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Permanent link: https://doi.org/10.4095/331831

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Recommended citation
Beckett-Brown, C.E. and Kidder, J.A. 2023. TGI Activity Report: Geochemical footprint of the undisturbed Casino porphyry Cu-Mo-Ag-Au deposit, Yukon (NTS 115 J/10 and 115 J/15); Geological Survey of Canada, Open File 8971, 17 p. https://doi.org/10.4095/331831

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

ISSN 2816-7155
ISBN 978-0-660-48437-2
Catalogue No. M183-2/8971E-PDF

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ABSTRACT

A detailed geochemical sampling survey at the remote Casino porphyry Cu-Mo-Ag-Au deposit in west central Yukon is described. This new sampling follows-up on previous sampling around the deposit by the Geological Survey of Canada (GSC) in 2017. In late August-early September of 2022, a variety of sample media were collected, including bulk stream sediments, fine-grained stream sediment, pebbles, stream and groundwaters, and vegetation at 27 sites. Sampling was conducted to establish a geochemical baseline around an undisturbed, unglaciated porphyry Cu-Mo-Ag-Au deposit and to demonstrate the applicability of multi-media surficial geochemical methods for exploration in terrains with little to no bedrock outcrop. Bulk stream sediment samples will be processed to recover 0.25-2.0 mm indicator minerals, which may be subjected to further analyses (e.g., electron microprobe and LA-ICP-MS). Fine-grained sediment samples will be submitted for routine geochemical analysis to highlight the proximal geochemistry and to better understand the signal decay downstream from the deposit. Water samples will be subjected to a variety of analytical methods including trace and ultra-trace geochemistry, as well as traditional ($\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S_{(SO4)}$, and $\delta^{18}O_{(SO4)}$) and non-traditional ($\delta^{98}Mo$ and $\delta^{65}Cu$) stable isotope analyses. The purpose of this open file is to report fieldwork activities conducted by the GSC as part of the targeted geoscience initiative (TGI-6) program. The objective of this study is to further develop research concepts conceived since 2017 and provide critical knowledge advancement for the exploration of porphyry Cu-Mo-Au deposits.

INTRODUCTION

Major glaciations of Canada in the past 2 million years have deposited an extensive cover of glacial sediments that obscures bedrock. In the glaciated terrain of Canada, till geochemistry and indicator minerals are commonly used to explore for mineralization (McClenaghan, 2005; McClenaghan and Paulen, 2018). In unglaciated parts of Canada, a broader range of surficial geochemical tools as well as an understanding of element dispersion is needed. This study addresses those needs.

Located in the remote west-central Yukon, the Casino Cu-Mo-Ag-Au deposit is one of the largest undeveloped porphyry copper deposits within Canada (Roth et al., 2020), with a current total measured and indicated resource of 2.173 billion tonnes grading 0.16% Cu, 0.18 g/t Au, 0.17% Mo, and 1.4 g/t Ag (Western Copper and Gold Corporation, 2022). Casino is unique among Canadian hydrothermal metal deposits due to the exceptional preservation of a deep (up to 300 m) weathering profile that is zoned and includes a: (i) leached cap; (ii) supergene oxide; (iii) supergene sulfide; and (iv) primary hypogene mineralization (Casselman and Brown, 2017). The presence of this intact weathering profile is due to a lack of recent glaciation in this region (Bond and Lipovsky, 2011,

2012). 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.

There is a long history of utilising stream sediment geochemistry in mineral exploration globally as well as Canada (e.g., Archer and Main, 1971; Fletcher, 1997; Yilmaz et al., 2015). Despite an extensive history of aqueous geochemistry research in Canadian mineral exploration, the method remains intermittently applied (Cameron, 1978; Kidder et al., 2022). One of the goals of this study is to demonstrate the effectiveness of hydrogeochemical vectoring in stream water using modern techniques and detection limits. Recent advances in analytical technologies have facilitated the application of ultra-trace dissolved Au analysis (Buskard et al., 2020) and stable-metal analysis of dissolved phase metals (Mathur et al., 2005; Leybourne and Cameron, 2006; Leybourne et al., 2006; Mathur et al., 2012, 2013; Skierszkan et al., 2019; and Kidder et al., 2021). Such techniques can potentially assist in the interpretation of aqueous geochemical data or provide direct vectors to mineralization from large secondary dispersion halos.

The Casino deposit is known to have metal-rich sediments and waters within the creeks draining the deposit (Archer and Main, 1971) and has been minimally disturbed by exploration activities to date (not yet mined). The deposit area, therefore, represents an excellent opportunity to investigate secondary element dispersion in the surficial environment and document the deposit's geochemical footprint. As part of the Geological Survey of Canada (GSC) Targeted Geoscience Initiative 5 (TGI-5), stream sediment and water samples were collected around the deposit in 2017 as part of a larger study of the deposit's indicator mineral and surficial geochemical signatures (McClenaghan et al., 2018, 2019, 2020, 2023; McCurdy et al., 2019; Beckett-Brown et al., 2019, 2023a, 2023b; Kidder et al., 2022). The purpose of this open file is to report fieldwork activities conducted by the Geological Survey of Canada as part of the TGI-6 program. Samples were collected in the creeks proximal to the Casino deposit from August to early September 2022. The objective of this study is to further develop research concepts conceived since 2017.

PHYSIOGRAPHIC, AND CLIMATIC, SETTING

The Casino deposit is in west-central Yukon, 300 km northwest of Whitehorse (Fig. 1a) and within the Klondike Plateau ecoregion (Smith et al., 2004). The study area is remote and can only be accessed by fixed-wing aircraft or helicopter. Casino resides at 62°44'N/

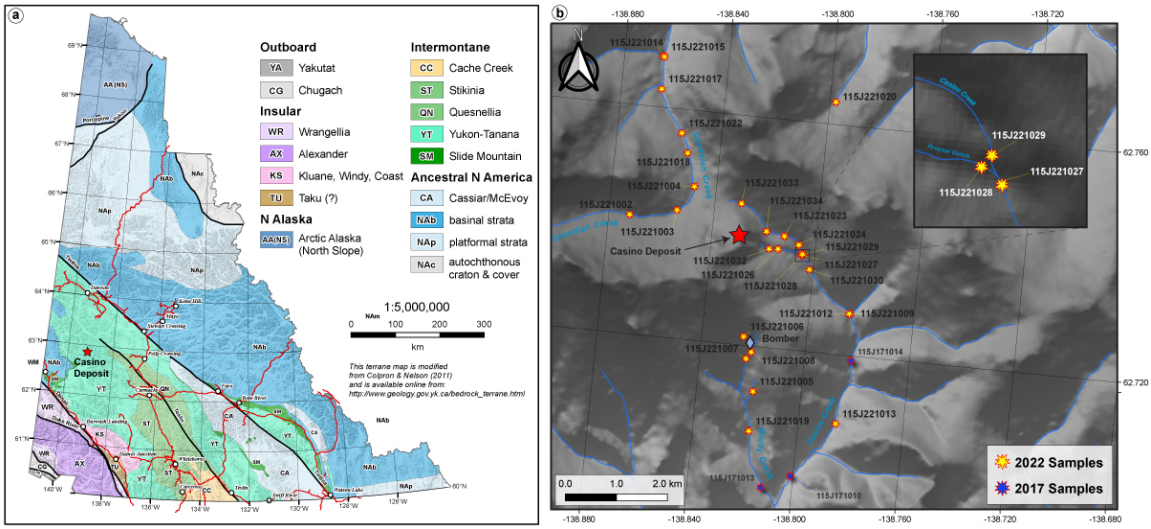

Figure 1: a) Bedrock geology map of the Yukon showing the location of the Casino deposit (red star) (Colpron et al. 2016). b) Sample locations from the 2022 field season as well as samples collected in 2017 that occur within the 2022 study area. Red star is the Casino deposit, the blue diamond is the Bomber veins.

138°50'W (Latitude/Longitude) and within NTS map areas 115J J/10 (Colorado Creek) and 115J J/15 (Britannia Creek). The topography of the study lies within an elevation range of 1000 to 1500 m, with Patton Hill (the highest point of the Patton porphyry intrusion) reaching 1432 m *asl.* Bond and Lipovsky (2011) described the climate of the study as cold and semi-arid, with mean average temperatures ranging from 10.5 °C in the summer to -23 °C in the winter and mean annual precipitation of 300 to 450 mm (Smith et al., 2004).

GEOLOGIC SETTING

The Casino deposit area is underlain by metamorphosed and deformed basement rocks of the Yukon-Tanana terrane (Ryan et al., 2013; Colpron et al., 2006, 2016) including the Snowcap assemblage of metamorphosed sedimentary and minor volcanic rocks; and the arc metavolcanic and associated metasedimentary rocks consisting of the Finlayson, Klinkit and Klondike assemblages of the Yukon-Tanana terrane, extending over 2000 km from Alaska, through Yukon and into British Columbia (Allan et al., 2013; Mortensen and Friend, 2020). The bedrock geology of the deposit and surrounding area is described in detail in Archer and Main (1971), Godwin (1975), (1976), Bower et al. (1995), Ryan et al. (2013) and Casselman and Brown (2017). The Casino deposit is of calc-alkalic affinity, and ore is hosted in a quartz monzonite and associated breccias at the contact of the intrusion and the country rock (Casselman and Brown, 2017).

In the deposit area, first and second-order streams (e.g., Casino and Canadian Creeks) occur in narrow V-shaped valleys and contain subangular to subrounded gravel to boulders that are derived from local bedrock. This study area is a periglacial environment; 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. The presence of permafrost is indicated by solifluction lobes, pingos, and thermokarst features. Frost shattering, cryoturbation, solifluction soil creep, and land sliding are all mechanisms by which bedrock is released into the surficial environment and unconsolidated sediments move down slope and into creeks (Bond and Lipovsky, 2012). Fluvial erosion of older gravel deposits, including placers, also contribute material to modern creeks.

SAMPLING METHODS

A total of 34 fine-grained stream sediment samples, 26 heavy mineral stream sediment samples, 34 stream water samples, and 1 ground water sample were collected at 27 sites (Fig. 1b) around the Casino deposit in August/September 2022 using GSC protocols described by Friske and Hornbrook (1991) and Day et al. (2013). Samples sites were accessed primarily by helicopter or all-terrain vehicle. Field observations were recorded on a tablet (Fig. 2) using a preloaded digital form developed by the GSC and the Northwest Territories Geological Survey. Duplicate samples for fine-grained sediment and water samples were collected every 10 or so samples.

Figure 2: GSC geologist Chris Beckett-Brown logging site field data on the tablet after collecting stream sediment samples at site 115J221030 near the Casino deposit. Note the pale white precipitate on the stream bed, which is suspected to be an Al-sulfate. Photograph by J.E. Kidder. NRCan Photo 2022-449.

Bulk Sample

A total of 26 bulk stream sediment samples were collected from 27 sites downstream of the deposit (Fig. 3) using GSC National Geochemical Reconnaissance (NGR) sampling protocols similar to those previously reported (Day et al., 2013; McCurdy and McNeil, 2014). Bulk stream sediment samples (~10 ± 2 kg wet) were collected primarily in boulder traps and in the bed of streams surrounding the Casino deposit, mainly in Casino, Canadian, and Meloy Creeks (Fig. 2). An individual sample was collected from a single hole at most sites, with only a few exceptions when the streams were dominated by boulders and thus multiple holes had to be dug. No post-collection processing of the bulk

Figure 3: Collection of a bulk stream sediment (12 kg) sample in Proctor Gulch at site 115J221032. The bulk sample was sieved to into a 20 L (5 gallon) pail lined with a labelled plastic sample bag in order to recover the <2 mm fraction for heavy mineral analysis. Water is drained from the sample bag after sufficient sample material has been collected and before closing the sample bag. Photograph by J.E. Kidder. NRCan Photo 2022-450.

samples was carried out in the field. Bulk samples were collected by lining a 20 litre (5-gallon) pail with a labelled heavy-duty plastic bag, filling the bag with water, placing a nested #2 and #10 ASTM sieves on top of the pail and then wet-sieving a mixture of coarse sand and gravel through the sieves (Fig. 3, 4) to collect ~12 kg of <2 mm material. Once a ~12 kg sample is obtained, the water is carefully drained from the bag and then the sample bag is closed with a zip-tie and then double bagged with an additional sample tag between bags. The bulk stream sediment samples were shipped to Overburden Drilling Management Ltd. (ODM), Ottawa, for recovery of heavy mineral concentrates (HMC) using methods outlined in McClenaghan et al. (2020). No field duplicate heavy mineral samples were collected. Four quality control samples were added to the heavy mineral sample batch approximately every 8 samples. The 0.25 to 2.0 mm mid-density and heavy mineral fraction will be recovered, and porphyry Cu indicator minerals will be counted as well as any other noteworthy mineral grains. Mineral chemistry will be determined for selected indicator mineral grains using electron microprobe and/or laser ablation-inductively coupled plasma-mass spectrometry to determine major, minor, trace, and isotopic analyses.

Figure 4: An example of GSC geologist Chris Beckett-Brown separating the 2-10 mm clast fraction at sample site 115J221004 following wet sieving the bulk stream sediment sample into the plastic sample bag lined pail. Photograph by J.E. Kidder. NRCan Photo 2022-451.

Fine-grained stream sediment

At each sample site, a synthetic cloth bag (18 cm x 32 cm) was two-thirds filled (~1-2 kg wet mass) with silt to fine sandy material collected from the active stream channel bed. The sample was always collected after and downstream of the water sampling. The sampler collected the sediment sample over 5-15 m while

walking upstream. If silt-sized material was sparse to absent, silt from the underside of moss growing on the stream edge, which can trap silt-sized material was collected. Samples in the upper sections of Canadian Creek (115J221002, 115J221003, and 115J221004), where historic placer mining operations occurred, created challenges for sampling as the natural stream bed had been destroyed removing many of the natural silt traps and thus ideal sampling locations. Field duplicates were collected approximately every 10 samples. Fine-grained stream sediment samples will be dried at low temperatures (<40 °C) at the GSC Sedimentology Laboratory, Ottawa. These samples will be sieved to recover the <177 µm fraction and this fine fraction will be analyzed using modified aqua regia digestion/ICP-MS, instrumental neutron activation analysis, lithium meta/tetra borate fusion/ICP-MS and portable XRF.

Stream clasts

Approximately 1-2 kg of >2 mm (granule to pebble-sized) material (Fig. 5) was also collected during bulk sediment sampling. This material was retained between the #2 mesh (~10 mm) sieve and #10 mesh (~2 mm) sieves while sieving in the field to collect the heavy mineral sample. The >2 mm clast fraction collected around the Casino deposit will be dried at low temperatures (<40 °C) at the GSC Sedimentology Laboratory, Ottawa, and will be visually examined to aid in determination of the bedrock source of detrital material.

Figure 5: An example of the coarse fraction (2-10 mm) recovered after sieving to collect the <2 mm bulk stream sediment for heavy mineral analysis. The sample shown is from site 115J221003 (Canadian Creek). This fraction was collected for lithological classification. Photograph by C.E. Beckett-Brown. NRCan Photo 2022-452.

Stream Water

A total of 34 stream water samples (including blanks and duplicates) were collected from 27 sites both upstream and downstream of the Casino deposit and from downstream tributaries considered to be 'background'. The goals of sampling waters from around the Casino deposit is fourfold: (i) ascertain the mobility of critical metals in streams draining porphyry copper deposits; (ii) test ultra-trace analysis of Au in stream waters as an exploration vector; (iii) develop metal stable isotope methodologies for stream water vectoring; and (iv) test current and develop new methodologies for field sampling.

To monitor potential sources of field contamination, four field blanks were inserted in the sample suite, consisting of ultra-pure deionised water sourced from the GSC Ottawa IGRL Laboratories and poured into sample bottles at field sites. Field duplicate water samples were collected at four sites. To ascertain potential sources of contamination

during sample transit, ‘travel blanks’, a blank aliquot sealed in a laboratory environment and not transferred to a collection vessel, were prepared at GSC IGRL Laboratory, Ottawa, and included in all sample shipments.

Two water samples were collected in the mid-channel of streams at each site: i) a filtered sample, acidified on arrival at the laboratory (‘FA’) for major and trace elements analysis; and ii) a filtered, unacidified sample (‘FU’) for anions analysis, alkalinity, and DOC. On-site, 60 ml of water was collected by filling a 60 ml sterile plastic syringe from the active part of the stream channel and filtered through a single-use Millipore Sterivex-HV® 0.45 µm filter unit attached to the syringe into each of the triple rinsed FA and FU 60 ml Nalgene® bottles.

In-situ water measurements were completed using a YSI Pro DSS® multi-parameter meter (Fig. 6) placed in the center of the stream which simultaneously measured temperature, pH, conductivity, specific conductivity (SPC), dissolved oxygen (DO), and oxidation-reduction potential (ORP) with automatic temperature compensation for pH and dissolved oxygen. These parameters were measured by immersing the probe head with sensor cage directly in the active portion of the steam channel and after instrument measurements had stabilised, usually 15 minutes. The multi-parameter probe was calibrated daily to ensure accurate measurements. Stream water flow measurements were recorded for each sample site using a Global Water Instruments flow probe (model: FP111). Observations of the physical characteristics of each water sample (i.e., colour, transparency, smell, and colloid type) were reported for each sample site and colour photographs were taken.

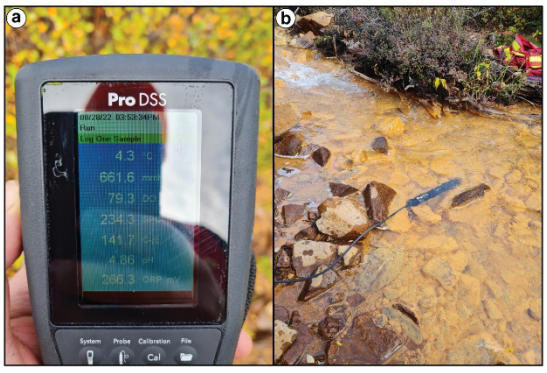

Figure 6: a) A YSI probe was placed in the stream at each sample site to record some properties of the stream water including temperature, pH, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP) with automatic temperature compensation for pH and dissolved oxygen. b) Photo shows site 115J221027, note the pale orange precipitate on the stream bed, which is suspected to be an Al or Fe-sulfate. Photograph by J.E. Kidder. NRCan Photo 2022-453 and 2022-454.

Field sample filtration is a potential source of contamination and inefficiency during sampling. To ascertain if the current GSC surface water sample protocols can be improved, two field sampling protocols were tested, including: (i) a single-use Millipore Sterivex-HV® 0.45 µm filter unit attached to a 60 ml sterile plastic syringe, based on GSC protocols devised by Hall et al. (1996) and used in previous studies (Day et al., 2013; McCurdy and McNeil, 2014); and (ii) a Waterra Spectra Field-Pro peristaltic pump coupled with in-line 0.45 µm pre-rinsed Waterra capsule filters (Model: FHT-45 for metal analysis) and Teflon tubing. Pumping and capsule filtration was chosen to compare

to the current GSC sampling protocols as it isolates as much as possible the sampling and filtration from human interaction.

At each site a total of eight samples were collected from the active part of the stream channel, including:

- Two water samples collected using syringe filtration (Fig. 7): (i) a filtered, acidified sample 'FA (S)'; and (ii) a filtered, un-acidified sample ('FU (S)').
- Five water samples collected using peristaltic pump with in-line filter (Fig. 7): (i) three filtered, acidified samples 'FA (P)', 'AuFA', and 'ISO-FA-Cu'; and (ii) two filtered, un-acidified samples 'FU (P)' and 'ISO-FU'.
- A 'raw' 60 mL aliquot (Fig. 7), consisting of un-filtered and un-acidified ('UA') sample water was recovered for the analysis of the 'total' (unfiltered, particulate phase) concentrations.

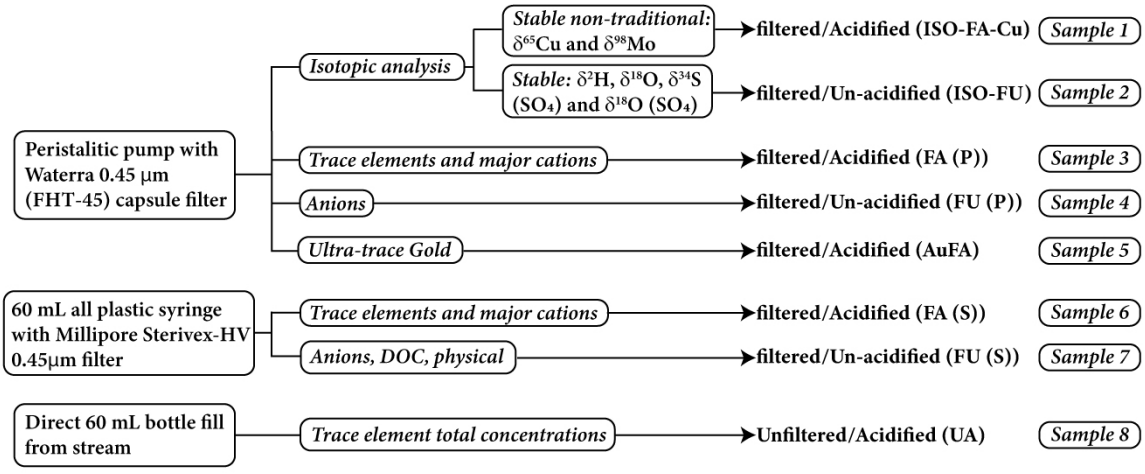

Figure 7: Summary of filtering methodology and analytical purpose of the eight water aliquots collected from each sampling location. (S) – syringe, (P) – pump, (F) – filtered, (A) – acidified, (U) – unacidified.

In addition, to ascertain the mineralogy and speciation of colloids and precipitates in suspension, an aliquot of sample water was filtered using a polysulfone Nalgene™ 250 ml reusable filter holder (10432941), coupled with a Nalgene 25" Hg vacuum hand pump (MV8121) and 0.45µm Merk 47 mm Durapore membrane filters. The filter papers were retained for analysis at GSC-Ottawa Mineralogy Laboratory. In addition to the stream water samples, a single groundwater sample (115J221034) was collected from a discharging borehole, using the same protocols as the stream waters.

All samples were stored and shipped in cooler boxes with ice packs to maintain a stable temperature. Following to the recommendations of Hall et al. (1996), water samples were not acidified in the field and instead underwent preservation once received in the GSC's Inorganic Geochemistry Research Laboratory, Ottawa, where they were acidified within 48 hours of arrival with 0.5 ml 8M Ultrapure HNO_3. The raw 'UA" sample will undergo

analysis of: (i) conductivity and pH, using an Accumet AR50 dual channel pH/ion/conductivity meter with temperature compensation; (ii) alkalinity, using a Man-Tech PC-Titrate^{TM} system with a Titra-Sip^{TM} Module; (iii) total organic carbon (TOC) will be ascertained using a Shimadzu TOC-L analyser using a 680°C combustion catalytic oxidation method combined with NDIR detection, reported as dissolved organic carbon (DOC) on a 0.45-µm Durapore®-filtered sample; and (iv) total concentrations of trace and major elements analysed using the same protocols as 'FA (P)' and 'FA (S)' sample aliquots.

The 'FU (S)' and 'FU (P)' sample aliquots will be analysed for anion concentrations using a Dionex ICS 2100 Ion Chromatograph fitted with an AS-AP auto-sampler and a bromide, chloride, fluoride, nitrate, phosphate and sulfate separation three-step gradient elution (12 to 52 mm KOH eluant) with an AS-18 column. The 'FA (P)' and 'FA (S)' aliquot will be analysed for both major cations and trace metals. Major elements will be measured using inductively coupled plasma optical emission spectrometer (ICP-OES), with a Burgener Teflon Mira Mist Nebulizer and a cyclonic spray chamber. Whereas trace metals will be performed using a Thermo X Series II quadrupole inductively coupled plasma mass spectrometer (ICP-MS) with Xt cones, PlasmaScreen fitted, standard concentric nebulizer and Peltier cooled conical impact bead spray chamber (3 °C) using Rh and Ir as internal standards.

The 'AuFA' aliquot will undergo commercial analysis at ALS Laboratories, including 'ultra-trace' (Au-PATH14L – Au, Ag, As, Co, Pd, Sb, Tl, and W) concentration determination and preparation with a chemical treatment to desorb Au from the sample bottle wall (WAT-PREP05).

Water samples will be analyzed for $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$, $\delta^{65}Cu$, and $\delta^{98}Mo$ at Queen's Institute for Isotope Research (QFIR). The 'ISO-FU' sample will be used for the analysis of $\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S_{SO4}$ and $\delta^{18}O_{SO4}$. The hydrogen isotopic composition ($\delta^{2}H$) of the waters will be measured using a Thermo-Finnigan MAT 253 IRMS. The ratio of ^{18}O to ^{16}O will be analyzed using a Thermo-Finnigan Gas Bench coupled to a Thermo-Finnigan DeltaPlus XP Continuous-Flow Isotope-Ratio Mass Spectrometer (CF-IRMS). The measure of $\delta^{34}S$ and $\delta^{18}O$ of dissolved sulfate will utilise a MAT 253 IRMS coupled to a Costech ECS 4010 Elemental Analyzer.

The 'ISO-FA-Cu' sample aliquot will be analysed for stable metal isotopes $\delta^{65}Cu$ and $\delta^{98}Mo$. Both Cu and Mo will be separated using an ESI PrepFAST-MC automated chromatography system, using the protocols of Kidder et al. (2021), in a Class 100 clean laboratory and analyzed on a Thermo Scientific Neptune multi-collector (MC)-ICP-MS.

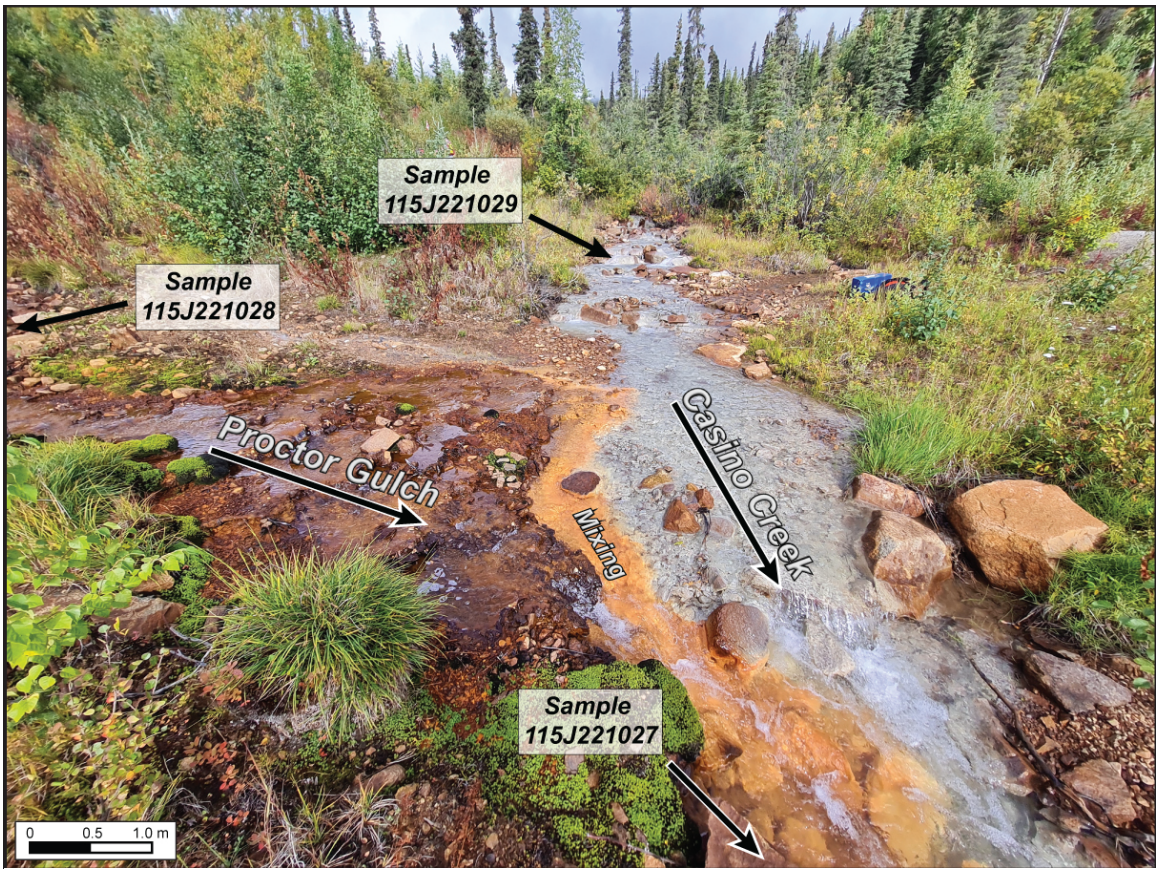

Figure 8: Field photo looking north from the confluence of Proctor Gulch, flowing southeast (right) and Casino Creek flowing south (out of the page). Proctor Gulch has a dark brown-red precipitate on the stream bed and Casino Creek has a white precipitate on the stream bed (presumed to be an Al-sulfate). Where the waters from the two streams mix, a light orange coloured precipitate was observed (presumed to be a mixture of Fe and Al-sulfates). Sample 115J221027 was collected to the south of the image where the waters from the two streams completely mixed. Sample 115J1028 was collected approximately five meters to the west of the photo in Proctor gulch. Sample 115J1029 was collected in Casino Creek upstream of the confluence. Water flow directions are denoted by the arrows underneath the stream names. Photograph by J.E. Kidder. NRCan Photo 2022-455.

A unique phenomenon was observed while sampling at the confluence of Proctor Gulch and Casino Creek. The Proctor Gulch stream bed is covered by dark red to brown Fe-precipitate crust, while the Casino Creek stream bed is made up of boulders, cobbles, and sand coated with a white precipitate (Fig. 8). At the confluence between these streams, where they mix, an orange precipitate was observed on the stream bed (Fig. 8).

Black Spruce tree bark

Tree bark samples were collected from black spruce trees along drainage pathways around Casino. The aim of this work was to ascertain if porphyry-related elements mobilised in stream waters could be up taken by streams in the drainages and accumulated in the tree tissues. To test this, a total of 17 tree bark samples were collected from 11 sites proximal to stream water and stream sediment sampling sites, including two field duplicates. The bark scale of black spruce trees was recovered (Fig. 9), where possible, using the protocols of Dunn et al. (1992). Approximately 50 grams of tree bark

scales were collected using a paint scraper and plastic dustpan. Samples were placed in polyester soils bags and air dried at GSC-Ottawa following the completion of fieldwork. The circumference and height of the trees sampled at each site were recorded. Dried samples will be dispatched to ALS Laboratories for biogeochemical analysis with control samples to be provided by Colin Dunn (Colin Dunn Consulting Inc). Samples will be prepared by milling bark tissues to less than 1 mm (VEG-MILL01) and 1 g of sample analysed using ICP-MS (ME-VEG41).

Figure 9: An example of a black spruce tree (25 cm in diameter, ~8 m tall) from which bark was sampled for geochemical analysis. Photo is of site 115J221024. NRCan Photo 2022-456.

Fe-Precipitate

While sampling Proctor Gulch (Fig. 10a), Fe-oxide precipitation was observed forming a layered, hardpan formation (Fig. 10b) along the entirely of the bed and banks of the gulch. Four samples of Fe-precipitate from the Proctor Gulch were collected to better understand metal cycling in the surficial environment. Even with the harsh conditions in Proctor Gulch, moss and vegetation are adapting and surviving in this

Figure 10: a) Field photo downstream of site 115J221026 (Proctor Gulch) showing the vegetation growing along the stream bank. Photograph by C.E. Beckett-Brown. NRCan Photo 2022-457. b) Field photo of the Fe-precipitate that has precipitated on the stream bed. Note the rhythmic layering of lighter and darker brown layers of different thicknesses. The lighter brown layers are thicker than the darker brown layers. Photograph by C.E. Beckett-Brown. NRCan Photo 2022-458. c) sphagnum moss growing along the stream bank located in the white box from (a). Photograph by C.E. Beckett-Brown. NRCan Photo 2022-459. d) a cross-section of some of the moss that also shows the rhythmic alternating layers of light and dark brown sections, like the Fe-precipitate on the stream bed. Photograph by C.E. Beckett-Brown. NRCan Photo 2022-460.

environment with pH values averaging 3.2 (n = 3) along the gulch (Fig. 10c, 10d). These samples will be sieved to recover the <177 μm fraction for analysis using modified aqua regia digestion/ICP-MS, and instrumental neutron activation analysis. Additionally, some of this material will be mounted into epoxy ring mounts for electron microprobe and laser ablation-inductively coupled plasma-mass spectrometry to determine major, minor, trace element concentrations and isotopic analyses.

ACKNOWLEDGEMENTS

This report is a contribution to Geological Survey of Canada's Targeted Geoscience Initiative Program (TGI-6). We gratefully acknowledge the support of Western Copper and Gold Corporation and the Casino Mining Corporation, including access to the deposit and drill core and logistical support, in particular Jay Corman, Melanie Dallow, Shena Shaw, Chandni Kher, and Calvin Delwisch for their assistance in organizing the field visit as well as accommodating onsite. Justin Sinclair of Aurora Geosciences is thanked for conducting follow up sampling of Proctor Gulch. Scott Casselman and Justin Emberely, Yukon Geological Survey, are thanked for logistical assistance, bedrock samples, and advice about the geology of the Casino area. A special thanks to M.B. McClenaghan for her review of the report.

REFERENCES

Allan, M.M., Mortensen, J.K., Hart, C.J.R., Bailey, L.A., Sanchez, M.G., Ciolkiewicz, W., McKenzie, G.C., Creaser, R.A., 2013. Magmatic and metallogenic framework of west-central Yukon and eastern Alaska; *in* Tectonics, Metallogeny, and Discovery: The North American Cordillera and Similar Accretionary Settings. (ed.) Colpron, M., Bissig, T., Rusk, B.G., and Thompson, J.F.H.: Society of Economic Geologists, Special Publication v. 17, p. 111–168.

Archer, A.R., and Main, C.A., 1971. Casino, Yukon—a geochemical discovery of an unglaciated Arizona-type porphyry. In Boyle R.W. Geochemical Exploration, Proceedings of the 3rd International Geochemical Exploration Symposium, Toronto: Canadian Institute of Mining and Metallurgy. v. 11, p. 67–77

Beckett-Brown, C.E., McDonald, A.M., and McClenaghan, M.B., 2023a. Recognizing tourmaline in mineralized porphyry copper systems: Textures and major-element chemistry. The Canadian Journal of Mineralogy and Petrology, 61, 3-29. https://doi.org/10.3749/2200011

Beckett-Brown, C.E., McDonald, A.M., and McClenaghan, M.B., 2023b. Trace-element characteristics of tourmaline in porphyry copper systems: development and

application to discrimination. The Canadian Journal of Mineralogy and Petrology, 61, 31-60. https://doi.org/10.3749/2200037

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. https://doi.org/10.4095/313623.

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. MacFarlane, L. Weston, and C. Relf; Yukon Geological Survey, p. 19–32.

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

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

Boyle, R.W., Hornbrook, E.H.W., Allan, R.J., Dyck, W. and Smith, A.Y., 1971. Hydrogeochemical methods - Application in the Canadian Shield; Geochemical exploration in the Canadian Shield: State of the art - water. Canadian Institute of Mining, Metallurgy and Petroleum, Bulletin 64, no. 715, p. 60–71.

Buskard, J., Reid, N., and Gray, D., 2020. Parts per trillion (ppt) gold in groundwater: can we believe it, what is anomalous and how do we use it?; Geochemistry: Exploration, Environment, Analysis, v. 20, p. 189–198. https://doi.org/10.1144/geochem2019-032.

Cameron, E.M., 1978. Hydrogeochemical methods for base metal exploration in the northern Canadian Shield; Journal of Geochemical Exploration, v. 10, p. 219–243. https://doi.org/10.1016/0375-6742(78)90022-5.

Casselman, S.G., 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.

Colpron, M., Nelson, J., and Murphy, D.C., 2006. A tectonostratigraphic framework for the pericratonic terranes of the northern Canadian Cordillera; in Paleozoic

evolution and metallogeny of pericratonic terranes at the ancient Pacific margin of North America, Canadian and Alaskan Cordillera, 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.

Day, S.J A., Wodicka, N., and McMartin, I., 2013. Preliminary geochemical, mineralogical and indicator mineral data for heavy mineral concentrates and waters, Lorillard River area Nunavut (parts of NTS 56-A, -B, and -G); Geological Survey of Canada, Open File 7428. https://doi.org/10.4095/293113.

Dunn, C.E., Adcock, S.W., Spirito, W.A., 1992. Reconnaissance biogeochemical survey, southeastern Cape Breton Island, Nova Scotia, Part 1 - black spruce bark, parts of NTS 11F, G, J, K; Geological Survey of Canada, Open File 2558. https://doi.org/10.4095/133470.

Fletcher, W.K., 1997. Stream sediment geochemistry in today's exploration world; in Proceedings of Exploration 97: Fourth Decennial International Conference on Mineral Exploration, (ed.) A.G. Gubins, p. 249–260.

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 Science, v. 100, p. 47–56.

Godwin, C.I., 1975. Geology of the Casino porphyry copper-molybdenum deposit, Dawson Range, Yukon Territory: Ph.D. thesis, Vancouver, Canada, The University of British Columbia, 257 p.

Godwin, C.I., 1976. Casino; *in* Porphyry Deposits of the Canadian Cordillera: A Volume Dedicated to Charles S. Ney, (ed.) A.S. Brown; Canadian Institute of Mining and Metallurgy. Special Volume 15, p. 344–358.

Hall, G.E., Bonham-Carter, G.F., Horowitz, A.J., Lum, K., Lemieux, C., Quemerais, B., and Garbarino, J.R., 1996. The effect of using different 0.45 μm filter membranes on 'dissolved' element concentrations in natural waters; Applied Geochemistry, v. 11, no. 1-2, p. 243–249. https://doi.org/10.1016/0883-2927(96)00059-5.

Kidder, J.A., Voinot, A., Leybourne, M.I., Layton-Matthews, D., and Bowell, R.J., 2021. Using stable isotopes of Cu, Mo, S, and $^{87}Sr/^{86}Sr$ in hydrogeochemical mineral exploration as tracers of porphyry and exotic copper deposits; Applied Geochemistry, v. 128, p. 104935. https://doi.org/10.1016/j.apgeochem.2021.104935.

Kidder, J.A., McClenaghan, M.B., Leybourne, M.I., McCurdy, M.W., Pelchat. P., Layton-Matthews, D., and Voinot, A., 2022. Hydrogeochemistry of porphyry-related solutes in ground and surface waters; an example from the Casino Cu-Au-Mo deposit, Yukon, Canada; Geochemistry: Exploration, Environment, Analysis, v. 22, no. 2. https://doi.org/10.1144/geochem2021-058.

Leybourne, M.I., Boyle, D.R., and Goodfellow, W.D., 2003. Interpretation of stream water and sediment geochemistry in the Bathurst Mining Camp, New Brunswick: Applications to mineral exploration; *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; Society of Economic Geologists, Inc., Littleton, CO, p. 741–762. https://doi.org/10.5382/Mono.11.33.

Leybourne, M.I., and Cameron, E.M., 2006. Composition of groundwaters associated with porphyry-Cu deposits, Atacama Desert, Chile: Elemental and isotopic constraints on water sources and water-rock reactions; Geochimica et Cosmochimica Acta, v. 70(7), p. 1616–1635. https://doi.org/10.1016/j.gca.2005.12.003.

Leybourne, M.I., Clark, I.D., and Goodfellow, W.D., 2006. Stable isotope geochemistry of ground and surface waters associated with undisturbed massive sulfide deposits; constraints on origin and water-rock reactions; Chemical Geology, v. 231(4), p. 300–325. https://doi.org/10.1016/j.chemgeo.2006.02.004.

Mathur, R., Munk, L., Nguyen, M., Gregory, M., Annell, H. and Lang, J., 2013. Modern and paleofluid pathways revealed by Cu isotope compositions in surface waters and ores of the Pebble Porphyry Cu-Au-Mo deposit, Alaska; Economic Geology, v. 108, no. 3, p. 529–541. https://doi.org/10.2113/econgeo.108.3.529.

Mathur, R., Ruiz, J., Titley, S., Liermann, L., Buss, H. and Brantley, S., 2005. Cu isotopic fractionation in the supergene environment with and without bacteria; Geochimica et Cosmochimica Acta, v. 69, no. 22, p. 5233–5246. https://doi.org/10.1016/j.gca.2005.06.022.

Mathur, R., Titley, S.R., Schlitt, W.J., and Wilson, M., 2012. Cu isotope fractionation in exploration geology and hydrometallurgy: examples from porphyry copper deposits; Mining Engineering, v. 64, p. 42–46.

McClenaghan, M.B., McCurdy, M.W., Garrett, R.G., Beckett-Brown, C.E., and Casselman, S.G., 2020. Indicator mineral signatures of the Casino porphyry Cu-Au-Mo deposit, Yukon; Geological Survey of Canada, Open File 8711, 42 p. https://doi.org/10.4095/322191.

McClenaghan, M.B., 2005. Indicator mineral methods in mineral exploration; Geochemistry: Exploration, Environment, Analysis, v. 5, no. 3, p. 233–245. https://doi.org/10.1144/1467-7873/03-066.

McClenaghan, M.B., Beckett-Brown, C.E., McCurdy, M.W., and Casselman, S., 2023. Stream sediment indicator mineral signatures of the Casino porphyry Cu-Au-Mo deposit, Yukon, Canada; Economic Geology, v. 118, no. 2, p. 411-431. https://doi:10.5382/econgeo.4970.

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. https://doi.org/10.4095/306427.

McClenaghan, M.B., and Paulen, R.C., 2018. Application of till mineralogy and geochemistry to mineral exploration; *in* Past Glacial Environments (Sediments, Forms and Techniques) A new & revised edition, (ed.) J. Menzies and J.J. van der Meer; Elsevier, p. 689–751. https://doi.org/10.1016/B978-0-08-100524-8.00022-1.

McClenaghan, M.B., Parkhill, M.A., Pronk, A.G., McCurdy, M.W., Boldon, G.R., Leybourne, M.I., Pyne, R.M. and Rice, J.M., 2015. Geochemical and indicator mineral data for stream sediments and waters around the Sisson Sn-W-Mo deposit, New Brunswick (NTS 21-J/06, 21-J/07); Geological Survey of Canada, Open File 7756, 62 p. https://doi.org/10.4095/297246

McClenaghan, M.B., McCurdy, M.W., Garrett, R.G., Beckett-Brown, C.E., Leybourne, M.E., 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. https://doi.org/10.4095/313623

McCurdy, M.W., and McNeil, R.J., 2014. Geochemical data from stream silts and surface waters in the Pine Point mining district, Northwest Territories (NTS 85-B); Geological Survey of Canada, Open File 7577, 17 p. https://doi.org/10.4095/293913

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, 37 p. https://doi.org/10.4095/321381.

Mortensen, J.K., and Friend, M., 2020. An overview of porphyry style deposits in Yukon; *in* Porphyry Deposits of the Northwestern Cordillera of North America: A 25 Year Update, (ed.) E.R., Sharman, J.R. Lang, and J.B. Chapman; Canadian Institute of Mining and Metallurgy, Special Volume 57, p. 176–193.

Roth, D., Hester, M., Tahija, L.M., Schulze, C., and Vallat, C.J., 2020. Casino Project: Form 43-101F1 Technical report mineral resource statement, Yukon, Canada. M3 Engineering & Technology Corporation, prepared for Western Copper and Gold, 150 p.

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

Skierszkan, E.K., Robertson, J.M., Lindsay, M.B., Stockwell, J.S., Dockrey, J.W., Das, S., Weis, D., Beckie, R.D., and Mayer, K.U., 2019. Tracing molybdenum attenuation in mining environments using molybdenum stable isotopes; Environmental Science & Technology, v. 53, p. 5678–5686. https://doi.org/10.1021/acs.est.9b00766.

Smith, C., Meikle, J. and Roots, C., 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.

Western Copper and Gold Corporation. 2022. Casino Project – Technical Report; https://www.westerncopperandgold.com/casino-project/technical-reports/ [accessed: March 2, 2023]

Yilmaz, H., Sonmez, F.N., and Carranza, E.J.M., 2015. Discovery of Au–Ag mineralization by stream sediment and soil geochemical exploration in metamorphic terrain in western Turkey; Journal of Geochemical Exploration, v. 158, p. 55–73. https://doi.org/10.1016/j.gexplo.2015.07.003