Natural Resources Canada	Ressources naturelles Canada

Preliminary observations on styles of mineralization and sulphide-mineral zonation in the Cambrian Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive-sulphide deposit, Newfoundland and Labrador

S.B. Gill and S.J. Piercey

Geological Survey of Canada
Current Research 2014-5

2014

Canada

Geological Survey of Canada
Current Research 2014-5

Preliminary observations on styles of mineralization and sulphide-mineral zonation in the Cambrian Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive-sulphide deposit, Newfoundland and Labrador

S.B. Gill and S.J. Piercey

2014

ISSN 1701-4387
Catalogue No. M44-2014/5E-PDF
ISBN 978-1-100-24452-5
doi:10.4095/294603

Recommended citation
Gill, S.B. and Piercey, S.J., 2014. Preliminary observations on styles of mineralization and sulphide-mineral zonation in the Cambrian Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive-sulphide deposit, Newfoundland and Labrador; Geological Survey of Canada, Current Research 2014-5, 17 p. doi:10.4095/294603

Critical review
P. Mercier-Langevin

Authors
S.B. Gill (s.gill@mun.ca)
S.J. Piercey (spiercey@mun.ca)
Department of Earth Sciences
Memorial University of Newfoundland
St. John's, Newfoundland
A1B 3X5

Correction date:

Preliminary observations on styles of mineralization and sulphide-mineral zonation in the Cambrian Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive-sulphide deposit, Newfoundland and Labrador

S.B. Gill and S.J. Piercey

Gill, S.B. and Piercey, S.J., 2014. Preliminary observations on styles of mineralization and sulphide mineral zonation in the Cambrian Zn-Pb-Cu-Ag-Au Lemarchant volcanogenic massive-sulphide deposit, Newfoundland and Labrador; Geological Survey of Canada, Current Research 2014-5, 17 p. doi:10.4095/294603

Abstract: The precious-metal-bearing, polymetallic, bimodal felsic Lemarchant volcanogenic massive-sulphide deposit is located in the Tally Pond belt, Dunnage Zone, Newfoundland Appalachians and consists of a stratiform, massive to semimassive sulphide zone and an underlying stringer sulphide zone. Five principal types of mineral assemblage are present: 1) semimassive white (low-Fe) sphalerite–granular barite–recrystallized pyrite–galena–minor tetrahedrite; 2A) bornite-galena-stromeyerite±chalcopyrite; 2B) bladed barite–coarse-grained tetrahedrite–galena-electrum-colusite±bournonite-polybasite-miargyrite; 3) massive red (high-Fe) sphalerite–fine- to medium-grained pyrite–chalcopyrite–galena; and 4) chalcopyrite-pyrite±orange sphalerite stringers. The stratiform sulphide zone contains the type 1 assemblage, which is crosscut by the type 2A and type 2B assemblages. The type 3 assemblage overprints the type 1 assemblage at the top of the stratiform zone. The basal stringer zone is host to the type 4 assemblage. The type 3 and type 4 assemblages represent minor zone refinement of the stratiform and stringer zones, as the hydrothermal fluids from which they were deposited were relatively hotter (>300°C) than the lower temperature fluid (<250°C) from which the type 1 and type 2 assemblages were deposited.

The Lemarchant deposit shows zone refinement typical of Kuroko-style volcanogenic massive-sulphide mineralization; however, the precious-metal–enriched low-Fe sphalerite, bornite, electrum, and sulphosalt-rich type 2 assemblages suggest processes analogous to high-sulphidation epithermal-style volcanogenic massive-sulphide mineralization early in the evolution of the deposit. A direct magmatic contribution to the hydrothermal fluid and intermittent boiling during deposition of the type 1 and type 2 assemblages may be partially responsible for precipitation of epithermal-suite minerals and precious-metal enrichment.

Résumé : Le gisement de Lemarchant, un gîte de sulfures massifs volcanogènes de type bimodal felsique à minéralisation polymétallique et à métaux précieux, est situé dans la ceinture de Tally Pond, de la Zone de Dunnage, dans les Appalaches de Terre-Neuve. La minéralisation est constituée d'une zone stratiforme de sulfures massifs à semi-massifs qui surmonte une zone de filonnets de sulfures. Cinq principaux types d'associations minérales sont présents : 1) sphalérite blanche (faible teneur en Fe) semi-massive-barytine granulaire-pyrite recristallisée-galène-tétraédrite accessoire; 2A) bornite-galène-stromeyérite±chalcopyrite; 2B) barytine lamellaire-tétraédrite à grain grossier-galène-électrum-colusite±bournonite-polybasite-miargyrite; 3) sphalérite rouge (forte teneur en Fe) massive-pyrite à grain fin à moyen-chalcopyrite-galène; 4) chalcopyrite-pyrite±filonnets de sphalérite orange. La zone stratiforme de sulfures est formée de minéraux de l'association de type 1, qui sont recoupés par des minéraux des associations de type 2A et de type 2B. Des minéraux de l'association de type 3 se superposent à ceux de l'association de type 1 au sommet de la zone stratiforme. La zone filonienne basale renferme des minéraux de l'association de type 4. Les associations de type 3 et de type 4 témoignent d'un raffinement mineur des zones stratiforme et filonienne, étant donné que les fluides hydrothermaux à partir desquels elles ont été formées étaient relativement plus chauds (>300 °C) que les fluides de plus basse température (<250 °C) qui ont mené à la formation des associations de minéraux de type 1 et de type 2.

Le gisement de Lemarchant présente un raffinement de zones représentatif d'une minéralisation de sulfures massifs volcanogènes de type Kuroko. Cependant, les associations minérales de type 2 à sphalérite à faible teneur en fer, bornite, électrum et sulfosels, enrichies en métaux précieux, permettent de supposer l'existence de processus analogues à ceux des minéralisations de sulfures massifs volcanogènes de style épithermal à fort degré de sulfuration apparues tôt dans l'évolution du gisement. Une contribution magmatique directe aux fluides hydrothermaux et une ébullition intermittente lors de la formation des associations minérales de type 1 et de type 2 peuvent être en partie responsables de la précipitation des minéraux de la suite épithermale et de l'enrichissement en métaux précieux.

INTRODUCTION

The Newfoundland Appalachians are host to numerous volcanogenic massive-sulphide deposits, including a number of past-producing and presently producing deposits (e.g. Buchans and Duck Pond; Swinden and Kean (1988); Piercey and Hinchey (2012)). Although the massive-sulphide deposits in this area represent a range of volcanogenic massive-sulphide deposit types and have been explored since the 1850s (Martin, 1983; Piercey and Hinchey, 2012), there are few well studied volcanogenic massive-sulphide deposits with significant precious-metal enrichment (cf. Hurley and Crocket, 1985; Santagulda and Hannington, 1993; Santagulda and Hannington, 1996; Brueckner et al., in press). The Lemarchant deposit is hosted in the Tally Pond volcanic belt of the Victoria Lake Supergroup (Rogers et al., 2006; McNicoll et al., 2010) and is a type example of precious-metal enrichment in Appalachian polymetallic volcanogenic massive-sulphide deposits. The Lemarchant deposit occurs in the same volcanic belt as the currently producing Duck Pond and Boundary Cu-Zn deposits, but is distinct in precious-metal content from these deposits as they have normal volcanogenic massive-sulphide mineralization without significant precious-metal enrichment (Squires et al., 2001; Piercey and Hinchey, 2012; Piercey et al., 2014).

The Lemarchant deposit was initially discovered in the 1980s with further expansion in the late 2000s, and has since had abundant exploration work undertaken on it; however, the styles of sulphide mineralization at Lemarchant are poorly documented and the cause(s) of precious metal enrichment are not well understood. The objectives of this study are to: 1) produce a more thorough documentation of mineralization styles, siting of precious metals, and 3-D base- and precious-metal zonation in the Lemarchant deposit; and 2) propose a genetic model of deposition and precious-metal enrichment. Refined drill-core observations and petrographic and scanning electron microscope results are presented here as part of an M.Sc. project at the Memorial University of Newfoundland and are a contribution to the precious-metal–rich volcanogenic massive-sulphide subproject of the Geological Survey of Canada Targeted Geoscience Initiative 4 program. The deposit model presented here is the basis for more detailed mineral chemical analysis that will further constrain the environmental and depositional conditions required for the formation of the Lemarchant deposit and allow comparison to precious-metal–enriched volcanogenic massive-sulphide deposit analogues in the Appalachians and globally.

EXPLORATION HISTORY

The Lemarchant deposit is part of the South Tally Pond property owned by Canadian Zinc Corporation, and is located approximately 35 km south-southwest of Millertown, in central Newfoundland. The deposit has an NI 43-101 defined geological resource of 2.58 Mt at 0.49% Cu, 4.51% Zn, 1.01% Pb, 54.62 g/t Ag, and 1.00 g/t Au and lies southwest of the currently producing Duck Pond and Boundary Cu-Zn volcanogenic massive-sulphide deposits (D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012). The Lemarchant deposit was first discovered in 1983 by Noranda Inc. and discontinuously drilled until 1993 (Squires and Moore, 2004). In 2001 and 2004, Altius Minerals Corp. re-examined the existing data on the property, and tested the geochemical results and airborne surveys to better define the Lemarchant prospect (D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012). Paragon Minerals Corp. drilled the majority of the deposit from 2007 to 2011, through which the National Instrument 43-101 resource was obtained. In 2012, Canadian Zinc Corporation acquired a 100% interest in Paragon Minerals Corp. and drilled through the 2013 season, physically expanding the Lemarchant deposit beyond the 2012 resource definition to include the 'Lower Felsic Block' mineralization originally proposed by Fraser and co-workers (D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012).

REGIONAL GEOLOGY

Volcanogenic massive-sulphide deposits make a significant contribution to the mineral resources that occur in the Central Mobile belt of Newfoundland (Swinden and Dunsworth, 1995; Evans and Kean, 2002). This early Paleozoic Appalachian accretionary zone is called the Dunnage Zone, and is divided by the 'Red Indian line' into the Notre Dame subzone to the west and Exploits subzone to the east (Fig. 1, inset; Evans and Kean, 2002; Rogers et al., 2006; van Staal et al., 2007). The 'Red Indian line' defines a Silurian suture between island- and rifted-arc volcanic complexes of western, peri-Laurentian and eastern, peri-Gondwanan affinity (Rogers et al., 2006; Zagorevski et al., 2007). The Lemarchant deposit is found in the peri-Gondwanan Exploits subzone, hosted by the Cambrian-Ordovician nascent arc volcanic rocks of the Tally Pond group in the Victoria Lake Supergroup (Swinden and Dunsworth, 1995; McNicoll et al., 2010).

The Late Cambrian Tally Pond group is host to the Lemarchant deposit and is the stratigraphically lowest volcanic sequence in the mineral-rich Victoria Lake Supergroup (Fig. 1; Swinden and Dunsworth, 1995; Evans and Kean, 2002). The Victoria Lake Supergroup is composed of nascent- to mature-arc volcanic sequences arranged east to west from Cambrian to Ordovician (Rogers et al., 2006; Zagorevski et al., 2007; Piercey and Hinchey, 2012). The Tally Pond group consists of the lower, mafic-rock–dominated Lake Ambrose formation and the upper, felsic-rock–dominated Bindons Pond formation, which range from 514 Ma to 509 Ma (Dunning et al., 1991; Rogers et al., 2006; McNicoll et al., 2010). Polymetallic volcanogenic massive-sulphide–type mineralization, such as at the Lemarchant deposit and adjacent Duck Pond and Boundary deposits, is abundant in the Bindons Pond formation, whereas the Lake Ambrose formation is relatively barren (Squires et al., 2001; Piercey and Hinchey, 2012). The deposits and occurrences in the Bindons Pond formation are hosted in aphyric to quartz-phyric rhyolite and dacite flows, and breccia and tuff units, and other volcaniclastic sedimentary rocks, with minor pillowed to massive mafic flows (Moore, 2003; McNicoll et al., 2010). Geochemically distinct and younger mafic sills and dykes that crosscut the Tally Pond belt stratigraphy are interpreted to be relate to the Ordovician Harpoon Hill gabbro (~465 Ma; Pollock (2004); Squires and Moore (2004); Piercey and Hinchey (2012)); crosscutting felsic intrusions are also common to the area (McNicoll et al., 2010). Low-grade Silurian-Devonian greenschist metamorphism overprints the host rocks, mineralization, and late-stage intrusions of the Lemarchant deposit (Dunning et al., 1991; Evans and Kean, 2002; D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012).

HOST ROCKS AND ALTERATION

The Lemarchant deposit is hosted in an upright anticlinal structure that is composed of a bimodal volcanic sequence (Fig. 2a; D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012). The mineralized horizon occurs at a depositional contact between footwall felsic volcanic flows and volcaniclastic rocks, and a hanging-wall sequence consisting of a lower pyritic to graphitic mudstone layer immediately overlying sulphide mineralization and an upper layer of mafic volcanic flows (Fig. 2b).

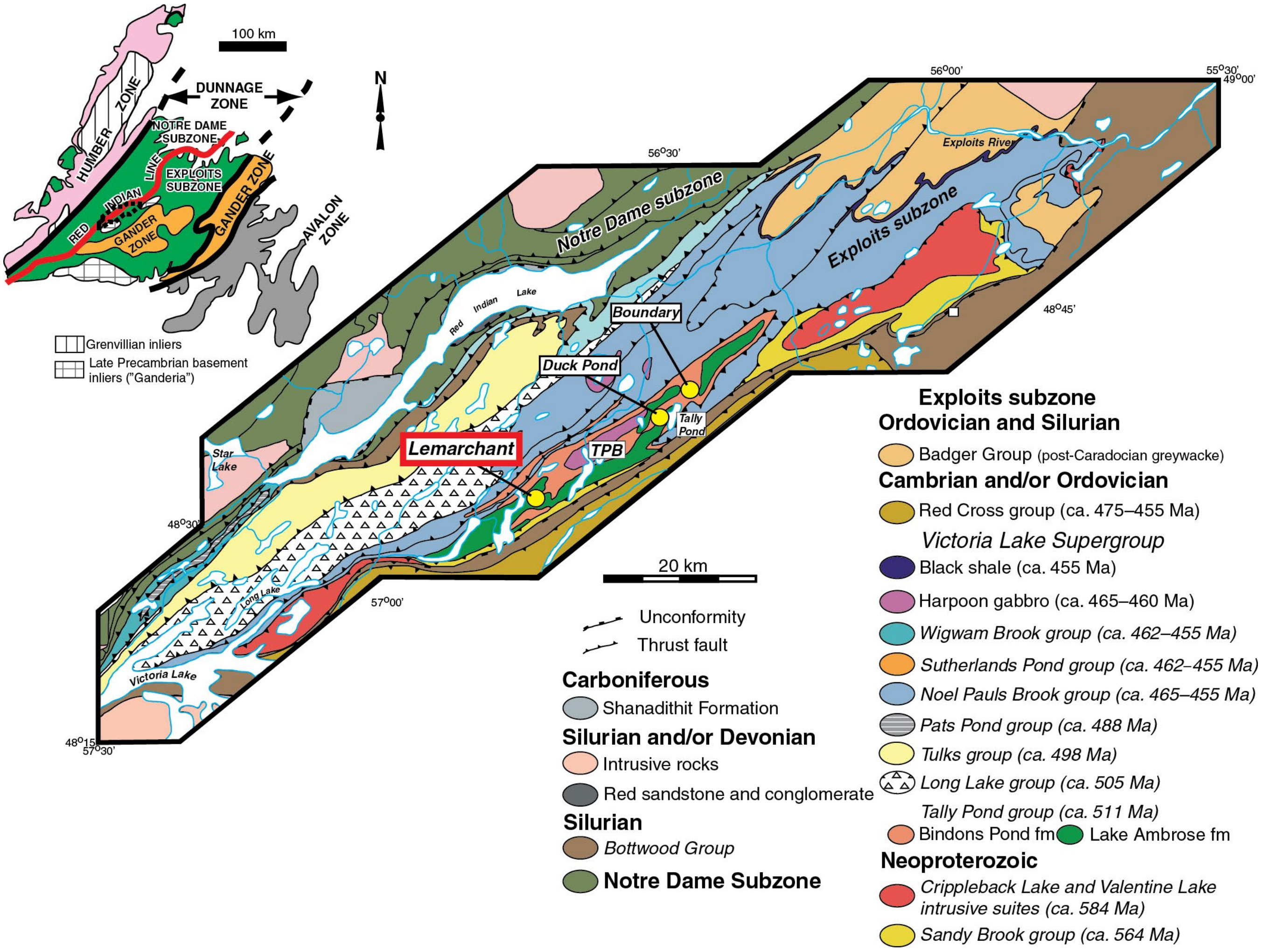

Figure 1. Geological map of volcanic sequences comprising the Exploits subzone, which defines the eastern half of the Dunnage Zone in central Newfoundland. The lowermost assemblage in the Victoria Lake Supergroup of the Exploits subzone is the Tally Pond volcanic belt (TPB). The Tally Pond belt is host to the Lemarchant volcanogenic massive-sulphide deposit (in red), as well as the Duck Pond and Boundary volcanogenic massive-sulphide deposits to the northeast. *Modified from* Piercey and Hinchey (2012). Inset *after* Williams (1979).

The footwall felsic unit is composed of rhyolite breccia, flows, and lapilli tuffs. The rhyolite is fine grained and aphyric, with local quartz and feldspar phenocrysts, and minor, less than 1 mm, black, platy biotite crystals. Massive white-grey rhyolite flows sometimes contain evidence of columnar jointing, which may have concentric banding (Fig. 3a); flow-banded rhyolite in the felsic footwall is rare. Rhyolite breccia units are generally monolithic, pink- to green-white or grey, and range from angular, clast-supported, in situ breccia units to rounded and subangular, tuff and lapilli tuff. Breccia block size is generally 1–10 cm; some blocks more than 10 m can be flow-banded or spherulitic. Rhyolite lapilli are heterolithic and consist of subrounded, 1–0 mm, grey to white, quartz-phyric to aphyric particles. Rhyolite tuff consists of subrounded, less than 2 mm, white to grey-green particles. Angular, more than 0.5 cm, dark green glass fragments are variably present with lapilli tuff at rhyolite flow contacts (Fig. 3b).

Mineralization consists of medium-grained, granular to locally bladed, white barite with massive to semimassive sulphide minerals (Fig. 3c, d). The barite and sulphide minerals are interstitial to rhyolite breccia and lapilli tuff in the footwall, and crosscut the sulphide-rich mudstone.

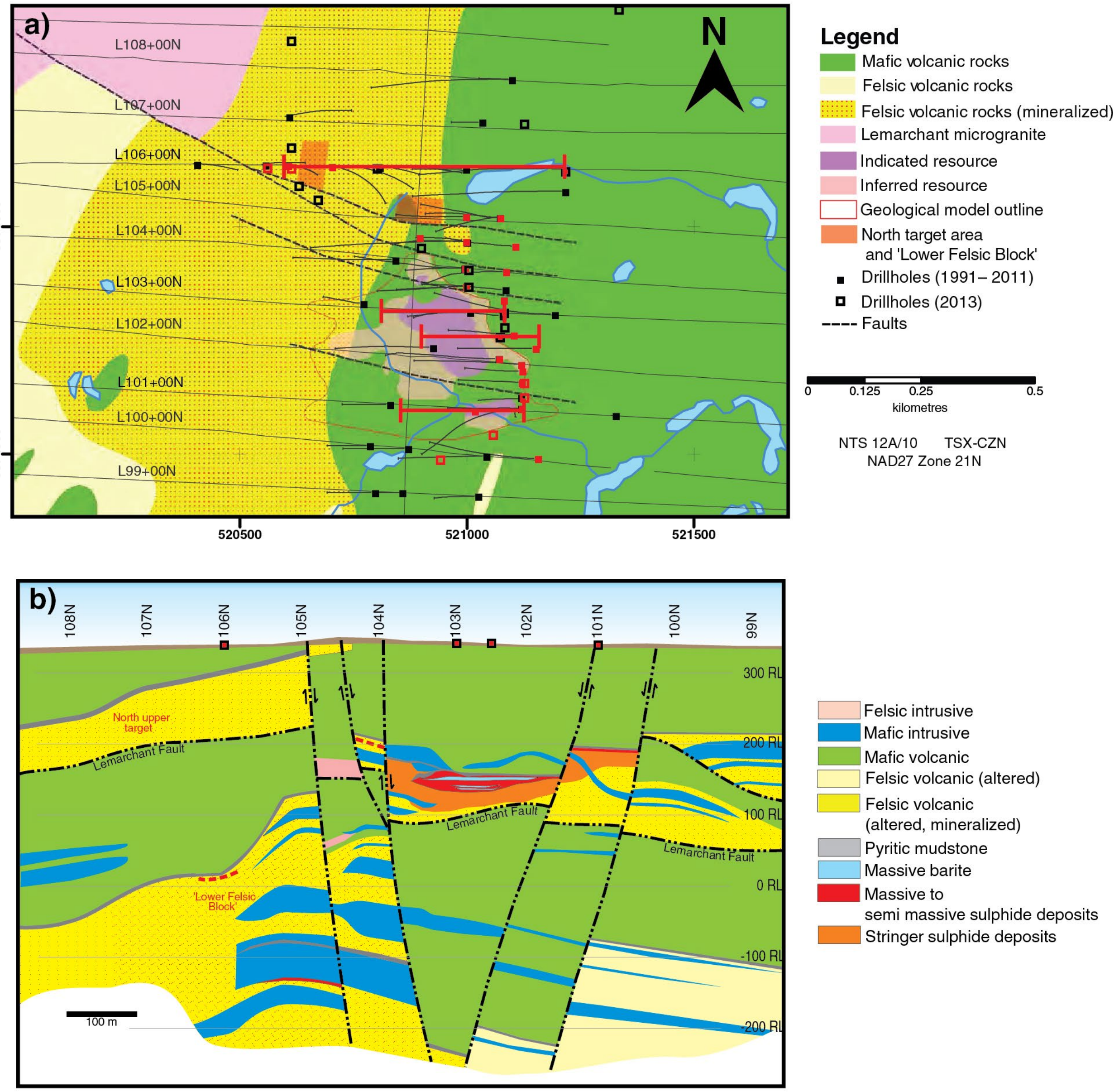

Figure 2. Map and idealized cross-section of the Lemarchant geology. **a)** Plan view of Lemarchant geology. Red drillholes have been logged for this project. Red cross-sections pictured in Figure 4. **b)** Idealized north-south cross-section of the Lemarchant deposit looking east. Red markers indicate cross-section locations of Figure 3. *Modified from* D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012.

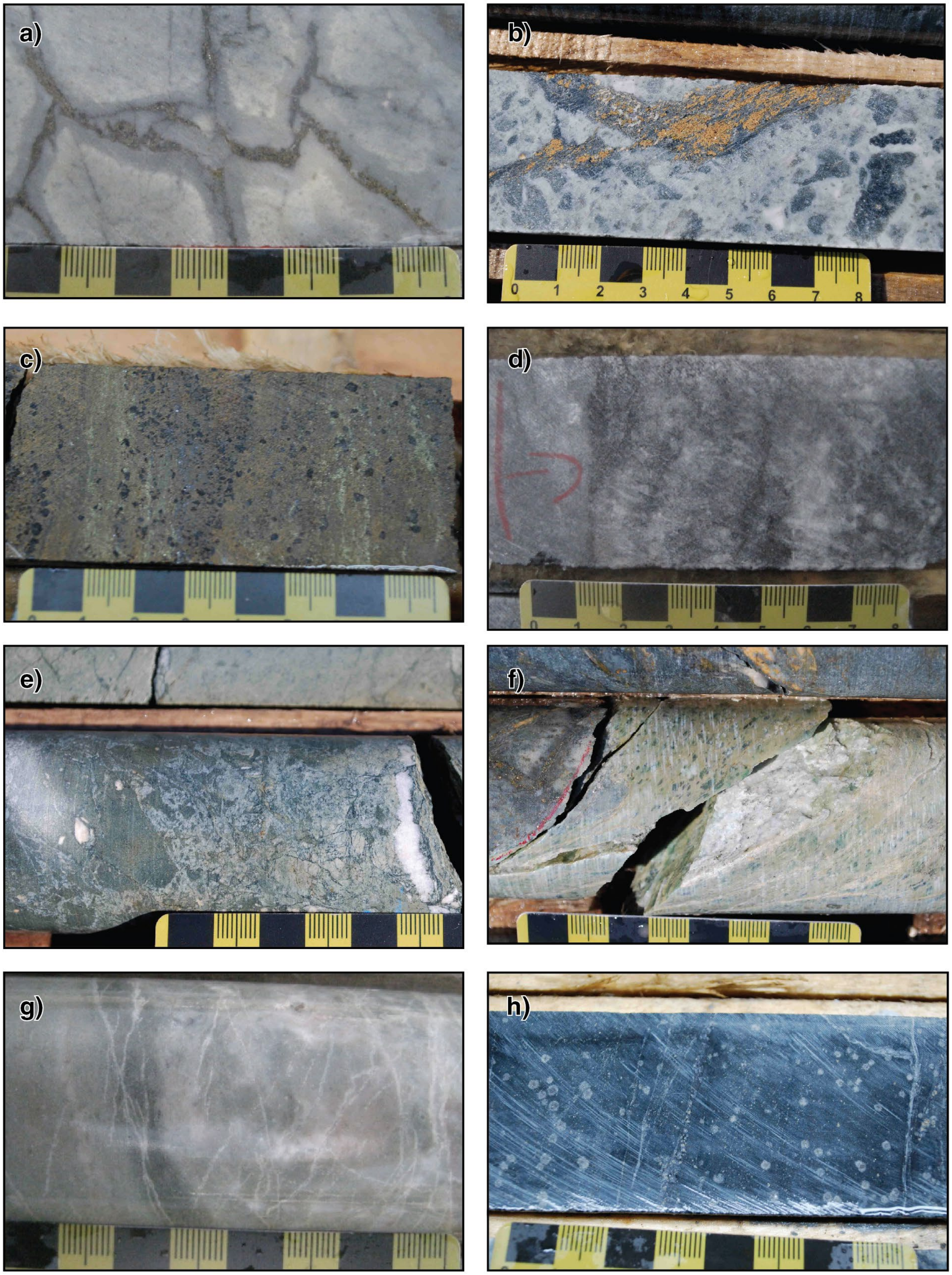

Figure 3. Drill-core photograph field mosaic of type lithologies hosting the Lemarchant deposit. Black squares = 1 cm. **a)** Columnar jointing in massive rhyolite flows with concentric alteration and interstitial sulphide mineralization (drillhole LM08-29 at 316.3 m depth); 2014-161. **b)** Glass-rich felsic tuff with crosscutting stringer sulphide mineralization (LM93-11 at 413.8 m); 2014-155. **c)** Albite rhomb alteration replacing massive sulphide minerals (LM11-68 at 205 m); 2014-156. **d)** Massive to bladed mineralized barite (LM13-73 at 330.35 m); 2014-158. **e)** Hyaloclastite flow-top breccia in hanging-wall basalt. Outermost breccia is partially carbonate altered (LM07-17 at 276.8 m); 2014-157. **f)** Bleached mafic dyke with green mica ((?)fuchsite) crosscutting felsic footwall (LM08-39 at 295.4 m); 2014-153. **g)** Amorphous felsic dyke crosscutting rhyolite breccia (LM08-32 at 208.9 m); 2014-150. **h)** Massive chlorite with spherulitic ((?)carbonate) alteration (LM11-69 at 203.8 m); 2014-159. All photographs by S. Gill.

The mudstone layer overlying the massive sulphide minerals is thin, and is locally intercalated with the hanging-wall mafic volcanic rocks. It is considered to represent a dominantly exhalative sedimentary layer (Lode et al., 2012). Very fine-grained pyrite is disseminated throughout the mudstone, but pyrite also occurs as fine-grained bands and minor coarse-grained euhedra. The pyritic mudstone is variably graphitic and locally contains chalcopyrite stringers, blebby pyrrhotite, or euhedral arsenopyrite (<1 cm).

The hanging-wall mafic rock is composed of massive to pillowed basalt and basaltic andesite. The basalt and basaltic andesite flows are fine grained, green to grey, and variably amygdalar. Amygdales and lesser euhedral pyrite crystals more than 1 mm are commonly present at pillow contacts that sometimes contain hyaloclastic flow-top breccia (Fig. 3e). Pillow selvages and amygdales are filled with chlorite and/or carbonate. Minor pyrrhotite blebs and trace euhedral arsenopyrite occur in the mafic flows proximal to intercalated pyritic mudstone.

Mafic and felsic dykes crosscut the mineralization at Lemarchant. Mafic intrusions are of two main types that include: 1) fine- to medium-grained synvolcanic dykes that are beige-brown and aphanitic, with minor pyroxene phenocrysts, peperitic margins, and carbonate- and/or chlorite-filled amygdales; and 2) medium-grained gabbro to diabase intrusions that crosscut the synvolcanic dykes and have sharp contacts in surrounding units. The latter mafic intrusions are potentially correlative to the Harpoon Hill gabbro (Pollock, 2004; McNicoll et al., 2010). In some cases, the synvolcanic dykes have been deformed and exhibit carbonate bleaching and chlorite and/or fuchsite clots (Fig. 3f). Felsic intrusions are thin (10–15 cm), white to pink, and mostly aphyric (Fig. 3g).

Alteration in the felsic footwall generally consists of quartz-sericite±chlorite; however, chlorite is locally dominant as a less than 5 m dark green, massive layer present below barite-rich mineralization in the footwall (Fig. 3h). Barite and massive-sulphide minerals have abundant quartz-chlorite-albite±sericite alteration (Fig. 3c). The mafic hanging wall contains some silica-chlorite-epidote, but is not significantly altered. Crosscutting silica-carbonate veins, spotty ankerite, and carbonate bleaching of host rock and synvolcanic dykes occur near faulted, locally deformed zones. The footwall lapilli tuff and pyritic mudstone layer are the most strained units, and may appear banded.

MINERALIZATION

The Zn-Pb-Cu-Ag-Au Lemarchant deposit is composed of a main massive-sulphide lens and a smaller mineralized body that lies to the northwest of the main deposit (Fig. 2a). The main Lemarchant deposit consists of a lenticular, stratiform massive to semimassive zone and underlying stringer sulphide zone. The stratiform sulphide zone occurs at depth about 200 m, strikes north-northwest along its longest axis (~350 m), and is generally less than 20 m wide (Fig. 4a). The smaller sulphide mineral body, termed the 'Lower Felsic Block' by Fraser and co-workers (D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012), is found about 200 m north-northwest of the main sulphide zones, and sits over 300 m below the surface (Fig. 4b). The Lemarchant deposit is crosscut by the north-striking Lemarchant fault, a west-dipping thrust fault that causes repetition in the host-rock stratigraphy and may have displaced part of the main sulphide lens, as evidenced by the 'Lower Felsic Block' (Fig. 2b; Copeland et al., 2008; D. Fraser, G.H. Giroux, D.A. Copeland, and C.A. Devine, unpub. technical report, 2012). Upright, east-west-oriented normal faults crosscut the Lemarchant deposit in four or five locations, resulting in minor offsets within the main sulphide lens and possibly the 'Lower Felsic Block'. Although the Lemarchant deposit has undergone brittle fault deformation and greenschist-facies metamorphism, the primary textures observed in some sulphide phases (e.g. colloform pyrite) suggest exceptional preservation of primary and hydrothermal textures. Local remobilization of the more ductile sulphide minerals (e.g. bornite, chalcopyrite, and galena) is minor.

SULPHIDE MINERAL ASSEMBLAGES

The mineralization at Lemarchant is divided into a Zn-Pb-rich stratiform sulphide zone and an underlying Cu-rich stringer sulphide zone that are characterized by five distinct sulphide mineral assemblages. The stratiform zone is variably composed of massive-sulphide and massive-barite assemblages. The massive-sulphide minerals are dominated by sphalerite, with lesser pyrite and minor galena, and generally overlie the barite-rich assemblage containing semimassive sphalerite, pyrite, marcasite, galena, copper-sulphide minerals, and sulphosalt minerals. The basal stringer sulphide zone is composed of chalcopyrite- and pyrite-dominated stringers.

The stratiform zone contains four sulphide-mineral assemblage types (Fig. 4). The type 1 assemblage is composed of granular barite, semimassive white sphalerite, fine- to medium-grained pyrite, galena, and trace chalcopyrite and tetrahedrite-group minerals (Fig. 5a). Two types of copper sulphide and sulphosalt assemblages crosscut the type 1 assemblage: the type 2A assemblage is composed of bornite, galena, and chalcopyrite stringers (Fig. 5b); and the type 2B assemblage is composed of locally bladed barite, tetrahedrite-group minerals, galena, and precious metals (i.e. visible gold; Fig, 5c). Type 2A mineralization occurs only in the central portion of the stratiform zone, whereas type 2B mineralization extends from the centre to the distal edges of the stratiform zone (e.g. L10300N and L10100N, respectively; Fig, 4). The type 3 mineral assemblage overlies the type 1 assemblage and is composed of massive red sphalerite, fine- to medium-grained pyrite, lesser galena and

a)

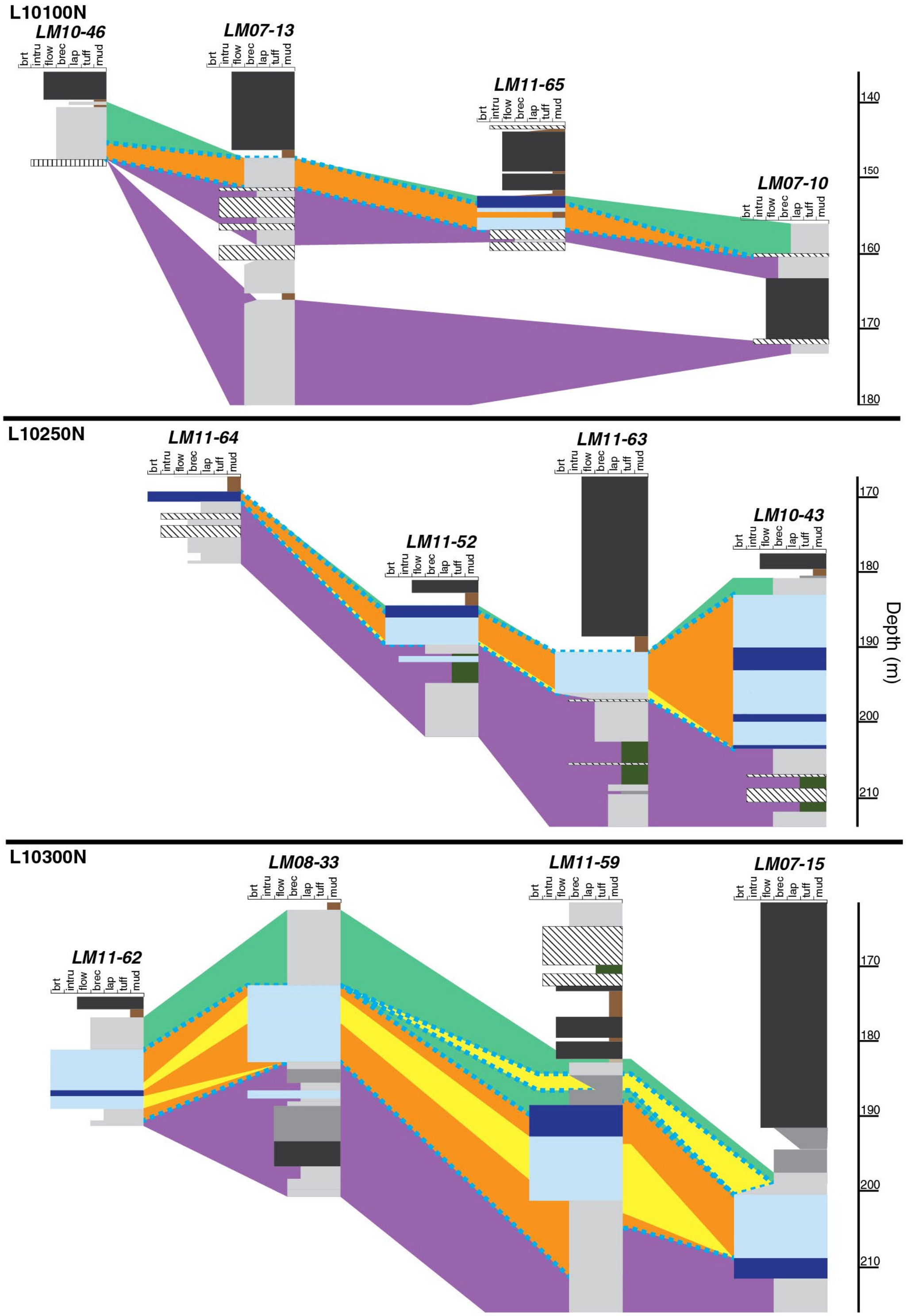

Figure 4. Stratigraphic fence diagrams of representative sections across the Lemarchant deposit. Types of mineralization have been interpolated between drillholes. Locations are shown on Figure 2. **a)** Sections L10100N, L10250N, and L10300N crosscut the main portion of the Lemarchant deposit.

chalcopyrite, and relatively little barite (<15%; Fig. 5d). The basal stringer sulphide zone contains the type 4 assemblage that consists of chalcopyrite, pyrite, and lesser orange sphalerite stringers (Fig. 5e).

The type 2A and type 2B mineral assemblages contain minor to trace marcasite, sulphosalt minerals, copper-sulphide minerals, and precious-metal–bearing sulphide minerals. Silver-rich sulphide minerals (e.g. stromeyerite and Ag-bearing bornite; Table 1) and nickel-sulphide minerals occur with the type 2A mineral assemblage. Type 2B mineralization contains the tetrahedrite-group minerals, which encompass the range of minerals in the tetrahedrite-freibergite-tennantite series and are variably silver-rich, and represent up to 5% of the stratiform zone. The type 2B assemblage also contains marcasite, colusite-group minerals, and trace bournonite, polybasite, miargyrite, and silver-telluride minerals.

MINERAL DESCRIPTIONS

Sphalerite

Sphalerite is the most abundant sulphide in the Lemarchant deposit and represents more than half of the sulphide minerals. Sphalerite in drill core is massive and blocky or forms local blocky clusters, and ranges from low-iron honey to white sphalerite to high-iron red to honey-brown sphalerite (Fig. 6a, b). Honey to white sphalerite occurs in the type 1 assemblage and contains irregular, fine-grained chalcopyrite; the type 1 sphalerite is crosscut and overgrown by sulphide minerals from the type 2A, 2B, and 3 assemblages and late gangue (e.g. galena, tetrahedrite, bornite, chalcopyrite, chlorite, albite, quartz). The type 3 assemblage is composed of red to honey-brown sphalerite that is devoid of fine-grained chalcopyrite and is clear in transmitted light (Fig. 6b). Type 3

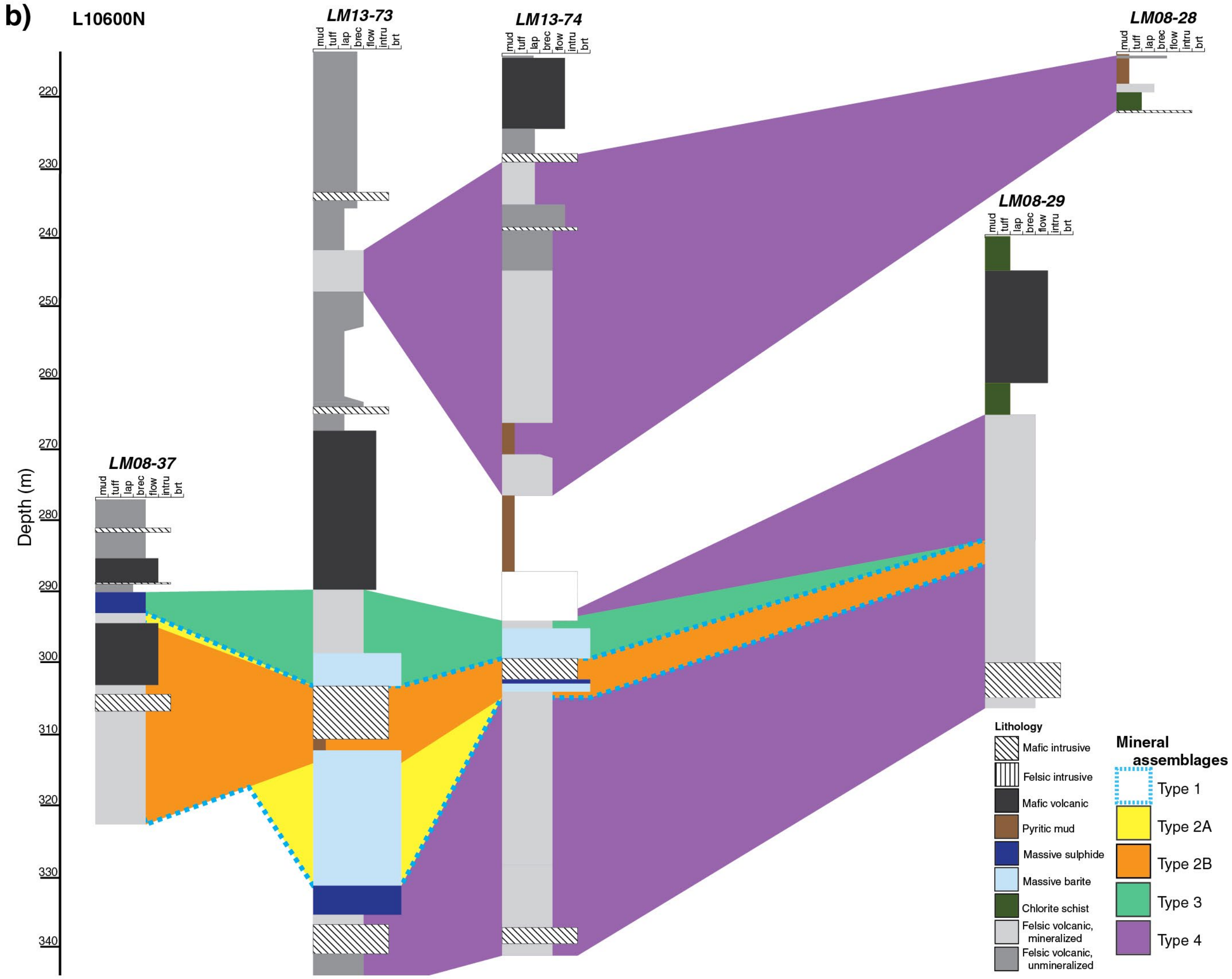

Figure 4. Continued. Stratigraphic fence diagrams of representative sections across the Lemarchant deposit. Types of mineralization have been interpolated between drillholes. Locations are shown on Figure 2. **b)** Section L10600N crosscuts the 'Lower Felsic Block' of mineralization. lap = lapilli tuff, brec = breccia, intru = intrusion, brt = barite

red to honey-brown sphalerite overgrows type 1 sphalerite and galena. Type 1 sphalerite also exists as inclusions in colloform pyrite and recrystallized pyrite atolls (Fig. 6c).

Pyrite and marcasite

Disseminated fine- to medium-grained pyrite is common in all mineralized drill core from the Lemarchant deposit; massive coarse-grained pyrite is less abundant. In thin section, pyrite forms fine-grained colloform clusters in sphalerite (Fig. 6c), irregular to eudedral, medium- to coarse-grained recrystallized atolls (Fig. 6d, e), and euhedral fine-grained disseminations; these textures represent successive stages of pyrite recrystallization and deposition. Pyrite atolls commonly contain galena, sphalerite, and lesser chalcopyrite, tetrahedrite-group minerals, bornite, and colusite-group minerals; recrystallized pyrite may be locally zoned in arsenic (Fig. 6f). The type 1 and type 3 assemblages contain colloform pyrite to variably recrystallized pyrite atolls; however, pyrite euhedra are more common in the type 3 assemblage. Marcasite in the type 4 and type 2B

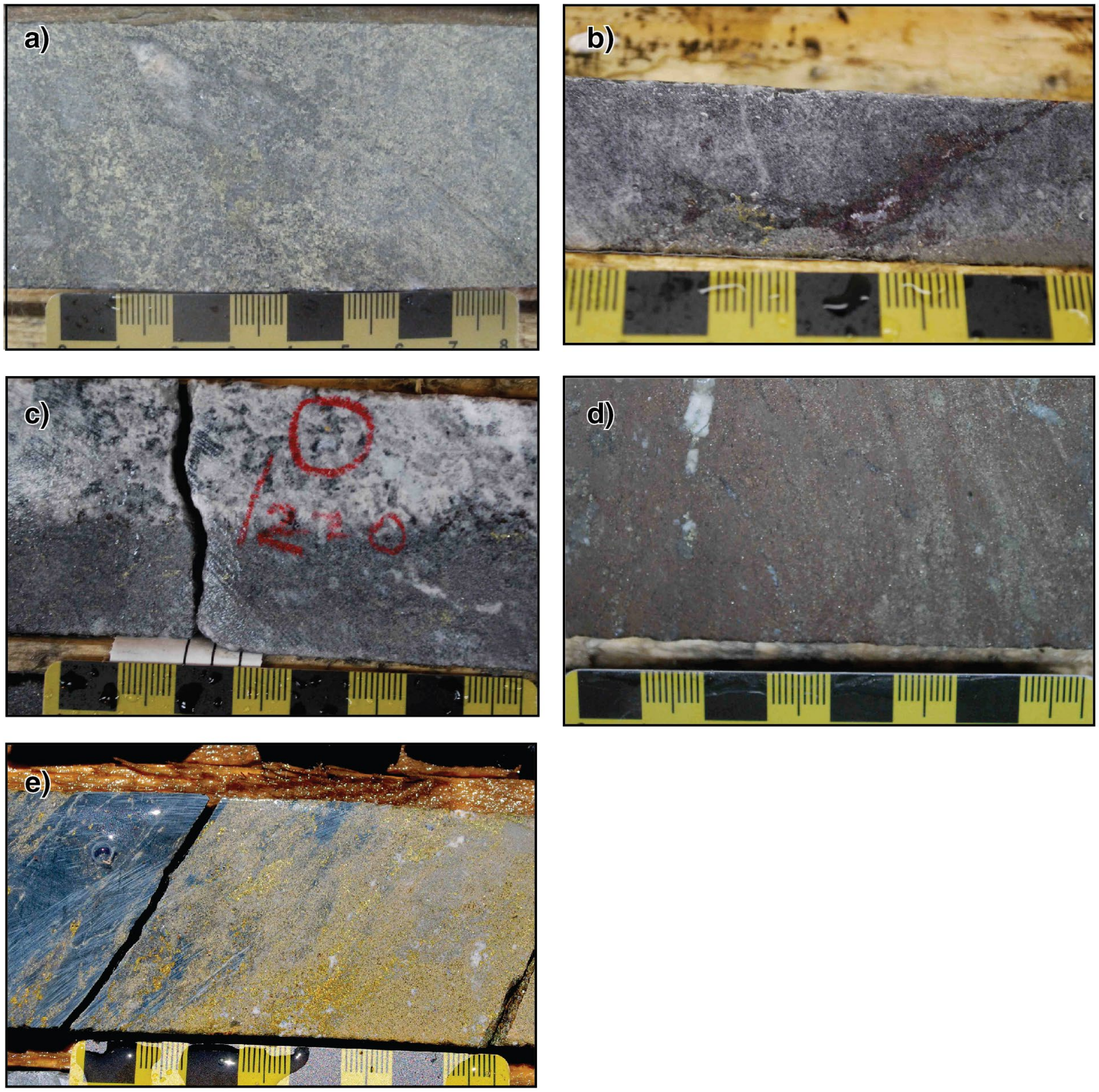

Figure 5. Drill-core photograph field mosaic of type mineral assemblages that comprise the Lemarchant deposit. Black squares = 1 cm. **a)** Type 1 semimassive white sphalerite, granular barite, and fine-grained pyrite and galena with minor carbonate-silica alteration (LM11-64 at 218.8 m); 2014-152. **b)** Type 2A bornite-galena-chalcopyrite stringers crosscutting type 1 white sphalerite–barite-pyrite-galena mineralization (LM11-62 at 259.6 m); 2014-151. **c)** Type 2B bladed barite–coarse-grained tetrahedrite–galena stringers with visible gold crosscutting type 1 white sphalerite–barite-pyrite-galena mineralization (LM10-43 at 220 m); 2013-232. **d)** Type 3 massive red sphalerite with fine- to medium-grained pyrite in minor barite-silica gangue (LM11-69 at 184 m); 2014-160. **e)** Type 4 orange sphalerite–chalcopyrite-pyrite stringers crosscutting chlorite schist in the felsic footwall (LM 11-63 at 224.7 m); 2014-154. All photographs by S. Gill.

Table 1. Sulphide mineral phases present at the Lemarchant deposit, including mineral formulas. The relative abundance of each phase in each mineral assemblage type is indicated as follows: () = absent, (±) = rare, (+) = common, (++) = abundant, (+++) = dominant.

Sulphide phase	Mineral formula	Type 1	Type 2A	Type 2B	Type 3	Type 4
Sphalerite (white to honey)	(Zn,Fe)S	+++		+		
Sphalerite (honey brown to red)	(Zn,Fe)S				+++	+
Pyrite (colloform)	FeS_2	++			+	
Pyrite (recrystallized to atoll)	FeS_2	++		+	++	++
Pyrite (euhedral)	FeS_2			±	+	++
Marcasite	FeS_2			±		±
Galena	PbS	+	++	++	+	±
Chalcopyrite	$CuFeS_2$	±	++	+	+	+++
Tetrahedrite-group minerals	$(Cu,Ag]_{10}(Fe,Zn)_2(As,Sb)_4S_{13}$	±		++		
Bornite	Cu_5FeS_4		++			
Stromeyerite	AgCuS		+			
Covellite	CuS		±			
Colusite-group minerals	$Cu_{26}V_2(As,Ge,Sb,Sn)_6S_{32}$		±	+		
Electrum	(Au,Ag)			+		
Polybasite	$[(Ag,Cu)_6(Sb,As)_2S_7][Ag_9CuS_4]$			±		
Miargyrite	$AgSbS_2$			±		
Bournonite	$PbCuSbS_3$			±		
Ag-Cu sulphide minerals	------		±	±		
Silver-telluride minerals	------			±		
Nickel-sulphide minerals	------		±			

assemblages was distinguished from pyrite by thin-section textures (e.g. reniform to dendritic growths and fine-grained lamellae, respectively; Fig. 6d, 6g).

Galena

Galena is abundant in the Lemarchant deposit, but less so than sphalerite and pyrite. In drill core, galena forms disseminated, fine- to coarse-grained, metallic silver grains in semimassive and massive sphalerite. In thin section, individual grains are irregular to angular, and sparsely pitted. Inclusions of galena in type 3 sphalerite and pyrite atolls are sometimes rounded. Galena is primarily associated with type 2A bornite, and type 2B tetrahedrite, electrum, colusite, and trace Pb-As-Sb sulphosalt minerals (Fig. 6d, e, f, g, h, 7a, b, c, d).

Chalcopyrite

Chalcopyrite is found in every mineral assemblage in the Lemarchant deposit, but is most abundant in the type 4 mineral assemblage. In drill core, chalcopyrite occurs as bronze blebby stringers crosscutting massive barite and massive sphalerite, and is interstitial to the rhyolite host rock. In thin section, fine-grained chalcopyrite inclusions occur in type 1 white sphalerite, recrystallized pyrite, and in type 2B tetrahedrite group minerals (Fig. 6d). Chalcopyrite also infills cracked pyrite, bornite, galena, and tetrahedrite-group minerals from the type 2A and 2B mineral assemblages (Fig. 7a). Fine-grained, amorphous chalcopyrite is found at sphalerite, galena, and tetrahedrite-group–mineral boundaries (Fig. 7d).

Tetrahedrite-group minerals

The tetrahedrite-freibergite-tennantite series of sulphosalt minerals occur in drill core as dark grey, metallic, medium-grained crystals with type 2B galena and bladed barite in type 1 semimassive sphalerite and massive barite. In reflected light, these sulphosalt minerals are amorphous and grey-green (tetrahedrite) to steel grey (tennantite). The tetrahedrite-group minerals primarily occur with type 2B galena and type 1 white sphalerite and are closely associated with type 2B colusite, electrum, and marcasite (Fig. 7c). Tetrahedrite-group minerals are intergrown with type 2A bornite and stromeyerite, and overgrown by chalcopyrite. Some tetrahedrite-group minerals are zoned in arsenic, antimony, and silver; tennantite mineral boundaries are enriched in Sb and Ag relative to the As-rich core (Fig. 7d, e, f).

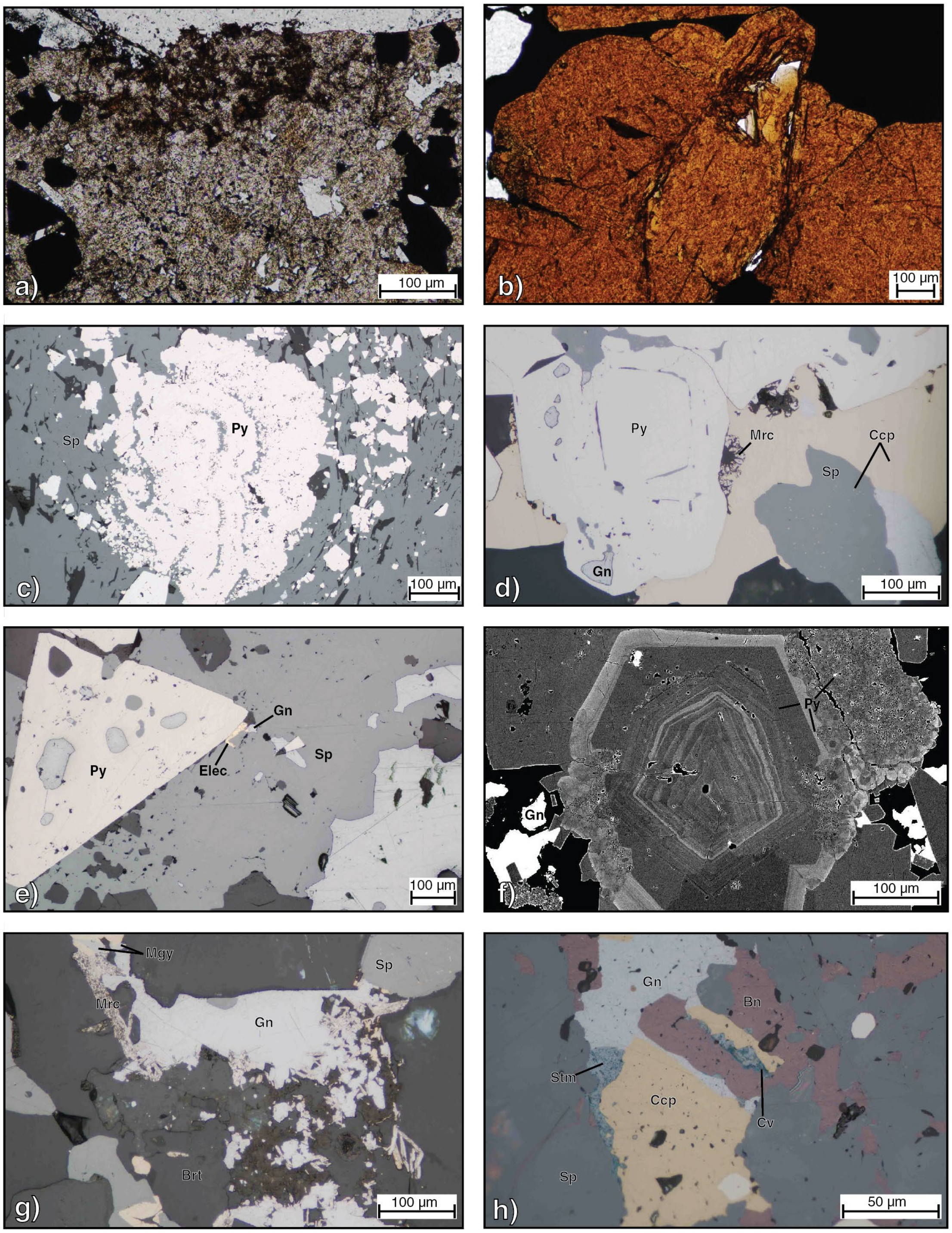

Figure 6. Thin-section photomicrographs and back-scatter electron images of sulphide and sulphosalt minerals in type mineral assemblages at Lemarchant. **a)** Transmitted-light image of type 1 white sphalerite (sample CNF29959 in drillhole LM11-59 at 207.7 m); 2014-126. **b)** Transmitted-light image of type 3 massive red sphalerite (CNF29959 from LM11-59 at 207.72 m); 2014-127. **c)** Reflected-light image of type 3 colloform and euhedral pyrite in sphalerite (CNF29960 in LM11-59 at 216 m); 2014-128. **d)** Type 4 recrystallized atoll pyrite with entrained galena, in chalcopyrite with dendritic marcasite and diseased sphalerite (CNF14257 in LM11-62 at 266.8 m); 2014-129. **e)** Type 2B galena-electrum at euhedral pyrite atoll boundary in massive sphalerite (CNF14291 in LM11-65 at 159.3 m); 2014-130. **f)** Back-scatter electron image of type 1 recrystallized fine-grained pyrite with zoned growth rings of higher As-content (light grey; CNF25134 in LM11-56 at 158.7 m); 2014-131. **g)** Type 2B assemblage of galena-sphalerite-barite-marcasite-tetrahedrite-miargyrite and type 4 chalcopyrite (CNF25109 in LM13-74 at 328.6 m); 2014-132. **h)** Type 2A bornite-galena-stromeyerite in sphalerite with type 4 chalcopyrite replacement; stromeyerite and chalcopyrite host late blue covellite (CNF29967 in LM07-17 at 247.6 m); 2014-133. All photographs by S. Gill. Brt = barite, Sp = sphalerite, Py = pyrite, Mrc = marcasite, Gn = galena, Ccp = chalcopyrite, Stm = stromeryite, Elec = electrum, Mgy = miargyrite

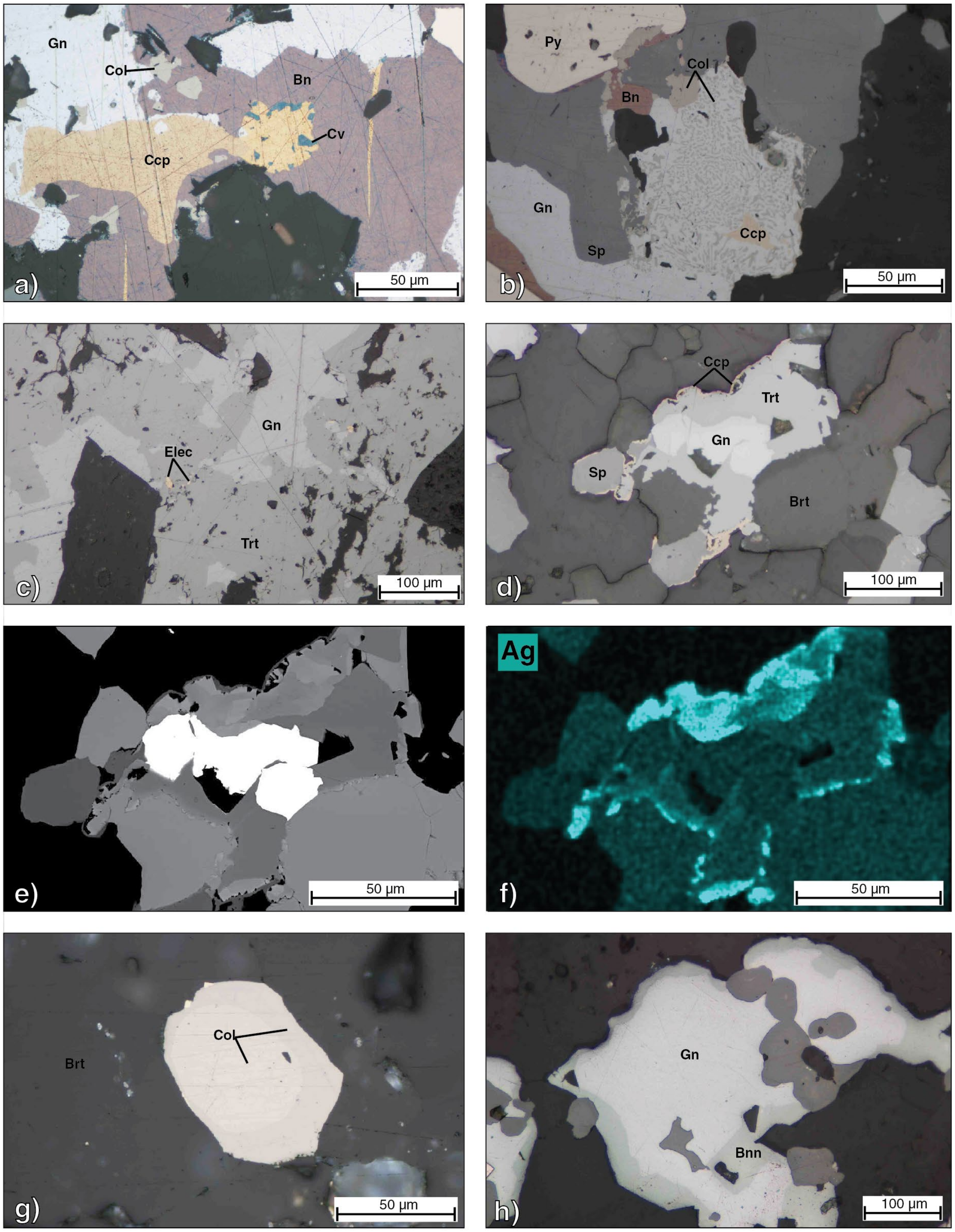

Figure 7. Thin-section photomicrographs and back-scatter electron images of sulphide and sulfosalt minerals in type mineral assemblages at Lemarchant. **a)** Reflected-light image of type 4 chalcopyrite replacing and infilling cracks in type 2 bornite, galena, and colusite; chalcopyrite is host to late blue covellite (CNF14279 in LM08-33 at 230.8 m); 2014-134. **b)** Myrmekitic growth of type 2B galena-colusite-sphalerite and replacement of type 2A bornite at the pyrite atoll–sphalerite interface; type 4 chalcopyrite is replacing galena-colusite intergrowth (CNF14279 in LM08-33 at 230.8 m); 2014-135. **c)** Type 2B galena-electrum in tetrahedrite (CNF25121 in LM11-52 at 212.3 m); 2014-136. **d)** Rounded galena in type 2B tetrahedrite, sphalerite, and barite; tetrahedrite is rimmed by chalcopyrite (CNF14293 in LM11-65 at 161.8 m); 2014-137. **e)** Backscatter-electron image of tetrahedrite zoning in sample CNF14293; 2014-138. **f)** False-colour element map of relative Ag distribution in type 2B tetrahedrite from sample CNF14293; 2014-139. **g)** Reflected-light image of type 2B zoned colusite in barite (CNF14259 in LM07-14 at 204.4 m); 2014-140. **h)** Type 2B bournonite rimming anhedral galena (CNF14291 in LM11-65 at 159.3 m); 2014-141. All photographs by S. Gill. Brt = barite, Sp = sphalerite, Py = pyrite, Gn = galena, Ccp = chalcopyrite, Trt = tetrahedrite, Bn = bornite, Col = colusite, Cv = covellite, Elec = electrum, Bnn = bournonite

Bornite

Purple bornite occurs in drill core with type 2A galena and chalcopyrite as stringers that crosscut type 1 white sphalerite and massive barite, but is also present with type 2B tetrahedrite-group minerals and bladed barite mineralization. In thin section, bornite forms amorphous grains to wiry strands (Fig. 6h, 7a, b). Bornite occurs as a local dominant phase in thin section or as inclusions in pyrite atolls and blebs in massive barite. Scanning electron microscopy suggests bornite is enriched in silver relative to other sulphide minerals. Bright blue covellite replaces bornite at stromeyerite and chalcopyrite mineral boundaries (Fig. 6h).

Colusite-group minerals

Colusite, germanocolusite, and other vanadium-germanium-copper sulphosalt minerals are notable minor components of the type 2B mineral assemblage. These minerals generally occur as amorphous 50 µm grains and are only visible in thin section. In reflected light, colusite-group minerals are pink- to orange-brown (Fig. 7a); zoning of colusite-group minerals can occur in more than 50 µm grains (Fig. 7g). Colusite-group minerals occur in type 1 white sphalerite and barite with type 2B tetrahedrite-group minerals, galena, and lesser type 2A bornite, and as inclusions in rounded pyrite atolls. Myrmekitic intergrowths with type 1 sphalerite and type 2B galena are rare, but notable (Fig. 7b).

Stromeyerite

Stromeyerite is a minor phase that occurs with other copper-rich sulphide phases in the type 2A mineral assemblage. This mineral is not visible in hand sample, but appears in thin section as thin, rimming, dark grey grains that radiate from sulphide-mineral boundaries. Stromeyerite is generally associated with type 2A bornite, chalcopyrite, and lesser galena mineral boundaries, and rarely occurs with less than 10 µm nickel-sulphide minerals. Irregular blue covellite commonly discolours the grey stromeyerite at mineral boundaries (Fig. 6h, 7a).

Electrum

Currently, the only known source of gold in the Lemarchant deposit is in trace electrum. Visible gold in drill core is situated in type 2B tetrahedrite-group minerals and galena stringers or in type 1 massive barite and white sphalerite proximal to type 2B mineralization. In thin section, electrum is found in type 1 white sphalerite or type 2B tetrahedrite-group minerals proximal to recrystallized pyrite and type 2B galena and colusite-group minerals (Fig. 6e, 7c). Electrum occurs as bright silver-yellow, amorphous grains at sphalerite-pyrite-galena and tetrahedrite-galena mineral boundaries. Some variation in Au:Ag content is suggested by scanning electron microscope analyses.

Trace minerals

Trace minerals in the Lemarchant deposit are visible only by thin section and scanning electron microscope analyses. The Cu-Ag-sulphosalt minerals polybasite and miargyrite are associated with type 2B tetrahedrite-group minerals and galena (Fig. 6g). Bournonite is dark grey in thin section and rims type 2B galena (Fig. 7h). Silver-telluride minerals occur as greenish-grey radiating clusters or tabular crystals and are associated with silver-rich type 2B tetrahedrite in sphalerite and proximal to pyrite. Amorphous nickel sulphide minerals are found with type 2A bornite, galena, stromeyerite, and galena.

PARAGENESIS

Sulphide mineral paragenesis at Lemarchant can be broadly divided into three stages of deposition based on crosscutting relationships (Fig. 8). During stage 1 of the paragenetic sequence, type 1 barite–semimassive white sphalerite–colloform pyrite–minor galena sulphide minerals were deposited below the early exhalative pyritic mudstone. Stage 2 paragenesis resulted in variable replacement of the central type 1 mineral assemblage by type 2A bornite-galena-stromeyerite–nickel-sulphide stringers and the type 2B barite–As-rich tennantite–galena-colusite-electrum-marcasite–silver-telluride assemblage. At the end of stage 2 paragenesis, type 2B Sb-Ag-rich tetrahedrite–galena-electrum–Sb-Cu-Ag sulphosalt stringers replaced type 1 barite and white sphalerite at the distal edges of the deposit. Covellite was formed as a result of diagenesis after stage 2 deposition. In the final stage of sulphide-mineral deposition, or stage 3 paragenesis, type 3 and type 4 mineral assemblages were deposited with minor zone refinement of the stratiform and stringer zones of the Lemarchant deposit, respectively. The type 3 massive red sphalerite–medium-grained atoll pyrite–galena-chalcopyrite assemblage replaced the upper portion of the type 1 mineral assemblage, and type 1 white sphalerite was partially replaced by fine-grained chalcopyrite. Type 4 chacopyrite-pyrite±sphalerite stringers were deposited in the stringer sulphide zone below the type 1, type 2, and type 3 mineral assemblages.

DISCUSSION AND SUMMARY

The Lemarchant deposit is composed of mineralization styles and mineral assemblages characteristic of polymetallic, Kuroko-type, volcanogenic massive-sulphide deposits and high-sulphidation, epithermal gold deposits. The bimodal felsic lithostratigraphic host-rock assemblage, sedimentary-exhalative cap rock, abundance of barite and Zn-Pb-rich massive-sulphide minerals, and zoning of mineral assemblages are features common to Kuroko-type volcanogenic massive-sulphide deposits (Shimazaki, 1974; Eldridge et al., 1983; Ohmoto, 1996); however, the enrichment of precious metals (Ag, Au), sulphosalt- and bornite-rich mineral assemblages and abundance of low-Fe sphalerite are not

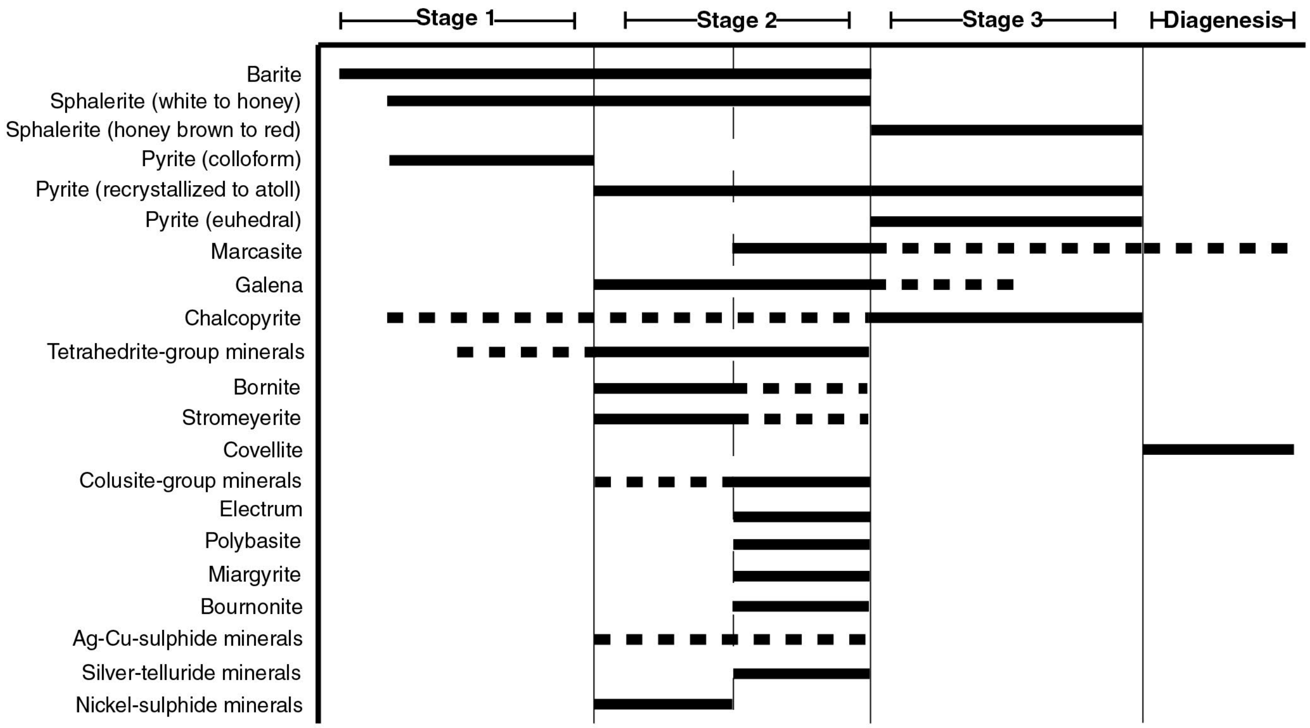

Figure 8. Sulphide-mineral paragenesis at Lemarchant. Relative timing of mineral deposition is indicated (solid lines) or inferred (dashed lines) from documented mineral associations and textures.

common to most Kuroko-type deposits and suggest a possible magmatic contribution to hydrothermal fluids, typical of epithermal gold deposits (Hannington and Scott, 1989; Sillitoe et al., 1996; Dubé et al., 2007).

The spatial arrangement of sulphide-mineral assemblages in the Lemarchant deposit has similarities to the idealized Kuroko-type deposit outlined by Eldridge et al. (1983). In the stratiform zone, type 1 barite-rich semimassive white sphalerite and type 3 massive red sphalerite assemblages correspond to the barite ore, semimassive black ore, and massive black ore in the idealized Kuroko-type massive-sulphide deposit; the type 4 chacopyrite-pyrite±sphalerite assemblage in the underlying stringer zone corresponds to the siliceous black ore and siliceous yellow ore of the idealized Kuroko-type stockwork zone (Eldridge et al., 1983). The idealized Kuroko-type deposit represents a mineralogically zoned sequence that grades from barite-dominant at the top, to sphalerite>galena, then to chalcopyrite- and pyrite-dominant at the base (Shimazaki, 1974; Eldridge et al., 1983; Ohmoto, 1996). The Lemarchant deposit also shows mineralogical evidence of zonation in the microscopic chalcopyrite in type 1 sphalerite (i.e. chalcopyrite disease; Eldridge et al. (1983)), in type 3 red sphalerite overprinting type 1 sulphide minerals, and in type 4 chalcopyrite-dominant stringers below the barite-rich mineralization; however, the Lemarchant deposit differs from the idealized Kuroko-type deposit zonation as the massive sphalerite (type 3) assemblage is overlying the barite-rich (type 1, type 2A, and type 2B) assemblage in the stratiform massive-sulphide zone. The absence of a pyrite-dominant assemblage below the type 4 chalcopyrite-rich assemblage in the stringer zone could be attributed either to a relatively short lifetime of the hydrothermal system (Ohmoto, 1996), or to physical displacement of a possible 'stockwork' stringer zone due to faulting (i.e. the Lemarchant fault).

The abundance of sulphosalt minerals, precious metals, and precious-metal–bearing sulphide minerals in the type 2A and type 2B mineral assemblages at Lemarchant are not typical of normal volcanogenic massive-sulphide systems. Although bornite, tetrahedrite-group minerals and Ag-rich tetrahedrite, stromeyerite, colusite-group minerals, electrum, silver-telluride minerals, nickel-sulphide minerals, and a number of Sb-Cu-Ag- and Sb-Pb-Ag-sulphosalt minerals have been documented in Kuroko-type volcanogenic massive-sulphide deposits (Shimazaki, 1974), they are neither present in abundance nor do they commonly form the complete array observed at the Lemarchant deposit. The diverse mineralogy in the type 2A and type 2B assemblages is considered to be primary in the Lemarchant deposit, and indicates that precious-metal deposition was synvolcanic (Hannington et al., 1999; Dubé et al., 2007). Furthermore, the type 2A and type 2B assemblages are analogous to a high-sulphidation epithermal mineral and trace-element suite (i.e. Au, Ag, As, Sb, Te, Ni), and suggest a direct magmatic contribution to the hydrothermal fluid (Sillitoe et al., 1996; Hannington et al., 1999; Roth et al., 1999; Dubé et al., 2007). Currently, an advanced argillic alteration assemblage typical of high-sulphidation epithermal systems has not been documented at Lemarchant (Sillitoe et al., 1996;

Mercier-Langevin et al., 2011), but is the focus of ongoing infrared spectroscopic research at the deposit (J. Cloutier, pers. comm., 2014).

The spatial association of type 2B visible gold (electrum) and type 1 low-Fe, white sphalerite is consistent with the stable transport of gold as a bisulphide complex ($Au(HS)_2$) in low-temperature (<250°C) hydrothermal fluids (Hannington and Scott, 1989; Huston and Large, 1989), and is also consistent with the lower temperature Zn-Pb-Ba-rich sulphide minerals of the type 1, type 2A, and type 2B assemblages. The bladed barite and visible gold in the type 2B assemblage also suggest that localized boiling may have occurred during deposition of the type 2A and type 2B assemblages, possibly due to emplacement of the deposit in a shallow-water environment (<1500 m; Sillitoe et al. (1996); Hannington et al. (1999); Huston (2000); Dubé et al. (2007); Hannington (2009)). In contrast, the copper-rich type 4 stringer suphide minerals, type 3 high-Fe sphalerite, and recrystallized pyrite of the stratiform zone suggest that the hydrothermal fluids that formed these assemblages were higher temperature (>250°C) than those that deposited type 1, type 2A, and type 2B sulphide and sulphosalt minerals (Huston and Large, 1989; Ohmoto, 1996; Huston, 2000).

The combination of Kuroko-style and high-sulphidation epithermal-style volcanogenic massive-sulphide mineralization at Lemarchant requires further investigation to determine the source(s) of precious metals, and the conditions of fluid transport and deposition that resulted in precious-metal enrichment of the deposit. Variation in mineral chemistry and S- and Pb-isotope characteristics of the Lemarchant sulphide deposits will be investigated with electron microprobe, laser ablation ICP-MS, and secondary ion mass spectrometry. These analyses will provide further insight to the depositional conditions and enrichment mechanisms that caused precious-metal enrichment at the Lemarchant deposit and in analogous precious-metal–enriched volcanogenic massive-sulphide systems in the Appalachians and globally.

ACKNOWLEDGMENTS

Funding for this project is primarily supported by the GSC Targeted Geoscience Initiative 4 Program and the Research Affiliate Program of Natural Resources Canada. This research is also supported by additional grants to S.J. Piercey, including an NSERC Discovery Grant and the NSERC-Altius Industrial Research Chair in Mineral Deposits supported by NSERC, Altius Minerals Corp., and the Research and Development Corporation of Newfoundland and Labrador. Access to the Lemarchant drill core, core logs, and assay database was provided by the Canadian Zinc Corp. and the Paragon Minerals Corp. (a 100% owned subsidiary of Canadian Zinc Corp.). Many thanks to S. Lode, G. Layne, M. Schaeffer, D. Grant, and D. Fost for their technological help and interpretive guidance.

REFERENCES

Brueckner, S.M., Piercey, S.J., Sylvester, P.J., Pilgrim, L., and Maloney, S., in press. Evidence for syngenetic precious metal enrichment in an Appalachian volcanogenic massive sulfide (VMS) system: the 1806 Zone, Ming Mine, Newfoundland, Canada; Economic Geology and the Bulletin of the Society of Economic Geologists.

Copeland, D.A., Toole, R.M.S., and Piercey, S.J., 2008. Assessment report on diamond drilling and soil sampling, Licence 8183M (10th Year) and 9569M (5th Year) South Tally Pond property, Rogerson Lake area, Newfoundland and Labrador, NTS 12A/10 and 12A/07; Newfoundland and Labrador Geological Survey, Assessment Report, 956 p.

Dubé, B., Gosselin, P., Mercier-Langevin, P., Hannington, M., and Galley, A., 2007. Gold-rich volcanogenic massive sulphide deposits; *in* Mineral Deposits of Canada: a Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods; Geological Association of Canada, Mineral Deposits Division, Special Publication 5, p. 75–94.

Dunning, G.R., Swinden, H.S., Kean, B.F., Evans, D.T.W., and Jenner, G.A., 1991. A Cambrian island arc in Iapetus; geochronology and geochemistry of the Lake Ambrose volcanic belt, Newfoundland Appalachians; Geological Magazine, v. 128, p. 1–17. doi:10.1017/S0016756800018008

Eldridge, C.S., Barton, P.B., Jr., and Ohmoto, H., 1983. Mineral textures and their bearing on formation of the kuroko orebodies; Economic Geology Monographs, v. 5, p. 241–281.

Evans, D.T.W. and Kean, B.F., 2002. The Victoria Lake Supergroup, central Newfoundland - its definition, setting and volcanogenic massive sulphide mineralization, Newfoundland and Labrador Department of Mines and Energy, Geological Survey; Open File NFLD, v. 2790, p. 68.

Hannington, M., 2009. Modern submarine hydrothermal systems — a global perspective on distribution, size and tectonic settings; *in* Submarine Volcanism and Mineralization: Modern Through Ancient, (ed.) B. Cousens and S. Piercey; Geological Association of Canada, Short Course, 29–30 May 2008, Quebec City, Quebec, p. 91–146.

Hannington, M. and Scott, S.D., 1989. Sulfidation equilibria as guides to gold mineralization in volcanogenic massive sulfides; evidence from sulfide mineralogy and the composition of sphalerite; Economic Geology and the Bulletin of the Society of Economic Geologists, v. 84, p. 1978–1995. doi:10.2113/gsecongeo.84.7.1978

Hannington, M.D., Poulsen, K.H., Thompson, J.F.H., and Sillitoe, R.H., 1999. Volcanogenic gold in the massive sulfide environment; Reviews in Economic Geology, v. 8, p. 325–356.

Hurley, T.D. and Crocket, J.H., 1985. A gold-sphalerite association in a volcanogenic base-metal-sulfide deposit near Tilt Cove, Newfoundland; Canadian Mineralogist, v. 23, p. 423–430.

Huston, D.L., 2000. Gold in volcanic-hosted massive sulfide deposits; distribution, genesis, and exploration; Reviews in Economic Geology, v. 13, p. 401–426.

Huston, D.L. and Large, R.R., 1989. A chemical model for the concentration of gold in volcanogenic massive sulphide deposits; Ore Geology Reviews, v. 4, p. 171–200. doi:10.1016/0169-1368(89)90017-6

Lode, S., Piercey, S.J.P., Copeland, D.A., Devine, C.A., and Sparrow, B., 2012. Setting and styles of hydrothermal mudstones near the Lemarchant volcanogenic massive sulfide (VMS) deposit, Central Mobile Belt, Newfoundland (abstract); *in* Abstracts Volume 35, Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, St. John's, Newfoundland, May 27–29, 2012, 166 p.

Martin, W., 1983. Once upon a mine: story of pre-confederation mines on the island of Newfoundland; Canadian Institute of Mining and Metallurgy, Special Volume 26, 98 p.

McNicoll, V., Squires, G., Kerr, A., and Moore, P., 2010. The Duck Pond and Boundary Cu-Zn deposits, Newfoundland: new insights into the ages of host rocks and the timing of VHMS mineralization; Canadian Journal of Earth Sciences, v. 47, p. 1481–1506. doi:10.1139/E10-075

Mercier-Langevin, P., Hannington, M., Dubé, B., and Bécu, V., 2011. The gold content of volcanogenic massive sulfide deposits; Mineralium Deposita, v. 46, p. 509–539. doi:10.1007/s00126-010-0300-0

Moore, P., 2003. Stratigraphic implications for mineralization: preliminary findings of a metallogenic investigation of the Tally Pond volcanics, central Newfoundland; Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 03-1, p. 241–257.

Ohmoto, H., 1996. Formation of volcanogenic massive sulfide deposits; the Kuroko perspective; Ore Geology Reviews, v. 10, p. 135–177. doi:10.1016/0169-1368(95)00021-6

Piercey, S.J. and Hinchey, J.G., 2012. Volcanogenic massive sulphide (VMS) deposits of the Central Mobile Belt, Newfoundland; Geological Association of Canada–Mineralogical Association of Canada Joint Annual Meeting, Field Trip Guidebook B4, Open File NFLD/3173, Newfoundland and Labrador Department of Natural Resources, Geological Survey, 56 p.

Piercey, S.J., Squires, G.C., and Brace, T.D., 2014. Lithostratigraphic, hydrothermal, and tectonic setting of the Boundary volcanogenic massive sulfide deposit, Newfoundland Appalachians, Canada: formation by subseafloor replacement in a Cambrian rifted arc; Economic Geology and the Bulletin of the Society of Economic Geologists, v. 109, p. 661–687. doi:10.2113/econgeo.109.3.661

Pollock, J., 2004. Geology and paletectonic history of the Tally Pond Group, Dunnage zone, Newfoundland Appalachians: an integrated geochemical, geochronological, metallogenic and isotopic study of a Cambrian island arc along the Peri-Gondwanan margin of Iapetus; M.Sc. thesis, Memorial University, St. John's, Newfoundland, 420 p.

Rogers, N., van Staal, C.R., McNicoll, V., Pollock, J., Zagorevski, A., and Whalen, J., 2006. Neoproterozoic and Cambrian arc magmatism along the eastern margin of the Victoria Lake Supergroup: a remnant of Ganderian basement in central Newfoundland; Precambrian Research, v. 147, p. 320–341. doi:10.1016/j.precamres.2006.01.025

Roth, T., Thompson, J.F.H., and Barrett, T.J., 1999. The precious metal-rich Eskay Creek deposit, northwestern British Columbia; Reviews in Economic Geology, v. 8, p. 357–373.

Santagulda, F. and Hannington, M., 1993. Preliminary results on gold mineralization in volcanogenic massive sulphide deposits, central Newfoundland; *in* Current Research, (ed.) C.P.G. Pereira, D.G. Walsh and R.F. Blackwood; Government of Newfoundland and Labrador, Department of Mines and Energy, Geological Survey Branch, Report 93-01, p. 373–381.

Santagulda, F. and Hannington, M., 1996. Characteristics of gold mineralization in volcanogenic massive sulphide deposits of the Notre Dame Bay area, central Newfoundland; Canadian Journal of Earth Sciences, v. 33, p. 316–334. doi:10.1139/e96-024

Shimazaki, Y., 1974. Ore minerals of the Kuroko-type deposits; Mining Geology, v. 6, Special Issue, p. 311–322.

Sillitoe, R.H., Hannington, M.D., and Thompson, J.F.H., 1996. High sulfidation deposits in the volcanogenic massive sulfide environment; Economic Geology and the Bulletin of the Society of Economic Geologists, v. 91, p. 204–212. doi:10.2113/gsecongeo.91.1.204

Squires, G. and Moore, P., 2004. Volcanogenic massive sulphide environments of the Tally Pool Volcanics and adjacent area; geological, lithogeochemical and geochronological results; Newfoundland Department of Mines and Energy, Geological Survey, Report 04-1, p. 63–91.

Squires, G.C.S., Brace, T.D., and Hussey, A.M., 2001. Newfoundland's polymetallic Duck Pond Deposit: earliest Iapetan VMS mineralization, formed within a sub-seafloor, carbonate-rich alteration system; *in* Geology and Mineral Deposits of the Northern Dunnage Zone, Newfoundland Appalachians, (ed.) D.T.W. Evans and A. Kerr; Geological Association of Canada–Mineralogical Association of Canada Annual Meeting, St. John's, Newfoundland, May 28–30, 2001, Field Trip Guide A2, p. 167–187.

Swinden, H.S. and Dunsworth, S.M., 1995. Metallogeny; Chapter 9 *in* Geology of the Appalachian-Caradocian Orogeny in Canada and Greenland, (ed.) H. Williams; Geological Survey of Canada, Geology Canada, no. 6, p. 681–814 (*also* Geological Society of America, The Geology of North America, v. F-1).

Swinden, H. and Kean, B., 1988. The Volcanogenic Sulphide Districts of Newfoundland: A Guidebook and Reference Manual for Volcanogenic Sulphide Deposits in the Early Paleozoic Oceanic Volcanic Terranes of Central Newfoundland; Geological Association of Canada, Mineral Deposits Division; p. 2–27.

van Staal, C.R., Whalen, J.B., McNicoll, V.J., Pehrsson, S., Lissenberg, C.J., Zagorevski, A., van Breemen, O., and Jenner, G.A., 2007. The Notre Dame arc and the Taconic orogeny in Newfoundland; Geological Society of America, v. 200, p. 511–552. doi:10.1130/2007.1200(26)

Williams, H., 1979. Appalachian orogen in Canada; Canadian Journal of Earth Sciences, v. 16, p. 792–807. doi:10.1139/e79-070

Zagorevski, A., Van Staal, C.R., McNicoll, V., and Rogers, N., 2007. Upper Cambrian to Upper Ordovician peri-Gondwanan Island arc activity in the Victoria Lake Supergroup, Central Newfoundland: tectonic development of the northern Ganderian margin; American Journal of Science, v. 307, p. 339–370. doi:10.2475/02.2007.02

Geological Survey of Canada Project # 340321NU61