Ore Geology Reviews 72 (2016) 914–939

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Mineralogy and mineral chemistry of the metamorphosed and precious metal-bearing Ming deposit, Canada

Stefanie M. Brueckner *, Stephen J. Piercey, Jean-Luc Pilote, Graham D. Layne, Paul J. Sylvester [1]

Department of Earth Sciences, Memorial University of Newfoundland, 300 Prince Philip Drive, St. John's, NL A1B 3X5, Canada

ARTICLE INFO

Article history:
Received 26 June 2015
Received in revised form 8 September 2015
Accepted 17 September 2015
Available online 25 September 2015

Keywords:
Metamorphosed volcanogenic massive sulfide deposit
Epithermal elements
Precious metals
Tellurides
Magmatic source

ABSTRACT

The Ming deposit in the northwestern Canadian Appalachians is a metamorphosed, bimodal-mafic, precious-metal (Au, Ag)-bearing and Cu-rich volcanogenic massive sulfide (VMS) deposit consisting of several, spatially proximal lenses in a sericite- to chlorite-altered rhyodacitic footwall. The various lenses (1807 Zone, 1806 Zone, Ming South Up Plunge, Ming South Down Plunge, and the Lower Footwall Zone) have variations in Cu, Au, Ag, and Zn grades that reflect varying physico-chemical conditions of ore formation. This study describes the complex ore mineralogy of the orebodies and constrains the genesis of the deposit using field methods, mineralogy, whole rock sulfide geochemistry, and micro-analytical methods.

The orebodies are predominantly pyrite, chalcopyrite, with lesser sphalerite, pyrrhotite, and trace galena and arsenopyrite, with the exception of the Lower Footwall Zone, which consists of a high temperature (>320 °C) chalcopyrite–pyrrhotite–pyrite ± cubanite assemblage. The other orebodies (1806, 1807, Ming South Up Plunge and Down Plunge) contain trace amounts of tellurides (hessite, altaite, tsumoite, unnamed bismuthtelluride), sulfosalts (Ag-poor and Ag-rich tennantite–tetrahedrite, meneghinite, AgSb phases, stannite), and precious metal phases (electrum, AgHg ± Au alloys). The 1807 Zone is enriched in Te, Bi, and Se, whereas the 1806 Zone is telluride-free and contains As, Sb, Hg, Au, and Ag. Mineral chemistry of sphalerite shows strong variations in Fe content (1.12–11.04 wt.%). Intermediate Fe (4.33–6.33 wt.% Fe) and Fe-rich (7.327–11.04 wt.% Fe) sphalerite are common in all orebodies, whereas Fe-poor sphalerite (1.12–3.57 wt.% Fe) occurs exclusively in the 1807 and 1806 zones. Tennantite-tetrahedrite is typically Ag-poor (0.25–2.19 wt.%) in the 1807 Zone, but is significantly enriched in Ag (up to 29.3 wt.%) in the 1806 Zone. Galena in the 1807 Zone and Ming South orebodies is commonly myrmekitically intergrown with tellurides and has high concentrations of Te, Bi, Se, and Ag. In contrast, galena in the 1806 Zone is less enriched in Te, Bi, and Se, but high in Ag.

Variations in mineralogy, epithermal elements (As, Bi, Hg, Sb, Se, Sn, Te) and precious metal (Ag, Au) content, and mineral chemistry between the different orebodies indicate that they were formed from predominantly reduced, acidic hydrothermal fluids with varying fTe_2/fS_2, fSe_2/fS_2, and m_{Bi}/m_{Sb} ratios as temperatures steadily decreased from >300 °C to <260 °C during ore formation. In the 1807 and Ming South orebodies, late-stage deposition of Te-, Bi-, Se-, Ag-rich galena and tellurides occurred prior to precipitation of Ag-poor tennantite-tetrahedrite, whereas in the 1806 Zone hydrothermal fluids low in fTe_2/fS_2, fSe_2/fS_2, and m_{Bi}/m_{Sb} favored the precipitation of Te-, Bi-, Se-poor galena and Ag-rich tennantite-tetrahedrite. A magmatic source for epithermal elements and precious metals is suggested and was part of the depositional history of the Ming deposit.

1. Introduction

In recent years, the number of studies describing the detailed ore mineralogy in ancient (Cook et al., 1998; Maslennikov et al., 2009; McClenaghan et al., 2009) and modern (Törmänen and Koski, 2005) volcanogenic massive sulfide (VMS) systems using micro-analytical methods has increased. These studies commonly show complex mineral assemblages including minerals that contain epithermal elements (As, Bi, Hg, Sb, Se, Sn) and precious metals (Ag, Au), although most of these deposits do not necessarily classify as either auriferous or Au-rich (Mercier-Langevin et al., 2011). Processes explaining the enrichment in epithermal elements and precious metals in these deposits vary between different studies. Nevertheless, the application of scanning electron microscopy (SEM) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) has offered new insights into the formation of these deposits. This is especially important in metamorphosed VMS deposits where detailed mineralogy and LA-ICP-MS studies can help to constrain between syngenetic and orogenic origins of metal enrichment (Wagner et al., 2004; Wohlgemuth-Ueberwasser

* Corresponding author.
E-mail address: s.brueckner@mun.ca (S.M. Brueckner).
[1] Current address: Department of Geosciences, Texas Tech University, 125 Science Bldg., Lubbock, TX 79049-1053, USA.

http://dx.doi.org/10.1016/j.oregeorev.2015.09.016
0169-1368/

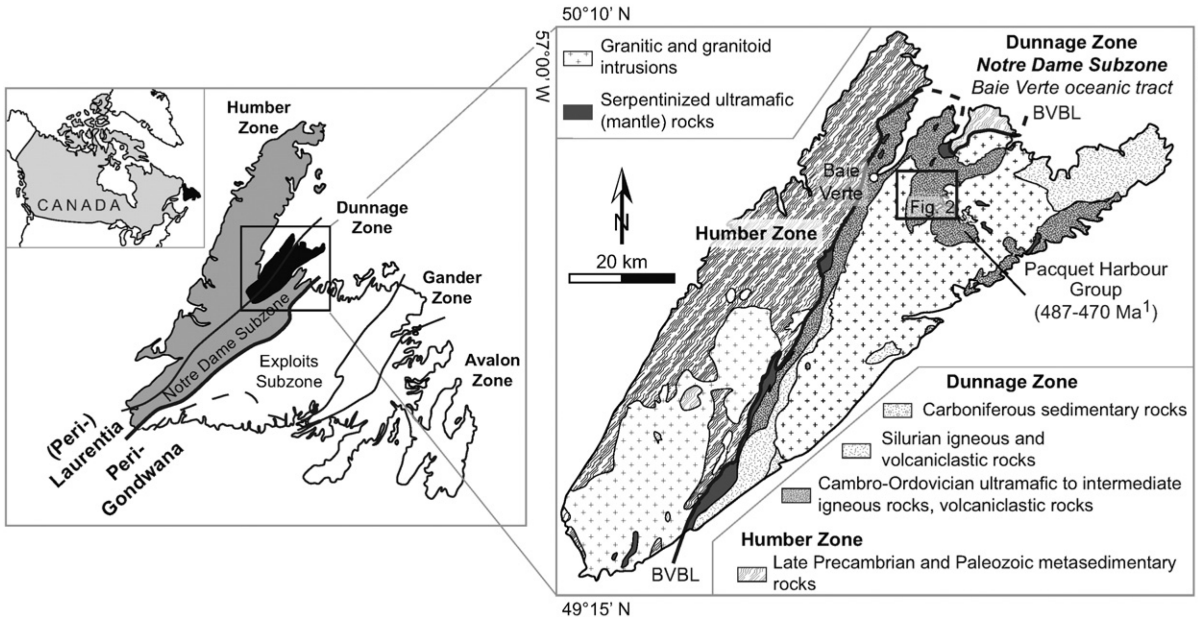

Fig. 1. Geology of Newfoundland (left; after Williams, 1979) and simplified geology of the Baie Verte Peninsula (right) from Hibbard (1983). [1] Age data for the Pacquet Harbour Group (PHG) from Castonguay et al. (2009) and Skulski et al. (2010).

et al., 2014). However, studies using cutting edge technologies to explain mineralogical and chemical variations between different ore lenses or chimneys in metamorphosed, precious metal-bearing VMS deposits are rare (e.g., Maslennikov et al., 2009; McClenaghan et al., 2009).

The Ming deposit in the Canadian Appalachians is a Cambro–Ordovician, bimodal-mafic, VMS deposit with epithermal elements and precious metals that was metamorphosed to upper greenschist/lower amphibolite facies conditions during the Silurian and Devonian. The several, spatially proximal orebodies of the deposit locally contain anomalous Au (up to 2.96 g/t Au) and epithermal (magmatic–hydrothermal) element enrichment and have variable precious and base metal grades. This deposit also contains lenses virtually devoid of Au, but which are enriched in base metals. Correspondingly, the Ming deposit provides a unique opportunity to study the variations in setting, style, mineralogy, and genesis of both base and precious metals in an ancient metamorphosed orebody.

In this paper, traditional reflected light microscopy and whole rock sulfide geochemistry of mineralized samples are combined with SEM, electron microprobe and LA-ICP-MS to understand the variations in epithermal and precious element content, mineral assemblages, mineral textures, and mineral chemistry between the different orebodies. The results are used to constrain the physio-chemical hydrothermal fluid conditions that were responsible for the variations in the orebodies of the Ming deposit. Moreover, the depositional mechanisms for semi-massive to massive sulfides and discordant sulfide stringers are explained to provide insight into the sources and deposition of base metals, epithermal elements, and precious metals. The findings of this study have implications for base and precious metal-bearing VMS deposits located in both the Appalachians and orogenic belts worldwide.

2. Tectonic setting

The Ming deposit is located on the Baie Verte Peninsula, Canadian Appalachians, which hosts both metamorphosed Precambrian rocks of Laurentia (Humber Zone) and peri-Laurentian Paleozoic rocks of the Notre Dame subzone of the Dunnage Zone. The contact between both zones is marked by the NE-SW oriented Baie Verte Brompton Line (BVBL; Fig. 1; Hibbard, 1983). The Ming deposit is located within the Baie Verte oceanic tract (BVOT), a Cambro–Ordovician to early Ordovician remnant arc complex in the eastern half on the peninsula. The detailed stratigraphy and tectonic environment of the BVOT are well documented (Hibbard, 1983; van Staal, 2007; Castonguay et al., 2009; Skulski et al., 2010; van Staal and Barr, 2012), and only a brief outline is provided below.

The Ming deposit is located within the Pacquet Harbour Group (PHG) in the BVOT (Fig. 2). The PHG is a remnant, partial ophiolitic basement assemblage consisting of low-Ti to medium-Ti boninites, tholeiitic basalts, and minor rhyodacite to rhyolite. The rhyodacitic to rhyolitic volcanic rocks form a 2.5 km thick sequence of quartz-bearing, consolidated felsic tuff and tuff breccia, which is referred as Rambler rhyolite or Rambler rhyolite formation (Hibbard, 1983; Skulski et al., 2010). The Rambler rhyolite has a U–Pb zircon age of 487 ± 4 Ma (unpubl. data by V. McNicoll in Castonguay et al., 2009; Skulski et al., 2010), forms the upper part of the PHG, and hosts massive sulfide mineralization (Fig. 2; Hibbard, 1983, Skulski et al., 2010). The formation of VMS deposits within the Rambler rhyolite was coeval with the formation of the PHG rocks in an arc setting (Swinden and Thorpe, 1984; van Staal, 2007). The ophiolitic cover sequence of the PHG is the Snooks Arm Group, which consists of early Ordovician (483–467 Ma) volcano–sedimentary rocks and tholeiitic mafic volcanic rocks (Hibbard, 1983; unpubl. data by V. McNicoll in Castonguay et al., 2009; Skulski et al., 2010). The PHG with its cover sequence is interpreted to have formed in a supra-subduction setting during the closure of the Humber Seaway during the Taconic Orogeny (van Staal, 2007; van Staal and Barr, 2012).

Silurian and early Devonian intrusions (Cape Brulé Porphyry, Burlington Granodiorite, Cape St. John Group; Figs. 1, 2) formed during the Salinic and Acadian orogenies cross-cut the PHG and Snooks Arm Group and caused polyphase deformation and uppergreenschist to lower amphibolite facies metamorphism (Tuach and Kennedy, 1978; Hibbard, 1983; Castonguay et al., 2009). At least four different deformation events (D_1 to D_4) are recorded in the BVOT basement rocks and their cover sequence (Tuach and Kennedy, 1978; Hibbard, 1983;

Fig. 2. Detailed geological map of the Pacquet Harbour Group (PHG) with VMS deposits of the Rambler camp (modified after Skulski et al., 2010; outside coordinates are in WGS 1984 and inside coordinates are in UTM NAD83, Zone 21 N). All orebodies of the Ming deposit, including mined out and present orebodies, are projected to surface and highlighted in gray and black, respectively. The inlay shows the spatial relationship between the different orebodies of the Ming deposit underground (Rambler Metals & Mining, 2011).