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GEOLOGICAL SURVEY OF CANADA
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2018

Canada

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2018

Permanent link: https://doi.org/10.4095/308213

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Recommended citation
McClenaghan, M.B., Kjarsgaard, I.M., and Ames, D.E., 2018. Indicator mineral data for bedrock samples from the Broken Hammer Cu-Ni-PGE-Au deposit, North Range, Sudbury Structure, Ontario; Geological Survey of Canada, Open File 8369, 1 .zip file. https://doi.org/10.4095/308213

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ABSTRACT

Bedrock samples were collected from the Broken Hammer Cu-Ni-PGE-Au deposit and surrounding host lithologies by the Geological Survey of Canada (GSC) to determine which indicator minerals are indicative of this deposit type. The deposit is known for world-class sperrylite crystals that are as large as 15 mm. The bedrock samples were processed using a combination of crushing, tabling, and heavy liquid separation to produce heavy mineral (>3.2 specific gravity) concentrates, which were then visually examined under binocular microscope. Ore minerals recovered from the mineralized samples include sperrylite (up to 2 mm in size), michenerite, tellurobismuthite, kotulskite, and merenskyite, as well as gold and chalcopyrite. GSC open file 8384 reports the results presented for GSC till samples collected around the deposit.

INTRODUCTION

In contrast to till geochemical methods, few indicator mineral case studies have been conducted around magmatic Ni-Cu-PGE deposits in glaciated terrain. To address this knowledge gap, the Geological Survey of Canada (GSC), through its Targeted Geoscience Initiative 3 (TGI-3) collected and analyzed a suite of bedrock and till samples from around the Broken Hammer Cu-(Ni)-PGE deposit on the North Range of the Sudbury Structure, northeastern Ontario (Fig. 1).

The Broken Hammer magmatic-Ni-Cu-PGE-Au deposit was chosen as an indicator mineral test site because the deposit (1) was known to contain coarse-grained platinum group minerals; (2) bedrock and surficial geology are well known; (3) subcrops and thus was exposed to direct glacial erosion; (4) is easily accessible by road; and (5) is located north of the Sudbury Structure and hence up-ice of the major Ni-Cu-PGE deposits, mines, and smelters within the Sudbury region. The objectives of the research project are (1) to determine the indicator minerals signatures that are indicative of magmatic-Ni-Cu-PGE deposits and (2) to establish practical methods for their recovery from glacial sediments and for their identification that can be routinely applied during exploration in glaciated terrain. The purpose of this open file is to report the indicator mineral data for bedrock samples collected from and around the deposit. GSC OF 8384 (McClenaghan et al., 2018) reports the indicator mineral results for GSC till samples collected around the deposit in 2006.

LOCATION

The Broken Hammer deposit is located approximately 30 km north of the city of Sudbury, in Wisner Township, Ontario. It is in the North Range of the Sudbury Structure (latitude 46°45'46"N and longitude 82°57'55"W) (Fig. 1) and can be accessed by a combination of logging roads and exploration access roads and trails. The property is currently held by Wallbridge Mining Company Ltd.

GEOLOGY

Regional bedrock geology

The world-class Sudbury Ni-Cu mining district is associated with the 1.85 Ga Sudbury Igneous Complex (SIC), an elliptical body with offset dykes that straddle the boundary between the Archean Superior Province in the north and the Paleoproterozoic Southern Province to the south (Fig. 2). Over 1.7 billion tonnes of Ni, Cu, Co, Pt, Pd, Au, and Ag ore (Lydon, 2007) has been mined from this exceptional mining district, which remains a vital exploration target. The polymetallic ore is hosted within one of Earth's largest preserved impact craters, the Sudbury Structure (Lightfoot, 2016).

The basement host rocks on the southern part of the Sudbury Structure, termed the "South Range", comprise Paleoproterozoic rocks of the Huronian Supergroup—dominantly metasedimentary and mafic metavolcanic rocks that have been intruded by a series of mafic magmatic episodes (Nipissing, Sudbury and Grenville dyke swarms)—with minor felsic episodes (Murray-Creighton plutons). The basement rocks along the northern and eastern part of the Sudbury Structure, called the "North Range", comprise Neo-Archean supracrustal and intrusive rocks, which have been deformed and metamorphosed under granulite facies

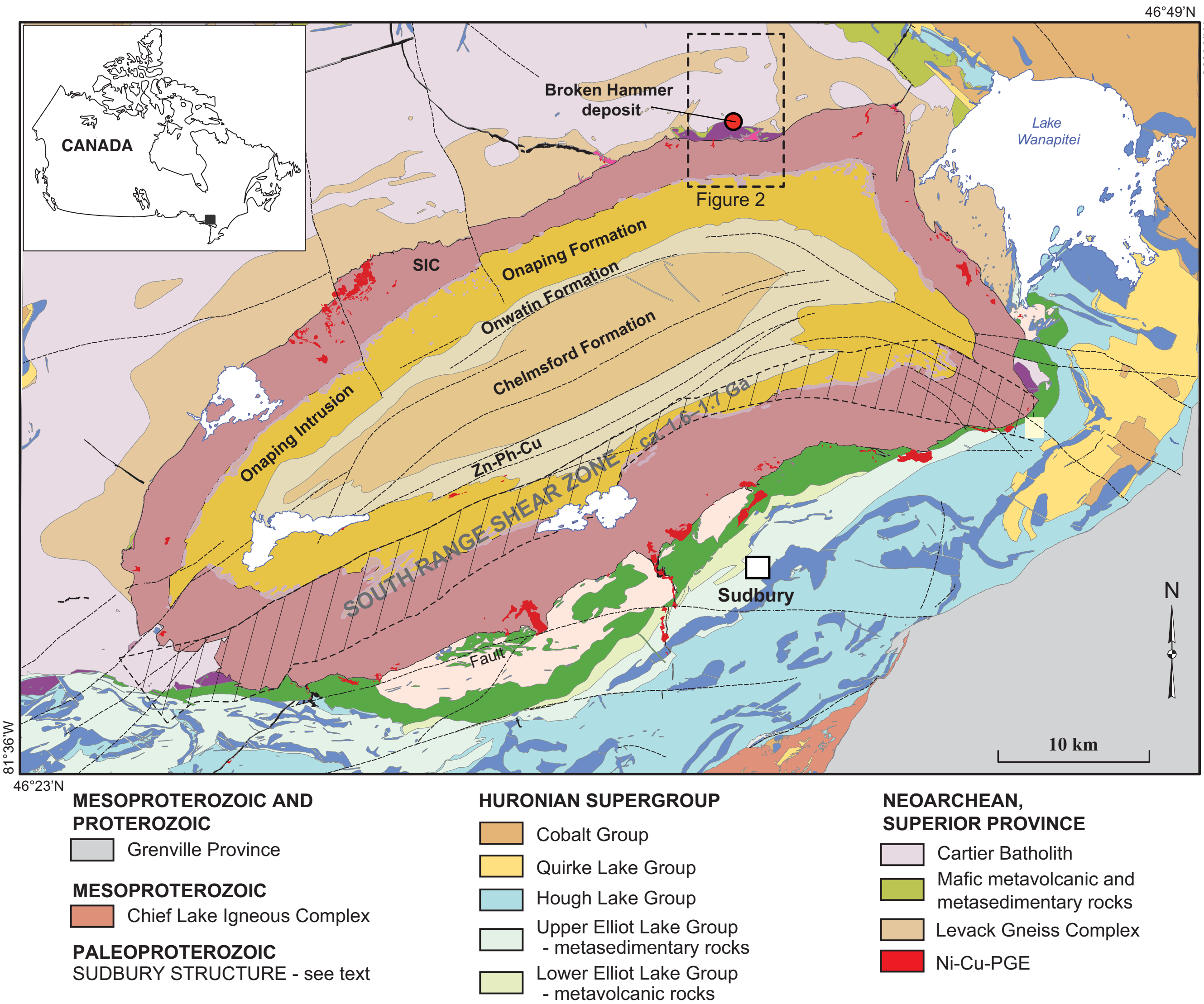

Figure 1. Location of the study area in the Sudbury Basin in northeastern Ontario (modified from Ames and Farrow 2007). SIC = Sudbury Igneous Complex.

conditions to form the Levack Gneiss Complex, and late Archean granite of the Cartier Batholith (Card, 1994; Ames et al., 2005). These rocks were strongly affected by the shock and thermal effects of the Sudbury impact at 1.85 Ga.

The shocked and brecciated basement rocks (Sudbury breccia unit) and melt rocks (SIC) control, host, and significantly contributed to the formation of the ores. The igneous rocks of the Sudbury Structure form the 60 x 30 km elliptical outline of the SIC together with radial and concentric, quartz diorite dykes in offset structures (Fig. 1). Sudbury breccia, in the stratigraphic and structural footwall to the SIC, consists of country rock fragments in a cataclastic to pseudotachylitic matrix and forms randomly oriented stringers and large zones or "belts" of breccia that can be found up to 200 km from the base of the SIC (Speers, 1957; O'Callaghan et al., 2016a,b). Sudbury breccia represents an important economic target as a host to Sudbury's largest Ni-Cu-PGE deposit (Frood-Stobie) and Cu-PGE and PGE-only "footwall deposits".

Sudbury Ni-Cu-PGE ore deposits

Some of the Sudbury area mines have operated for over a century, whereas new ore deposits and ore types have recently come into production or are in the process of being developed (i.e. advanced prospects). Sudbury Ni-Cu contact-type deposits are widely accepted to be of magmatic origin, having formed during differentiation of the SIC followed by sulphide segregation and subsequent collection in topographic lows or "embayments" at the base of the SIC. The origin of the Cu-Ni-PGE systems is controversial: both magmatic and hydrothermal processes having been supported in the literature (e.g. Ames et al., 2006). More recently, a

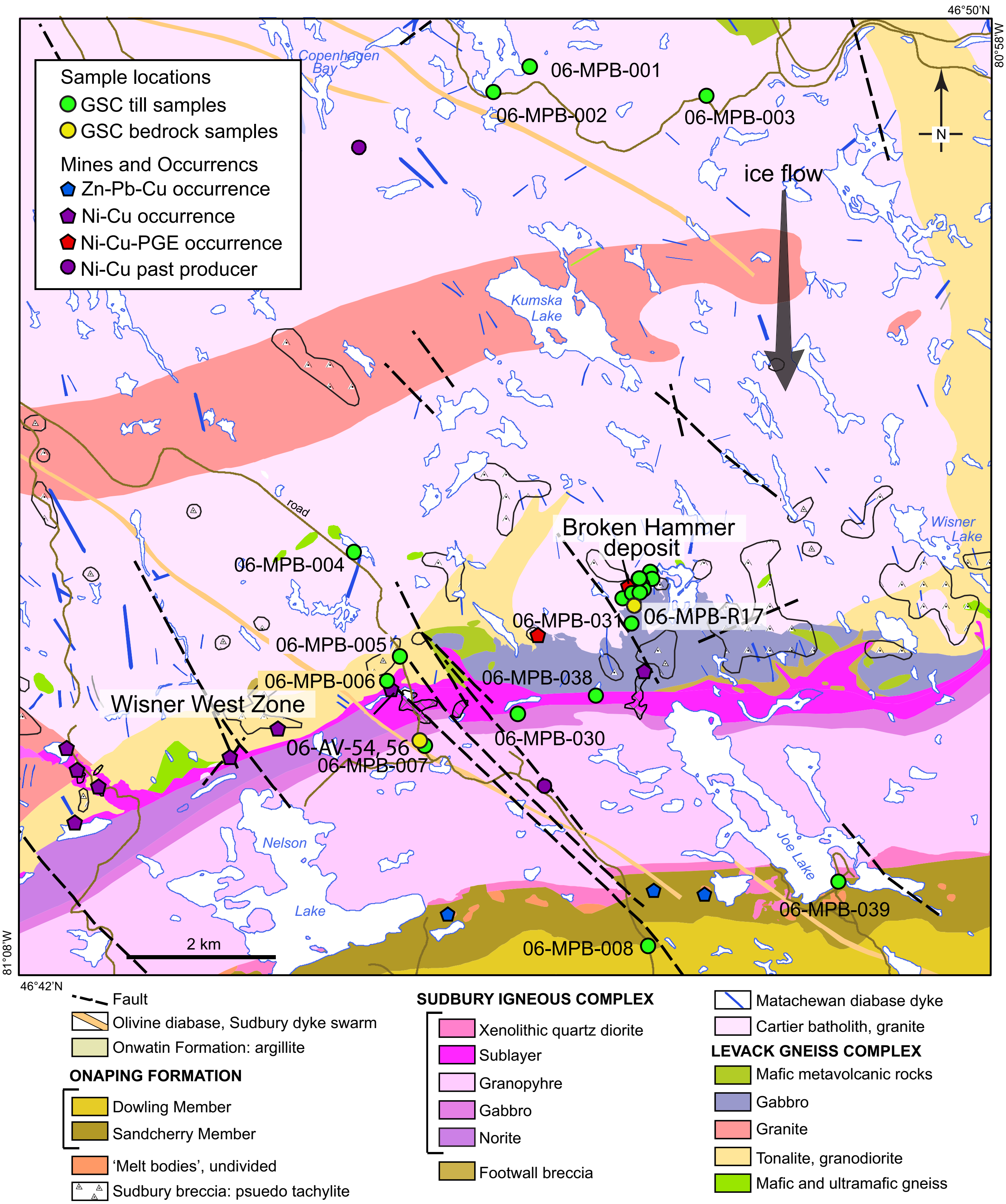

Figure 2. Regional bedrock geology map (Ames et al., 2005) with the location of bedrock and till samples collected in 2006 by the Geological Survey of Canada around the Broken Hammer deposit.

magmatic-hydrothermal origin was postulated whereby initial magmatic differentiation of the sulphide liquid resulted in the formation of a residual sulphide liquid enriched in Cu, Pt, Pd, and Au. This liquid was then remobilized into structural pathways or permeable zones of brecciated country rock or Sudbury breccia in the footwall of the SIC. The recent division of footwall Cu-(Ni)-PGE deposits into high-sulphide, (sharp-walled vein) and low-sulphide (PGE-rich) systems based on large geochemical mine databases (Farrow et al., 2005) instigated a series of comprehensive geoscience studies to determine the characteristics, origin, mode of transport. and timing of the low-sulphide PGE-rich mineralization relative to the high-sulphide largely magmatic veins. Later hydrothermal mobilization resulted in redistribution of base and precious metals, modification of the ore composition, and the formation of Cl-rich alteration haloes. Fluid inclusion stable isotope evidence suggests ore metal transport and redistribution involved mixing between regional groundwater and metal-rich ore fluid with a magmatic component to form a metal-enriched brine that partitioned, causing Au precipitation and phase separation of Cu, Au, Ag, and Bi into a CH_4-bearing fluid that further dispersed Cu, Pt, Au, Ag, and Bi (Farrow et al., 1994; Hanley et al., 2005; 2006).

Footwall-hosted Cu-PGE deposits are a relatively new resource in the Sudbury camp, except for the earlier discoveries in the Onaping-Levack area that included the McCreedy deposits and the Strathcona Deep Copper zone (Coats and Snajdr, 1984). Rising metal prices triggered an exploration surge for footwall deposits in the last 15 years in the Sudbury Camp due to their high Cu and precious metal content. This surge resulted in the discovery of numerous PGE-rich mineralized zones, including the hybrid Broken Hammer zone (Péntek et al., 2008). Cu-Ni-PGE deposits and occurrences that have been studied by the GSC include Creighton 403, Creighton Deeps, Barnett, McCreedy East 153 zone, Victor Deep, Levack Footwall, McCreedy West PM zone, Segway, and Broken Hammer Cu-PGE (Ames et al., 2007; 2013a).

Local bedrock geology

The Broken Hammer deposit and Wisner west zone are situated on the North Range of the Sudbury Structure in Wisner Township, 1.5 km north of the SIC contact with footwall rocks of the Archean Joe Lake gabbro and/or granite and quartzo-feldspathic and mafic gneiss of the Levack Gneiss Complex and Cartier Batholith (Fig. 2). Numerous contact Ni-Cu mineralized zones occur along the base of the moderately (30°S) south-dipping SIC contact (i.e. WD-13, WD-16, Rapid River; Ames et al., 2005). The Wisner west zone is situated in the footwall to a 12 km-long embayment in the SIC (Bowell embayment) that is bounded to the west by the Foy offset and to the east by the Joe Lake intrusion. The Wisner west area is dominated by felsic and mafic gneiss with plagioclase-porphyritic diabase dykes of probable Matachewan origin. Zones of Sudbury breccia (WW- 750 x 2 km SW-NE trending) host the Cu-PGE disseminations and veinlets and are commonly altered to quartz-epidote-carbonate-chlorite rich assemblages.

Two outcrop areas stripped by Vale-Lonmin at the Wisner west occurrence exposed a few sulphide veinlets, quartz-carbonate, epidote-quartz, and disseminations hosted in Sudbury breccia (pseudotachylite). The decoupling of PGE grades from the abundance of chalcopyrite is what characterizes this low-sulphide high-PGE mineralization at Wisner west (Ames and Kjarsgaard, 2013).

Approximately 3.5 km to the west of Wisner west is the Broken Hammer Cu-Ni-PGE-Au deposit, situated 1.3 km from the base of the SIC along the northern margin of the Joe Lake gabbroic intrusion. It is a shallow surface zone of vein- and vein stockwork-hosted Cu-PGE mineralization (Fig. 3) within Sudbury breccia (Figs. 4, 5) developed in Neoarchean quartz monzonite of the Levack Gneiss Complex (Peterson et al., 2004; Péntek et al., 2006, 2008). The Broken Hammer deposit was discovered in 2003 by Wallbridge Mining Company Ltd. through surface prospecting and sampling for Cu-Ni-PGE mineralization sulphide veins (Doran et al., 2012). A stripped bedrock outcrop and adjacent till were sampled by the GSC in 2006 for mineralogical analyses that are the subject of this report.

The main 2 to 120 cm-wide en echelon chalcopyrite vein named 'Big Boy' (Fig. 6), which was uncovered by stripping the outcrop, is dominated by chalcopyrite-magnetite-millerite with numerous trace and rare precious metal minerals, such as tellurides, bismuthides, selenides, and stannides (Table 1). A thin (cms) post-glacial regolith or gossan, whose location is indicated in Figure 3, has developed on a small part of the Cu-PGE vein and was exposed on the stripped bedrock surface in 2006 (Fig. 7). This gossan contains abundant sperrylite, chalcopyrite (Fig. 8), and other minerals (Se-galena, cassiterite, kotulskite, merenskyite, electrum, arsenopyrite and native silver) in a goethite matrix (Fig. 9). Trace elements in the mineral assemblages in the weathered sulphide include Pd-Pt-Sn-Pb-Au-Ag-As-Bi-Te, which are reflected in the sulphide ore lithogeochemistry (Ames et al., 2007; Péntek et al., 2008). Epidote is a common alteration mineral in the local rocks (Fig. 10).

In 2011, a 30,000 tonne bulk sample was taken from Broken Hammer, creating an open pit and removing much of the till and bedrock that was sampled by the

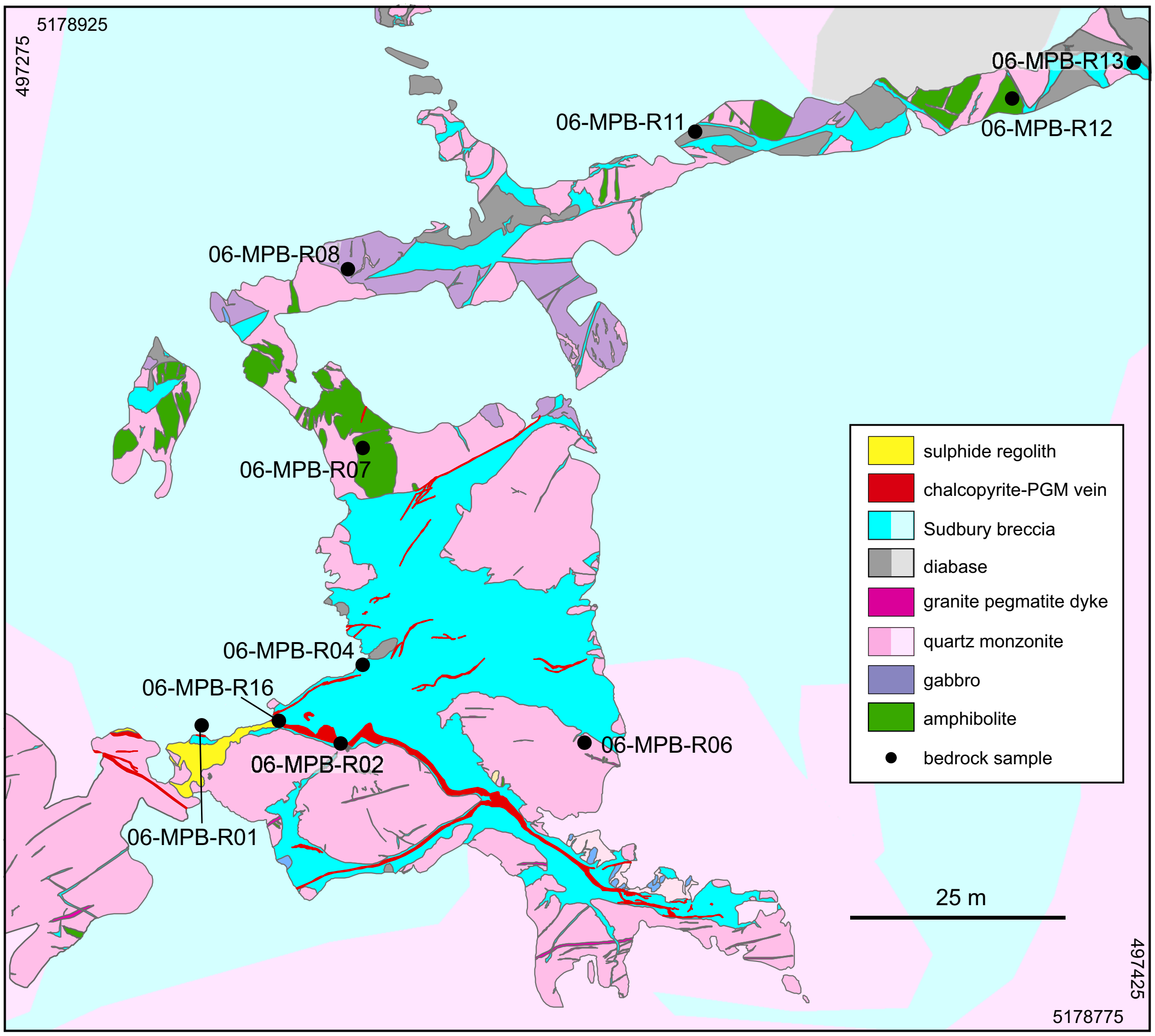

Figure 3. Detailed bedrock geology of the area (Peterson et al., 2004) superimposed on the regional bedrock geology (Ames et al., 2005). The location of the bedrock samples collected proximal to the Big Boy chalcopyrite vein are also shown. The detailed bedrock geology, which was exposed in 2006 by stripping on the Broken Hammer property, is shown by darker shades of each corresponding lighter colour of the regional bedrock geology.

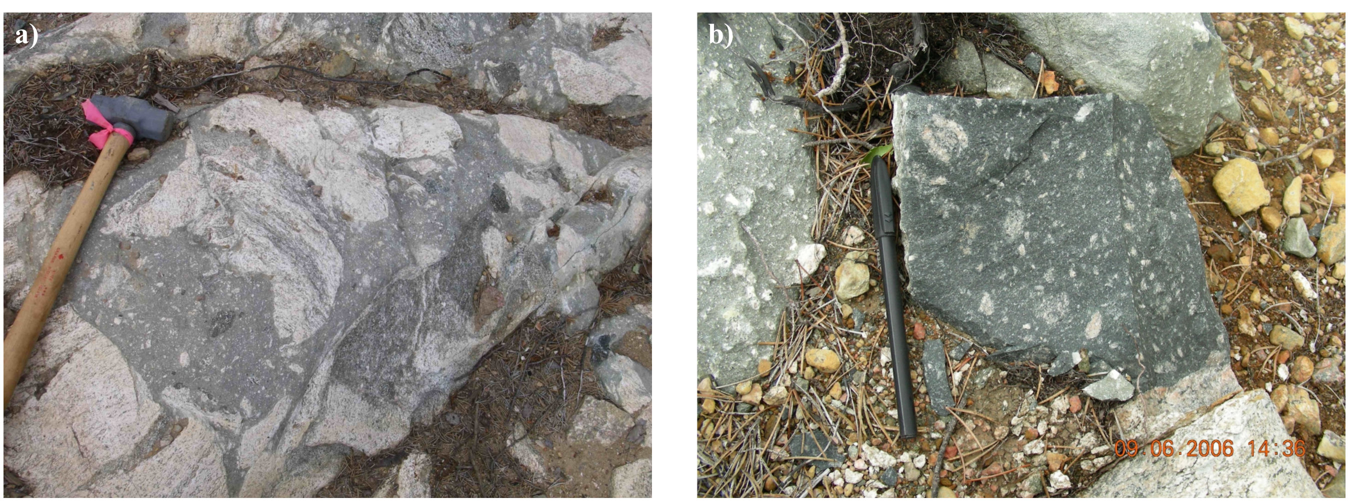

Figure 4. Colour photographs of Sudbury breccia: **a)** proximal to the main chalcopyrite vein, with pink xenoliths of gneiss in a dark grey fine-grained matrix (note sledge hammer for scale); and **b)** freshly broken surface of Sudbury breccia (note black pen for scale).

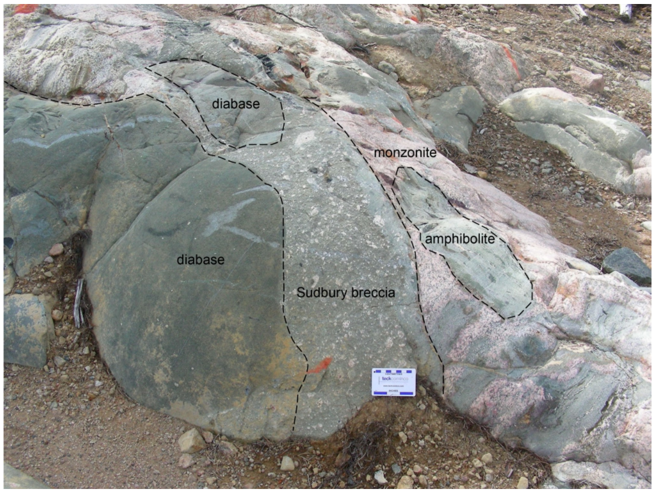

Figure 5. Colour photograph of the exposed bedrock surface of the Broken Hammer occurrence showing juxtaposed bedrock lithologies adjacent to the Big Boy chalcopyrite vein: diabase, Sudbury breccia, quartz monzonite, and amphibolite. Note white scale card.

Figure 6. Colour photograph of the Big Boy chalcopyrite vein exposed in the pre-2007 stripped area at the Broken Hammer deposit. Note hammer for scale. Cp = chalcopyrite.

GSC in 2006. New exposures in the pit revealed a "super", high-grade sperrylite zone comprising a hydrothermal assemblage of coarse epidote-quartz-sperrylite with world-class sperrylite crystals as large as 15 mm (Wilson, 2012; Ames et al., 2013b). Positive results from this initial bulk sample led to a prefeasibility study and resource estimates.

Open pit mining at Broken Hammer started in 2014 and from 2014 to 2015, 10,265 tonnes of Cu concentrate was delivered to a Cu smelter with an average grade of 24.15% Cu and 60.4 g/t PGM (18.6 g/t Pt, 34.5 g/t Pd, and 7.3 g/t Au). In addition, 180 tonnes of high-grade gravity concentrates were shipped to a PGM smelter in Europe with an average PGM grade of 1,924 g/t (1,551 g/t Pt, 145 g/t Pd, and 228 g/t Au).

Figure 7. Colour photographs of the post-glacial gossan that developed on the Big Boy chalcopyrite vein and was exposed in a small open pit in 2006. Gossan samples 06-MPB-R01 and 06-MPB-010 were collected at this site: **a)** overview of site; **b)** close-up of the honeycomb texture that has developed in the gossan. The sample site is marked by a yellow dashed line. Note hammer for scale.

Mining at the Broken Hammer deposit ceased in October 2015 (Wallbridge Mining Company Ltd., 2018).

METHODS

Field sampling

A total of 15 bedrock samples were used in this study: 12 samples (series 06-MPB-) were collected from the Broken Hammer mineralization and surrounding host lithologies. Two samples (06AV-54 and 06AV-56) were collected from the Wisner west occurrence, 3.5 km to the west, and one other sample (05AV-23) was collected from the McCreedy West PM zone, 30 km to the southwest. Each sample was examined as a polished thin section (PTS), and a separate portion was processed to recover indicator minerals. Bedrock sample numbers, lithologies, and locations are listed in

Table 1. Summary of the ore mineralogy of the Broken Hammer Cu-(Ni)-PGE-Au deposit (modified from Ames et al., 2007; data from Mealin, 2005; Watkinson et al., 2005; Péntek et al., 2008; Kjarsgaard and Ames, 2010).

Mineral	Formula	Hardness*	Density*	At Broken Hammer, Identified by others	Identified in Broken Hammer PTS this study	Identified in bedrock HMC this study	Identified in till HMC this study
Sulphide minerals							
arsenopyrite	$FeAsS$	5	6.07	Ames et al. (2007)	no	no	no
bornite	Cu_5FeS_4	3	4.9–5.3	Péntek et al. (2008)	yes	no	no
chalcocite	Cu_2S	2.5–3	5.5–5.8	no	no	yes	no
chalcopyrite	$CuFeS_2$	3.5	4.1–4.3	Péntek et al. (2008)	yes	yes	yes
covellite	CuS	1.5–2	4.6–4.76	Péntek et al. (2008)	yes	no	no
crerarite	$PtBi_3S_{4-x}$	3	not reported	Péntek et al. (2008)	no	no	no
emplectite	$CuBiS_2$	2	6.3–6.5	Ames et al. (2007)	no	no	no
galena (Se)	$Pb(S,Se)$ ±Bi,Ag	2.5	7.2–7.6	Ames et al. (2007)	no	galena	no
millerite	NiS	3–3.5	5.5	Péntek et al. (2008)	no	yes	no
pentlandite	$(Fe,Ni,Co)_9S_8$	3.5–4	4.6–5	Péntek et al. (2008)	no	no	no
polydymite	Ni_2S_4	4.5–5.5	4.5–4.8	Kjarsgaard & Ames (2010)	no	no	no
pyrite	FeS_2	6.5	5	Péntek et al. (2008)	yes	yes	yes
pyrrhotite	$Fe_{1-x}S$	3.5–4	4.58–4.65	Péntek et al. (2008)	no	yes	no
sphalerite	$(Zn,Fe,Cd)S$	3.5–4	3.9–4.2	Péntek et al. (2008)	yes	no	no
tetradymite	Bi_2Te_2S	1.5–2	7.2–7.9	Péntek et al. (2008)	no	no	no
malyshevite	$PdCuBiS_3$	not reported	not reported	Kjarsgaard & Ames (2010)	no	no	no
violarite	$(Fe,Ni)_3S_4$	4.5–5.5	4.5–4.8	Péntek et al. (2008)	no	no	no
wittichenite	Cu_3BiS_3	2.5	6.3–6.7	Péntek et al. (2008)	no	no	no
Oxide and hydroxide minerals							
cassiterite	SnO_2	6–7	6.8–7	Péntek et al. (2008)	no	no	no
magnetite	$FeFe_2O$	5.5–6	5.1–5.2	Péntek et al. (2008)	yes	yes	yes
malachite	$Cu_2CO_3(OH)_2$	3.5–4	3.6–4	no	no	yes	no
hematite	Fe_2O_3	6.5	5.3	Péntek et al. (2008)	no	yes	yes
goethite	$FeO(OH)$	5–5.5	3.3–4.3	no	no	yes	yes
jarosite	$KFe_3(SO4)_2(OH)_6$	2.5–3.5	2.9–3.3	no	no	yes	no
Selenide minerals							
bohdanowiczite	$AgBiSe_2$	3	7.87	Péntek et al. (2008)	no	no	no
clausthalite	$PbSe$	2.5	7.6–8.8	Péntek et al. (2008)	no	no	no
naumannite	Ag_2Se	2.5	6.5–8	Péntek et al. (2008)	no	no	no
Telluride minerals							
hessite	Ag_2Te	1.5–2	7.2–7.9	Péntek et al. (2008)	no	no	no
kawazulite	$Bi_2(Te,Se,S)_3$	1.5	7.79	Ames et al. (2007)	no	no	no
kotulskite	$Pd(Te,Bi)$	4–4.5	8.26	Péntek et al. (2008)	no	no	no
melonite	$NiTe_2$	1–1.5	7.3	Péntek et al. (2008)	no	no	no
Pd-melonite	$(Ni,Pd)Te_2$	not reported	not reported	Ames et al. (2007)	no	no	no
merenskyite	$(Pd)(Te,Bi)_2$	2–3	9.14	Péntek et al. (2008)	no	no	no
michenerite	$PdBiTe$	2.5	9.5	Péntek et al. (2008)	no	yes	no
moncheite	$(Pt,Pd)(Te,Bi)_2$	2–3	10	Péntek et al. (2008)	no	no	no
sopcheite	$Ag_4Pd_3Te_4$	3.5	9.95	Péntek et al. (2008)	no	no	no
tellurobismuthite	Bi_2Te_3	1.5–2	7.82	Péntek et al. (2008)	no	yes	no
volynskite	$AgBiTe_2$	2.5–3	8.0	Ames et al. (2007)	no	no	no
Other precious minerals							
electrum	$Au_{65}Ag_{35}$	2.5–3	12.5–15	Péntek et al. (2008)	no	yes	yes
gold	Au	2.5–3	16–19.3	Mealin (2005)	no	yes	yes
native silver	Ag	2.5–3	10–11	Ames et al. (2007)	no	no	no
sperrylite	$PtAs_2$	6–7	10.58	Péntek et al. (2008)	no	yes	yes

*data from www.webmineral.com; HMC = heavy mineral concentrate; PTS = polished thin section.

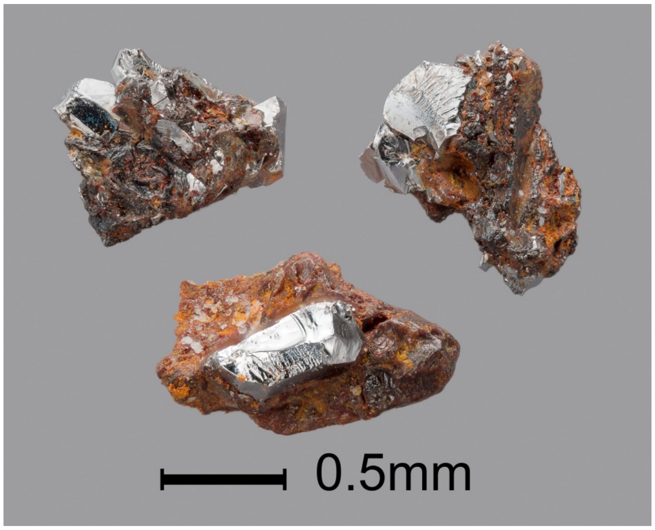

Figure 8. Colour photograph of a small fragment of gossan sample 06-MPB-010. The presence of sperrylite (silver mineral) in the goethite matrix illustrates its resistance to near surface weathering. Photo by Michael J. Bainbridge Photography.

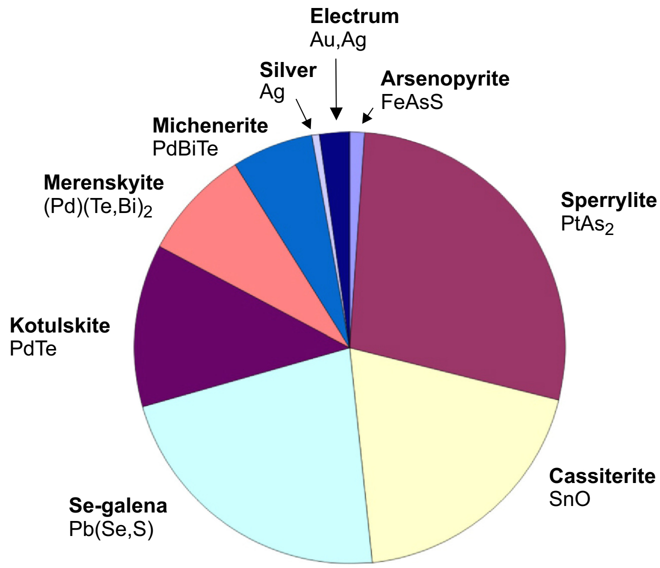

Figure 9. Relative abundance of Pt-Pd-As-Sn minerals in a 1 kg sample (06-MPB-R01) of post-glacial gossan developed on the chalcopyrite vein (N=180 mineral grains). From Ames et al. (2007).

Appendix A1. Colour photographs of sample sites, with the exception of sites 06-MPB-R08 and -R17 are included in Appendix A2. Bedrock sample locations are plotted in Figures 2 and 3.

Sudbury breccia samples were collected at varying distances from the main Big Boy chalcopyrite vein at Broken Hammer: 06-MPB-R02 at 0.3 m, 06-MPB-R04 at 7.5 m, and 06-MPB-R13 at 109.25 m. Sample 06-MPB-R01 (small fragments) and sample 06-MPB-010 (bag of loose material) are from a postglacial gossan that had developed on the mineralization. Sample 06-MPB-R16 is an unoxidized sample of the massive Big Boy chalcopyrite vein. Samples collected from unmineralized lithologies that surround the deposit (Figs. 2, 3) include quartz monzonite (06-MPB-R08), amphibolite (06-MPB-R07 proximal to mineralization, 06-MPB-R12 distal to mineralization), gabbro (06-MPB-R08), and diabase (06-MPB-R11). One sample of the Joe Lake gabbro (06-MPB-R17) was collected 1.3 km south of the deposit (Fig. 2).

Samples 06AV-54 and 06AV-56 from the Wisner west property consist of granophyre with traces of chalcopyrite and pyrite, and sample 05AV-23 from the McCreedy West PM zone is mineralized Sudbury breccia.

Sample processing and indicator mineral recovery

Splits of nine bedrock sample were submitted to the commercial laboratory, Overburden Drilling Management Ltd. (ODM), Ottawa, for production of heavy mineral concentrates, details of which can be found in McClenaghan and Ames (2013).

A separate polished slab of each bedrock sample, except for samples 06-MPB-010 and 06-MPB-R01, was prepared at the GSC and subsequently examined under a binocular microscope and described by a senior geologist at ODM (Appendix B1). A polished thin section (PTS) was prepared for each bedrock sample and described by G. Budulan (Appendix B2) as part of her B.Sc. thesis (Budulan, 2007). Petrographic descriptions of the three AV series mineralized bedrock samples were completed by I. Kjarsgaard (Appendix B3).

All bedrock samples, except for sample 06-MPB-010, were disaggregated (milled) using a conventional rock crusher to <1.0 mm at ALS Chemex Laboratories. The crushed material of each bedrock sample, weighing between 70 and 1300 g, was then processed at ODM to produce a non-ferromagnetic heavy mineral concentrate for picking indicator minerals; the weights for all fractions produced are reported in McClenaghan

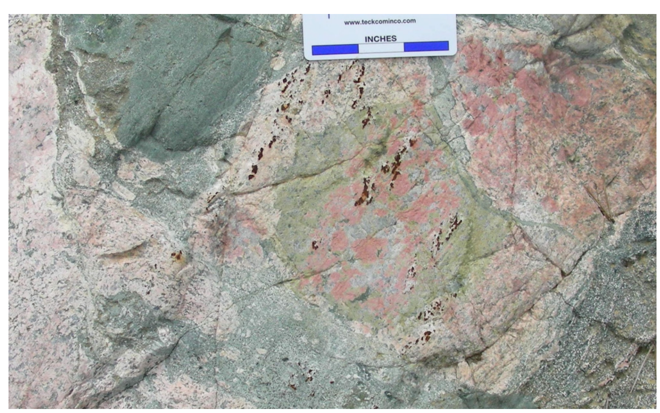

Figure 10. Colour photograph of the bright green epidote alteration that is typical in the local quartz monzonite.

and Ames (2013) and Appendix B4. Sample 06-MPB-010 was processed at ODM in a separate batch and weights for all fractions produced for this sample are reported in McClenaghan and Ames (2013) and Appendix B5.

The <1.0 mm crushed material was not preconcentrated by tabling. Instead, it was micro-panned to recover gold, sulphide, and platinum group minerals (PGM). The minerals in the pan were counted and their size and shape characteristics recorded, and then all material was returned to the sample. The <1.0 mm crushed material was then sieved at 0.18 and 1.0 mm. The 0.18 to 1.0 mm material was further refined using methylene iodide diluted to a specific gravity (SG) of 3.2. The ferromagnetic fraction of each bedrock sample, including magnetite and pyrrhotite, was then removed using a hand magnet and set aside. The non-ferromagnetic heavy mineral fraction was sieved into four size fractions: 0.18–0.25, 0.25–0.5, 0.5–1.0, 1.0–2.0 mm. The 0.18–0.25 mm fraction was archived and the 0.25–0.5 mm fraction was subjected to paramagnetic separations using a Carpco® magnetic separator to produce <0.6, 0.6–0.8, 0.8–1.0, and >1.0 amps to assist picking this fine-grained fraction.

Although each crushed bedrock sample was sieved at 1.0 mm and only the <1.0 mm proceeded through the entire processing flow sheet, some >1.0 mm was recovered after heavy liquid and ferromagnetic separations. These large grains have b and c axes of <1 mm and an ‘a’ axis of >1 mm, thus a few grains were reported for the 1.0–2.0 mm fraction.

The four 0.25–0.5 mm paramagnetic fractions, and the 0.5–1.0 and 1.0–2.0 mm non-ferromagnetic fractions were visually examined under a binocular microscope and potential indicator minerals counted, including gold, sulphide, and PGM, as well as potential oxide and silicate indicators of massive sulphide deposits, which are included in ODM’s suite of magmatic or metamorphosed massive sulphide indicator mineral (MMSIM®) suite — an indicator mineral assemblage that is used to explore for a broad spectrum of massive sulphide base metal deposits (Averill, 2001).

Later, the number of epidote, titanite, rutile, and ilmenite grains were determined by re-examining and counting each concentrate. These previously unreported grain abundances can be found in Appendix B4, in the “additional picking” worksheet and the “Epidote estimates” worksheet. Appendix B4 presents an updated version of the ODM data file that was first reported in Appendix B2 in OF 7388 (McClenaghan and Ames, 2013).

Electron microprobe analysis

Four mineral grain mount maps are included in Appendix C1. Electron microprobe (EMP) data for grains from the bedrock samples are listed in the mounts shown in Appendix C2 to C5. EMP analyses of grains were completed at GSC, Ottawa. Data were acquired on a Cameca SX-50 microprobe fitted with 4 wavelength-dispersive spectrometers with a take-off angle of 40°. Normal operating conditions were 20 kv accelerating voltage and 10 nA current. Count times were 10 seconds on peak and 5 seconds off-peak. Standards used were a mixture of natural and synthetic pure metals, simple oxides, and simple compounds. Data reduction was accomplished with a ZAF matrix correction (Armstrong, 1988) using *Probe For Windows* software.

Microprobe re-analyses of selected epidote grains were carried out at Carleton University, Ottawa using the 4 wavelength-dispersive spectrometer CAMECA Camebax. Oxides were analyzed at 20 kV and 25 nA sample current with 10–20 seconds counting time. Standards used were $MgAl_2O_4$ for Mg and Al, Cr_2O_3 for Cr, MnTi for Mn, $CaSiO_3$ for Si and Ca, $FeTiO_3$ for Ti and Fe, NiO for Ni, $ZnAl_2O_4$ for Zn, and V for V. Silicates were analyzed at 15 kV and 20 nA with counting times of 20 seconds per element. Standards used were $CaSiO_3$ for Si and Ca, $MgAl_2O_4$ for Al, Mg_2SiO_4 for Mg, Fe_2SiO_4 for Fe, Cr_2O_3 for Cr, MnTi for Ti and Mn, NiO for Ni, $KAl_3Si_3O_8$ for K, $NaAl_3Si_3O_8$, for Na, and $ZnAl_2O_4$ for Zn. Overlap corrections were performed using the PAP procedure. Calibrations were checked by analyzing known USNM standards (that were not used for calibration) as samples. Electron microprobe (EMP) data are listed in Appendix C.

RESULTS

Macroscopic descriptions of the bedrock hand samples are reported in Appendix B1. Petrographic descriptions of the Broken Hammer bedrock PTS, which are reported in Appendix B2, are from Budulan (2007). Petrographic descriptions of the AV series bedrock polished thin sections were completed by I. Kjarsgaard (Appendix B3). Indicator mineral grain counts for the 0.25–0.5 mm fraction of heavy mineral concentrates of crushed Broken Hammer bedrock samples were normalized to a 1 kg sample weight (<2 mm table feed) to allow compare samples of variable mass; these are listed in Table 2 and discussed below. Results for the Wisner west and McCreedy bedrock samples are listed in the appendices but are not described or discussed in this report.

The first two bedrock samples in the batch of heavy metal concentrates (HMC) (samples 06-MPB-R06 and -R04) contained steel fragments (Appendix B4, worksheet “Detailed VG”) that are likely contamination from the crushing process. Because of this contamination, all GSC bedrock samples in subsequent indicator mineral studies were disaggregated using electronic

Table 2. Abundance of selected indicator minerals in bedrock samples examined in this study. Counts reported are for pan concentrates (pan conc.) and for the 0.25–0.5 mm heavy mineral fractions normalized to 1 kg sample weight.

a) Unedited grain counts for bedrock samples

Sample Number	Deposit/ Occurrence	Lithology	Weight <1 mm fraction (kg)	pan conc. PGM	pan conc. Gold	0.25–0.5 mm non-magnetic fraction: Chalco-pyrite	Malachite	Chalco-cite	Millerite	Pyrite	Galena	Epidote	Allanite	Titanite	Ilmenite	Apatite
06-MPB-010	Broken Hammer	gossan	1.70	100	299	140000	0	0	0	0	0	0	0	0	0	trace
06MPB-R01	Broken Hammer	gossan	0.09	5	3	50,000	0	17	0	0	0	0	0	0	0	0
06MPB-R02	Broken Hammer	Sudbury breccia	0.31	0	0	0	0	0	0	20	0	21	0	0	0	0
06MPB-R04	Broken Hammer	Sudbury breccia	0.29	0	0	0	0	0	0	3	0	2	0	0	0	0
06MPB-R06	Broken Hammer	quartz monzonite	1.29	0	0	1	0	0	0	80	0	43	0	34	0	7
06MPB-R07	Broken Hammer	amphibolite	0.43	0	13	2	0	0	0	0	0	4000	0	0	0	20
06MPB-R08	Broken Hammer	gabbro	0.32	0	0	0	0	0	0	200	0	30	0	0	0	0
06MPB-R11	Broken Hammer	diabase	0.24	0	0	0	0	0	0	80	0	0	0	0	0	0
06MPB-R12	Broken Hammer	amphibolite	0.32	0	0	0	0	0	0	300	0	400	0	0	0	20
06MPB-R13	Broken Hammer	Sudbury breccia	0.15	0	0	0	13	0	0	300	0	21	15	0	0	30
06MPB-R16	Broken Hammer	chalcopyrite vein	0.07	150	0	120,000	0	0	0	0	0	0	0	0	0	0
06MPB-R17	Broken Hammer	gabbro (Joe Lake)	0.35	0	0	0	0	0	0	800	0	32	0	0	30	60
05AV-23	McCreedy W-PM	Sudbury breccia	0.19	0	8	20,000	0	0	2500	20	1	0	0	0	0	0
06AV-54	Wisner west	mineralized granophyre	0.17	0	0	300	25	0	0	100	0	13	0	0	0	trace
06AV-56	Wisner west	mineralized granophyre	0.13	20	4	1500	150	0	0	50	0	20	0	6	0	trace

b) Bedrock grain counts normalized to 1 kg sample weight

Sample Number	Deposit/ Occurrence	Lithology	pan conc. PGM	pan conc. Gold	0.25–0.5 mm non-magnetic fraction: Chalco-pyrite	Malachite	Chalco-cite	Millerite	Pyrite	Galena	Epidote	Allanite	Titanite	Ilmenite	Apatite
06-MPB-010	Broken Hammer	gossan	59	176	82353	0	0	0	0	0	0	0	0	0	0
06MPB-R01	Broken Hammer	gossan	54	33	542299	0	184	0	0	0	0	0	0	0	0
06MPB-R02	Broken Hammer	Sudbury breccia	0	0	0	0	0	0	64	0	6	0	0	0	0
06MPB-R04	Broken Hammer	Sudbury breccia	0	0	0	0	0	0	10	0	0	0	0	0	0
06MPB-R06	Broken Hammer	quartz monzonite	0	0	1	0	0	0	62	0	16	0	3	0	trace
06MPB-R07	Broken Hammer	amphibolite	0	30	5	0	0	0	0	0	9350	0	0	0	4
06MPB-R08	Broken Hammer	gabbro	0	0	0	0	0	0	625	0	63	0	0	0	0
06MPB-R11	Broken Hammer	diabase	0	0	0	0	0	0	338	0	0	0	0	0	0
06MPB-R12	Broken Hammer	amphibolite	0	0	0	0	0	0	935	0	1246	0	0	0	trace
06MPB-R13	Broken Hammer	Sudbury breccia	0	0	0	87	0	0	2015	0	67	101	0	0	30
06MPB-R16	Broken Hammer	chalcopyrite vein	2177	0	1741655	0	0	0	0	0	0	0	0	0	0
06MPB-R17	Broken Hammer	gabbro (Joe Lake)	0	0	0	0	0	0	2305	0	6	0	0	30	60
05AV-23	McCreedy W-PM	Sudbury breccia	0	42	104932	0	0	13116	105	5	0	0	0	0	0
06AV-54	Wisner west	mineralized granophyre	0	0	1801	150	0	0	600	0	78	0	0	0	trace
06AV-56	Wisner west	mineralized granophyre	156	31	11728	1173	0	0	391	0	156	0	47	0	trace

pulse disaggregation methods, instead of crushing, to reduce sample contamination.

Mineral abundances

Platinum group minerals

Sperrylite ($PtAs_2$) is a platinum group mineral (PGM) that is easily recognizable in pan concentrates by its bright silver-white colour. Five 75–100 µm sperrylite grains were recovered from the pan concentrate of gossan sample 06-MPB-R01, three of which were confirmed by SEM to be sperrylite. Gossan sample 06-MPB-010, also processed by ODM, contained an estimated 100 grains of sperrylite in the pan concentrate as well as 9 grains in the 0.25–0.5 mm heavy mineral concentrate. Sperrylite grains in the coarser 0.5–1.0 mm and 1.0–2.0 mm fractions of sample 06-MPB-010 are aggregates of sperrylite (silver) + goethite (orange) + chalcopyrite (yellow) (Fig. 8).

A sample of unoxidized chalcopyrite vein (sample 06-MPB-R16) contained an estimated 150 grains of PGM in the pan concentrate. SEM checks on three of these grains indicated that two of them were michenerite (25–50 µm) and the other was tellurobismuthite (Bi_2Te_3), 150 µm in size. Ames et al. (2007) reported finding sperrylite, kotulskite (PdTe), merenskyite ($(Pd(Te,Bi)_2)$), and michenerite (PdBiTe) in a separate heavy mineral concentrate of gossan sample 06-MPB-R01 (Fig. 9).

Gold

Between 31 and 42 gold grains/kg were recovered from the pan concentrate of gossan sample 06-MPB-R01 and 06-MPB-R07 (amphibolite). Gold grains recovered from bedrock samples vary in size from 15 to 150 µm, but most are 50 µm or less. All grains were classified as pristine, using the gold grain shape classification scheme of DiLabio (1990). Ames et al. (2007) reported finding electrum in a second heavy mineral concentrate of gossan sample 06-MPB-R01 (Fig. 9).

Chalcopyrite

Not unexpectedly, hundreds of thousands of chalcopyrite grains/kg were present in the 0.25–0.5 mm heavy mineral concentrate of chalcopyrite vein samples 06-MPB-R16 and gossan sample 06-MPB-R01. All host and background bedrock lithologies at Broken Hammer contain zero to 5 grains/kg, which is considered to be background content in all local lithologies. In general, chalcopyrite is most abundant in the 0.25–0.5 mm fraction, but some samples also contained coarser (0.5–2.0 mm) grains. Chalcopyrite was reported in the PTS of sample 06-MPB-R07 (amphibolite).

Pyrite

Pyrite was recovered from the 0.25–0.5 mm HMC fraction of all bedrock samples, except gossan sample 06-MPB-R01, chalcopyrite vein sample 06-MPB-R16, and amphibolite sample 06-MPB-R07. Samples 06-MPB-R12, -R13, and -R17 contained the most pyrite, 100 to 1000s of grains/kg. In sample 06-MPB-R011, pyrite grains are intergrown with pyrrhotite.

Other minerals

ODM identified trace amounts of other sulphide minerals in the bedrock samples (Appendix B4, worksheet 'Detailed VG'). Galena was recovered from the pan concentrate and millerite was recovered from the 1.0–2.0 mm fraction of gossan sample 06-MPB-R01. Bornite and covellite were reported in the PTS of sample 06-MPB-R07 (amphibolite). Sphalerite was reported in the PTS and millerite was reported in the heavy mineral concentrate of sample 06-MPB-R16 (chalcopyrite vein). Ames et al. (2007) reported finding arsenopyrite and native silver, Se-galena, and cassiterite in a second heavy mineral concentrate that was prepared from gossan sample 06-MPB-R01 (Fig. 9).

Secondary minerals

Jarosite ($KFe_3(SO_4)_2(OH)_6$), chalcocite (Cu_2S), and goethite were recovered from the 0.25–0.5 mm heavy mineral concentrate of sample 06-MPB-R16 (massive chalcopyrite vein). Malachite ($Cu_2(CO_3)(OH)_2$) was recovered from the 0.25–0.5 mm and 0.5–1.0 mm heavy mineral concentrates of sample 06-MPB-R13 (Sudbury breccia).

Epidote

Epidote is both a hydrothermal mineral occurring with quartz ± sulphides in hydrothermal veinlets and cavities in Sudbury rocks (Fig. 10) (e.g. Ames and Tuba, 2015), as well as a product of greenschist-facies regional metamorphism. Epidote was recovered from the heavy mineral concentrates of all bedrock samples except gossan sample 06-MPB-R01, diabase sample 06-MPB-R11, and chalcopyrite vein sample 06-MPB-R16. The highest numbers of grains of epidote per kg were recovered from amphibolite samples 06-MPB-R07 and -R12. Epidote in the bedrock samples is intimately intergrown with other minerals (K-feldspar, chlorite, amphibole, quartz), and many of the epidote grains recovered are composite grains and very inhomogeneous (Fig. 11), especially in sample 06-MPB-R17 (Joe Lake gabbro). Epidote in amphibolite sample 06-MPB-R07 contains chalcopyrite inclusions (Fig. 11). Epidote EMP data are reported in Appendix C2.

Titanite

Titanite can be a primary magmatic phase in intermediate to felsic igneous rocks (e.g. syenite) but is more commonly a product of hydrothermal or regional meta-

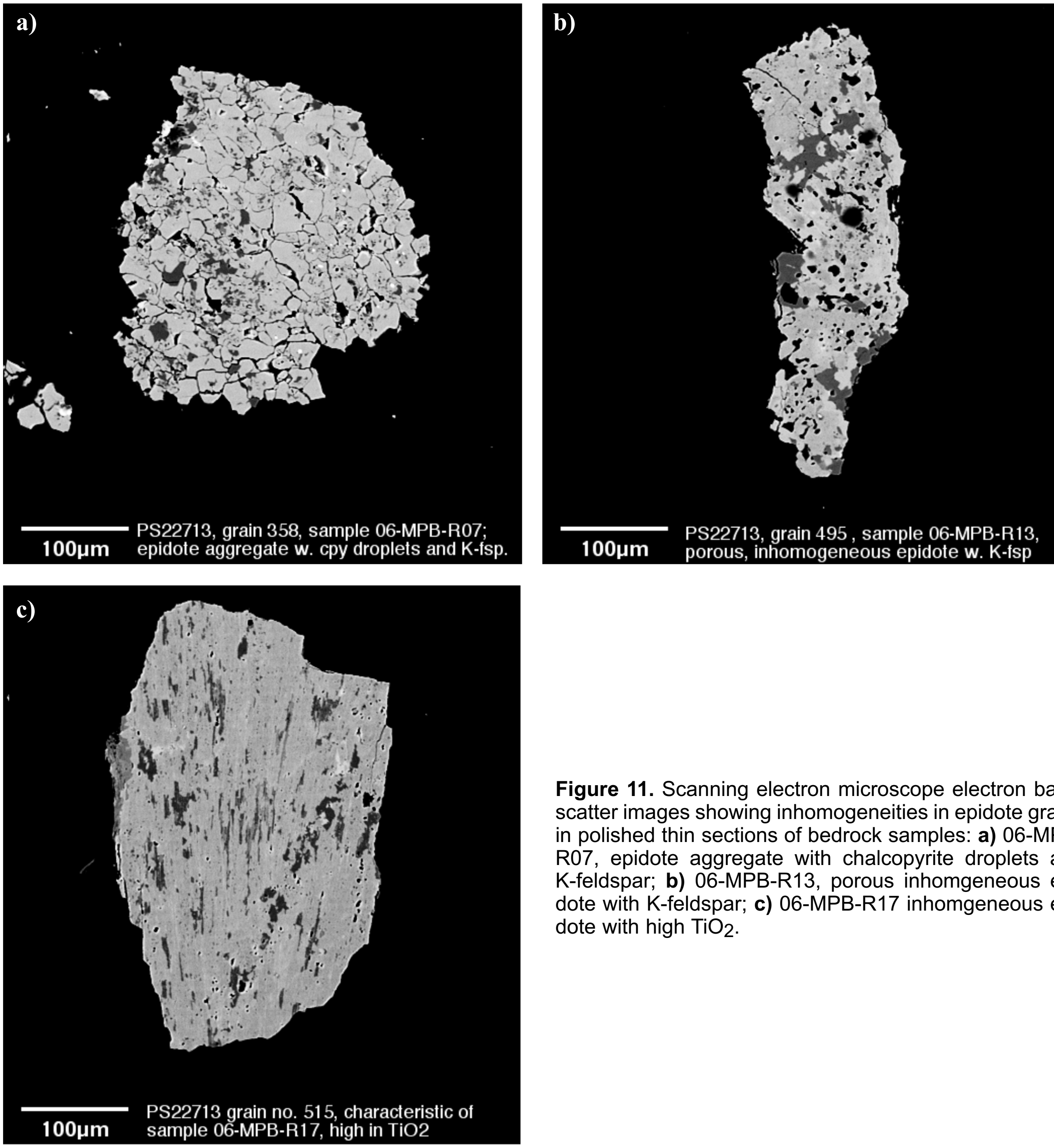

Figure 11. Scanning electron microscope electron backscatter images showing inhomogeneities in epidote grains in polished thin sections of bedrock samples: **a)** 06-MPB-R07, epidote aggregate with chalcopyrite droplets and K-feldspar; **b)** 06-MPB-R13, porous inhomgeneous epidote with K-feldspar; **c)** 06-MPB-R17 inhomgeneous epidote with high TiO_2.

morphic alteration of FeTi-oxides (magnetite, ilmenite) or the breakdown of titanian biotite to chlorite and titanite. The latter is typically very fine grained and not likely to be recovered in the >0.25 mm heavy mineral concentrate examined in this study. Coarser euhedral (hydrothermal) titanite occurs occasionally in amygdule fillings and veins of Sudbury rocks, where it can be zoned with colours ranging from pale to reddish brown. Titanite was only recovered from the 0.25–0.5 mm heavy mineral concentrate of two bedrock samples, 06-MPB-R06 (quartz monzonite) and 06-MPB-R17 (Joe Lake intrusion). These grains had been visually identified as possible ilmenite grains. EMP data for these titanite grains are reported in Appendix C3.

Apatite

Apatite is common as a primary magmatic mineral in SIC rocks, but it may not occur as grains sufficiently large enough to be recovered in the >0.25 mm fraction and its SG of 3.16 to 3.22 is borderline for the SG >3.2 heavy mineral fraction that was examined in this study. However, apatite (>0.25 mm) was recovered from the heavy mineral concentrate of seven bedrock samples. It comprises 30 to 60% of the concentrates of samples 06-MPB-R13 (Sudbury breccia) and 06-MPB-R17 (Joe Lake intrusion), respectively. A few tens of apatite grains were recovered from samples 06-MPB-R06 (quartz monzonite), 06-MPB-R07 and 06-MPB-R12 (both amphibolite), and mineralized Sudbury breccia samples 06AV-54 and 06AV-56. Apatite EMP data are reported in Appendix C4.

Allanite

Allanite ($(Ce,Ca,Y,La)_2(Al,Fe)_3(SiO_4)_3(OH)$) was recovered from one bedrock sample (06-MPB-R13), a sample of Sudbury breccia collected 109 m from mineralization. Allanite is an epidote group mineral that contains a significant amount of rare earth elements. It occurs mainly in metamorphosed clay-rich sedimentary rocks and in felsic igneous rocks. It was initially visually identified as tourmaline in the heavy mineral concentrate of sample 06-MPB-R13. EMP analyses of the grains indicated they were allanite. A total of 15 allanite grains from sample 06-MPB-R13 were analyzed by EMP and the data are reported in Appendix C5.

DISCUSSION

The chalcopyrite vein samples (06-MPB-R01, -R16) contained abundant chalcopyrite ± PGM but were devoid of pyrite and contained none of the other minerals (epidote, titanite, allanite, apatite) examined in this study, which makes it difficult to link these potential indicator minerals to mineralization. The Sudbury Breccia samples (06-MPB-R02, -R04, and -R13) contained comparatively little epidote, apatite, and allanite. The amphibolite samples (06-MPB-R07, -R12) were the most epidote-rich samples and also contained apatite.

Indicator mineral recovery

With the exception of allanite, minerals identified in heavy mineral concentrates (i.e. epidote, apatite, ilmenite, titanite) were also identified in PTS. This similarity demonstrates that the examination of the 0.25–0.5 mm heavy mineral fraction of bedrock samples (100–400 g of sample material) provides sufficient mineralogical information comparable to or even exceeding that obtained from PTS.

Ore minerals

The main metallic minerals identified in mineralized bedrock samples in this study are chalcopyrite and pyrite, with minor PGM and gold. Millerite, galena, and sphalerite were recovered from the gossan and fresh sample of the main chalcopyrite vein. Notable is the inverse correlation of chalcopyrite and pyrite — the typical Sudbury high PGM chalcopyrite veins contain less pyrite than barren bedrock samples.

Samples of the postglacial gossan contained the primary ore minerals chalcopyrite, gold, and sperrylite, as well as secondary minerals goethite, jarosite, and chalcocite, which are typical minerals for the oxidation zone of Cu-sulphide deposits. The well preserved sperrylite in the gossan samples is an indication that this mineral is fairly resistant to surficial weathering and should be found in till.

Non-ore indicator minerals

Epidote, allanite, titanite, and apatite were picked as potential indicator minerals because they are common in Sudbury rocks and could potentially show chemical variations that might be used as vectors to mineralization. Epidote, allanite, and titanite of hydrothermal origin could have been formed by the same fluids that precipitated the sulphide-PGM veins. However, in this study none of these minerals were discovered in the ore-bearing samples and hence a link to mineralization is tenuous.

CONCLUSIONS

This open file describes the indicator mineral data for 9 bedrock samples from the Broken Hammer deposit. Samples of mineralization and surrounding host rocks, though small on number, provide insights into the types and size range of minerals that are indicative of the Cu-PGE mineralization of the Broken Hammer deposit. Both PTS and non-ferromagnetic heavy mineral concentrates were examined because each may provide information on the presence and size of indicator minerals.

Ore minerals seen in bedrock samples include chalcopyrite, pyrite, PGM, and gold. These heavy minerals (Table 1) are visually distinct and easily recovered by common sample processing methods (*cf.* McClenaghan, 2011) used to recover indicator minerals. Galena, millerite, pyrrhotite, and sphalerite were identified in the rocks studied here; however, pyrrhotite, galena and sphalerite are also commonly found in other base metal deposits such as volcanogenic massive sulphide (VMS), sedimentary exhalative (SEDEX), Mississippi Valley type (MVT). and epi- to meso-thermal vein deposits. Only millerite is characteristic (and possibly unique) to magmatic Cu-Ni-PGE deposits such as the Sudbury sharp-walled chalcopyrite veins.

Of the non-ore minerals studied here as potential indicators to ore, only epidote shows some potential because of its common occurrence in hydrothermal assemblages and close relationship to mineralization. However, trace element analyses would have to be performed (preferably by Laser ablation-ICP-MS) to detect elevated levels of Sr, Ni, Pb, Sn, and Co—elements that were identified as potential vectors to mineralization by Ames and Tuba (2015)—in order to distinguish epidote from mineralized assemblages from barren ones. A challenge when examining epidote is the strong and intricate intergrowth of hydrothermal epidote with other minerals such as quartz, titanite, chlorite, K-feldspar, and its compositional inhomogeneities make analyses and discrimination based on composition difficult.

Titanite does not occur consistently and in sufficient amounts in the 0.25–0.5 mm fraction and apatite is considered to be a primary igneous accessory mineral that is not related to hydrothermal activity and ore deposition. Thus, neither mineral was considered to be useful indicators in this study.

ACKNOWLEDGEMENTS

Funding for this study was provided under the Geological Survey of Canada's Targeted Geoscience Initiative 3 (TGI-3) (2005-2010). G. Budulan (U. Ottawa summer student) provided able field assistance in 2006 and completed petrographic descriptions of bedrock samples as part of her B.Sc. thesis. Wallbridge Mining Company Ltd., and, in particular, B. Jago, M. Croteau, and P. Anderson, are thanked for providing access, field support, confidential geological information and samples, and field personnel to assist with the sampling. M. Stewart of Vale is thanked for access to information and samples for the Wisner west area. C. Farrow, FNX Mining Company Inc., is thanked for providing geological discussions and guidance in selecting study sites. A. Plouffe, GSC, is thanked for reviewing the manuscript. Page layout was completed by E. Ambrose.

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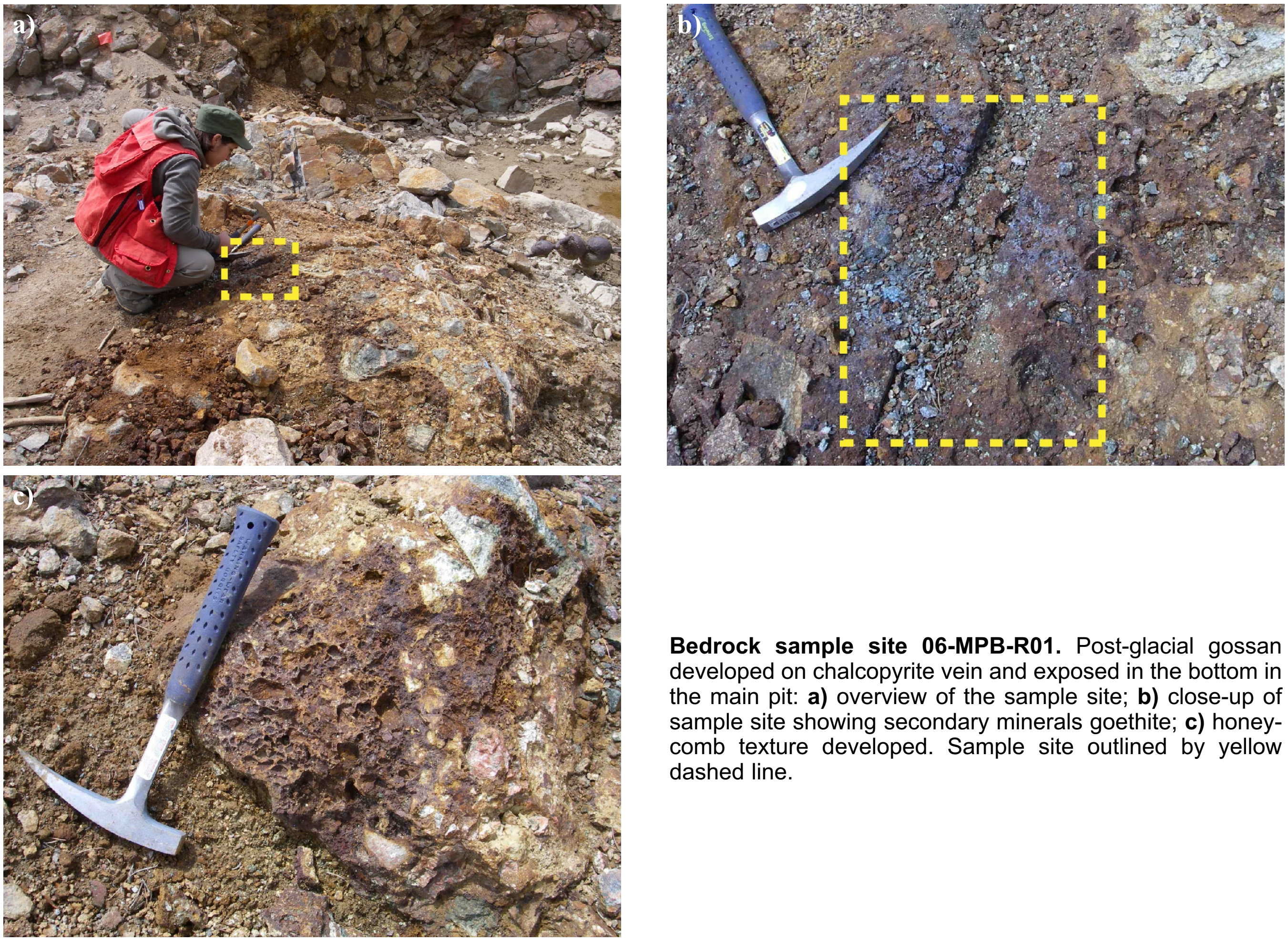
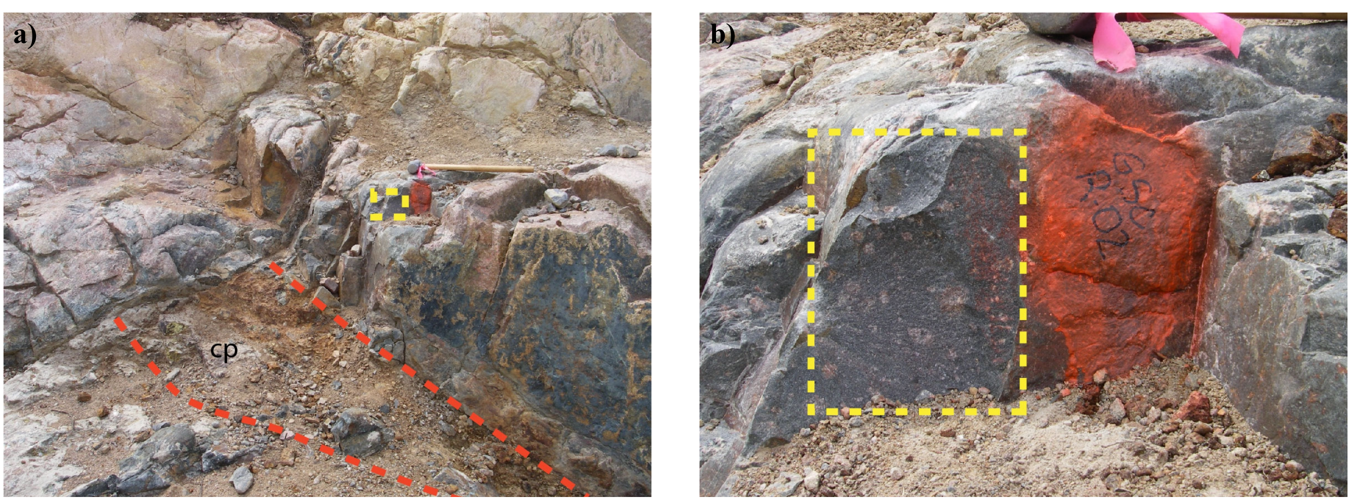
APPENDICES

Appendix A2. Colour photographs of bedrock hand samples.



Bedrock sample site 06-MPB-R01. Post-glacial gossan developed on chalcopyrite vein and exposed in the bottom in the main pit: **a)** overview of the sample site; **b)** close-up of sample site showing secondary minerals goethite; **c)** honey-comb texture developed. Sample site outlined by yellow dashed line.

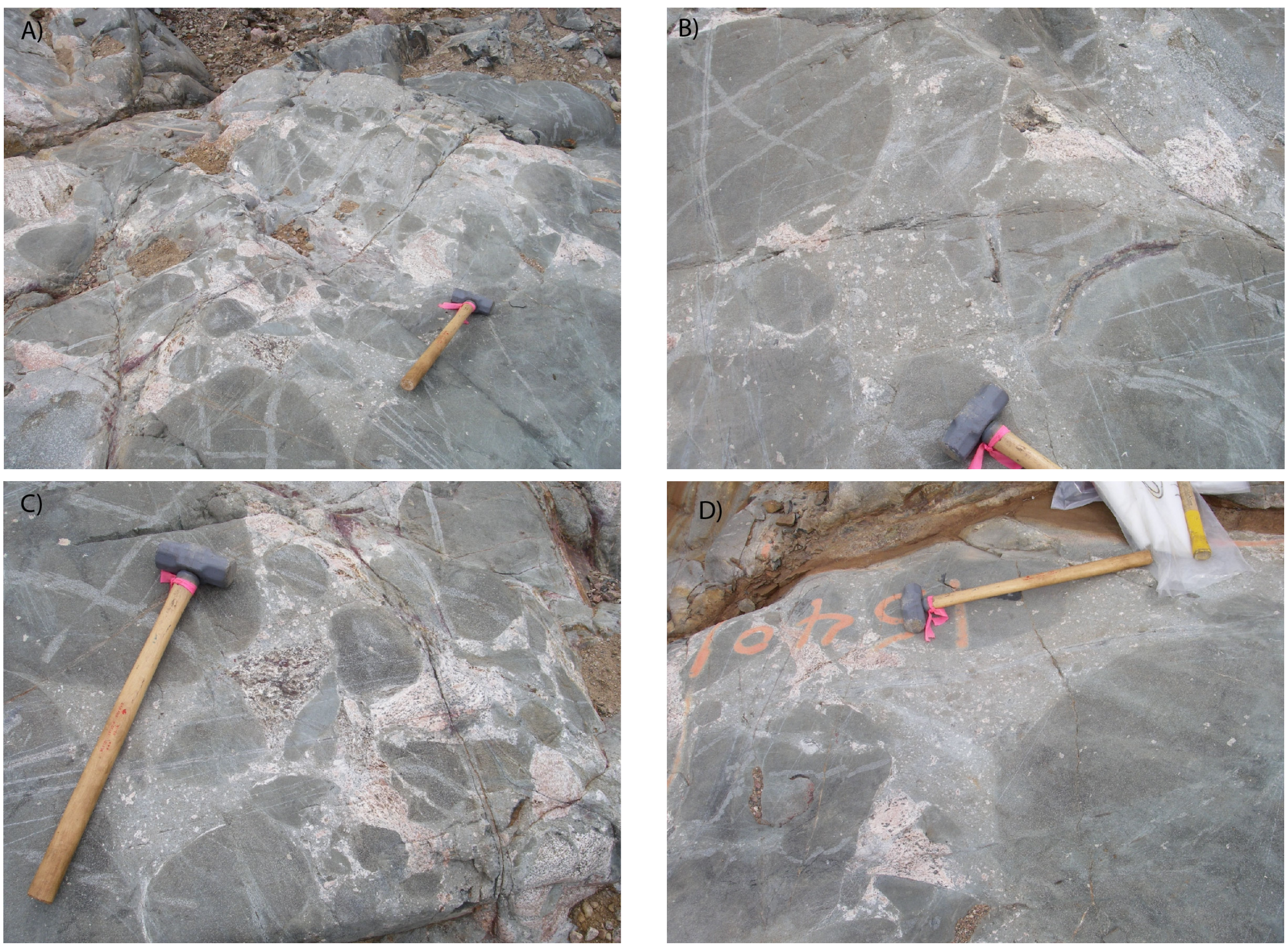


Bedrock sample site 06-MPB-R02. Sudbury breccia 0.3 m from the main chalcopyrite (cp) vein (outlined in red): **a)** overview of the sample site; **b)** close-up of the sample site. Sample site outlined by a yellow dashed line.

Appendix A2 continued.

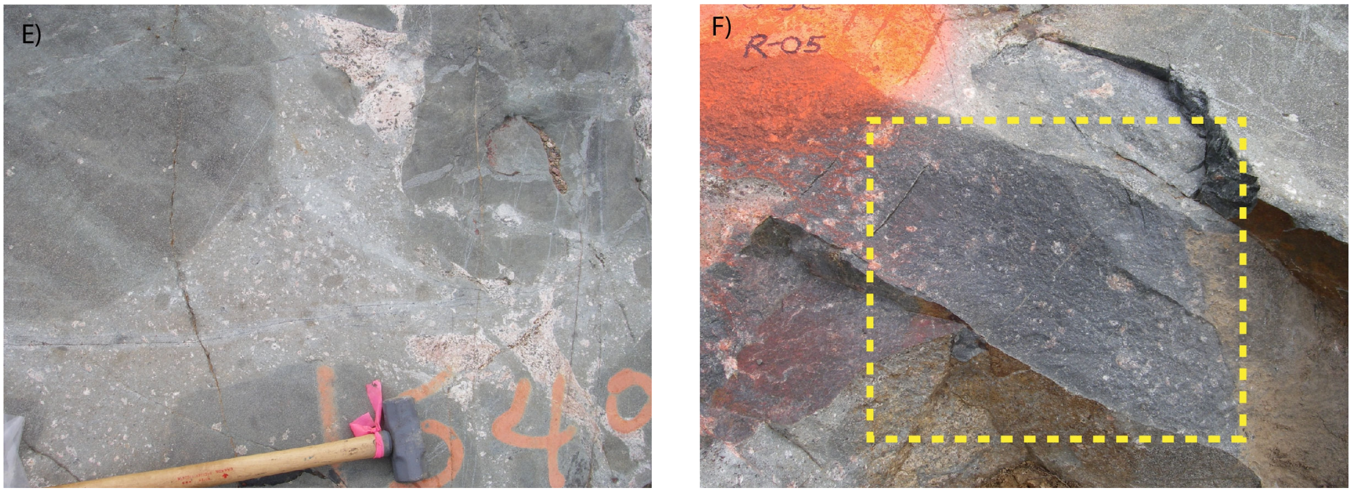
Bedrock sample site 06-MPB-R03. Sudbury breccia 3.0 m from the main chalcopyrite vein. Both the weathered and fresh broken surfaces are visible.

Bedrock sample site 06-MPB-R04. Sudbury breccia 7.5 m from the main chalcopyrite vein.

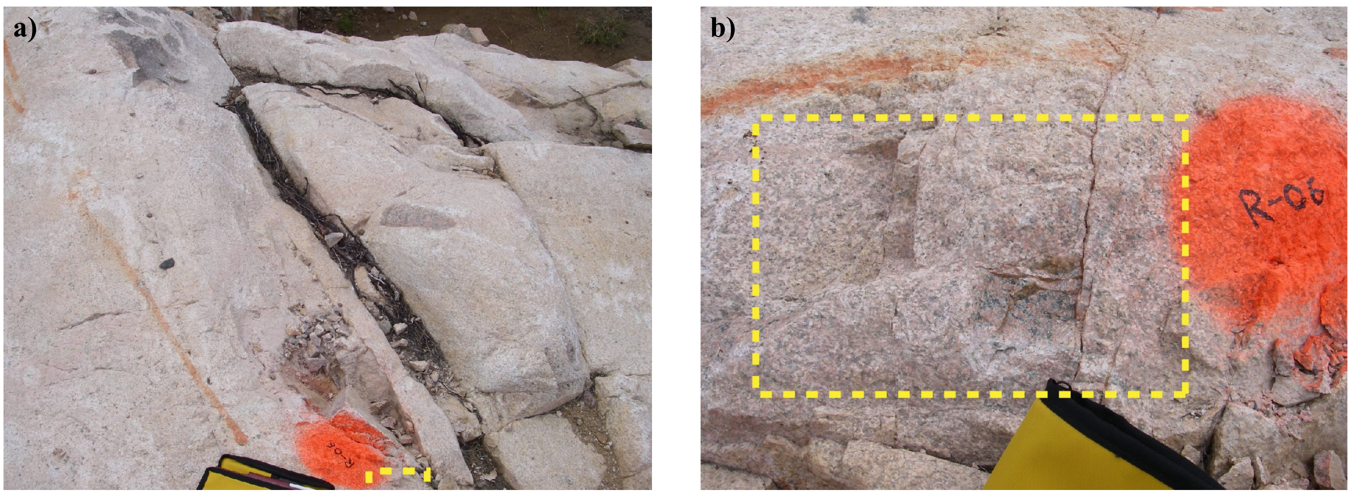


Bedrock sample site 06-MPB-R05. Sudbury breccia 13.75 m from the main chalcopyrite vein. **a–d)** Highly polished surface showing large clasts in a breccia matrix.

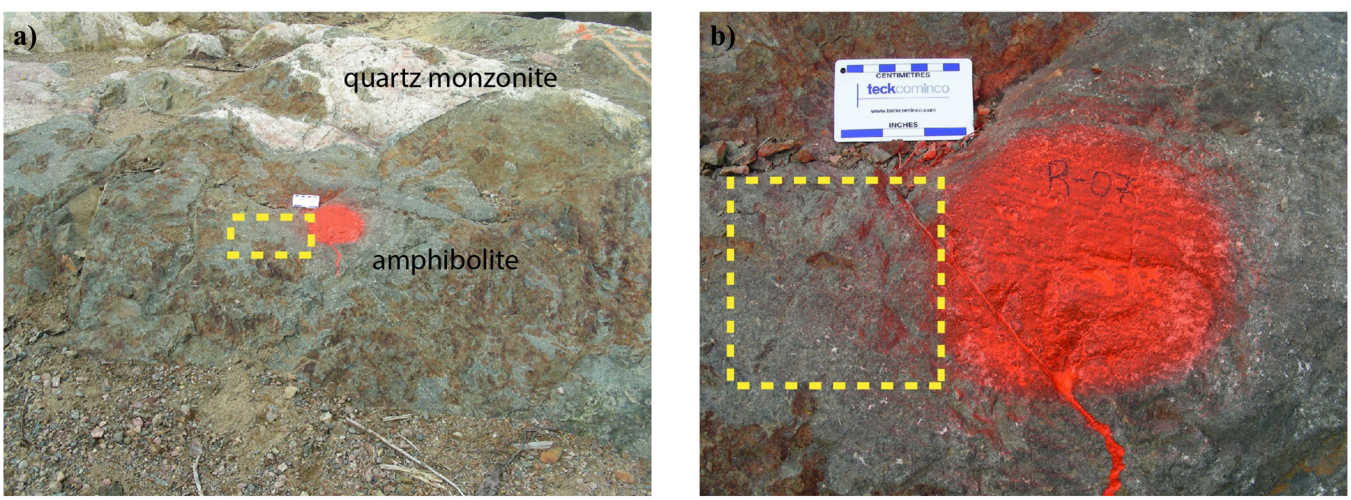
Appendix A2 continued.



Bedrock sample site 06-MPB-R05 continued. e) Highly polished surface showing large clasts in a breccia matrix; **f)** close-up of the freshly broken surface of the sample site. Yellow dashed line outlines the sample site.

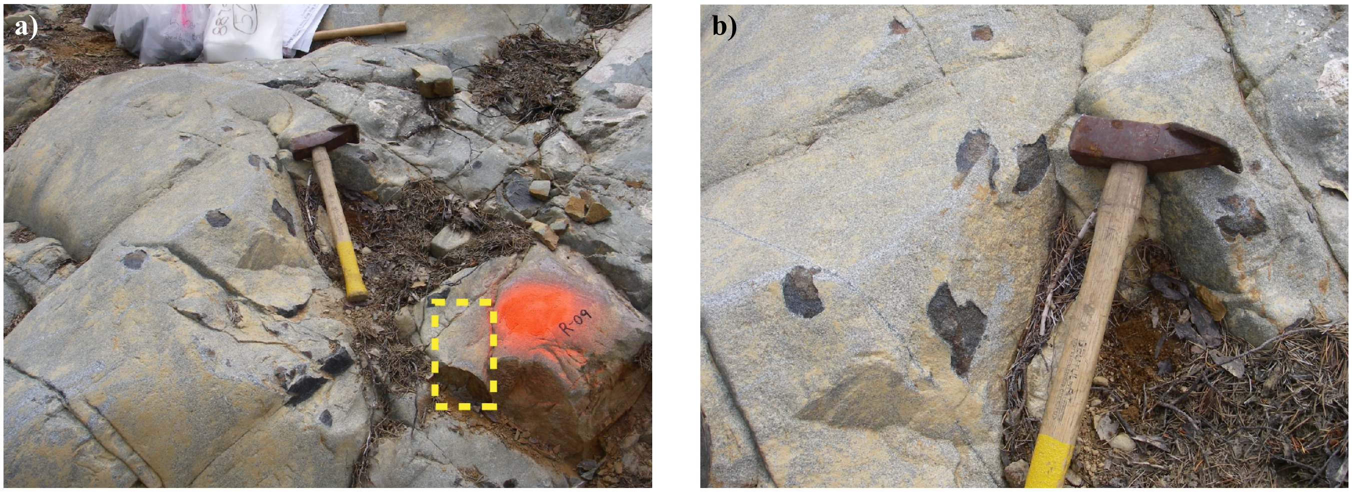


Bedrock sample site 06-MPB-R06. Quartz monzonite: **a)** overview of the site; **b)** close-up of the sample site. Yellow dashed line outlines the sample location.



Bedrock sample site 06-MPB-R07. Large amphibolite xenolith in quartz monzonite: **a)** overview of the site; **b)** close-up of the sample site, which is outlined by yellow dashed line in both photographs.

Appendix A2 continued.



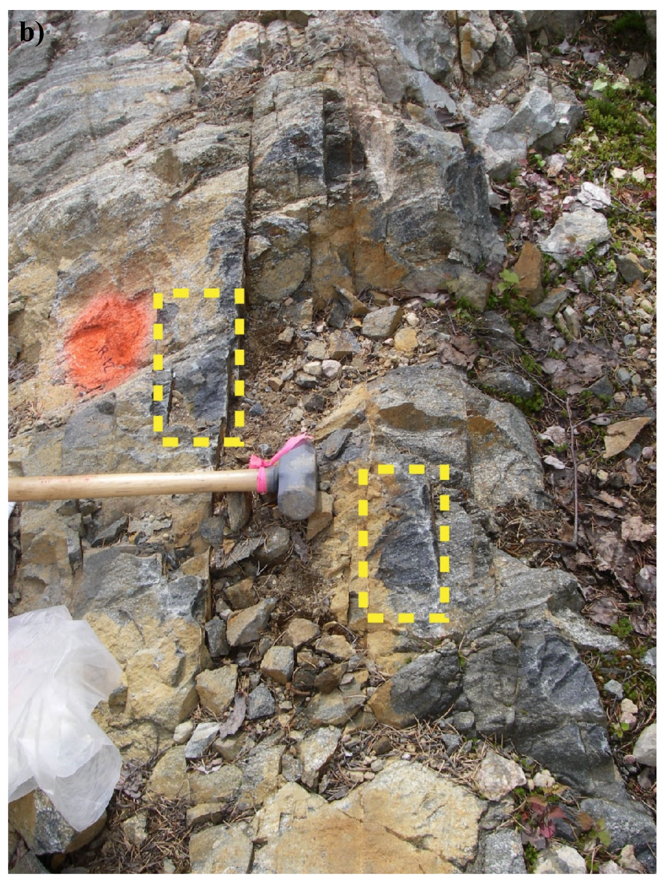
Bedrock sample site 06-MPB-R09. Non-porphyritic diabase: **a)** overview of the sample site, which is outlined by the yellow dashed line; **b)** close-up of the outcrop that was sampled.

Bedrock sample site 06-MPB-R10. Sudbury breccia, 66 m from the main chalcopyrite (cp) vein. **a–c)** Quartz monzonite clasts (pink) in a breccia, which is visible on various parts of the outcrop. Sample site is outline by a yellow dashed line.

Appendix A2 continued.

Bedrock sample site 06-MPB-R11. Porphyritic Matachewan diabase.

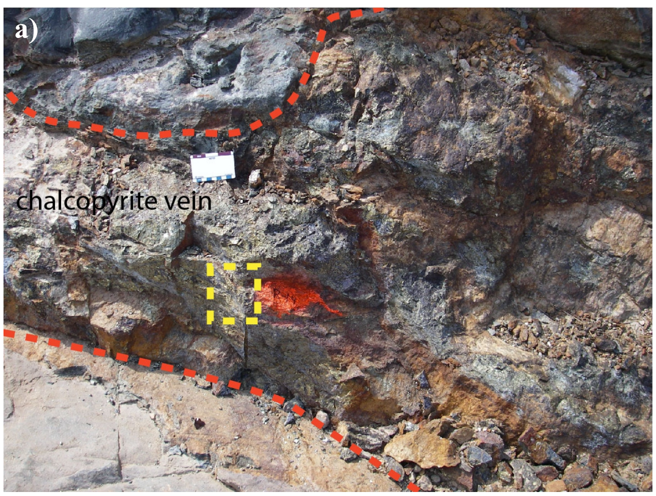
Bedrock sample site 06-MPB-R13. Sudbury breccia 109 m from the main chalcopyrite vein. Sample site is outlined by a yellow dashed line.

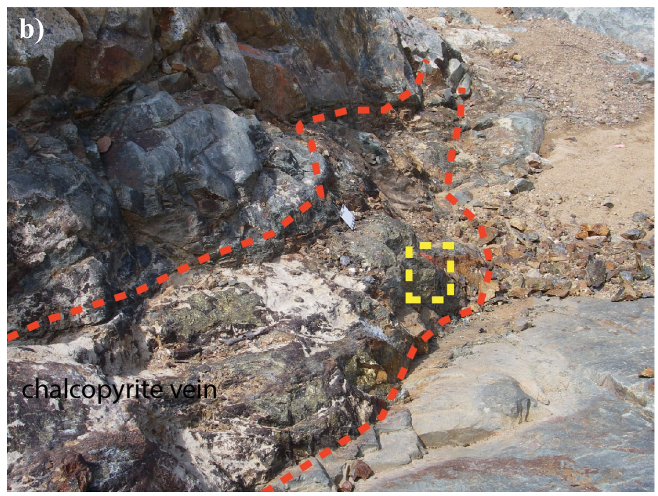


Bedrock sample site 06-MPB-R12. Amphibolite xenolith. Sample site is outlined by a yellow dashed line.

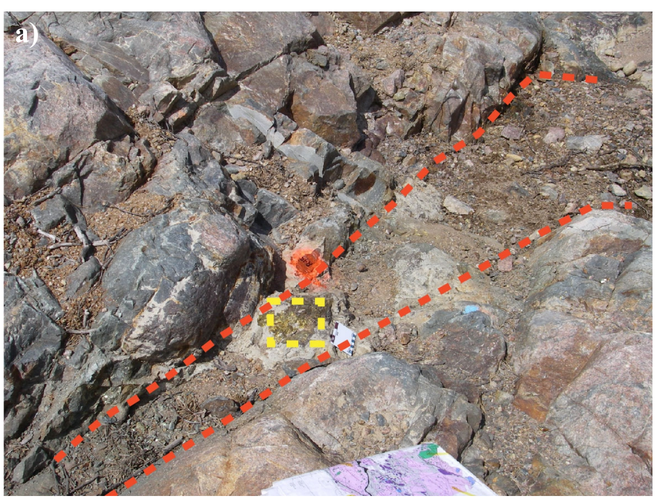
Appendix A2 continued.

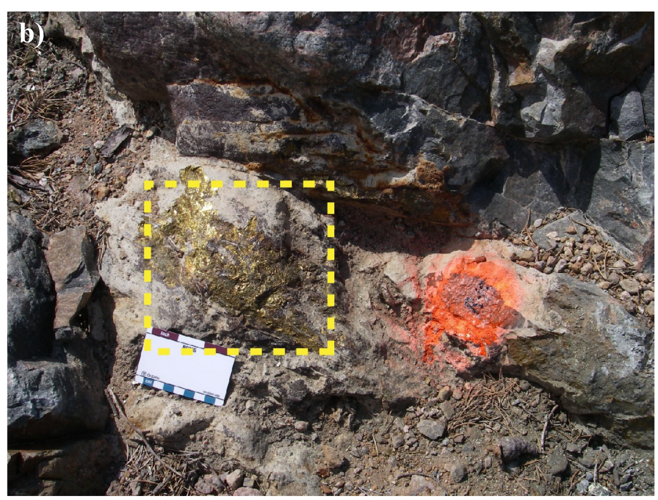
Bedrock sample site 06-MPB-R13. Sudbury breccia 109 m from the main chalcopyrite vein. Sample site is outlined by a yellow dashed line.





Bedrock sample site 06-MPB-R14. Main chalcopyrite vein (outlined in red): the sample site is outlined by a yellow dashed line.





Bedrock sample site 06-MPB-R15. Main chalcopyrite vein (outlined in red): the sample site is outlined by a yellow dashed line.

Appendix A2 continued.

Bedrock sample site 06-MPB-R16. Main chalcopyrite vein is outlined by a red dashed line; sample site is outlined by a yellow dashed line.

Appendix B. Bedrock sample descriptions

Appendix B1. *Binocular microscope descriptions of bedrock hand sample descriptions completed by S. Averill, Overburden Drilling Management.*

Sample 06MPB-R01 Sulphide breccia. Gossan consisting of 30% fresh, coarse-grained (<1 cm) chalcopyrite cemented by secondary goethite with some adhering overburden pebbles and sand grains. Other less stable sulphides destroyed by weathering.

Sample 06MBP-R02 Metabreccia. 15% small (0.5–15 mm), rounded to irregularly bounded fragments of coarse-grained (1–3 mm), pink granitic gneiss in a nonmagnetic, medium grey-green, finely inequigranular (aphanitic to 0.2 mm), granoblastic, felsic, unfoliated, autogenous but less felsic (quartzo-feldspathic with 20% visible chlorite) tectonic rock-flour matrix. Trace disseminated chalcopyrite.

Sample 06MPB-R04 Metabreccia. 20% small (0.5–15 mm), rounded to irregularly bounded and wispy fragments of mostly coarse-grained (1–3 mm), massive granitic gneiss neosome, but locally of finer grained (0.3–0.5 mm), more mafic (30% chlorite) paleosome, in a nonmagnetic, medium grey-green, finely inequigranular (aphanitic to 0.3 mm), unfoliated, granoblastic, autogenous but less felsic (quartzo-feldspathic with 20% visible chlorite and no calcite) tectonic rock-flour matrix. Unmineralized.

Sample 06MPB-R06 Quartz monzonite. Pink, moderately foliated, weakly magnetic, aphyric, coarse-grained (2–3 mm) rock consisting of 70% subhedral, pink to white, perthitic to saussuritized feldspar, 25% quartz, 5% chlorite, no epidote or calcite, 0.1% finely disseminated magnetite and 0.1% leucoxene. Unmineralized.

Sample 06MPB-R07 Amphibolite. Mottled dark grey-green and white, massive, coarse-grained (0.5–1.5 mm) rock consisting of 40–50% fibrous grey-green amphibole (probably actinolite), 15% biotite, 20% saussuritized plagioclase + epidote, 15% interstitial magnetite and 3% emerald green to blue-green celadonite mica (SEM confirmed). Unmineralized.

Sample 06MPB-R08 Metagabbro. Speckled dark green and white, weakly foliated, moderately magnetic, coarse-grained (1–2 mm), aphyric rock consisting of 15% primary biotite, 20% secondary (after augite) chlorite + hornblende/actinolite, 60% saussuritized plagioclase, <1% quartz, no calcite, 2% disseminated magnetite, trace titanite, 0.2% finely disseminated pyrite and trace chalcopyrite.

Sample 06MPB-R11 Diabase. Dark grey-black, massive, strongly magnetic, unmetamorphosed, relatively fine-grained (0.3–0.5 mm) rock consisting of subequally of fresh plagioclase and grey-green clinopyroxene (probably augite) with 10% biotite, no discernible olivine or quartz, 7% interstitial magnetite, and 1% interstitial Fe-sulphides (pyrrhotite with subordinate pyrite).

Sample 06MPB-R12 Amphibolite. Finely speckled dark green and white, strongly foliated, moderately magnetic, aphyric, medium-grained (0.5–1 mm) rock consisting of 40% plagioclase, 25% pale green diopside (SEM confirmed), 20% primary dark green-black hornblende (SEM confirmed), 15% biotite, 1% quartz, no calcite, and 1% each finely disseminated magnetite and pyrite.

Sample 06MPB-R13 Metabreccia. 20% very small (0.5–10 mm), mostly monomineralic (quartz or feldspar), rounded to irregularly bounded, pink granite gneiss fragments in a medium grey-green, variably magnetic, finely inequigranular (aphanitic to 0.1 mm), unfoliated, autogenous but less felsic (cherty with 10% visible chlorite, and 2% finely disseminated magnetite) tectonic rock-flour matrix. 0.5% fine-grained pyrite clustered in extra cherty spots suggesting, together with the disseminated magnetite, that the original protolith of the granitic gneiss was cherty iron formation.

Sample 06MPB-R16 Massive chalcopyrite. Very coarse-grained (3–5 mm), fresh with patchy indigo oxidation film. No other sulphides or host rock present.

Sample 06MPB-R17 Metagabbro. Speckled dark green and white, moderately foliated, moderately magnetic, weakly phyric rock consisting of 1% augite phenocrysts of 5 mm size in a coarse-grained (1–2 mm) ground-

Appendix B1 continued.

mass of 60% fresh to saussuritized, anhedral plagioclase, 35% augite, 5% chlorite, trace quartz, no calcite, 1% interstitial magnetite, and 0.1% disseminated pyrite.

Sample 05AV-23 Metabreccia. Sparse (10%), small (0.5–2.0 mm), irregularly bounded to wispy fragments of coarse-grained (0.5–1.0 mm), pink, foliated granitic gneiss in a nonmagnetic, medium grey-green, finely inequigranular (aphanitic to 0.3 mm), unfoliated, granoblastic, autogenous but less felsic (quartzo-feldspathic with 20% visible chlorite or locally biotite) tectonic rock-flour matrix. Cut by one 2 cm dyke of fresh, medium-grained (0.5 mm) diorite-gabbro (70% plagioclase, 30% diopside, trace magnetite) and a 0.5 mm dykelet of pink granophyre. 3% mm-scale stockwork sulphide veinlets consisting of coarse-grained (1–5 mm) chalcopyrite with subordinate millerite (SEM confirmed; contains hessite inclusions) and trace acicular actinolite alteration (SEM confirmed).

Sample 06AV-54 Metabreccia. 30% small to large (0.5 to >100 mm), irregularly bounded to wispy fragments of very coarse-grained (2 mm to pegmatitic; therefor essentially unfoliated) pink granitic gneiss with 0.5% leucoxene/titanite alteration in a nonmagnetic, medium grey-green, finely inequigranular (aphanitic to 0.3 mm), unfoliated, granoblastic, autogenous but less felsic (quartzo-feldspathic with 20% visible chlorite) tectonic rock-flour matrix. 0.1% disseminated chalcopyrite.

Sample 06AV-56 Metabreccia. Moderately magnetic, incompletely tectonized and brecciated; therefor fragments grade both texturally and mineralogically into matrix and matrix is streaky and foliated rather than massive. 30% granitic gneiss fragments/streaks 0.5–50 mm long and up to 10 mm wide in a medium grey-green, finely inequigranular (aphanitic to 0.3 mm), autogenous but less felsic (quartzo-feldspathic with 30% visible chlorite) tectonic matrix. 1% each of fine- to medium-grained (0.1 to 0.5 mm) magnetite and chalcopyrite concentrated along irregular contacts between fragments and matrix.

Appendix B2. Petrographic descriptions of polished thin sections of bedrock samples completed by G. Budulan.

Sample 06-MPB-R04

Rock Type: Sudbury breccia
Sample Location: Broken Hammer, 7.5 m from the main sulphide vein

Polished Thin Section Composition:

Silicate Minerals: 97%

Percent	Mineral	Shape	Size (mm)
57	Matrix	Anhedral	< 0.1
19	Quartz	Anhedral	0.5–6
10	Plagioclase	Anhedral	0.5–6
7	Alkali feldspar	Anhedral	0.5–6
4	Biotite	Anhedral	<0.1–0.5

Opaque Minerals: 3%

Percent	Mineral	Shape	Size (mm)
1	Pyrite	Subhedral-anhedral	<0.1
1	Oxides	Anhedral	<0.1
0.5	Magnetite	Euhedral	<0.1
0.5	Ilmenite	Anhedral	<0.1

Matrix vs Fragments: 60:40

Polished Thin Section Description:

- Matrix: quartz, epidote (1%), biotite (4%), amphibole (3%), chlorite (3%), feldspar
- Biotite: greenish to brown
- Quartz fragments: recrystallized, brecciated
- Feldspar fragments: recrystallized, brecciated, microcline (tartan twinning), albite and Carlsbad twinning
- Chlorite: green therefore rich in magnesium and high in Ni (note: if Berlin blue=Fe-rich)
- Oxides: red, possibly sphene/leucoxene
- Biotite wrapping around chlorite, possible replacement
- Biotite and epidote surrounding quartz
- Alterations: chlorite to biotite
  pyroxene to amphibole-pyroxene no longer present

Appendix B1 continued.

Sample 06-MPB-R06a

Rock Type: Quartz monzonite
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 98.5%

Percent	Mineral	Shape	Size (mm)
35	Plagioclaseioclase	Subhedral-euhedral	1–5
35	Quartz	Subhedral-anhedral	1–5
15	Alkali feldspar	Subhedral-euhedral	1–5
3	Chlorite	Anhedral	0.2
2	Epidote	Subhedral-anhedral	0.1
1	Biotite	Subhedral-anhedral	0.2
0.5	Titanite	Subhedral-anhedral	0.5
<0.5	Apatite	Subhedral-euhedral	0.2

Opaque Minerals: 1.5%

Percent	Mineral	Shape	Size (mm)
1	Magnetite	Subhedral-anhedral	0.1–0.8
0.5	Pyrite	Anhedral-euhedral	0.1–0.8

Polished Thin Section Description:

- Quartz: conpolygonal (1 crystal that recrystallized with triple junctions)
- Feldspar-plagioclase and minor microcline: Carlsbad twinning, plagioclase laths, recrystallized
- Chlorite: bluish grey and brown/green, alteration product (pyroxene → amphibole → chlorite)
- Biotite: greenish brown
- Epidote: zoned
- Oxide and grey (magnetite?) rim around pyrite
- Plagioclase altering to sericite (sericite = ~7% of plagioclase), very fine-grained
- Perthitic textures (exsolution lamellae)
- Granophyric texture found around quartz clusters surrounded by sericite, feather-like texture
- Quartz seems to be elongated along the top of the slide and oriented at about 35°NW with N being the top of the slide
- Reaction rim around magnetite, possibly clinozoisite (lighter than epidote)
- Chlorite rim around magnetite

Appendix B1 continued.

Sample 06-MPB-R06b

Rock Type: Quartz monzonite
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 97.5%

Percent	Mineral	Shape	Size (mm)
50	Plagioclase	Anhedral-euhedral	1–5
35	Quartz	Anhedral-subhedral	2–5
6	Alkali feldspar	Anhedral-euhedral	1–5
2	Chlorite	Anhedral	0.2–1
1	Biotite	Subhedral-anhedral	0.2–1
1	Epidote	Subhedral-euhedral	0.1
1	Clinozoisite	Subhedral-euhedral	0.1–0.3
1	Titanite	Subhedral-euhedral	0.1
0.5	Apatite	Euhedral	0.2

Opaque Minerals: 2.5%

Percent	Mineral	Shape	Size (mm)
2	Magnetite	Subhedral-anhedral	0.2–1
<0.5	Chalcopyrite	Anhedral	0.1
<0.5	Pyrite	Subhedral-anhedral	0.1

Polished Thin Section Description:

- Feldspar: mostly plagioclase with some microcline, Carlsbad and tartan twinning
  -perthitic texture, larger feldspar grains contain perthite (exsolution lamellae) and epidote in fractures, more present than 06-MPB-R06a
  -large grains are recrystallized into finer (<1 mm) laths and anhedral to subhedral grains, some radiating plagioclase laths
  -altering to sericite and sausserite
- Quartz: conpolygonal (1 larger crystal that has recrystallized showing triple junctions), some contain cloudy dark brown centres
- Chlorite: green, brown, and blue coloured grains (Fe- and Mg-rich), altering to biotite
- Biotite: green, displays similar orientation as the quartz in 06-MPB-R06a in the top half of the slide; no preferred orientation in the bottom portion of the slide
- Clinozoisite: pink/yellow in colour
- Granophyric texture at the interface between quartz and feldspar

Appendix B1 continued.

Sample 06-MPB-R07

Rock Type: Amphibolite
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 79%

Percent	Mineral	Shape	Size (mm)
55	Amphibole	Subhedral-anhedral	0.2–3
10	Biotite	Subhedral-euhedral	0.1–1
10	Apatite	Subhedral-euhedral	0.05–0.2
5	Sericite	Anhedral	0.2–3
2	Plagioclase	Anhedral	0.2–2.5
1	Sausserite	Anhedral	0.2–1.5

Opaque Minerals: 19%

Percent	Mineral	Shape	Size (mm)
15	Magnetite	Euhedral	0.1–2
3	Ilmenite	Anhedral	0.2
<0.5	Chalcopyrite	Subhedral-anhedral	<0.1
<0.5	Bornite	Anhedral	<0.1
<0.5	Covelite	Anhedral	<0.1
<0.5	Pyrite	Euhedral	<0.1

Polished Thin Section Description:

- Amph-2 types:1) green: 0.5–3mm, possibly hornblende, anhedral, ~20%, altered from clinopyroxene
  2) brown: 0.2–3mm, possibly anthophylite, bladed, subhedral-euhedral, altered from pyroxene, altering tobiotite
- Biotite-altering to unknown cloudy material, possibly a clay mineral, biotite perpendicularly crosscuts amphibole
- Plagioclase: mostly altered to sericite (white/grey)
- Chalcopyrite: very little present and is usually surrounded by magnetite
- Magnetite: sometimes surrounded by ilmenite, which is itself surrounded by an Fe-oxide, magnetite grains are very fractured but show a euhedral and octahedral shape
- Sulphides were emplaced post amphibole since they are formed on top of the amphibole and the amphibole does not wrap around the sulphides

Appendix B1 continued.

Sample 06-MPB-R08

Rock Type: Gabbro
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 93%

Percent	Mineral	Shape	Size (mm)
56	Plagioclase	Anhedral	<0.1–2
25	Pyroxene	Anhedral-euhedral	0.5–1
10	Amphibole	Subhedral-euhedral	0.1–0.5
2	Apatite	Euhedral	0.1

Opaque Minerals: 7%

Percent	Mineral	Shape	Size (mm)
5	Magnetite	Anhedral-euhedral	0.1–0.8
1	Ilmenite	Lamellae	<0.05
1	Pyrite	Anhedral-euhedral	0.05–0.5

Polished Thin Section Description:

- Plagioclase: some is albite, rimmed and partly altered to sausserite (epidote), appear as fine-grained crystals but on a larger view these small grains are part of larger recrystallized laths, mottled
- Apatite throughout slide
- Pyroxene: altering to amphibole (amphibole coronas) and amphibole altering to biotite
- Magnetite with ilmenite lamellae, magnetite within pyroxene

Appendix B1 continued.

Sample 06-MPB-R11

Rock Type: Matachewan diabase dyke
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 93%

Percent	Mineral	Shape	Size (mm)
45	Plagioclase	Subhedral-euhedral	0.1–1.5
40	Pyroxene	Subhedral-anhedral	0.2–1
4	Amphibole	Subhedral-anhedral	0.2–1
2	Sausserite	Anhedral	<0.1
1	Biotite	Euhedral	0.2–1
0.5	Apatite	Euhedral	<0.1
0.5	Unidentified Blades	Euhedral	<0.4

Opaque Minerals: 7%

Percent	Mineral	Shape	Size (mm)
6	Magnetite	Subhedral-anhedral	0.1–1
1	Pyrite	Subhedral-euhedral	0.1–2

Polished Thin Section Description:

- Plagioclase: recrystallized laths forming subophitic texture, looks fine-grained (<0.1) on close inspection but when zoom out it is actually larger recrystallized laths, partially altering to sericite
- Pyroxene: altered, cloudy, pyroxene crosscut by plagioclase
- Biotite: brown
- Amphibole: orange→ brown
- Opaque minerals: surrounded by amphibole, present in pyroxene
- Magnetic

Appendix B1 continued.

Sample 06-MPB-R12

Rock Type: Amphibolite
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 97.5%

Percent	Mineral	Shape	Size (mm)
47	Plagioclaseioclase	Anhedral	0.5-1.5
25	Amphibole	Anhedral-euhedral	0.2-2
15	Pyroxene	Anhedral-subhedral	0.3-1
5	Biotite	Subhedral-euhedral	0.2-2
4.5	Chlorite	Anhedral	0.2-1
1	Apatite	Euhedral	<0.1

Opaque Minerals: 2.5%

Percent	Mineral	Shape	Size (mm)
2	Magnetite	Anhedral-euhedral	<0.2
0.5	Pyrite	Anhedral-subhedral	<0.1

Polished Thin Section Description:

- Less altered, more felsics and fewer sulphides than sample 06-MPB-R07
- Biotite: dark brown, alteration of amphibole, altering to chlorite, mostly oriented E-W along PTS, foliated
- Plagioclase: albite and Carlsbad twins
- Pyroxene: similar to gabbro sample, pyroxene altering to amphibole, amphibole corona around pyroxene
- Amphibole: 2 types: 1) brown, tabular, 5%, altering tobiotite
  2) green, blocky, 20%, possibly hornblende?
- Pyrite: surrounded by magnetite (intergrowth of magnetite and pyrite) and also occur as separate grains

Sample 06-MPB-R16

Rock Type: Massive sulphide ore
Sample Location: Broken Hammer

Polished Thin Section Composition:

Silicate Minerals: 0%
Opaque Minerals: 100%

Percent	Mineral	Shape	Size (mm)
94.5	Chalcopyrite	Massive	Massive
4	Magnetite	Euhedral	0.1–1
0.5	Sphalerite	Anhedral	<0.2
0.5	Unknown 1	Euhedral	0.2
0.5	Unknown 2	Anhedral	0.1

Polished Thin Section Description:

- Chalcopyrite: massive ore vein, no individual grains
- Sphalerite: 1 grain, may be more smaller grains
- Unknown 1: very white mineral, hexagonal, similar hardness to chalcopyrite
- Unknown 2: light grey mineral attached to Unknown 1

Appendix B1 continued.

Sample 06-MPB-R17

Rock Type: Joe Lake intrusion
Sample Location: South of Broken Hammer - Joe Lake intrusion

Polished Thin Section Composition:

Silicate Minerals: 95%

Percent	Mineral	Shape	Size (mm)
55	Plagioclase	Andedral	2–5
20	Chlorite	Anhedral	0.1–2
10	Amphibole	Subhedral-anhedral	0.2–4.5
8	Pyroxene	Anhedral-euhedral	0.1–1
2	Apatite	Subhedral-euhedral	0.2–0.8

Opaque Minerals: 5%

Percent	Mineral	Shape	Size (mm)
4	Magnetite	Anhedral-subhedral	0.1–4
0.5	Ilmenite	Anhedral	<0.1
0.5	Pyrite	Subhedral-euhedral	<0.1

Polished Thin Section Description:

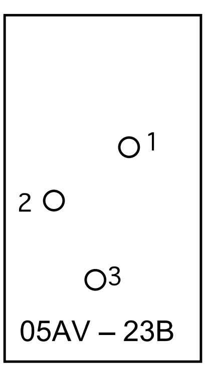
- Plagioclase: large (2–5mm) crystals that have been recrystallized, these large crystals are composed of many smaller (<0.1–0.5) euhedral crystals, altering to sericite
- Amphibole: brown, altering to biotite and clay (talc?) (corona)
- Pyroxene: altering to chlorite and amphibole (corona)
- Magnetite: with ilmenite lamellae, fractured, occurs within and along grain boundaries of amphibole and pyroxene

Appendix B3. Petrographic descriptions of polished thin sections of AV-series bedrock samples completed by I.M. Kjarsgaard.

Sample 05AV-23B

Lithology: Pseudotachylite with chalcopyrite and millerite
Location: McCreedy West PM zone
Description: inhomogeneous rock with rounded patches of granoblastic quartz and rare emulsion textured intergrowths of medium-grained chalcopyrite with euhedral amphibole ± epidote in fine-grained plagioclase-epidote-actinolite matrix with poikilitic biotite, minor altered ilmenite, and trace zircon and apatite

Quartz (5%) clear, anhedral, medium-grained, in granoblastic patches in fine-grained matrix
K-feldspar (23%) as fine-grained, clear, euhedral to subhedral, tabular grains in pockets associated with clear granoblastic quartz, in emulsion-textured intergrowth with chalcopyrite and epidote; as abundant fine-grained tabular grains in matrix
Plagioclase (Albite ?) (30%) anhedral masses with brownish hue due to alteration (kaolinite-sericite) intergrown with actinolite and clinopyroxene in matrix
Actinolitic Hornblende (5%) 1) medium-grained (pale) green pleochlorite euhedral, elongate, prismatic grains intergrown with chalcopyrite and epidote; 2) rare, fine-grained colourless to pale green acicular aggregates and pseudomorphs in fine-grained matrix
Diopside (10%) fine-grained granular rounded (drop-like) grains intergrown with quartz-feldspar in fine-grained matrix
Epidote (1%) fine-grained, anhedral poikilitic in emulsion-textured intergrowth with chalcopyrite
Biotite (10%) ± chlorite-titanite altered, medium-grained tan pleochroic, poikilitic grains intergrown with quartz-fedlspar in matrix
Chlorite (15%) fine-grained, green pleochlorite with intense blue interference colour, pseudomorph after biotite with very fine-grained titanite inclusions in between sheets
Titanite (tr.) fine-grained anhedral in chlorite-pseudomorphs; discrete grains (up to 90 µm) are rare
Zircon (tr.) fine-grained subhedral brownish, zoned grain with very high relief in feldspar-epidote-actinolite-matrix
Ilmenite (tr.) fine-grained subhedral rounded grains disseminated in matrix; larger rounded altered grains form aggregates, fresh, pinkish grey in reflected light
Apatite (tr.) fine-grained (up to 200 µm) rounded grains with inclusions in plagioclase matrix
Chalcopyrite (1%) anhedral, coarser, intergrown with euhedral actinolite and interstitial to granoblastic quartz, fine-grained in emulsion textured intergrown with K-feldspar
UM1 (tr.) anhedral, cream coloured mineral (darker than millerite, not anisotropic) slightly altered with funny texture intergrown with chalcopyrite
Millerite (tr.) cream coloured anhedral-subhedral inclusions in chalcopyrite
Pyrite (tr.) fine-grained euhedral grains in gangue



1) rare euhedral titanite (~80 um) and rounded ilmenite in fine-grained chlorite-epidote-feldspar matrix
2) millerite intergrown with and sphalerite in chalcopyrite
3) UM1 intergrown with chalcopyrite and coarse amphibole and epidote

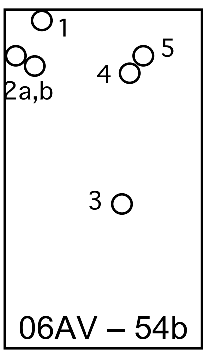
Appendix B3 continued.

Sample 06AV-54b

Locality: Wisner-West
Lithology: granophyre with trace chalcopyrite and pyrite

Chalcopyrite (tr.) traces interstitial to silicates and in epidote
Pyrite (tr.) tiny, anhedral to rare euhedral, cream grains in gangue or chalcopyrite
Hematite (tr.) rimming chalcopyrite
Ilmenite/hematite (tr.) heavily altered grains and pseudomorphs

Gangue (95%)
Quartz (20%) as coarse, deformed, anhedral grains and in graphic intergrowths with K-feldspar
K-Feldspar (30%) in graphic intergrowth with quartz and coarse euhedral overgrowths
Plag (30%) coarse, euhedral to subhedral, zoned crystals intergrown with quartz - K-feldspar
Calcite (2%) fine- to coarse-grained, granular to slightly deformed, interstitial to quartz/feldspar
Chlorite (3%) fine-grained, green, purple-brown interference colour in pockets interstitial to quartz/feldspar
Epidote (10%) euhedral grains to anhedral masses interstitial to feldspar and intergrown with calcite



1) tiny pyrite bits in fine-grained feldspar-chlorite intergrowth
2a) tiny pyrite bits in fine-grained feldspar-chlorite intergrowth
2b) chalcopyrite and pyrite in graphic intergrowth of K-feldspar-quartz
3) rounded pyrite grain associated with altered ilmenite ? needle in quartz/feldspar
4) chalcopyrite bits in coarse epidote
5) chalcopyrite with sphalerite at rim and euhedral pyrite in epidote

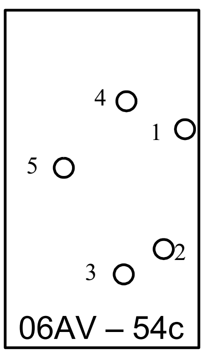
Sample 06AV-54c

Locality: Wisner-West
Description: granophyre bordering on fine-grained mafic portion with trace sulphides

Chalcopyrite (tr.) traces interstitial to silicates and in epidote
Pyrite (tr.) tiny, rare, euhedral, cream grains in gangue or chalcopyrite
Hematite (tr.) rimming chalcopyrite
Ilmenite/hematite (tr.) heavily altered grains and pseudomorphs

Granophyre (75%)
Quartz (30%) in graphic intergrowths with K-feldspar and as medium-grained subhedral grains in feldspar
K-Feldspar (30%) in graphic intergrowth with quartz and coarse tabular overgrowths on graphic intergrowths
Plagioclase (30%) coarse, euhedral to subhedral, zoned crystals intergrown with quartz - K-feldspar
Calcite (15%) coarse-grained, granular to slightly deformed, interstitial to quartz/feldspar
Chlorite (5%) fine-grained, green, purple-brown interference colour in pockets interstitial to quartz/feldspar
Epidote (10%) anhedral brownish masses interstitial to feldspar and intergrown with calcite
Clinopyroxene ?? (tr.) medium-grained subhedral to euhedral, high-relief mineral with high interference colour
Titanite (tr.) euhedral grains in calcite, also as fine-grained sugary grains in fine-grained portion
Rutile (tr.) intergrown with titanite in pseudomorphs after ilmenite?

Fine-grained recrystallized mafic portion (25%) consists of very fine-grained feldspar, olive biotite, green chlorite, overprinted by fine granular epidote ± titanite with anhedral quartz inclusions.



1) tiny euhedral pyrite intergrown with chalcopyrite in epidote in fine-grained portion
2) tiny euhedral pyrite with chalcopyrite in quartz in fine-grained portion, also chalcopyrite in chlorite and pyrite (?) in epidote
3) small rounded pyrite in granophyre
4) small sulphide bits in epidote in fine-grained portion
5) tiny bright multicoloured grain in quartz

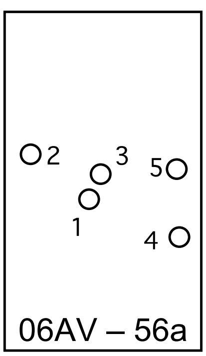
Appendix B3 continued.

Sample: 06AV-56a

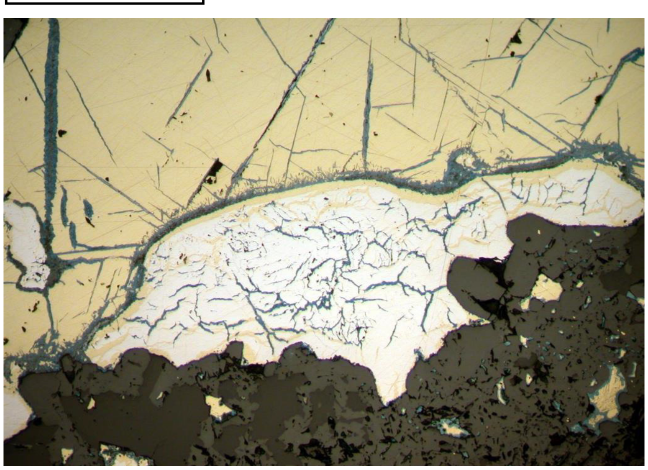
Locality: Wisner-West
Lithology: chalcopyrite mineralization in granophyre

Chalcopyrite (15%) massive, some grains are heavily tarnished (oxidized ?)
Pyrite (tr.) subhedral, partly resorbed cubes intergrown with magnetite in chalcopyrite
Polydymite (1%) cream coloured, coarse, anhedral mass intergrown with chalcopyrite, veined by digenite
Digenite (tr.); greenish blue, fine-grained alteration veining chalcopyrite and polydymite
Hessite (tr.) tiny, greyish grain intergrown with merenskyite
Naumannite (tr.) tiny white spec in chalcopyrite
Moncheite (Pd) (tr.) tiny white spec in chalcopyrite
Merenskyite (±Pd) tiny white spec in chalcopyrite
Kotulskite (tr.) tiny white grains in chalcopyrite
Magnetite (tr.) fine-grained subhedral grains overgrowing pyrite in chalcopyrite
Hematite (tr.) veining and rimming chalcopyrite and pyrite

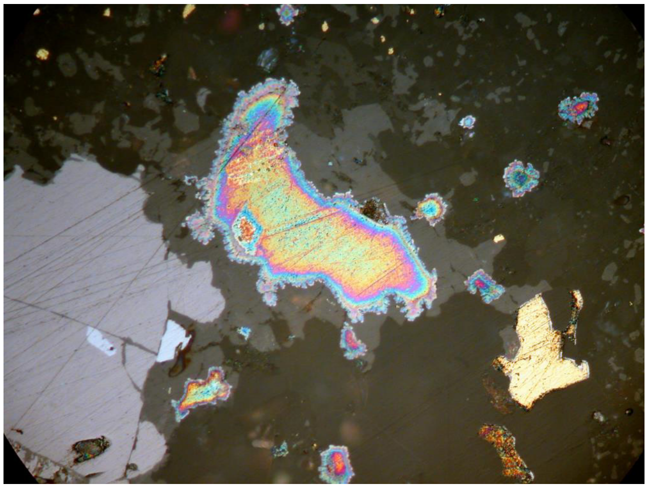
Feldspar (50%) fine- to coarse-grained microperthitic anhedral interlocking grains anhedral remnant altered grains
Quartz (10%) medium-grained, anhedral rounded grains in graphic intergrowths with K-feldspar
K-feldspar (10%) in graphic intergrowths with quartz
Hornblende (15%) coarse, beige grains, heavily fractured and altered, disintegrating at the edges into biotite + chlorite + epidote ± titanite
Epidote (tr.) anhedral grains intergrown with sulphides
Titanite (tr.) fine-granular grains replacing amphibole
Chlorite (tr.) fine-grained, green, dark violet interference colour replacing biotite and amphibole
Biotite (tr.) fine-grained, anhedral, olive-brown flakes surrounding and replacing amphibole
Apatite (tr.) fairly coarse (medium-grained), euhedral to subhedral, six-sided grains in matrix
Zircon (tr.) square to rounded. High-relief grains with fractures



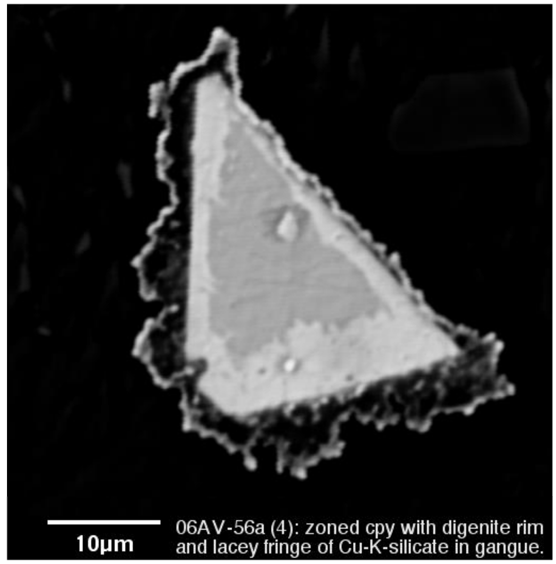
1) covellite veining chalcopyrite and large polydymite inclusion intergrown with epidote
2) pyrite surrounded by magnetite ± hematite in chalcopyrite
3) six tiny white specs (merenskyite, Pd-moncheite, kotulskite, naumannite) in chalcopyrite. Merenskyite intergrown with hessite
4) heavily tarnished chalcopyrite rimmed by covellite ± hematite; also granular titanite-hematite aggregates
5) heavily tarnished chalcopyrite in gangue with hematite altered ilmenite



06-AV-56a (1) polydymite (cream) intergrown with chalcopyrite, both veined by digenite (blue-green). Long edge of photo: 1.3 mm, reflected light.



Sample 06-AV-56a continued.

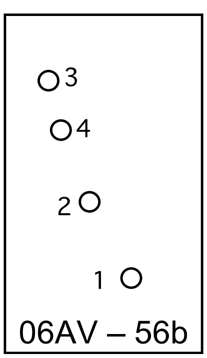


06AV-56a (4): zoned cpy with digenite rim and lacey fringe of Cu-K-silicate in gangue.

Sample 06AV-56b

Locality: Wisner-West
Description: fine-grained mafic zone bordering on granophyre (left) with trace interstitial chalcopyrite, pyrite, and abundant ilmenite

Quartz (15%) medium-grained, anhedral granoblastic grains and in graphic intergrowths
K-feldspar (5%) in graphic intergrowths with quartz
Feldspar (20%) fine- to coarse-grained, anhedral, interlocking grains altered by sericite and epidote
Amphibole (60%) remnants of coarse, beige grains, heavily fractured and altered, replaced by fine-grained acicular actinolite, biotite + chlorite + ilmenite ± titanite
Epidote-Allanite (1-2%) fine granular grains overprinting amphibole and anhedral grains (intergrown with olive to reddish brown allanite) intergrown with sulphides
Titanite (tr.) small- to medium-grained euhedral grains in granophyre
Actinolite (tr.) fine-grained acicular replacing primary amphibole
Pumpelleyite? (tr.) intense emerald green acicular aggregates in small pockets
Chlorite (tr.) fine-grained, green, dark violet interference colour replacing biotite and amphibole
Biotite (tr.) fine-grained, anhedral olive-brown flakes surrounding and replacing amphibole
Apatite (tr.) fairly coarse (medium-grained), euhedral to subhedral, six sided grains in matrix
Zircon (tr.) square to rounded, high-relief grains with fractures
Chalcopyrite (tr.) tiny anhedral bits in gangue
Pyrite (tr.) medium-grained, euhedral, poikilitic porphyroblasts intergrown with gangue
oxidized Chalcopyrite (tr.) small anhedral, tarnished grains with iridescent colours and lacey fringes
Ilmenite (2%) anhedral, rounded, medium-sized grains, fractured and rimmed by hematite, also as tiny grains dusting matrix
Hematite (tr.) rimming chalcopyrite and pyrite, replacing ilmenite



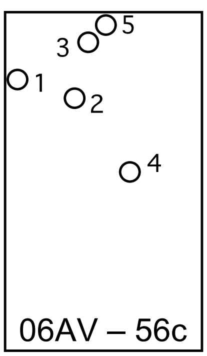
1) highly tarnished chalcopyrite rimmed by hematite with ilmenite-hematite; check out tiny sulphide pinpricks in ilmenite
2) pyrite porphyroblast, poikilitic intergrown with gangue; what are sulphide inclusions in pyrite ? chalcopyrite ?
3) chalcopyrite in granophyre with ilmenite-hematite and euhedral titanite
4) similar to (3), no chalcopyrite

Appendix B3 continued.

Sample 06AV-56c

Locality: Wisner-West
Description: similar to 06AV-56b, but no granophyre present: primary amphibole altered to fine-grained mass of secondary amphibole + biotite + chlorite + epidote + titanite

Quartz (10%) fine- to medium-grained, anhedral together with feldspar in schlieren in amphibole
Feldspar (10%) subhedral to anhedral grains, slightly altered with quartz in schlieren and pockets; larger grains altered by sericite
Amphibole (10%) remnants of coarse beige grains, heavily altered, replaced by fine-grained acicular actinolite, fine-grained epidote, ilmenite ± biotite
Epidote (30%) fine granular grains overprinting amphibole; coarser anhedral grains in quartz-feldspar pockets and intergrown with sulphides
Actinolite (30%) fine-grained acicular replacing primary amphibole
Chlorite (1%) fine-grained, green, khaki interference colour in quartz/feldspar
Biotite (1%) fine-grained, anhedral, oliv- brown flakes with chlorite in quartz-feldspar pockets
Pumpelleyite ? (tr.) intense emerald green acicular aggregates in small pockets
Apatite (tr.) fairly coarse (medium-grained), subhedral to anhedral grains in quartz/feldspar pockets
Titanite (tr.) dark granular aggregates with rutile cores in matrix
Ilmenite (5%) anhedral, rounded, medium-sized grains, fractured and altered by hematite, also as abundant evenly spaced tiny grains in altered amphibole
Hematite (tr.) rimming chalcopyrite, replacing ilmenite
Goethite (tr.) associated with alteration of sulphides, staining matrix yellow-orange
Chalcopyrite (3%) anhedral intergrown with chlorite, highly altered by hematite and goethite
oxidized chalcopyrite (tr.) small anhedral, tarnished grains with iridescent colours and lacey fringes
UM11 (tr.) chalcopyrite-like soft, anhedral mineral with dark golden tarnish (gold ??)

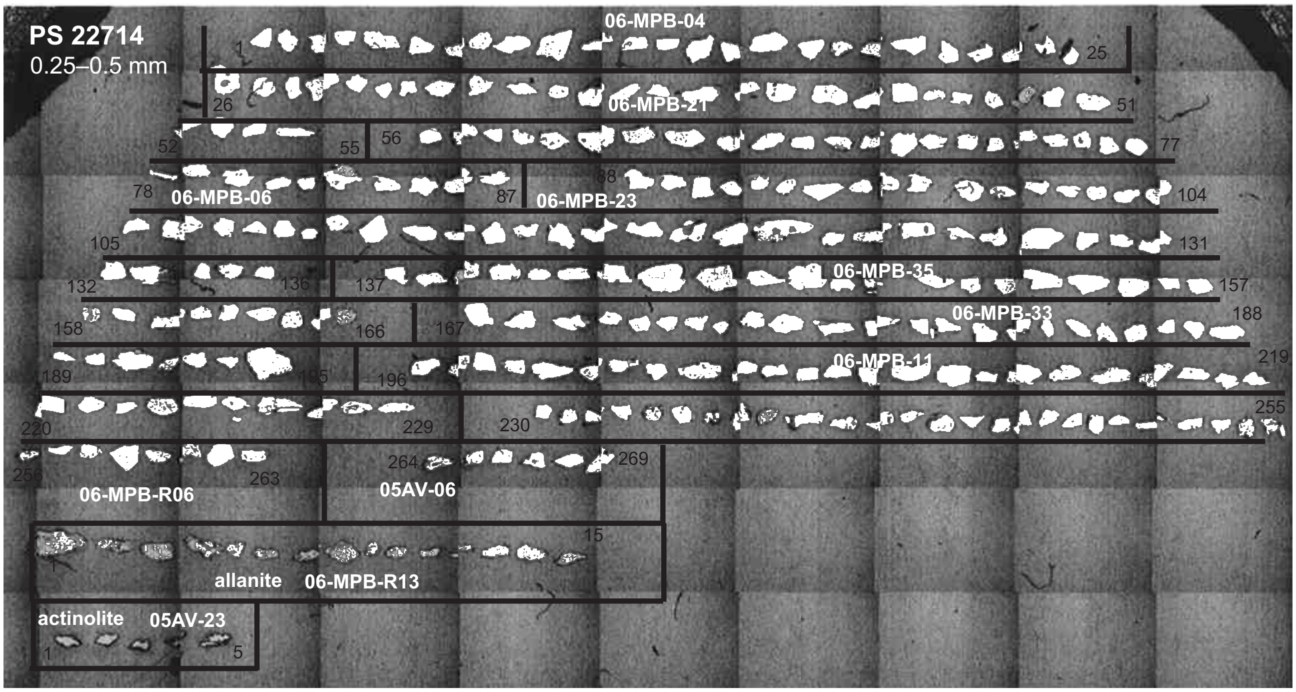


1) several strongly tarnished spots in altered amphibole with several coarse and abundant tiny ilmenite grains
2) ditto in matrix dotted by tiny ilmenites
3) chalcopyrite and coarse ilmenite in matrix
4) chalcopyrite intergrown with coarse chlorite and rimmed by hematite and tarnished chalcopyrite in matrix
5) coarse ilmenite (rimmed by titanite) with tiny sulphide droplets

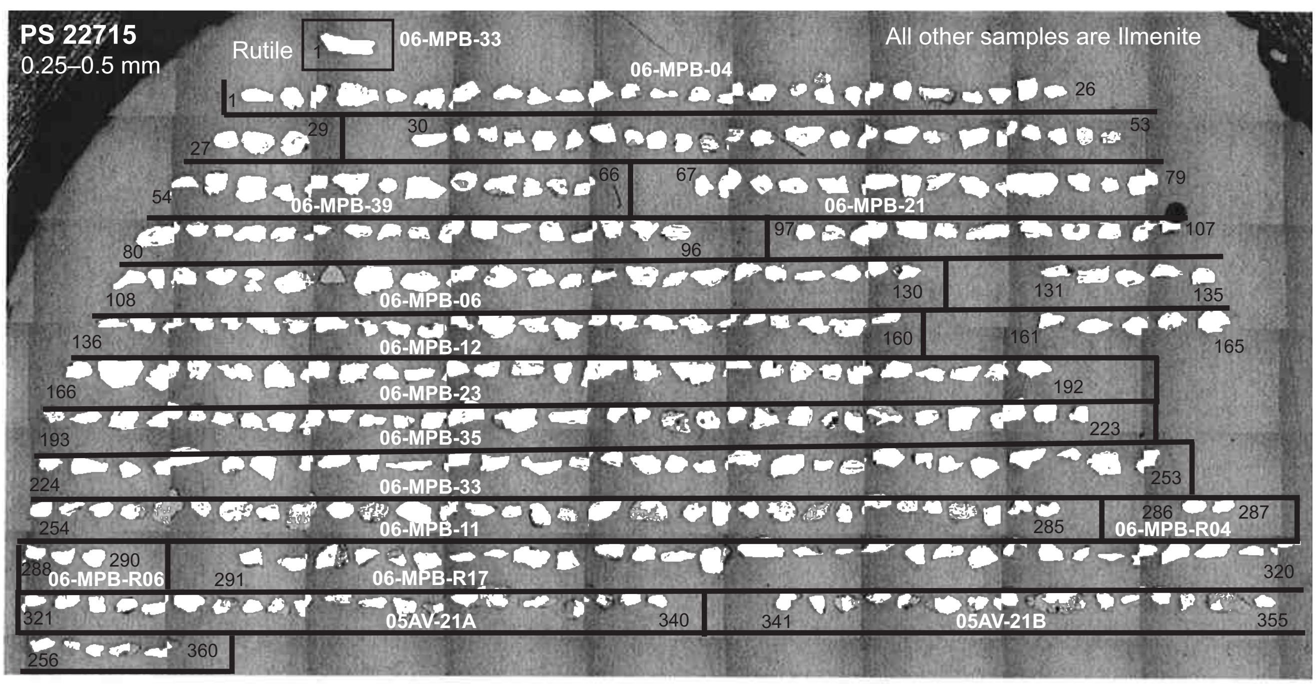
Appendix C1. Grain mount maps for electron microprobe analysis.

Grain mount map 22713. Epidote grains in the 0.25–0.50 mm fraction of samples 06-MPB-R02, -R04, and -R06.

Appendix C1 continued.

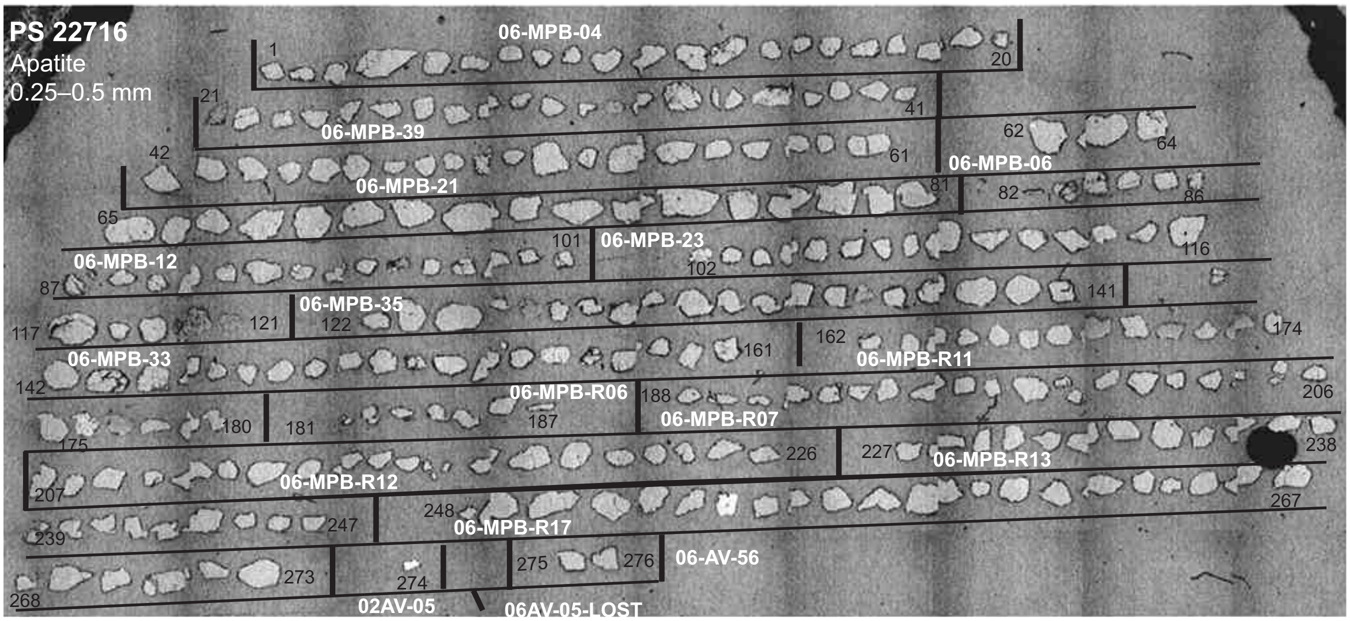


Grain mount map 22714. Allanite grains in the 0.25–0.50 mm fraction of bedrock samples 06-MPB-R06 and -R13; actinolite grains in bedrock sample 05AV-23.



Grain mount map 22715. Ilmenite grains in the 0.25–0.50 mm fraction of bedrock samples 06-MPB-R04, -R06, and -R17.

Appendix C1 continued.



Grain mount map 22716. Apatite grains in the 0.25–0.50 mm fraction of bedrock samples 06-MPB-R06, -R07, -R11, -R12, -R13, and -R17 and bedrock sample 06AV-56.