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Joe Andrew describing metasedimentary rocks of the Totatlanika Schist, and gossanous metasedimentary and metavolcanic rocks, with the Red Mountain–Dry Creek massive sulfide prospect in the background. Photo by Melanie Werdon.

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by

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INTRODUCTION

Mineral Resources Section personnel from the Alaska Division of Geological & Geophysical Surveys (DGGS) carried out a geologic field survey, including mapping and sampling, in the eastern part of the Bonnifield mining district in the Fairbanks A-1 and A-2 and the Healy D-1 and D-2 quadrangles, Alaska, from June 16 through July 18, 2008. The fieldwork provides basic information critical to building an understanding of Alaska's geology and is part of an integrated program of airborne geophysical surveys followed by geologic mapping. Specifically, this work provides geologic context for geophysical surveys conducted in 2006 (Burns and others, 2016). Interpretation and synthesis of this data has been presented in professional and trade meetings (Freeman and others, 2009, 2013). This report and associated geologic map data are preliminary, have not undergone rigorous peer review, and will be superseded by a subsequent Report of Investigations map and report that will be issued later in 2016.

The objective of the eastern Bonnifield project is to produce a 1:50,000-scale geologic map to foster a better understanding of the area's geology and mineral potential. Although DGGS concentrated on mapping the Paleozoic metamorphic rocks that host the volcanogenic massive sulfide deposits (VMS) and Mesozoic igneous rocks associated with Au–Ag–As–Sb veins, we also studied the Tertiary sedimentary section, which could contain coal resources.

The geologic map data are available in digital format as ESRI shapefiles. Additional details about the organization of information are noted the accompanying metadata file. All files can be downloaded from the DGGS website (doi: 10.14509/29661).

DOCUMENTATION OF METHODS

Field Data Collection

Field traverses were planned and prioritized to cross important geophysical marker features (Burns and others, 2016), previously identified mineral occurrences (Newberry and others, 1997; Freeman and Schaefer, 2001; Stevens, 2001), key outcrops, and sample sites from previous geologic investigations (Wahrhaftig, 1970a, b; Gilbert, 1977; Dusel-Bacon and others, 2004, 2006).

Field observations were recorded in field notebooks and transcribed into a computer database in the field office and later completed in the DGGS offices. Location coordinates of observation sites were derived using hand-held Garmin GPS 12XL GPS units (no differential correction was applied). Estimated position errors calculated by the hand-held GPS were a minimum of 3 m; at some locations the horizon was limited by steep topography, resulting in positional errors of more than 100 m. Coordinates were downloaded to an MS Access database as UTM Zone 6 coordinates projected in NAD27 datum, and field observation site station identifiers were programmatically

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matched to the location. These matches were verified by field personnel. Field observation station locations are provided in this dataset as a point feature shapefile.

Structural measurements of planar surfaces and lineation were collected from outcrops, sometimes multiple measurements were collected; in some cases where an outcrop trend or a trend of a lithology or fault could only be seen in two dimensions just the azimuthal trends were collected. Structural data was stored in the field database using the American right-hand rule (strike azimuth is 90 degrees counter-clockwise from the down-dip direction) for planar structures and as azimuth and plunge for lineation structures. Structural data were transcribed from geologists' field notes into an MS Access field database during the field season, and queried out of the database into the ESRI shapefile. Structural data are provided as a point feature shapefile in this dataset. The dataset includes all structural measurements that were collected and verified; not all measurements will be portrayed on the final map.

Rock Sample Collection

Rock samples were collected for hand specimen, petrography, geochemistry, geochronology, coal quality, palynology, and fossil identification. Geochemical data have been released (Freeman and others, 2009, 2016). Geochronological data have already been released (Benowitz and others, 2011). Palynological, coal quality, and sandstone data are in preparation.

Map Construction Methods

Geologists recorded field observations and geologic interpretations on field maps; information on these field sheets, along with observations from field stations were compiled on a hand-drawn interpretive bedrock map in the field office. This compilation allowed the geologic team to collaboratively compile observations and interpretations and to aid in reaching a consensus among alternative interpretations. Once in the office this interpretive compilation was scanned and digitized. Final interpretation of geologic polygons, contacts, and geologic unit composition were completed in ArcGIS. Bedrock polygons have been edited to be topologically complete with no overlap, but have not received technical review. The current dataset does not include the identity, or identity and location confidence of contacts.

DISCUSSION

Immobile trace-element geochemistry was used extensively to supplement textural and mineral composition identity of the metamorphic rocks, especially of the Totatlanika Schist. Previous studies determined that metavolcanic rocks of the Totatlanika schist comprise a bimodal suite composed of volcanic arc rhyodacite, peralkaline metarhyolite, and alkaline basalt compositions (Dusel-Bacon and others, 2004). Our field team used a hand-held X-ray fluorescence (XRF) spectrometer to provide semi-quantitative major- and trace-element analyses of hand specimens in the field office. These analyses were helpful in distinguishing among metamafic rocks, peralkaline rhyolite, and rhyodacite on the basis of absolute values of niobium, zirconium, and titanium; however, the qualitative nature of the data left many rock identities ambiguous. Post-field season quantitative analyses (Freeman and others, 2009, 2016) provide more accurate absolute elemental values, a more complete suite of elements, and can be plotted on discriminant diagrams (Winchester and Floyd, 1977). The geologic map units in this dataset do not use the lithostratigraphic subdivisions of the Totatlanika Schist as used by previous studies (Wahrhaftig, 1968, 1970a, b; Gilbert, 1977; Dusel-Bacon and others, 2004), but rather distinguish rocks on the basis of their field identifiable textures and composition, with further subdivision of coherent metavolcanic rocks by geochemistry (Freeman and others, 2009, 2013, 2016).

DESCRIPTION OF BEDROCK-GEOLOGIC MAP UNITS

Tertiary Sedimentary Rocks

Our mapping and supporting data refine the mapping of Tertiary sedimentary rocks (units Tn, Tcb, Thc, Tlc, and Tsu of Wahrhaftig [1970a, b] and Gilbert [1977]). The Tertiary sedimentary rocks occur in three strongly fault-modified synclines roughly coaxial with the valleys of Kansas Creek, Sheep Creek–Red Mountain Creek, and Slide Creek.

Tn NENANA GRAVEL (Pliocene)—Gravel, sand, pebbly sand. Eroded hillside mantled with cobbles and gravel. Characterized by the presence of gray conglomerate cobbles. Pliocene age adapted from Ridgway and others (2007).

USIBELLI GROUP

Tsu SUNTRANA FORMATION (middle Miocene)—Pebbly quartz sandstone and clinkered coal beds; two outcrop areas at north end of field area. Age adapted from Wahrhaftig and others (1969).

Thc HEALY CREEK FORMATION (middle Miocene)—Poorly consolidated gray sandstone, pebbly sandstone, mudstone, and coal; minor conglomerate. Coal beds are frequently clinkered; leaf and sedge casts can be found in baked sediments near clinkered coal beds. Unpublished palynological determinations indicate an early to middle Miocene age, except for one sample from the southernmost basin that is middle or late Eocene.

Igneous Rocks

Tf RHYOLITE BRECCIA DIKES (Tertiary)—White to tan aphanitic rhyolite breccia with clasts of schist and pumice; local banding along margins. Forms a prominent dike that crosses Dry Creek west of Red Mountain Creek. Magnetic susceptibility ranges from 0.01 to 0.14 with a mean of 0.03×10^{-3} SI [Système International].No radiometric age available; may be equivalent to rhyolite of Sugar Loaf Mountain 48 km west that is dated at early Oligocene to late Eocene (Albanese and Turner, 1980).

Kgd HORNBLENDE–BIOTITE GRANODIORITE (Cretaceous)—Fine- to medium-grained equigranular to seriate monzodiorite to granite composition; occurs as the Kansas Creek pluton, which is mostly south of the map area, and smaller dikes in the headwaters of Dry Creek. Magnetic susceptibility ranges from 0.05 to 0.44 with a mean of 0.15×10^{-3} SI. Radiometric ages range from 85 to 92.3 Ma (Benowitz and others, 2011). Previously mapped as Mesozoic granodiorite and Tertiary felsic dikes by Wahrhaftig (1970a) and granitic rocks by Gilbert (1977).

Kqm QUARTZ MONZONITE (Cretaceous)—Potassium feldspar megacryst-bearing, seriate to porphyritic orthopyroxene–hornblende–biotite quartz monzonite. Forms a single pluton in the northeast part of the map that is mostly concealed by Nenana Gravel (Tn). Magnetic susceptibility ranges from 0.16 to 14.5, averaging 3.38×10^{-3} SI. Hornblende from this pluton yielded an $^{40}Ar/^{39}Ar$ plateau age of 92.6 ± 0.9 Ma (Benowitz and others, 2011). Previously mapped as Granite of Coal Creek (Mzg) by Wahrhaftig (1970a) and granitic rocks by Gilbert (1977).

Km BIOTITE QUARTZ MONZODIORITE (Cretaceous)—Fine- to medium-grained quartz monzodiorite to tonalite. Occurs in a small stock in Glory Creek. Magnetic susceptibility ranges from 0.04 to 0.29, with a mean of 0.13×10^{-3} SI. Biotite from this pluton yielded an $^{40}Ar/^{39}Ar$ plateau age of 94.1 ± 0.6 Ma (Benowitz and others, 2011). Previously mapped as granitic rocks by Gilbert (1977).

Kgb GABBRO (Cretaceous)—Occurs as dikes up to tens of meters wide; volcanic arc basalt geochemical signature. A whole-rock sample yielded an $^{40}Ar/^{39}Ar$ plateau age of 95.5 Ma ± 0.7 Ma (Benowitz and others, 2011). Magnetic susceptibility ranges from 0.11 to 4.55, with a mean value of 0.55×10^{-3} SI. Previously mapped as Tertiary basalt dikes (Wahrhaftig, 1970a; Gilbert, 1977).

Metamorphic Rocks

Paleozoic and older sedimentary and igneous rocks are metamorphosed to greenschist facies. This map retains the previous nomenclature for the three main units: Healy schist (Newberry and others, 1997), Keevy Peak Formation, and the Totatlanika Schist (Wahrhaftig, 1970a, b; Gilbert, 1977). This map refines and redefines the metamorphic rock units, their distribution, and their relationships.

TOTATLANIKA SCHIST

The Totatlanika Schist covers most of the northern East Bonnifield map area. Rather than adopting the five lithostratigraphic packages defined on previous maps for the Totatlanika Schist (Wahrhaftig, 1970a, b; Gilbert, 1977), DGGS defined new units based on field observations of lithology, relict textures, and compositions, as determined by semiquantitative lithogeochemical measurements using a portable handheld XRF spectrometer. Field observations and semiquantitative analyses were followed up with petrographic study and quantitative XRF spectrographic analysis. Contact relationships between the subunits are complex.

Mqw METASILICICLASTIC ROCKS (Mississippian)—Dominantly quartz metawacke, quartzite, metagritstone, and quartz schist with lesser intercalated slate, phyllite, schist, greenstone, metarhyolite, and metarhyodacite. Appears to stratigraphically overlie all other lithologic units of the Totatlanika Schist. Previously mapped as an epiclastic subunit of the Sheep Creek Member of the Totatlanika Schist of Wahrhaftig (1970a) and the Sheep Creek Member of Gilbert (1977).

MDph GRAY, GREEN, AND MAROON PHYLLITE (Mississippian to Devonian)—Dominantly phyllite, siliceous phyllite, and slate with intercalated quartz- and feldspar porphyroclasitc schist, semischist, and metavolcaniclastics. Contains lenses and bodies of metarhyodacite, peralkaline metarhyolite, and metamafic rocks. Geochemical analyses indicate that the unit has mixed epiclastic and volcaniclastic provenance, with contributions from mafic, rhyodacitic, and peralkaline rhyolitic volcanics. Previously mapped in part as Mystic Creek Member and in part as Sheep Creek Member of the Totatlanika Schist (Wahrhaftig, 1970a, b; Gilbert, 1977).

MDm IMPURE MARBLE (Mississippian to Devonian)—Black to gray and tan impure marble and recrystallized limestone. Occurs as lenses and beds no thicker than a few meters within and at the contacts of DMgp, DMvc, and DMph. One lens of marble too small to map contains fossil fragments of *Syringipora* tabulate coral that indicate a Mississippian(?) age (Warhaftig, 1968) and *Polygnathus* conodont ramiform elements that indicate a Middle Devonian to Early Mississipian age (Csejtey and others, 1986). Previously included in the Mystic Creek Member (Wahrhaftig, 1970a).

MDgp GRAPHITIC TO CARBONACEOUS PHYLLITE AND SLATE (Mississippian to Devonian)—Fine-grained graphitic phyllites and schist. Black to dark gray, can by very carbonaceous and sooty with up to 9.11 percent non-carbonate carbon (Freeman and others, 2009), and locally contains clasts of apparent volcanic rocks. Unit includes lenses of metavolcanic and metavolcaniclastic rocks. Previously mapped as black carbonaceous schist and slate in the California Creek and Sheep Creek members (Wahrhaftig, 1970a). Mapped in part by tracing areas of low resistivity in the airborne electromagnetic maps (Burns and others, 2016).

MDvc METAVOLCANICLASTIC ROCKS (Mississippian to Devonian)—Green, brown, and tan coarse-grained volcaniclastic rocks, porphyroclastic schist, phyllite, and mylonite. Characterized by megascopic lithic clasts in a fine-grained matrix, rocks are variably deformed by penetrative deformation. Locally, primary volcaniclastic textures such as concave, cuspate, angular fragments and shards are preserved. Geochemical analyses indicate that the unit has mixed volcaniclastic provenance, with contributions from mafic, rhyodacitic, and peralkaline rhyolitic volcanics. Previously mapped as Moose Creek, Chute Creek, Mystic Creek, and Sheep Creek members of the Totatlanika Schist (Wahrhaftig, 1970a; Gilbert, 1977).

MDr PERALKALINE METARHYOLITE (Mississippian to Devonian)—Black to tan, aphanitic to porphyritic metarhyolite and orthogneiss. Relict igneous textures include laminations (flow banding?), amygdules, pepperites, chilled and baked margins, and columnar joints. Characterized by remarkably enriched high-field-strength elements: Nb > 93, Y > 57, Zr > 460 (Dusel-Bacon and others, 2004). U/Pb ages range from 356 to 363 Ma (Dusel-Bacon and others, 2010). Previously mapped as portions of the Mystic Creek Member and rhyolite schist of the Totatlanika Schist and Tertiary felsite (Wahrhaftig 1970a; Gilbert, 1977).

Db METAMAFIC ROCKS (Devonian)—Dominantly chloritic schist, greenstone, and metagabbro. Geochemical analyses indicate the rocks are alkali basalt and have within-plate tectonic affinity. Previously mapped as the Chute Creek Member (Warhrhaftig, 1970a, b; Gilbert, 1977).

Drd METARHYODACITE (Devonian)—Gray to tan, aphanitic to porphyritic metarhyolite, orthogneiss, and schist. Relict igneous textures are rare but include laminations (flow banding?). This unit has continental volcanic arc geochemical characteristics indistinct from Totatlanika Schist metagranite (unit Dg), and is therefore assumed to be the same age. Previously mapped as portions of the California Creek and Chute Creek Member (Gilbert, 1977).

Dg METAGRANITE (Devonian)—Orthoclase and quartz porphyroclastic orthogneiss and blastomylonite, characterized by 1–3 cm orthoclase augen and 2–5 mm quartz porphyroclasts. Protolith is megacrystic porphyritic granite and rhyolite with continental volcanic arc geochemical characteristics. Occurs as bodies that cross-cut Healy schist, Keevy Peak Formation, and Devonian units of the Totatlanika Schist. Zircons are dated by U/Pb to be 360 to 376 Ma (Dusel-Bacon and others, 2010). Previously mapped as portions of the Moose Creek and California Creek Members (Warhaftig, 1970a; Gilbert, 1977).

Daw ARKOSIC METAWACKE (Devonian)—Dominantly quartz and feldspar porphyroclastic schist, mylonite, and semischist, with lesser intercalated phyllite, schist, graphitic schist, greenschist, and metavolcaniclastic rocks. Includes bodies of metarhyolite, porphyroclastic orthogneiss, and metagabbro too small to map. Protolith is dominantly feldspar- and quartz-rich volcaniclastics derived from metarhyodacite and metarhyolite of the Totatlanika Schist. Previously mapped as portions of the Moose Creek and California Creek members of the Totatlanika Schist (Wahrhaftig, 1970a, b; Gilbert, 1977).

Dcs CALCAREOUS SCHIST (Devonian)—Calcite- and dolomite-rich schist and phyllite. Previously mapped as portions of the Moose Creek Member (Wahrhaftig, 1970a; Gilbert, 1977).

KEEVY PEAK FORMATION

Dgq GRAY TO BLACK QUARTZITE, QUARTZ SCHIST, AND GRAPHITIC MICA SCHIST (Devonian or older)—Rhythmically intercalated gray to black quartzite, quartz schist, and graphitic mica schist. Lenses up to several meters thick of quartz and chert pebble metaconglomerate and metagrit are common. The unit is distinctly conductive and can be easily traced using airborne electromagnetic surveys. A single detrital zircon sample (unpublished data) indicates a dominantly Paleoproterozoic provenance with a small component from late Mesoproterozoic. The unit is cut by bodies of Devonian metagranite (Dg), and the contact with the Totatlanika Schist arkosic metawacke unit (Daw) appears to be locally gradational. On the basis of these field relationships we assign the unit to Devonian and older (?). Previously mapped as Keevy Peak Formation and black schist of the Birch Creek Schist (Wahrhaftig, 1970a; Gilbert, 1977).

Dcg METACONGLOMERATE (Devonian or older)—Schistose, polydeformed, stretched pebble conglomerate; forms prominent outcrops, may or may not contain graphitic interbeds. Occurs as discontinuous bodies typically at the contact with Healy Schist. Corresponds with stretched pebble conglomerate of Keevy Peak Formation (Wahrhaftig, 1970a).

HEALY SCHIST

We redefine the Healy schist as being distinct from the Keevy Peak Formation by the lack of appreciable graphite. Previously the Healy schist was defined as the oldest carbonaceous epiclastic schist unit in the Bonnifield district (Newberry and others, 1997); it was previously mapped as Birch Creek Schist (Wahrhaftig, 1970a; Gilbert, 1977).

PzPq QUARTZITE AND SCHIST (Paleozoic to Proterozoic)—Quartzite, quartz schist, schist, and rare marble. Generally green to tan and locally maroon in color. Quartzite has abundant quartz and lesser feldspar porphyroclasts; relict graded bedding is observable in some outcrops. The unit is cut by bodies of Devonian metagranite (Dg). Marble south of the field area is reported to contain crinoid fragments (Gilbert and Bundtzen, 1979). Similar rocks 48 km west contain detrital zircon dated at 660 Ma (Bradley and others, 2007). A single detrital zircon sample from the map area indicates a dominantly Paleoproterozoic provenance (Freeman and others, 2013). Previously mapped as Birch Creek Schist (Wahrhaftig, 1970a; Gilbert, 1977).

PzPc CALCAREOUS QUARTZITE AND SCHIST (Paleozoic to Proterozoic)—Calcareous quartzite, calcareous schist, and marble. Generally green to tan and locally maroon in color. The unit is cut by bodies of Devonian metagranite (Dg). Marble south of the field area is reported to contain crinoid fragments (Gilbert and Bundtzen, 1979).

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