ALASKA DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

REPORT OF INVESTIGATIONS 2020-07
Twelker and others, 2020
SHEET 1 OF 1
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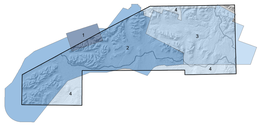
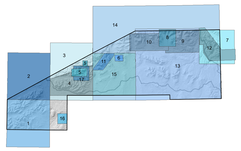
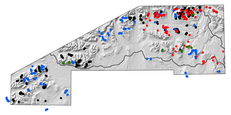


GEOPHYSICAL SURVEYS
1. Valdez Creek (Burns and others, 2004)
2. Burns and others, 2014
3. Southern Delta River (Burns and others, 2003)
4. Saltus and Simmons, 1997

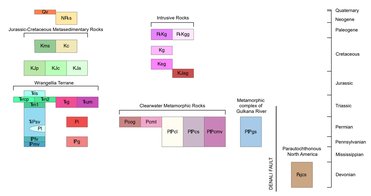


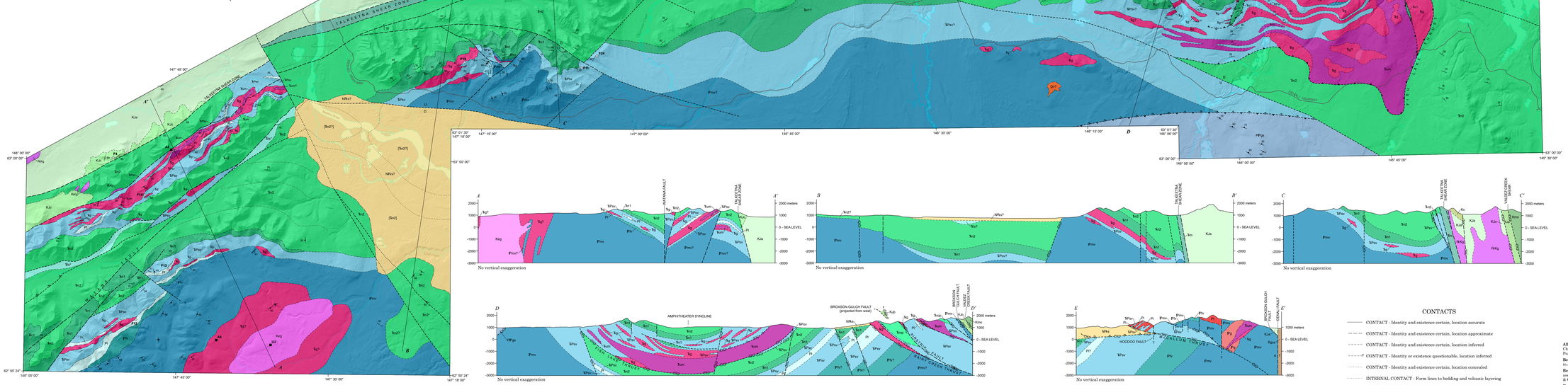
GEOLOGIC MAPS
1. Kline and others, 1990
2. Smith and others, 1988
3. Smith, 1981
4. Silberling and others, 1981
5. Mooney, 2010
6. Eden, 2013
7. Waldron, 2015
8. Waldron and Roeske, 2017
9, 10. Rose, 1966
11. Clautice and others, 1989
12. Bond, 1976
13. Stout, 1976
14. Nokleberg and others, 2015
15. Smith, T.E., unpublished Mount Hayes A-6
16. Bundtzen, 2013
17. Stevens, 1971



FIELD STATIONS
- Alaska Division of Geological & Geophysical Surveys 2013 stations
- Alaska Division of Geological & Geophysical Surveys 2015 stations
- Selected Bureau of Land Management stations (Bittenbender and others, 2007)
- Samples of Greene and others (2008)

CORRELATION OF MAP UNITS





INTRODUCTION

This map presents interpreted bedrock geology for a portion of the northeastern Talkeetna Mountains and the eastern Alaska Range that is primarily underlain by Pennsylvanian through Triassic rocks of the Wrangellia terrane, plus structurally emplaced Jurassic through Cretaceous metasedimentary rocks that formed north and east of Wrangellia prior to its accretion to North America. It provides the geologic framework for known and potential mineral resources related to the geology of Wrangellia, including magmatic nickel-copper-cobalt-platinum group element deposits hosted by Late Triassic mafic and ultramafic intrusions, copper-silver deposits related to metamorphism of the Late Triassic Nikolai Greenstone, and copper-gold skarn deposits associated with Early Cretaceous plutonism.

This map synthesizes and reinterprets multiple generations of geologic maps, geophysical surveys, geochronology, and geochemistry, plus incorporates targeted field observations by geologists from the Alaska Division of Geological & Geophysical Surveys, the University of Alaska, and the University of California, Davis. Additional discussion of the geology and mineral potential of the map area is presented in a companion report, Twelker and others (2020).

EXPLANATION OF MAP UNITS

CENOZOIC SEDIMENTARY AND VOLCANIC UNITS

Qa VOLCANIC FLOWS (QUATERNARY)—Aphanitic, medium-gray olivine-phyric basalt flows unconformably overlie late Paleozoic to Triassic bedrock and form two subtle topographic highs, subsequently modified by glaciation. $^{40}Ar/^{39}Ar$ dating of whole-rock indicates an age of 0.990 ± 0.028 Ma (map location A1; J.A. Benowitz, University of Alaska, Fairbanks, written commun., 2017).

NPks SEDIMENTARY ROCKS (PALEOGENE TO NEOGENE)—Mixed unit including poorly to moderately indurated, clast-supported, fine-grained to pebble sandstone, siltstone, sparse thin coal layers, and conglomerate containing sparse sand lenses. As mapped, the unit comprises multiple successive sedimentary units as young as Pliocene and possibly as old as Paleocene (map location D23; Waldien and others, 2020). Interbedded volcanic rocks are as young as 3.808 ± 0.054 Ma ($^{40}Ar/^{39}Ar$ dating of interbedded tephra; map location A2; Allen, 2016) and as old as 31.1 Ma (K-Ar, hornblende in tuff; Nokleberg and others, 1992). Plant fossils and pollen indicate ages spanning from late Eocene to Pliocene (map locations F1–F3 ; Nokleberg and others, 1992).

JURASSIC-PALEOGENE INTRUSIVE UNITS

PzKgg GRANITIC ROCKS (CRETACEOUS TO PALEOGENE)—Small stocks and plugs of fine- to medium-grained, equigranular to porphyritic granitic rocks, mainly of intermediate composition. Subordinate lithologies range from gabbro to felsite. In the Windy Creek area, Smith (1981) interprets these intrusions as having been emplaced prior to the final stages of Late Cretaceous metamorphism. In the Butte Creek area, the intrusions are strongly altered to sericite, clay, and pyrite (Kline and others, 1990).

PzKgn GNEISSOSE GRANITIC ROCKS (LATE CRETACEOUS TO PALEOGENE)—Gneissose, fine- to medium-grained granodiorite, diorite, quartz diorite, trondjemite, quartz monzonite, and minor granite. Characterized by relict igneous mineralogy and textures, as well as a penetrative foliation defined by aligned biotite and white mica, plus elongate grains of quartz and feldspar; this fabric parallels that of the Maclaren schist (unit Kms). U-Pb zircon dating indicates a magmatic crystallization age of 70 Ma (Nokleberg and others, 1992). This unit is part of the East Susitna batholith of Nokleberg and others (2015).

Kg GRANITIC ROCKS (MIDDLE CRETACEOUS)—Small intrusions of hornblende-quartz monzonite, diorite, and granodiorite; may grade into gneissose and olivine-cumulate phases. Exhibits a weakly to moderately developed magmatic-emplacement fabric defined by aligned amphibole and plagioclase. The quartz commonly has undulose extinction and exhibits shear bands. The lower contact is strongly altered to sericite, clay, or chlorite. In the immediate vicinity of the Brewery Creek fault, Zircons from this intrusion yield a magmatic age of 102.19 ± 0.77 Ma (map location U1; Waldien and others, 2020).

Keg GRANITIC ROCKS (EARLY CRETACEOUS)—Widely scattered stocks and plutons of fine- to medium-grained granodiorite, granite, diorite, and monzonite. The largest of these plutons has a U-Pb zircon age of 114.9 ± 2.7 Ma (map location U2; Hohn Dennoma and others, 2020). $^{40}Ar/^{39}Ar$ dating of hornblende returned an age of 138.4 ± 0.8 Ma for a granodiorite stock in the Maclaren River drainage (map location U3; Benowitz and others, 2017), while $^{40}Ar/^{39}Ar$ biotite yielded an age of 124.6 ± 0.5 Ma for monzonite 10 km to the southwest (map location A3; Benowitz and others, 2014). Gneissose texture occurs locally. Metamorphosed at lower greenschist facies (Nokleberg and others, 2015).

Ksg ALKALI GABBRO (LATE JURASSIC TO EARLY CRETACEOUS)—A single, 5-square-km stock of biotite-hornblende-clinopyroxene-olivine gabbro. Heterogeneous gabbroic rocks dominated by hornblende monogabbro; less abundant phases include theralite, monzonite, and monzodiorite (Smith, 1981). Alkali gabbro from the stock yielded a U-Pb zircon age of 142.2 ± 1.7 Ma (map location U3; Mooney, 2010). The stock has been metamorphosed to prehnite-pumpellyite facies (Smith, 1981).

JURASSIC-CRETACEOUS METASEDIMENTARY UNITS

Kms MACLAREN SCHIST (LATE CRETACEOUS)—Quartz-mica schist, plus lesser interlayered calc-schist and amphibolite. Quartz-mica schist is generally fine grained (approximately 0.5–3 mm) and consists of quartz and a penetrative foliation defined by white mica, biotite, chlorite, and graphite. Accessory minerals include porphyroblasts of garnet and calcic plagioclase, calcite, epidote-clinozoisite, hornblende, staurolite, and local kyanite and sillimanite. Detrital quartz and plagioclase grains are rare. Protoliths are pelitic sediments, sandstone, and greywacke with minor mafic volcanic rocks (Nokleberg and others, 1992; 2015). Metamorphosed to amphibolite facies. The maximum depositional age, based on detrital zircons, is late Paleocene (map location D22; Waldien and others, 2020).

Kc CONGLOMERATE (LATE CRETACEOUS)—A single, fault-bound wedge of pebble to boulder conglomerate with a matrix of poorly sorted, fine-grained lithic sandstone. Well-rounded, monomictic clasts include basalt, diorite, and greywacke. The unit has undergone regional metamorphism to prehnite-pumpellyite facies. Detrital zircons from the conglomerate range from Late Cretaceous to Jurassic in age; the maximum depositional age based on the youngest population is approximately 86 Ma (map location D21; Waldien and others, 2020).

KJp PHYLLITE (LATE JURASSIC TO EARLY CRETACEOUS)—White mica-quartz phyllite, and lesser phyllitic metagreywacke, greenschist, calcareous phyllite, and quartzose schist. Fine-grained, grain size approximately 0.05 to 0.1 mm. Metamorphosed to upper greenschist facies, evidenced by actinolite, epidote, and chlorite, plus local biotite and garnet. Detrital zircon spectra from this unit (map location D26; Waldien and others, 2020; map location D26; Hohn Dennoma and others, 2020) show a single prominent Late Jurassic population. This unit occurs along the northwestern margin of the map as a fault-bound belt, separated from the Maclaren schist (Kms) by a south-vergent thrust fault or by the Valdez Creek shear zone. It is intruded by mid-Cretaceous granite (unit Kg) and Paleocene-Eocene rocks of the Talkeetna Mountains and the Alaska Range.

KJa ARGILLITE (LATE JURASSIC TO EARLY CRETACEOUS)—Argillite, slate, metawacke, and meta-andesite. Fine-grained metasediments contain local metagreywacke interbeds. Average grain size is 0.01–0.05 mm. Characterized by a well-developed planar fabric and metamorphosed to lower greenschist facies; diagnostic metamorphic minerals are graphite, chlorite, clinozoisite, and white mica. Detrital zircon spectra from this unit (map location D25; Mooney, 2010; map location D27; Waldien and others, 2020) are dominated by a Late Jurassic population similar to that found in the structurally adjacent unit KJp.

Ts CONGLOMERATIC SEDIMENTARY ROCKS (LATE JURASSIC TO EARLY CRETACEOUS)—Interbedded shale, siltstone, sandstone, lithic wacke, and polymictic conglomerate. Exhibits numerous graded, fining-upward sequences. Conglomerate contains subrounded to well-rounded, granule- to small-boulder-sized clasts of basalt, andesite, diabase, greywacke, and siliceous argillite in a matrix of calcareous greywacke. Ars argillite bed within this unit (map location F3) contains an assemblage of Late Jurassic fossils, including pelecypods *Buchia rugosa* (Smith and others, 1988).

PENNSYLVANIAN-TRIASSIC IGNEOUS AND SEDIMENTARY UNITS (WRANGELLIA TERRANE)

Ts1 MÉLANGE (TRIASSIC)—Tectonic mixture of fine-grained metavolcanic and metasedimentary rocks, including chlorite schist, thin (less than 1 m-thick) layers of filated gray marble, calcareous metasedimentary rocks, volcaniclastic rocks, greenish phyllite, carbonaceous argillite, and chert. Metamorphosed to greenschist facies. Fossil evidence, including the hydroconn *Heterastridium* (map location F5; Silberling and others, 1981), indicates a Late Triassic (late Norian) age for at least part of this unit.

Ts LIMESTONE AND SHALE (LATE TRIASSIC)—Thin to medium-bedded to massive, light- to dark-gray, fine-grained limestone. Limestone is subdivided into high and low thick and kilometers-long) within black shale, siltstone, and volcaniclastic sedimentary rock. Macrofossils including *Monotis subcircularis* and *M. salinaria* (map location F6; Clautice and others, 1989), *Tropites* cf. *T. kellyi*, and *Halobia* cf. *H. superba* (map location F7; Silberling and others, 1981) indicate a Late Triassic age. This unit overlies the Nikolai Greenstone (unit TRn).

TRn NIKOLAI GREENSTONE, UPPER MEMBER (LATE TRIASSIC)—Dark gray-green to maroon, massive, amygdaloidal metabasalt flows and flow breccia. Flows are thin to thick, locally columnar, and generally interpreted as subaerial. Metamorphosed to lower greenschist facies. Locally porphyritic, with plagioclase phenocrysts up to 7 mm. For the purposes of this map, the Nikolai Greenstone is subdivided into high and low TiO₂ subgroups following the criteria of Greene and others (2008); greenstones of unit TRn2 have TiO₂ greater than about 1.4 percent, Unit TRn1 positions and stratigraphically overlies unit TRt (where present). A combination of radiometric age, paleontological data, and magnetostratigraphic constraints indicate that the entirety of the approximately 3500-m-thick Nikolai Greenstone (TRn1 and TRn2) erupted during a short time period around 230 to 225 Ma (Greene and others, 2010).

TRn1 NIKOLAI GREENSTONE, LOWER MEMBER (LATE TRIASSIC)—Dark gray-green metabasalt flows, including pillow structures and minor flow breccia. Other minor interlayered lithologies include aquagene and epiclastic tuff, breccia, argillite, and chert. Metamorphosed to lower greenschist facies. For the purposes of this map, greenstones of unit TRn1 have less than about 1.4 percent TiO₂. Unit TRn1 occurs discontinuous across the map area, and it predates and underlies unit TRn2. The map distribution and stratigraphic position of TRn1 (a geochemically defined unit) are similar to, but not entirely the same as, that of pillowed greenstone units (defined by depositional environment) mapped at the base of the Nikolai Greenstone by previous workers (Reiff of Stout, 1976; Tripp of Silberling and others, 1981).

TRnp RAINY CREEK PICRITE (LATE TRIASSIC)—Black, aphanitic, massive to fragmental picrite volcanic rocks and related hypabyssal dikes. May have originated as pyroclastic rocks, submarine volcaniclastic rocks, or flow breccia. In thin section, the rock is aphanitic, lacking phenocrysts or serpentinite pseudomorphs after olivine. The dominant identifiable mineral is fine-grained secondary actinolite, which can account for up to 95 percent of some samples and is consistent with metamorphism at lower greenschist facies. Picrite volcanic rocks overlie units TRpw and TRzrt on an apparent angular unconformity, and clasts of dunite appear locally in picrite intrusions. $^{40}Ar/^{39}Ar$ analysis of hornblende from this unit yielded an age of 225.7 ± 2 Ma (map location A7; Bittenbender and others, 2007), in agreement with other ages for Nikolai Greenstone magmatism. Trace-element geochemistry indicates that unit TRnp is the chemically primitive relative of the high-Ti upper member of the Nikolai Greenstone (unit TRn2).

Ts2 GABBRO (LATE TRIASSIC)—Sill-form intrusions of fine- to medium-grained, dark greenish-gray gabbro, hornblende gabbro, olivine gabbro, and diorite. Primary minerals are clinopyroxene and plagioclase, plus local hornblende, biotite, quartz, magnetite, and olivine. Metamorphosed to lower greenschist facies. $^{40}Ar/^{39}Ar$ dating of biotite from olivine gabbro in the Butte Creek area yielded a Late Triassic age of 225.8 ± 1.1 Ma (map location A9; Benowitz and others, 2014). Unit Ts2 gabbro sills represent comagmatic intrusive equivalents of the Nikolai Greenstone (units TRn1 and TRn2) and share the same geochemical characteristics, including bimodal Ti concentrations, but are not differentiated at this map scale.

TRzrt ULTRAMAFIC ROCKS (LATE TRIASSIC)—Sill-form intrusions of olivine ± clinopyroxene cumulate rocks, mainly dunite, wehrlite, troctolite, plagioclase peridotite, and olivine gabbro. Intrusions are typically fine to medium grained, and mineralogy includes olivine, poikilitic clinopyroxene, plagioclase, chromite, and hornblende. Metamorphosed to lower greenschist facies; olivine is partially to completely serpentinized. The larger intrusions are multiphase sill complexes and are comagmatic to both TRn1 and TRn2 (Lande, 2016).

Pz HYPABYSSAL INTRUSIONS (PERMIAN)—Hypabyssal dikes, sills, and stocks of andesite porphyry, plus lesser porphyry dacite porphyry and rhyolite. This unit intrudes the Early Permian to Middle Pennsylvanian Slana Spur Formation (part of unit PPzw) and is interpreted as comagmatic with volcanic rocks interbedded within that unit (Nokleberg and others, 2015). This unit may correlate to middle Permian orthogneiss (unit Pzogg) of the Gulkana complex.

Pl LIMESTONE (PERMIAN)—Light- to medium-gray bioclastic limestone, calcarenite, impure marble, and dolomitic marble. Locally interlayered with volcaniclastic sediments. Metamorphosed to greenschist facies. Characterized by abundant macro- and microfossils, including brachiopods and corals of Late Permian age (map locations F15 [Rose, 1966], F22; F23 [Nokleberg and others, 1992]). Conodonts from this unit in the Talkeetna Mountains D-2 Quadrangle are also of Early Permian age (map locations F12, F13; Solie and others, 2015).

SPzw SEDIMENTARY AND VOLCANIC ROCKS (PERMIAN TO TRIASSIC)—A mixed unit of interlayered sedimentary and volcanic rocks of Permian to Triassic age, including argillite, chert, shale, limestone, volcaniclastic rocks, pyroclastic deposits, and andesitic to basaltic flows. Larger beds of Permian limestone within this unit are mapped as unit Pl. Metamorphosed to lower greenschist facies. Fossils from within this unit indicate ranges from Middle Pennsylvanian (F24; Bittenbender and others, 1992) to Early Permian (F16 [Solie and others, 1990], F21 [Silberling and others, 1981]). Conodonts from this unit yield a Permian (277.3 ± 11.8 Ma) U-Pb magmatic crystallization age (map location U6; Twelker and O'Sullivan, 2016). This age, and the relatively mafic volcanic and sedimentary facies of the unit, strongly suggest a correlation to Permian portions of the sedimentary and volcanic rock unit SPzu.

PPzt MARBLE (PENNSYLVANIAN TO PERMIAN)—Laminated to massive marble and argillaceous marble. Locally carbonaceous. Forms two mappable layers and numerous smaller interlayers within adjacent units. Metamorphosed to greenschist facies. Age is likely Permian based on the correlation of previously mentioned carbonaceous rocks of Permian age (unit PPzcs).

PPzcs MAFIC METAVOLCANIC ROCKS (PENNSYLVANIAN TO PERMIAN)—Dark green-gray and olive-brown to black massive basaltic agglomerate and pillowed metabasalt, with local andesite and gabbroic rocks. Volcanic rocks are interlayered with local thin layers of chert and siliceous, argillaceous tuff. Metamorphosed to greenschist facies. The only age control for this unit is from interlayered limestone, which includes conodonts of post-Middle Devonian age (Clautice and others, 1989). The composition of chert of this unit, including the interlayered sedimentary rocks and the stratigraphically overlying(?) metavolcaniclastic rocks of Permian age (unit PPzmv), is similar to that of the Pennsylvanian mafic volcanic rocks of the Wrangellia terrane (unit Pzmv).

PPzmv FELSIC VOLCANIC ROCKS (PENNSYLVANIAN)—Predominantly felsic volcanic rocks, including volcaniclastic rocks of dacite to rhyolite composition, plus lesser flows of rhyolite to dacite composition. A few thin interbeds of argillaceous siltstone, claystone, calcareous sandstone, marble, and dolomitic marble are present. Metamorphosed to lower greenschist facies. Fossils from this unit indicate a Middle Pennsylvanian age (Read, 1976); the top of the unit is interpreted to be the boundary between Pennsylvanian and Permian strata (Stout, 1976).

Pzmv MAFIC VOLCANIC ROCKS (PENNSYLVANIAN)—Flows, volcanic breccias, and volcaniclastic rocks primarily of andesitic, basaltic, and locally dacitic composition. Interbedded with volcanically derived lithic sandstone, greywacke, calcareous sandstone, and limestone. Metamorphosed to lower greenschist facies. Unit is correlative with felsic volcanic rocks of unit PPzmv, and on this basis is interpreted to be of Pennsylvanian age.

PALEOZOIC METAMORPHIC UNITS OF THE CLEARWATER MOUNTAINS (WRANGELLIA TERRANE?)

Pzog ORTHOGNEISS (PERMIAN)—Medium- to coarse-grained orthogneiss of granite, quartz monzonite, quartz diorite, and granodiorite composition. Metamorphosed to greenschist facies. Zircons from this unit yield a Permian (268.1 ± 11.6 Ma) U-Pb magmatic crystallization age (map location U5; Twelker and O'Sullivan, 2016). Other granitoid rocks in the Clearwater Mountains have been earlier phases of Slana Spur plutonism (Silberling and others, 1992). This inheritance, as well as the lack of any Precambrian zircons, suggests the Clearwater may be metamorphosed equivalents of the Wrangellia terrane. This unit may be temporally equivalent to the early to middle Permian hypabyssal intrusions in the Rainbow Ridge area (unit Pz).

PPzs METASEDIMENTARY ROCKS (PENNSYLVANIAN TO PERMIAN)—A mixed metasedimentary and metavolcanic assemblage including quartz-mica schist, graphite argillite, gray-green to apple-green schistose metavolcaniclastic rocks, and tabular-bedded metagraywacke of volcaniclastic provenance. Metamorphosed to greenschist facies. Age is likely Permian based on the presence of conformable layers of Permian metavolcaniclastic rocks (unit Pzmt) within the unit.

Pzmt METAVOLCANICLASTIC ROCKS (PERMIAN)—Light-green to gray-green phyllitic metavolcaniclastic rocks with subordinate chlorite-quartz-plagioclase metavolcaniclastic rocks, massive greenstone flows, metagraywacke, and argillite. Metamorphosed to greenschist facies. Zircons from this unit yield a Permian (277.3 ± 11.8 Ma) U-Pb magmatic crystallization age (map location U6; Twelker and O'Sullivan, 2016). This age, and the relatively mafic volcanic and sedimentary facies of the unit protolith, suggest a correlation to Permian portions of the sedimentary and volcanic rock unit SPzw.

Pzu GRANITIC ROCKS (LATE PENNSYLVANIAN)—Pluton and smaller stocks of medium- to coarse-grained quartz monzonite, granodiorite, granite, and quartz diorite. This unit is characteristically altered, resulting in near-total replacement of biotite and hornblende by chlorite, epidote, and iron oxides; plagioclase is altered to sericite, epidote, and clay minerals. Microcline is much less altered, but quartz is strained (Stout, 1976). U-Pb zircon ages range from 301.1 ± 2.7 to 306.4 1.6 Ma (see selected U-Pb zircon geochronology table).

Pzm PLAGIOGRANITE (MIDDLE PENNSYLVANIAN)—Hypabyssal stock of medium- to coarse-grained quartz monzonite, granodiorite, and granite. Metamorphosed to greenschist facies. The only age control for this unit is from Middle Pennsylvanian (Desmoinesian) fossils in the Ancient Parkfield Formation of Northeastern Alaska (Dutro and others, 1985). The Clearwater may be the southernmost exposure of Slana Spur Pluton (Silberling and others, 1992).

PPzu MAFIC METAVOLCANIC ROCKS (PENNSYLVANIAN TO PERMIAN)—Mostly dark green-gray and olive-brown to black massive basaltic agglomerate and pillowed metabasalt, with local andesite and gabbroic rocks. Volcanic rocks are interlayered with local thin layers of chert and siliceous, argillaceous tuff. Metamorphosed to greenschist facies. The only age control for this unit is from interlayered limestone, which includes conodonts of post-Middle Devonian age (Clautice and others, 1989). The composition of chert of this unit, including the interlayered sedimentary rocks and the stratigraphically overlying(?) metavolcaniclastic rocks of Permian age (unit PPzmt), is similar to that of the Pennsylvanian mafic volcanic rocks of the Wrangellia terrane (unit Pzmv).

METAMORPHIC COMPLEX OF GULKANA RIVER (WRANGELLIA TERRANE?)

PPzgs GREENSCHIST (PENNSYLVANIAN TO PERMIAN)—Metamorphosed mafic rocks of basaltic to andesitic composition. Hornblende phenocrysts and volcaniclastic textures are preserved locally. In the map area, these rocks have been metamorphosed to greenschist facies. These rocks are part of the regional Strelna metamorphic complex, which is thought to represent the metamorphosed equivalent of Paleozoic Wrangellia stratigraphy (Wilson and others, 2015; units SPzw, Pzv, Pzmv of this map).

PARAUTOCHTHONOUS NORTH AMERICA

Pzps JARVIS CREEK SCHIST (NEOPROTEROZOIC AND OLDER)—Intensely deformed metasedimentary rocks including quartz-mica schist, albite-chlorite-white mica schist, quartz-biotite schist, calc-schist, and marble. Metamorphosed to lower-greenschist to lower-amphibolite facies. This unit is part of the Jarvis Belt of metamorphosed parautochthonous continental margin rocks of Interior Alaska (Dusel-Bacon and others, 2006).

ACKNOWLEDGMENTS

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SELECTED $^{40}Ar/^{39}Ar$ GEOCHRONOLOGY

Label	Map Unit	Sample No.	Material	Age	Reference
A1	Qa	13ET166	Whole rock	0.990 ± 0.028 Ma	J. Benowitz, written commun., 2018
A2	NPks	WAFTUFF	Whole rock	3.808 ± 0.054 Ma	Allen, 2016
A3	Keg	13ET270	Biotite	124.6 ± 0.5 Ma	Benowitz and others, 2014
A4	Keg	15DR110	Hornblende	138.4 ± 0.8 Ma	Benowitz and others, 2017
A5	Keg	71ANT-42	Amphibole	146.6 ± 4.4 Ma (K-Ar)	Turner and Smith, 1974; Wilson and others, 2015
A6	TRt?	13ET134	Ca-amphibole	219.1 ± 7.4 Ma	Benowitz and others, 2017
A7	TRnp	HB03-29	Hornblende	225.7 ± 2.0 Ma	Bittenbender and others, 2007
A8	TRt	13RN428A	Biotite	225.8 ± 1.1 Ma	Benowitz and others, 2014
A9	TRt	AK25515	Biotite	228.3 ± 1.1 Ma	Bittenbender and others, 2007

SELECTED U-Pb ZIRCON GEOCHRONOLGY

Map No.	Map Unit	Sample No.	Age	Reference
U1	Kg	15ATW-51	102.4 ± 1.1 Ma	Waldien and others, 2020
U2	Ksg	13ET135	134.9 ± 2.1 Ma	Holm-Denoma and others, 2020
U3	Ksng	07CSR89b	142.2 ± 1.7 Ma	Mooney, 2010
U4	KJa	07CSR22c	149.8 ± 1.7 Ma	Mooney, 2010
U5	Pzog	13RN372A	268.1 ± 11.6 Ma	Twelker and O'Sullivan, 2016
U6	Pzmt	13ET205	277.3 ± 11.8 Ma	Twelker and O'Sullivan, 2016
U7	Pzg	15DR129	301.8 ± 2.7 Ma	Holm-Denoma and others, 2020
U8	Pzg	16CSB17A	306.4 ± 3.2 Ma	T. Waldien, written commun., 2018
U9	Pzg	16ATW-81	306.9 ± 2.6 Ma	Waldien and others, 2020
U10	Pzg	17ATW-11	304.0 ± 3.5 Ma	T. Waldien, written commun., 2018

SELECTED DETRITAL ZIRCON GEOCHRONOLOGY

Map No.	Map Unit	Sample No.	Maximum depositional age	Reference
D21	NPks	16ATW-86	6 Ma	Waldien and others, 2020
D22	NPks	15ATW-06	30 Ma	Waldien and others, 2020
D23	NPks	16ATW-77	60 Ma	Waldien and others, 2020
D24	Kms	15ATW-29	88 Ma	Waldien and others, 2020
D25	Kc	08CPM101	86.4 Ma	Mooney, 2010
D26	KJa	08CPM134	148.5 Ma	Mooney, 2010
D27	KJa	16ATW-10	156 Ma	Waldien and others, 2020
D28	KJp	15ATW-23	160 Ma	Waldien and others, 2020
D29	KJp	15LF204B	169 Ma	Holm-Denoma and others, 2020

SELECTED PALEONTOLOGICAL DATA

Map No.	Map Unit	Fossils	Age	Ref.
F1	NPks	Pollen: *Pinus*, *Betula*, Monocots, Nap (indeterminate), Sphagnum, *Picea*, *Tsuga/cicuta*, *Ericales*, *Pseudotsuga*	Pliocene	1
F2	NPks	Pollen: *Alnus*, *Picea*, *Pinaceae*, *Betula*, indeterminate monocots, indeterminate dicots	Miocene and Pliocene (?)	1
F3	NPks	*Alnus evidens*, *Metasequoia* (?) sp.	Oligocene	1
F4	KJc	*Buchia rugosa*	Late Jurassic	2
F5	Ts1	*Heterastridium*	Late Triassic	3
F6	Ts	*Monotis subcircularis* and *M. salinaria*	Late Triassic (Norian)	4
F7	Ts	*Tropites* cf. *T. kellyi* and *Halobia* cf. *H. superba*	Late Triassic	3
F8	Ts	Pelecypods *Halobia* sp. cf. *H. superba*	Late Triassic	1
F9	Ts1	Pelecypods *Daonella* or *Halobia*	Middle or Late Triassic	1
F10	SPzu	Conodonts *Neogondolella* cf. *N. pakistanensis*	Early Triassic	3
F11	SPzu	Radiolarians	Triassic	3
F12	Pl	Conodonts *Rhipidognathus ziemovitus*, *Xaniognathus* sp., *Neogondolella biteri*	Probably late Early to early Late Permian	5
F13	Pl	Conodonts *Neogondolella gracilis*, *Neogondolella* sp.	latest Early Permian	5
F14	Pl	Conodonts *Neogondolella bisselli* and *Neogondolella idahoensis pleyna*	middle to late Early Permian	5
F15	SPzu	Antiquatonia (possibly related to *A. reticulata*)	Permian	6
F16	SPzu	Brachiopods *Arctitreta* sp., *Spiriferella* sp., *Neospirifer* (?) sp.	Permian	1
F17	PPzu	Rugose corals, *Bothrophyllum* sp. cf. *B. pseudoconicum Dobrolyubova*	Permian	1
F18	SPzu	Rugose corals *Pseudobradyphyllum* (?) sp. A., *Bradyphyllum* (?) sp. A., *Bothrophyllum* sp. A.; Brachiopods *Spiriferella* sp., *Choristites* sp., *Reticulatia* sp., *Yakovlevia* sp., *Kochiprodactus* (?) sp.; Fusulinids *Pseudofusulinella* (?) sp.	Early Permian	1
F19	SPzu	Brachiopods *Chonetinella* sp., *Spiriferellina* sp.; Bryozoans; Echinoderms	Early Permian	7
F20	SPzu	Rugose corals *Bothrophyllum pseudoconicum Dobrolyubova*; Brachiopods *Neospirifer* sp., *Choristites* sp., *Unispirifer* (?) sp., *Yakovlevia* sp., *Linoproductus* sp., *Calliprotonia* (?) sp., *Dentirostrahorn* (?) sp.; Fusulinids *Pseudofusulinella* sp., *Eoparafusulinina* (?) sp.	Early Permian	1
F21	SPzu	Corals *Timania* sp. cf. *T. schmidti Stuckenberg*, *Durhamina olaahamania* n. sp., *Sinopora nintsi*; Fusulinids *Pseudofusulinella* sp., *Schwagerina* sp.	Early Permian	1
F22	Pl	Fusulinids *Schwagerina manhimmensis*; Brachiopods *Anemonoria* sp.; Bryozoans indeterminate Acanthocladiid (?), *Dyscritella* (?) sp., *Fenestella* spp., indeterminate Fenestellid, *Polypora* (?) spp., indeterminate Rhabdomesids (?), *Rhombotrypella* sp., *Streblotrypa* sp.	Early Permian	1
F23	Pl	Fusulinids *Schwagerina* sp. *moffitti*, *haiseri*, *colloun*, *Pseudofusulinella* sp., *Eoparafusulina wuddellii*; Tabulate corals *Sinopora* sp., Rugose corals *Hapsiphyllid* sp., *Chinophyllum* sp.; Brachiopods *Antiquatonia* sp., *Cameriana* sp., *Neospirifer*, sp., *Spiriferellina* (?), *Spiriferella* sp.	Early Permian	1
F24	SPzw	Brachiopods	Early Permian	3
F25	SPzw	Brachiopods *Waagenoconcha* sp. and *Neospirifer* sp.	Early Permian	1
F26	SPzw	Rugose corals *Bothrophyllum* sp. cf. *B. pseudoconicum Dobrolyubova*, *Carninia* (?) sp.; Tabulate corals *Michelinia* sp.; Indeterminate brachiopods	Early Permian	1
F27	PPzu	Fusulinids *Fusulinella* sp.	Middle Pennsylvanian	1
F28	PPzu	Rugose corals *Cryptophyllum stratum*; Tabulate corals *Chaetoporus* sp., *Michelinia* sp.; Brachiopods *Linoproductus* sp., *Juresania* sp., *Stenocisma* sp., *Institina*(?) sp., *Chonetites* sp.; Gastropods *Bellerophon*/*Euomphalus*	Early to Middle Pennsylvanian	1

[1] Nokleberg and others, 1992; [2] Smith and others, 1988; [3] Silberling and others, 1981; [4] Clautice and others, 1989; [5] Kline and others, 1990; [6] Rose, 1966; [7] Stout, 1976.

Ages are those assigned by the source reports and have not been reinterpreted

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