lower temperature “VMS-type” hydrothermal fluid cooling and mixing with seawater (Fig. 13A). Stage 2 was characterized by the deposition of epithermal suite minerals (*i.e.*, bornite, tetrahedrite, colusite, covellite, and gold) and sulfide mineralization with magmatic trace-element signatures (*i.e.*, Au, Ag, As, Bi, Co, Cr, In, Mo, Ni, Sb, Sn, Te) from a low-temperature, oxidized, intermediate-sulfidation, near-neutral, magma-derived hydrothermal fluid (Fig. 13B). Gold enrichment occurred due to intermittent boiling of the hydrothermal fluid at shallow depth, whereas Ag was precipitated due to fractional crystallization, mixing with seawater, and subsequent cooling of the hydrothermal fluid. Stage 3 deposition formed a chalcopyrite-pyrite-dominated basal stringer zone and typical Zn-Pb-Cu VMS mineralization that partially overprinted the stratiform sulfide zone (Fig. 13C) and occurred below the boiling point (>1500 mbsl) for higher-temperature hydrothermal fluids.

A direct magmatic contribution of precious and trace metals to the hydrothermal fluid is thus inferred from the intermediate-sulfidation epithermal mineral assemblages and epithermal element suite of the type 2A and type 2B mineral assemblages at Lemarchant. The combination of a shallow seawater environment and the extremely close spatial association of a magmatic body, within a rifted-arc environment, enabled precious-metal enrichment of polymetallic massive sulfides at the Lemarchant deposit, in the absence of acidic (advanced argillic) alteration. Precious-metal enrichment in the polymetallic Le-

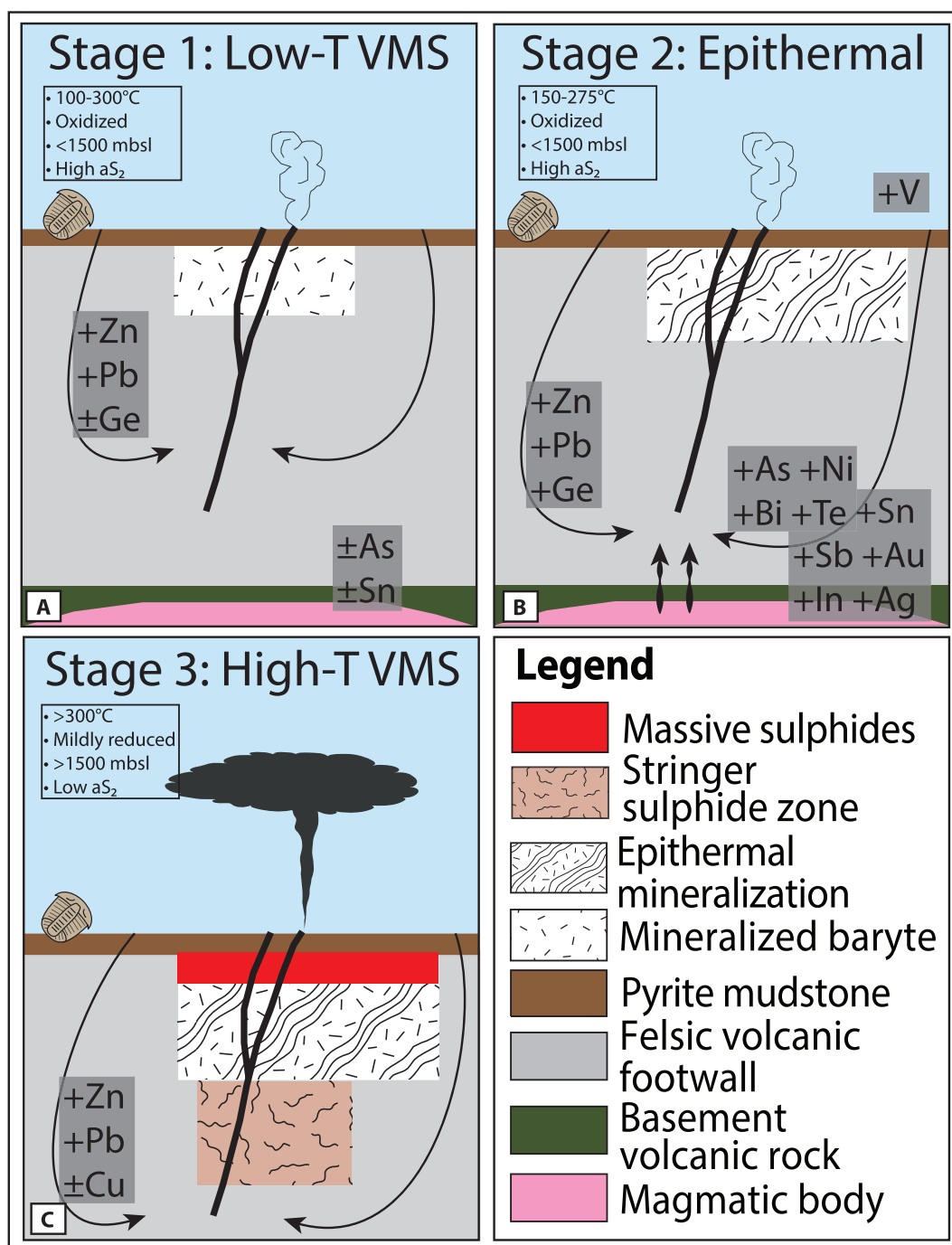


FIG. 13. Schematic diagram of three-stage Lemarchant paragenesis. (A) Stage 1, shallow water, low-temperature polymetallic VMS mineralization. (B) Stage 2, shallow water, intermediate-sulfidation epithermal-style mineralization, with boiling and pulsed magmatic fluid. (C) Stage 3, deep water, high-temperature Cu-rich VMS mineralization, with zone refinement and formation of a stringer sulfide zone.

marchant VMS deposit has implications for similar VMS deposits in the Appalachians and globally.

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