Natural Resources Canada   Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8711

Indicator-mineral signatures of the Casino porphyry Cu-Au-Mo deposit, Yukon

M.B. McClenaghan, M.W. McCurdy, C.E. Beckett-Brown, and S.C. Casselman

2020

Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8711

Indicator-mineral signatures of the Casino porphyry Cu-Au-Mo deposit, Yukon

M.B. McClenaghan[1], M.W. McCurdy[1], C.E. Beckett-Brown[2], and S.C. Casselman[3]

[1]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8
[2]Harquail School of Earth Sciences, Laurentian University, 935 Ramsey Lake Road, Sudbury, Ontario P3E 2C6
[3]Yukon Geological Survey, 300 Main Street, Whitehorse, Yukon Y1A 2B5

2020

Permanent link: https://doi.org/10.4095/322191

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
McClenaghan, M.B., McCurdy, M.W., Beckett-Brown, C.E., and Casselman, S.C., 2020. Indicator-mineral signatures of the Casino porphyry Cu-Au-Mo deposit, Yukon; Geological Survey of Canada, Open File 8711, 1 .zip file. https://doi.org/10.4095/322191

Publications in this series have not been edited; they are released as submitted by the author.

Table of Contents

APPENDIXES

Appendix A *(Digital data only)*

Appendix A1 Metadata for bedrock and stream sediment samples
Appendix A2 Sample location data for bedrock and stream cobble samples
Appendix A3 Sample location data for heavy mineral stream sediment samples
Appendix A4 Colour photographs of bedrock and stream cobble samples

Appendix B *(Digital data only)*

Appendix B1 Heavy mineral data for 11 bedrock drill core samples reported by Overburden Drilling Management Ltd. (ODM Batch No. 7895)

Appendix B2 Heavy mineral data for five stream cobble samples and 3 bedrock samples from the Casino deposit, and 2 bedrock samples from Woodjam deposit and reported by Overburden Drilling Management Ltd. (ODM Batch 7749)

Appendix B3 Heavy mineral data for 3 tourmaline-bearing bedrock drill core samples reported by Overburden Drilling Management Ltd. (ODM Batch 7810)

Appendix B4 Heavy mineral data for 22 stream sediment samples reported by Overburden Drilling Management Ltd.

Appendix C *(Digital data only)*

Appendix C1. Abundance of selected indicator minerals in the >3.2 specific gravity and the 2.8-3.2 specific gravity 0.25-0.5 mm non-ferromagnetic fractions of bedrock samples. Counts have been normalized to 1 kg of <2 mm (table feed) material. Gold grain counts are for the pan concentrate fraction.

AppendixC2. Abundance of selected indicator minerals in the >3.2 specific gravity and the 2.8-3.2 specific gravity 0.25-0.5 mm non-ferromagnetic fractions of stream sediment samples. Counts have been normalized to 10 kg of <2 mm (table feed) material. Gold grain counts are for the pan concentrate fraction.

Appendix C3. Abundance, size, and shape of gold grains recovered from stream sediments samples collected from local creeks around the Casino deposit (data from Appendix B4).

Appendix D *(Digital maps only)*
Proportional dot maps showing indicator mineral abundance in stream sediment samples around the Casino deposit. Bedrock geology from Yukon Geological Survey (2020c,d). Grains counts normalized to 10 kg mass of <2 mm material (table feed). See bedrock geology legend in Figure 2.

Map D1 Chalcopyrite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction.
Map D2 Gold grains in the <2.0 mm pan concentrate fraction.
Map D3 Pyrite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction.
Map D4 Location of samples that contain molybdenite, bismuthinite, arsenopyrite, sphalerite, plumbojarosite, pyrolusite and beudantite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction and cinnabar in the pan concentrate.
Map D5 Tourmaline in the 0.25-0.5 mm non-ferromagnetic mid-density (>2.8-3.2 SG) fraction
Map D6 Scheelite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction
Map D7 Barite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction
Map D8 Epidote in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction
Map D9 Jarosite in the 0.25-0.5 mm non-ferromagnetic mid-density (>2.8-3.2 SG) fraction
Map D10 Goethite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction
Map D11 Hematite in the 0.25-0.5 mm non-ferromagnetic heavy mineral (>3.2 SG) fraction

LIST OF TABLES

highlighted in a colour unique to each deposit/occurrence. Background abundances for indicator minerals defined using samples 1006 and 1009.

LIST OF FIGURES

ABSTRACT
This open file reports the results of an indicator mineral case study carried out around the Casino porphyry Cu-Mo-Au deposit in the unglaciated terrain of the west central Yukon. The research was part of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative 5 (TGI-5) Program. The purpose of the study was to test the use of indicator minerals as a porphyry Cu exploration tool in unglaciated terrain. At 22 sites around the deposit, a bulk stream sediment sample was collected to document the indicator mineral signature of the deposit. Steam water and stream silt samples were also collected at the same sites to compare geochemical to heavy mineral signatures. This open file presents indicator mineral abundance data for the bulk stream sediment samples.

The Casino deposit has an obvious indicator mineral signature in the <2 mm heavy (>3.2 specific gravity (SG)) and mid-density (2.8-3.2 SG) fractions of stream sediments that consists of, in order of usefulness: gold>chalcopyrite>molybdenite>sphalerite >jarosite>goethite>pyrite that is detectable at least 14 km downstream. Similar indicator mineral patterns in other creeks indicate the presence of additional porphyry style mineralization nearby. Detailed characterization of the mineral chemistry of tourmaline and scheelite that is in progress will determine their suitability for porphyry Cu exploration in this unglaciated terrain. Government and exploration surveys will benefit from the addition of indicator mineral sampling to routine stream sediment sampling protocols.

INTRODUCTION
For more than 40 years, indicator minerals have been a common exploration tool in the glaciated terrain of Canada for gold (e.g. Averill, 2001; McClenaghan and Cabri, 2011) and diamonds (e.g. McClenaghan and Kjarsgaard, 2007 and references there in). More recently, indicator mineral methods have been tested for porphyry Cu exploration in glaciated terrain (e.g. Kelley et al., 2011; Hashmi et al., 2015; Chapman et al., 2015, 2018; Plouffe et al., 2016; Plouffe and Ferbey, 2017). The objective of the Geological Survey of Canada's (GSC) Targeted Geoscience Initiative (TGI) porphyry indicator mineral research activity was to further develop the porphyry Cu indicator mineral suite that can be used for surficial sediment sampling in both glaciated and unglaciated terrains (McClenaghan et al., 2018, 2019). This new GSC research includes the detailed examination and chemical characterization of tourmaline (Beckett-Brown et al., 2019), epidote, rutile, and zircon (Plouffe et al., 2018, 2019; Kobylinksi et al., 2017, 2018).

One component of the TGI5 porphyry Cu indicator mineral research included studies carried out at the Casino porphyry Cu-Au-Mo deposit, one of Canada's largest and highest-grade porphyry Cu deposits. The deposit was chosen as an indicator mineral test site because it has been minimally disturbed by exploration drilling and not yet mined, is known to contain tourmaline, and local streams waters and sediments around the deposit are known to be metal-rich (Archer and Main, 1971). This open file reports the abundances of porphyry Cu indicator minerals in mid-density and heavy mineral concentrates of mineralized bedrock and stream sediments around the deposit. The chemistry of stream silt samples collected at the same sample sites were reported in McCurdy et al. (2019). Stream water geochemical data will be released at a later date.

Location and access

The study area is in west-central Yukon, 300 km north of Whitehorse (Fig. 1) and within the Klondike Plateau ecoregion (Smith et al., 2004). The deposit is located at latitude 62°44'N and longitude 138°50'W, in NTS map areas 115J J/010 (Colorado Creek) and 115J J/15 (Britannia Creek) and is accessed by fixed wing aircraft or helicopter. Creeks draining the northwest side of the deposit flow northward and eventually into the Yukon River which flows northwest. Most of the terrain lies at elevations of 1000-1500 m asl. The climate of the study area is cold and semi-arid (Bond and Lipovsky, 2011) with a mean annual temperature of approximately -5.5°C: the mean annual summer temperature is 10.5°C and the winter mean annual temperature is -23°C. The mean annual precipitation ranges from 300 to 450 mm (Smith et al., 2004).

GEOLOGY

Deposit discovery history

The earliest exploration in the Casino area was for placer gold in the lower reaches of Canadian Creek in 1911 (Bostock, 1959) (Fig. 2). Further upstream, a gold-tungsten placer at the junction of Canadian Creek and Patton Gulch on the northwest flank of the deposit was first worked to mine the tungsten in 1916. When the upper placer was worked again in 1940s, the following minerals were recovered from the black sand: ferberite, gold, magnetite, hematite, scheelite, molybdenum, zircon, cassiterite, tourmaline and titanite (Bostock, 1959; Archer and Main, 1971). Over the years, placer gold mining also took place on Rude Creek (Fig. 2), southeast of the Casino deposit (Chapman et al., 2014). Other early exploration in the Casino area focused on the silver-lead-zinc veins at the Bomber occurrence (Yukon Geological Survey, 2020a) on the south periphery of what is now known as the Casino deposit (Fig. 2).

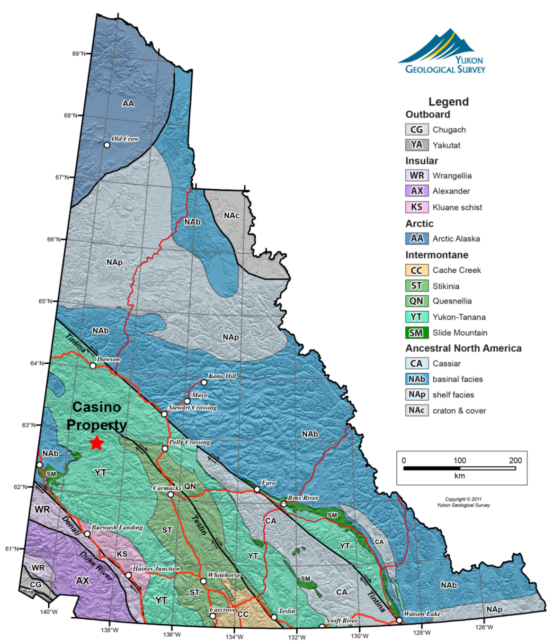

Figure 1. Location of the Casino porphyry Cu deposit in west central Yukon (modified from Relf, 2020).

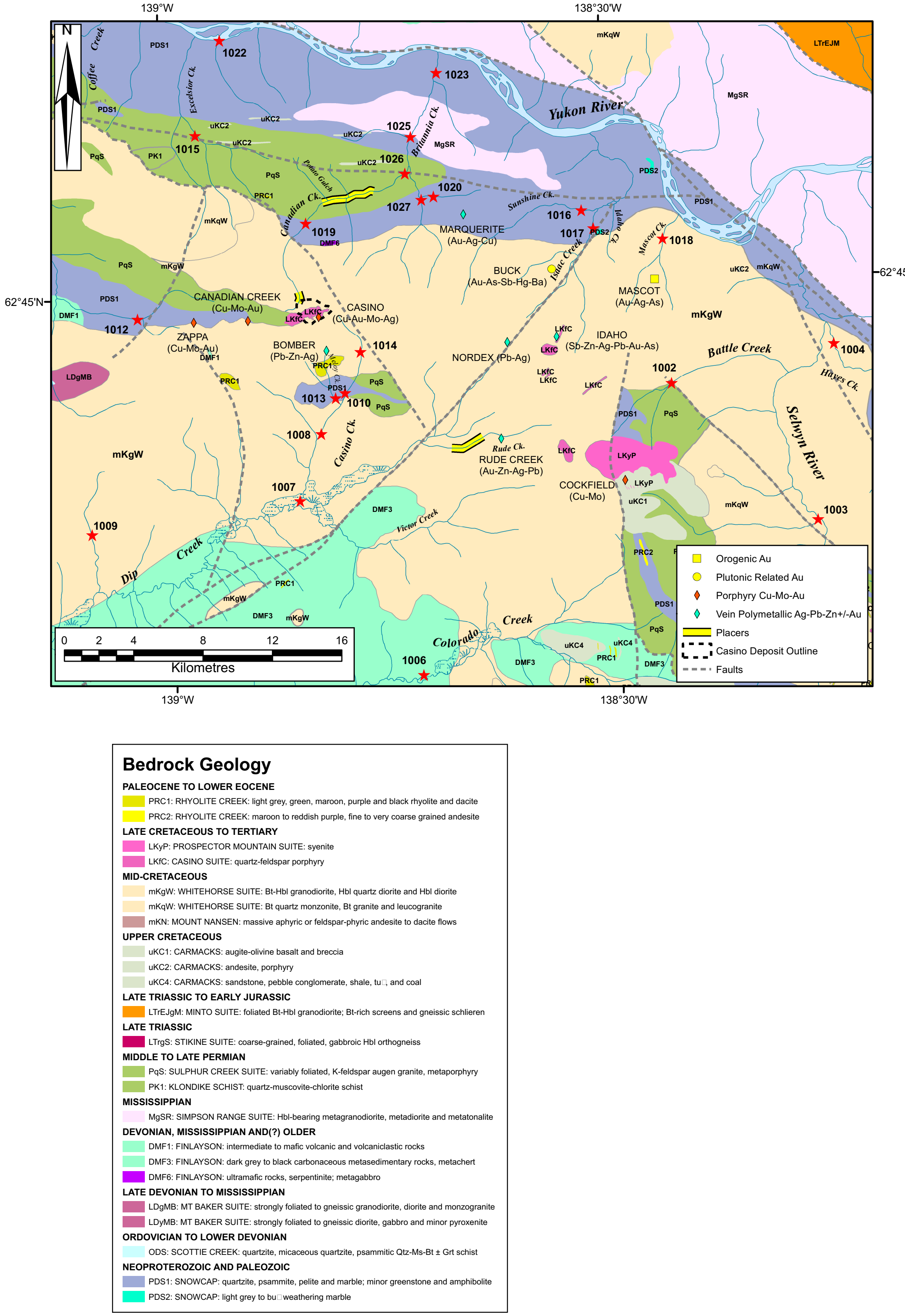

Figure 2. Local bedrock geology, mineral occurrences and location of heavy mineral sample sites (red stars). Sample numbers in black. Geology and mineral occurrences from YGS (2020a to m).

Prior to the initial diamond drilling that resulted in discovery of the deposit, surface indications of the presence of the deposit included: the prominent (730 m long) limonite gossan along a small creek on southeast side of the deposit that empties into upper Casino Creek; the presence of the local gold-tungsten placer; intense hydrothermal alteration and presence of limonite; jarosite and weak malachite staining in leached rocks at the surface; the peripheral silver-zinc-lead veins; and anomalous Cu concentrations in -80 mesh stream silt samples in Casino Creek as compared to values for the Dawson Range compiled over several years by Archer and Main (1971). Anomalous contents of Cu and Mo in -80 mesh soil samples collected in 1968 were used to guide the exploration drilling in 1969 that led to the discovery of Cu-Au mineralization (Archer and Main, 1971). Current total measured, indicated, and inferred resources of the deposit are: 101 million tonnes of 0.39 g/t Au in the oxide gold zone, 87 million tonnes grading 0.25% Cu, 0.29 g/t Au, 0.02% Mo, and 1.7 g/t Ag in the supergene oxide enriched zone, and 2.7 billion tonnes of sulphide ore grading 0.16% Cu, 0.19 g/t Au, 0.02% Mo and 1.5 g/t Ag in the supergene sulphide + hypogene zones (Huss et al., 2013; Casselman and Brown, 2017; Yukon Geological Survey, 2020b).

Bedrock geology

The Casino deposit area is underlain by metamorphosed and deformed basement rocks of the Yukon-Tanana terrane, an allochthonous tectonic terrane that extends over 2000 km from Alaska, through Yukon and south into British Columbia. The terrane consists of rocks formed in a Mid- to Late Paleozoic continental arc system that separated the Yukon-Tanana arc from the western margin of Laurentia (Nelson et al., 2006, 2013). The terran consists of the Snowcap assemblage of metamorphosed sedimentary and minor volcanic rocks which is unconformably overlain by the Finlayson, Klinkit and Klondike assemblages, predominantly arc metavolcanic rocks and associated metasedimentary rocks (Colpron et al., 2006, 2016; Ryan et al., 2013).

The bedrock geology of the deposit and surrounding area is briefly summarized below from Archer and Main (1971), Godwin (1975, 1976), Bower et al. (1995), Ryan et. al. (2013), Casselman and Brown (2017), and Yukon Geological Survey (2020 c,d). The Casino deposit is classified as a calc-alkaline porphyry deposit and is centered on the Patton Porphyry, a Late Cretaceous (72-74 Ma) stock that intrudes the Mesozoic Dawson Range Batholith and Paleozoic Yukon Crystalline Complex schists and gneisses. The intrusion of the small porphyry into these older rocks caused brecciation along its contacts. The porphyry is locally mineralized and is surrounded by a potassically-altered intrusion breccia at its outer contacts. Elsewhere, the porphyry consists of discontinuous dikes (up to 10s of m wide) that cut both the porphyry and Dawson Range Batholith. The overall composition of the porphyry is rhyodacite, with phenocrysts of dacite composition and a matrix of quartz latite composition.

Primary copper, gold and molybdenum mineralization was deposited from hydrothermal fluids in the contact breccias and fractured wall rocks and consists of pyrite, chalcopyrite, molybdenite, and minor huebnerite. Supergene mineralization is concentrated in the phyllic zone and surrounded by weakly developed argillic and propylitic alteration zones. Grades decrease away from the contact zone towards the centre of the stock and outward into the wall rocks.

During the warm and wet climate of the Paleogene (, the deposit was subjected to deep (up to 300 m) chemical weathering because of the porous nature of the breccias and strongly altered zones. The deep weathering profile is largely intact because of minimal to no glacial erosion of the region during the last 2 million years (Bond and Lipovsky, 2011, 2012a,b). Thus, the deposit has a well-formed zonation consisting of a leached cap, supergene oxide mineralization, supergene sulphide mineralization, and hypogene (primary) mineralization.

Goodwin (1975, 1976) suggested that the warm and wet climate of the Paleogene (Zachos et al., 2001; Moran et al., 2006; Vavrek et al., 2012) was the likely time frame for supergene enrichment of the deposit. The deep weathering profile is largely intact because of minimal to no glacial erosion of the region during the last 2 million years (Bond and Lipovsky, 2011, 2012a,b). Thus, the deposit has a well-formed zonation consisting of a leached cap, supergene oxide mineralization, supergene sulphide mineralization, and hypogene (primary) mineralization. The leached cap is on average 70 m thick, enriched in gold, depleted in Cu, and consists primarily of boxwork textures filled with jarosite, limonite, goethite, and hematite. The deep weathering has obliterated bedrock textures and replaced most minerals with clay. The supergene oxide zone consists of a few isolated lenses within the leached cap and is thought to have formed by more recent fluctuations in the water table. It is Cu-rich and contains chalcanthite, malachite, brocanthite along with minor cuprite, azurite, tenorite, neotocite, and trace molybdenite as coatings on fractures and in vugs. The supergene sulphide zone underlies the leached cap, is on average 60 m thick and outcrops at surface in places. It has Cu grades commonly almost double those in the hypogene zone and contains pyrite, chalcopyrite, bornite, and tetrahedrite that may be altered along grain boundaries to chalcocite, digenite, or covellite, as well as molybdenite that is locally altered to ferrimolybdite. Hypogene mineralization underlies the supergene sulphide zone and consists of pyrite, chalcopyrite, molybdenite, sphalerite, bornite, and tetrahedrite. In the hypogene zone, gold occurs as discrete grains (50-70 μm) in quartz and as inclusions in pyrite and chalcopyrite (1-15 μm). On the eastern and northern flanks of the deposit, the supergene oxide zone is absent, the other zones are thinner, and hypogene zone is closest to surface (<25 m). Potential indicator minerals in the deposit are listed in Table 1.

Mineral occurrences near the Casino deposit are shown on Figure 2 and listed in Table 2. They include porphyry Cu-Mo-Au occurrences on Mount Cockfield 20 km to the southeast (Yukon Geological Survey, 2020e) and west of the Casino deposit (Zappa, Canadian Creek; Yukon Geological Survey, 2020 f,g). Additional polymetallic vein occurrences are located 10 km northeast of Casino (Marquerite; Yukon Geological Survey, 2020h), 10 km east (Nordex, Idaho; Yukon Geological Survey, 2020i,j) and 12 km southeast (Rude Creek; Yukon Geological Survey, 2020k). Two gold occurrences have been reported 13 to 16 km ENE of the deposit (Buck and Mascot; Yukon Geological Survey, 2020l,m). Mineral occurrences near the Casino deposit are shown on Figure 2.

Table 1. Potential indicator minerals of the Casino porphyry Cu-Au-Mo deposit summarized from deposit descriptions by Godwin (1975), Casselman and Brown (2017), and Huss et al. (2013) and indicator minerals found in stream sediment samples in this study.

Mineral	Interpretation	Formula	Specific Gravity	Hardness	in bedrock HMC in this study	in stream sed HMC in this study	Presence first reported in deposit by others
hematite	potassic alteration	Fe_2O_3	5.3	6.5	no	yes	Goodwin (1975)
magnetite	potassic alteration	Fe_3O_4	5.1-5.2	5.5-6	yes	yes	Goodwin (1975)
anhydrite	potassic alteration	$CaSO_4$	2.96-2.98	3.5	no	no	Goodwin (1975)
tourmaline	potassic alteration	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	2.98-3.2	7-7.5	yes	yes	Goodwin (1975)
ankerite	potassic alteration	$Ca(Fe,Mg,Mn)(CO_3)_2$	3-3.1	3.5-4	no	no	Goodwin (1975)
pyrite	potassic alteration	FeS_2	5-5.0	6.5	yes	yes	Goodwin (1975)
chalcopyrite	potassic alteration	$CuFeS_2$	4.1-4.3	3.5	yes	yes	Goodwin (1975)
molybdenite	potassic alteration	MoS_2	5.5	1.0	yes	yes	Goodwin (1975)
sphalerite	potassic alteration	(Zn,Fe)S	3.9-4.2	3.5-4	no	yes	Goodwin (1975)
bornite	potassic alteration	Cu_5FeS_4	4.9-5.3	3	no	no	Goodwin (1975)
jarosite	potassic alteration	$KFe_3(SO_4)_2(OH)_6$	2.9-3.3	2.5-3.5	no	yes	Goodwin (1975)
tourmaline	phyllic alteration	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	2.98-3.2	7-7.5	yes	yes	Archer & Main (1971)
titanite	phyllic alteration	$CaTiSiO_5$	3.4-3.56	5-5.5	no	yes	Huss et al. (2013)
pyrite	phyllic alteration	FeS_2	5-5.0	6.5	yes	yes	Archer & Main (1971)
chalcopyrite	phyllic alteration	$CuFeS_2$	4.1-4.3	3.5	yes	yes	Archer & Main (1971)
molybdenite	phyllic alteration	MoS_2	5.5	1.0	yes	yes	Archer & Main (1971)
hematite	phyllic alteration	Fe_2O_3	5.3	6.5	no	yes	Archer & Main (1971)
magnetite	phyllic alteration	Fe_3O_4	5.1-5.2	5.5-6	yes	yes	Goodwin (1975)
jarosite	phyllic alteration	$KFe_3(SO_4)_2(OH)_6$	2.9-3.3	2.5-3.5	no	yes	Archer & Main (1971)
epidote	propylitic alteration	$Ca_2(FeAl)_3(SiO_4)_3(OH)$	3.3-3.6	7	yes	yes	Goodwin (1975)
pyrite	propylitic alteration	FeS_2	5-5.0	6.5	yes	yes	Goodwin (1975)
limonite	leached cap	$FeO(OH) \cdot nH_2O$	2.7-4.3	4-5.5	no	no	Archer & Main (1971)
jarosite	leached cap	$KFe_3(SO_4)_2(OH)_6$	2.9-3.3	2.5-3.5	no	yes	Archer & Main (1971)
plumbojarosite	leached cap	$PbFe_6(SO_4)_4(OH)_{12}$	3.6-3.67	1.5-2	no	yes	Huss et al. (2013)
beudantite	leached cap	$PbFe_3(AsO_4)(SO_4)(OH)_6$	4.1-4.3	4	no	yes	Huss et al. (2013)
pyrolusite	leached cap	MnO_2	4.4-5.06	6-6.5	no	yes	Huss et al. (2013)
goethite	leached cap	FeO(OH)	3.3-4.3	5-5.5	yes	yes	Goodwin (1975)
hematite	leached cap	Fe_2O_3	5.3	6.5	no	yes	Archer & Main (1971)
ferrimolybdite	leached cap	$Fe_2(MoO_4)_3 \bullet 8(H_2O)$	4-4.5	2.5-3	no	no	Goodwin (1975)
chalcanthite	supergene oxide	$Cu(SO_4) \bullet 5(H_2O)$	2.12-2.3	2.5	no	no	Goodwin (1975)
brochantite	supergene oxide	$Cu_4(SO_4)(OH)_6$	3.97	3.5-4	no	no	Goodwin (1975)
malachite	supergene oxide	$Cu_2(CO_3)(OH)_2$	3.6-4	3.5-4	no	no	Goodwin (1975)
azurite	supergene oxide	$Cu_3(CO_3)_2(OH)_2$	3.77-3.89	3.5-4	no	no	Goodwin (1975)
tenorite	supergene oxide	CuO	6.5	3.5-4	no	no	Goodwin (1975)
cuprite	supergene oxide	Cu_2O	6.1	3.5-4	no	no	Bower et al. (1995)
neotocite	supergene oxide	$(MnFe)SiO_3 \bullet (H_2O)$	2.8	3-4	no	no	Goodwin (1975)
native copper	supergene oxide	Cu	8.94-8.95	2.5-3	no	no	Goodwin (1975)
digenite	supergene sulphide	Cu_9S_5	5.6	2.5-3	no	no	Archer & Main (1971)
chalcocite	supergene sulphide	Cu_2S	5.5-5.8	2.5-3	no	no	Archer & Main (1971)
covellite	supergene sulphide	CuS	4.6-4.76	1.5-2	no	no	Archer & Main (1971)
enargite	supergene sulphide	Cu_3AsS_4	4.4-4.5	3	no	no	Casselman&Brown (2017)
bornite	supergene sulphide	Cu_5FeS_4	4.9-5.3	3	no	no	Huss et al. (2013)
pyrite	hypogene zone	FeS_2	5-5.0	6.5	yes	yes	Archer & Main (1971)
chalcopyrite	hypogene zone	$CuFeS_2$	4.1-4.3	3.5	yes	yes	Archer & Main (1971)
molybdenite	hypogene zone	MoS_2	5.5	1	yes	yes	Archer & Main (1971)
sphalerite	hypogene zone	(Zn,Fe)S	3.9-4.2	3.5-4	no	yes	Goodwin (1975)
bornite	hypogene zone	Cu_5FeS_4	4.9-5.3	3	no	no	Goodwin (1975)
gold	hypogene zone	Au	16-19.3	2.5-3	yes	yes	Archer & Main (1971)

Continued on next page…

Mineral	Interpretation	Formula	Specific Gravity	Hardness	in bedrock HMC in this study	in stream sed HMC in this study	Presence first reported in deposit by others
galena	hypogene zone	PbS	7.2-7.6	2.5	no	no	Archer & Main (1971)
tetrahedrite	hypogene zone	$(CuFe)_{12}Sb_4S_{13}$	4.6-5.2	3.5-4	no	no	Bower et al. (1995)
bismuthinite	hypogene zone	Bi_2S_3	6.8-7.2	2.0	no	yes	Huss et al. (2013)
ankerite	hypogene zone	$Ca(Fe,Mg,Mn)(CO_3)_2$	3-3.1	3.5-4	no	no	Bower et al. (1995)
barite	polymetalic veins	$BaSO_4$	4.5	3-3.5	yes	yes	Archer & Main (1971)
sphalerite	polymetalic veins	$(Zn,Fe)S$	3.9-4.2	3.5-4	no	yes	Archer & Main (1971)
Ag-rich galena	polymetalic veins	$PbAgS$	7.2-7.6	2.5	no	no	Archer & Main (1971)
scheelite	polymetalic veins	$CaWO_4$	5.9-6.1	4-5	no	yes	Archer & Main (1971)
chalcopyrite	polymetalic veins	$CuFeS_2$	4.1-4.3	3.5	yes	yes	Archer & Main (1971)
pyrite	polymetalic veins	FeS_2	5-5.0	6.5	yes	yes	Archer & Main (1971)
gold	Canadian Ck placer	Au	16-19.3	2.5-3	yes	yes	Bostock (1959)
ferberite	Canadian Ck placer	$Fe(WO_4)$	7.4-7.5	4.5	no	no	Bostock (1959)
scheelite	Canadian Ck placer	$CaWO_4$	5.9-6.1	4-5	no	yes	Bostock (1959)
molybdenite	Canadian Ck placer	MoS_2	5.5	1.0	yes	yes	Bostock (1959)
cassiterite	Canadian Ck placer	SnO_2	6.8-7	6-7	no	no	Bostock (1959)
tourmaline	Canadian Ck placer	$NaMg_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$	2.98-3.2	7-7.5	yes	yes	Bostock (1959)
titanite	Canadian Ck placer	$CaTiSiO_5$	3.4-3.56	5-5.5	no	yes	Bostock (1959)
hematite	Canadian Ck placer	Fe_2O_3	5.3	6.5	no	yes	Bostock (1959)
magnetite	Canadian Ck placer	Fe_3O_4	5.1-5.2	5.5-6	yes	yes	Bostock (1959)
cinnabar	stream sediments	HgS	8.1	2-2.5	no	yes	this study
grossular garnet	stream sediments	$Ca_3Al_2(SiO_4)_3$	3.42-3.72	6.5-7.5	no	yes	this study
andradite garnet	stream sediments	$Ca_3Fe_2(SiO_4)_3$	3.7-4.1	6.5-7	no	yes	this study
arsenopyrite	stream sediments	$FeAsS$	6.1	5	no	yes	this study
fluorite	deposit	CaF_2	3.01-3.25	4	no	yes	Archer & Main (1971)

Table 2. Summary of known mineral occurrences in the study area. Data from Yukon Geological Survey, 2020a,b, e to m).

Name	Occurrence Number	Type	Reference
Bomber	115J 027	Vein Polymetallic Ag-Pb-Zn+/-Au	YGS, 2019a
Cockfield	115J 017	porphyry Cu-Mo-Au	YGS, 2019e
Zappa	115J 036	porphyry Cu-Mo-Au	YGS, 2019f
Canadian Creek	115J 101	porphyry Cu-Mo-Au	YGS, 2019g
Marquerite	115J 070	Porphyry-related Au, Vein Polymetallic Ag-Pb-Zn+/-Au	YGS, 2019h
Nordex	115J 023	Vein Polymetallic Ag-Pb-Zn+/-Au	YGS, 2019i
Idaho	115J 099	Porphyry-related Au, Vein Polymetallic Ag-Pb-Zn+/-Au	YGS, 2019j
Rude Creek	115J 022	Vein Polymetallic Ag-Pb-Zn+/-Au	YGS, 2019k
Buck	115J 071	orogenic Au, plutonic related Au	YGS, 2019l
Mascot	115J 074	orogenic Au, Au-Ag-As	YGS, 2019m

Surficial geology

The surficial geology of the Casino area is summarized below from maps and reports published by Duk-Rodkin (2001), Huscroft (2002a,b,c), Duk-Rodkin et al. (2002), Bond and Sanborn (2006), Bond and Lipovsky (2011, 2012a,b), Lipovsky and Bond (2012), and McKillop et al. (2013). The deposit is in the Dawson Range, a series of broad ridges and summits that vary in elevation from about 1000 to 1800 m asl. The highest peaks in the study area are an unnamed peak (1672 m asl) 3 km to the northwest of Patton Hill (highest point of the Patton porphyry intrusion, ~1432 m asl) and Mount Cockfield (1856 m asl) 20 km to the southeast (Fig. 3).

Figure 4 shows an idealized cross section of the surficial geology southwest from Patton Hill, down through Dip Creek, and up to the Stevenson Ridge (Fig. 3) that is typical for the area. The landscape is largely unglaciated and as a result, bedrock in the region is weathered and leached. Bedrock outcrop and tors (rocky peaks) are common along the ridges and summits and have disintegrated *in situ* by mechanical (freeze/thaw) and/or chemical weathering. Surficial material in upland areas flanking ridges and tors consists of colluvium and weathered bedrock intermixed with variable amounts of loess. Material moves downslope by gravity-driven processes such as creep, solifluction, landslides, and snow avalanches, and it is these processes that feed debris that eventually ends up in creeks. Lower lying areas are covered with loess.

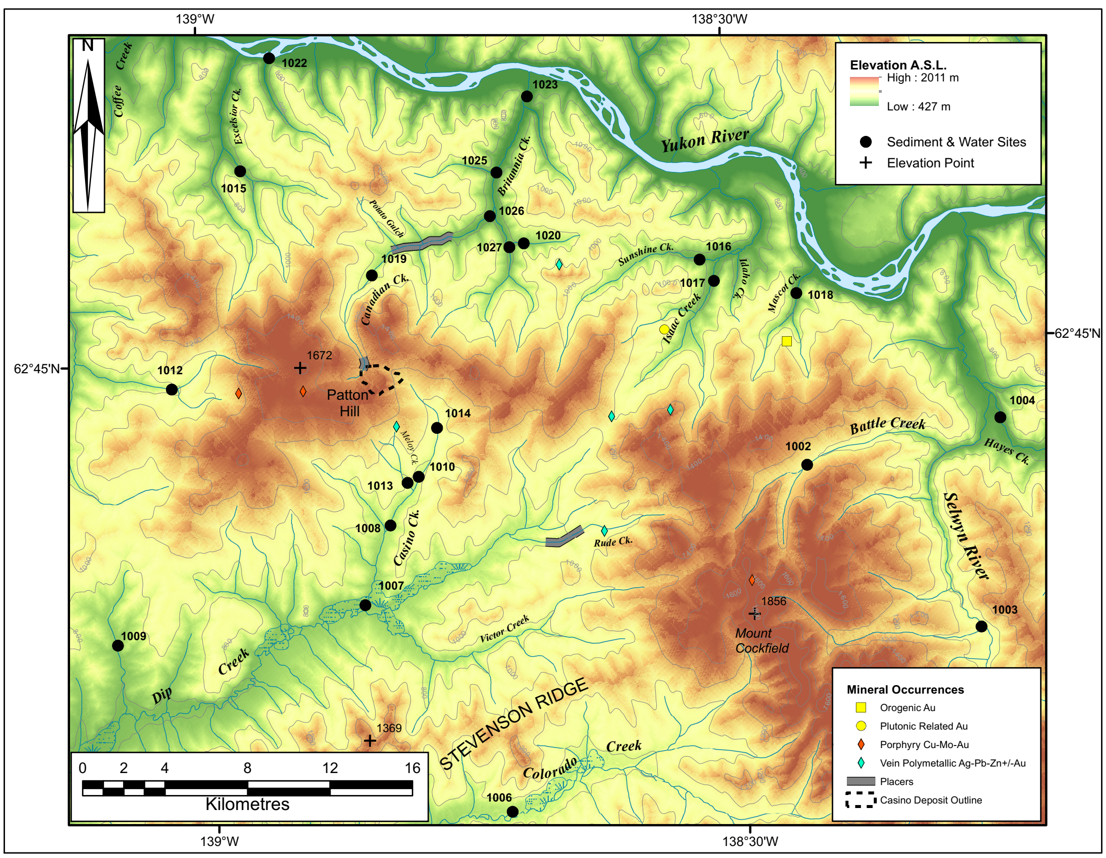

Figure 3. Digital elevation map (DEM) showing the location of stream sediment bulk samples collected by the Geological Survey of Canada in 2017 for heavy mineral processing (black dots). DEM from Natural Resources Canada (2017).

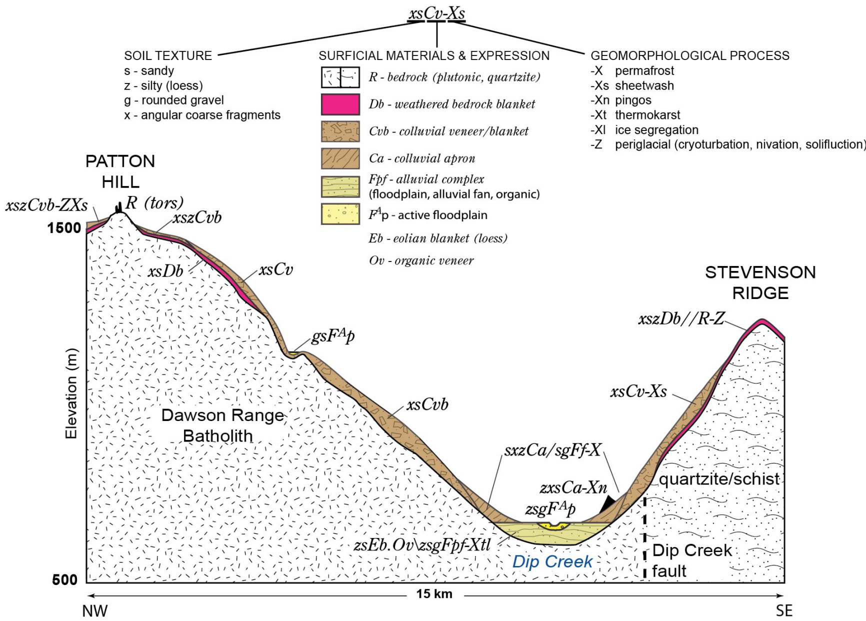

Figure 4. Idealized cross section of the surficial geology from the Casino deposit (Patton Hill) towards the southeast across Dip Creek to the Stevenson Ridge. From Bond and Lipovsky (2011).

Maximum glacial limits for the region are shown in Figure 5, as summarized by Duk-Rodkin (2001). Isolated alpine glaciers existed on Mount Cockfield that extended west into the headwaters of Victor and Colorado creeks tributary valley and eastward into an unnamed tributary that drains into the Selwyn River during the Reid glaciation (middle Pleistocene) (Bond and Lipovsky, 2012a). Glacial sediments (end moraines) and cirques are present on the east flank of Mount Cockfield. Stream sediments in the creeks draining this east flank will, in part, be derived from the glacial deposits. Evidence of past glaciation also exists in the headwaters of Canadian Creek, immediately northwest of Patton Hill, where cirques were formed during early Pleistocene (preReid) glaciation (Duk-Rodkin et al., 2002; Bond and Lipovsky, 2012a), the areal extent of which is shown in Figure 5.

The study area is a periglacial environment; that is the land surface is subject to seasonal freeze-thaw cycles and cryoturbation. Permafrost is widespread but discontinuous and is most common on north-facing slopes and in the bottoms of valleys that are covered by thick colluvium and organic veneers. Its presence is indicated by the presence of solifluction lobes, pingos, and thermokarst features. Frost shattering, cryoturbation, solifulcution soil creep, and landsliding are all mechanisms by which bedrock is released into the surficial environment and unconsolidated sediments move down slope and into creeks (Bond and Liposky, 2011). Fluvial erosion of older gravel deposits, including placers, also contribute material to modern creeks.

First and second order streams (e.g. Casino Creek) are found in narrow V-shaped valleys and contain subangular to subrounded gravel to boulders that are derived from local bedrock. Higher order streams occur in broader valleys and are filled with more distally derived colluvium, loess, and rounded gravel (e.g. Dip Creek, Colorado Creek). Bond and Lipovsky (2012a,b) reported that understanding the relationship between valley morphology and the variable texture and sources of fluvial sediments is important when sampling and interpreting stream silt geochemical surveys. Because loess content in fluvial sediments is variable, they recommended that stream samples ideally should be collected from high-energy streams in narrow valleys where the loess content will be lowest.

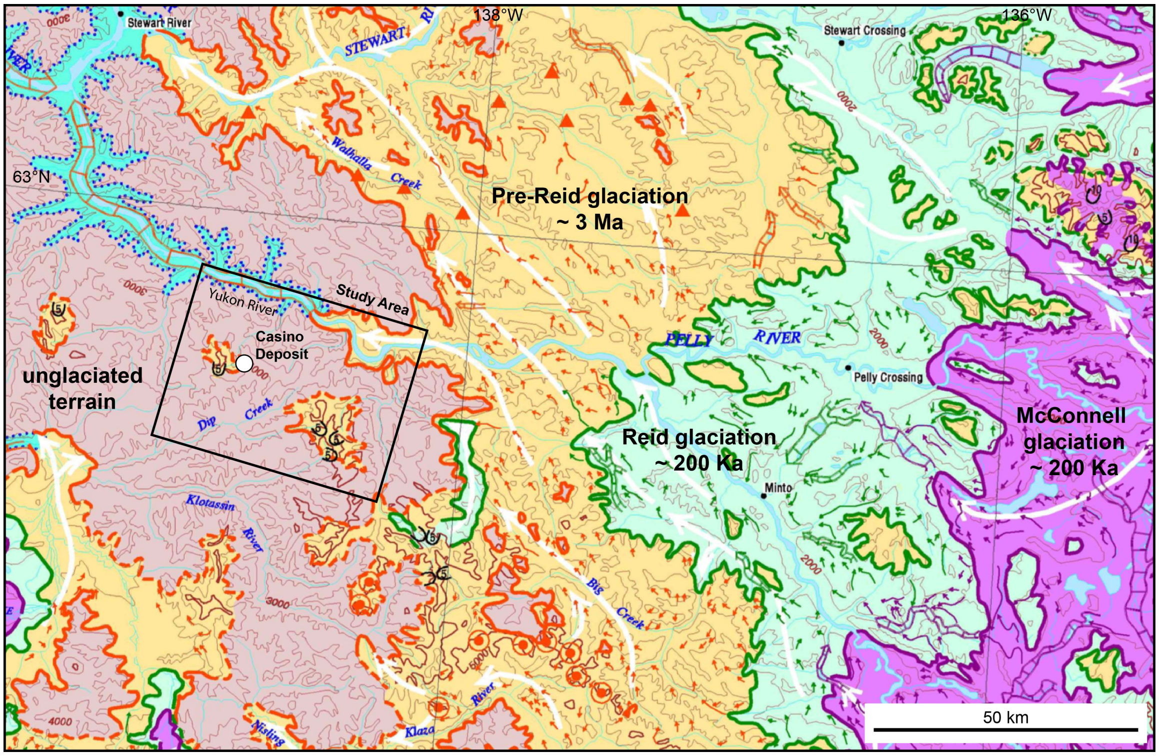

Figure 5. Maximum limits of glaciation as shown on the glacial limits map of the Yukon by Duk-Rodkin (2001), showing two mountain tops in the vicinity of the Casino deposit that were affected by glaciation.

Previous stream sediment geochemical surveys

Archer and Main (1971) reported that at the time of discovery, the Casino deposit had an obvious geochemical signature in stream silts (Cu, Mo, Au and Ag) and waters (Cu) overlying the deposit. Subsequent reconnaissance-scale stream silt and water sampling in the Yukon by the GSC (Geological Survey of Canada, 1987; 19 elements in <0.177 mm silt using 3:1 HNO_3:HCl, pH, 2 elements in water) and subsequent reanalyses of these GSC stream sediment samples (53 elements in <0.177 mm silt using 1:3 HNO_3:HCl, Jackaman, 2011; Yukon Geological Survey, 2016; Mackie et al., 2017; Arne et al., 2018) show that a multi-element geochemical anomaly (Ag, Cu, Mo, Pb, Sb, W) is obvious in the local creeks draining the Casino deposit.

The Yukon Geological Survey collected a few isolated heavy mineral samples from local creeks while mapping the surficial geology of the Casino area. They reported the presence of gold grains in two of their nine samples, one sample from upper Casino

Creek and one sample from Rude Creek (Bond and Lipovsky, 2012a,b; Lipovsky and Bond, 2012) (Table 3).

Table 3. Summary of the gold content of heavy mineral samples collected from local creeks around the Casino deposit by the Yukon Geological Survey.

Sample	Creek	Heavy minerals	NTS	Reference
10PLO23	Casino	4 colour + 1 wire gold	115J/10	Bond & Lipovsky, 2012a
10PLO24	Colorado	no gold	115J/10	Bond & Lipovsky, 2012a
10PLO27	Colorado	no gold	115J/10	Bond & Lipovsky, 2012a
10PLO28	Colorado	no gold	115J/10	Bond & Lipovsky, 2012a
10PLO31	Colorado	no gold	115J/10	Bond & Lipovsky, 2012a
10PLO35	tributary to Rude	no gold	115J/10	Bond & Lipovsky, 2012a
10JB035	Rude	4 colours	115J/10	Bond & Lipovsky, 2012a
10JB016	Dip	no gold	115J/11	Lipovsky & Bond, 2012
10JB005	unamed, E of Mt Cockfield	no gold	115J/09	Bond & Lipovsky, 2012b

colour = gold flake

Chapman et al. (2014, 2018) compared lode gold signatures in the Casino deposit and large bulk (100 kg) gravel samples from known placers along Casino, Canadian and Rude creeks, and Potato Gulch (Fig. 2). They reported that gold grains in Casino bedrock samples were between 50 to 1000 µm and between 500 to 2000 µm in gravel samples. Using gold grain trace element chemistry and inclusion compositions, they concluded that the large gold placer in the middle reaches of Canadian Creek contained a mixture of gold derived from two sources: the Casino porphyry and unknown epithermal mineralization.

Barkov et al. (2008) reported the presence of several indicator minerals in a heavy mineral concentrate sample from the same large placer on Canadian Creek, below where Potato Gulch (Fig. 2) empties into the creek. In addition to Sn-rich hematite, they recovered ferberite ($FeWO_4$), hübnerite ($MnWO_4$), bismuthinite (Bi_2S_3), daubréeite ($BiO(OH,Cl)$), tetradymite (Bi_2Te_2S), and goethite in the sample. Fedortchouk and LeBarge (2008) reported the presence of one platinum-iron alloy grain and determined the composition of ilmenite grains in the same placer sample.

METHODS

Metadata for this project, all samples collected, and analytical methods used are reported in Appendix A1.

Bedrock sampling

Bedrock grab samples were collected from surface and core samples were collected from drill core stored on site at the deposit and in the Yukon Geological Survey Core Library. Samples were collected to establish the indicator mineral suite for the deposit and alteration zones for comparison to the stream sediment heavy mineral samples (McClenaghan et al., 2018). Samples were collected from the major bedrock lithologies present and the mineralized zones. These samples were examined as heavy mineral concentrates that were prepared at a commercial laboratory. Appendix A2 lists the samples collected and their field location data. The data listing also includes two bedrock samples from the Woodjam deposit because these samples were processed together with the Casino samples as a single batch. The results for the two Woodjam samples will be discussed in a separate open file.

Stream sediment and cobble sampling

A total of 22 bulk (8-16 kg) stream sediment for heavy mineral analysis were collected at 22 sites around the Casino deposit in the fall of 2017 (Fig. 2) following GSC protocols established by Friske and Hornbrook (1991) and described in Day et al. (2013). No field duplicates were collected. The ideal site for collecting bulk stream sediment is a reasonably well-sorted, high-energy, mid-channel environment where there is sufficient gravel to allow the entire sample to be collected from the same hole dug into the streambed. Samples were collected from a variety of environments including large gravel bars (longitudinal, transverse and point bars) in rivers, boulder traps, and tiny pools of sediment in rocky narrow creeks. Where possible, the upstream head of active longitudinal bars were preferentially selected. Photographs of all stream sediment samples sites are included in McCurdy et al. (2019). Each sample site was assigned a unique ID number (e.g. 115J20171026) that includes the NTS map sheet number, the year of collection, and sample number (e.g. 1026). In the description and discussion of results and on mineral distribution maps, sample sites are referred to by their abbreviated sample number only (e.g. 1026). Appendix A3 lists the samples collected and their field location data.

Samples were collected by wet-sieving samples weighing between 8 and 16 kg into a 19 litre (5-gallon) pail lined with a pre-labeled, heavy duty polyethylene (4 Mil) bag measuring 46 x 61 cm (18 x 24 inches) subsequently closed with a cable-tie. The sample was then placed into a second polyethylene bag for greater protection and closed with a cable-tie looped through a Tyvek tag that has been pre-labeled with the sample number. At the end of each day, samples were catalogued and packed into 19-litre pails for shipping to the GSC for preparation and analysis.

Five cobbles that contained visible tourmaline were collected from four sample sites: CEBB-1019a and CEBB-1019b+c were collected at sample site 1019 on Canadian Creek; CEBB-1023 was collected at site 1023 on Britannia Creek, CEBB-1025 was collected at site 1025 on Britannia Creek, and CEBB-1026 was collected at site 1026 on Canadian Creek. Appendix A2 lists the cobble samples collected and their field location data. Appendix A4 includes a composite photograph of the cobbles collected.

Sample processing

Bedrock and cobble samples

Bedrock samples were photographed (Appendix A4) at GSC and then shipped to Overburden Drilling Management Limited (ODM), Ottawa for production of heavy mineral concentrates (HMC) in three separate batches, according the schemes outlined in Figures 6 and 7 and described below:

1) ODM Batch 7895 consisted of 11 drill core samples with barren quartz blanks ('blk') processed at the start of the batch and between each bedrock sample. Processed weights and data are reported in Appendix B1 and the flow chart is shown in Figure 6.

2) ODM Batch 7749 consisted of three bedrock samples and five stream cobble samples, as well as two bedrock samples (13CDBWJ05, 13CDBWJ06) from the Woodjam porphyry Cu-Au-Mo prospect in British Columbia that were used for a separate study of tourmaline chemistry (Beckett-Brown et al., 2019). Location data for the Woodjam samples will be reported in a subsequent GSC open file. Batch 2 samples were processed with barren quartz blanks ('blk') at the beginning of the batch and between each bedrock sample. Processed weights and data are reported in Appendix B2 and the flow chart is shown in Figure 6.

3) ODM Batch 7810 consisted of three bedrock samples containing very fine-grained tourmaline. Barren quartz blanks ('blank') were processed at the start and between each sample and the data for the three samples are reported in Appendix B3 and the flow chart is shown in Figure 7.

At ODM, each bedrock sample was disaggregated using a custom-built CNT Spark-2 electric pulse disaggregator (EPD) (Rudashevsky et al., 1995; Cabri et al., 2008) to preserve natural grain sizes, textures, and shapes instead of using a conventional rock crusher. The mass of <2.0 mm material that was produced by disaggregation ranged from 44 g to 802 g. The <2.0 mm material of each sample was micro-panned to recover any fine-grained gold, sulphides, and other indicator minerals. The minerals in the panned concentrates were counted and their size and shape characteristics recorded and then returned to the concentrate. The sample was then further refined using heavy liquid and ferromagnetic separations to produce two fractions: a) 2.8-3.2 specific gravity (SG) and, b) >3.2 (Figs. 6 and 7).

Sample 18-MPB-010 in ODM Batch 7895 and sample 13CDBWJ06 in ODM batch 7749 were processed slightly differently to produce a 2.8-3.2 SG, a 3.2-3.3. SG, and a >3.3 SG fraction (Fig. 6 - right side of flow chart).

The non-ferromagnetic fraction >3.2 SG fraction of each bedrock samples was sieved into four size fractions: <0.25 mm, 0.25-0.5 mm, 0.5-1.0 mm, 1.0-2.0 mm. The 0.25-0.5 mm fraction was further subjected to paramagnetic separations using a Carpco® magnetic separator at 0.6, 0.8, and 1.0 amps to facilitate mineral identification in this finer size fraction based on the minerals' magnetic properties. Indicator minerals were visually identified in the 0.25-0.5 mm, 0.5-1.0 mm, 1.0-2.0 mm fractions of the >3.2 SG fraction and the 0.25-0.5 mm 2.8-3.2 SG fraction using a binocular microscope. The 1.0-2.0 mm, 0.5-1.0 mm, and nonparamagnetic (>1.0 amp) 0.25-0.5 mm HMC fractions of all bedrock samples were examined under short wave UV light to determine the number of scheelite grains present. In addition to the 0.25 to 2.0 mm fractions being prepared, the 0.18-0.25 mm fraction for batch 7810 samples was also prepared in order to recover smaller tourmaline grains for trace element analysis.

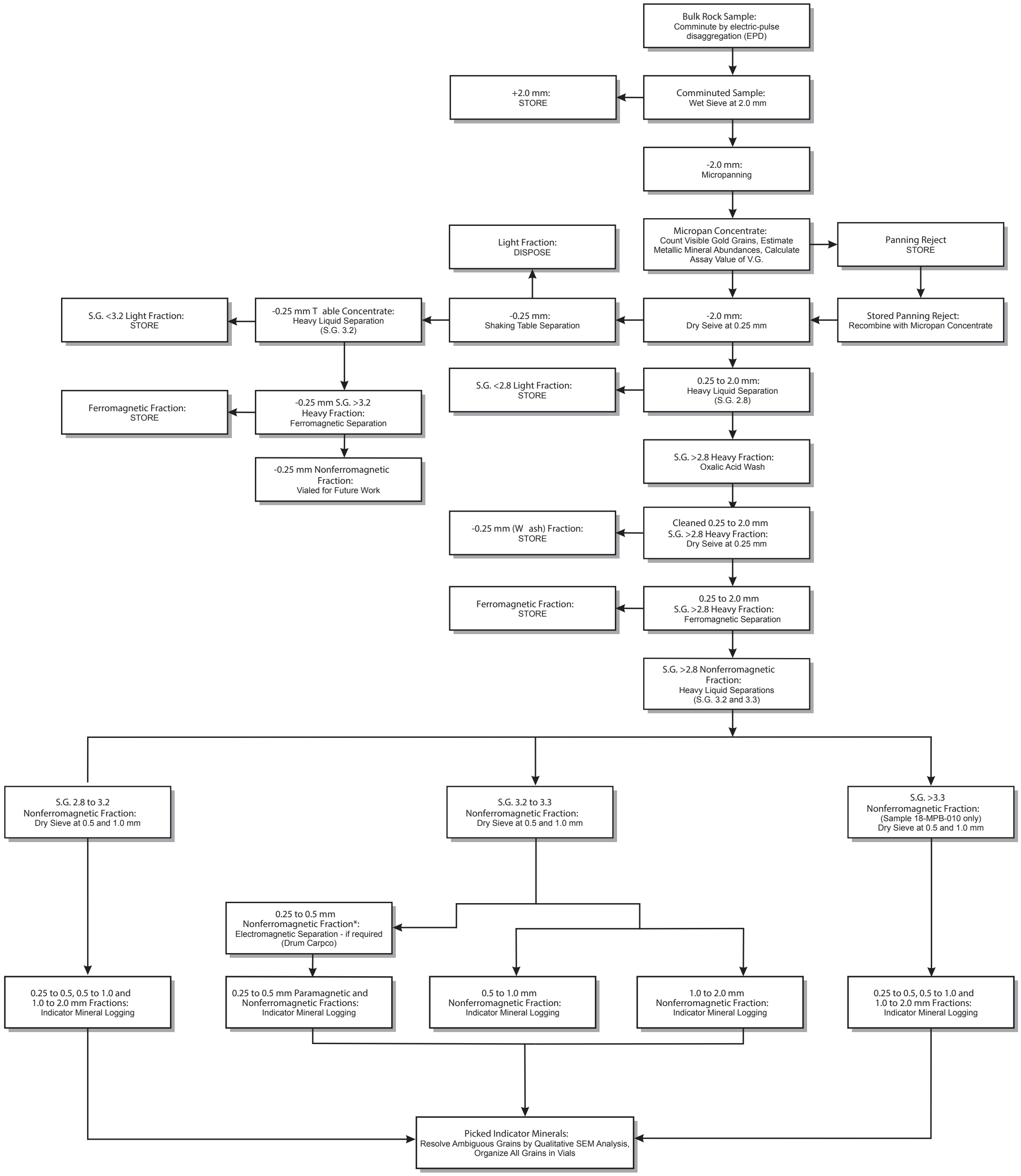

Figure 6. Schematic flow sheet showing the processing steps for: a) ODM Batch No. 7895 bedrock samples 18-MPB-001 to -012; and b) ODM Batch No. 7749 bedrock + stream cobble samples CEBB-DR-01, -PP-01, -038, -1019, -1023, -1025, -1026).

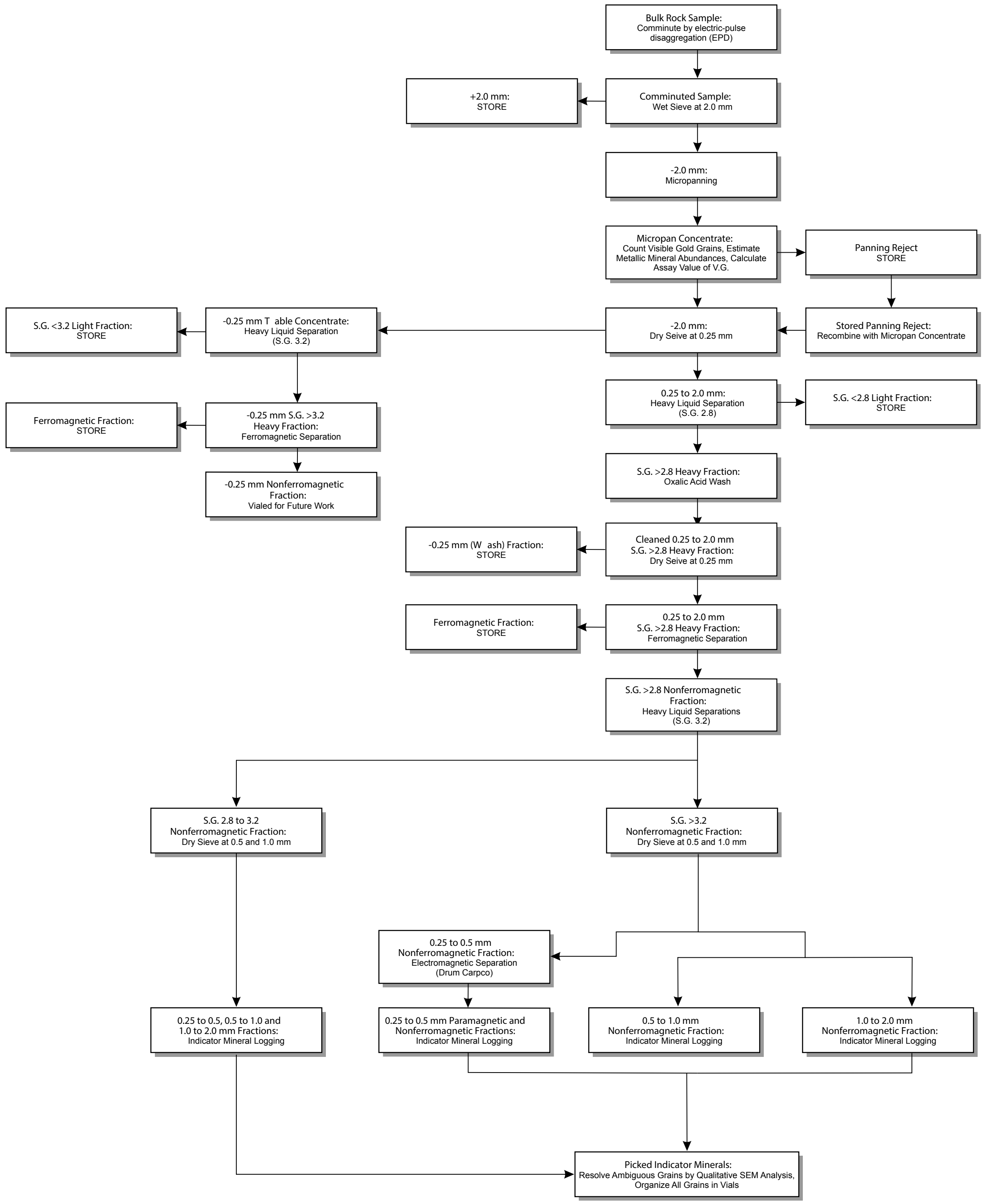

Figure 7. Schematic flow sheet showing the processing steps for ODM Batch No. 7810 bedrock samples CEBB-039, -042, -045 to produce a 2.8-3.2 SG and >3.2 SG fraction for heavy mineral counting.

Stream sediment samples
Stream sediment heavy mineral samples were shipped to ODM for sample processing and production of HMC as outlined in the flowsheet in Figure 8. A total of 22 stream sediment samples plus three quality control samples (for a total of 25 samples) were processed in an order that was suspected to be least metal-rich to most metal-rich, and the data are reported in this same order (i.e., not numerical order). The <2.0 mm fraction of stream sediment was processed in a slightly different manner than bedrock samples. Samples were first processed using a shaking table to prepare a <2.0 mm preconcentrate. The preconcentrate was micro-panned to recover fine-grained gold, sulphides, and other indicator minerals. The indicator minerals in the panned concentrates were counted, and all gold grains were sized, and their shape classified using the pristine-modified-reshaped classification scheme that relates shape to transport distance (DiLabio, 1990). All panned grains were then returned to the preconcentrate.

The preconcentrate was subsequently subjected to two heavy liquid separations and ferromagnetic separations (Fig. 8) to produce 2.8-3.2 SG and >3.2 SG non-ferromagnetic heavy mineral concentrates for visual identification and counting of indicator minerals. The 0.25-0.5, 0.5-1.0, and 1.0-2.0 mm non-ferromagnetic >3.2 G fraction and the 0.25-0.5 mm non-ferromagnetic 2.8 to 3.2 SG fraction of bedrock and stream sediment samples were examined by ODM and potential indicator minerals were counted.

GSC inserted three 'blank' sand samples into the stream sediment batch prior to processing to monitor for potential cross contamination: samples 1001, 1011, and 1021. The blank material is a GSC 'in house' standard informally referred to as the "Bathurst blank". It consists of weathered Silurian-Devonian granite (grus) of the South Nepisiguit River Plutonic Suite (Wilson, 2007) and was collected approximately 66 km west of Bathurst, New Brunswick (McClenaghan et al., 2012; Plouffe et al., 2013). Indicator mineral results for the three Bathurst blank samples are reported along with the routine stream sediment samples in Appendix B4.

Data plotting
Proportional dot maps showing the abundance of selected minerals were plotted using the ESRI ArcMap™ desktop application. Data were classified into three, four or five concentration ranges using the Jenks natural breaks method using ArcMap™.

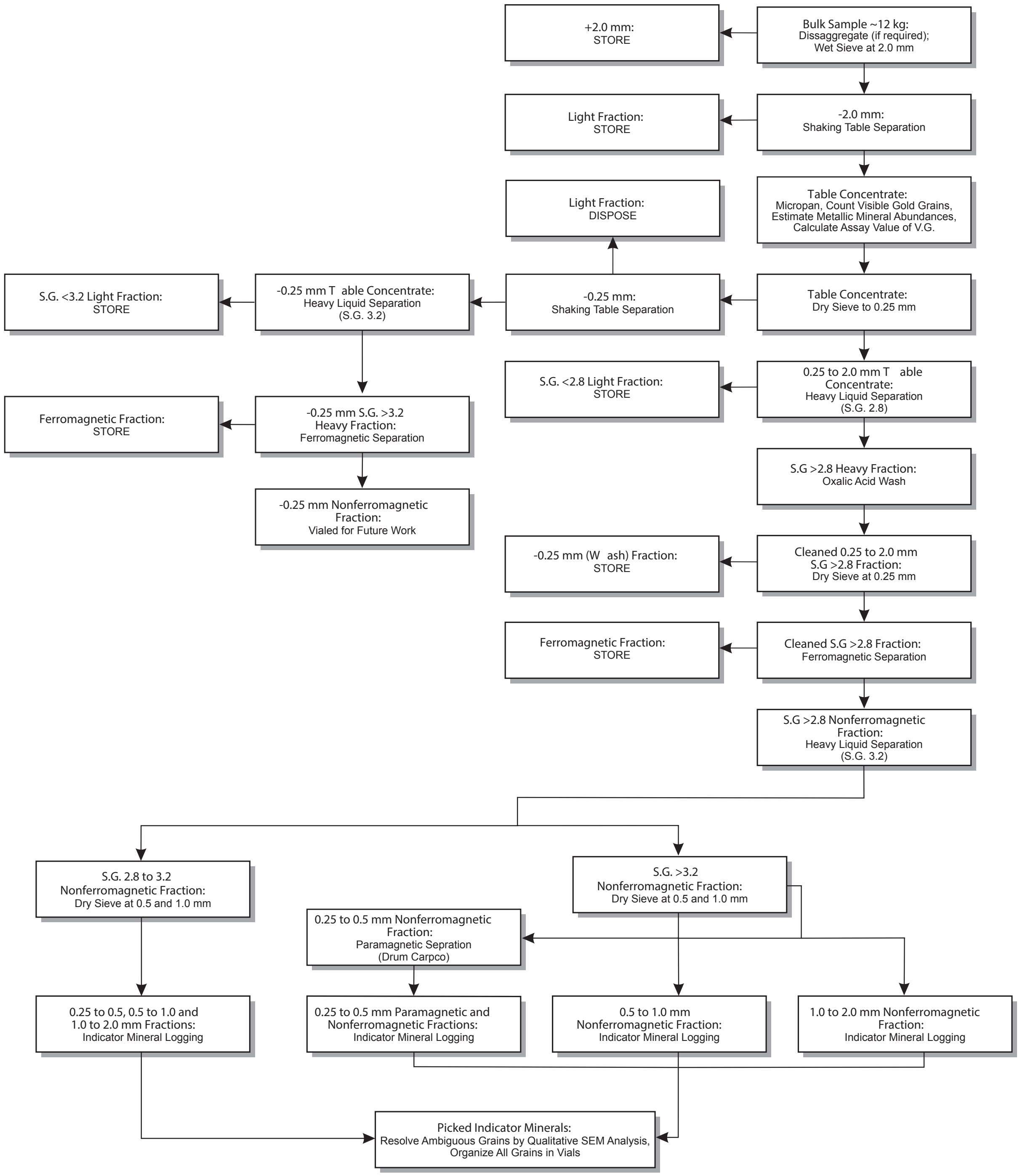

Figure 8. Schematic flow sheet showing the processing steps for Casino stream sediment samples to produce a 2.8-3.2 SG and >3.2 SG fraction for heavy mineral counting

RESULTS

Grain counts of selected minerals in the 0.25-0.5 mm >3.2 SG and 2.8-3.2 SG fractions of bedrock samples are reported in Appendix C2 as raw values (A) and normalized to 1 kg (B) in order to compare results between bedrock samples with different masses.

Grain counts for selected minerals in the 0.25-0.5 mm >3.2 SG and 2.8-3.2 SG fractions of stream sediment samples are reported in Appendix C2 as raw mineral counts (A) and counts normalized to 10 kg of <2 mm material (B). Mineral distributions are described below and unless otherwise stated, describe the normalized 0.25-0.5 mm size fraction data. Because no regional indicator mineral survey data have been published for the Casino area, background values were established using stream sediment samples farthest from the deposit that contained few indicator minerals, samples 1006 and 1009 (Fig. 2).

Quality assurance/quality control

Bedrock samples

Pan concentrate count data for quartz blank samples inserted into each bedrock batch are listed along with the routine sample data in Appendixes B1 to B3. The blank samples did not contain any indicator minerals in the pan concentrate fraction, except for one goethite grain recovered in two blank samples in batch 7749 (Appendix B2-worksheet PCIM Counts1).

Stream sediments samples

Indicator mineral counts for the pan concentrate and 0.25-0.5 mm fraction of the three Bathurst blank samples (1001, 1011, 1021) are listed along with the routine stream sediment samples in Appendix B4 (worksheet PCIM Counts 1). In the 0.25-0.5 mm heavy mineral fraction, blank sample 1021 contained 100 goethite grains and blank sample 1011 contained 3 pyrite grains. Previous data reported for the Bathurst blank indicates that it does contain the occasional pyrite and goethite grain (Oviatt et al., 2013; Plouffe et al., 2013, Geological Survey of Canada unpublished data, 2015). The goethite in blank sample 1021 is likely contamination from the three goethite-rich stream sediment samples (1008, 1010, 1013) that were processed before it.

Chalcopyrite

Chalcopyrite was identified in the >3.2 SG fraction of HMCs by its brassy yellow metallic luster and crystal habit (Fig. 9a). It was recovered from a few bedrock samples (Appendix C1), most notably samples 18-MPB-001 (potassically altered Dawson Range batholith), 18-MPB-010 (hypogene zone), and 18-MPB-012 (propylitic zone). Chalcopyrite grains from the latter two samples were submitted to Queen's University for Cu isotopic analysis.

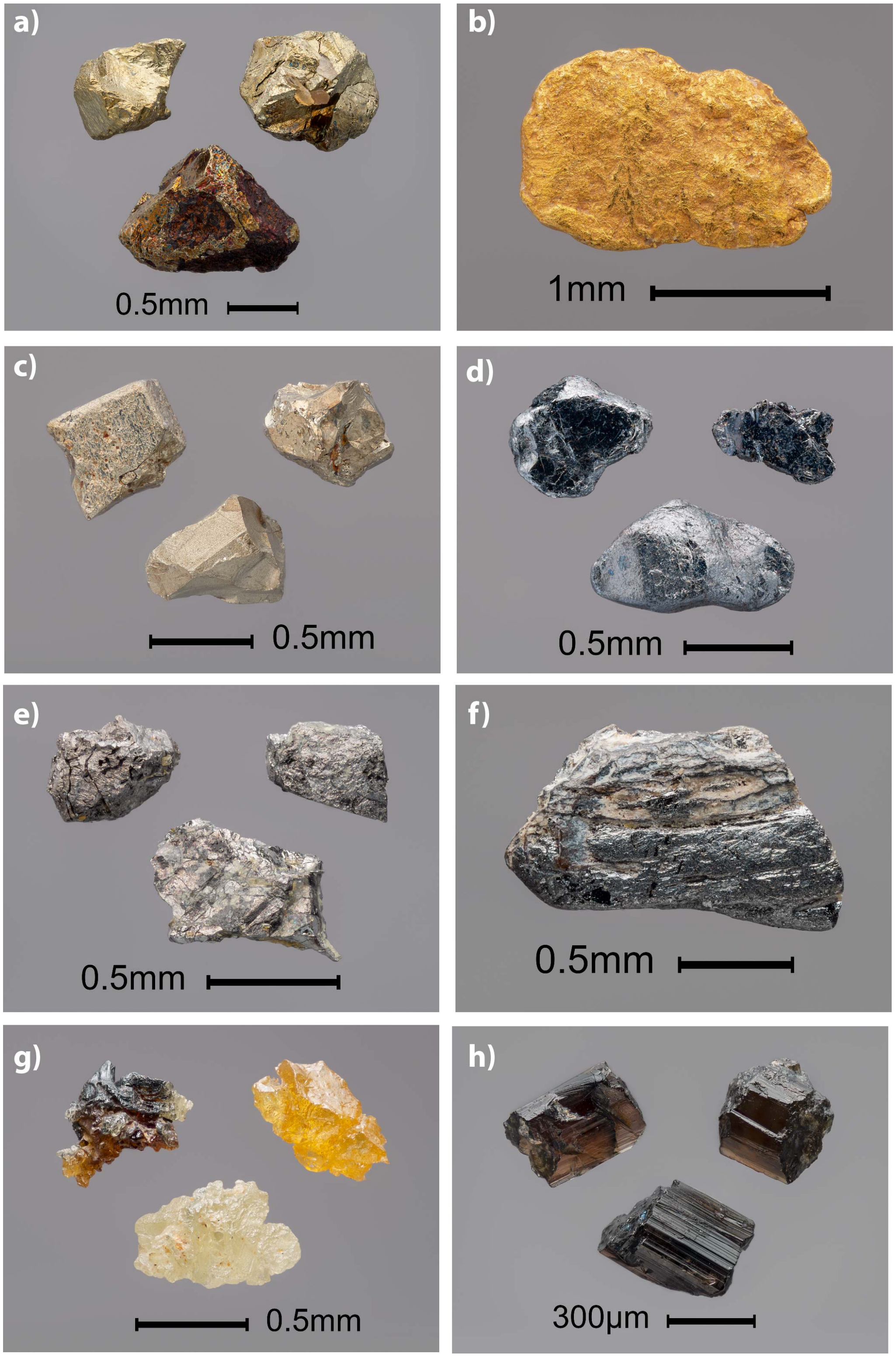

Figure 9. Colour photographs of indicator minerals recovered from the heavy mineral fraction of stream sediments around the Casino deposit: a) chalcopyrite; b) gold; c) pyrite; d) molybdenite; e) arsenopyrite; f) bismuthinite; g) sphalerite; and h) tourmaline. Photographs provided by Michael J. Bainbridge Photography.

Background content of chalcopyrite is zero grains (AppendixC2, Appendix D map D1). The largest number of grains were recovered from samples 1003 (26 grains) downstream to the east of the Cockfield occurrence, sample 1012 (13 grains) downstream of the Zappa occurrence, and sample 1019 downstream of the Buck occurrence (7 grains). Most other stream sediment samples contained between 0 and 4 grains. The highest number of grains in creeks that immediately drain the Casino deposit was 7 grains in sample 1019, from Canadian Creek. The presence of chalcopyrite is somewhat unexpected as the terrain, except for east of Mount Cockfield, is unglaciated thus the deep weathering of local rocks would have been expected to have destroyed chalcopyrite in local bedrock exposed at surface.

Gold

Gold grains counts reflect the abundance of grains in the pan concentrate of each sample prior to heavy liquid separation. Bedrock samples contain between zero and 160 gold grains (Appendix C1). Bedrock sample 18MPB-001 (potassically altered Dawson Range batholith) contained 7 gold grains between 15 to 25 µm in diameter. Sample CEBB-PP-01 (Patton porphyry - phyllic alteration) contains the most gold (160 grains) and these grains were 15 to 25 µm in diameter. Cobble sample CEBB-1025 (Patton porphyry with tourmaline veins) collected from Britannia Creek, contained 13 gold grains between 15 to 50 µm. Two Canadian Creek cobble samples CEBB1019a and CEBB1019b+c also contained 5 and 4 gold grains, respectively that were 15 to 100 µm. Bedrock sample CEBB-038 (biotite breccia) contained 9 grains, from 15 to 50 µm.

Stream sediments contain between zero and 44 gold grains (Fig. 9b) (Appendix C2) in the panned table preconcentrate. Abundances are highest in samples from Casino Creek draining the south side of the deposit and Canadian/Britannia creeks draining the north side of the deposit (Appendix D Map D2). Gold grains in stream sediments range in size from 25 to 1500 µm, with most grains between 25 and 200 µm (Appendix C3) and displaying a modified to reshaped appearance (Fig. 9b).

Pyrite

Pyrite was identified in >3.2 SG HMCs by its pale yellow metallic luster and crystal habit (Fig. 9c). It was recovered from most bedrock samples (AppendicC1), most notably sample 18-MPB-002 (potassic alteration zone) contains about ~280,000 grains, 18MPB-001 (potassically altered Dawson Range batholith) contains ~65,0000 grains, and samples 18-MPB-008, 18-MPB-009 (Patton porphyry) and 18-MPB-010 (hypogene zone) contain ~36,000 to 49,000 grains.

In stream sediments (Appendix C2), pyrite is most abundant in sample 1012 (2113 grains) from the creek draining westward from the Zappa occurrence, sample 1003 (397 grains) on a stream draining eastward from the Cockfield occurrence, 1004 (194 grains) on Hayes Creek, and 1015 (168 grains) on Excelsior Creek (Appendix D map D3). The highest value in stream sediments in Casino Creek is 79 grains in sample 1015 closest to the deposit.

Molybdenite
Molybdenite was identified in >3.2 SG HMC by its metallic to dull silver colour, rounded shape, and its extreme softness (H=1) (Fig. 9d). It was recovered from three bedrock samples (Appendix C1): sample 18-MPB-010 (hypogene zone) contained 4 grains, sample 18-MPB-012 (propyllitic zone) contained 12 grains, and sample CEBB-045 (Patton porphyry) contained 5 grains.

Only four stream sediment samples were found to contain molybdenite (Appendix C1, Appendix D map D4): sample 1014 about 1 km downstream of the deposit contained 1 grain; sample 1003 downstream of the Cockfield occurrence contained 3 grains; sample 1023 20 km downstream of the deposit in Britannia Creek contained 1 grain; and sample 1012, 2 km downstream to the west of the Zappa occurrence, contained 3 grains. Molybdenite in Casino Creek stream sediments was not unexpected as it was reported to be present in the upper Canadian Creek placer by Bostock (1959).

Arsenopyrite
Arsenopyrite was identified in the >3.2 SG HMC by its light steel grey metallic colour, brittle fracture, and moderate hardness (H=5) (Fig. 9e). No grains were recovered from bedrock samples. It was recovered in only three stream sediment samples (Appendix C2) - samples 1003, 1018, and 1019 each contained a few grains (Appendix D Map D4).

Bismuthinite
Bismuthinite (Bi_2S_3) was identified in the >3.2 SG HMC of stream sediment samples by its silvery white metallic colour, foliated form (Fig. 9f) and extreme softness (H=2). It was only recovered from two samples (Appendix C2); 1003 and 1018 each contained one grain (Appendix D Map D4).

Sphalerite
Low-Fe sphalerite grains were identified in the >3.2 SG HMC of stream sediment samples by their honey brown colour (Fig. 9g). Some of the grains appear to be corroded indicating that they have undergone chemical weathering. Samples 1013 and 1014 from Casino Creek contained 9 and 11 grains, respectively (Appendix C2, Appendix D map D4). One grain was also recovered from sample 1019 from Canadian Creek.

Tourmaline
Tourmaline can be a common accessory mineral of porphyry-style mineralization (Averill, 2001, 2011; van Hinsberg et al., 2011; Baksheev et al., 2012; Chapman et al., 2015). The tourmaline in Cu porphyries is dravite, which has a specific gravity of 3.0-3.2 and a hardness of 7-7.5. It was identified in bedrock and stream sediment mid-density and heavy mineral fractions in this study by its dark brown colour, prismatic crystal habit, parallel striations on crystal surfaces, and brittle fracture (Fig. 9h). It was most abundant in the mid-density (2.8-3.2 SG) fraction as compared to the heavy mineral fraction of all samples. Stream cobbles CEBB-1019, -1023, -1025, -1026 contain up to ~250,000 grains (Appendix C1). Bedrock sample 18-MPB-003 (phyllic alteration - Patton Porphyry) contained ~3000 grains.

A few tourmaline grains were recovered from the 2.8-3.2 SG fraction of samples in Casino Creek, but the greatest number of grains were recovered farther downstream in the lower part of Canadian Creek (sample 1019) and Britannia Creek (sample 1025), downstream of the Cockfield occurrence (samples 1002, 1003), and Sunshine Creek (sample 1016) (Appendix C2, Appendix D map D5). The presence of tourmaline in local stream sediments around the deposit was not unexpected as it occurs throughout the deposit as disseminations, in veins, and in the breccias (Beckett-Brown et al., 2019) and it was reported to be in the upper Canadian Creek placer (Bostock, 1959).

Scheelite

Scheelite ($CaWO_4$) can be an accessory mineral in a wide variety of deposit types, including porphyry deposits (Poulin et al., 2018). It has a specific gravity of 5.9 - 6.12 and a hardness of 4 to 5. It was identified in stream sediment >3.2 SG HMC by its pale yellow colour under normal light (Fig. 10a), its bright whitish blue to yellow (higher Mo content) fluorescence under short wave UV light (Fig. 10b), and its cleavage. The presence of scheelite in the Casino deposit was reported by Chapman et al. (2014) in a bedrock sample from the hypogene zone. Scheelite was reported in the placer deposit at the confluence of Canadian Creek and Patton Gulch (Bostock, 1959; Archer and Main, 1971). No grains were recovered from bedrock samples in this study. Stream sediments contain between zero and 40 grains (Appendix C2, Appendix D map D6). Samples with the largest number of grains (23 to 40 grains) include: 1007 and 1010 in Casino Creek; 1012 downstream of the Zappa occurrence; 1003 downstream of the Cockfield occurrence; and 1016 on Sunshine Creek.

Barite

Barite can be an indicator of epithermal gold mineralization associated with porphyry deposits (Averill, 2011). It has a specific gravity of 4.5 and hardness of 3-3.5. Barite grains were identified in the >3.2 SG HMC fraction by their white to colourless translucence and sometimes granular appearance. Barite was recovered from only one bedrock sample, CEBB-045 (Patton porphyry) (Appendix C1). Barite content in stream sediments varied between 0 and 31,000 grains (Appendix C2). Most samples contained <10,000 grains (Appendix D map D7). Samples with the highest barite counts include: 1004 on Hayes Creek; 1020 and 1027 in creeks draining the area around the Marquerite occurrence; 1022 at the mouth of an unnamed creek beside the Yukon River, 16 km northwest of the Casino deposit; and 1016 from Sunshine Creek.

Epidote

Green epidote can be a useful indicator mineral porphyry Cu mineralization, in both bedrock (Cook et al., 2014) and surficial sediments (Plouffe et al., 2016; Plouffe and Ferby, 2017; Kobylinski et al., 2017). Epidote in bedrock and stream sediment HMC samples in this study was identified by its pistachio green colour (Fig. 10c). Its abundance in bedrock samples was not counted.

Epidote abundance in stream sediment samples was counted and reported separately in Appendix B4, worksheet 'Epidote Grains' and Appendix C2. Its distribution is shown

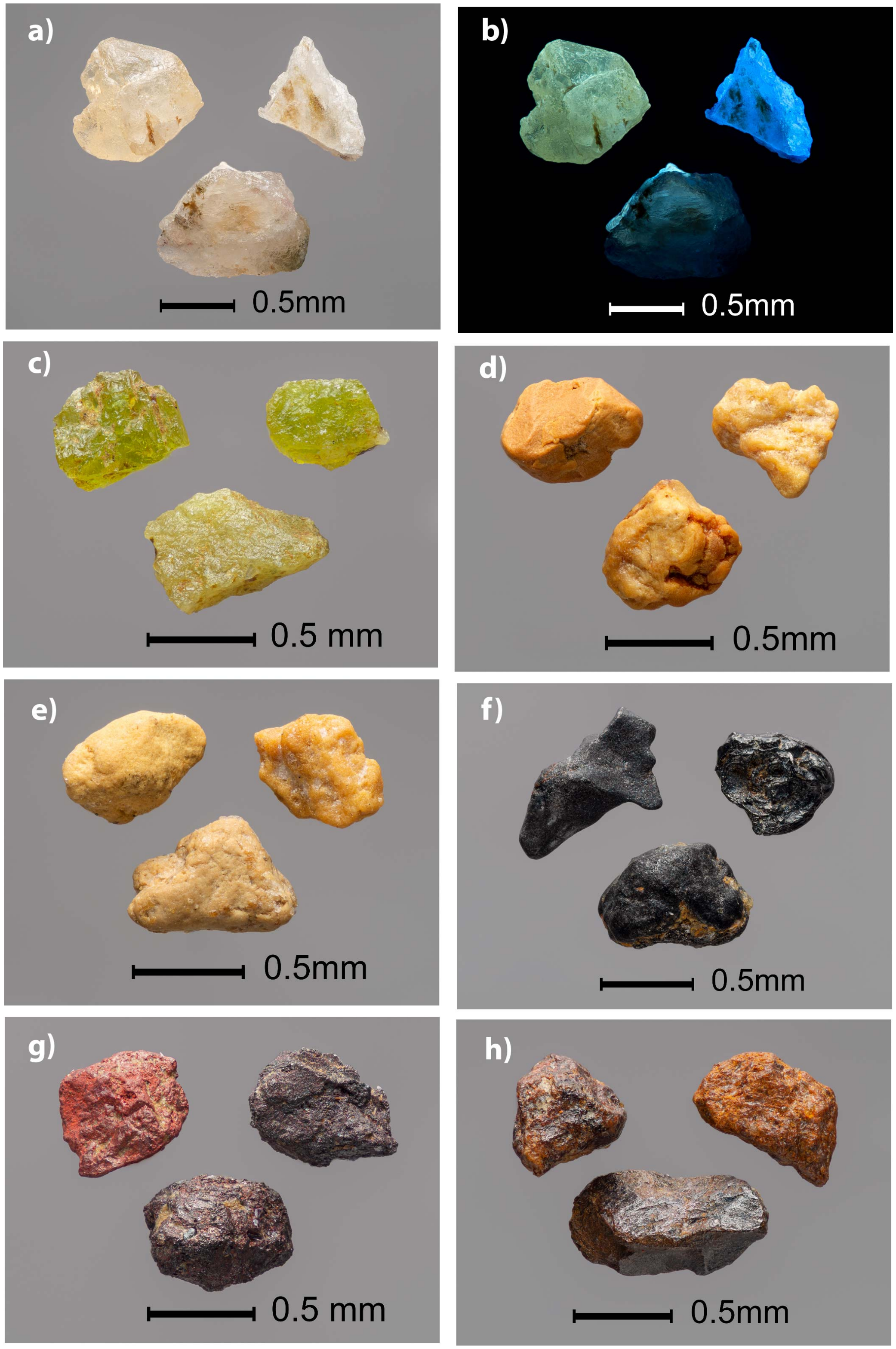

Figure 10. Colour photographs of indicator minerals recovered from the heavy mineral fraction of stream sediments around the Casino deposit: a) scheelite normal light; b) scheelite short wave ultraviolet light; c) green epidote; d) jarosite; e) plumbojarosite; f) pyrolusite; g) goethite, and h) hematite. Photographs provided by Michael J. Bainbridge Photography.

in Appendix D map D8 and ranges from zero grains in samples from background areas south (sample 1006) and southwest (sample 1009) of the Casino deposit to more than 200,000 grains in Britannia Creek (samples 1023, 1025, 1026) and its tributary (sample 1020). Casino Creek samples contained 10,000 to 33,000 grains.

Secondary Minerals

Jarosite

Jarosite ($KFe_3(SO_4)_2(OH)_6$) is a secondary mineral formed from the oxidation and weathering of Fe sulphides. Averill (2011), Kelley et al. (2011), and Plouffe and Ferbey (2017) reported that it can be a useful indicator mineral of porphyry Cu mineralization in glaciated terrain and Averill (2011) reported its usefulness in unglaciated terrains. It has a specific gravity of 2.9 to 3.3 and a hardness of 2.5-3.5. It was visually identified in the 2.8-3.2 SG fraction of stream sediments by its yellowish to light brown colour (Fig. 10d). It is visually similar to goethite, but different in that it has a waxy to vitreous appearance. When its presence was suspected in the HMC in this study, the grains were checked by ODM using an scanning electron microscope (SEM) to confirm their visual identification. Once recognized, the grains were then more readily identified in other samples.

Most bedrock samples did not contain jarosite (Appendix C1) as they were relatively fresh drill core samples. It was recovered from stream cobble samples CEBB-1019, CEBB-PP-01 (Patton porphyry- phyllic alteration) and bedrock samples CEBB-042 and CEBB-045 (Patton porphyry). Stream sediment samples 1025 and 1026 contained the greatest number of jarosite grains (1200-1300) (Appendix C2). Samples that contained 100s of grains include those from Casino Creek, as well as samples downstream of the Cockfield and Zappa porphyry occurrences (Appendix D map D9).

Plumbojarosite

Plumbojarosite ($PbFe_6(SO_4)_4(OH)_{12}$) is a secondary mineral formed in the oxidized zone of Pb sulphide deposits. It has a specific gravity of 3.6 and a hardness of only 1.5-2.0. It is visually similar to jarosite but is duller looking (Fig. 10e) and is softer. When its presence was suspected in the HMC samples, the grains were checked by ODM using an SEM to confirm their visual identification. A total of 86 grains were recovered from stream sediment sample 1013 (Appendix C2) in Meloy Creek (Appendix D map D4). The site is 3 km downstream from the Bomber Pb-Ag-Zn veins on the south flank of the deposit (Fig. 2). One grain was recovered from sample 1002, downstream of the Cockfield occurrence.

Beudantite

Beudantite ($PbFe_3(AsO_4)(SO_4)(OH)_6$) is a secondary mineral formed from the oxidation and weathering of polymetallic deposits (e.g. Boyle, 2003; Nieto et al., 2003). It has a specific gravity of 4.1 to 4.3 and a hardness of 4. One grain was identified in sample 1010 from upper Casino Creek (Appendix C2, Appendix D map D4) by its orangey brown colour, which is lighter than that of goethite, and its earthy but waxier texture as compared to goethite. The visual identification was confirmed by SEM.

Pyrolusite
Pyrolusite (MnO_2) is a secondary mineral formed from the oxidation of Mn-bearing minerals. It has a specific gravity of 4.4 to 5.1 and a hardness of 6 to 6.5. It was identified in stream sediment >3.2 SG HMC by its dull black amorphous appearance (Fig. 10f) and was confirmed by SEM. Approximately 2500 grains were recovered from sample 1013 from Meloy Creek (Appendix C2, Appendix D map D4).

Goethite
Goethite is a secondary mineral that forms from the oxidation of Fe-rich minerals. It has a hardness of 5 to 5.5 and a specific gravity 3.3 to 4.3. It was identified in stream sediment HMC by its dark orangey brown colour and earthy appearance (Fig. 10g). It was recovered from approximately half of the bedrock samples, in which it ranges in abundance from 100s to 1000s of grains (Appendix C1). Goethite was recovered from all stream sediments samples and ranges in abundance from 28 to more than 34,000 grains per sample. Samples with the greatest amount of goethite are from Casino, and Canadian creeks, and Britannia creek and its tributaries (Appendix C2, Appendix D map D10).

Hematite
Hematite has a hardness of 6.5 and a specific gravity 5.3. It was identified in stream sediment HMC by its dark black metallic or red appearance (Fig. 10h). Bostock (1959) reported abundant hematite in the upper Canada Creek placer. Hematite abundance in this study was determined only for stream sediment samples (Appendix C2). It was recovered from all but two samples (Appendix D Map D11) and ranges in abundance from 0 to about 87,000 grains per sample. Samples with the largest number of grains include: sample 1020, draining the area around the Marquerite occurrence; 1007 from Casino Creek; 1004 on Hayes Creek; 1006 from Colorado Creek; and 1016 from Sunshine Creek.

DISCUSSION
Studies of porphyry Cu indicator minerals in glaciated terrain have reported two groups of indicators (Plouffe and Ferbey, 2017). The first includes minerals that can be directly linked to porphyry mineralization based on their spatial distribution and abundance in bedrock and surficial sediments. The second group includes minerals for which mineral chemistry must be used to establish the link to porphyry Cu mineralization. Group 1 indicator minerals recovered from stream sediment samples around the Casino deposit (Casino, Meloy, Canadian creeks) include chalcopyrite, pyrite, gold, molybdenite, sphalerite, jarosite, and goethite. The distribution of these minerals in local creeks is a direct indication of the presence of the porphyry Cu deposit or its peripheral Pb-Zn-Ag veins.

Local stream sediments also contain potential group 2 minerals including epidote, tourmaline, scheelite, zircon, magnetite and barite. Studies of tourmaline chemistry are ongoing (Beckett-Brown, 2019, in press) and results to date indicate that a combination of physical (lack of inclusions, dark brown-black color) and chemical characteristics (oxy-dravite to povondraite trend, high concentrations of Sr, low concentrations of Zn and Pb) of tourmaline grains can be used to distinguish between porphyry-derived and background tourmaline in stream sediments. Future studies comparing mineral chemistry of tourmaline, magnetite, epidote, zircon, and scheelite in the Casino deposit to those recovered from local stream sediments may provide additional insights into the bedrock source(s) of these minerals (e.g. Baksheev et al., 2012; Cooke et al., 2014, 2017; Bouzari et al., 2016; Wilkinson et al., 2017; Kobylinski et al., 2017, 2018; Poulin et al., 2018; Plouffe et al., 2019, in press).

Well-rounded molybdenite grains (not flakes) (Fig. 3d) were recovered from sediments downstream of the Casino deposit as well as downstream of two porphyry Cu occurrences in the area. Molybdenite was observed in the upper Canadian Creek placer on the west flank of the deposit by Bostock (1959). Its presence in local creeks is unexpected because molybdenite is soft (hardness=1) and thus not expected to survive fluvial transport. In the glaciated terrain of eastern Canada, molybdenite was only recovered from till and steam sediment samples that directly overlie (i.e., <1 km of transport) the intrusion-hosted Sisson W-Mo deposit (McClenaghan et al., 2017) and not in samples down-ice or downstream.

Gold grains

Numerous gold grains between 25 and 100 µm were recovered from bedrock samples examined in this study which is similar to the gold grain size range (50-70 µm) reported by Huss et al. (2013) for the hypogene zone. Gold grains in this study are, however, smaller than those reported by Chapman et al. (2014) for bedrock samples (5 µm -1000 µm). The largest dimension of ~80% of the gold grains from creeks immediately draining the Casino deposit (Appendix C3) is similar (25 to 200 µm) to that for bedrock samples. Gold grain shapes in local creeks around Casino are a combination of modified and reshaped (DiLabio, 1990), reflecting limited fluvial transport.

Based on gold grain alloy compositions and mineral inclusion assemblages, Chapman et al. (2014, 2018) concluded that gold in the Canadian Creek placer downstream of Potato Gulch was a mixture of grains derived from the Casino deposit and from shallow level epithermal mineralization. The chemistry and inclusion compositions of gold grains in GSC samples are under investigation and will be compared to Chapman et al.'s (2014, 2018) results.

Comparison of local creeks

Because no previous indicator mineral data for stream sediments in the unglaciated part of the Yukon are available, thresholds between background and anomalous indicator mineral abundances were defined using distal samples 1006 and 1009 that contain very few indicator minerals. This estimation of background based on just two samples is not optimal, and could be better improved if additional heavy mineral sampling is conducted in the area.

The threshold values were compared to the highest values reported in each creek in Table 7 and anomalous values (values above the threshold) are highlighted with coloured polygons. In creeks draining the Casino deposit, concentrations of gold, chalcopyrite, pyrite, molybdenite, sphalerite, jarosite, goethite, and scheelite (grey polygons) exceed the thresholds. Meloy Creek, which drains the Bomber Pb-Zn-Ag vein area, displays a similar suite of anomalous indicators minerals (blue polygons) but also two additional minerals: pyrolusite and plumbojarosite. The presence of pyrolusite in this sample was not unexpected because black Mn coatings were observed on stream cobbles and pebbles at this site. Pyrolusite and plumbojarosite likely formed from preglacial weathering of the Pb-Zn-Ag vein area. The pipe draining the Bomber vein adit and discharging water into the headwaters of Meloy Creek may have contributed Mn-rich groundwater to the creek that in turn contributed to the formation of pyrolusite grains or pyrolusite coatings on other minerals in the stream bed.

Sediments downstream of the Cockfield (purple polygons) and Zappa (pink polygon) occurrences (Table 4), display similar suites of anomalous indicator minerals to those in the two creeks draining the Casino deposit. The other creeks listed in the table contain noteworthy combinations of gold, sulphides, secondary minerals, scheelite and tourmaline that could indicate the presence of other types of mineralization.

Table 4. Comparison of the highest values of indicator minerals stream sediment heavy mineral fraction in the various creeks draining the Casino deposit and other known mineral occurrences in the area. Values greater than the background values are highlighted in a colour unique to each deposit/occurrence. [1]Background abundances for indicator minerals defined using samples 1006 and 1009.

Element/ Mineral	Background threshold[1]	Casino (Casino Ck)	Casino (Canadian Ck)	Bomber Veins (Meloy Ck)	Cockfield (Battle + unnamed ck)	Mascot (Mascot Ck)	Buck (Isaac Ck)	Sunshine Ck	Marquerite (unnamed ck)	Zappa (unnamed ck)
gold	1	44	29	0	1	3	6	0	14	1
chalcopyrite	0	4	7	4	27	1	0	1	0	13
molybdenite	0	1	0	0	3	0	0	0	0	3
pyrite	0	79	115	11	397	28	3	22	26	2113
sphalerite	0	9	1	11	0	0	0	0	0	0
bismuthinite	0	0	0	0	1	1	0	0	0	0
arsenopyrite	0	0	2	0	3	2	0	0	0	0
jarosite	45	291	1231	36	331	0	0	144	0	423
plumbojarosite	0	0	0	86	1	0	0	0	0	0
pyrolusite	0	0	0	2518	0	0	0	0	0	0
goethite	379	18,000	7700	18,000	3311	1724	840	1079	35,000	141
hematite	7576	6711	2308	1439	5298	1035	1261	7194	87,000	352
scheelite	1	40	23	2	27	4	8	36	11	35
tourmaline	30	11	62	0	27	0	0	360	0	0

CONCLUSIONS AND IMPLICATIONS FOR EXPLORATION

This study is one of the first detailed indicator mineral studies around a major porphyry Cu deposit in unglaciated terrain. The deposit has an obvious indicator mineral signature in stream sediments that consists of, in order of effectiveness: gold>chalcopyrite >molybdenite>sphalerite>jarosite>goethite>pyrite. The signature is detectable at least 14 km downstream. Similar indicator mineral patterns in creeks downstream of other local occurrences (Cockfield, Zappa) indicate the presence of porphyry mineralization. Scheelite and tourmaline are present downstream from the deposit but also in other parts of the study area. The distribution of epidote, a known porphyry Cu indicator mineral, does not reflect the presence of the Casino deposit at all. Detailed characterization of the mineral chemistry of tourmaline and scheelite is underway to determine their bedrock source and to understand their distribution patterns and their suitability for porphyry Cu exploration in this unglaciated terrain.

The presence of fresh sulphide minerals in the stream sediments around Casino indicates that the streams are eroding, in places, less oxidized material that contains sulphides. The exposure of some of this sulphide-bearing material may, in part, be related to surface disturbances due to exploration activity on the property. Some fresh sulphide grains in Canadian Creek might have been eroded from sediment banks and bedrock during placer operations or exploration. These minerals in stream sediments would be derived from a natural source but their presence might have been enhanced by anthropogenic activities.

The purpose of the study was not to redefine the already well known geochemical signature of the Casino deposit or to prove that stream silt geochemistry is well suited to porphyry Cu exploration. Instead, the focus was on testing the use of indicator minerals as an additional porphyry Cu exploration tool in unglaciated terrain. Our study demonstrates that indicator minerals can be recovered from 10-15 kg sediment samples from creeks draining a porphyry Cu deposit in this unglaciated terrain and that they do reflect the presence of mineralization.

Heavy mineral samples provide additional information that silt geochemistry alone cannot. Indicator minerals are physical evidence of the presence of mineralization (fragments of the ore or alteration zones) and can be examined with a binocular or scanning electron microscope and chemically analyzed to provide detailed information about the nature of the mineralizing system. They may be present in very low abundances (e.g. 1-2 grains of molybdenite in a 10 kg sample) that do not have a coincident anomalous fine fraction geochemical signature.

Having indicator mineral information can be especially important in reconnaissance to regional scale surveys, where the mere presence of a few indicator grains in broadly spaced samples may indicate that a region is worth sampling in more detail. Government and exploration surveys in which detailed follow-up work is not possible in the same field season would benefit the most from the addition of indicator mineral sampling to stream sediment sampling programs.

ACKNOWLEDGMENTS

This report is a contribution to NRCan's Targeted Geoscience Initiative Program (TGI-5), a collaborative federal geoscience program with the mandate to provide industry with the next generation of geoscience knowledge and innovative techniques that will result in more effective targeting of buried mineral deposits. Support was provided through the Porphyry-style Mineral Systems Project, Activity P-3.3: Mineralogical markers of fertility porphyry-style systems. We gratefully acknowledge the support of Western Copper and Gold Corporation and the Casino Mining Corporation, and in particular Mary Mioska and Heather Brown. Jeff Bond, Yukon Geological Survey, is thanked for sharing geological information about the area and advice about sampling. This report benefited from a GSC review by Wendy Spirito.

REFERENCES

Arne, D., Mackie, R., and Pennimpede, C., 2018. Catchment analysis of re-analyzed regional stream sediment geochemical data from the Yukon; EXPLORE, No. 179, p. 1-13.

Averill, S.A. 2001. The application of heavy indicator mineralogy in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrains; *in* Drift Exploration in Glaciated Terrain, (ed.) M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall, and S.J. Cook; Geological Society of London, Special Publication 185, p. 69-81.

Averill, S.A., 2011. Viable indicators in surficial sediments for two major base metal deposit types: Ni-Cu-PGE and porphyry Cu; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 279-291.

Archer, A.R. and Main, C.A., 1971. Casino, Yukon- A geochemical discovery of an unglaciated Arizona-type porphyry; *in* Geochemical Exploration, Proceedings, 3rd International Geochemical Exploration Symposium, (ed.) R.W. Boyle; Canadian Institute of Mining and Metallurgy, Special Volume 11, p. 67-77.

Baksheev, I.A., Prokof'ev, Vs.Y., Zaraisky, G.P., Chitalin, A.F., Yapaskurt, V.O., Nikolaev, Y.N., Tikhomirov, P.L., Nagornaya, E. V, Rogacheva, L.I., Gorelikova, N. V, and others, 2012. Tourmaline as a prospecting guide for the porphyry-style deposits; European Journal of Mineralogy, v. 24, p. 957–979.

Barkov, A.Y., Martin, R.F., Shi, L., LeBarge, W. and Fedortchouk, Y., 2008. Oscillatory zoning in stanniferous hematite and associated W-and Bi-rich minerals from Canadian Creek, Yukon, Canada; The Canadian Mineralogist, v. 46, p. 59-72.

Beckett-Brown, C.E., McDonald, A.M., and McClenaghan, M.B., 2019 Unravelling tourmaline in mineralized porphyry systems: assessment as a valid indicator mineral; *in* Targeted Geoscience Initiative: 2018 Report of Activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8549, p. 345-351.

Beckett-Brown, C.E., McDonald, A.M., McClenaghan, M.B, Plouffe, A., and Ferbey, T. in press. An investigation of tourmaline characteristics in bedrock and surficial samples from two Canadian porphyry copper systems; *in* TGI5 Porphyry Hosted deposits Synthesis Volume, Geological Survey of Canada, Bulletin.

Bond, J.D. and Sanborn, P.T., 2006.Morphology and geochemistry of soils formed on colluviated weathered bedrock: Case studies from unglaciated upland slopes in west-central Yukon; Yukon Geological Survey, Open File 2006-19, 70 p.

Bond, J.D. and Lipovsky, P.S., 2011. Surficial geology, soils and permafrost of the northern Dawson Range; *in* Yukon Exploration and Geology 2010, (ed.) K.E. MacFarlane, L.H. Weston, and C. Relf; Yukon Geological Survey, p.19-32.

Bond, J.D. and Lipovsky, P.S., 2012a. Surficial geology of Colorado Creek (NTS115J/10) Yukon; Yukon Geological Survey, Open File 2012-2.

Bond, J.D. and Lipovsky, P.S., 2012b. Surficial geology Selwyn River (NTS115J/09) Yukon; Yukon Geological Survey, Open File 2012-1.

Bostock, H.S., 1959. Yukon Territory; *in* Tungsten Deposits of Canada, H.W. Little; Geological Survey of Canada, Economic Geology Series No. 17, p. 14-37

Bouzari, F., Hart, C.J.R., Bissig, T., and Barker, S., 2016. Hydrothermal alteration revealed by apatite luminescence and chemistry: a potential indicator mineral for exploring covered porphyry copper deposits; Economic Geology, v. 111, p. 1397-1410.

Bower, B., Payne, J., DeLong, C., and Rebagliati, C.M., 1995. The oxide-gold, supergene and hypogene zones at the Casino gold-copper-molybdenum deposit, west central Yukon; *in* Porphyry Deposits of the northwestern Cordillera of North America, (ed.) T.G. Schroeter; Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 46, p. 352-366.

Boyle, D.R., 2003. Preglacial weathering of massive sulphide deposits in the Bathurst Mining Camp: economic geology, geochemistry, and exploration applications; *in* Massive Sulphide Deposits of the Bathurst Mining Camp, New Brunswick and Northern Maine, (ed.) W.D. Goodfellow, S.R. McCutcheon, and J.M. Peter; Economic Geology, Monograph 11, p. 689–721.

Cabri, L.J., Rudashevsky, N.S., Rudashevsky, V.N., and Oberthür, T., 2008. Electric-pulse disaggregation (EPD), hydroseparation (HS) and their use in combination for mineral processing and advance characterization of ores; *in* Canadian Mineral Processors 40th Annual Meeting, Proceedings, Paper 14, p. 211-235.

Casselman, S.C. and Brown, H., 2017. Casino porphyry copper-gold-molybdenum deposit, central Yukon (Yukon MINFILE 115J 028); *in* Yukon Exploration and Geology Overview 2016, (ed.) K.E. MacFarlane; Yukon Geological Survey, p. 61-74.

Chapman, J.B., Plouffe, A., and Ferbey, T., 2015. Tourmaline: The universal indicator?; *in* Short Course 02 Application of Indicator Mineral Methods to Exploration, 27th International Applied Geochemistry Symposium, Tucson, Association of Applied Geochemists, p. 25–31.

Chapman, R.J., Grimshaw, M.R., Allan, M.M., Mortensen, J.K., Wrighton, T.M., and Casselman, S., 2014. Pathfinder signatures in placer gold derived from Au-bearing porphyries; *in* Yukon Exploration and Geology 2014, (ed.) K.E. MacFarlane, M.G. Nordling, and P.J. Sack; Yukon Geological Survey, p. 21-31.

Chapman, R.J., Allan, M.M., Mortensen, J.K., Wrighton, T.M., and Grimshaw, M.R., 2018. A new indicator mineral methodology based on generic Bi-Pb-Te-S mineral inclusion signature in detrital gold from porphyry and low/intermediate sulfidation epithermal environments in Yukon Territory, Canada; Mineralium Deposita, v. 58, p. 815-834.

Colpron, M., Nelson, J. L., and Murphy, D. C., 2006. A tectonostratigraphic framework for the pericratonic terranes of the northern Cordillera; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 1-23.

Colpron, M., Israel, S., Murphy, D., Pigage, L., and Moynihan, D. 2016. Yukon bedrock geology map; Yukon Geological Survey, Open File 2016-1, scale 1:1 000 000.

Cooke, D.R., Baker, M., Hollings, P., Sweet, G., Chang, Z., Danyushevsky, L.D., Gilbert, S., Zhou, T., White, N.C., Gemmell, J.B., and Inglis, S.I., 2014. New advances in detecting the distal geochemical footprints of porphyry systems – Epidote mineral chemistry as a tool for vectoring and fertility assessments; Society of Economic Geologists Special Publication 18, p. 127–152.

Cooke, D.R., Agnew, P., Hollings, P., Baker, M., Chang, Z., Wilkinson, J.J., White, N.C., Zhang, L., Thompson, J., Gemmell, J.B., Fox, N., Chen, H. and Wilkinson, C.C., 2017. Porphyry indicator minerals (PIMS) and porphyry vectoring and fertility tools (PVFTS) – indicators of mineralization styles and recorders of hypogene geochemical dispersion haloes; *in* Proceedings of Exploration ’17: Sixth Decennial International Conference on Mineral Exploration, (ed.) V. Tschirart and M.D. Thomas; p. 457-470.

Day, S.J.A., Wodicka, N., and McMartin, I., 2013. Preliminary geochemical, mineralogical and indicator mineral data for stream silts, heavy mineral concentrates and waters, Lorillard River area, Nunavut (parts of NTS 56 -A, -B, and -G); Geological Survey of Canada, Open File 7428.

DiLabio, R.N.W. 1990. Classification and interpretation of the shapes and surface textures of gold grains from till on the Canadian Shield: *in* Current Research, Part C, Geological Survey of Canada, Paper 90-1C, p. 323-329.

Duk-Rodkin, A. 2001. Glacial limits of Stevenson Ridge, Yukon Territory (115J&K); Geological Survey of Canada, Open File 3804, scale l:250,000.

Duk-Rodkin, A., Weber, F. and Barendregt, R.W. 2002. Glacial limits of Upper Yukon River; Geological Survey of Canada, Open File 4275, scale l:1 000 000.

Duk-Rodkin, A., Barendregt, R.W., Froese, D.G., Weber, F., Enkin, R., Smith, I.R., Zazula, G.D., Waters, P., Klassen, R., 2004. Timing and extent of Plio-Pleistocene

glaciations in northwestern Canada and east-central Alaska. In:
Quaternary Glaciations – Extent and Chronology, Part II: North America, (ed.) J. Ehlers and P.L. Gibbard; Developments in Quaternary Science, v. 2b, p. 313–345.

Fedortchouk, Y. and LeBarge, W., 2008. Sources of placer platinum in Yukon: provenance study from detrital minerals; Canadian Journal of Earth Sciences, v. 45, p. 879-896.

Friske, P.W.B. and Hornbrook, E.H.W., 1991. Canada's National Geochemical Reconnaissance programme; Institution of Mining and Metallurgy, Transactions, Section B: Applied Earth Sciences, v. 100, p. B47–B56.

Geological Survey of Canada, 1987. Regional stream sediment and water geochemical reconnaissance data, Yukon (NTS 115J, 115K (E1/2)); Geological Survey of Canada, Open File 1363, 142 pages (25 sheets); 1 diskette, https://doi.org/10.4095/130284

Godwin, C.I., 1975. Geology of the Casino porphyry copper-molybdenum deposit, Dawson Range, Yukon Territory; Unpublished PhD Thesis, University of British Columbia.

Godwin, C.I., 1976. Casino; *in* Porphyry Deposits of the Canadian Cordillera, Canadian Institute of Mining and Metallurgy, Special Volume 15, p. 344-358.

Hashmi, S, Ward, B.C., Plouffe, A., Leybourne, M.I., and Ferbey, T., 2015. Geochemical and mineralogical dispersal in till from the Mount Polley Cu-Au porphyry deposit, central British Columbia; Canada; Geochemistry: Exploration, Environment, Analysis, v. 15, p. 234–249.

Huscroft, C.A., 2002a. Surficial geology, Britannia Creek, Yukon Territory (115J/15); Geological Survey of Canada, Open File 4345.

Huscroft, C.A., 2002b. Surficial geology, Coffee Creek, Yukon Territory (115J/14); Geological Survey of Canada, Open File 4344.

Huscroft, C.A., 2002c. Surficial geology, Cripple Creek, Yukon Territory (115J/16); Geological Survey of Canada, Open File 4346.

Huss, C., Drielick, T., Austin, J., Giroux, G., Casselman, S., Greenaway, G., Hester, M. and Duke, J., 2013.Casino Project: Form 43-101F1 Technical Report, Feasibility Study, Yukon, Canada. Internal report, M3 Engineering and Technology Corp., 248 p.

Jackaman, W., 2011. Regional stream sediment geochemical data Stevenson Ridge, Yukon (NTS 115J & K); Yukon Geological Survey, Open File 2011-28.

Kelley, K.D., Eppinger, R.G., Lang, J., Smith, S.M., and Fey, D.L., 2011. Porphyry copper indicator minerals (PCIMs) in glacial till samples as an exploration tool: example from the giant Pebble porphyry Cu-Au-Mo deposit; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 321–334.

Kobylinski, C.H., Hattori, K., Plouffe, A. and Smith, S.W., 2017. Epidote associated with the porphyry Cu-Mo mineralization at the Gibraltar deposit, south-central British Columbia; Geological Survey of Canada, Open File 8279.

Kobylinski, C.H., Hattori, K., Smith, S.W., and Plouffe, A., 2018. High cerium anomalies in zircon from intrusions associated with porphyry copper mineralization in the Gibraltar deposit, south central British Columbia; Geological Survey of Canada, Open File 8430.

Lipovsky, P.S. and Bond, J.D., 2012. Surficial geology of Doyle Creek (115J/11), Yukon; Yukon Geological Survey, Open File 2012-3.

Mackie, R.A., Arne, D.C., and Pennimpede, C., 2017. Assessment of Yukon regional stream sediment catchment basin and geochemical data quality; Yukon Geological Survey, Open File 2017-4.

McClenaghan, M.B., and Cabri, L.J., 2011. Gold and Platinum Group Element indicator minerals in surficial sediments; Geochemistry: Exploration, Environment, Analysis, v. 11, p. 251–263.

McClenaghan, M.B., and Kjarsgaard, B.A., 2007. Indicator mineral and surficial geochemical exploration methods for kimberlite in glaciated terrain: Examples from Canada: *in* Mineral Deposits of Canada: A Synthesis of Major Deposit-Types, District Metallogeny, the Evolution of Geological Provinces, and Exploration Methods, (ed.) W.D. Goodfellow; Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, pp. 983-1006.

McClenaghan, M.B., Budulan, G., Averill, S.A., Layton-Matthews, D. and Parkhill, M.A. 2012. Indicator mineral abundance data for bedrock and till samples from the Halfmile Lake Zn-Pb-Cu Volcanogenic Massive Sulphide Deposit, Bathurst Mining Camp, New Brunswick; Geological Survey of Canada, Open File 7076.

McClenaghan, M.B., Parkhill, M.A., Pronk, A.G., Seaman, A.A., McCurdy, M., and Leybourne, M.I., 2017. Indicator mineral and geochemical signatures associated with the Sisson W-Mo deposit, New Brunswick, Canada; Geochemistry: Exploration, Environment, Analysis, v. 17, p. 297-313.

McClenaghan M.B., Beckett-Brown, C.E., McCurdy, M.W., McDonald, A.M., Leybourne, M.I., Chapman, J.B., Plouffe, A., and Ferbey, T., 2018. Mineral markers of porphyry Cu mineralization: Progress report on the evaluation of tourmaline as an indicator mineral; *in* Targeted Geoscience Initiative: 2017 Report of Activities, Volume 1, (ed.) N. Rogers; Geological Survey of Canada, Open File 8358, p. 69-77.

McClenaghan M.B., McCurdy, M.W., Garrett, R.G., Beckett-Brown, C.E., Leybourne, M.I., Casselman, S.G and Pelchat, P., 2019. Mineral and geochemical signatures of porphyry copper mineralization: work in progress at the Casino Cu-Au-Mo-Ag porphyry deposit; *in* Targeted Geoscience Initiative: 2018 Report of Activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8549, p. 333-344.

McCurdy, M.W., McClenaghan, M.B., Garrett, R.G., and Pelchat, P., 2019. Geochemical signatures of the silt fraction from streams near the Casino porphyry Cu-Au-Mo deposit, Yukon Territory; Geological Survey of Canada, Open File 8632.

McKillop, R., Turner, D., Johnston, K., Bond, J., 2013. Property-scale classification of surficial geology for soil geochemical sampling in the unglaciated Klondike Plateau, west-central Yukon; Yukon Geological Survey, Open File 2013-15.

Moran, K., and 36 others. 2006. The Cenozoic paleoenvironment of the Arctic Ocean; Nature, v. 441, p. 601–605.

Natural Resources Canada, 2017. Canadian Digital Elevation Model. <https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333> [accessed February 13, 2020]; Contains information licensed under the Open Government Licence – Canada; < https://open.canada.ca/en/open-government-licence-canada>

Nelson, J. L., Colpron, M., Piercey, S. J., Dusel-Bacon, C., Murphy, D. C., and Roots, C. F., 2006. Paleozoic tectonic and metallogenic evolution of the pericratonic terranes in Yukon, northern British Columbia and eastern Alaska; *in* Paleozoic Evolution and Metallogeny of Pericratonic Terranes at the Ancient Pacific Margin of North America, Canadian and Alaskan Cordillera, (ed.) M. Colpron and J.L. Nelson; Geological Association of Canada, Special Paper 45, p. 323-360.

Nelson, J.L., Colpron, M., and Israel, S., 2013. The Cordillera of British Columbia, Yukon, and Alaska: Tectonics and Metallogeny; *in* Tectonics, Metallogeny, and Discovery: The North American Cordillera and similar accretionary settings, (ed.) M. Colpron, T. Bissing, B.G. Rusk, and J.F.H. Thompson; Society of Economic Geologists, Special Publication 17, p. 53-109.

Nieto, J.M., Capitán, M.A., Sáez, R., and Almodovar, G.R., 2003. Beudantite: a natural sink for As and Pb in sulphide oxidation processes; Applied B293- Sciences, Transactions of the Institute of Mining and Metallurgy, v. 112, p. B293–B296.

Oviatt, N.M., McClenaghan, M.B., Paulen, R.C., Gleeson, S.A., Averill, S.A., and Paradis, S., 2013. Indicator minerals in till and bedrock samples from the Pine Point Mississippi Valley-Type (MVT) district, Northwest Territories; Geological Survey of Canada, Open File 7432.

Plouffe, A. and Ferbey, T., 2017. Porphyry Cu indicator minerals in till: A method to discover buried mineralization; *in* Indicator minerals in till and stream sediments of the Canadian Cordillera, (ed.) T. Ferbey, A. Plouffe, and A. Hickin; Mineral Association of Canada, Topics in Mineral Sciences Volume 47, Geological Association of Canada, Special Paper 50, p. 129-159.

Plouffe, A., McClenaghan, M.B., Paulen, R.C., McMartin, I., Campbell, J.E., and Spirito, W.A., 2013. Processing of unconsolidated glacial sediments for the recovery of indicator minerals: protocols used at the Geological Survey of Canada. Geochemistry: Exploration, Environment, Analysis, v. 13, p. 303-316.

Plouffe, A., Ferbey, T., Hashmi, S., and Ward, B.C., 2016. Till geochemistry and mineralogy: vectoring towards Cu porphyry deposits in British Columbia, Canada; Geochemistry: Exploration, Environment, Analysis, v. 16, p. 213-232.

Plouffe, A., Kobylinksi, C.H., Hattori, K., Wolfe, L., and Ferbey, T., 2018. Mineral markers of porphyry copper mineralization: work in progress at the Gibraltar deposit, British Columbia; *in* Targeted Geoscience Initiative: 2017 Report of Activities, Volume 1, (ed.) N. Rogers; Geological Survey of Canada, Open File 8358, p. 57–67.

Plouffe, A., Kjarsgaard, I., Kobylinski, C., Hattori, K., Petts, D., Venance, K., and Ferbey, T., 2019. Discovering the next generation of Cu porphyry deposits using mineral markers; *in* Targeted Geoscience Initiative: 2018 Report of Activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8549, p. 321-331.

Poulin, R.S., McDonald, A., Kontak, D.J., and McClenaghan, M.B., 2018. Assessing scheelite as an ore-deposit discriminator using its trace-element and REE chemistry; The Canadian Mineralogist, v. 56, p. 265-302.

Relf, C., 2020. Yukon Geological Survey: Planning for the future; *in* Yukon Exploration and Geology Overview 2019, (ed.) K.E. MacFarlane; Yukon Exploration & Geology Overview 2019, Yukon Geological Survey, p. 1–22.

Rudashevsky, N.S., Burakov, B.E., Lupal, S.D., Thalhammer, O.A.R., and Saini-Eidukat, B., 1995. Liberation of accessory minerals from various rock types by electric-pulse disintegration - method and application; Transactions of the Institute of Mining and Metallurgy, v. 104, p. C25–C29.

Ryan, J.J., Zagorevski, A., Williams, S.P., Roots, C., Ciolkiewicz, W., Hayward, N. and Chapman, J.B., 2013. Geology, Stevenson Ridge (northeast part), Yukon; Geological Survey of Canada, Canadian Geoscience Map 116 (preliminary), scale 1:100 000.

Smith, C.A.S., Meikle, J.C., and Roots, C.F. (editors), 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon landscapes; Agriculture and Agri-Food Canada, PARC Technical Bulletin No. 04-01, Summerland, British Columbia, 313 p.

van Hinsberg, V.J., Henry, D.J., and Marschall, H.R., 2011. Tourmaline: an ideal indicator of its host environment; The Canadian Mineralogist, v. 49, p. 1-16.

Vavrek, M.J., Evans, D.C., Braman, D.R., Campione, N.E. and Zazula, G.D. 2012. A Paleogene flora from the upper Bonnet Plume Formation of northeast Yukon Territory, Canada; Canadian Journal of Earth Sciences, v. 49, p. 547–558.

Wilkinson, J.J., Cooke, D.R., Baker, M.J., Chang, Z., Wilkinson, C.C., Chen, H., Fox, N., Hollings, P., White, N.C., Gemmell, J.B., Loader, M.A., Pacey, A., Sievwright, R.H., Hart, L.A., and Brugge, E.R., 2017. Porphyry indicator minerals and their mineral chemistry as vectoring and fertility tools; *in* Geological Survey of Canada, Open File 8345, p. 67-77.

Wilson, R.A. 2007. Bedrock geology of the Nepisiguit Lakes area (NTS 21O/7), Restigouche and Northumberland counties, New Brunswick; New Brunswick Department of Natural Resources, Map Plate 2007-32.

Yukon Geological Survey, 2016. RGS RE-analysis. http://data.geology.gov.yk.ca/Compilation/21 (accessed January 24, 2020).

Yukon Geological Survey, 2020a. Occurrence 115J 027. Bomber occurrence. http://data.geology.gov.yk.ca/Occurrence/14376 (accessed January 24, 2020).

Yukon Geological Survey, 2020b. Occurrence 115J 028. Casino occurrence. http://data.geology.gov.yk.ca/Occurrence/15019 (accessed January 24, 2020).

Yukon Geological Survey, 2020c. Overview of Yukon geology. http://www.geology.gov.yk.ca/overview_bedrock_geology.html (accessed January 24, 2020).

Yukon Geological Survey, 2020d. Yukon digital bedrock geology. http://www.geology.gov.yk.ca/update_yukon_bedrock_geology_map.html, (accessed January 24, 2020).

Yukon Geological Survey, 2020e. Occurrence 115J 017. Cockfield occurrence. http://data.geology.gov.yk.ca/Occurrence/14367 (accessed January 24, 2020).

Yukon Geological Survey, 2020f. Occurrence 115J 036. Zappa occurrence. http://data.geology.gov.yk.ca/Occurrence/14384 (accessed January 24, 2020).

Yukon Geological Survey, 2020g. Occurrence 115J 101. Canadian Creek occurrence. http://data.geology.gov.yk.ca/Occurrence/14431 (accessed January 24, 2020).

Yukon Geological Survey, 2020h. Occurrence 115J 070. Marquerite occurrence. http://data.geology.gov.yk.ca/Occurrence/14417 (accessed January 24, 2020).

Yukon Geological Survey, 2020i. Occurrence 115J 023. Nordex occurrence. http://data.geology.gov.yk.ca/Occurrence/14372 (accessed January 24, 2020).

Yukon Geological Survey, 2020j. Occurrence 115J 099. Idaho occurrence. http://data.geology.gov.yk.ca/Occurrence/15100 (accessed January 24, 2020).

Yukon Geological Survey, 2020k. Occurrence 115J 022. Rude Creek occurrence. http://data.geology.gov.yk.ca/Occurrence/14371 (accessed January 24, 2020).

Yukon Geological Survey, 2020l. Occurrence 115J 071. Buck occurrence. http://data.geology.gov.yk.ca/Occurrence/14418 (accessed January 24, 2020).

Yukon Geological Survey, 2020m. Occurrence 115J 074. Mascot occurrence. http://data.geology.gov.yk.ca/Occurrence/14421 (accessed January 24, 2020).

Zachos, J.C., Pagani, M., Sloan, L., Thomas, E., and Billups, K., 2001. Trends, rhythms, and aberrations in global climate 65 Ma to present; Science, v. 292, p. 686–693.