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

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Map C14 Ga

Map C15 Hg

Map C16 K

Map C17 Li

Map C18 LOI determined by LECO/gravimetric methods

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Map C20 Mn

Map C21 Mo

Map C22 Na

Map C23 Ni

Map C24 P

Map C25 Pb

Map C26 Sb

Map C27 Sc

Map C28 Se

Map C29 Sn

Map C30 Sr

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ABSTRACT

The Casino calc-alkaline porphyry copper-gold-molybdenum deposit, located within the Yukon-Tanana terrane in west-central Yukon, is hosted in Late Cretaceous quartz monzonite of the Casino suite. It is unique among Canadian porphyry Cu deposits in that it has a substantially preserved outcropping leached cap. Samples of stream sediment and water were collected at 22 sites over a period of eight days in September 2017 around the deposit in order to determine if the metal zoning of elements associated with the porphyry copper system is reflected in the geochemical composition of the <177 µm stream sediment fraction. Ten elements are considered in this report: Au, Cu, Mo, Ag, Sb, As, Zn, Pb, Bi and Mn. These elements were selected based on previous studies and correlation analysis using symmetric coordinates. Statistical comparisons (Reduced Major Axis regression and Kolmogorov-Smirnov tests) of the Casino samples confirmed that these data are comparable with an older regional data set of 19,471 samples and a subset of 1,301 samples from areas around the deposit and within the Yukon-Tanana terrane that were collected by the Geological Survey of Canada in 1986. Data for element concentrations determined on dry unsieved stream sediments collected in 2017 using a portable X-ray fluorescence device are also included in this report.

INTRODUCTION

The Casino porphyry copper-gold-molybdenum deposit within the Yukon-Tanana terrane in west-central Yukon (Fig. 1) is one of Canada's largest and highest-grade porphyry deposits. It provides an ideal site for testing modern stream sediment geochemical methods because the deposit has only been minimally disturbed by exploration, is not yet mined, and is known to have metal-rich waters and sediments in creeks draining the deposit (Archer and Main, 1971).

The study area is unique in that the landscape has remained largely unglaciated within the last 200,000 years (Bond and Lipovsky, 2011). Glaciers originating around local peaks in the eastern Dawson Range (glacial maximum at 130,000 BP) have left alpine glacial features and deposits on the east flank of Mount Cockfield and the mountain peak northwest of the Casino deposit, as well as along the Yukon River in the northeast quadrant of the survey area (Fig. 2). The surface over much of the area consists of a veneer of frost-shattered weathered bedrock and colluvium mixed with loess. The composition of stream sediments is affected primarily by locally derived material from bedrock entering the drainage systems through periglacial and mass wasting processes.

Samples of stream sediment and water were collected at 22 sites (Fig. 2) around the Casino deposit over a period of eight days in September 2017 using a helicopter, truck and all-terrain vehicles to access sample sites. At each site, two water samples, one silt sample, one bulk sediment sample for indicator minerals and one pebble sample were collected. Samples were collected primarily from fast or moderately fast flowing second- and third-order streams. Slow flowing streams with a high loess suspended load were avoided (Bond and Lipovsky, 2011).

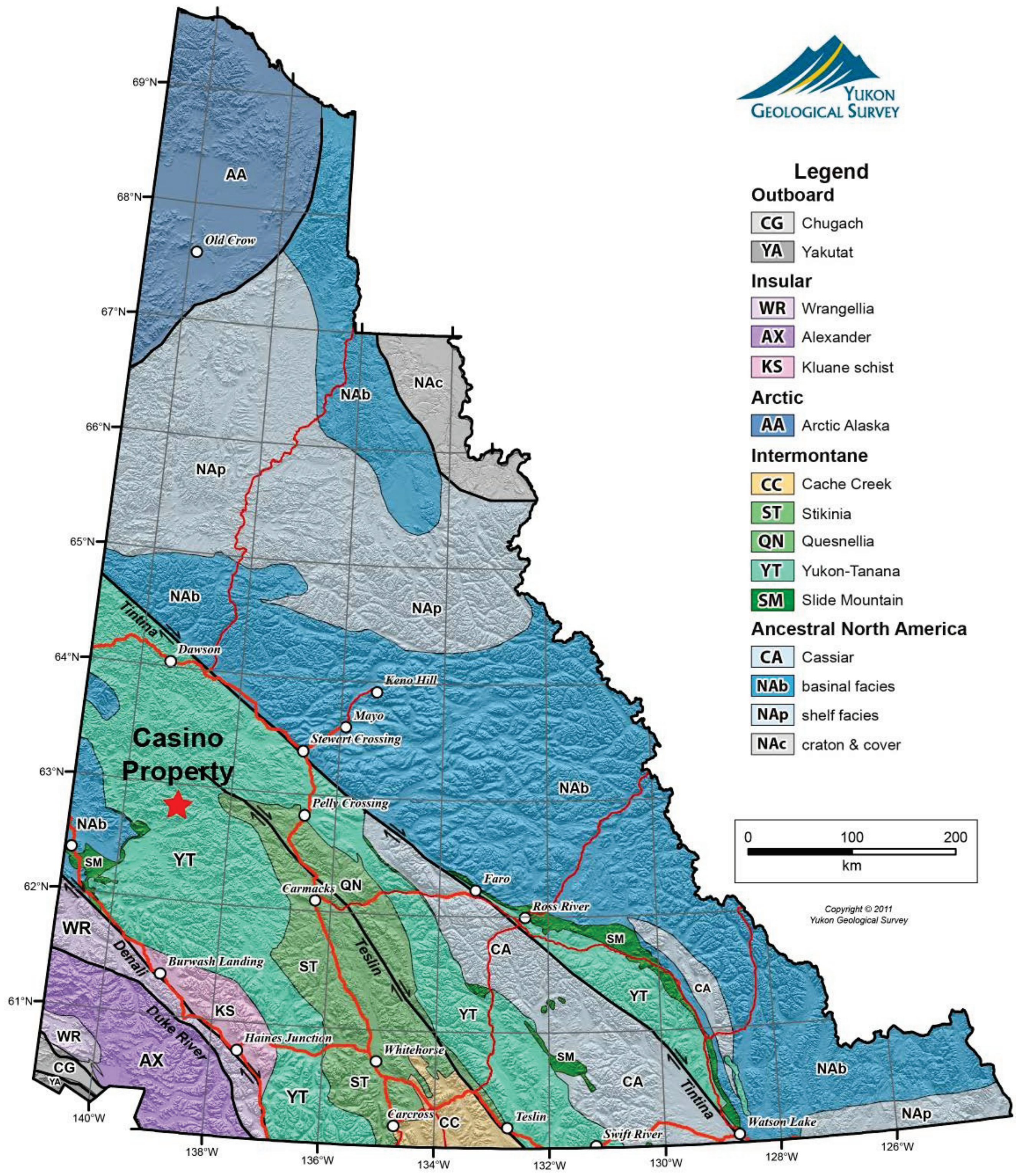

Figure 1. Bedrock terrane maps for Yukon showing the location of the Casino porphyry Cu-Mo-Au deposit in west central Yukon (modified from Colpron and Nelson, 2011).

This stream sediment and water study was carried out as part of the Geological Survey of Canada (GSC) Targeted Geoscience Initiative 5 (TGI-5), a collaborative federal-provincial-territorial geoscience program with a 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. TGI-5 includes other activities targeted at porphyry deposits and more specifically studies on porphyry indicator minerals (Plouffe et al., 2017, 2018, 2019; McClenaghan et al., 2018, 2019; Beckett Brown et al., 2019). We report on stream sediment geochemistry obtained in 2017 around the Casino deposit and we compare these new results with previously published regional-scale GSC stream sediment data for the Yukon.

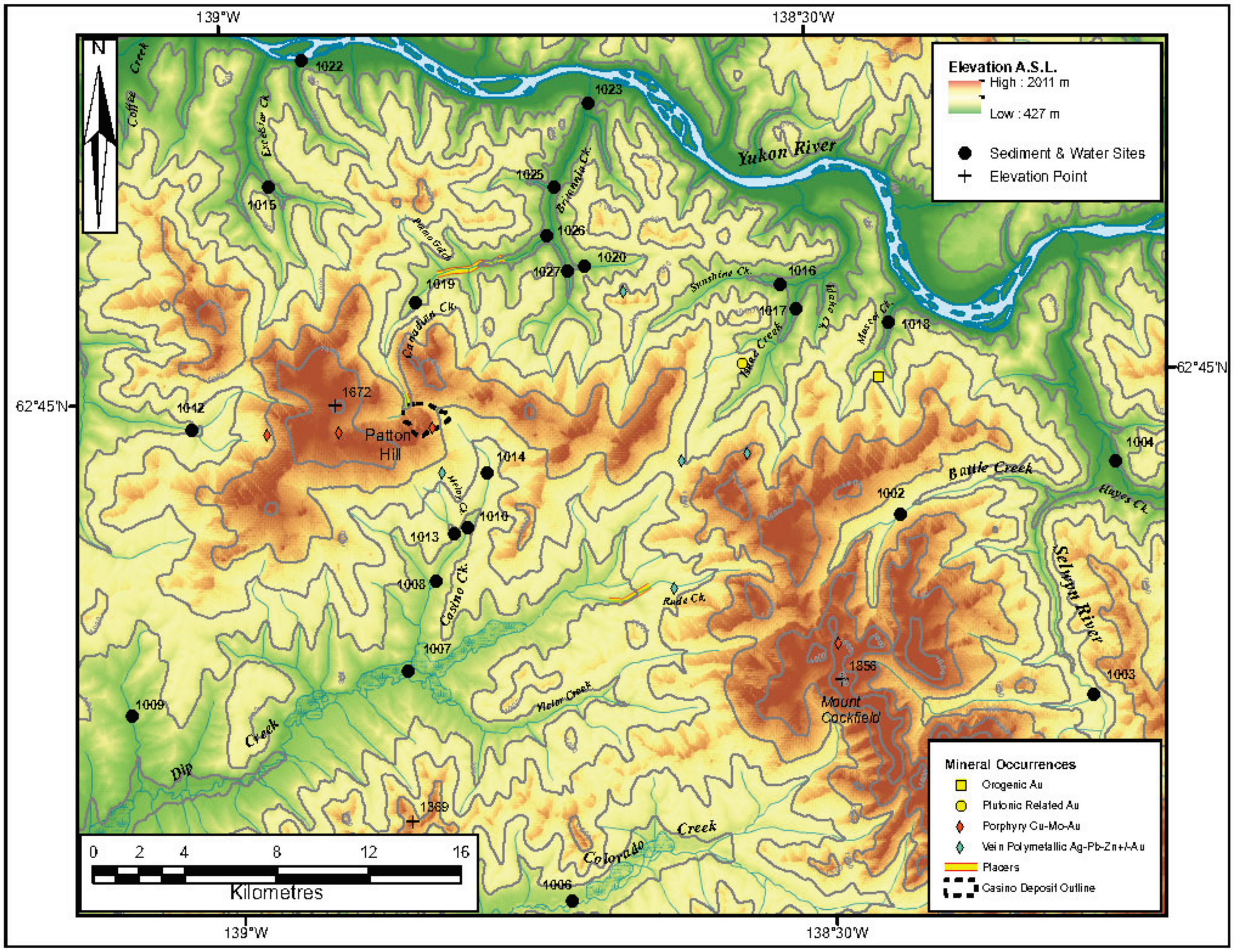

Figure 2. Digital elevation model (DEM) showing the location of stream sediment samples collected by the Geological Survey of Canada in 2017 (black dots) around the Casino deposit. DEM from Natural Resources Canada (2017).

REGIONAL SETTING

Location and Physiography

The survey area is in west-central Yukon, 300 km north of Whitehorse and within the Klondike Plateau ecoregion (Smith et al., 2004). The deposit is at latitude 62° 44' North and longitude 138° 50' West, in National Topographic System (NTS) map areas 115J J/10 and 115J J/15. Creeks draining the northeast side of the deposit flow northward into the northwest-flowing Yukon River. Southwest of the deposit, southward-flowing streams drain into the Donjek River.

Most of the local terrain lies at elevations of 1000-1500 metres above sea level (a.s.l.). 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 is -23 °C. The mean annual precipitation ranges from 300 to 450 mm (Smith et al., 2004). The characteristic vegetation consists of open black and white spruce forests with aspen and occasionally lodgepole pine. Black spruce and paper birch prevail on slopes underlain by permafrost. Balsam poplar occurs along floodplains. Scrub birch and willow form extensive stands in subalpine sections from valley bottoms to well above the treeline. Characteristic terrain features include smooth, largely unglaciated, rolling plateau topography with moderate to deeply incised valleys. The unglaciated Klondike Plateau is dissected by deep, narrow, V-shaped valleys. Permafrost is extensive and discontinuous with medium ice content in fine-textured valley deposits. Turbic Cryosols associated with permafrost and Eutric Brunisols developed on irregular, steeply sloping, loamy colluvial materials are dominant in the region. Regosols occur on sandy floodplains. Characteristic wildlife includes caribou, grizzly and black bear, Dall sheep, moose, beaver, fox, wolf, hare, raven, rock and willow ptarmigan, and golden eagle. Land uses include wilderness recreation, tourism, hunting, and trapping (Canadian Council on Ecological Areas, 2014).

Regional Bedrock Geology

The survey area is underlain by the oldest part of Yukon-Tanana terrane (Fig. 1), consisting of multi-deformed and metamorphosed mostly amphibolite-facies siliciclastic rocks including quartzite, micaceous quartzite and psammitic quartz-muscovite-biotite (±garnet) schist of the pre-Devonian Snowcap assemblage (PDS1). Decametre-thick lenses of light grey to white marble (PDS2) interlayered with amphibolite and garnet amphibolite, interpreted as the metamorphosed equivalents of mafic sills and dikes, are also mapped within the survey area (Fig. 3a, b; Ryan et al., 2013; Casselman and Brown, 2017).

The Snowcap assemblage is locally in structural contact with Devonian to Mississippian strongly foliated massive amphibolite of the Finlayson assemblage (DMF1) and grey to black carbonaceous quartzite, quartz-mica schist, and phyllite of the Stevenson Ridge schist (DMF3). Serpentinized, silicified or carbonatized ultramafic rocks (DMF6), including harzburgite, dunite, orthopyroxenite, and serpentinite, occur as 10 to 100 m wide tectonic slivers (Fig. 3a, b; Ryan et al., 2013; Casselman and Brown, 2017).

The highly foliated early Mississippian Simpson Range suite (MgSR) is present as a small outlier south of the Yukon River and is also mapped north of the river. Felsic to intermediate granitoids and orthogneiss are interlayered with pink to grey hornblende-biotite or biotite granodiorite, monzogranite, quartz diorite and diorite. The Mississippian age distinguishes the Simpson Range suite from the strongly foliated to gneissic Devonian Mt. Baker suite of diorite, granodiorite, gabbro, monzogranite and minor pyroxenite (LDgMB, LDyMB) in the White River assemblage (Fig. 3a, b; Ryan et al., 2013; Casselman and Brown, 2017).

The Snowcap and Finlayson assemblages are intruded by K-feldspar porphyroclastic augen granite of the Permian Sulphur Creek suite (PqS). A less-extensive extrusive equivalent, the Permian Klondike quartz-muscovite-chlorite schist (PK1) is mapped as undivided interlayered felsic and mafic metavolcanic rocks northwest of the Casino deposit and includes highly strained Sulphur Creek suite monzogranite (Fig. 3a, b; Ryan et al., 2013).

The main country rock of the Casino deposit is the middle Cretaceous Dawson Range phase (mKgW) of Whitehorse suite granitoids, composed of medium to coarse grained white to beige, hornblende-biotite granodiorite and lesser granite, tonalite, quartz diorite and diorite. Foliation is weak to absent. A second phase, the Coffee Creek granite (mKqW), occurs as unfoliated medium to coarse-grained pink to beige, biotite monzogranite, locally pegmatitic, containing smoky quartz phenocrysts. Phases generally occur as distinct plutons (Fig. 3a, b; Godwin, 1975; Ryan et al., 2013; Casselman and Brown, 2017).

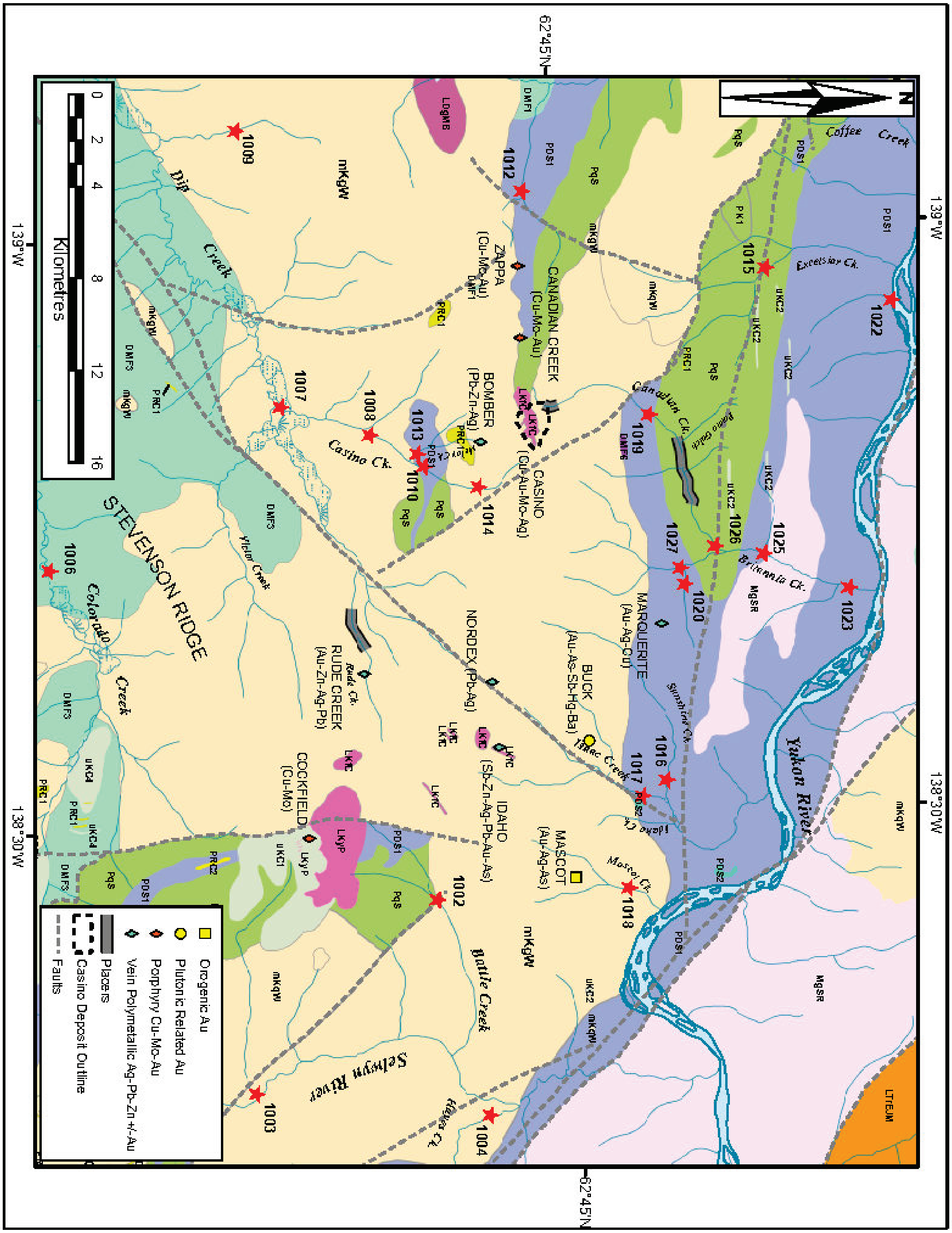
62°45'N
139°W
138°30'W
N
Kilometres
0 2 4 8 12 16
Yukon River
Coffee Creek
Excelsior Ck.
Canadian Ck.
Britannia Ck.
Casino Ck.
Dip Creek
Colorado Creek
Victor Creek
Selwyn River
Battle Creek
Mascot Ck.
Isaac Creek
STEVENSON RIDGE
CASINO
(Cu-Au-Mo-Ag)
CANADIAN CREEK
(Cu-Mo-Au)
ZAPPA
(Cu-Mo-Au)
BOMBER
(Pb-Zn-Ag)
MARQUERITE
(Au-Ag-Cu)
BUCK
(Au-As-Sb-Hg-Ba)
NORDEX (Pb-Ag)
RUDE CREEK
(Au-Zn-Ag-Pb)
IDAHO
(Sb-Zn-Ag-Pb-Au-As)
MASCOT
(Au-Ag-As)
COCKFIELD
(Cu-Mo)
1002
1003
1004
1006
1007
1008
1009
1010
1012
1013
1014
1015
1016
1017
1018
1019
1020
1022
1023
1025
1026
1027
Orogenic Au
Plutonic Related Au
Porphyry Cu-Mo-Au
Vein Polymetallic Ag-Pb-Zn+/-Au
Placers
Casino Deposit Outline
Faults

Figure 3. Bedrock geology map (3a; previous page) and legend (3b) showing the location of mineral occurrences in the survey area (Yukon Geological Survey, 2018a) and showing the location of stream sediment samples collected by the Geological Survey of Canada in 2017 (red stars) around the Casino deposit. Bedrock geology from Yukon Geological Survey (2017).

The Late Cretaceous Casino suite (LKfC) hosting the Casino Cu-Au-Mo porphyry and other intrusion-related mineralization in the region comprises sparse, small volume porphyritic quartz monzonite plutons. Intrusions are fine to medium-grained, and are alkali feldspar-plagioclase-biotite-quartz-phyric. The Prospector Mountain Suite (LKyP), mapped around Mount Cockfield (Fig. 3), is largely co-spatial with the Casino suite and characterized by light grey to pink alkali feldspar-biotite-hornblende porphyritic, fine to medium-grained quartz monzonite dikes, sills and hypabyssal plugs (Fig. 3a, b; Ryan et al., 2013; Casselman and Brown, 2017).

The Late Cretaceous Carmacks Group (uKC1, uKC2, uKC4; Fig. 3), widespread throughout west-central Yukon (Ryan, et al., 2013), consists of an intermediate to mafic volcanic and volcaniclastic lower sequence, and a more mafic, flow-dominated upper sequence. Basalt to andesite flows, sills, and tuff-breccia are the most abundant rock types, and are in part coeval with the Prospector Mountain Suite (Fig. 3a, b; Ryan et al., 2013).

Small erosional remnants and intrusions of the Paleogene Rhyolite Creek complex (PRC1, PRC2) are mapped south and southwest of the Casino deposit (Fig. 3). Quartz (generally smoky) and feldspar-porphyritic dikes predominate; less common are flow-banded rhyolite and locally grey-green to mauve andesitic volcanic to hypabyssal rocks. These can be easily mistaken for similar looking hypabyssal varieties of the Casino suite and the Coffee Creek phase, while andesitic rocks may be confused with Carmacks Group andesites (Fig. 3a, b; Ryan et al., 2013; Casselman and Brown, 2017).

Deposit Geology

The bedrock geology of the deposit is briefly summarized below from detailed descriptions of its discovery history and geology reported by Archer and Main (1971), Godwin (1975, 1976), Bower et al. (1995), Casselman and Brown (2017), and Yukon Geological Survey (2017). The porphyry Cu-Au-Mo deposit is hosted in a Late Cretaceous calc-alkaline intrusion ('Patton Porphyry') of quartz monzonite and associated breccia along the intrusion margins.

The earliest exploration in the deposit area was for placer gold in Canadian Creek (Fig. 2), immediately north of the deposit in the early 1900s. Over the years, placer gold mining has taken place in three locations proximal to the deposit (Chapman et al., 2014), indicated in Figures 2 and 3. Early exploration of mineralized bedrock in the area focused on the silver-lead-zinc veins at the Bomber occurrence (Yukon Geological Survey, 2018f) on the south periphery of what is now known to be the Casino deposit (Fig. 3).

Porphyry style mineralization on the Casino property was discovered through prospecting in 1968 (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).

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 200,000 years (Bond and Lipovsky, 2011). 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 enriched in gold, depleted in Cu, and consists primarily of jarosite, limonite, goethite and hematite. The supergene oxide zone is Cu-rich and contains calcanthite, malachite, brocanthite along with minor cuprite, azurite, tenorite, neotocite, and trace molybdenite as coatings on fractures and in vugs. The supergene sulphide zone has Cu grades often almost double those in the hypogene zone. It consists of pyrite, chalcopyrite, bornite, and tetrahedrite that may be altered along grain boundaries with chalcocite, digenite, or covellite, as well as molybdenite that may be altered to ferrimolybdite. Hypogene mineralization occurs in the potassic, phyllic, and propylitic alteration zones and includes 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).

Surficial geology

The surficial geology of the Casino area is summarized below from maps and reports published by Huscroft (2002), Bond and Lipovsky (2011, 2012a, b) and McKillop et al. (2013). The part of the Dawson Range hosting the deposit consists of broad ridges and summits that vary in elevation from about 1000 to 1800 m a.s.l. The two highest peaks in the study area are an unnamed peak (1672 m a.s.l.), just to the northwest of Patton Hill, and Mount Cockfield (1856 m a.s.l.) some 20 km to the southeast (Fig. 2). Patton Hill, just to the west of the deposit is at an elevation of 1372 m a.s.l.

The landscape is largely unglaciated. Bedrock outcrops and tors are common along the ridges and summits. Surficial material in upland areas consists of colluvium and weathered bedrock intermixed with loess that has been modified by processes related to seasonal thawing of permafrost, including cryoturbation and solifluction. Lower areas and valley bottoms are covered with loess-rich aprons.

During the Pleistocene, glaciers partly covered the region. During the Late Wisconsin McConnell glaciation (glacial maximum at 15,000 BP), glaciers fed by the Cassiar and Selwyn lobes of the Cordilleran Ice Sheet reached the eastern slope of Mount Cockfield. During the Reid glaciation (glacial maximum at 130,000 BP), alpine glaciers over Mount Cockfield extended west into the headwaters of Victor Creek and eastward into an unnamed tributary valley that drains eastward into the Selwyn River. Glacial sediments mapped on the east flank of Mount Cockfield were deposited during the Reid and McConnell glaciations. There, stream sediments will, in part, be derived from these glacial deposits. Evidence of pre-Reid (ca. 3 Ma BP) glaciation has been identified near the headwaters of Canadian Creek, immediately northwest of Patton Hill (Bond and Lipovsky, 2011).

Permafrost is discontinuous and is most common on north-facing slopes and valley bottoms covered by thick fine-grained colluvium and organic veneers. Its presence is indicated by features such as solifluction lobes, open system pingos, and thermokarst.

First and second order streams (e.g., Casino Creek) are confined to narrow v-shaped valleys that contain mostly sub-angular to sub-rounded gravel to boulders of locally derived bedrock. Higher order streams are found in much broader valleys filled with more distally derived colluvium, loess and rounded gravel (e.g., Dip Creek, Colorado Creek).

Previous stream water geochemical surveys

Stream sediments and waters were collected around the then newly discovered Casino deposit in 1968 to study geochemical dispersion. The deposit was shown to have an obvious geochemical signature in stream silts (Cu, Mo, Au and Ag) by Archer and Main (1971). Regional-scale stream silt sampling was carried out by the GSC and data were reported in 1987 (Geological Survey of Canada, 1987). Re-analysis of the archived GSC samples was carried out by the Yukon Geological Survey between 2011 and 2016 and these data have been compiled into a large database (Yukon Geological Survey, 2016). Analytical methods for both the 1987 and 2011-2016 datasets are listed in Table 1. Mackie et al. (2016) and Arne et al. (2018) subsequently published interpretations of these new data. Both the original and reanalysis datasets indicate that a multi-element geochemical anomaly (Ag, Cu, Pb, Sb, W) is apparent in the local creeks draining the Casino deposit.

Table 1. Elements determined and analytical methods used for the 1987 and 2011 regional data.

Variable	1987 regional dataset	2011-2016 re-analysis of regional dataset	Variable	1987 regional dataset	2011-2016 re-analysis of regional dataset
Ag	reverse aqua regia/AAS	aqua regia/ICP-MS	**Na**		aqua regia/ICP-MS
Al		aqua regia/ICP-MS	**Nb**		aqua regia/ICP-MS
As	reverse aqua regia/hydride AAS	aqua regia/ICP-MS	**Ni**	reverse aqua regia/AAS	aqua regia/ICP-MS
Au	fire assay/ INAA	aqua regia/ICP-MS	**P**		aqua regia/ICP-MS
B		aqua regia/ICP-MS	**Pb**	reverse aqua regia/AAS	aqua regia/ICP-MS
Ba	3 acid/AAS	aqua regia/ICP-MS	**Pd**		aqua regia/ICP-MS
Bi		aqua regia/ICP-MS	**Pt**		aqua regia/ICP-MS
Be		aqua regia/ICP-MS	**Rb**		aqua regia/ICP-MS
Ca		aqua regia/ICP-MS	**Re**		aqua regia/ICP-MS
Cd	reverse aqua regia/AAS	aqua regia/ICP-MS	**S**		aqua regia/ICP-MS
Ce		aqua regia/ICP-MS	**Sb**	aqua regia/hydride AAS	aqua regia/ICP-MS
Co	reverse aqua regia/AAS	aqua regia/ICP-MS	**Sc**		aqua regia/ICP-MS
Cu	reverse aqua regia/AAS	aqua regia/ICP-MS	**Se**		aqua regia/ICP-MS
Cr		aqua regia/ICP-MS	**Sn**	acid digestion/AAS	aqua regia/ICP-MS
Cs		aqua regia/ICP-MS	**Sr**		aqua regia/ICP-MS
F	Fluoride ion electrode		**Ta**		aqua regia/ICP-MS
Fe	reverse aqua regia/AAS	aqua regia/ICP-MS	**Te**		aqua regia/ICP-MS
Ga		aqua regia/ICP-MS	**Th**		aqua regia/ICP-MS
Ge		aqua regia/ICP-MS	**Ti**		aqua regia/ICP-MS
Hf		aqua regia/ICP-MS	**Tl**		aqua regia/ICP-MS
Hg	acid digestion/vapour AS	aqua regia/ICP-MS	**U**	INAA	aqua regia/ICP-MS
In		aqua regia/ICP-MS	**V**	reverse aqua regia/AAS	aqua regia/ICP-MS
K		aqua regia/ICP-MS	**W**	fusion	aqua regia/ICP-MS
La		aqua regia/ICP-MS	**Yb**		aqua regia/ICP-MS
Li		aqua regia/ICP-MS	**Yb**		aqua regia/ICP-MS
Mg		aqua regia/ICP-MS	**Zn**	reverse aqua regia/AAS	aqua regia/ICP-MS
Mn	reverse aqua regia/AAS	aqua regia/ICP-MS	**Zr**		aqua regia/ICP-MS
Mo	reverse aqua regia/AAS	aqua regia/ICP-MS			

SAMPLE COLLECTION

Stream Sediments (Silts)

Protocols for stream sediment sampling in this study followed those established by the GSC more than 30 years ago by Friske and Hornbrook (1991). At each site, a synthetic cloth bag (18 cm x 32 cm) was two-thirds filled (approximately 1 to 2 kg) with silt and fine sand collected from the active stream channel (Fig. 4). The silt sample was collected after a water sample(s) and before a screened (<1.68 mm) bulk sediment sample. Commonly, the sampler collected sediment by hand from various points in the active channel while moving upstream, over a distance of 5 to 15 m. If the stream channel was found to consist mainly of clay, coarse material or organic sediment from which suitable sample material is scarce or absent, moss mat from the stream channel, which commonly contains trapped silt, may have been added to the sample. Field observations were digitally recorded on a tablet using a standard form developed jointly by the GSC and the Northwest Territories Geological Survey. Project metadata are reported in **Appendix A**. Field data are reported **Appendix B - Field Observations and Geochemical Data, Worksheet 'Field observations'.** Site photographs are reported in **Appendix C**. Samples sites are referred to in the text in an abbreviated format, e.g., **115J171010** is referred to **1010.**

Figure 4. At each site, a stream silt sample (wet mass 1 – 2 kg), two 60-ml filtered stream water samples, a bulk stream sediment sample (wet mass 10-15 kg) and a stream pebble sample (in synthetic bag beside bulk sample) were collected.

SAMPLE PREPARATION

Stream Sediments (Silts)

The synthetic cloth bags containing the silt samples were drip-dried in the field before being placed into individual plastic bags, taped with electrical tape and shipped to the GSC Sedimentology Laboratory in Ottawa, where they were unpacked and air-dried at temperatures below 40^{o}C. After drying, samples were disaggregated and sieved to recover the <177 µm fraction for geochemical analysis (Girard et al., 2004).

ANALYTICAL METHODS USED FOR 2017 DATASET

Analytical methods used for determining elemental abundances in the 1987 and 2011-2016 datasets are listed in Table 1.

Instrumental Neutron Activation

Samples of the <177 µm fraction were analysed by instrumental neutron activation (INA) at Maxxam Analytics (formerly Becquerel Labs), Mississauga, Ontario. A 30 g aliquot of each sample was encapsulated and packaged for irradiation along with certified reference materials, field and analytical duplicates. Samples and quality control insertions were irradiated together with neutron flux monitors in a two-megawatt pool type reactor. After a seven-day decay period, samples were measured with a high-resolution germanium detector. Typical counting time per sample was 500 seconds. Elements determined by INA analysis are listed below in Table 2 and the data are reported in **Appendix B - Field Observations and Geochemical Data, Worksheet 'Maxxam'.**

Table 2. Elements determined by instrumental neutron activation analysis of the <177 µm fraction of stream silt samples collected around the Casino deposit in 2017.

Variable	Detection Limit	Units of Measurement	Variable	Detection Limit	Units of Measurement
Ag	2	ppm	**Ni**	10	ppm
As	0.5	ppm	**Rb**	5	ppm
Au	2	ppb	**Sb**	0.1	ppm
Ba	50	ppm	**Sc**	0.2	ppm
Br	0.5	ppm	**Se**	5	ppm
Cd	5	ppm	**Sm**	0.1	ppm
Ce	5	ppm	**Sn**	100	ppm
Co	5	ppm	**Ta**	0.5	ppm
Cr	20	ppm	**Tb**	0.5	ppm
Cs	0.5	ppm	**Te**	10	ppm
Eu	1	ppm	**Th**	0.2	ppm
Fe	0.2	%	**Ti**	500	ppm
Hf	1	ppm	**U**	0.2	ppm
Ir	50	ppb	**W**	1	ppm
La	2	ppm	**Weight**	0.01	g
Lu	0.2	ppm	**Yb**	2	ppm
Mo	1	ppm	**Zn**	100	ppm
Na	0.02	%	**Zr**	200	ppm

Aqua Regia Digestion/Inductively Coupled Plasma – Mass Spectrometry and Other Methods

Aliquots of 0.5 g of the 177 µm fraction were analysed for 65 elements at Bureau Veritas Commodities Canada (BVCC), Vancouver, using a proprietary 'AQ250 – Ultratrace by ICP Mass Spec.' package with the optional extended packages for rare earth elements (+REE) and precious metals Pt and Pd (+PGM) (Table 3). The procedure involves an aqua regia dissolution ($HCl:HNO_3$, 1:1)followed by inductively coupled plasma - mass spectroscopy (ICP-MS) analysis. 'Lead collection fire assay fusion' was used to determine the concentrations of Au, Pt and Pd in a 30 g aliquot of <177 µm stream silt. The bead resulting from the fusion of the sample was digested in HNO_3 and analysed by ICP-MS. Data for aqua regia/ICP-MS and fire assay/ICP-MS are reported in **Appendix B- Field Observations and Geochemical Data, Worksheet 'Bureau Veritas'.**

Total C and S (BVCC Code TC003 C & S) were determined by igniting 0.1 g of <177 µm sample with a flux in an induction furnace. Released carbon was measured by adsorption in an infrared spectrometric cell. Results are total and attributed to the presence of carbon and sulphur in all forms (Bureau Veritas Minerals, 2017a). Total C and S data are reported in **Appendix B – Field Observations and Geochemical Data, Worksheet 'Bureau Veritas'.**

Loss-on-ignition (LOI; BVCC Code TG001) was determined using a 1 g sample. Each sample, in a crucible, was placed into a muffle furnace and ignited to 1000 °C for one hour. The oven was then cooled to 100 ^{o}C and the crucibles transferred to a desiccator followed by cooling to room temperature. The crucibles were re-weighed to determine the loss-on-ignition. The lower limit of detection is indicated as -5.1% to allow for reporting if negative loss on ignition results. Negative LOI results may occur in some samples where a weight gain occurs during ignition, generally due to the oxidation of iron minerals (Bureau Veritas Minerals, 2017b). LOI data are reported in **Appendix B – Field Observations and Geochemical Data, Worksheet 'Bureau Veritas'.**

Table 3. Variables determined for the <177 µm fraction of stream sediments using by Inductively Coupled Plasma –Mass Spectroscopy (ICP-MS) with a modified *aqua regia* digestion, Fire Assay/ICP-MS (FA), and LECO methods, with their detection limits. 'GRAV' is an abbreviation of 'Gravimetric'.

Element	Detection Limit	Units of Measurement	Element	Detection Limit	Units of Measurement
Au (FA/ICP-MS)	2	ppb	**Mg**	0.01	pct
Pt (FA/ICP-MS)	3	ppb	**Mn**	1	ppm
Pd (FA/ICP-MS	2	ppb	**Mo**	0.01	ppm
Total C (LECO)	0.02	%	**Na**	0.001	%
Total S (LECO)	0.02	%	**Nb**	0.02	ppm
Ag	2	ppb	**Nd**	0.02	ppm
Al	0.01	%	**Ni**	0.1	ppm
As	0.1	ppm	**P**	0.001	%
Au	0.2	ppb	**Pb**	0.01	ppm
B	20	ppm	**Pd**	10	ppb
Ba	0.5	ppm	**Pt**	2	ppb
Be	0.1	ppm	**Pr**	0.02	ppm
Bi	0.02	ppm	**Rb**	0.1	ppm
Ca	0.01	%	**Re**	1	ppb
Cd	0.01	ppm	**S**	0.02	%
Ce	0.1	ppm	**Sb**	0.02	ppm
Co	0.1	ppm	**Sc**	0.1	ppm
Cr	0.5	ppm	**Se**	0.1	ppm
Cs	0.02	ppm	**Sm**	0.02	ppm
Cu	0.01	ppm	**Sn**	0.1	ppm
Dy	0.02	ppm	**Sr**	0.5	ppm
Er	0.02	ppm	**Ta**	0.05	ppm
Eu	0.02	ppm	**Tb**	0.02	ppm

Element	Detection Limit	Units of Measurement	Element	Detection Limit	Units of Measurement
Fe	0.01	%	**Te**	0.02	ppm
Ga	0.1	ppm	**Th**	0.1	ppm
Gd	0.02	ppm	**Ti**	0.001	%
Ge	0.1	ppm	**Tl**	0.02	ppm
Hf	0.02	ppm	**Tm**	0.02	ppm
Hg	5	ppb	**U**	0.1	ppm
Ho	0.02	ppm	**V**	2	ppm
In	0.02	ppm	**W**	0.1	ppm
K	0.01	%	**Y**	0.01	ppm
La	0.5	ppm	**Yb**	0.02	ppm
Li	0.1	ppm	**Zn**	0.1	ppm
LOI (GRAV)	0.1	%	**Zr**	0.1	ppm
Lu	0.02	ppm			

Portable X-Ray Fluorescence

A split of each dry unsieved stream sediment was transferred to a 4-dram vial, covered with a 4 µm Prolene film fixed on the vial with a small elastic band. Each sample was shaken 10 times in an up-down motion and read on the pXRF. The sample was shaken again and re-analysed a second time to provide two readings per sample. The shaking motion brings the smaller grains size on the face covered by Prolene film.

The pXRF instrument used was the Innov-X Delta Premium DP-4000 (serial number 510964) with a Ta tube anode. The analysis was performed in the 3 beam Soil (La, Ce) mode @60 sec per beam. An estimate of the limit of detection (LOD) is provided in the brochure attached (manufacturer LOD therefore on the low side).

For the pXRF analysis, CONTROL TBLK is a Teflon Block that was used as a 'blank' sample. The low but detectable values reported for S, Cl, K, Ni, etc. in the blank are contaminant in the Teflon block. This blank was analyzed throughout the batch, at the beginning, middle and end of each day. A high value out of the normal range for this blank would mean contamination of the viewing window of the instrument and was dealt with immediately, until the blank values returned to their expected range. Certified reference materials CANMET TILL-1 to TILL-4 (Lynch, 1996) were analyzed at the beginning of the analysis of a batch each day. TILL-4 was also analyzed in the middle and the end of the batch. Portable XRF data and QA-QC data are reported in **Appendix E – Portable XRF Data** along with the date of analysis.

QUALITY CONTROL FOR GEOCHEMICAL RESULTS FROM COMMERCIAL LABS

Analytical accuracy of elemental determinations was assessed by inserting one of two Canadian Certified Reference Materials STSD-1 or STSD-4 at pre-selected random locations in a block of 20 consecutive samples. STSD-1 consists of the -80 mesh (<177 µm) fraction of sediment collected from Lavant Creek, about 75 km southwest of Ottawa, ON (NTS 31-F). STSD-4 is a composite sample made up from stream sediments collected throughout NTS map sheet 31-F and 93-A and 93-B. All -80 mesh material was ball-milled and sieved through a 200 mesh (<74 µm) screen prior to homogenisation and bottling (Lynch, 1990; CANMET, 2019).

We collected field duplicates and prepared analytical duplicates to assess site variability and analytical precision.

One set of two field duplicates was collected for each group of twenty consecutive samples. A field duplicate sample is a second sample taken at or within a few metres of the first sample. One analytical duplicate was prepared in the laboratory for each block of twenty consecutive samples. An analytical duplicate sample is a split from a routine Sample or a field duplicate after the samples have been prepared for analysis but before analysis, and analyzed using the same methods as the routine samples. (McCurdy and Garrett, 2016). Excess <177 µm material was archived for future reference. Data for all quality control samples are listed in **Appendix B – Field Observations and Geochemical Data, Worksheet 'Quality Control'.**

In **Appendix B – Field Observations and Geochemical Data, Worksheet 'Quality Control'**, the means and standard deviations (MEAN ± SD) for control reference standards STSD-1 and STSD-4 for which provisional values have been published by Lynch (1990, 1999) and Burnham and Schweyer (2004) are compared with the values for these elements determined by total and partial methods in Casino samples (Tables A-1 and A-2). Accepted values in square brackets are derived from published and unpublished data (n > 30) collected from recent projects at the GSC. The lower detection limits (LDL) for each element estimated by the commercial laboratories are also listed.

Control reference materials (CRM) were analyzed by Instrumental Neutron Activation (INA) and aqua regia/ICP-MS (AR). Elements having concentrations at or below detection in both CRMs include Mo (INA), Pd (AR), Ag (INA), Cd (INA), Hf (AR), Ta (AR), W (INA), Re (Ar), Ir (INA), Sn (INA), Pt (AR), Se (INA), B (AR), Ge (AR) and Te (INA). Zn (INA) and Zr (INA) are below detection in STSD-4 only. The concentrations of many of the remaining elements analyzed by aqua regia/ICP-MS fall below two standard deviations of the accepted values, however this may be caused by minor changes in the aqua regia digestion used by the commercial laboratory over time, such as a reduced period of heating, reduced acid strength, or both. Accuracy may also be affected by elemental concentrations held within discrete, often refractory, minerals, including spinels, beryl, tourmalines, chromite, zircon, monazite, pyrochlore, scheelite, wolframite, topaz, tantalite and cassiterite (Crock and Lamothe, 2011). Concentrations of a number of elements in CRMs at or just above lower detection limits, can also result in less than satisfactory analytical accuracy. Finally, for some elements, such as Pt and Au, the difficulty of creating homogeneous standard materials can result in reduced accuracy of measurement (Harris, 1982).

GEOCHEMICAL MAPS (APPENDIX D)

Graduated symbol maps for selected elements were generated using the ESRI ArcMap desktop application and are included in **Appendix D – Geochemistry Maps**. Data were classified into four or five concentration ranges, depending on the range of data, using the Jenks optimization method. The size of each dot represents a range of elemental concentrations, with larger dots representing ranges of values with higher concentrations. Values reported as less than detection limit were reassigned values of one-half the lower detection prior to plotting dot maps and calculation of statistics.

Tukey box plots constructed from the regional stream silt geochemistry (Yukon Geological Survey, 2016) and classified into five major lithologies are included as tables in this report for each element for which there is geochemical map except for Au by INAA (map C4b), Au FA/ICP-MS (map C4c), LOI (map C18), and W by INAA (map 36b). Because data for many elements determined in stream silts are strongly right-skewed, Tukey boxplots were constructed using log-transformed data in order to avoid underestimating lower extreme values or overestimating upper extreme values (Reimann et al., 2008).

RESULTS

The GSC under the National Geochemical Reconnaissance (NGR) program collected over 19,000 samples at a regional scale across the Yukon between 1976 and 1995 (Geological Survey of Canada, 2019). Most of these stream sediment samples were reanalyzed by the Yukon Geological Survey (YGS) between 2011 and 2014 using similar analytical methods (Yukon Geological Survey, 2016) to those used in our Casino study.

Of the 53 elements available from the YGS re-analysis dataset, data for ten elements (Au, Cu, Mo, Ag, Sb, As, Zn, Pb, Bi and Mn) known to be associated with Cu porphyry mineralization (Sillitoe, 2010) were compared to the new (2017) data from the Casino study using Tukey log-boxplots, Kolmogorov-Smirnov tests and Reduced Major Axis regressions. These routines are available in '*rgr*' (Garrett, 2018), an R-based package of statistical routines.

A subset of 1986 GSC regional stream sediment samples that are located in NTS map sheets 115J and 115K and that were reanalyzed by the Yukon Geological Survey (2016) is located within the Yukon-Tanana terrane. This subset (N=1,301) was used to make statistical comparisons with the Casino samples collected in 2017 overlying similar Yukon-Tanana terrain lithologies.

In order to compare regional reanalyzed samples with the Casino survey samples, from one to four regional samples less than five kilometres upstream and/or downstream from each of the 2017 Casino survey sites were selected (Fig. 3). Where more than one regional sample was selected to match to a 2017 site, the mean element concentration was used to compare with the 2017 sample. No distance weighting was used, although this might have improved results. Each pair of element concentrations (2017 vs. 2014) from the two sets of samples were compared using Reduced Major Axis (RMA) regression and the Kolmogorov-Smirnov (K-S) test to establish that there is no statistical difference at the 95% confidence level between the two sets of samples. A similar method was employed by Amor et al. (2016) to establish relationships between Quebec and Labrador lake sediment samples along the border between the two provinces.

The 'fences' routine in the R package 'rgr' (Garrett, 2018) was used to estimate upper and lower bounds of background variability, following a log-transformation of the data, for the both the entire regional re-analyzed data (n=19,471 sample sites) and the Yukon-Tanana subset (n=1,301). The Tukey fences were calculated values based on the median and quartiles (25th and 75th percentiles) of the data to obtain the interquartile range (IQR) of the data. The actual values are the observed measurements immediately inside the calculated fences (Tables 3-6).

Gold

Gold content of the <177 µm fraction the 2017 stream sediment samples was determined by three different methods, as indicated in Tables 1 and 2. Gold values determined by aqua regia/ICP-MS on 0.5 g aliquots range from 0.8 ppb to 23.7 ppb, by INA on 30 g aliquots range from <0.2 ppb to 211 ppb and by FA-ICP-MS on 30 g aliquots vary from 6 ppb to 4056 ppb. Distribution patterns of gold for each method are plotted on the three maps (**Appendix D, Maps 4a, 4b, 4c**). There are certain similarities between each map, but also noticeable differences. The highest gold concentrations are generally found in Casino and Canadian creeks, i.e. on each side of the drainage divide at Casino. Despite this overall pattern, there is considerable variation between sites due to nugget and various hydraulic effects combined with the effects of grain size on transport processes (Nichol et al., 1994). For example, a sample in Hayes Creek returned the following Au concentrations: 3.2 ppb by AR/ICP-MS, 9 by FA/ICP-MS and 140 ppb by INA.

Both the Yukon regional reanalysis data for Au by aqua regia/ICP-MS (n=15,706), reanalyzed between 2011 and 2016, and the new 2017 sample set (n=22) were analyzed using a similar aqua regia/ICP-MS method. A comparison can be made between re-analyzed regional Au data from Yukon Geological Survey (2016) and Casino study area data from 2017 (this report), using the routines described above. Reduced Major Axis regression establishes a mathematical relationship between the 2017 samples and the 2014 re-analyzed samples (Fig. 5a). A two-sample K-S test, illustrates that there is no statistical difference at the 95% confidence level between the two sets of samples. (Fig. 5b). The influence of environmental factors such as climate, variable water levels, pH or differing rates of sediment transport do not appear to have significantly affected the distribution of Au in the <177 µm fraction of stream sediments over the past 40 years.

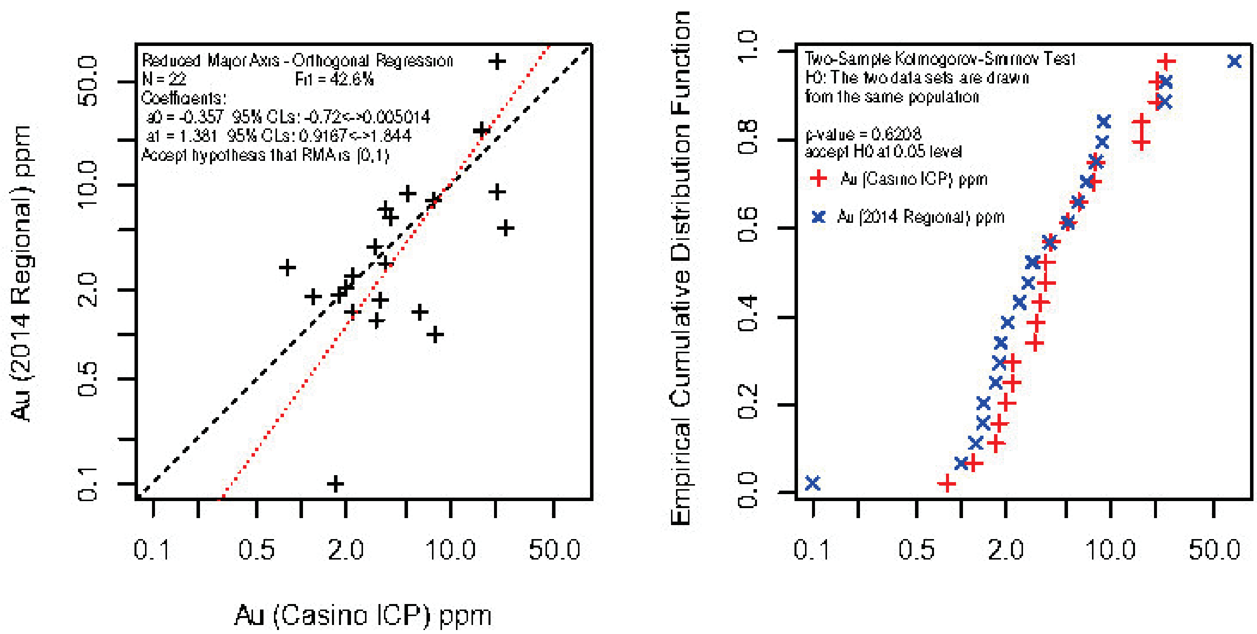

Figure 5. Reduced Major Axis (a) and Kolmogorov-Smirnov (b) plots comparing Au concentrations in stream silt samples collected in 2017 with nearby stream silt samples collected in 1986 and re-analyzed between 2011 and 2014. Data are log-transformed. Reduced Major Axis plots include a black dashed 1:1 line and a red dashed line representing the slope of the reduced major axis.

Mackie et al. (2016) published geochemical catchment basin maps for a number of base and precious metal deposit types, including epithermal and orogenic Au, that were produced using catchment basin analysis and weighted sums modelling (Garrett and Grunsky, 2001) of the Yukon regional stream sediment data. Catchment basins forming the watersheds of the Canadian and Casino creeks were ranked in the top five per cent for mineral potential for epithermal Au-Ag using the dominant lithology within the catchment basin to level the data. Mackie et al. (2015) noted that correcting for different bedrock units was less important for precious metals because of the relatively minor variations between lithological units. Several samples from our 2017 Casino survey collected within these catchment basins exceed the upper level of background variability of 12.5 ppb Au (Table 4) for the entire Yukon dataset, supporting the evaluation by Mackie et al. (2016). However, Chapman et al. (2014) reported that a placer system in the mid-section of Canadian Creek, downstream of the Casino deposit (Fig. 3) contains a mixture of gold derived from porphyry and peripheral or shallow level epithermal mineralization, indicating more than one source of Au.

Table 4. Upper and lower threshold values for Au (aqua regia/ICP-MS) in the <177 µm fraction of stream silt samples estimated for the Yukon reanalysis of GSC NGR samples (Yukon Geological Survey, 2016 for: 1) regional data (n=15,706); 2) subsets of the regional sample points plotting within individual rock types that are present in the Casino survey area; and 3) a subset of sample points plotting within the Yukon-Tanana terrane peripheral to the Casino deposit (n=1,301).

Au (ppb)	n	Upper Tukey Fence (Actual) ppb	Lower Tukey Fence (Actual) ppb
Yukon regional reanalysis data (ICP-MS, 2011-2014)	15,706	12.5 (12.4)	0.154 (0.2)
Yukon-Tanana reanalysis Subset (ICP-MS, 2014)	1,301	12.8 (12.3)	0.183 (0.2)
Yukon-Tanana Subset (Fire Assay/INAA, 1986)	1,302	158 (134)	0.0158 (0.5)

Cu, Mo, Ag

Elevated values of Cu are present in samples collected in 2017 along the upper reaches of Casino Creek and Canadian Creek, draining the Casino deposit. Two Cu values (943 ppm and 441 ppm) from the 2017 Casino survey exceed the 2011-2014 regional stream sediment reanalysis data set threshold of 126 ppm (Table 5): both are on the upper reaches of Casino Creek (**Appendix C, Map C12**). Compared with the Yukon-Tanana subset of regional reanalysed samples, Cu concentrations from 2017 in Casino Creek sediment samples exceed the upper Yukon-Tanana threshold of 56.8 ppm in all samples taken within that drainage basin, as well as in an upstream sample nearest the deposit taken on Canadian Creek. A 2017 sample from the upper reaches of Battle Creek, sample 1002, also exceeds the threshold value for Yukon-Tanana terrain samples. Sample 1014, collected in 2017 from Casino Creek returned a value of 943 ppm Cu (Map C12). A 1986 sample collected less than 700 metres upstream from site 1014 returned 345 ppm Cu upon reanalysis in 2014. This high concentration in the 2017 sample is most likely due to the presence of fine-grained mineralization weathering products in the sample.

Table 5. Upper and lower threshold values for Cu, Mo, and Ag estimated using data from the Yukon reanalysis of regional GSC NGR stream sediment samples collected between 1976 to 1995 (Yukon Geological Survey, 2016) (n=19,471) and for a subset (n=1,301) of samples plotting within the Yukon-Tanana terrane around the Casino deposit.

Cu (ppm)	**n**	**Upper Tukey Fence (Actual)**	**Lower Tukey Fence (Actual)**
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	57.2 (56.8) ppm	6.22 (6.5) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	126 (126) ppm	3.79 (3.79) ppm
Mo (ppm)			
Yukon-Tanana	1,301	3.81 (3.77) ppm	0.108 (0.11) pm

reanalysis Subset (ICP-MS, 2011-2016)			
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	14.1 (14.1) ppm	0.0589 (0.06) ppm
Ag (ppb)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	321 (309) ppb	14.4 (15) ppb
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	1800 (1770) ppb	8.02 (9) ppb

The concentration of Mo in a 2017 sample (1019) collected from Canadian Creek immediately north of the Casino deposit (**Appendix D, Map C21**) exceeds the regional threshold value of 14.1 ppm (Table 5). At the 'local' scale, 2017 outlier value highlight the Casino deposit along Canadian and Casino creeks. An additional local outlier (6 ppm Mo) is noted in one sample of Battle Creek flowing from the Cockfield showing (Fig. 3a).

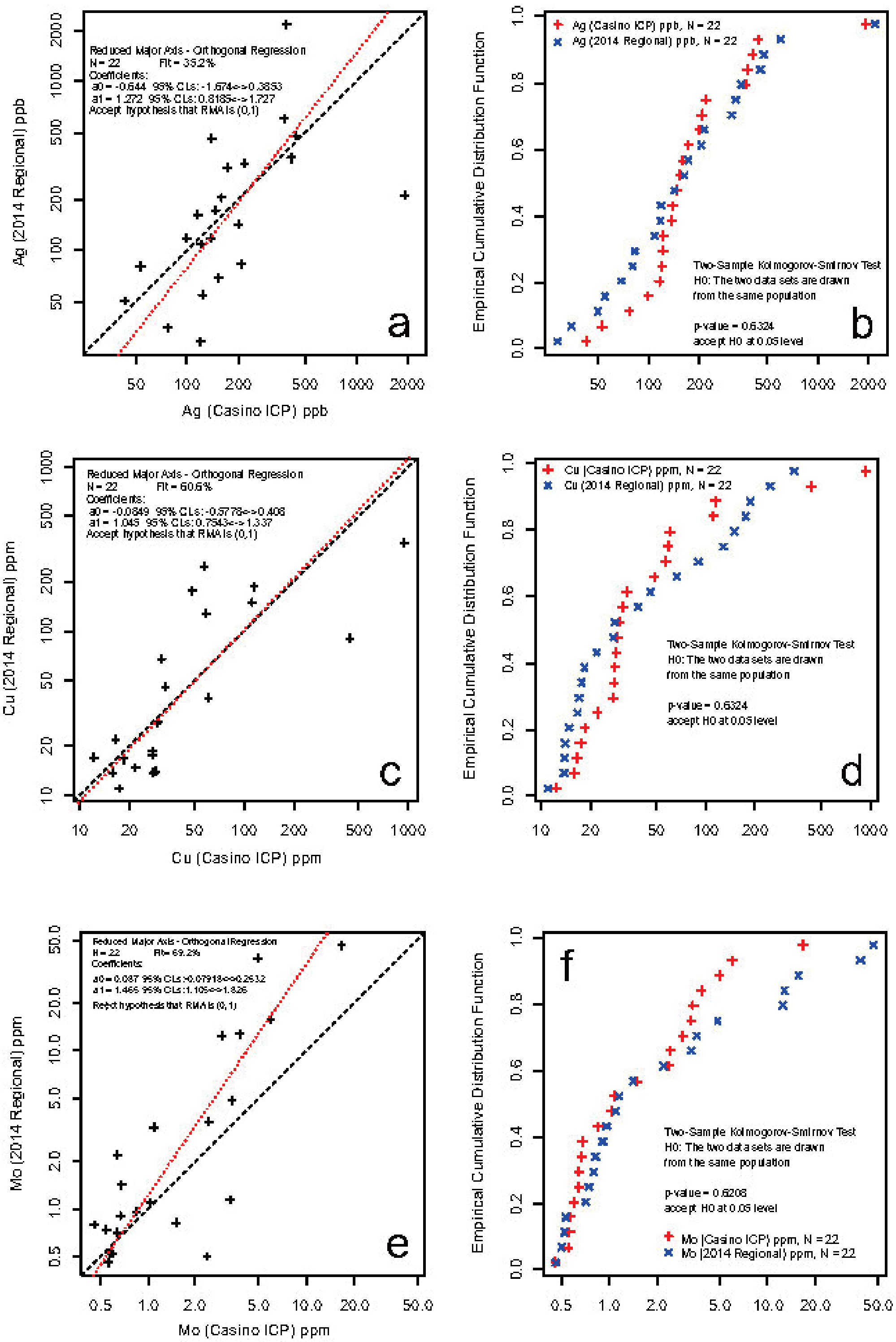

Figure 6. Reduced Major Axis (a, c, e) and Kolmogorov-Smirnov (b, d, f) plots comparing Ag, Cu and Mo concentrations in stream silt samples collected in 2017 with nearby samples collected in 1986 and re-analyzed in 2014. Data are log-transformed. Reduced Major Axis plots include a black dashed 1:1 line and a red dashed line representing the slope of the reduced major axis.

Of 11 deposits, showings and prospects shown in Figure 3a, seven were reported to contain Ag, including the Casino deposit, where Ag is listed as a major commodity (Yukon Geological Survey, 2018b-k). When compared with 2014 regional reanalysis data (n=19,471), one 2017 sample collected from Meloy Creek (1013) exceeds the regional reanalysis upper threshold concentration for Ag of 1800 ppb. The high upper threshold value for Ag in the regional data reflects the presence of several Ag-rich (>50,0000 ppb Au) samples collected around Keno Hill and elsewhere (Yukon Geological Survey, 2016; Table 5; **Appendix C, Map C1**). Compared with a subset of data from the Yukon-Tanana terrane (n=1,301), Ag is anomalous in the 2017 samples from the upper reaches of Canadian and Casino Creeks, with one outlier on Battle Creek, draining the Cockfield showing (Fig. 3a; Table 5; Yukon Geological Survey, 2018i).

RMA regression and K-S testing indicate that there is no statistical difference at the 95% confidence level between the concentrations of Ag (Fig. 6a, b) and Cu (Fig. 6c, d) in stream sediment samples collected within 5 km of each other in 1986 (Geological Survey of Canada, 1987) and 2017. Both sets of samples were analyzed using similar aqua regia digestion/ ICP-MS procedures. The influence of environmental factors such as climate, variable water levels, pH or differing rates of sediment transport, do not appear to have significantly affected the distribution of Ag and Cu in the <177 µm fraction of the stream sediments in the Casino area over the past 40 years. At higher concentrations however, Mo abundance (Fig. 6e, f) is higher in the 2014 reanalyzed GSC samples as compared to the 2017 Casino samples, suggesting that environmental factors or slightly different analytical methods may be influencing the analytical results.

Pb, Zn

One sample collected in 2017 from Meloy Creek (115J-2017-1013), which drains the Bomber past producer, contains 568 ppm Pb exceeding the upper threshold of 65.5 ppm Pb established from the 2014 reanalysis of regional samples (n=19,471; Fig. 3a; Table 6). The Bomber past producer (Yukon Geological Survey, 2018f) is a known Pb-Zn-Ag source, with mineralization consisting of galena with sphalerite, pyrite and minor chalcopyrite in a quartz-barite gangue. Samples from Canadian, Battle and Casino creeks and from an unnamed tributary of Selwyn River contain Pb concentrations above the 18.4 ppm Pb threshold established from the data subset of the Yukon-Tanana terrane (n=1301). (Fig. 3a; **Appendix D, Map C25**).

Table 6. Upper and lower threshold values for Pb and Zn estimated using data from the Yukon reanalysis of regional GSC NGR stream sediment samples collected between 1976 to 1995 (Yukon Geological Survey, 2016) (n=19,471) and for a subset (n=1,301) of sample plotting within the Yukon-Tanana terrane around the Casino deposit.

Pb (ppm)	**n**	**Upper Tukey Fence (Actual) ppm**	**Lower Tukey Fence (Actual) ppm**
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	18.4 (18.1) ppm	1.75 (1.80) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	65.5 (65.5) ppm	1.37 (1.37) ppm

Zn (ppm)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	127 (123) ppm	34.3 (34.6) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	441 (441) ppm	16.3 (16.5) ppm

The threshold value for Zn in 2014 regional reanalysis data is 441 ppm (Table 6). The same threshold is lower at 127 ppm in the Yukon-Tanana terrane sample subset (Table 6). Although concentrations in the 22 Casino survey silts collected in 2017 do not exceed the 2014 regional threshold, one sample from Meloy Creek that drains the Bomber past producer (Fig. 3a) returned a value of 439 ppm, i.e., very close to the threshold. Compared with the Yukon-Tanana terrane subset, Zn concentrations exceed threshold values in the upper reaches of Casino and Canadian Creeks, draining the Casino deposit (**Appendix D, Map C38**).

RMA regression and K-S testing indicate that there is no statistical difference at the 95% confidence level between the concentrations of Pb (Fig. 7a, b) and Zn (Fig. 7c, d) in stream sediment samples collected within 5 km of each other in 1986 (Geological Survey of Canada, 1987) and 2017. Both sets of samples were analyzed using similar aqua regia digestion and ICP-MS procedures. The influence of environmental factors such as climate, variable water levels, pH or differing rates of sediment transport, , over a 40-year period do not appear to significantly affect the distribution of Pb and Zn in the <177 µm fraction of stream sediments.

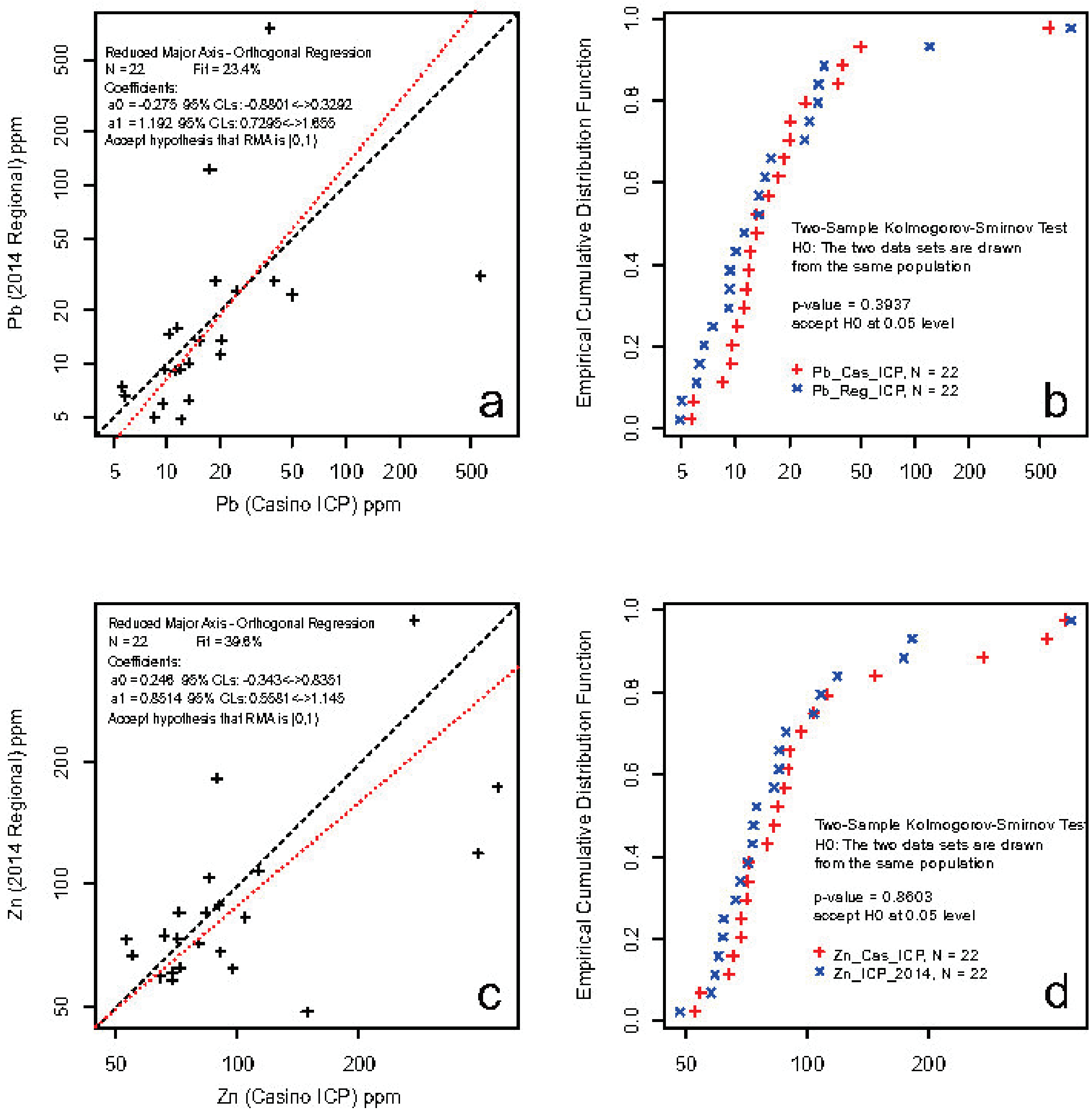

Figure 7. Reduced Major Axis (a, c) and Kolmogorov-Smirnov (b, d) plots comparing Pb and Zn concentrations in stream silt samples collected in 2017 with nearby stream silt samples collected in 1986 and re-analyzed between 2011 and 2014. Data are log-transformed. Reduced Major Axis plots include a black dashed 1:1 line and a red dashed line representing the slope of the reduced major axis.

As, Bi, Mn, Sb

RMA regression and K-S testing indicate that there is no statistical difference at the 95% confidence level between the concentrations of As, Bi, Mn and Sb in stream sediment collected in 1986 (Geological Survey of Canada, 1987) and 2017 (**Appendix E – RMA & K-S Plots**). When compared with regional reanalysis data (n=19,471), none of the 22 As values collected in 2017 from the Casino study area are outliers. However, when compared with the subset of the 1,301 samples plotting within the Yukon-Tanana terrain, As concentrations in Hayes and Battle Creeks, and an unnamed stream south of Battle Creek draining the Cockfield occurrence (Fig. 3; Yukon Geological Survey, 2018i) exceed the upper threshold of 31.8 ppm (Table 7). Concentrations of As in the 22 Casino survey samples are high in stream sediments from creeks draining the Buck, Mascot and Idaho occurrences (Yukon Geological Survey, 2018d, k, j) as well as those draining the Casino deposit (**Appendix C, Map C3**).

Yukon-Tanana terrane data and regional re-analysis data upper thresholds of Bi in stream silts are 0.55 and 1.31 ppm, respectively (Table 7). Concentrations in samples 115J171002 and 115J171003 collected in 2017, one on Battle Creek (1.81 ppm) and one on an unnamed creek to the south (1.73 ppm) exceed the 2014 regional reanalysis threshold. Sites on Meloy Creek (0.64 ppm), Casino Creek (0.71 and 0.83 ppm) and Canadian Creek (1.22 ppm) exceed the upper threshold of the Yukon-Tanana terrane subset data (**Appendix D, Map C6**).

Table 7. Upper and lower threshold values for As, Bi, Mn and Sb estimated using data from the Yukon reanalysis of regional GSC NGR stream sediment samples collected between 1976 to 1995 (Yukon Geological Survey, 2016) (n=19,471) and for a subset (n=1,301) of sample points plotting within the Yukon-Tanana terrane around the Casino deposit.

	n	**Upper Tukey Fence (Actual) ppm**	**Lower Tukey Fence (Actual) ppm**
As (ppm)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	31.8 (31.6) ppm	0.975 (1.4) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	83.7 (83.6) ppm	0.698 (0.7) ppm
Bi (ppm)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	0.553 (0.55) ppm	0.0203 (0.03) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	1.31 (1.31) ppm	0.0213 (0.03) ppm
Mn (ppm)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	1390 (1360) ppm	130 (134) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	18,687	1790 (1780) ppm	97.4 (98) ppm
Sb (ppm)			
Yukon-Tanana reanalysis Subset (ICP-MS, 2011-2016)	1,301	0.893 (0.89) ppm	0.0629 (0.07) ppm
Yukon regional reanalysis data (ICP-MS, 2011-2016)	19,471	7.67 (7.63) ppm	0.0224 (0.03) ppm

Concentrations of Mn in the 22 stream silt samples collected in 2017 exceed the 2014 regional reanalysis data upper threshold value of 1790 ppm on Casino Creek (1850 ppm) and Meloy Creek (2194 ppm; Table 7). A second sample on Casino Creek exceeds the Yukon-Tanana terrain subset threshold of 1390 ppm (1154 ppm) (**Appendix D, Map C20**).

All 22 values of Sb from Casino survey samples are below the 2014 regional reanalysis data threshold of 7.7 ppm, but the Yukon-Tanana subset data threshold of 0.89 ppm is exceeded by all but four of the 2017 sample sites (Table 7). A sample from Meloy Creek, draining the Bomber past-producer, returned the highest concentration of Sb in the Casino samples, 5.74 ppm (**Appendix D, Map C26**).

pXRF Results

Using the '**gx.ks.test'** routine available in '*rgr*' (Garrett, 2018), an R-based package of statistical routines, for Kolmogorov-Smirnov tests, geochemical data for several elements from the <177 µm fraction of 22 samples collected in 2017 and analyzed by aqua regia/ICP-MS were compared with data from the portable X-ray Fluorescence instrument (Fig. 8). With some caution, pXRF data of the stream sediments (**Appendix B – Portable XRF Data**) provide comparable results to commercial lab analysis of the <177 µm fraction by aqua regia/ICP-MS for As, Cu, Fe, Mn, Mo, Zn (Fig. 8) and S. Concentrations for the other elements determined by pXRF were either, or simply much lower than the values determined by aqua regia/ICP-MS. Concentrations determined by pXRF are higher than those determined by aqua regia/ICP-MS for Mn (Fig. 8a), Fe (Fig. 8b), and S whereas for Cu (Fig. 8c) and Zn (Fig. 8d), results are similar. For As (Fig. 8e), aqua regia/ICP-MS concentrations are lower than pXRF results at low concentrations, and higher than pXRF results above 20 ppm. Molybdenum (Fig. 8f) concentrations by pXRF at low concentrations are not precise, but come closer to aqua regia/ICP-Ms values as the Mo concentrations increase.

DISCUSSION

Porphyry Cu systems host a number of different mineralization types centred on the intrusion and extending into the peripheral zones, including skarn, carbonate-replacement and sediment-hosted Au deposits. They also include base metal or Au-bearing veins and mantos in non-carbonate wall rocks. Elements associated with porphyry copper systems are Cu ± Mo ± Au in the hypogene zone, characterizing the potassic, chlorite-sericite, and sericitic cores of systems (Sinclair, 2007; Sillitoe, 2010). The Cu ± Mo ± Au cores typically have kilometer-scale halos defined by anomalous Zn, Pb, and Ag values that reflect lower temperature, hydrothermal conditions. In some systems, Mn (± Ag) is also enriched in the outer parts of the halos (Sillitoe, 2010). The main geochemical differences between the hypogene and supergene zones are elevated As (± Sb) and greater trace amounts of Bi, W, Sn and/or Te with appreciable amounts of Mo in the overlying lithocap environment (Sillitoe, 2010). Distal ore formation in porphyry Cu systems with igneous wall rocks tend to be fault- and fracture-controlled, sub-epithermal Zn-Pb-Cu-Ag ± Au of limited economic importance (Sillitoe, 2010).

A graphic display of the correlation coefficients between elements measured in this study (n = 22) is shown in Figure 9, where the elements are grouped using a statistical package in *R* called **corrplot (https://cran.r-project.org/web/packages/corrplot/vignettes/corrplot-intro.html)**. Significantly, this clustering (Cu, Mo, Pb, Zn, Ag, Cd, Bi) is in accordance with the expected associations in porphyry systems. Spearman's rank correlation coefficients are displayed as they are resistant to the influence of outliers. The upper triangle uses the symmetric coordinate procedure that is uninfluenced by the closure inherent to geochemical data, i.e. they are relative and sum to a constant, and the lower triangle the traditional Spearman's rank correlation coefficients (Reimann et al., 2017; Garrett et al., 2017).

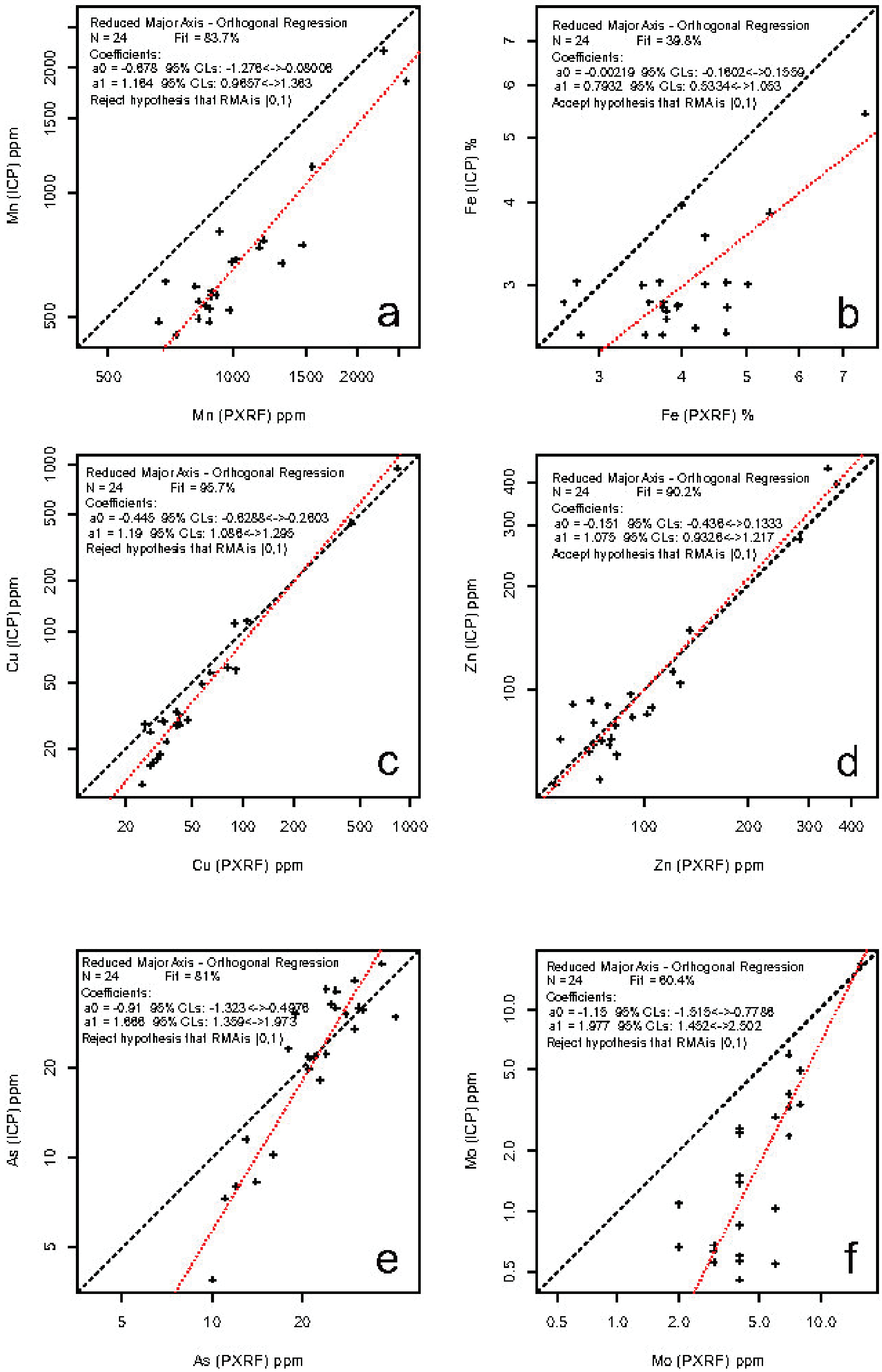

Figure 8. Reduced Major Axis plots comparing concentrations in the <177 µm fraction of stream silt samples determined by aqua regia/ICP-MS with those in dry unsieved stream silt samples determined by pXRF for selected elements. Data are log-transformed. Reduced Major Axis plots include a black dashed 1:1 line and a red dashed line representing the slope of the reduced major axis.

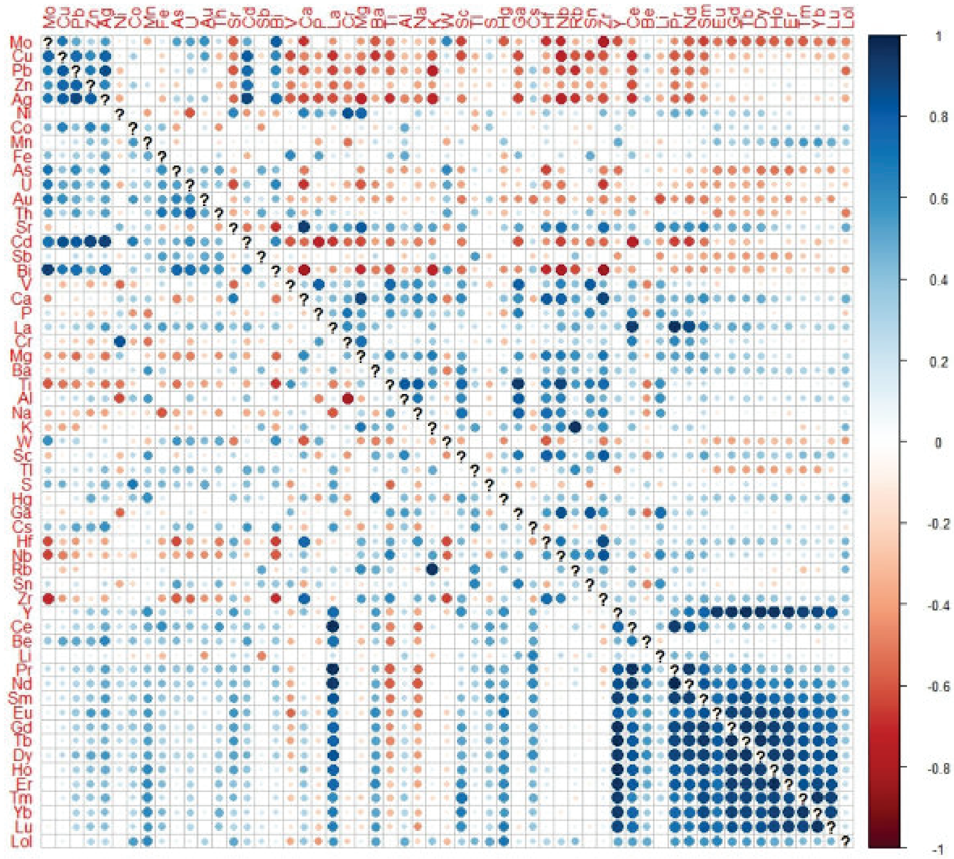

Figure 9. Graphic display from the *R* statistical package **corrplot** (see above) using symmetric coordinates to calculate Spearman's rank correlation coefficients between elements and Loss-on-Ignition in the <177 µm fraction of 22 Casino stream silt samples determined by aqua regia/ICP-MS. The upper triangle represents the symmetric coordinate procedure that is uninfluenced by the closure inherent to geochemical data, i.e. they are relative and sum to a constant, and the lower triangle represents the traditional Spearman coefficients (Reimann et al., 2017; Garrett et al., 2017). A small dot size represents a weak correlation; a large dot represents a strong correlation.

Figure 9 shows a strong Cu-Mo-Pb-Zn-Ag-Cd-Bi association reflecting the porphyry system and its surrounding epithermal vein occurrences. Gold, however, only displays a strong association with Cu and Mo, and to a lesser extent with As, U, Bi, W, Cd and Hg. The Au concentrations in the stream sediments reflect both primary hypogene relationships and subsequent weathering and sediment transportation processes. The Au-W association may reflect the documented association of gold with scheelite and ferberite in the placer in upper Canadian Creek on the northwest flank of the deposit (Bostock, 1959). The strong associations of some elements, such as Ni with Cr and Mg, commonly associated with mafic bedrock units, suggest the possibility that natural groupings in Figure 9 in the stream silt data may be an indication of the bedrock source, and that element ratios could be devised that would assist in narrowing the geochemical targets to assist mineral exploration.

Comparison of data for elements associated with porphyry copper systems (Mn, Fe, Cu, Zn, As, Mo) by two different methods of analysis, pXRF and aqua regia/ICP-MS, is shown in Figure 8. Copper (Fig. 8c) and Zn (Fig.

8d) appear to produce similar results, although ‘noise’ increases at low concentrations. Manganese (Fig. 8a) and As (Fig. 8e) are not directly comparable, however, provided the user is aware that pXRF values of Mn are systematically higher than aqua regia/ICP-MS values, these data may be of use. Molybdenum (Fig. 8f) ICP-MS concentrations are lower than pXRF values and data are noisy at low concentrations. Fe (Fig. 8b), although not described in detail in this report, appears to be less precise at low concentrations, and ICP-MS values are systematically lower than pXRF values. In addition to the difference between total and partial analysis, factors that affect results include elements locked in refractory minerals and not dissolved in aqua regia (higher pXRF results) and dilution of the unsieved pXRF samples. Results presented here indicate that pXRF could be used in the field to analyze dry unsieved stream silt samples and follow up geochemical anomalies in the same field season.

CONCLUSIONS

It is well known that porphyry copper systems have large geochemical dispersion haloes (Sinclair, 2007; Sillitoe, 2010) and that stream sediment surveys are an effective and efficient method for outlining the extent of proximal and distal mineralization (e.g., Archer and Main, 1971). Our study has confirmed that stream silt geochemistry is a useful exploration tool in the unglaciated terrain of west central Yukon.

Data from 22 stream sediment samples collected around the Casino porphyry copper-gold-molybdenum deposit were compared with re-analysis data from 19,471 samples originally collected under the National Geochemical Reconnaissance program in 1986. Kolmogorov-Smirnov tests and Reduced Major Axis regressions) established for the elements considered in this report that there is no statistical difference at the 95% confidence level between the 22 samples collected in 2017 and samples collected nearby in 1986 and reanalyzed in 2011-2016 . Ten elements associated with porphyry copper systems, Au, Cu, Mo, Ag, Sb, As, Zn, Pb, Bi and Mn, display relatively high concentrations in the 2017 stream sediments near the deposit as part of our study. Around the Casino deposit, values of Cu, Ag, Mo, Pb, Mn and Bi in stream sediments exceed upper threshold limits both within the 2011-2016 regional data set of 19,471 samples and within a more local Yukon-Tanana terrain subset of 1301 samples. Zinc values from stream sediments peripheral to the deposit are anomalous within the Yukon-Tanana terrane data subset. Antimony and As values from stream sediments near the deposit also exceed upper threshold values for the Yukon-Tanana terrane subset and may be useful for future follow-up studies investigating the use multi-element ratios to narrow exploration targets. Cadmium is elevated in the stream sediments collected in 2017 close to the deposit, shows a strong association with Cu-Mo-Pb-Zn-Ag-Bi in Figure 9, and should be considered as a potential pathfinder element for porphyry Cu mineralization. While Au values in stream sediments around the deposit are also anomalous, there may be more than one source for the Au in stream sediments. In our study, however, it was shown to be important pathfinder to porphyry Cu-Au systems. Three analytical methods, aqua regia/ICP-MS, fire assay/ICP-MS and INA analysis, were used to determine Au concentrations in stream sediments. All three methods display similar patterns of elevated Au in stream sediments collected for this study undertaken in 2017.

Our study has demonstrated that the use of pXRF in the field during a sampling program can provide reasonable data for Cu, Zn, Mn, and As that can be useful for identifying and following up geochemical anomalies while still in the field. Care should be taken when directly comparing pXRF data of unsieved samples with *aqua regia*/ICP-MS data for <177 µm samples. In addition to using different size fractions of the stream sediment sample (i.e. pXRF samples are unsieved), pXRF measures ‘total’ concentrations of elements in samples whereas *aqua regia*/ICP-MS measures partial to near-total concentrations.

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REFERENCES

Amor, S.D., McCurdy, M.W., Garrett, R.G., Corrigan, D., and Solgadi, F., 2016. Amalgamated lake-sediment data from Quebec and Labrador, Canada; EXPLORE, Association of Applied Geochemists, no. 173, p. 1-17.

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

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

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.

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 Selwyn River (115J/09), Yukon (1:50 000 scale); Yukon Geological Survey Open File 2012-1.

Bond, J.D. and Lipovsky, P.S., 2012b. Surficial geology of Colorado Creek (115J/10), Yukon (1:50 000 scale); Yukon Geological Survey Open File 2012-2.

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

Bower, B., DeLong, C., Payne, J., 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.

Bureau Veritas Minerals, 2017a. Method description for Carbon and Sulphur analysis by Leco, TC000 2017_1; available on request.

Bureau Veritas Minerals, 2017b. Method description for Loss-on-ignition analysis by muffle furnace ignition, TG001 2017_01; available on request.

Burnham, O.M. and Schweyer, J., 2004. Trace element analysis of geological samples by inductively coupled plasma mass spectrometry at the Geoscience Laboratories: revised capabilities due to improvements to instrumentation; *in* Summary of Field Work and Other Activities 2004; Ontario Geological Survey, Open File Report 6145, p. 54-1 to 54-20.

Canadian Council on Ecological Areas, 2014. The Ecological Framework of Canada. <http://ecozones.ca/english/> [accessed March 4, 2019]

CANMET, 2019. Stream sediment reference materials STSD- to STSD-4. <https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/mineralsmetals/pdf/mms-smm/tect-tech/ccrmp/cer-cer/stsd-1-eng.pdf> [accessed April 10, 2019]

Casselman, S.C. and Brown, H., 2017. Casino porphyry copper-gold-molybdenum deposit, central Yukon (Yukon MINFILE115J028); *in* Yukon Exploration and Geology Overview 2016, (ed.) K.E. MacFarlane; Yukon Geological Survey, p.61-74.

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.

Colpron, M. and Nelson, J.L., 2011. A Digital Atlas of Terranes for the Northern Cordillera. <https://yukon.ca/en/yukon-geology#bedrock-geology> [accessed August 6, 2019)]

Crock, J.G. and Lamothe, P.J., 2011. Inorganic chemical analysis of environmental materials – A lecture series; U.S Geological Survey Open-File Report 2011-1193, 117 p.

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

Garrett, R.G., 2018. The GSC Applied Geochemistry EDA Package. <http://cran.r-project.org/web/packages/rgr/index.html> [accessed February 22, 2019]

Garrett, R.G., and Grunsky, E.C., 2001. Weighted sums – knowledge based empirical indices fir use in exploration geochemistry; Geochemistry: Exploration, Environment, Analysis, v. 1 (2), p. 135-141.

Garrett, R.G., Reimann, C., Hron, K., Kynčlová, P., and Filzmoser, P., 2017. Finally, a correlation coefficient that tells the geochemical truth; EXPLORE, Association of Applied Geochemists, no. 176, p. 1-10.

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/disquette, https://doi.org/10.4095/130284 (Open Access)

Geological Survey of Canada, 2019. Canadian Database of Geochemical Surveys (CDoGS); Geological Survey of Canada, <https://geochem.nrcan.gc.ca> [accessed November 26, 2019]

Girard, I., Klassen, R.A., and Laframboise, R.R., 2004. Sedimentology laboratory manual, Terrain Sciences Division; Geological Survey of Canada, Open File 4823.

Godwin, C.I., 1975. Geology of the Casino porphyry copper-molybdenum deposit, Dawson Range, Yukon Territory; Unpublished Ph.D. thesis, University of British Columbia, 197 p.

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

Harris, J.F., 1982. Sampling and analytical requirements for effective use of geochemistry in exploration for gold; *in* Precious Metals in the Northern Cordillera, Proceedings of a Symposium Sponsored by the Association of Exploration Geochemists and the Cordilleran Section of the Geological Association of Canada, (ed.) A.A. Levinson; pp. 53-67.

Huscroft, C.A., 2002, Late Cenozoic history of the Yukon River valley, Fort Selkirk to the Stevenson Ridge map area (115 I/13, 14 & J/13, 14, 15); Unpublished MSc thesis, Simon Fraser University, Vancouver, Canada, 111 p + appendices.

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 & 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.

Lynch, J. 1990. Provisional values for eight new geochemical lake sediment and stream sediment reference materials LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STSD-2, STSD-3, STSD-4; Geostandards Newsletter, v. 14 (1), p. 153-167.

Lynch, J.J., 1996. Provisional elemental values for four new geochemical soil and till reference materials, TILL-1, TILL-2, TILL-3 and TILL-4; Geostandards Newsletter, v. 20 (2), p. 277-287.

Lynch, J.J., 1999. Additional provisional elemental values for LKSD-1, LKSD-2, LKSD-3, LKSD-4, STSD-1, STDS-2, STSD-3 and STSD-4; Geostandards Newsletter, v. 23 (2), p. 251-260.

Mackie, R.A., Arne, D.C., and Brown, O., 2015. Enhanced interpretation of regional geochemical stream sediment data from Yukon: catchment basin analysis and weighted sums modelling; Yukon Geological Survey, Open File 2015-10, 9 p.

Mackie, R., Arne, D., and Pennimpede, C., 2016. Weighted sums model for epithermal Au-Ag deposits levelled by geology: *in* Enhanced interpretation of stream sediment geochemical data for NTS map sheet 115J and 115K; Yukon Geological Survey, Open File 2016-15, scale 1:250,000, sheet 1 of 13.

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 copper 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 for the Casino Cu-Au-Mo-Ag porphyry deposit, Yukon; *in* Targeted Geoscience Initiative: 2018 report of activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8549, p. 333-344.

McCurdy, M.W. and Garrett, R.G., 2016.Geochemical Data Quality Control for Soil, Till and Lake and Stream Sediment Samples; Geological Survey of Canada, Open File 7944, 35 p.

McKillop, R., Turner, D., Johnston, K., and 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, 85 p. including appendices.

Natural Resources Canada, 2017. Canadian Digital Elevation Model. <https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333> [accessed August 8, 2019]

Nichol, I., Hale, M., and Fletcher, W.K., 1994. Drainage geochemistry in gold exploration; *in* Handbook of Exploration Geochemistry, Volume 6, (ed.) G.J.S. Govett, Drainage Geochemistry (ed.) M. Hale and J. Plant; Elsevier Science B.V., 766 p.

Plouffe, A., Kobylinski, 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. 59-69.

Plouffe, A., Ferbey, T., Kobylinski, C.H., Hattori, K., Grenier, A., and McClenaghan, M.B., 2017. Deconvolution of complex spatial-temporal records of porphyry fertility recorded in till minerals; *in* Targeted Geoscience Initiative - 2016 Report of Activities, (ed.) N. Rogers; Geological Survey of Canada, Open File 8199, p. 79-85.

Plouffe, A., Kjarsgaard, I.M., Kobylinski, C., Hattori, K., Petts, D.C., Venance, K.E., and Ferbey, T., 2019. Discovering the next generation of copper 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.

Reimann, C., Filzmoser, P., Garrett, R.G., and Dutter, R., 2008. Statistical Data Analysis Explained. John Wiley & Sons, Ltd. 343 p.

Reimann, C., Filzmoser, P., Hron, K., Kynčlová, P., and Garrett, R.G., 2017. A new method for correlation analysis of compositional (environmental) data – a worked example; Science of the Total Environment, v. 607-608, p. 965-971.

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 (2nd edition, preliminary), scale 1:100 000. Doi:10.4095/292407

Sillitoe, R.H., 2010. Porphyry copper systems; Economic Geology, v. 105, p. 3-41.

Sinclair, W.D., 2007. Porphyry deposits; *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 Number 5, p. 223-243.

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.

Yukon Geological Survey, 2016. Yukon Geological Survey Integrated Data System – Regional Geochemical Survey (RGS) Reanalysis Data. <http://data.geology.gov.yk.ca/Compilation/21> [accessed March 6, 2019]

Yukon Geological Survey, 2017. Yukon Geological Survey Integrated Data System – Bedrock geology dataset. <http://data.geology.gov.yk.ca/Compilation/3> [accessed September 5, 2019]

Yukon Geological Survey, 2018a. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile<http://data.geology.gov.yk.ca/Search?q=ygsids#Minfile> [accessed September 5, 2019]

Yukon Geological Survey, 2018b. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Zappa). <http://data.geology.gov.yk.ca/Occurrence/14384> [accessed August 13, 2019]

Yukon Geological Survey, 2018c. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Canadian Creek). <http://data.geology.gov.yk.ca/Occurrence/14431> [accessed August 13, 2019]

Yukon Geological Survey, 2018d. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Buck). <http://data.geology.gov.yk.ca/Occurrence/14418> [accessed August 13, 2019]

Yukon Geological Survey, 2018e. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Casino). <http://data.geology.gov.yk.ca/Occurrence/15019> [accessed August 13, 2019]

Yukon Geological Survey, 2018f. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Bomber). <http://data.geology.gov.yk.ca/Occurrence/14376> [accessed August 13, 2019]

Yukon Geological Survey, 2018g. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Marquerite). <http://data.geology.gov.yk.ca/Occurrence/14417> [accessed August 13, 2019]

Yukon Geological Survey, 2018h. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Rude Creek). <http://data.geology.gov.yk.ca/Occurrence/14371> [accessed August 13, 2019]

Yukon Geological Survey, 2018i. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Cockfield). <http://data.geology.gov.yk.ca/Occurrence/14367> [accessed August 13, 2019]

Yukon Geological Survey, 2018j. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Idaho). <http://data.geology.gov.yk.ca/Occurrence/15100>[accessed August 13, 2019]

Yukon Geological Survey, 2018k. Yukon Geological Survey Integrated Data System (YGSIDS) – Minfile (Mascot). <http://data.geology.gov.yk.ca/Occurrence/14421> [accessed August 13, 2019]