Mineral markers of porphyry copper mineralization: Progress report on the evaluation of tourmaline as an indicator mineral

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Abstract

Tourmaline is considered a potential indicator of porphyry-style mineralization as it is a relatively common accessory mineral and has a broad range of compositions. The aim of this study is to test discrimination criteria for tourmaline in relation to porphyry copper mineralization. Work to date has focussed on the collection of tourmaline in bedrock samples from a broad range of known porphyry deposits, the detailed examination of tourmaline in archived till samples from the vicinity of the Woodjam deposit, and the collection of new bedrock and stream sediment samples in the area of the Casino deposit. Three different types of tourmaline were identified in bedrock from Casino: i) breccia-style; ii) vein-style; and iii) disseminated. A paragenetic analysis based on associated minerals and tourmaline textures indicates that tourmaline is one of the first hydrothermal minerals to form in the mineralized porphyry system. Diffusion-like textures found in some tourmaline grains from bedrock samples from other deposits is significant because chemical diffusion in tourmaline is considered to be virtually non-existent. Future work includes the completion of trace element analysis of tourmaline, comparison of tourmaline chemical signatures in bedrock to those recovered in till or stream sediments at the two test sites, and investigation of Fe^{2+}/Fe^{3+} using Raman spectroscopy.

Introduction

Indicator minerals are an established exploration tool in glaciated terrain for gold (e.g. Averill and Zimmerman, 1986; Averill, 2001; McClenaghan and Cabri, 2011) and diamonds (e.g. McClenaghan and Kjarsgaard, 2007), and more recently have been tested for porphyry copper deposits (e.g. Kelley et al., 2011; Hashmi et al., 2015; Plouffe et al., 2016). The objective of this research activity is to further develop the porphyry copper indicator mineral suite for both glaciated and unglaciated terrains through the detailed examination and testing of the mineral tourmaline. Discrimination criteria will be developed for identifying tourmaline in bedrock and unconsolidated sediments (i.e. till, stream sediments) that is indicative of fertile porphyry copper intrusions.

Sampling of GSC archives

Archived bedrock samples housed at Geological Survey of Canada's sample repository in Ottawa from a broad range of porphyry copper deposits and pegmatites that had been collected by R. Kirkham, D. Sinclair, R. Mulligan, A. Soregaroli and R. Boyle from British Columbia, Yukon, Ontario, Quebec, Nova Scotia, Chile and Mexico have been subsampled. At least half the subsamples selected for this study are from locations that are no longer accessible or represent upper parts of deposits that have been mined out. Tourmaline in these samples are being examined in polished thin section and/or heavy mineral concentrates to characterize textural relationships (grain size, mineral inclusions, colour, zonation, etc.), mineral chemistry (major, minor and trace) and isotopic ratios.

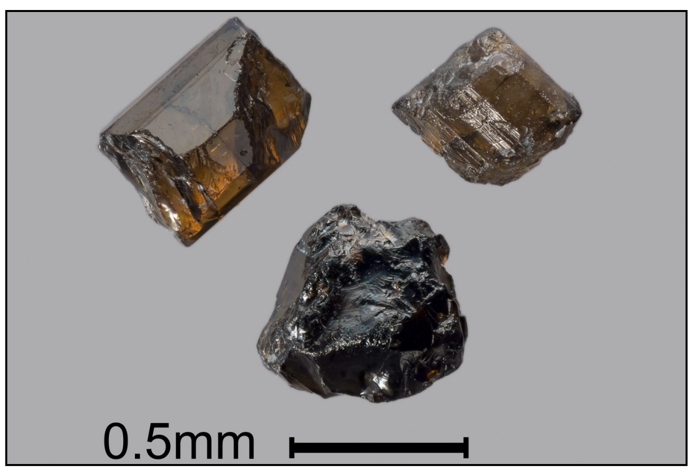

Figure 1. Brown tourmaline grains recovered from the mid-density fraction of till overlying mineralization at the Woodjam copper prospect, British Columbia.

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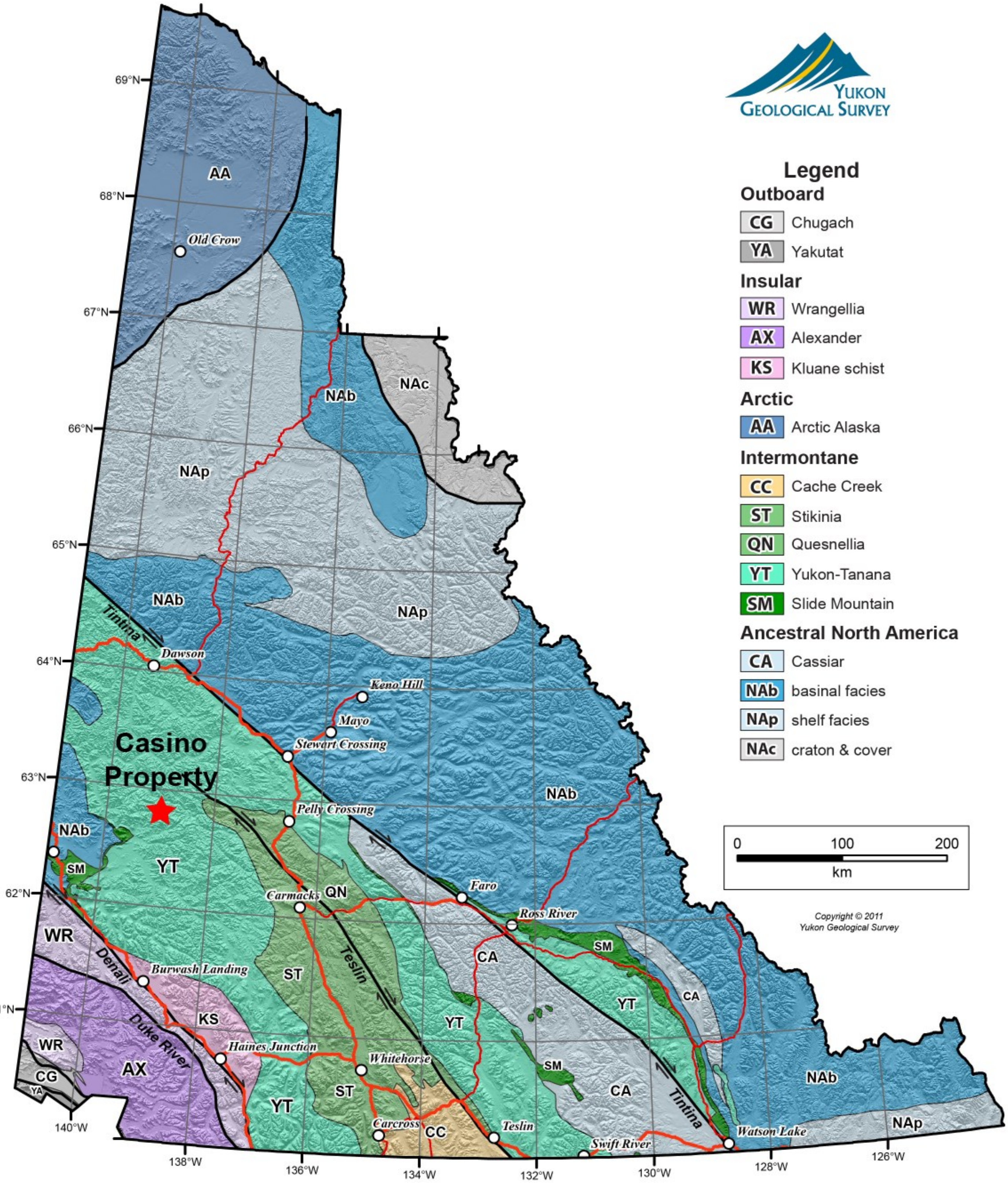

Figure 2. Terrane and geological map of Yukon showing the Casino property location. Modified after Colpron and Nelson (2011).

Woodjam tourmaline study

Mineral fractions of 91 archived till samples from a previous study of till indicator minerals down ice of the Woodjam copper-gold porphyry prospect, British Columbia (Plouffe et al., 2016) were re-examined. In particular, tourmaline (Fig. 1) was re-examined and recounted in both high (>3.2 SG) and mid-density (2.8–3.2 SG) fractions. The mineral chemistry and other features of tourmaline grains from four till samples up ice, overlying, and down ice of the deposit were initially examined by Chapman et al. (2015). Additional tourmaline grains from up ice, overlying, and at varying distances down ice of the deposit as well as newly acquired bedrock samples are currently being characterized, with special focus on understanding the differences in tourmaline recovered from the high- and mid-density mineral fractions.

Casino sampling

Bedrock and stream sediment samples were collected from the Casino copper-molybdenum-silver-gold porphyry deposit, 380 km northwest of Whitehorse, Yukon (Fig. 2). The deposit is a calc-alkalic porphyry and ore is hosted in quartz monzonite and associated breccias around the edge of the main intrusion (Casselman and Brown, 2017). Tourmaline occurs throughout the deposit in all rock types despite several different alteration types and styles (i.e. potassic, phyllic, propylitic and argillic). The Casino deposit was chosen for detailed study because of the abundance and widespread nature of tourmaline in the deposit, the availability of drill core from all parts of the deposit, and the relatively undisturbed nature of the deposit that was optimal for testing the effectiveness of tourmaline as an indicator mineral in surrounding stream sediments.

Thirty-eight bedrock samples were collected from drill core (Appendix 1). Surface bedrock sampling at the Casino deposit was not possible because of the thick cover of colluvium in this unglaciated terrain and the weathered bedrock masking hard competent bedrock. In addition to bedrock sampling, samples of stream sediment and water were collected at 22 sites (Fig. 3). At each site, two water samples, one stream silt sample, one bulk stream sediment sample for recovery of indicator minerals, and one pebble sample were collected following protocols described in Day et al. (2013).

Sand-size (<2 mm) bulk sample for indicator minerals

Samples were collected to determine the minerals that are indicative of porphyry copper mineralization. Material was

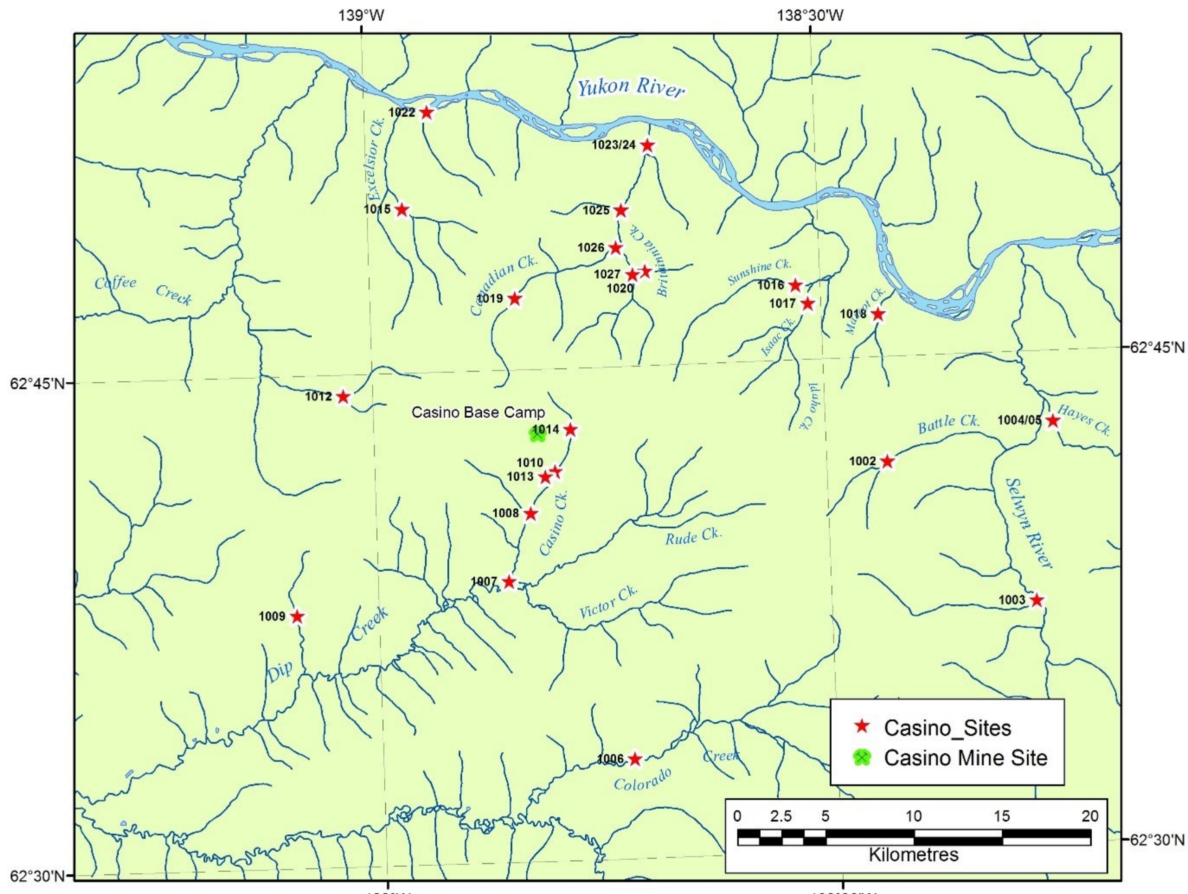

Figure 3. Location of stream sediment sample sites (red stars) around the Casino porphyry Cu deposit plotted on the digital topographic map for NTS 115J.

Table 1. Specifications for parameters measured in stream water samples collected around the Casino copper deposit.

	Range	Accuracy	Resolution	Units (Recorded)
Dissolved Oxygen (%)	0-500%	0 to 200% (±2% of reading or 2% air saturation, whichever is greater)	1% or 0.1% air saturation	%
Temperature	-5 to 70°C	±0.2°C	0.1°C	°C
Conductivity	0 to 200 mS/cm	±0.5% of reading or 0.001 mS/cm, whichever is greater	0 to 500 µS/cm=0.001; 501 to 5000 µS/cm=0.01	µS
pH	0 to 14 units	±0.2 units	0.01 units	pH units
Oxidation-Reduction Potential (ORP)	-1999 to +1999 mV	±20 mV in redox standards	0.1 mV	mV
Air Pressure	375 to 825 mmHg	±1.5 mmHg from 0 to 50°C	0.1 mmHg	kPa

collected from shovel holes dug at suitable sites (mid-channel bars, boulder or log traps, etc.) in the main channel of each stream (see Prior et al., 2009, for a full list of suitable sites). At each site, sediment was wet-sieved through a U.S. sieve series 12-mesh (1.68 mm) stainless steel sieve into a sample bag until a sample weight of 10-15 kg was collected. Bulk sediment samples for indicator minerals have been shipped to a commercial laboratory for heavy (>3.2 specific gravity) and moderate-density (2.8–3.2 specific gravity) fraction separation and identification of key indicator minerals (including tourmaline) of porphyry mineralization.

Stream sediments (silt)

At each site, a synthetic cloth bag was two-thirds filled with silt or fine sand collected from the active stream channel after collection of the water sample(s) and before the bulk sediment sample from various points in the active channel while moving upstream, over a distance of 5 to 15 m. If the stream channel consisted mainly of clay and coarse material or organic sediment was scarce or absent, trapped silt moss mats in the stream channel may have been collected. Field observations were digitally recorded on a tablet using a standard form developed jointly by the GSC and the Northwest Territories Geological Survey. Samples of stream silt collected around the Casino deposit are currently being dried at low temperatures (<40°C) at the GSC Sedimentology Laboratory, Ottawa. These samples will be sieved to recover the <177µm fraction and analyzed using modified aqua regia digestion /ICP-MS, instrumental neutron activation analysis, and portable XRF.

Stream waters

Stream water was collected at each site because it is a routine component of GSC stream sediment sampling protocols. At each site the six variables listed in Table 1 were measured in stream waters. Two water samples were collected in the mid-channel of streams at each site: i) a filtered, acidified sample ('FA'); and ii) a filtered, un-acidified sample ('FU') by drawing stream water into a 60 ml plastic syringe and filtering into each HDPE bottle through a 0.45 µm disposable filter unit. One set of filtered stream water samples will be acidified with 0.5 ml 8M HNO_3. Groundwater samples collected from drill holes during the same time period by Western Copper and Gold staff have been shared with GSC. Filtered and acidified (FA) stream water samples will be analyzed for trace metal and major elements at GSC laboratories in Ottawa. Conductivity, pH and alkalinity will be measured in the filtered, un-acidified set of waters.

Tourmaline types

Three different types of tourmaline were identified in bedrock samples at Casino, these being classified as breccia-style, vein-style and disseminated (Fig. 4). The breccia-style consists of a tourmaline-dominant breccia matrix with associated quartz. Tourmaline grains form euhedral acicular radiating masses appearing black in hand sample, but under closer inspection, grains actually range in colour from black-brown to a pale-green, some being colour-zoned along their length (from nucleation to termination). The tourmaline morphology is consistent with that observed in other deposits examined in this study (e.g. Schaft Creek and Woodjam). However, the occurrence of lighter-coloured tourmaline in the breccia style is a new observation. The vein-style tourmaline is very fine-grained and commonly develops along the margins of quartz – sulphide veins (generally pyrite), but can also be observed as tourmaline -dominant veins that exhibit a pinch and swell texture. Tourmaline vein textures at Casino are similar to those observed at the

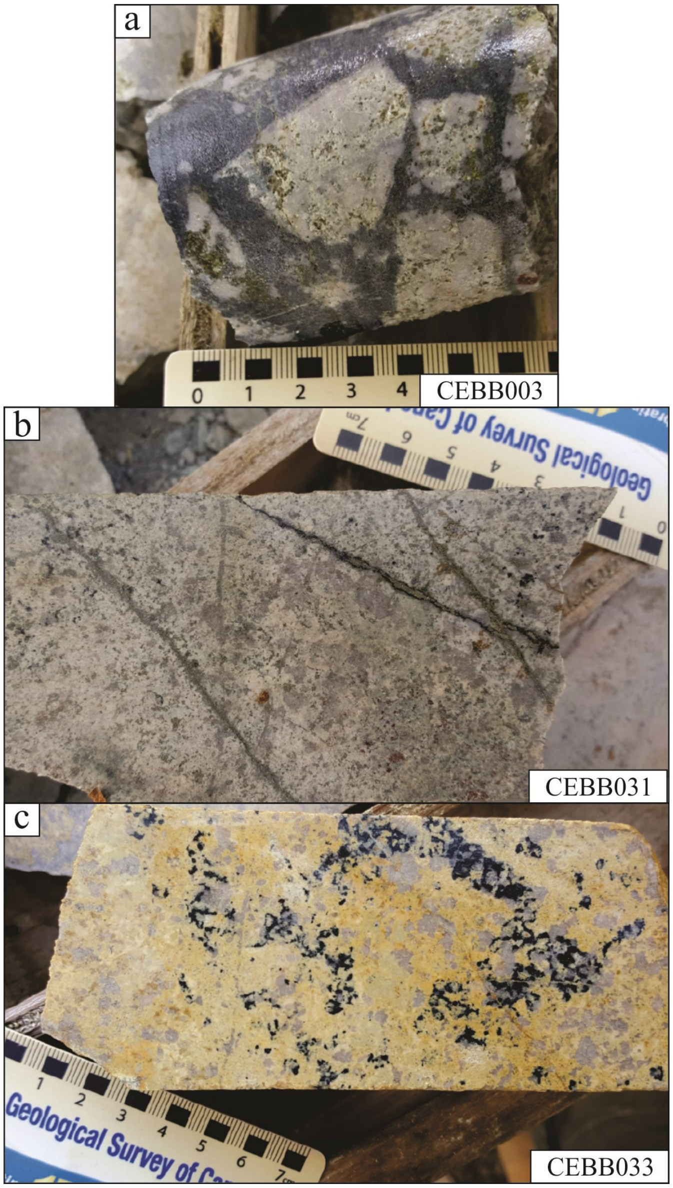

Figure 4. Casino deposit, Yukon, drill core samples: a) Hole 93-177 showing the breccia-style tourmaline (black matrix) surrounding mineralized fragments of Paton porphyry; b) Hole CAS-082 showing the vein-style tourmaline (black) forming along the rim of a pyrite vein; c) Hole CAS-084 showing the disseminated-style tourmaline (black).

other deposits in this study suggesting that they form from a similar process. Disseminated tourmaline is texturally similar to the breccia-style tourmaline (i.e. euhedral acicular radiating masses commonly infilled by quartz), but can also be observed overgrown by feldspars, sulphides, and clays and appears similar to that observed in other deposits in this study. A paragenetic analysis based on associated minerals and tourmaline textures indicates that tourmaline is one of the first hydrothermal minerals to form in the mineralized porphyry system. It is found in a barren breccia close to the core of the deposit that has been overprinted by minor pyrite that formed much later. It is also observed to have been overgrown by sulphides and does not appear to have been modified or impacted by the various subsequent alteration styles (i.e. potassic, phyllic, propylitic, and argillic).

Ongoing tourmaline analysis

Polished thin sections of bedrock samples from the GSC archives have been examined by transmitted and reflected light microscopy, providing preliminary documentation of important mineral textures and associations. Select samples were then investigated using a scanning electron microscope (SEM) to collect major and minor chemical data by energy dispersive spectroscopy. An important observation during SEM analyses was the identification of what may be interpreted as diffusion-like textures in tourmaline (Fig. 5). This finding is significant as chemical diffusion in tourmaline is considered to be virtually non-existent (van Hinsberg et al., 2011), and thus this observation challenges our current state of knowledge regarding the mineral. It will therefore be important to be able to determine if: a) the observed textures do conform to solid state diffusion; and b) if so, the extent to which chemical diffusion may occur in the mineral. Understanding the potential for significant diffusion will be important when analyzing and interpreting distinct growth zones of tourmaline.

Preliminary laser-ablation work on samples has been conducted to establish protocols (e.g. ablation conditions, beam size, isotope list, internal and external standards) that will produce the best results for tourmaline trace element analyses. Preparation and mounting of tourmaline grains in epoxy pucks is

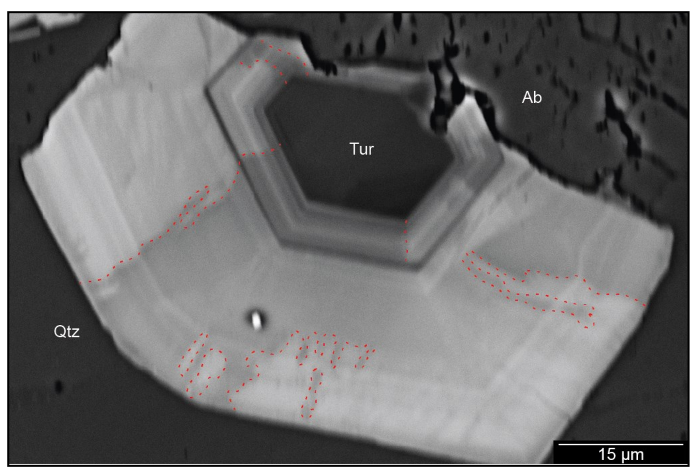

Figure 5. Backscattered electron image of a tourmaline (Tur) grain in quartz (Qtz) and albite (Ab) from a bedrock sample from the Highland Valley Cu deposit, British Columbia. Note the rhythmic oscillatory zonation which dominantly reflects changes in Fe:Mg:Al. Overprinting this zonation is what appears to be solid state diffusion, outlined by the dotted red lines for clarity.

ongoing for till samples collected at the Woodjam copper prospect as well as some other reference and background samples.

Future work includes the completion of trace-element analysis of tourmaline grains from the Schaft Creek and Woodjam copper deposits and other archived samples, the comparison of tourmaline chemical signatures to those recovered in till versus bedrock at Woodjam, investigation of Fe^{2+}/Fe^{3+} using Raman spectroscopy as a means of determining prevailing oxidation/reduction (fO_2) conditions, and the characterization of tourmaline in bedrock and stream sediments from the Casino deposit.

Acknowledgments

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References

Averill, S.A., 2001. The application of heavy indicator minerals in mineral exploration with emphasis on base metal indicators in glaciated metamorphic and plutonic terrain; *in* Drift Exploration in Glaciated Terrain, (ed.) M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall and S. Cook; Geological Society of London, Special Volume 185, p. 69–82.

Averill, S.A. and Zimmerman, J.R., 1986. The Riddle resolved: the discovery of the Partridge gold zone using sonic drilling in glacial overburden at Waddy Lake, Saskatchewan; Canadian Geology Journal of the Canadian Institute of Mining and Metallurgy, v. 1, p. 14–20.

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

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

Colpron, M. and Nelson, J.L., 2011. A Digital atlas of terranes for the northern Cordillera; <www.geology.gov.yk.ca> [accessed September 6, 2017]

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.

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

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

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

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

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

Prior, G.J., McCurdy, M.W., and Friske, P.W.B., 2009. Stream sediment sampling for kimberlite-indicator minerals in the Western Canada Sedimentary Basin: The Buffalo Head Hills survey, north-central Alberta; *in* Application of Till and Stream Sediment Heavy Mineral and Geochemical Methods to Mineral Exploration in Western and Northern Canada, (ed.) R.C. Paulen and I. McMartin; Geological Association of Canada Short Course Notes 18, p. 91–103.

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

Appendix 1. Casino copper deposit samples

Sample No.	Hole No.	Depth from (m)	Hole Collar Location (X,Y,Z), Azimuth, Dip	Brief Rock Description	Tourmaline Type	Tourmaline Description
CEBB001	93-147	29.00	610875.040, 6958325.680, 1370.700, 0.0, -90	Altered cap rock. Strong limonite alteration with other Fe-oxides.	Disseminated?	Fine-grained black grains that are not Fe-oxides. Too fine grained to definitively tell.
CEBB002	93-150	5.70	610963.040, 6958409.920, 1361.580, 0.0, -90	Milled breccia, with strong argillic and minor potassic alteration.	Vein, Disseminated	Tur found as clots and discontinuous veins. Tur forms as euhedral radial balls forming in association with quartz. Tur grains appear black in hand sample but are brownish up close.
CEBB003	93-177	189.00	610363.930, 6958203.960, 1331.580, 0.0, -90	Dawson range monolithic breccia with a Tur dominant matrix with phyllic alteration. Disseminated pyrite is observed both in the matrix and in the clasts and is likely later than the brecciation.	Breccia	Tur is forming the dominant phase in the breccia matrix. Tur forming as euhedral radial masses in the matrix, with significant quartz as the matrix colour is quite greyish.
CEBB004	93-177	191.82	610363.930, 6958203.960, 1331.580, 0.0, -90	Dawson range monolithic breccia with Tur dominant matrix with phyllic alteration. Disseminated pyrite is observed both in the matrix and in the clasts.	Breccia	Tur is forming the dominant phase in the breccia matrix as euhedral acicular radial masses. Some individual Tur grains observed are almost colourless.
CEBB005	93-177	200.33	610363.930, 6958203.960, 1331.580, 0.0, -90	Dawson range monolithic breccia with a Tur dominant matrix with phyllic alteration. Disseminated pyrite is observed both in the matrix and in the clasts.	Breccia	Tur is forming the dominant phase in the breccia matrix as radial masses. Some individual Tur grains are observed exhibiting an acicular habit which are almost colourless.
CEBB006	93-177	209.40	610363.930, 6958203.960, 1331.580, 0.0, -90	Dawson range monolithic breccia with Tur dominant matrix. Phyllic and argillic alteration. Disseminated pyrite is observed both in the matrix and in the clasts and is likely later than the brecciation.	Breccia	Tur is forming the dominant phase in the breccia matrix. Tur forming as radial masses in the matrix, with significant quartz as the matrix colour is quite greyish. Some individual almost colourless Tur grains are observed exhibiting an acicular habit. Breccia matrix appears greyish black but Tur grains themselves are quite light in colour.
CEBB007	93-177	217.81	610363.930, 6958203.960, 1331.580, 0.0, -90	Latite breccia. Breccia matrix is no longer dominated by Tur but appears to be a combination of milled material and minor disseminated Tur. Minor argillic and phyllic alteration.	Breccia	Tur is similar in textural style here forming as euhedral radial masses, but is less dominant in its abundance. Other disseminated grains of Tur are zoned with darker termination and lighter nucleation points.
CEBB008	93-177	218.95	610363.930, 6958203.960,1 331.580, 0.0, -90	Referred to as a "latite breccia". Dominated by a milled breccia matrix with roughly 5% breccia fragments. Minor kaolinite. Minor disseminated pyrite. Breccia fragments are strongly altered by Tur and pyrite.	Breccia	Tur forming as radial masses in the apparent breccia fragments. Colour at a distance appears black, but is actually quite light to even colourless at the nucleation point becoming black towards the termination.
CEBB009	93-177	225.84	610363.930, 6958203.960, 1331.580, 0.0, -90	Latite breccia dominated by a milled matrix with no more than 5% breccia fragments. Quartz-sericite-pyrite alteration with minor muscovite and kaolinite. Breccia fragments appear to be Paton porphyry.	Breccia, Disseminated	Tur forming as radial masses in the apparent breccia fragments. Colour at a distance appears black but is quite light to even colourless at the nucleation point becoming black towards the termination. Tur appears to be both within the breccia matrix as well as within the clasts.
CEBB010	93-177	226.69	610363.930, 6958203.960, 1331.580, 0.0, -90	Latite breccia dominated by a milled matrix with no more than 5% breccia fragments. Quartz-sericite-pyrite alteration with minor muscovite and kaolinite. Breccia fragments are apparently absent in this section.	Disseminated	Tur is forming as euhedral radial masses generally nucleating from another phase, either quartz or possibly pyrite. Tur appears black but is much more translucent under close observation.
CEBB011	93-177	155.63	610363.930, 6958203.960, 1331.580, 0.0, -90	Latite breccia dominated by a milled matrix. Breccia fragments contain Tur likely from earlier brecciation. Pyrite is dispersed throughout the sample. Alteration is dominated by quartz-sericite-pyrite and minor kaolinite.	Breccia	Tur again forming as euhedral radial masses. Colour appears black but is light to even colourless at the nucleation point and becomes black towards the terminus. Tur appears to be both within the breccia matrix as well as within the clasts.
CEBB012	CAS-035	153.92	609624.792, 6958755.792, 1222.899, 244, -70	Medium grained Dawson range batholith. Minor sericite, pyrite alteration not much quartz. Some late gypsum veins cross cutting the sample. Tur and chlorite forming in association.	Vein	Tur is forming in close association with chlorite and pyrite as irregular veins. Tur morphology is still in the form of radial aggregates of euhedral acicular Tur. Grains are strongly coloured appearing quite dark. Tur appears to overprint biotite in some places.
CEBB013	CAS-037	148.14	610561.858, 6958402.456, 1289.922, 0.0, -90	Paton Porphyry. Silica rich phyllic alteration with pitted plag phenos. Some kaolinite alteration and strong pyrite alteration. Some minor hematite alteration.	Disseminated	Tur forming as radial masses as euhedral grains. No apparent associations, observed within kaolinite, pyrite and with quartz and feldspar. Tur is quite a dominant phase despite it being disseminated in nature.
CEBB014	CAS-037	189.27	610561.858, 6958402.456, 1289.922, 0.0, -90	Paton Porphyry. Silica rich phyllic alteration with bleached yellow feldspar crystals. Some kaolinite alteration with strong pyrite alteration and minor hematite alteration. Minor chalcopyrite, covellite and bornite	Vein, Disseminated	Tur forming as radial masses of euhedral black grains. Found as blow out veins as well as disseminations. Disseminated grains seem to be in association with quartz.
CEBB015	CAS-040	87.20	610463.806, 6958398.500, 1282.253, 270, -45	Dawson Range Batholith. Texturally destructive phyllic alteration with some kaolinite alteration and significant Fe-oxide alteration.	Breccia?	Tur difficult to see due to pervasive Fe oxide alteration. Appears to be a breccia or infilling the matrix around the porphyritic feldspars.
CEBB016a	CAS-030	133.00	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry. Pervasive argillic alteration in the form of kaolinite and some minor sericite. Some quartz-rich regions are still evident.	Disseminated	Tur is forming in dark regions of the sample. Forming as euhedral radial masses as brown black grains almost acicular in nature. Appears to be an association with quartz

Appendix 1. Casino copper deposit samples (cont.)

Sample No.	Hole No.	Depth from (m)	Hole Collar Location (X,Y,Z), Azimuth, Dip	Brief Rock Description	Tourmaline Type	Tourmaline Description
CEBB016b	CAS-030	140.96	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry. Pervasive argillic alteration (kaolinite) with some minor sericite. Some indications this sample is a breccia, but the alteration is so intense it is difficult to tell.	Breccia?	Tur is forming within the dark regions in what appears to be the breccia matrix. Under close observation the Tur grains are quite light, almost a pale green-grey colour. Forming radial masses.
CEBB017	CAS-030	160.84	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry. Intense phyllic alteration overprinted by argillic alteration.	Disseminated	Tur is forming as disseminated clots in the darker zones with chlorite. Tur is forming as radial acicular masses of euhedral grains. Seem to have grown in open space, minor quartz filling the interstitial space.
CEBB018	CAS-030	174.75	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry. Intense phyllic alteration overprinted by argillic alteration. Some disseminated pyrite throughout the sample.	Disseminated	Tur is forming differently here, much darker than previous samples it seems. The radial masses of grains are much more solitary than being in clots. It is also accompanied by epidote.
CEBB019	CAS-030	185.05	610165.755, 6958302.961, 1294.661, 90, -45	Dawson range. Moderate argillic alteration. Sample seems to be dominated by a small quartz pyrite vein with a large alteration halo. Rimming the halo almost a cm away are some clots of Tur.	Disseminated	Tur is a similar colour here. Dark brown to black in colour. The Tur is still present as euhedral radial masses along the edge of a vein alteration halo in association with? epidote.
CEBB020	CAS-030	204.58	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry with moderate argillic alteration (kaolinite) with some phyllic alteration. Quartz remains, but some increased barren sinuous quartz veins are observed.	Disseminated	Tur is forming as euhedral disseminated acicular radial masses. Grains are darker in colour than seen in the potentially breccia material. Grains appear to be infilling what was open space, which is now filled by kaolinite.
CEBB021	CAS-030	217.57	610165.755, 6958302.961, 1294.661, 90, -45	Paton porphyry with large regions of sulfides.	Not Tur	What was first thought to be Tur is likely chalcocite along the edge of pyrite veins.
CEBB022	CAS-062	76.77	609861.924, 9658599.958, 1239.461, 181, -59	Granodiorite. Intense phyllic alteration with some vuggy quartz. Disseminated pyrite and minor molybdenite. Two periods of brecciation. First was cemented by tourmaline the second is dominated by quartz.	Disseminated	Tur is forming as disseminated euhedral acicular radial masses and clots. Grains are dark-black to brown in colour with some lighter grains. Generally enveloped by kaolinite and sometimes quartz. Some epidote and chlorite appear in association.
CEBB023	CAS-070	80.77	610169.786, 6958300.703, 1301.965, 180, -60	Paton porphyry. Intense silica flooding in the form of quartz veins.	Vein?	Could be some Tur within the quartz-molybdenite veins but is too fine-grained to determine.
CEBB024	CAS-070	92.04	610169.786, 6958300.703, 1301.965, 180, -60	Paton porphyry. Lots of quartz veining with molybdenite.	Vein?	Lots of magnetite. Could be some Tur within the quartz-molybdenite veins but is too fine-grained to determine.
CEBB025	CAS-070	107.92	610169.786, 6958300.703, 1301.965, 180, -60	Paton porphyry. Lots of quartz veining with molybdenite.	Vein?	Lots of magnetite and epidote. Could be some Tur within the quartz-molybdenite veins but is too fine-grained to determine.
CEBB026	CAS-082	20.27	610562.693, 6958097.496, 1384.832, 0.0, -90	Granodiorite. Intense argillic alteration, textures are almost destroyed. Relict feldspars are bleached yellow. Lots of disseminated magnetite.	Disseminated	Tur forms eudral disseminated acicular radial masses. Grains are dark in colour with some masses have quartz cores.
CEBB027	CAS-082	34.18	610562.693, 6958097.496, 1384.832, 0.0, -90	Granodiorite. Intense argillic alteration, destroying most of the textures. Yellow bleaching of relict feldspars is present, with lots of silica flooding in the form of quartz veins.	Disseminated	Tur is forming as euhedral disseminated acicular radial masses. Grains are dark in colour with many of the grains in samples seemingly intergrown with quartz.
CEBB028	CAS-082	64.97	610562.693, 6958097.496, 1384.832, 0.0, -90	Granodiorite. Significant magnetite and hematite. Some phyllic alteration. Tourmaline-quartz-pyrite veins are observed throughout the sample.	Disseminated	Tur forming as euhedral acicular radial masses. Appearing as a black colour and very fine-grained. Tur is found in association with quartz and pyrite in veins.
CEBB029	CAS-082	140.33	610562.693, 6958097.496, 1384.832, 0.0, -90	Si flooded granodiorite. Phyllic alteration with quartz-pyrite veins.	Not Tur	After close observation it was determined to be fine-grained biotite not Tur.
CEBB030	CAS-082	170.66	610562.693, 6958097.496, 1384.832, 0.0, -90	Granodiorite. Increasing phyllic alteration with some intense Si flooding. Intense quartz-pyrite veins present with some possible chalcocite. Molybdenite is also present.	Disseminated	Tur is forming as acicular radial masses as very fine grained euhedral veins in association with quartz and pyrite.
CEBB031	CAS-082	177.13	610562.693, 6958097.496, 1384.832, 0.0, -90	Granodiorite. Less Si flooding and more intense phyllic alteration. Minor pyrite-quartz +/- tourmaline veins.	Vein, Disseminated	Tur is forming as both disseminations and within sulphide veins. Appearing as extremely fine-grained within veins. Tur grains within the veins appear darker in colour.
CEBB032	CAS-084	6.64	610660.692, 6958099.915, 1383.54, 0.0, -90	Granodiorite. Strong phyllic alteration with some argillic alteration likely the result of the proximity to surface. Lots of a black non-magnetic sulphide, tennantite-tetrahedrite? There is also some minor disseminated pyrite.	Disseminated	Tur is forming as acicular radial masses as brown-black euhedral grains. These masses are in close association and commonly overgrown by quartz.
CEBB033	CAS-084	21.02	610660.692, 6958099.915, 1383.54, 0.0, -90	Granodiorite. Part of the cap rock assemblage. Strong phyllic alteration with some overprinting argillic alteration. Apparent quartz tourmaline clots in this sample.	Disseminated	Tur is forming as acicular radial clots with quartz almost appearing as an intergrowth? Tur appears as black grains, but under close inspection they are almost transparent and light in colour.

Appendix 1. Casino copper deposit samples (cont.)

Sample No.	Hole No.	Depth from (m)	Hole Collar Location (X,Y,Z), Azimuth, Dip	Brief Rock Description	Tourmaline Type	Tourmaline Description
CEBB034	93-177	143.43	610363.930, 6958203.960, 1331.580, 0.0, -90	Sample consists of a milled breccia with phyllic alteration. Clasts appear to be granodioritic in composition. Some minor argillic alteration which seems to be concentrated within the clasts.	Disseminated	Tur forms acicular radial masses. Tur appears as black grains, but under close inspection they are almost transparent and light in colour.
CEBB035	94-270	100.25	610999.390, 6958549.090, 1351.080, 0.0, -90	Sample is a milled breccia of the granodiorite. Sample exhibits phyllic and minor argillic alteration. Matrix exhibits more alteration than the clasts.	Breccia	Tur is forming within the breccia clasts. Tur is forming as acicular radial clots. Grains are a grey-black in colour.
CEBB036	94-270	70.82	610999.390, 6958549.090, 1351.080, 0.0, -90	Sample is a milled breccia matrix with no visible clasts. Sample contains disseminated pyrite, and tourmaline. Matrix shows phyllic alteration overprinted by argillic alteration.	Disseminated	Tur forms radial masses. Grains are commonly found enveloped by quartz.
CEBB037	94-268	153.57	611141.100, 6958682.620, 1239.840, 315, -47.5	Fine grained granodiorite with minor phyllic alteration. Disseminated pyrite is evident throughout the sample.	Disseminated	Tur is forming as black radial masses comprised of acicular euhedral grains.