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Results of Automated Scanning Electron Microscope (SEM) Analyses of Rock and Stream Sediment Samples from the Taurus Porphyry Copper Deposit Area, Tanacross Quadrangle, Eastern Alaska

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Contents

Figures

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
metric ton (t)	1.102	ton, short (2,000 lb)
metric ton (t)	0.9842	ton, long (2,240 lb)
Grams per metric ton (g/t)	0.03527	Ounces per metric ton
	Density	
kilogram per cubic meter (kg/m^3)	0.06242	pound per cubic foot (lb/ft^3)
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
	Energy	
electron volt (eV)	1000	kiloelectron volt (keV)

Abbreviations

BSE backscattered electron

EDX energy dispersive X-ray

PCIM porphyry copper indicator minerals

SEM scanning electron microscope

Cu copper

Au gold

Mo Molybdenum

Ag Silver

Pb Lead

Zn Zinc

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Karen D. Kelley,[1] Katharina Pfaff,[2] and Garth E. Graham[1]

Abstract

Numerous porphyry copper-molybdenum-gold and epithermal deposits define a belt that extends from Eastern Alaska to western Yukon, Canada. An orientation study conducted near the Taurus porphyry deposit was designed to test methods that require minimal sample collection, preparation, and analytical time to determine the viability of indicator mineral studies as a reconnaissance exploration method. Bulk stream sediments and altered and mineralized rocks were sieved to the 0.105–0.25 millimeter fraction (+140, −60 mesh) and passed over a shaking table to create a moderate to heavy mineral separate that was mounted in epoxy and subsequently analyzed using automated scanning electron microscope (SEM) techniques. Seven polished thin sections of core were also analyzed. Among the advantages of automated SEM techniques compared to visual mineral identification are that thousands of grains can be rapidly identified in each sample (about 1 hour per sample) and small quantities of indicator minerals that may be missed during traditional visual analyses can be detected. Automated SEM analyses of stream sediment and rock samples show that specific minerals (chalcopyrite, bornite, and jarosite) are indicators of potential mineralized areas. Svanbergite, an aluminum sulfate phosphate mineral, was identified in mineralized rocks and in nearly all stream sediment samples (up to 9 kilometers) downstream from the Taurus and other porphyry occurrences but not epithermal occurrences. It was not identified in areas with no known mineralization and thus it is possibly one of the best indicator minerals for porphyry copper (+/- molybdenum, gold) occurrences.

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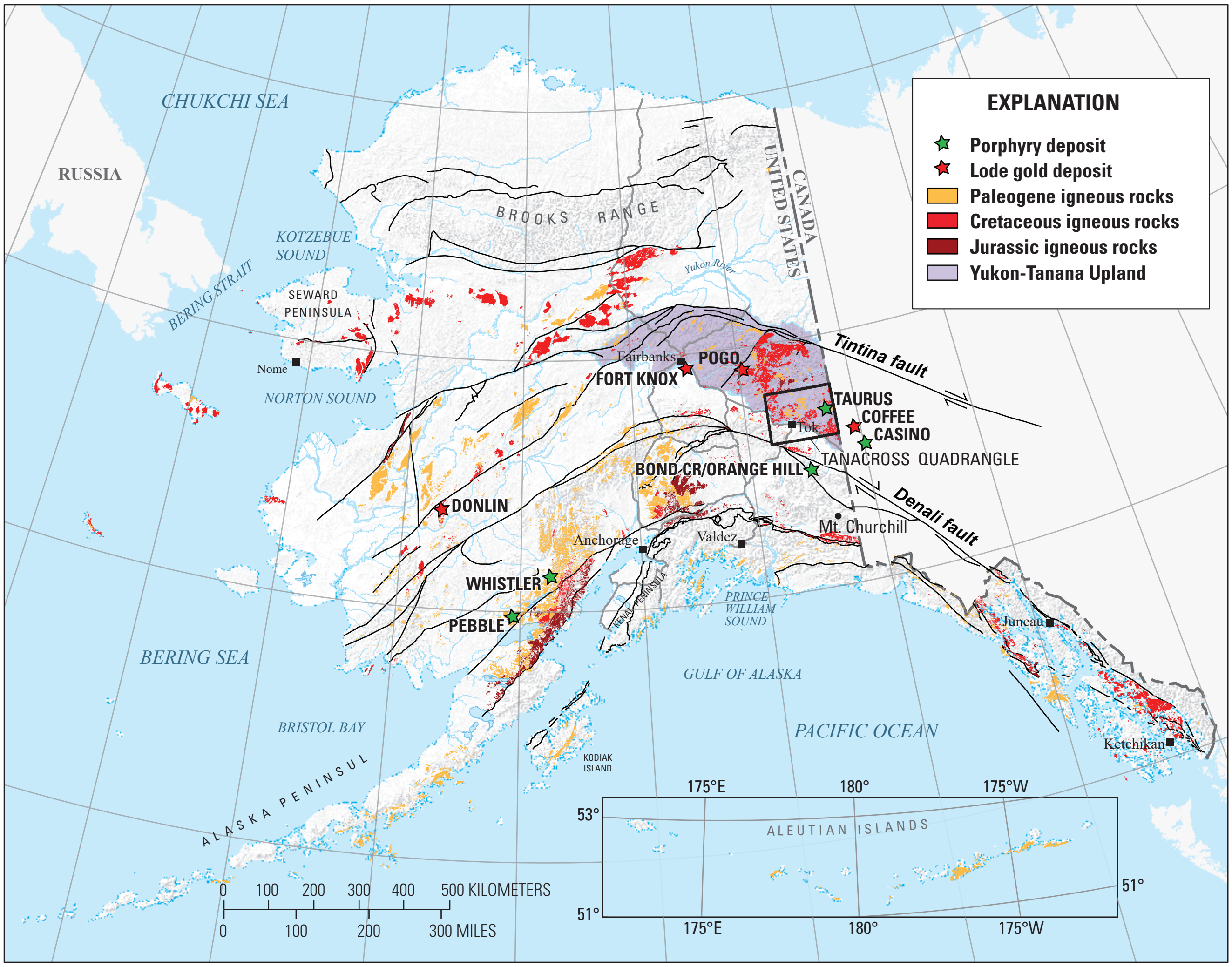
Introduction

The presence of specific minerals in a sample of surficial material (stream sediment, soil, glacial till) may indicate proximity to a mineralized area, and therefore, can provide a useful tool for exploration or mineral resource assessments. For example, specific minerals have been identified in surficial materials that are indicative of diamonds (McClenaghan and Kjarsgaard, 2001; 2007), gold (Au) and platinum group element deposits (McClenaghan and Cabri, 2011), and numerous other deposit types. Minerals such as chalcopyrite, molybdenite, bornite, gold, and other copper sulfide minerals like chalcocite or covellite may specifically indicate the presence of porphyry copper (Cu) deposits. These are called porphyry copper indicator minerals (PCIM). Methods for the recovery and identification of PCIMs from glacial sediments for porphyry Cu exploration have been tested in the glaciated terrain of Canada (for example, Averill, 2001, 2011; Chapman and others, 2015, 2018; Hashmi and others, 2015; Plouffe and others, 2016; Pisiak and others, 2017; Mao and others, 2016; Plouffe and Ferbey, 2017, 2019) and Alaska (Kelley and others, 2011; Eppinger and others, 2013), and one recent study in stream sediment samples has been completed near the Casino deposit in Yukon, Canada (McClenaghan and others, 2020; 2022).

Most of the published PCIM studies have used heavy mineral concentrate samples (derived from till or sediment) that require labor intensive magnetic and heavy liquid separations, followed by mineralogical determinations made visually using a binocular microscope. In this paper, we present a method we tested in eastern Alaska near the Taurus and Bluff porphyry copper deposits within the Tanacross quadrangle in the Yukon-Tanana Upland region (fig. 1). The method includes collection and preparation of bulk sediments from active streams with minimal sample collection and reduced preparation time. We also used recently developed automated techniques for determining mineralogy. Automated techniques rapidly yield results for an enormous number of minerals. The advantages of automated SEM techniques compared to visual mineral identification of indicator minerals (physical evidence



Base from US Geological Survey
1:16,000,000-Scale digital data
NAD 1983 Alaska Albers

Figure 1. Map of Alaska showing location of the Yukon-Tanana Upland region in the Tanacross quadrangle in eastern Alaska, along with the locations of Copper (+/- molybdenum, gold) and lode gold deposits, the distribution of major faults, and location of Jurassic Period, Cretaceous Period and Paleogene Period igneous rocks. The Taurus deposit and others in the immediate region of Taurus are similar to the Casino deposit in Yukon, Canada.

of the presence or absence of mineralization or alteration) are numerous and include: (1) small abundances of indicator minerals are detectable that may be missed during traditional visual analyses. The mere presence of a few indicator mineral grains in a sample may indicate a region that warrants more detailed examination and sampling; (2) indicator mineral grains can be subsequently analyzed to determine chemistry, which provides information about the nature of the mineralizing system; (3) minerals relatively lighter than heavy mineral concentrates produced by heavy liquid separations typically occur in alteration halos surrounding ore zones, and these minerals are detected by automated SEM techniques. Such alteration halos in the case of porphyry deposits may extend for many kilometers away from the core of the deposit; and (4) automated SEM techniques allow for the identification of mineral intergrowth textures, such that a matrix or assemblage of indicator minerals can be defined that might be specific to a deposit type. This study represents one of the first indicator mineral studies to utilize stream sediment samples and processing without heavy liquid or magnetic separations. Some mineral exploration companies are utilizing similar methods (Agnew, 2015) but details of the results are typically not publicly available. In addition to the indicator mineral work presented here, stream sediment geochemistry (Kelley and others, 2020) and hydrogeochemistry (Kelley and Graham, 2021) results are also available.

Characteristics of Mineralized and Altered Rocks in the Taurus Region

There are at least three mappable porphyry systems in the Taurus area (East and West Taurus, Bluff, and Dennison) representative of multiple pulses of mineralization spanning approximately 6 million years (Kreiner and others, 2020). All are associated with Late Cretaceous Period igneous rocks (fig. 1). Other poorly described porphyry systems include Oreo, Pushbush, and Baggage (fig. 2). Several silver (Ag)–Au–Cu (+/- lead [Pb], zinc [Zn]) occurrences north of Taurus are described as possible porphyry (Gill, 1977) or epithermal deposits of assumed younger (Late Cretaceous to early Tertiary Period) age (Gill, 1977; U.S. Geological Survey, 2008). These include the Pika Canyon, NE Pika Canyon, South Pika, and Fishhook occurrences (fig. 2).

All porphyry deposits in the Taurus region are associated with plutons characterized by small stocks, plugs, and dike swarms of predominantly quartz monzonite, granodiorite, and granite, and local syenite bodies (Kreiner and others, 2020). The Taurus deposit has two main mineralized centers: West Taurus and East Taurus, with a combined inferred resource of 68.3 million metric tons (Mt) at 0.275 percent Cu, 0.032 percent molybdenum (Mo), and 0.166 grams per metric ton (g/t) Au (Harrington, 2010; Lasley, 2018). At East Taurus, the supergene and hypogene Cu–Mo–Au mineralized zones are overlain by an approximately 50 meter (m) thick leach cap characterized by oxidation and argillic alteration (Harrington, 2010). Hypogene mineralized rocks include chalcopyrite and molybdenite with weak gold enrichment, and distal galena ± sphalerite zones. The Bluff occurrence has been drilled, but detailed information is not available. Tourmaline-rich, sericite-pyrite alteration and tourmaline breccia pipes are abundant across the Taurus, Bluff, and Dennison localities (Kreiner and others, 2020). Arsenic-rich pyrite and arsenopyrite have been noted in select samples.

Methods

The purpose of this study was to test methods that require minimal sample collection, preparation, and analytical time to determine the viability of indicator mineral studies as a reconnaissance exploration method. The sampling method, sample preparation, and analytical method are described below.

Stream Sediment Collection and Preparation

We collected 8–10 kilograms (kg) of bulk sediment from 47 stream sites within an area of 1,150 square kilometers (km^2), including mineralized drainages and those distal to any known deposits (fig. 2). At each site, we collected specifically from stream locations most likely to contain moderate or heavy minerals, such as point bars, gravel bars, behind and under large boulders or between cobbles; however, streams in the area vary from slow moving with mostly mud to silt sized material to high flow velocity streams with abundant coarse material. Samples were screened to less than (<) 10 mesh (<2 mm) and air dried and sieved in the laboratory to the 0.105–0.25 mm fraction (+140, –60 mesh sieve sizes). This size fraction was chosen based on previous studies that showed this approximate fraction provided optimal results for automated mineralogy (Wilton and Winter 2012; Wilton and others, 2017). Smaller grain size (approximately <0.100 mm) samples required longer analytical times (30–50 percent longer) and the minerals were more difficult to definitively identify. Larger grain sizes (approximately greater than [>] 0.250 mm) resulted in a significant decrease in the number of analyzed particles in a grain mount and the range of observable intergrowth textures decreased.

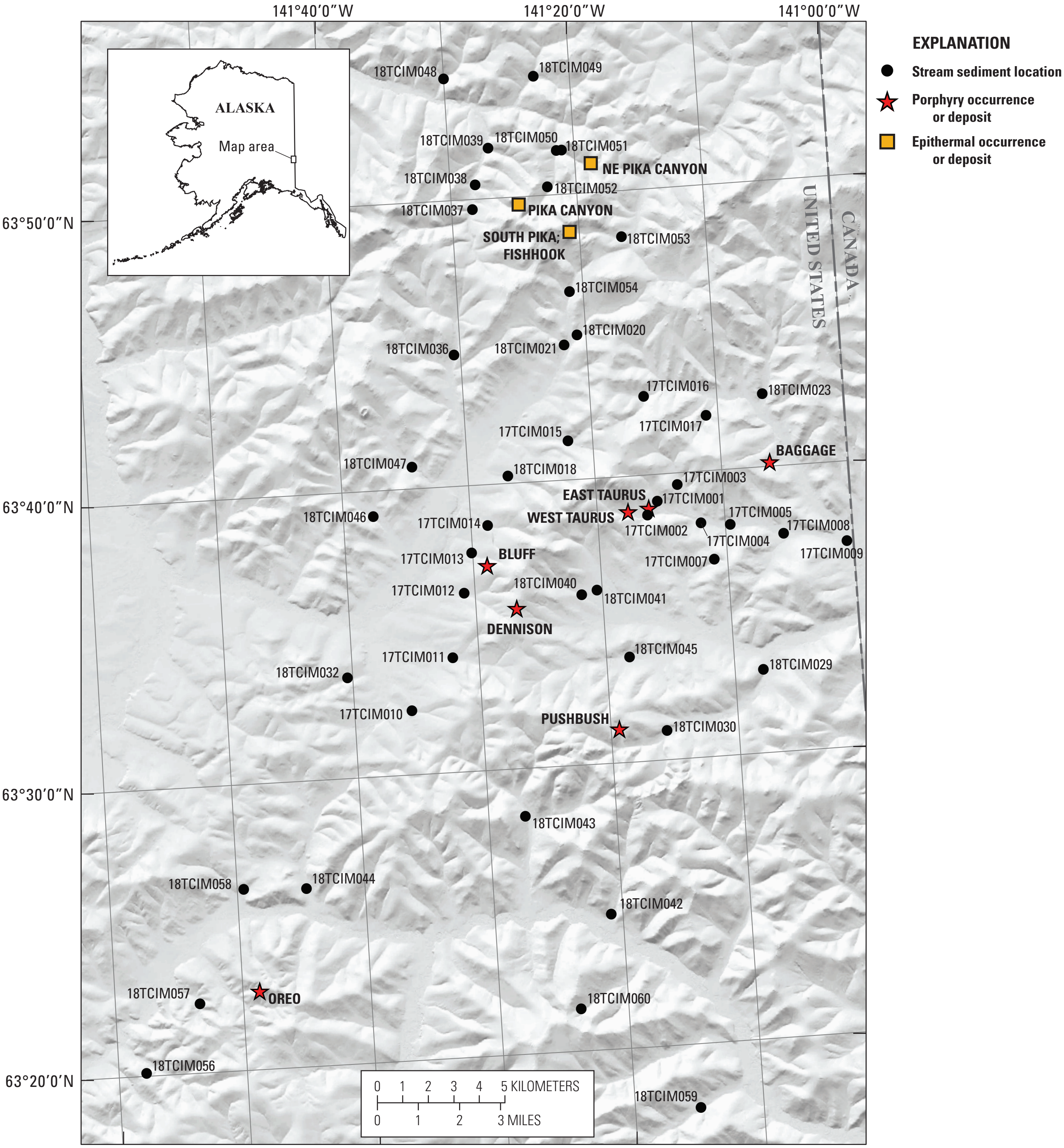
The 0.105–0.25 mm size fraction was further processed using a shaking table (also called a Wilfley table) to separate lighter from denser minerals; our specific gravity threshold between heavy and light minerals using the shaking table is about 2.6–2.8. This process is designed to minimize the occurrence of the lighter minerals (for example, quartz and feldspar), and it optimizes collection of minerals of intermediate to high density or dense-light intergrowths. Heavy liquid or magnetic separation techniques were not used in the processing. The resultant concentrate for each sample was then partitioned using a splitter to produce an approximate 0.5 grams (g) separate that was mounted in a 2.5 centimeter (cm) diameter epoxy mount and the hardened puck was polished (fig. 3).

Rock Sample Collection and Preparation

Seven samples were collected from approximately 15–20 cm interval of drill core from the Taurus deposit; there are two samples representative of the leach cap, two of the supergene, and three hypogene mineralized zones. General descriptions of the leach cap, supergene, and hypogene zones are provided in Harrington (2010). One unmineralized igneous outcrop sample was collected and processed in the same manner as the sediment samples. Each of these samples were crushed and sieved to 0.25–0.105 mm fraction and processed using the Wilfley table, like the method described for stream sediment samples. In addition, seven polished thin sections of hand samples from core were included in the automated mineralogy to obtain in situ textural relations and mineral associations. Identifying the prominent indicator minerals in each of the rock samples is a critical component for comparison to the stream sediment analyses.

Sample Analysis

Automated scanning electron microscopy (automated mineralogy) was done in the Mineral and Materials Characterization Facility at the Colorado School of Mines, Golden, Colo. Samples were loaded into the TESCAN-VEGA-3 Model LMU VP-SEM platform and analysis was



Base from U.S. Geological Survey digital data, 1:400,000
Geographic projection, North American Datum of 1983

Figure 2. Topographic map showing locations of stream sediment samples along with porphyry and epithermal deposits in the study area.

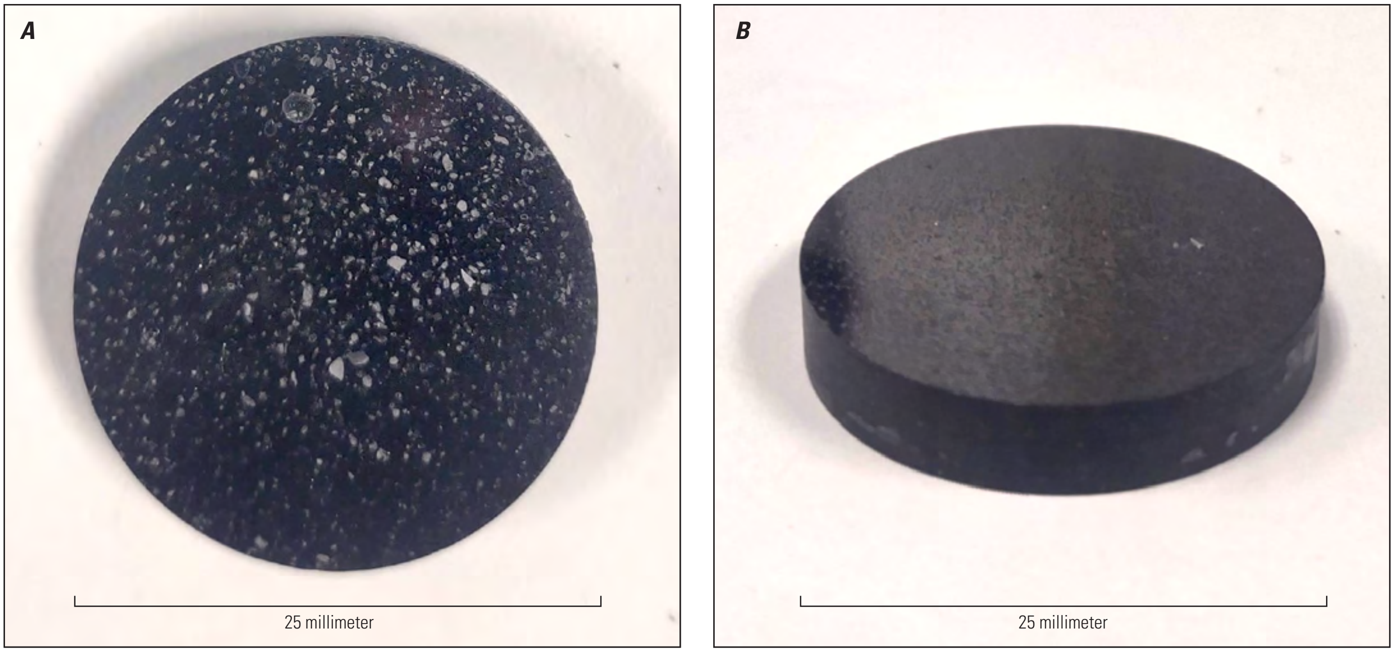


Figure 3. *A* and *B*, examples of prepared puck for TIMA analyses.

initiated using the control program TIMA (Tescan, 2012). Four energy dispersive X-ray (EDX) spectrometers acquired spectra in liberation analysis mode from each point with a user defined beam stepping interval (in other words, spacing between acquisition points) of 5 microns for backscattered electron (BSE) brightness and 15 microns for semiquantitative EDX spectroscopic analyses, an acceleration voltage of 25 kilo-electron volts (keV), and a beam intensity of 14. Interactions between the beam and the sample are modelled through Monte Carlo simulation. The EDX spectra are compared with spectra stored in a look-up table allowing a mineral or phase assignment to be made at each acquisition point. The assignment makes no distinction between mineral species and amorphous grains of similar composition. Results are output by the TIMA software as a spreadsheet giving the area percent, mass percent, number of mineral grains or percent of mineral grains of each composition in the look-up table. This procedure allows a compositional map to be generated. Composition assignments were grouped appropriately.

Results

This report is designed to provide basic results (app. 1, table 1.1) and BSE images of pucks (fig. 4) that highlight select minerals. The results of the TIMA analyses in table 1.1 are organized by mineral category (oxides, silicates, sulfides, sulfates, phosphates, and tungstates). The reported number of particles or grains of each mineral is given in addition to the total number of grains in the puck. Most studies utilizing heavy mineral concentrate samples from stream or till sediments are designed to significantly minimize quartz and other rock forming minerals, but this is less important with automated SEM techniques because each puck or thin section yields results of tens of thousands of grains (table 1.1). Thus, although some samples contain significant amounts of quartz (greater than 20 percent of total grains in the sample) after sieving and processing with Wilfley, many contain less than 10 percent (table 1.1).

The actual number of grains of a specific mineral is not as important in most cases as the presence or absence of a given mineral, especially ore minerals (sulfides) or those associated with them (for example, sulfates or tungstates). For example, 1–2 grains of chalcopyrite in one sample compared to 7–8 grains in another is not necessarily significant. The mere identification of chalcopyrite in a sample is indicative of its presence in bedrock upstream, and confidence in interpretation is strengthened if other copper sulfides, such as bornite, are associated with chalcopyrite in the sample.

Indicator Minerals in Bedrock

The indicator mineral analytical results of core (samples collected from approximately15–20 cm and processed like sediments, and hand sample polished thin sections) show all samples of mineralized and altered material, with the exception of one leach cap sample, contain pyrrhotite, pyrite, and chalcopyrite, with some samples containing grains of bornite, chalcocite, covellite, galena, molybdenite, and sphalerite (table 1.1). Tourmaline is present primarily in quartz-sericite altered porphyry, leach cap, and the hypogene and supergene zones.

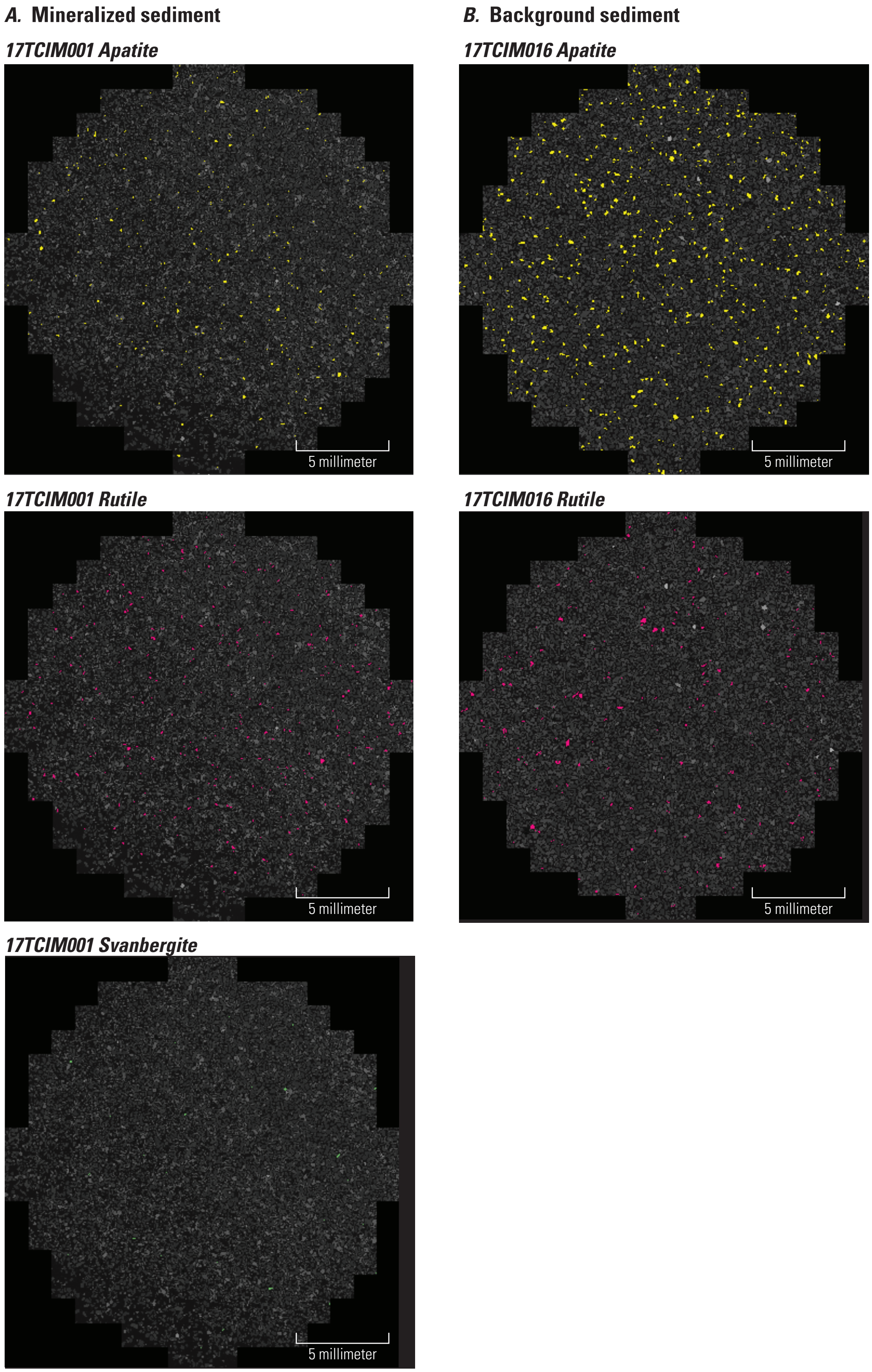


Figure 4. *A*, overview backscatter electron images of one mineralized (17TCIM001) and *B*, one background (17TCIM016) stream sediment sample highlighting the distribution and abundance of select minerals (apatite, top images highlighted in yellow; rutile, middle images in pink; and svanbergite, bottom images in green). Note svanbergite does not occur in the background sediment samples.

Altered monzonite and some mineralized rocks contain topaz. Tungstate minerals (scheelite and wolframite) are present in a few altered or mineralized samples. Jarosite was identified in all altered or mineralized rock samples and svanbergite, an aluminum phosphate sulfate (APS) mineral [$SrAl_3(PO_4)(SO_4)(OH)_6$], was identified in some of the altered or mineralized samples from Taurus, but not relatively unmineralized rocks (table 1.1), and in that sense may represent one of the best indicator minerals of Taurus-like porphyry mineralization. Other minerals such as rutile, apatite, zircon, and sphene (titanite) are present in all rock samples (table 1.1); therefore, their presence alone is not significant as indicator minerals, but chemistry of these has been shown to distinguish mineralized and altered rocks compared to barren intrusive rocks (Scott, 2005; Celis, 2015; Mao and others, 2016).

As expected, most sulfide minerals except pyrite are lacking or occur in small quantities in the leach cap samples. Supergene zone samples contain notably more covellite and chalcocite grains than most other rock types, except for one hypogene sample that contains abundant chalcocite and covellite along with chalcopyrite and bornite (table 1.1).

Indicator Minerals in Stream Sediment Samples

Based on the presence or absence of known mineralized rocks in each stream sediment drainage basin, the sediment samples are characterized as background (no known occurrences in drainage basin) or mineralized (occurrence is known; Cameron, 1999; U.S. Geological Survey, 2008). For example, sediment samples from McCord Creek that drains the Taurus deposit and other unnamed sites downstream from the Bluff, Dennison, and Oreo porphyry-style occurrences, and those near the epithermal Pika Canyon, NE Pika Canyon, South Pika, and Fishhook occurrences (fig. 2) are distinguished as mineralized sediments (table 1.1). Background sediments differ because they are from streams with no known occurrences in the region; however, many sediments contain grains of sulfide minerals that could reflect upstream mineralized bedrock yet to be identified.

Minerals observed in rocks but not sediments include molybdenite and covellite and only a few sediment samples contain chalcocite. Bornite is present in small amounts in many samples also contain relatively abundant chalcopyrite (table 1.1). Svanbergite is present in many of the mineralized stream sediment samples but is lacking in those classified as background. Scheelite and wolframite are present in some mineralized sediments, and relatively abundant in one sediment classified as background, which also contains a few grains of chalcopyrite, suggesting potential for mineralized rocks upstream.

All mineralized sediment samples except for three contain one or more grains of base metal sulfide minerals (galena, sphalerite, or copper sulfide minerals), supporting the idea of using indicator minerals in sediment samples is a valid tool for exploration. For example, all samples from McCord Creek, even those 9 km downstream, contain evidence of the upstream Taurus deposit (table 1.1; fig. 2). Jarosite is also variably abundant in mineralized sediments. Although many background sediment samples are barren of sulfides (except pyrite) as might be expected, many do contain zinc- or lead-rich base metal sulfide minerals (for example, 1–2 grains of sphalerite or galena).

Puck-Scale Mineral Maps

One of the most powerful aspects of automated SEM techniques is BSE images may be generated for entire pucks. This is important for identifying specific minerals of interest because they show the spatial distribution within a given puck. Figure 4 includes puck-scale BSE maps for apatite, rutile and svanbergite for select rock and sediment samples. Apatite and rutile are common indicator minerals in porphyry deposits in general, and svanbergite, as stated above, is observed to be diagnostic of porphyry deposits in our study area. These compositional maps were generated to show the overall quantity and distribution of each mineral in select samples so future mineral chemistry studies may be conducted. The puck-scale maps allow easy navigation to specific grains for subsequent microanalytical analysis.

Another powerful tool provided by TIMA is the ability to visualize mineral associations and grain size distribution. Figure 5 is an example of svanbergite grains in sediment sample 17TCIM001, located immediately downstream from the Taurus deposit. Phase maps show grain size distribution of select minerals in any given puck, as well as mineral associations. For example, in sample 17TCIM001, svanbergite grains range in size from less than 100 micrometers (µm) to many hundreds of microns, and the dominant associated minerals are quartz and aluminum silicate minerals, most likely pyrophyllite or dickite (fig. 5). Similar phase maps can be generated for rutile and apatite, with the aim of illustrating some grains are associated with sulfide minerals (possibly indicating hydrothermal origin), and some with minerals such as magnetite or ilmenite (possibly indicating igneous origin). Such information is valuable for distinguishing multiple sources of grains in the sediments. Mineral chemistry studies using microanalytical techniques such as electron microprobe and laser ablation-inductively coupled mass spectrometry (LA-ICP-MS) are planned for the future.

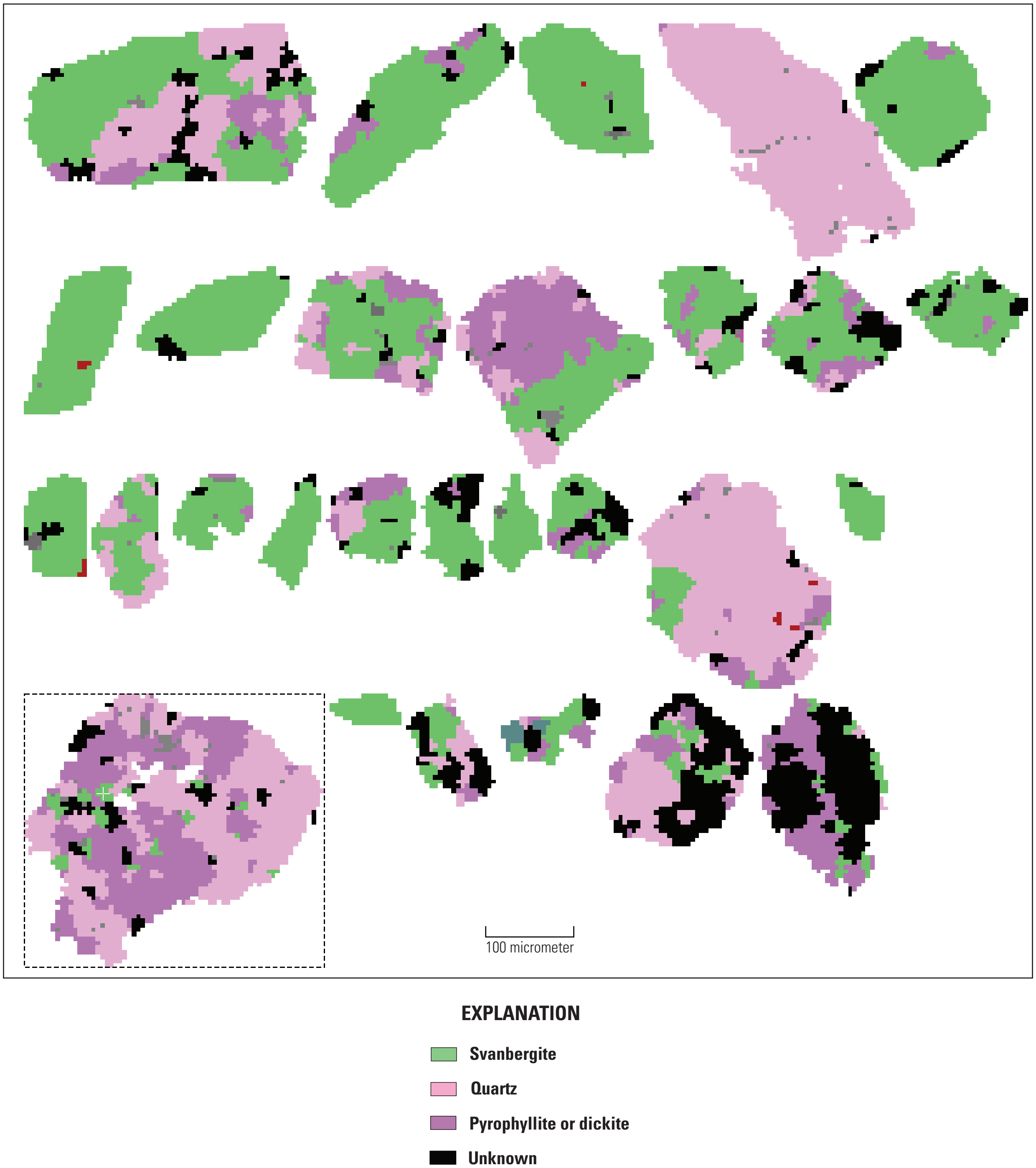


Figure 5. Phase map of particles containing svanbergite in sediment sample 17TCIM001, showing grain size distribution and mineral associations. Svanbergite is associated primarily with quartz and aluminum silicate minerals (most likely pyrophyllite or dickite). Each grain of svanbergite can be flagged using the TIMA software and labeled on overview backscatter electron images, making it easy to locate grains for future detailed scanning electron microscopy or other microanalytical work.

Conclusions

Indicator mineral studies of stream sediment samples using automated scanning electron microscope techniques is a relatively new tool that is useful in exploration and mineral resource assessments. Our orientation study conducted near the Taurus porphyry deposit in eastern Alaska shows the 0.105–0.25 millimeter fraction of bulk stream sediments and altered or mineralized rocks contain specific minerals are indicators of potential mineralized areas, specifically sulfide (chalcopyrite, bornite) and sulfate minerals (jarosite). Svanbergite, an aluminum sulfate phosphate mineral, was identified in mineralized rocks and in nearly all downstream stream sediment samples (up to 9 kilometers downstream) from the Taurus and other porphyry occurrences. Other minerals such as apatite and rutile occur in all sediment samples, so their presence alone is not significant, but the chemistry of these minerals may distinguish hydrothermal versus other sources. The automated mineralogy results serve as a foundation for future mineral chemistry studies using microanalytical techniques such as electron microprobe and laser ablation-inductively coupled mass spectrometry (LA-ICP-MS).

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Appendix 1. Results of TIMA Analyses

The results of the TIMA analyses in table 1.1 are organized by mineral category (oxides, silicates, sulfides, sulfates, phosphates, and tungstates).

Table 1.1. Number of particles of select indicator minerals in rock and stream sediment samples from the Taurus region. Bulk processed rock and stream sediment size fraction is 0.105 to 0.25 millimeters.

[Table is available as a comma separated values (csv) format file for download at https://doi.org/10.3133/ofr20221046. For locations, see figure 2 and Kelley and others, 2020. Ilm, ilmenite; FeOx, iron oxides and hydroxides; Cr, chromite; Cor, corundum; Spn, sphene; Tur, tourmaline; Sp, sphalerite; Aspy, arsenopyrite; Stbn, stibnite; Bn, bornite; Ccp, chalcopyrite; Cct, chalcocite; Cv, covellite; Mol, molybdenite; Po, pyrrhotite; Jrs, jarosite; Alu, alunite; Sv, svanbergite; Mnz, monazite; Sch, scheelite; Wlf, wolframite; PTS, polished thin section; SS-Mz, stream sediment, mineralized; Cr, creek; SS-Bkg, stream sediment, background; Bkg, background]

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