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DISCOVERING A PORPHYRY DEPOSIT USING TOURMALINE: A CASE STUDY FROM YUKON

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Introduction

As the exploration for porphyry systems becomes more challenging, there exists a need for exploration methods that can detect deposits under cover. This study investigates the physical and chemical characteristics of tourmaline in stream sediment samples around the Casino calc-alkaline porphyry Cu-Au-Mo deposit in the unglaciated terrain of west-central Yukon, Canada. Tourmaline is known to occur in porphyry deposits worldwide (Fig. 1) but its application as an indicator mineral has not yet been utilized.

The Casino deposit, owned by Western Copper and Gold, is one of the largest undeveloped porphyry Cu-Au-Mo deposits in Canada. The deposit is hosted in Late Cretaceous quartz monzonite and associated breccias and is known to contain dispersed tourmaline throughout the deposit. Bulk (10-14 kg) coarse-grained stream sediment samples were collected in creeks around the deposit, nearby by porphyry Cu occurrences, and background areas (Fig. 2).

Tourmaline was recovered in the <2 mm heavy (>3.2 specific gravity (SG)) and mid-density (2.8–3.2 SG) fractions of stream sediments in the study area (Fig. 2). The Casino deposit has a tourmaline anomaly downstream of the deposit, but also in some surrounding streams that do not contain known porphyry mineralization. Tourmaline anomalies in stream sediments can not be used on their own to identify prospective drainages for porphyry mineralization because other rocks may contain tourmaline. Additional characteristics of the tourmaline grains need to be investigated to identify prospective porphyry grains. The purpose of this study is to provide practical tools which can be applied during routine exploration for porphyry deposits in both glaciated and unglaciated terranes.

Porphyry Tourmaline Worldwide

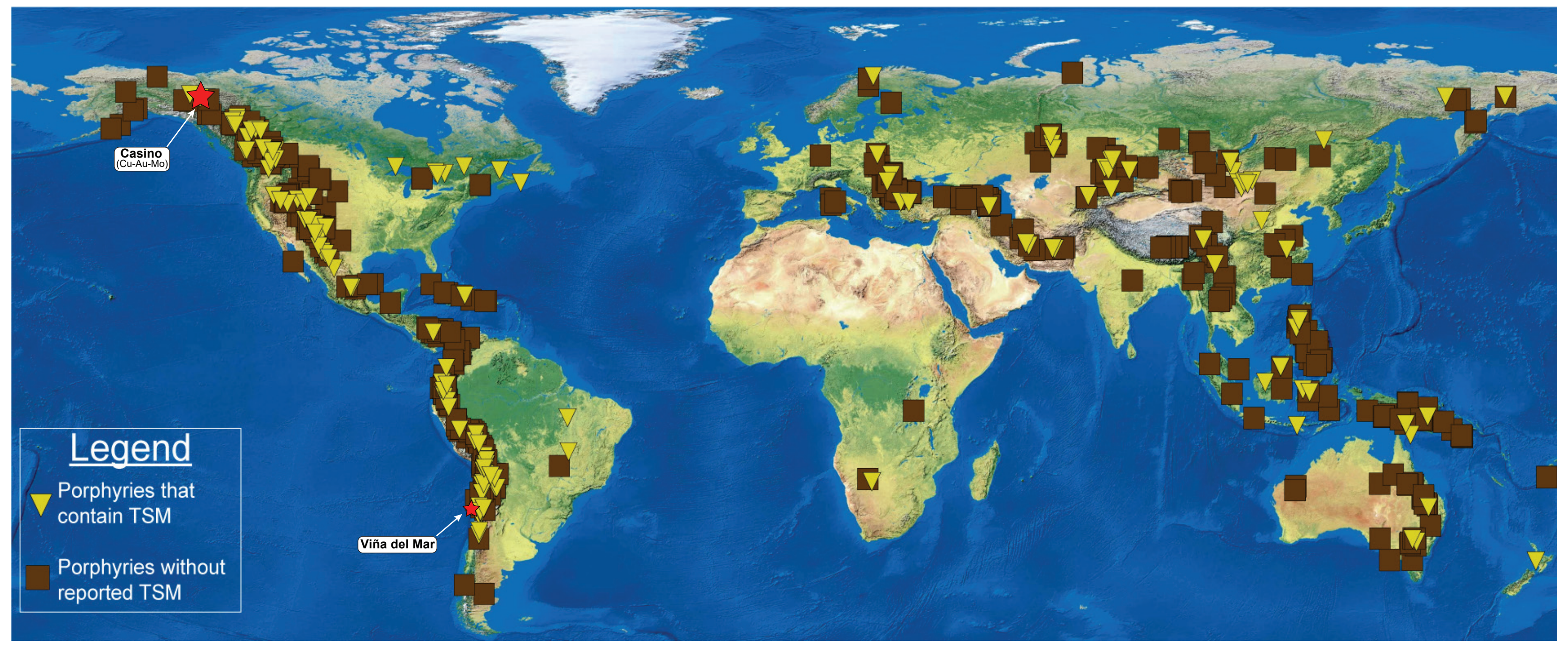

Figure 1: World map overlain by the world porphyry database (USGS porphyry database; Singer et al. 2008). Yellow symbols represent porphyry systems that are reported to contain tourmaline and brown squares represent deposits that do not contain tourmaline. Note how the occurrences of tourmaline correspond to the major porphyry belts and some of the most well-endowed, mineralized porphyries worldwide.

The Casino Deposit

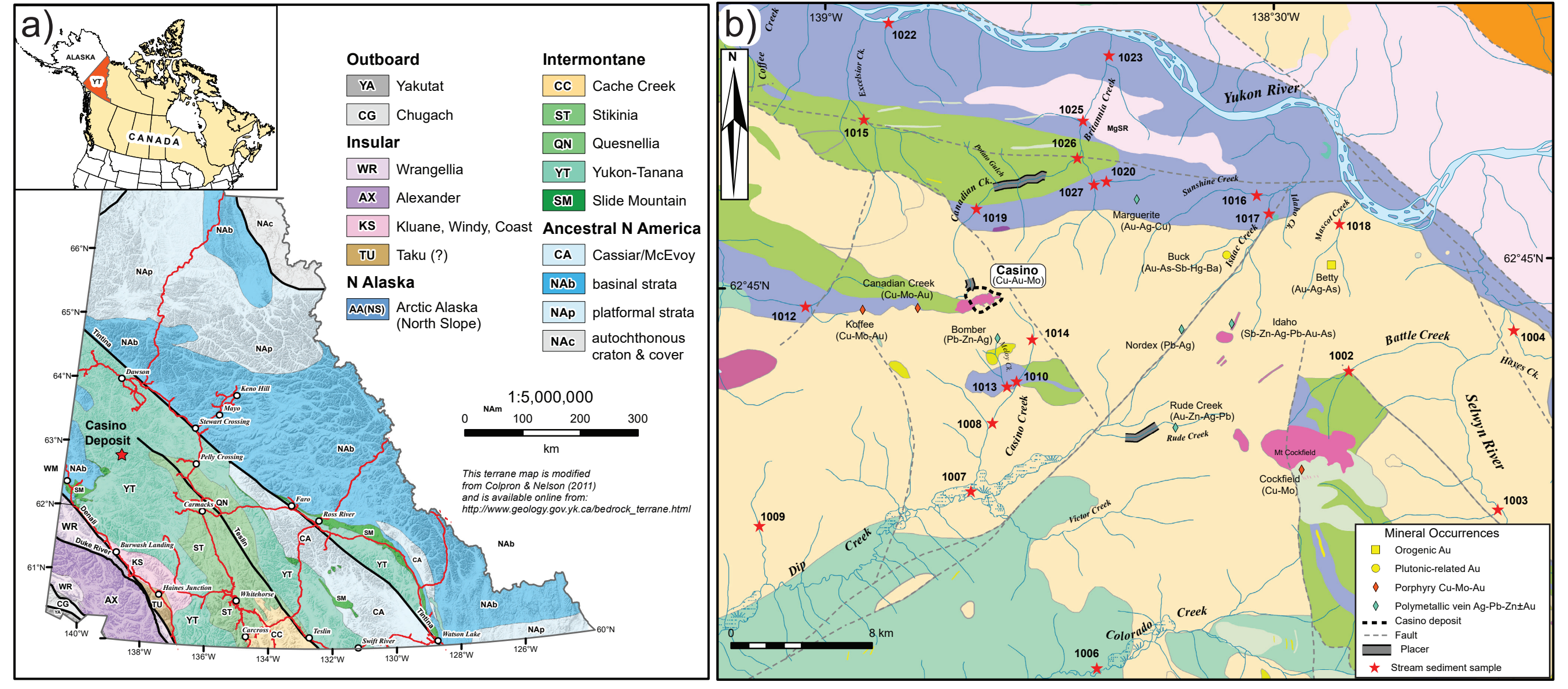

Figure 2: a) Map of the Yukon Territory, Canada showing the location of the Casino deposit. b) Map of the Casino deposit area showing the local bedrock geology (Yukon Geological Survey, 2015), location of mineral occurrences (Yukon Geological Survey MDI), and stream sediment samples (red stars). Sample numbers are listed in black beside each sample site. Bedrock legend presented below (left).

Bedrock Geology

PALEOCENE TO LOWER EOCENE
- RHYOLITE CREEK: rhyolite and dacite
- RHYOLITE CREEK: andesite

LATE CRETACEOUS
- PROSPECTOR MOUNTAIN SUITE: syenite
- CASINO SUITE: quartz-feldspar porphyry

MID-CRETACEOUS
- WHITEHORSE SUITE: granodiorite, diorite
- WHITEHORSE SUITE: quartz monzonite, granite, leucogranite
- MOUNT NANSEN: andesite to dacite flows

UPPER CRETACEOUS
- CARMACKS: augite-olivine basalt and breccia
- CARMACKS: andesite, porphyry
- CARMACKS: sandstone, pebble conglomerate, shale, tuff, coal

LATE TRIASSIC TO EARLY JURASSIC
- MINTO SUITE: granodiorite, gneissic schlieren

LATE TRIASSIC
- STIKINE SUITE: gabbroic Hbl orthogneiss

MIDDLE TO LATE PERMIAN
- SULPHUR CREEK SUITE: granite, metaporphyry
- KLONDIKE SCHIST: qtz-ms-chl schist

MISSISSIPPIAN
- SIMPSON RANGE SUITE: metagranodiorite, metadiorite, metatonalite

DEVONIAN, MISSISSIPPIAN, AND(?) OLDER
- FINLAYSON: intermediate to mafic volcanic and volcaniclastic rocks
- FINLAYSON: carbonaceous metasedimentary rocks, metachert
- FINLAYSON: ultramafic rocks, serpentinite; metagabbro

LATE DEVONIAN TO MISSISSIPPIAN
- MT BAKER SUITE: gneissic granodiorite, diorite, monzogranite, gabbro, minor pyroxenite

ORDOVICIAN TO LOWER DEVONIAN
- SCOTTIE CREEK: quartzite, Qtz-Ms-Bt±Grt schist

NEOPROTEROZOIC AND PALEOZOIC
- SNOWCAP: quartzite, psammite, pelite, marble; minor greenstone and amphibolite
- SNOWCAP: marble

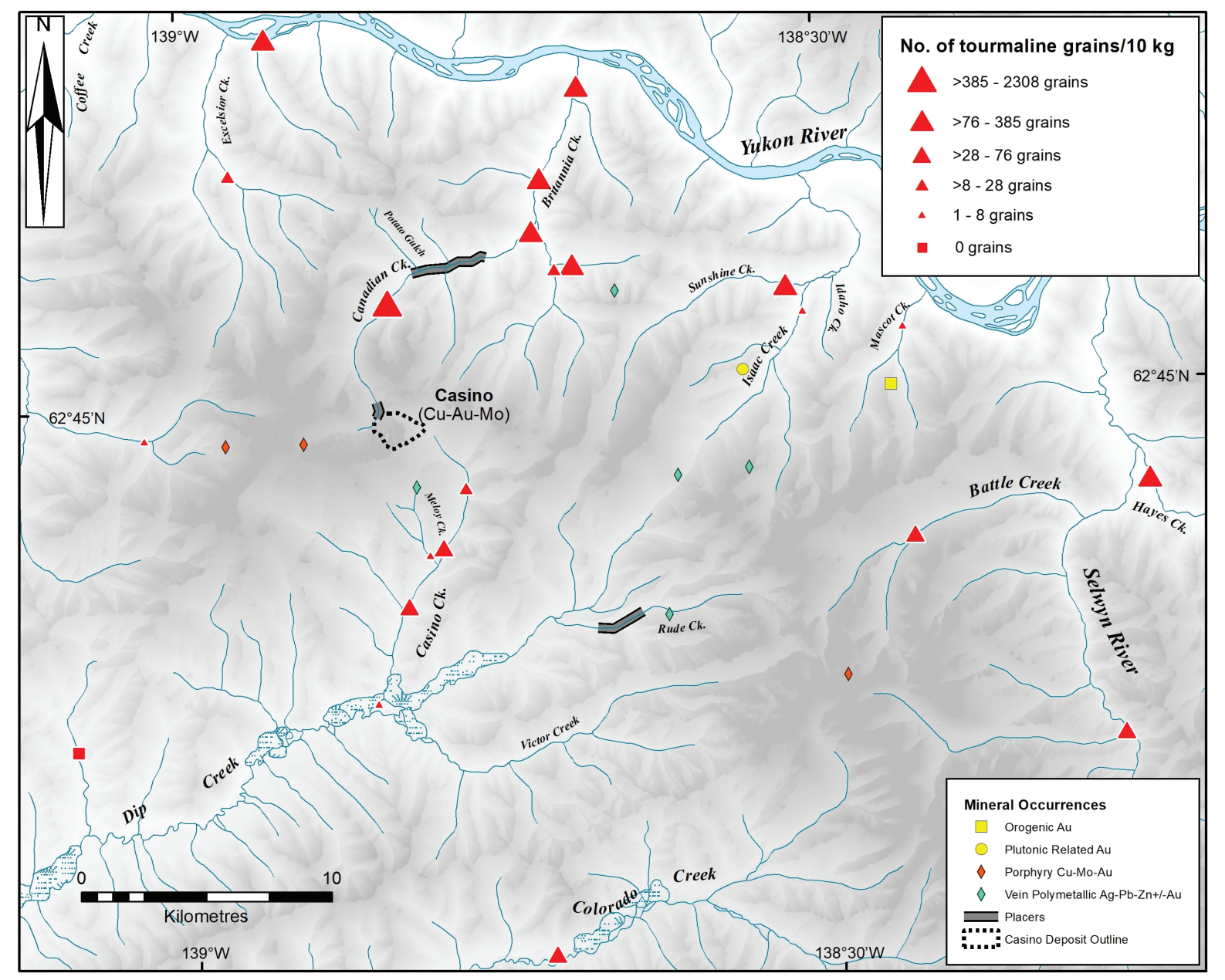

Figure 3: Tourmaline abundance in the 0.25 to 0.5 mm mid density (>2.8-3.2 SG) fraction of 17 bulk stream sediment samples collected in 2017 (Figure from McClenaghan *et al.* 2023).

Tourmaline Morphology

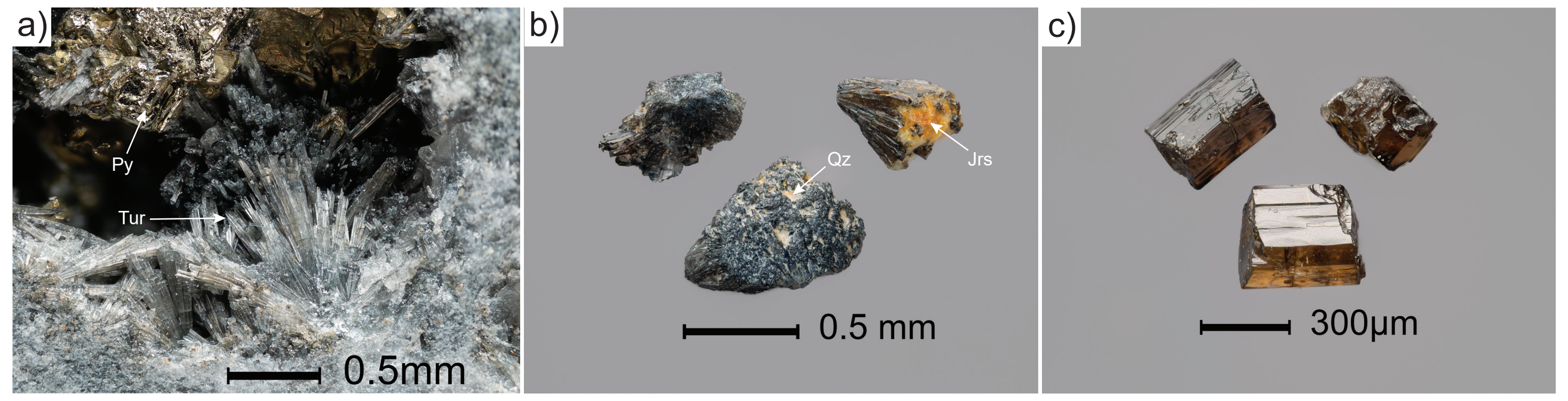

Figure 4: Photomicrographs by Michael Bainbridge of tourmaline from the Casino deposit. a) image of hypogene tourmaline from drill core (93-177) at the Casino deposit showing the typical texture of tourmaline (Tur) grains with accessory pyrite (Py). b) clusters of tourmaline crystals from stream sediment sample 1023 that are typical of tourmaline source from a porphyry deposit. Note the variable color of the grains from blue to brown as well as the attached minerals (jarosite-Jrs, quartz-Qz). c) individual tourmaline grains from sample 1023 that are typical grains sourced from background rocks.

Tourmaline morphology is a significant indicator of grains derived from porphyry systems (Beckett-Brown *et al.* 2023a, 2023b). These clustered crystals (Fig. 4a, b), also described as radiating aggregates of prismatic grains, reflect conditions of formation. This morphology reflects rapid crystallization as a result of pressure release during porphyry formation. Tourmaline in other environments forms more commonly as individual isolated grains that commonly contain inclusions of other minerals (Fig. 4c).

Trace Element Discrimination

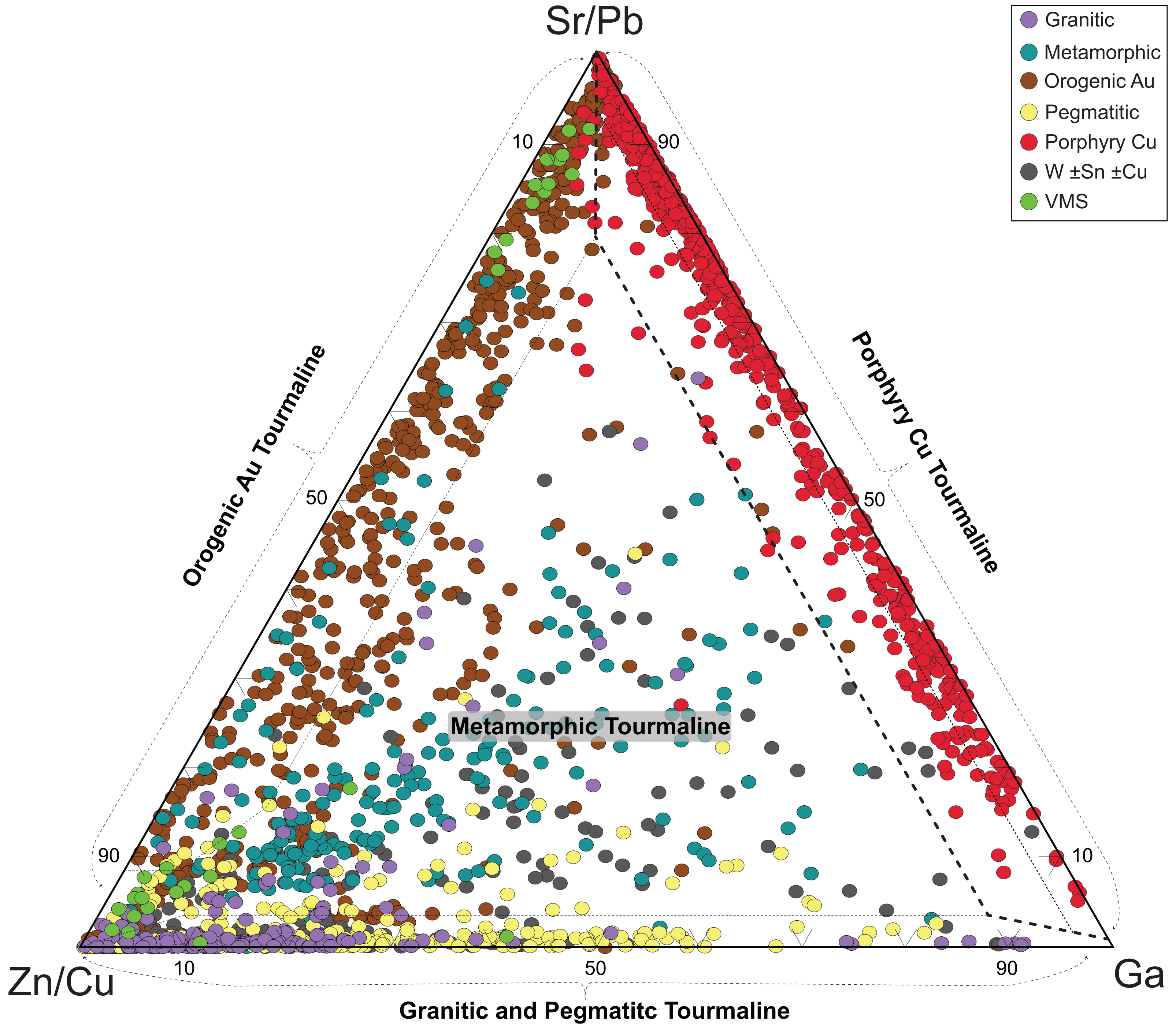

Figure 5: Tourmaline trace-element classification diagram. Dashed lines represent the typical field where tourmaline analyses from the respective environments listed plot. The porphyry Cu tourmaline field (thick dashed lines) represents a 99th percentile region of porphyry tourmaline analyses drawn in a straight line. This line coincides with the 10% marker on the ternary. The additional dashed line in the porphyry field represents the 95th percentile of the data at the 3% interval on the ternary scale. Grains plotting in this field should be considered most prospective, with samples plotting in the 99th percentile less so. Overlap between metamorphic (blue dots) and orogenic samples (brown dots) and potentially a reflect misidentification of environment of formation. Published data used for comparison are referenced in Beckett-Brown *et al.* 2023b. Porphyry Cu samples represent data from 7 deposits, granitic samples are from 9 different localities, metamorphic samples are from 6 different localities, orogenic Au samples are from 25 different localities, pegmatitic samples are from 9 different localities, W ±Sn ±Cu samples are from 8 different localities, VMS samples are from 3 different localities.

A ternary plot of Sr/Pb–Zn/Cu–Ga reveals that tourmaline associated with mineralized porphyry systems have trace element compositions that predominantly occur along the Sr/Pb-Ga join that reflect the chemistry of porphyry fluids (Beckett-Brown *et al.* 2023b). Porphyry tourmaline contain high Sr/Pb (*avg:* 297), variable Ga (*avg:* 58 ppm), and low Zn/Cu (*avg:* 4.8) values (Fig. 5). Conversely, the tourmaline associated with orogenic Au deposits clusters along the Sr/Pb-Zn/Cu join, and those having a granitic or granitic pegmatite affiliation plot along the Zn/Cu-Ga join (Fig. 5).

Tourmaline can exhibit high degrees of chemical variability that exists at the grain-scale for individual crystals but the application of trace-element ratios allows for any chemical zone to be analyzed and their distinct porphyry signature (*i.e.,* high Sr/Pb, low Zn/Cu and variable Ga) is still retained (Fig. 5). However, some porphyry-related tourmaline plot outside the porphyry tourmaline field (to the left of the Sr/Pb – Ga join) due to relative enrichments in Zn. These tourmaline samples are from a late-stage dike within the porphyry and may explain the Zn enrichment, similar to the zonation of Zn seen in porphyry systems. Based on this assumption, samples of tourmaline with high Zn could potentially be considered less prospective (*i.e.,* typically have concomitant decreases in Cu) because they occur distal to the porphyry center or are entirely unrelated to the mineralizing process.

Vectoring with Tourmaline

Tourmaline morphology and trace-element character are the most distinctive features allowing for identification of tourmaline grains sourced from porphyry deposits in the surficial environment. Figure 6 (below) highlights the potential of tourmaline morphology as a first pass exploration tool for porphyry deposits. Tourmaline trace-elements also provide a valuable tool for the identification of grains derived from porphyry deposits. Alone, these two characteristics have their strengths and weaknesses, but together provide an exciting new tool for the exploration of porphyry systems under cover in regions of both glaciated and unglaciated terrains.

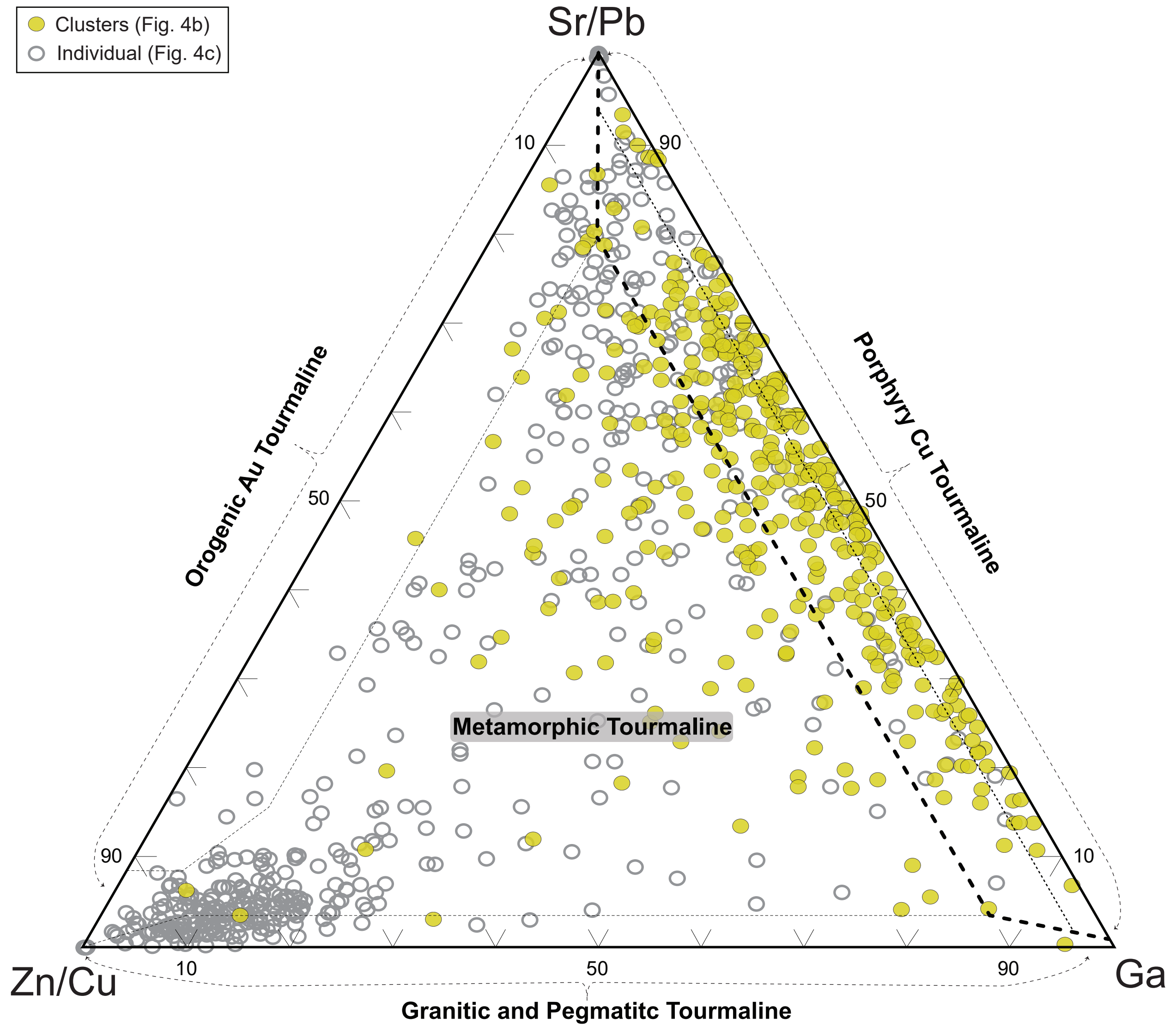

Figure 6: Casino stream sediment tourmaline analysis (1 analysis per grain) are plotted on trace-element classification diagram from Beckett-Brown *et al.* 2023b. Tourmaline grains are attributed based on their morphology, grey circles are individual tourmaline grains (*e.g.,* Fig. 4c) and yellow circles are clustered tourmaline crystals (*e.g.,* Fig. 4b). Spatial distribution of samples are shown on figure 7 below.

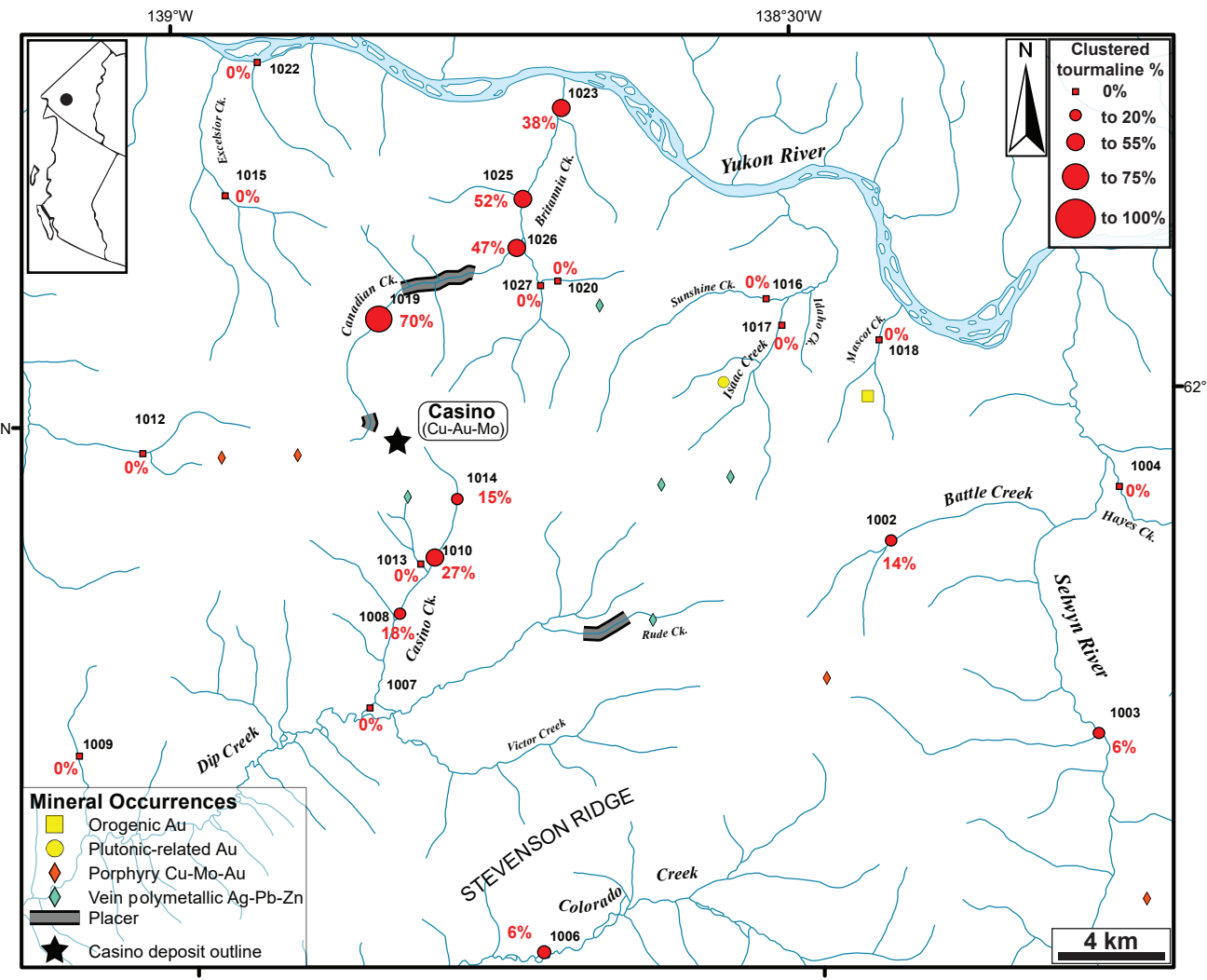

Figure 7: Percentage of tourmaline grains in a stream sediment sample that are clustered crystals (Fig. 4b).

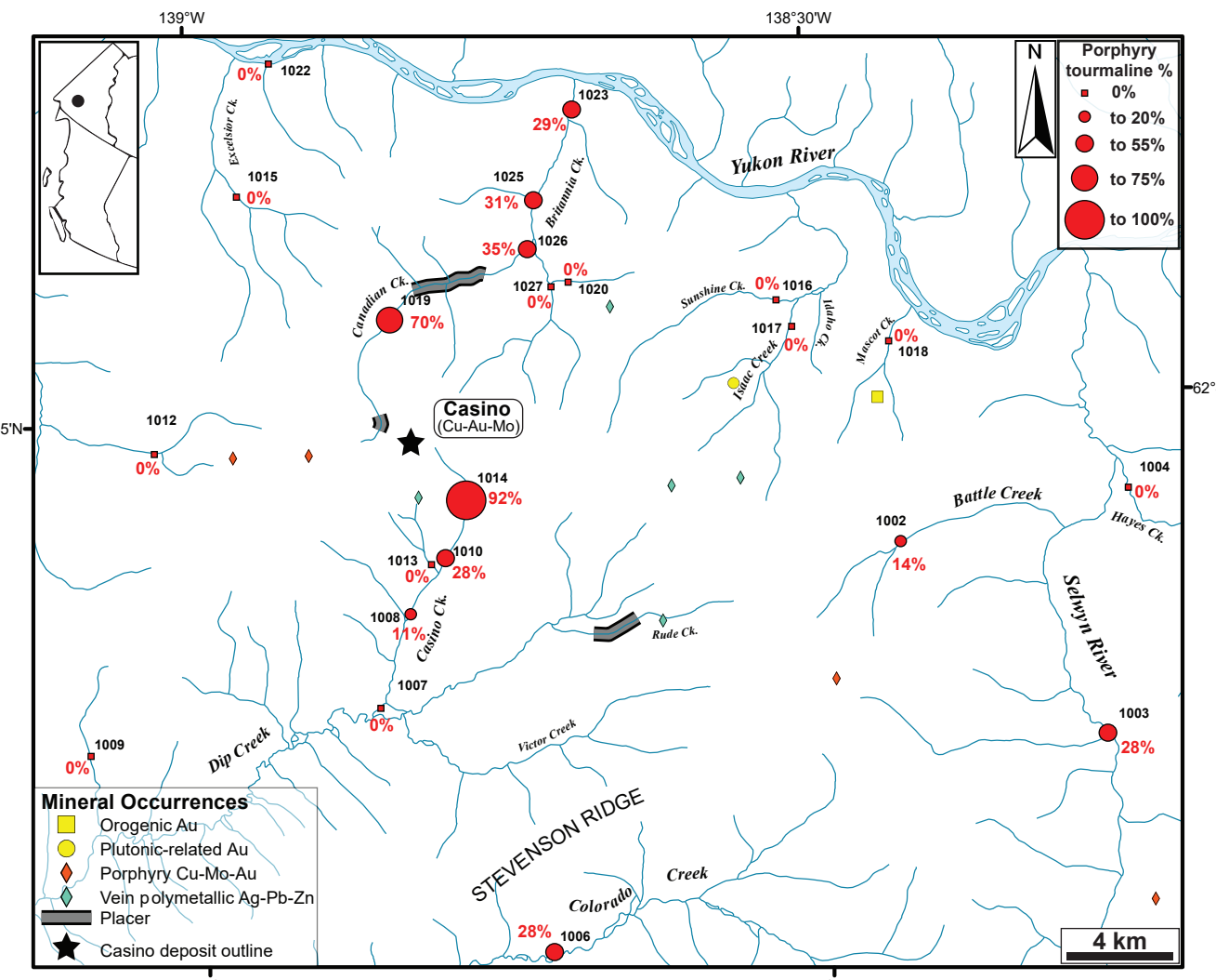

Figure 8: Percentage of tourmaline grains in a stream sediment samples that plot in the 10% porphyry field (Fig. 5, 6). Same data from Fig. 6.

Implications for Exploration

This study provides practical tools which can be applied during routine exploration for porphyry deposits. Tourmaline is an indicator for mineralized porphyry systems because of its distinct chemical and textural features. Key take aways from this research include:

- A combination of morphology and trace element signatures provide the best means for distinguishing porphyry tourmaline from background material
- Grain morphology identified by heavy mineral labs (commercially available) is an important first step which can provide valuable insight for exploration.
- Trace-element chemistry provides a more accurate method and are an important second step to identify prospective grains but morphology can provide an adequate cost effective method for identifying prospective grains in the surficial environment.
- This research is part of ongoing work at the Geological Survey of Canada - part of the Targeted Geoscience Initiative 6, developing and testing new methods for exploration under cover.

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