GEOLOGY AND MINERAL RESOURCES OF THE RUSSIAN MISSION C-1 QUADRANGLE, SOUTHWEST ALASKA

By T.K. Bundtzen and G.M. Laird

Professional Report 109

Published by

STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Fall
1991

Alaska Department of
NATURAL
RESOURCES

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This publication, released by the Division of Geological & Geophysical Surveys, was produced at a cost of $7.50 per copy which includes the text printed in Fairbanks, Alaska and the oversize maps which were printed in Washington, D.C. Publication is required by Alaska Statute 41, "to determine the potential of Alaskan land for production of metals, minerals,...[and] advance knowledge of the geology of Alaska."

Cover: *View east of outwash fan on East Fork Owhat River, Russian Mountains, Russian Mission C-1 Quadrangle, Alaska.*

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GEOLOGY AND MINERAL RESOURCES OF THE RUSSIAN MISSION C-1 QUADRANGLE, SOUTHWEST ALASKA

By
T.K. Bundtzen[1] and G.M. Laird[1]

ABSTRACT

The Russian Mission C-1 Quadrangle covers a 522 km^2 (201 mi^2) area near the western edge of the Kuskokwim Mountains, an upland dominated by accordant rounded ridges, isolated glaciated massifs, and broad sediment-filled lowlands in southwestern Alaska. The study area is sparsely populated; Chuathbaluk (population 185), is the only community with year-round residents. The Kuskokwim River flows westward across the study area, marking the divide between the northern uplands and southern lowlands. The region is dominated by the glacially carved Russian Mountains, which rise above lower, rounded hills to a maximum elevation of 1,059 m (3,474 ft).

Bedrock units range from Permian or older to late Tertiary in age. The older unit consists of Permian to Lower Cretaceous argillite, metabasalt, and metasandstone of the Gemuk Group that have undergone lower greenschist facies metamorphism. In fault contact with the Gemuk Group are turbidite-dominated deposits of the Kuskokwim Group, which, based on a sparse fossil assemblage range from late Early to Late Cretaceous in age. The Kuskokwim Group is about 2,000 m (6,500 ft) thick in the study area. Intruding and overlying the older layered rocks is an Upper Cretaceous volcanic-plutonic complex of peraluminous, alkali-calcic andesite flows and tuff and monzonite to quartz syenite plutonic rocks. In turn, peraluminous felsic dikes and mafic sills also believed to be of Late Cretaceous(?) age intrude the igneous complex and the older layered rocks. Tertiary basalt caps the Gemuk and Kuskokwim Groups immediately west of the Owhat River. Quaternary deposits in the Russian Mountains include four glacial sequences. These, combined with eolian, fluvial, and colluvial deposits, cover about 55 percent of the map area.

The Owhat fault, probably a splay of the Iditarod-Nixon transcurrent fault, trends roughly north-south along the Owhat River and juxtaposes the Gemuk Group against the Kuskokwim Group. Most recent movement along the fault occurred prior to extrusion of the overlying basalt, which yielded a K-Ar age of 6.19 Ma.

Principal mineral deposits consist of mesothermal, intrusive-hosted, polymetallic gold-sulfide-tourmaline greisen veins that intrude a prominent high-angle fracture system in the central Russian Mountains. Four prospects contain a minimum inferred reserve of 229,200 metric tons (253,500 short tons) of ore that grade 4.48 ppm (0.13 oz/ton) gold, 9.59 percent arsenic, 0.20 percent antimony, 0.01 percent tin, and 0.61 percent copper, and contain anomalous values of silver, lead, bismuth, tungsten, cobalt, zinc, and uranium. Placer gold is present on Mission and Cobalt Creeks, but no mining activity has been recorded. Aggregate sites in the study area could be developed for local construction projects. A promising riprap quarry site north of Chuathbaluk along the flanks of the Russian Mountains could supply riprap to communities along the Kuskokwim River for erosion-control programs.

INTRODUCTION AND GEOGRAPHY

During the periods July 23-26, 1985, July 15 and August 11, 1987, and June 12-26, 1988, we conducted 1:63,360-scale geologic mapping projects and related mineral-resource investigations in the Russian Mission C-1 Quadrangle of southwestern Alaska (fig. 1). The study area lies within the Kuskokwim Mountains geographic province, a maturely dissected, generally unglaciated upland that consists of accordant, rounded ridges [averaging eleva-

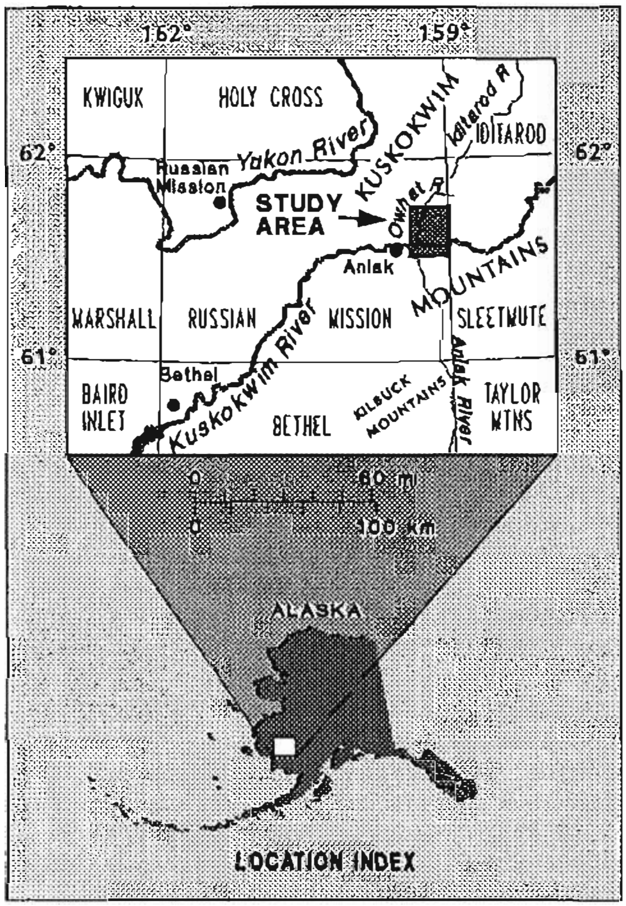

Figure 1. Location map of Russian Mountains and adjacent lowland.

[1]Division of Geological and Geophysical Surveys, 794 University Avenue, Suite 200, Fairbanks, Alaska 99709-3645.

tion 600 m (2,000 ft)] interspersed with broad, sediment-filled lowlands [average elevation 90 m (300 ft)] (Wahrhaftig, 1965). In the northern half of the quadrangle, rugged peaks of the Russian Mountains massif, composed of granitic, and volcanic rocks, and hornfels, cover an area of 140 km² (50 mi²) and rise about 700 m (2,300 ft) above the surrounding vegetated hills to an elevation of 1,057 m (3,468 ft). The massif is one of 13 isolated massifs or ridge complexes in the Kuskokwim Mountains that were sufficiently large and high enough to generate alpine glaciers during the Quaternary period (Kline and Bundtzen, 1986).

Western and northern slopes of the Russian Mountains are drained by the Owhat River, which flows through low, rolling hills of the Owhat River upland. Slightly metamorphosed sedimentary and volcanic rocks typically underlie the gently rolling hillslopes west of the Owhat River and are covered with climax white spruce, birch, and sphagnum moss. Bedrock exposures in these lower areas are poor and often confined to river cutbanks. The Owhat River joins the Kuskokwim River, which is situated along the westcentral boundary [elevation 18 m (59 ft)] of the quadrangle. From this point southward, the Kuskokwim River and its flood plain dominate the topography. The Kolmakof River empties into the Kuskokwim River east of the quadrangle and drains most of the eastern slopes of the Russian Mountains. The southern slopes of the Russian Mountains are drained by Mission Creek and other small drainages that also empty into the Kuskokwim River. Quaternary fluvial, colluvial, and eolian deposits cover about 55 percent of the study area.

The village of Russian Mission was established along the Kuskokwim River by Moravian missionaries in 1885 (Orth, 1971, p. 821), and rapidly became a major center of the Russian Orthodox Church. Sometime after 1969, the village was renamed "Chuathbaluk" partly because of frequent confusion with the village of Russian Mission located on the lower Yukon River. Today about 185 people live in the community. No thoroughfares have been built in the area aside from a short secondary road that links Chuathbaluk with an airport. Trails for off-road vehicles are abundant and extensively used, particularly during the winter months. The larger village of Aniak (population 540), situated west of the map area about 30 km (19 mi) downstream from Chuathbaluk, serves as a center of trade, manufacturing, and transportation for communities of the middle Kuskokwim River area.

Lands of the Russian Mission Quadrangle are owned by state (31 percent) and federal (35 percent) governments and native regional corporations (34 percent). The subsurface and surface estate of the central and southern Russian Mountains is owned by Calista Native Regional Corporation. Kuskokwim Village Corporation, another Native enterprise, manages the surface holdings of several Kuskokwim River villages, including Chuathbaluk. Outlying western and eastern outlier ridges of the Russian Mountains and the Owhat upland are owned by the federal government and managed by the U.S. Bureau of Land Management under multiple-use principles. The state of Alaska, which also manages its lands for multiple use (Alaska Department of Natural Resouces, 1986), owns most of the study area south of the Kuskokwim River and the beds of all navigable rivers.

ACKNOWLEDGMENTS

We thank Wyatt G. Gilbert (DGGS) for assisting us in the field during July 1987, and William W. Patton, Jr., and John M. Murphy (U.S. Geological Survey) for providing logistical support and technical advice during August 1987. We also thank Bruce Hickok and Mike Niemeyer of Calista Native Regional Corporation for permission to examine the geology of Calista lands in the study area. We appreciate the technical reviews by Richard C. Swainbank (Alaska Department of Commerce and Economic Development, Division of Business Development) and Jeffrey T. Kline, Mark S. Robinson, and Diana N. Solie (DGGS), and gratefully acknowledge the dedication of senior manuscript typist Roberta A. Mann (DGGS). We thank Ellen E. Harris for the cartography and for drafting most of the figures in this report.

GEOLOGIC UNITS

INTRODUCTION

Fifteen bedrock units, ranging from Permian to late Tertiary in age, are exposed in the study area. Samples of all units were studied by standard petrographic techniques in conjunction with microprobe, major-oxide, and multielement and radiometric analyses (tables 1-3). Fourteen glacial, fluvial, eolian, and colluvial units of Quaternary age were identified by field examination and photogeologic techniques. Abbreviated descriptions of all geologic units are provided on sheet 1.

GEMUK GROUP

The oldest known bedrock unit in the study area consists of poorly exposed argillite, mafic meta-igneous rocks (mainly metabasalt), and tuffaceous metasandstone believed to be part of the Gemuk Group (sheet 1, MzPzvs). Cady and others (1955) originally described the Gemuk Group for exposures near Cinnabar Creek, about 60 km (40 mi) southeast of the study area. Our descriptions are based on a brief examination of rubble crop west of the Owhat River, which Hoare and Coonrad (1959) originally assigned to the Kuskokwim Group on the basis of photogeology.

Table 1. *K-Ar age determinations for selected rock samples from Russian Mission C-1 Quadrangle, Alaska*
[Analyses by Robin Cotrell, DGGS-UAF Cooperative Geochronology Laboratory, Fairbanks, Alaska]

Map no.[a] (field no.)	1 (88BT113)	2 (85BT174)	3 (88BT85)	4 (88BT115)
Rock type	Vesicular basalt	Biotite-pyroxene quartz monzonite	Tuffaceous pyroxene andesite	Thermally altered pyroxene andesite
Mineral dated	Whole rock	Biotite	Whole rock	Plagioclase
Sample wt (g)	2.170	0.1197	0.8317	1.777
K_2O (wt %)	0.667	8.96	4.36	0.608
$^{40}Ar^*$ (10^{-11} mol/g)	0.5944	92.50	48.51	6.225
$^{40}Ar^*$ (%)	37.87	80.58	90.28	93.75
$\frac{^{40}Ar^*}{^{40}K \times 10^{-3}}$	0.36000	4.1658	4.4960	4.1322
Age (Ma)[b]	6.19 ± 0.19	70.3 ± 2.1	75.8 ± 2.2	69.8 ± 2.1[c]

[a]Sheet 1.
[b]Constants used in age calculations: $\lambda_\varepsilon = 0.581 \times 10^{-10} yr^{-1}$; $\lambda_\beta = 4.962 \times 10^{-10} yr^{-1}$; and $^{40}K/K_{total} = 1.167 \times 10^{-4}$ mol/mol.
[c]Minimum age, 10^6 yr.
*Radiogenic isotope.

Thin-section analyses (N=3) of lithic sandstone from the MzPzvs unit revealed subangular to angular grains of quartz (35 percent), angular clasts of chert (25 percent), rock fragments other than chert (17 percent), pumpellyite (2 percent), white mica (5 percent), albitized plagioclase (11 percent), chlorite and epidote (6 percent), and indeterminated matrix (10 percent). The clasts have been deformed and recrystallized by regional metamorphism, which, based on the secondary mineral assemblage epidote + pumpellyite + chlorite + albite probably reached lower greenschist facies conditions (Turner, 1968). The metasandstone and associated metasiltstone in the MzPzvs unit exhibit graded bedding that may have resulted from turbidity currents. Interbedded dark-gray, massive, cherty argillite consists of about 95 percent quartz and feldspar and 5 percent graphitic material. Locally the cherty argillite is difficult to differentiate from fine-grained igneous rocks. Together the metasedimentary rocks compose about 80 percent of the Gemuk(?) Group in the study area.

The remaining 20 percent of the MzPzvs unit consists of dark-green metabasalt and metadiorite present as discontinuous lenses or layers that extend along strike for several kilometers and are 5 to 50 m (16 to 160 ft) thick. The mafic meta-igneous rocks contain relict phenocrysts of olivine (altered to antigorite), highly corroded clinopyroxene, leucoxene, and albitized plagioclase in a groundmass of plagioclase, magnetite(?), and clinopyroxene. One major oxide analyses (table 2; no. 2) of metabasalt indicates an alkali-olivine basalt classification similar to those described from oceanic arc settings. Stratigraphic relations with adjacent metasedimentary rocks of the MzPzvs unit are uncertain due to lack of field exposures.

No fossils were recovered from the metasedimentary rocks, and the meta-igneous rocks were too altered for radiometric dating. Hoare and Coonrad (1959) reported Permian and Permian(?) fossil localities from correlative rocks immediately west of the study area. Box (1983, 1985) assigned rocks similar to those of the Gemuk(?) Group to the Hagemeister terrane, which he regards as an Early Cretaceous oceanic island arc sutured to North America during Early to Late Cretaceous time.

KUSKOKWIM GROUP

The two major stratigraphic units underlying the study area consist of poorly exposed, fine- to coarse-grained calcareous lithic sandstone and interbedded micaceous siltstone (Ksl) and fine- to coarse-grained, noncalcareous, micaceous lithic sandstone, interbedded siltstone, and minor shale (Kus). Both units are correlative with the Kuskokwim Group, which was originally described by Cady and others (1955). The Kuskokwim Group along the Kuskokwim River is fairly well exposed, but outcrops in upland areas are rare and generally collapsed into piles of frost-riven rubble.

In thin section, the calcareous lithic sandstone (Ksl) is composed of quartz (20 percent), chert (15 percent), slate (15 percent), calcite (10 percent), albite (5 percent), felsic igneous (3 percent), and white mica (2 percent) clasts in a calcite matrix (30 percent). Coarse-grained lithic sandstone (Kus) west of the Russian Mountains consists of subangular grains of quartz (35 percent), chert (20 percent), volcaniclastic material (15 percent), and white mica (3 percent) in a pseudomatrix of deformed rock fragments (25 percent) and is similar to that of the MzPzvs unit but less recrystallized. Prehnite and chlorite replace albite and white mica in the calcareous lithic sandstone (Ksl) and plagioclase in the noncalcareous lithic sandstone (Kus), suggesting zeolite-facies metamorphism.

According to Bundtzen and others (1989), river exposures of the calcareous sandstone and siltstone (Kls) in the southeastern corner of the map area consist of rhythmic beds 5 to 100 cm (2 to 39 in.) thick. Flute casts, rip-up clasts, and Bouma Ta-c intervals in sandstone beds of both units (Ksl, Kus) suggest that Kuskokwim sediments were deposited by turbidity currents. The general lack of contiguous exposures in the study area limited further study of sedimentary features.

Assuming the lithic sandstone beds (Ksl, Kus) exposed along the Kuskokwim River above Chuathbaluk are laterally continuous, we estimate a thickness of at least 2,000 m (6,500 ft) for the Kuskokwim Group in the study area. However, the Cretaceous section along the river could be structurally repeated by unrecognized isoclinal folding. Cady and others (1955) estimated a thickness of 12,000 m (40,000 ft) for a section of Kuskokwim Group exposed upriver from the study area between the villages of Sleetmute and Crooked Creek. Bundtzen and Gilbert (1983) and Bundtzen and others (1988a) estimated stratigraphic thicknesses from 2,200 to 3,500 m (7,200 to 11,500 ft) for the Kuskokwim Group to the northeast, which is similar to unit thicknesses assessed in the study area. The lithic sandstone units (Ksl, Kus) may be part of the thinner western edge of a northeasterly oriented, subsiding Late Cretaceous continental trough that was dislocated by transcurrent faults (Bundtzen and Gilbert, 1983).

Inoceramus shells of Cenomanian age (earliest Late Cretaceous) were reported by Hoare and Coonrad (1959) from seven localities within the Kuskokwim Group 12 to 16 km (7.2 to 10 mi) upriver from Chuathbaluk. Subsequent fossil evidence suggests that the Kuskokwim Group ranges from Cenomanian to Maastrichtian (latest Late Cretaceous) age; the most abundant fossil collections are of Turonian (early Late Cretaceous) age (Bundtzen and Gilbert, 1983; Bundtzen and Laird, 1983; Bundtzen and others, 1988a; Miller and others, 1989).

VOLCANIC-PLUTONIC COMPLEX

Intruding and overlying the Paleozoic to Mesozoic stratigraphic units are Upper Cretaceous volcanic and plutonic rocks in the Russian Mountains and mafic to felsic dikes and sills throughout the upland areas (sheet 1). For purposes of the following discussion, the igneous rocks are categorized by modal and normative mineralogy according to classification schemes of Peacock (1931), Hiatanen (1963), Irvine and Barager (1971), Streckeisen (1973), and McBirney (1984).

VOLCANIC ROCKS (TKvi, TKva, TKvm, TKvt)

Basaltic andesite and andesite flows (TKvm), andesite to dacite flows and tuff (TKvt, TKvi), and volcanic agglomerate (TKva) blanket the northern flanks of the Russian Mountains. Poorly exposed andesite to dacite flows (TKvi) also cover a small isolated area southwest of the mountains. Volcanic units weather to black-lichen-covered, slabby rubble that sharply contrasts with larger blocks of underlying and flanking plutonic rocks.

Individual basaltic andesite (TKvm) and andesite (TKvi) flows range from 5 to 20 m (16 to 66 ft) thick and display distinctive columnar joints, which suggests that the units were deposited in a subaerial environment. In thin section, plagioclase phenocrysts from both TKvm and TKvi flows show both normal and reverse zoning. The phenocrysts of placioclase range from An_{50-70} in composition whereas the groundmass averages An_{30-50}; the normative average plagioclase composition from four flow rocks is An_{42} (table 2). Mafic components of the flows include minor titanaugite, lesser olivine, and rare biotite (fig. 2). Most basaltic andesite samples exhibit ophitic texture; samples of the andesite and dacite more commonly show trachytic texture.

Tuff-dominated lithologies of the andesite to dacite flows and tuff unit (TKvt) contain abundant, altered shards and feldspar microlites in layers 5 to 30 cm (2-12 in.) thick separated by sandstone beds composed of andesite clasts (50 percent), quartz (25 percent), and chert (25 percent). In outcrop, angular, cobble-sized fragments near the base of an individual bed or layer fine upward to silt-sized particles. The graded nature of the alternating sandstone and tuffaceous layers suggests that much of the volcanic component was deposited by air-fall processes.

Agglomerate (TKva) contains rounded clasts of andesite and sandstone to 150 cm (59 in.) diam that are nested in zeolitized, green-gray lapilli tuff. The presence of sandstone suggests that the volcanic pile may have been deposited on the eroded surface of the Kuskokwim Group. Agglomerates in the Russian Mountains bear some resemblance to lahar and related deposits of the Iditarod Basalt in the DeCourcy Mountain area, about 50 km (31 mi) northeast of the Russian Mission C-1 Quadrangle (McGimsey McGimsey and Miller, 1988).

Despite limited outcrops of the Russian Mountains volcanic pile, we recognize a recurring regular stratigraphic

Table 2. *Major-oxide determinations and CIPW normative mineralogy for selected igneous rocks from Russian Mission C-1 Quadrangle, Alaska*

[Samples analyzed with X-ray fluorescence spectrography by Chemex Laboratories, Vancouver, British Columbia, Canada]

Map no.[a]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field no.	88BT109	88BT107	88BT113	88BT95C	88BT95B	88BT93	88BT82C	88BT103B	88BT103A	88BT67J	88BT67A	88BT89	88GL18	88BT88	88BT70	88BT73
Rock type (unit)	Quartz porphyry (TKdf)	Altered basalt (MzPzvs)	Basalt (Tvb)	Andesite tuff (TKvt)	Andesite (TKvm)	Basaltic andesite (TKvm)	Basaltic andesite (TKvm)	Quartz monzonite (TKmp)	Quartz monzonite (TKmp)	Syenite to monzonite (TKsym)	Quartz syenite (TKsy)	Quartz porphyry (TKdf)	Quartz syenite (TKsy)	Quartz syenite (TKsy)	Quartz syenite (TKsy)	Quartz syenite (TKsy)
Major oxides (weight percent)																
SiO_2	67.07	45.63	51.20	57.15	58.66	58.56	56.17	71.57	72.69	59.66	63.95	71.16	61.89	65.22	66.37	65.90
Al_2O_3	16.38	12.80	14.90	20.16	15.44	17.44	16.61	14.75	14.42	16.44	16.46	16.02	17.20	16.25	15.89	16.25
Fe_2O_3	1.67	6.50	3.80	1.98	2.10	1.21	1.55	1.36	1.18	1.59	0.63	0.67	1.31	0.87	1.30	1.07
FeO	2.13	14.60	6.60	3.04	3.98	4.41	4.85	0.76	0.81	4.74	2.64	0.52	3.00	2.45	2.18	1.97
MgO	0.96	2.41	7.20	2.26	4.97	2.82	3.81	0.29	0.21	2.39	1.60	0.16	1.74	1.74	1.48	0.97
CaO	1.42	7.85	7.77	7.56	5.20	4.78	5.19	0.79	0.55	4.50	2.92	2.12	3.23	2.80	1.92	2.00
Na_2O	4.85	1.71	3.47	3.33	2.84	3.17	2.68	3.55	3.49	2.94	3.63	4.03	3.92	3.43	3.27	3.84
K_2O	1.64	1.03	0.70	2.70	4.78	4.45	4.87	6.92	6.82	4.56	6.05	3.69	5.22	6.59	6.12	5.80
TiO_2	0.57	1.30	2.07	1.12	0.88	1.11	1.02	0.32	0.28	0.91	0.58	0.10	0.70	0.60	0.58	0.47
P_2O_5	0.26	0.79	0.28	0.60	0.42	0.52	0.50	0.08	0.07	0.41	0.26	0.07	0.24	0.21	0.17	0.18
MnO	0.08	0.50	0.14	0.09	0.10	0.08	0.07	0.02	0.02	0.11	0.05	<0.01	0.07	0.06	0.05	0.06
LOI*	2.67	3.00	0.77	0.54	0.77	0.16	1.68	0.54	0.62	1.30	0.55	1.73	1.66	1.02	1.49	1.35
CO_2	0.47	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	1.43	<0.20	<0.20	<0.20	<0.20	<0.20	0.51
Total	100.17	98.12	98.90	100.53	100.14	98.71	99.00	100.95	101.16	100.98	99.32	100.27	100.18	101.24	100.82	100.37
CIPW norms (weight percent)																
Quartz	28.91	4.74	2.97	8.87	6.25	7.78	4.69	22.45	24.83	10.79	10.77	29.33	8.98	11.36	17.27	15.44
Corundum	4.81	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.46	0.00	0.00	1.74	0.00	0.00	0.81	0.46
Orthoclase	9.99	6.54	4.18	15.96	28.42	26.68	29.57	40.72	40.08	27.43	36.20	22.13	31.31	38.86	36.41	34.79
Albite	42.29	15.54	29.65	28.18	24.18	27.22	23.30	29.91	29.37	25.32	31.10	34.60	33.67	28.96	27.85	32.98
Anorthite	5.51	26.00	23.23	32.09	15.36	20.51	19.43	3.38	2.26	18.52	10.88	10.21	14.13	9.46	8.47	8.88
Diopside	0.00	8.84	11.08	1.21	6.29	0.09	3.00	0.00	0.00	1.22	1.70	0.00	0.45	2.48	0.00	0.00
Hyperstene	4.26	23.61	18.70	7.31	13.77	12.58	14.53	0.72	0.61	11.65	6.70	0.66	7.63	6.01	5.79	4.55
Magnetite	2.50	10.12	5.56	2.87	3.06	1.78	2.31	1.84	1.70	2.35	0.92	0.99	1.93	1.26	1.90	1.58
Ilmenite	1.12	2.65	3.97	2.13	1.68	2.14	1.99	0.60	0.53	1.76	1.12	0.19	1.35	1.14	1.11	0.91
Apatite	0.62	1.96	0.66	1.39	0.98	1.22	1.19	0.18	0.16	0.97	0.61	0.16	0.56	0.48	0.40	1.42
Total	100.01	100.00	100.00	100.01	99.99	100.00	100.01	99.97	100.00	100.01	100.00	100.01	100.01	100.01	100.01	101.01
Differentiation index	81.19	26.82	36.79	53.00	58.85	61.68	57.56	93.09	94.28	63.54	78.06	86.05	73.95	79.18	81.53	83.21
Plagioclase composition (An)	11.52	62.59	43.94	53.24	38.84	42.98	45.47	10.16	7.14	42.24	25.93	22.78	29.56	24.62	23.32	21.21

[a]Sheet 1.
*Loss on ignition.

Table 3. *Geochemical determinations of selected samples from prospects and mineral occurrences in the Russian Mission C-1 Quadrangle, Alaska*

[Samples 87-88GL and BT analyzed with fire-assay and/or induced nuclear activation techniques by Nuclear Activation Services, Ltd., Hamilton, Ontario, Canada; samples 82MR and 85BT analyzed with fire-assay, X-ray fluorescence, and induced nuclear activation techniques by Bondar-Clegg, Vancouver, British Columbia, Canada. Underlined samples considered anomalous by data inspection]

Map no.[a]	Field no.	Cu	Pb	Zn	Au	Ag	As	Sb	Mo	Sn	W	Ni	Co	Cr	U	Th	La	Ta	Cd	Remarks
			(%)		(ppb)	(ppm)	(%)							(ppm)						
1	88GL31	--	--	0.01	ND	ND	<0.01	<0.01	10	ND	ND	ND	6	140	2.0	5	22	ND	--	Ferruginous breccia in felsite
2	88BT96	--	--	ND	8	ND	0.01	0.01	7	10	ND	ND	3	180	8.0	28	38	1	--	Ferruginous syenite
3	85BT174	0.02	0.94	ND	ND	45	0.46	0.30	--	ND	ND	--	--	700	41.0	9	--	--	900	Quartz veinlets in syenite
4	88BT94	--	--	0.10	36	75	0.27	0.02	ND	25	ND	ND	4	210	7.0	12	32	ND	--	Shear zone in andesite
5	88BT93C	--	--	0.01	180	7	0.02	ND	6	10	ND	ND	17	310	5.0	10	36	ND	--	Columnar-jointed pyroxene andesite
6	85BT178	<0.01	<0.01	ND	ND	ND	<0.01	0.002	--	ND	5	--	--	80	7.0	14	--	--	ND	Ferruginous shear zone in andesite
7	85BT180	<0.01	<0.01	ND	ND	2	<0.01	0.004	--	ND	ND	--	--	310	5.0	11	--	--	ND	Ferruginous shear zone in hornfelsed andesite
8	88BT91	--	--	<0.01	15	ND	0.03	<0.01	ND	5	25	ND	8	230	6.0	14	28	ND	--	Pan concentrate, Cobalt Creek
9	88BT92	--	--	0.04	68,000	ND	0.04	0.07	16	1,500	130	500	62	930	16.0	22	66	16	--	Pan concentrate, Cobalt Creek tributary fan
10	88BT101	--	--	0.01	ND	ND	<0.01	<0.01	ND	ND	ND	ND	31	620	4.0	6	19	ND	--	Euhedral quartz in vugs of basaltic andesite
11	88GL21	--	--	ND	ND	ND	0.01	0.01	ND	300	ND	ND	4	310	6.0	11	14	1	--	Ferruginous shear zone in peraluminous felsite
12	88BT68	--	--	0.07	4,100	ND	10.00	0.99	ND	1,200	ND	ND	40	200	ND	ND	ND	8	--	Arsenopyrite-chalcopyrite-quartz vein in greisen, Louise Prospect
13	88BT67A	--	--	0.05	1,600	120	2.80	0.21	ND	ND	ND	ND	8	500	ND	3	8	5	--	45-in. chip channel in vein, Owhat Prospect
	88BT67B	--	--	ND	9,600	460	23.00	0.46	ND	ND	ND	ND	79	300	ND	ND	ND	ND	--	48-in. chip channel in sulfide greisen vein, Owhat Prospect
	88BT67C	--	--	ND	9,500	ND	26.00	0.29	ND	ND	340	ND	170	300	ND	25	ND	ND	--	32-in. chip channel in sulfide greisen vein, Owhat Prospect
	88BT67D	--	--	ND	1,100	ND	4.20	0.39	ND	ND	ND	200	10	7	ND	ND	ND	ND	--	22-in. chip channel in sulfide-quartz vein, Owhat Prospect
	88BT67E	--	--	ND	4,000	ND	17.00	0.25	ND	ND	ND	600	34	290	0.5	3	ND	5	--	45-in. chip channel in sulfide vein, Owhat Prospect
	88BT67F	--	--	<0.01	5,400	ND	20.00	0.25	ND	ND	ND	900	ND	300	0.5	3	ND	11	--	28-in. chip channel in massive arsenopyrite vein, Owhat Prospect
	88BT67G	--	--	0.13	14,000	ND	23.00	0.40	ND	620	ND	800	170	110	ND	3	ND	25	--	44-in. chip channel in massive sulfide greisen vein, Owhat Prospect
	88BT67H	--	--	0.25	19,000	ND	14.00	0.19	ND	2,900	ND	500	160	150	ND	2	ND	ND	--	18-in. chip channel in sulfide-rich greisen, Owhat Prospect
	88BT67I	--	--	ND	4,200	ND	21.00	0.36	ND	ND	320	ND	40	200	0.5	4	<1	ND	--	38 in. chip channel in sulfide-rich greisen, Owhat Prospect
	88BT67L	--	--	0.03	2,900	ND	1.00	0.36	ND	ND	ND	900	41	250	0.5	5	<1	7	--	72-in. chip channel in tourmaline greisen, Owhat Prospect
	82MR318A[b]	0.21	0.04	--	1,240	17	5.70	0.06	--	ND	15	--	--	--	--	--	--	--	--	Tourmaline-rich grab sample, Owhat Prospect
	82MR318C[b]	0.16	0.06	--	4,650	85	20.80	ND	--	ND	5	--	--	--	--	--	--	--	--	Arsenopyrite-bearing quartz-tourmaline vein, Owhat Prospect
	82MR318D[b]	0.14	0.07	--	6,510	175	33.60	ND	--	ND	5	--	--	--	--	--	--	--	--	Massive arsenopyrite with accessory chalcopyrite in tourmaline, Owhat Prospect
	82MR318E[b]	--	0.01	--	310	6	0.24	0.01	--	ND	5	--	--	--	--	--	--	--	--	92-in. chip channel in quartz-tourmaline vein, Owhat Prospect
	82MR318F[b]	--	0.02	--	1,550	53	1.37	ND	--	ND	15	--	--	--	--	--	--	--	--	36-in. chip channel in quartz-tourmaline vein, Owhat Prospect
	82MR318G[b]	--	0.01	--	ND	5	0.47	0.04	--	60	ND	--	--	--	--	--	--	--	--	15-ft chip channel in tourmaline greisen, Owhat Prospect
14	88BT89A	--	--	0.07	470	ND	0.41	0.02	ND	30	10	ND	3	250	9.0	15	26	1	--	38-in. chip channel in greisen, Headwall Prospect
	88BT89B	--	--	0.07	1,900	ND	5.10	0.05	ND	250	ND	ND	1	110	3.0	2	4	ND	--	27-in. chip channel ln arsenopyrite-bearing vein, Headwall Prospect
	88BT89C	--	--	0.01	80	ND	0.12	0.02	ND	25	25	ND	4	220	17.0	25	46	1	--	85-in. chip channel in greisen, Headwall Prospect
	88BT89D	--	--	ND	7,900	ND	18.00	0.20	ND	ND	10	ND	170	310	0.5	2	ND	ND	--	34-in. chip channel in arsenopyrite-bearing vein, Headwall Prospect
	88BT89F	--	--	0.05	9,000	ND	20.00	0.70	ND	2,200	ND	900	75	190	ND	5	ND	9	--	72-in. chip channel in greisen, Headwall Prospect
	88BT89G	--	--	0.01	210	ND	0.29	<0.01	ND	15	20	ND	30	310	3.0	6	23	ND	--	65-in. chip channel in greisen, Headwall Prospect
15	88BT72B	--	--	0.03	ND	7	0.61	0.06	ND	ND	ND	ND	170	410	5.0	3	28	ND	--	40-in. chip channel in tourmaline vein, Mission Creek Prospect
	88BT72C	--	--	ND	1,900	ND	1.20	0.70	ND	ND	55	400	ND	360	15.0	8	13	5	--	65-in. chip channel in sulfide-bearing vein, Mission Creek Prospect
	88BT72D	--	--	0.01	900	ND	1.50	0.11	ND	35	ND	ND	20	120	10.0	11	22	1	--	Chip sample from greisen, Mission Creek Prospect
	88BT72E	--	--	0.03	360	ND	0.77	0.77	ND	ND	ND	ND	6	270	ND	18	28	4	--	24-in. chip channel in greisen, Mission Creek Prospect
	85BT184A	3.24	0.06	0.02	8,300	26	3.00	0.21	ND	200	20	--	--	220	106	3	--	--	300	15-in. chip channel in greisen, Mission Creek Prospect
	85BT184B	2.20	0.03	0.02	5,580	9	2.35	0.18	ND	200	10	--	--	220	66.0	3	--	--	300	High-grade ore from mine dump, Mission Creek Prospect
	85BT184C	0.70	0.04	0.01	4,000	182	1.49	0.30	ND	100	ND	--	--	700	41.0	11	--	--	900	36-in. chip channel in greisen, Mission Creek Prospect
	85BT184D	1.99	0.04	0.02	4,907	21	70.20	0.12	6	34	30	25	5	171	--	--	--	--	--	Grab sample of greisen mineralization; contains 112 ppm Bi, 12 ppm Hg
	82MR315A[b]	--	--	--	90	--	0.66	0.012	--	--	--	--	--	--	--	--	--	--	--	Grab sample from greisen, Mission Creek Prospect
	82MR315D[b]	--	--	--	90	--	0.05	0.03	--	--	--	--	--	--	--	--	--	--	--	Grab sample from greisen, Mission Creek Prospect
	82MR315E[b]	0.91	0.14	--	18,600	50	0.91	0.32	--	ND	5	--	--	--	--	--	--	--	--	High-grade ore with retrograde quartz vein, Mission Creek Prospect
	82MR315F[b]	--	--	--	ND	--	0.02	<0.01	--	--	--	--	--	--	--	--	--	--	--	Grab sample from greisen, Mission Creek Prospect
16	88BT76	--	--	--	22	ND	0.02	0.03	ND	ND	10	900	6	180	14.0	21	37	ND	--	Grab sample from quartz vein with gossan
17	88BT75	--	--	--	ND	ND	0.30	1.50	ND	ND	ND	ND	ND	310	52.0	11	54	ND	--	Quartz vein with gossan--contains 353 ppm neodymium
18	88GL36	--	--	0.01	220	ND	0.01	ND	ND	ND	15	ND	30	510	7.0	9	81	ND	--	Shear zone in gossan horizon of intrusive
19	87GL37	--	--	ND	ND	ND	<0.01	0.01	7	10	ND	ND	2	100	38.0	16	35	1	--	Amethyst-bearing vein in hornfels
20	87BT51	--	--	0.03	250	ND	0.02	ND	22	60	ND	ND	74	750	15.0	11	58	12	--	Grab sample at mine dump from quartz-bearing vein in hornfels

[a]Sheet 1.
[b]Geochemical data provided by M.S. Robinson, DGGS, Fairbanks, Alaska.
ND = Below limit of detection or masked by interference from other elements.
-- = Not analyzed.

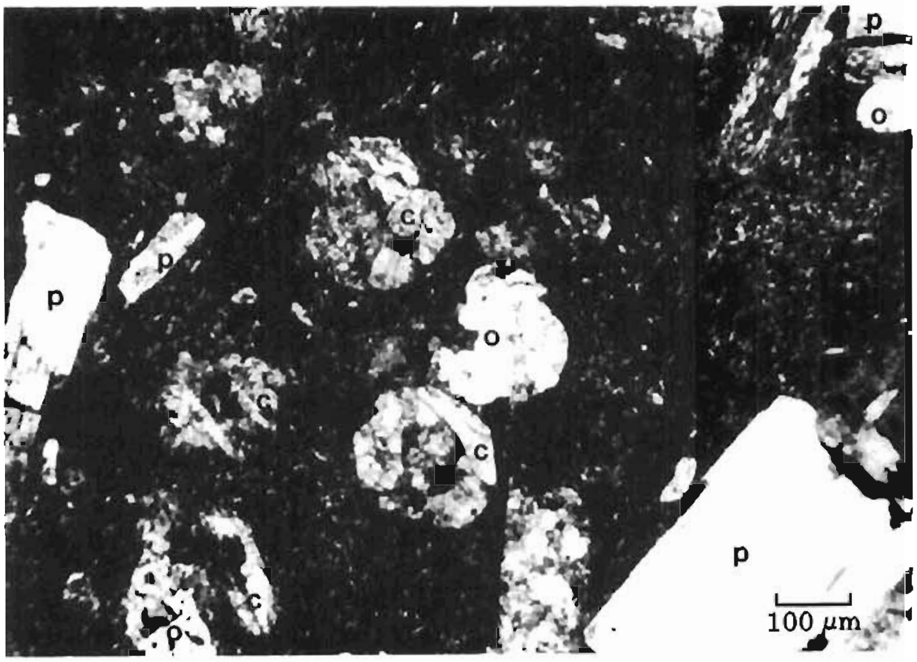

Figure 2. *Photomicrograph of basaltic andesite (85BT175) showing olivine (o), plagioclase (p), and altered clinopyroxene phenocrysts (c) in groundmass of andesine microlites, crossed nicols.*

pattern (sheet 1). Basal basaltic andesite and andesite flows (TKvm) are overlain by volcanic agglomerate (TKva), which is capped by andesite and dacite flows and tuff unit (TKvt). This succession–from more mafic flows near the base of the pile to intermediate flows and air-fall-dominated deposits at the top–is typical of stratovolcanoes worldwide (McBirney, 1984, p. 300-342). The basal basaltic andesite and andesite flows are thickest (325 m; 1,065 ft) in the southwestern part of the volcanic pile near VABM 3466 and thinnest to the north and northeast [150 m (430 ft) and 100 m (330 ft), respectively]. Inversely, air-fall and water-laid tuffs are thickest to the north and northeast [280 m (920 ft) and 320 m (1,050 ft), respectively] and thinnest (140 m; 460 ft) above the thick flow in the southwestern corner of the volcanic buildup. Additionally, clast size in the TKvt unit is coarsest in the southwest (1 to 3 cm; 0.5 to 1 in.) and fines to the north ($\leq$0.5 cm; 0.2 in.). We speculate that the flow buildup in the southwest is proximal to the volcanic vent, and that the air-fall tuff to the north and northeast was deposited "downwind" of the volcanic center. The stratigraphic relationship of the poorly exposed andesite to dacite flows (TKvi); (located south of the Russian Mountains) to the rest of the volcanic pile has not been determined.

The Russian Mountains mafic volcanic rocks (TKvm) lack the iron enrichment typical of tholeiitic suites. Instead, they show high alumina and normative plagioclase compositions indicative of calc-alkaline suites. Moreover, samples from the basaltic andesite unit show extreme potassium enrichment, falling within compositional fields of high-potassium andesite, shoshonite, and banakite (fig. 3). Rare-earth-element (REE) trends from three samples of the basaltic andesite (fig. 4) are more or less parallel, indicate a low degree of fractionization, and exhibit a modest Eu anomaly. Overall, the petrography, whole-rock chemistry, and REE trends of the Russian Mountains volcanic suite are consistent with those of calc-alkaline to quartz-alkalic igneous belts within intracontinental back-arc subduction complexes (McBirney, 1984).

PLUTONIC ROCKS (TKsym, TKsy, TKmp, TKdf, TKdm, TKda)

The Cretaceous volcanic pile and underlying Kuskokwim Group are intruded by a peraluminous, multiphase pluton (TKsym, TKsy, TKmp) that averages quartz monzonite in composition and by peraluminous quartz porphyry and altered mafic dikes and small intermediate hypabyssal intrusions (TKdf, TKdm, TKda).

The main intrusion, the Russian Mountains pluton, crops out in a circular-shaped massif that defines the limits of the Russian Mountains. Intrusive phases are in sharp contact with each other and, along the western, southern, and southeastern margins of the pluton, in sharp high-angle contact with contact-metamorphosed, sedimentary rocks. The Cretaceous volcanic units, often thermally altered, overlie the larger intrusive mass at a low angle; in the northern Russian Mountains, the pluton can be observed through several small windows in the volcanic stratigraphy. Together these contact relations suggest that the entire mountain range is underlain by intrusive rock (sheet 1).

A syenite to monzonite phase (TKsym) generally forms the outermost rim of the Russian Mountains pluton. Because xenoliths of syenite to monzonite are found in

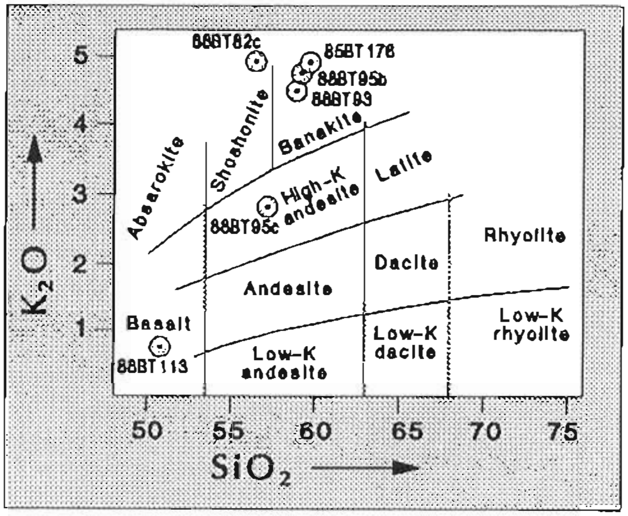

Figure 3. *Plot of Russian Mission C-1 Quadrangle volcanic rocks on K_2O-SiO_2 compositional diagram (after McBirney, 1984).*

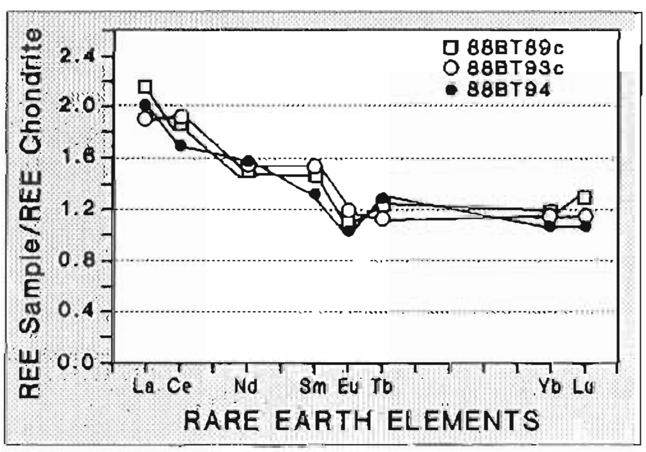

Figure 4. *Chondrite-normalized rare earth element (REE) concentrations in basaltic-andesite samples from Russian Mountains, Alaska. Analyses by Nuclear Activation Services, Ontario, Canada.*

quartz syenite (TKsy) and porphyritic quartz monzonite (TKmp), the syenite to monzonite is presumed to be the oldest intrusive phase. It generally exhibits a medium- to coarse-grained, hypidiomorphic-granular texture and contains zoned plagioclase phenocrysts rimmed by orthoclase (fig. 5) and glomeroporphyritic clusters of altered diopside to 1 cm (0.4 in) diam in a groundmass of andesine (An_{35}), quartz, biotite, and zircon. The immature textures suggest that the syenite to monzonite bodies were emplaced at shallow depths.

Quartz syenite (TKsy), is the most common intrusive phase in the Russian Mountains and comprises about 80 percent of the plutonic mass. Typically, this phase is a light green-gray, medium grained, equigranular to hypidiomorphic rock and consists of orthoclase, oligoclase, quartz, and biotite with minor or trace amounts of (≥1 percent) diopside, axinite, zircon, and hematite. In thin section, much of the axinite appears as distinct grains or platy aggregates to 5 mm in diam. The mineral was formed during primary crystallization of the igneous rocks rather than by replacement (fig. 6). This is corroborated by Hietanen and Erd (1978), who previously reported the presence of primary ferroaxinite in plutonic rocks from the study area and from the McGrath Quadrangle to the northeast. Distinct northwest-trending, linear zones of ankerite-sericite alteration in the valleys of Cobalt and Mission Creeks are probably associated with hydrothermal mineralization along joints and fractures in the quartz syenite.

Porphyritic quartz monzonite (TKmp) crops out as a structurally high intrusive phase in the northwestern Russian Mountains. The unit consists mainly of fine-grained to porphyro-aphanitic, diopside-bearing biotite quartz monzonite. Biotite is present as individual grains and as inclusions in altered diopside; subhedral feldspar grains to 2 cm (0.8 in.) long exhibit rapakivi and graphic textures (fig. 7). The unit has undergone pervasive hydrothermal alteration that includes chloritization and epidotization of biotite and diopside, sericitization of feldspar, and silicification of the groundmass. Axinite grains and clots to 1 cm (0.4 in.) diam are also present but are less abundant than in the quartz syenite (TKsy) unit. Further, much of the axinite in the porphyritic quartz monzonite replaces feldspar and biotite.

Although the three intrusive phases (TKsym, TKsy, TKmp) form sharp contacts with each other, they are probably end products of the same differentiation process. The average differention indexes for the three phases (TKsym = 63.5; TKsy = 79.2; TKmp = 93.7) suggest that a parent magma of syenite to monzonite composition progressively evolved to quartz syenite. This is similar to the differentiation sequence described for the Chicken Mountain and Black Creek plutons near Flat, about 72 km (45 mi) northeast of the Russian Mountains (Bull, 1988; Bundtzen and others, 1988b).

DIKES AND SILLS (TKdm, TKda, TKdf)

Dikes and small sills (TKdm, TKda TKdf) intrude along faults and joints in the Russian Mountains pluton and in the older layered units. The most abundant dikes are 1 to 3 m (3 to 9 ft) wide, up to 1 km (0.6 mi) long, and composed of medium-green, chloritized, porphyro-aphanitic, hornblende andesite porphyry (TKda) and lighter green quartz-orthoclase porphyry (TKdf) (fig. 8). Ubiquitous hydrothermal alteration of hornblende in the andesite porphyry

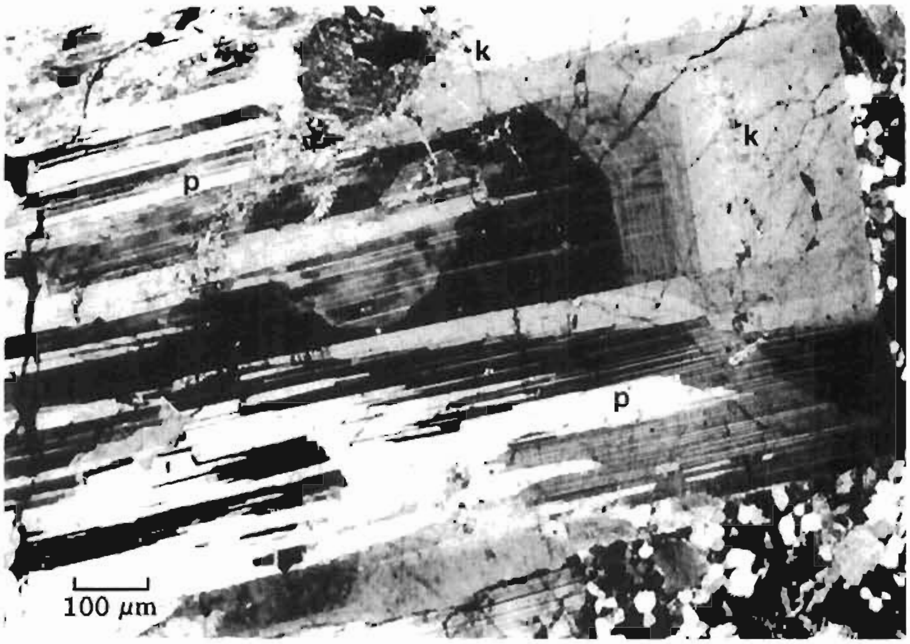

Figure 5. *Photomicrograph of zoned plagioclase (An_{30}) phenocrysts (p) jacketed by orthoclase (k) in syenomonzonite (TKsym), sample 85BT186, eastern Russian Mountains, Alaska, crossed nicols.*

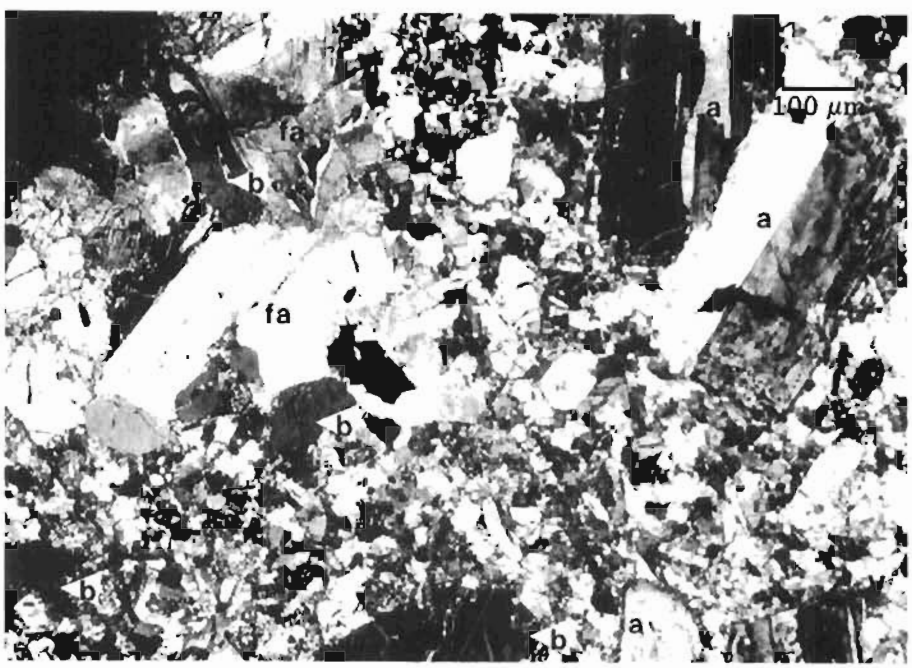

Figure 6. *Photomicrograph of quartz syenite (TKsy) from Owhat River drainage (88BT86) showing biotite (b), sericitized albite (a), and primary(?) aggregates of ferroaxinite (fa), crossed nicols.*

prevents K-Ar radiometric dating; secondary biotite clearly postdates hornblende and minor pyroxene but is itself altered. Secondary(?) axinite is also a common constituent of the andesite porphyry dikes (TKda) that appear to be associated with sulfide mineralization (see "Economic Geology" section).

Quartz-orthoclase porphyry sills 100 m (328 ft) wide and 3 km (2 mi) long intrude metasedimentary and mafic meta-igneous rocks (MzPzvs) parallel to the northeasterly structural grain west of the Owhat River. Because the felsite sills are compositionally the same as those intruding the Russian Mountains stock, they are believed to be equivalent.

Minor olivine-clinopyroxene mafic dikes (TKdm) previously described by Bundtzen and others (1989) crop out along the Kuskokwim River about 4 km (2.5 mi) upstream from Chuathbaluk. One prominent system of mafic dikes cuts dark-gray Kuskokwim Group calcareous

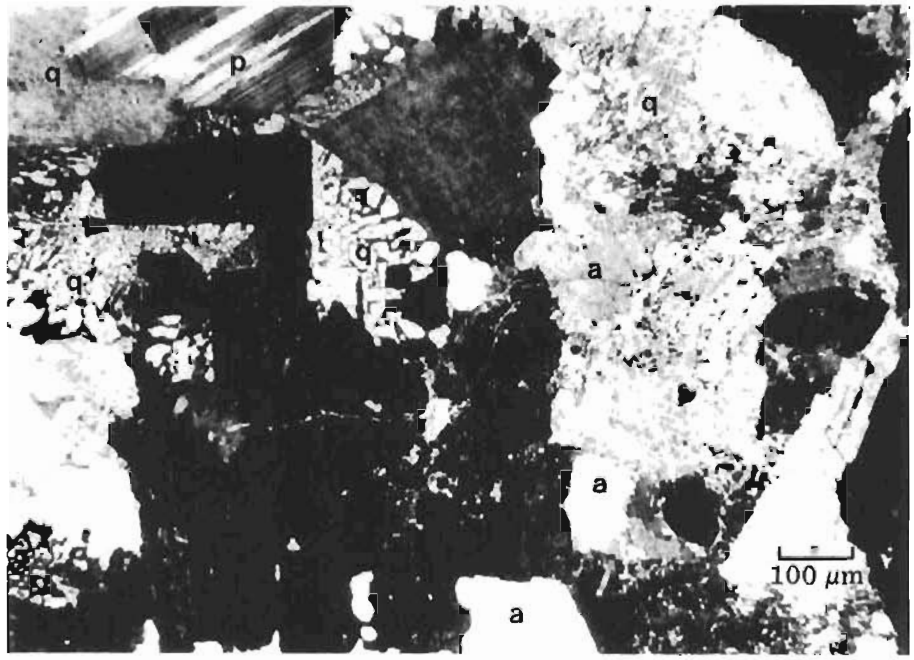

Figure 7. *Photomicrograph of porphyritic quartz monzonite (TKmp), sample 89BT103, showing albite* (An_{12}) *phenocrysts (a), and ubiquitous graphic replacement of K-spar by quartz (q) and plagioclase (p), crossed nicols.*

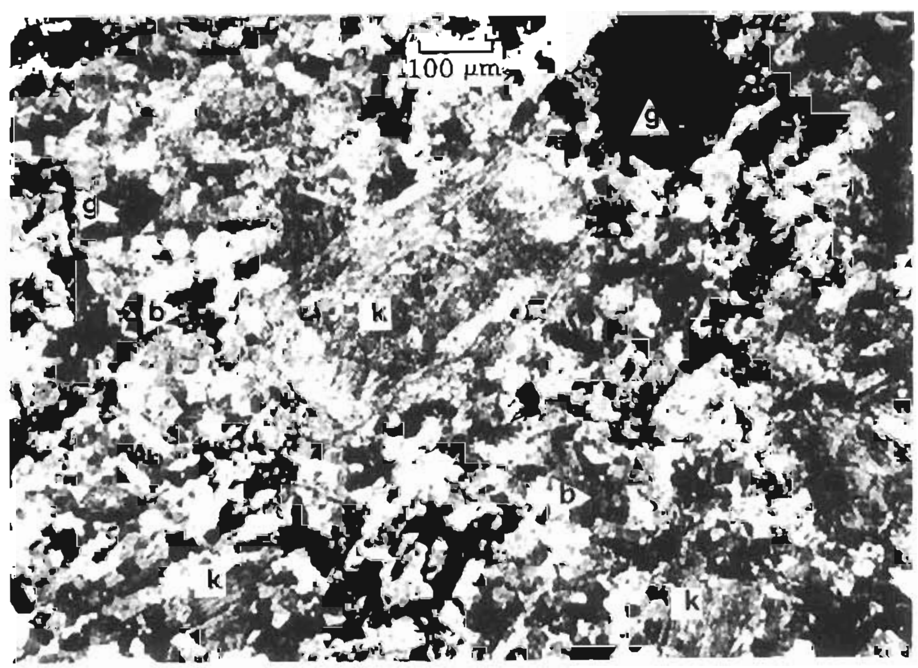

Figure 8. *Photomicrograph of quartz-orthoclase porphyry (TKdf), sample 88BT109, showing garnet (g), biotite (b), and sericitized K-spar (k) in undetermined quartz-feldspar, groundmass, crossed nicols.*

sandstone and siltstone (Ksl). Of these, a 15- to 20-m-thick (49 to 66 ft) dike that trends N. 30° W. generated enough heat during emplacement to produce a hornfels aureole 15 m (49 ft) wide, which is unusual for such a small intrusive body. The mafic dike is composed of up to 25 percent cumulus-like grains of olivine and intermeshed clinopyroxene. Unfortunately, no major-oxide determinations are available for the intrusion.

PETROGENESIS AND AGE OF VOLCANIC-PLUTONIC COMPLEX AND CROSSCUTTING DIKES AND SILLS

The Russian Mountains complex is a circular-shaped field of basaltic andesite to dacite tuff (SiO_2 = 56.17 to 59.66 percent) that flanks and overlies a monzonite to quartz syenite pluton (SiO_2 = 61.89 to 72.69 percent). The volcanics are older but probably comagmatic with the pluton. Normative mineral plots show the expected compositional ranges of plutonic rocks (fig. 9), and the expected geochemical evolution of volcanic and plutonic rocks are indicated on an AFM plot (fig. 10). One whole-rock analysis of pyroxene andesite (table 1, no. 3) yielded a K-Ar age of 75.8 Ma. The 76 Ma age agrees closely with the 75 to 77 Ma age range obtained from basal parts of the Iditarod Volcanics in the Iditarod Quadrangle 35 km (21.2 mi) north of the Russian Mountains (Miller and Bundtzen, 1988). The volcanics are also similar in age to the 74 Ma maximum age obtained from the Holokuk basalt north of the Kiokluk Mountains about 80 km (50 mi) southeast of the Russian Mountains (Reifenstuhl and others, 1984; Robinson and others, 1984).

The quartz syenite (TKsy) phase of the Russian Mountains pluton yielded a radiometric age of 70.31 Ma (table 1, no. 2). Overall contact relationships reinforce the contention that the volcanic rocks have been contact metamorphosed and partially assimilated by underlying plutons. Rare-earth-element distribution (figs. 4, 11) also supports a co-magmatic origin for the plutons and lavas. The alkali-lime index of Peacock (1931) indicates an alkali-calcic classification (fig. 12) similar to other volcanic-plutonic complexes studied in the Iditarod and McGrath Quadrangles north of the Russian Mountains (Bundtzen and Laird, 1982, 1983; Bundtzen and others, 1988a,b; Bundtzen and Swanson, 1984). Overall, the Russian Mountains volcanic-plutonic complex shows potassium enrichments similar to many shoshonitic suites (McBirney, 1984). The pattern of mineralogy and geochemistry distinguishes the Russian Mountains igneous complex from typical orogenic calc-alkaline magmas. Reifenstuhl and others (1984), Robinson and others (1984), and Decker and others (1984) describe similar volcanic-plutonic rocks, radiometric ages, and geochemistry in the Kiokluk and Chuilnuk Mountains southeast of the study area.

HORNFELS

A pronounced thermal aureole forms a sharp, high-angle boundary with plutonic rocks along the western, southern, and southeastern limits of the Russian Mountains

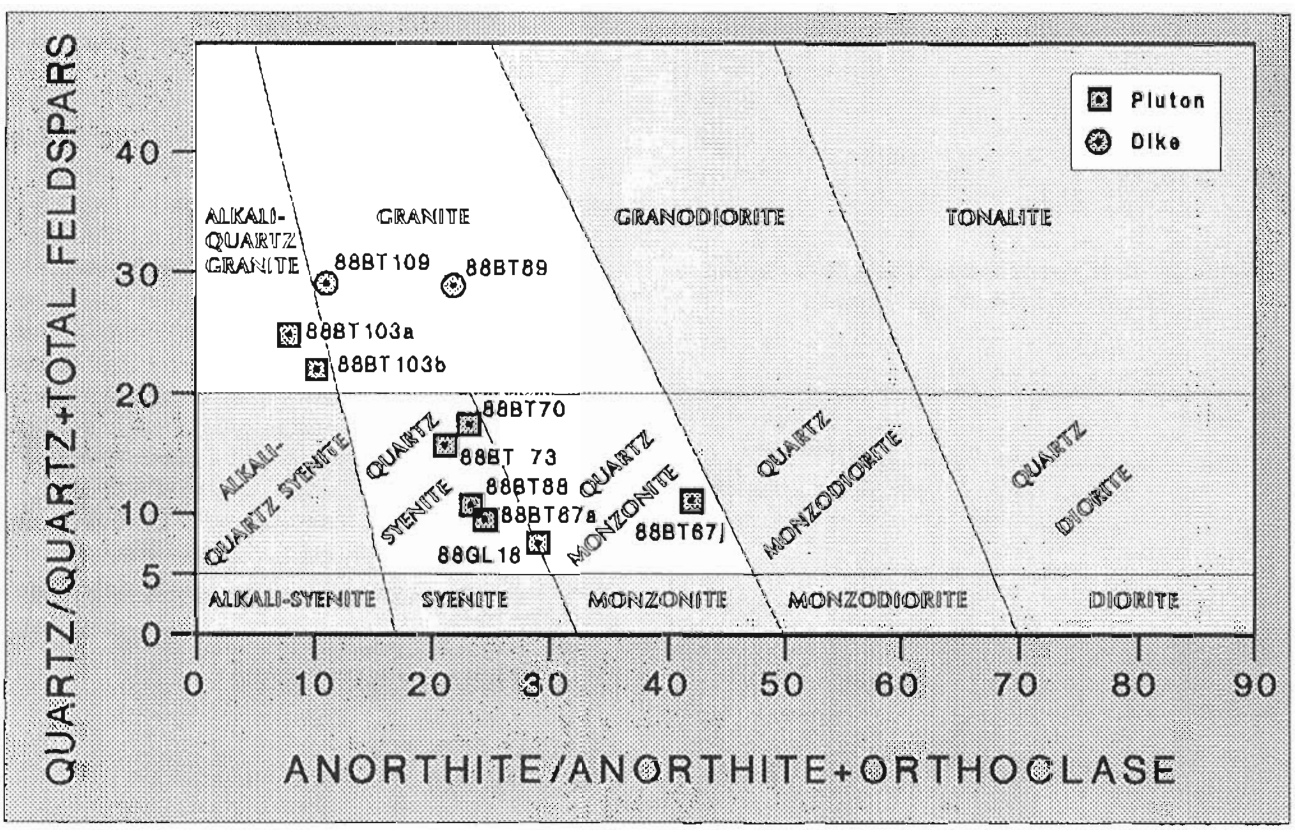

Figure 9. *Normative quartz-K-spar-plagioclase plutonic classification scheme for Late Cretaceous granitic rocks from Russian Mission C-1 Quadrangle, Alaska (after Streckeisen and LeMaitre, 1979). Solid square = plutonic rock; solid circle = dike rock.*

massif. The mapped hornfels (TKhf) is composed of a resistant rib of dark-gray, conchoidally fractured, massive metasiltstone-argillite and metasandstone. In thin section the hornfels is easily recognized as recrystallized sandstone and siltstone, but in outcrop it is nearly indistinguishable from aphanitic igneous rock. The metasiltstone-argillite contains white mica, epidote, and rare biotite porphyroblasts; the metasandstone is simply recrystallized quartz and feldspar. Rare porphyroblasts of andalusite are present in southeastern exposures of the hornfels within 100 m (328 ft) of the pluton. In general, the hornfels grades from massive aphanite near the pluton contact to dominantly cherty argillite and metasandstone 200 to 400 m (660 to 1,300 ft) from the contact to slightly recrystallized sandstone, mudstone, and siltstone 400 to 700 m (1,300 to 2,300 ft) from the contact. The total width of the thermally disturbed rocks is about 1 km (0.6 mi).

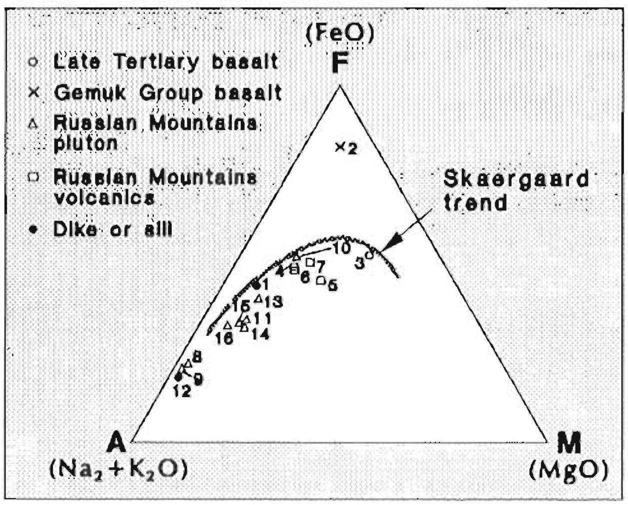

Figure 10. *AFM plot of igneous rocks from Russian Mission C-1 Quadrangle, Alaska.*

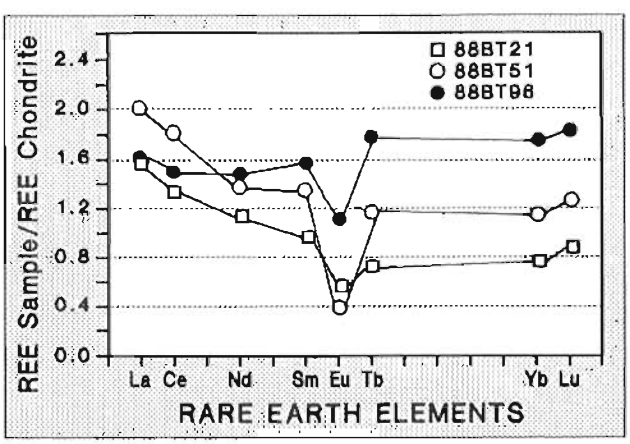

Figure 11. *Chondrite-normalized rare-earth element (REE) concentrations in plutonic rocks from Russian Mountains, Alaska. Analyses by Nuclear Activation Services, Ontario, Canada.*

Overlying volcanic strata have also been thermally affected by the pluton but are not mapped as hornfels because in the field the thermally affected areas are indistinguishable from unaffected exposures. However, the volcanic rocks are more reactive than the metasedimentary rocks and therefore result in a more pervasive contact-mineral assemblage of biotite, albite, epidote, actinolite, and locally pumpellyite. Locally biotite overprinting is pervasive, resulting in distinct red-brown outcrops and talus that sharply contrast with unaltered gray and purple lavas.

An age of 69.8 Ma (table 1, no. 4) was obtained from andesite hornfels. Thin-section analysis of sample 4 shows a pervasive biotite and sericite overprint of the fabric, which suggests that a thermal event re-equilibrated the K^{40}-Ar^{40} isotopic system. The extent of the contact-metamorphosed volcanic rocks could not be determined without additional detailed petrographic studies. Metamorphic conditions in both the volcanic and metasedimentary units are typical of epidote-hornfels to hornblende-hornfels metamorphic facies (Turner, 1968).

TERTIARY BASALT FLOWS

Three or four essentially unaltered, vesicular olivine-clinopyroxene basalt flows (Tvb) cover a 7-km^2 (4 mi^2), elliptical area near the western boundary of the map area. The flows are each about 10 m (32 ft) thick, slightly inclined, and columnar jointed. In a thin section of the basalt, partially antigorized, olivine grains and orthopyroxene are enclosed in a fine-grained, felted groundmass of calcic plagioclase (An_{65}) and indeterminate oxides. A major-oxide determination for the basalt results in a tholeiitic classification after schemes summarized by Irvine and Barager (1971). One whole-rock analysis of vesicular basalt (table 1, no. 1) yielded a K-Ar age of 6.19 Ma.

The basalt flows straddle and overlie the Kuskokwim Group Flysch and older Gemuk Group greenstone along the Iditarod-Nixon Fork transucrrent fault immediately west of the Owhat River.

QUATERNARY DEPOSITS

GLACIAL DEPOSITS
(Qgt_{1-4}, Qrg, Qgf)

Till (Qgt_{1-4}) in the study area, confined mainly to the Russian Mountains region, are divided into four distinct subunits based on morphology, lateral extent, and age. These subunits generally correspond to glacial units delin-

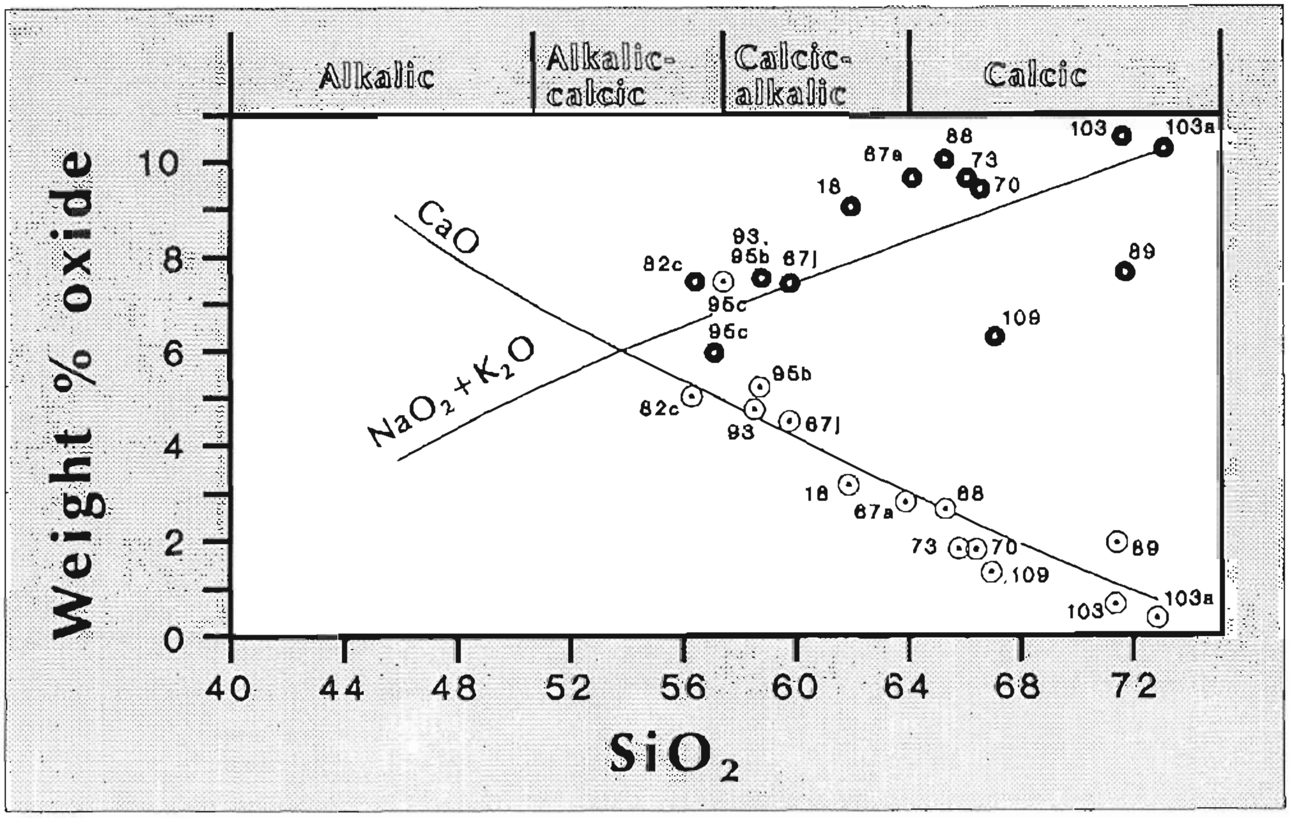

Figure 12. *Classification of volcanic and plutonic rocks in Russian Mission C-1 Quadrangle using the alkali-lime index of Peacock (1931). Solid circle = alkali; open circle = lime.*

cated by Bundtzen (1980) and Kline and Bundtzen (1986) in the Kuskokwim Mountains and the Alaska Range. Because no radiometric ages or fossils have been reported from till in the study area, age assignments are based on geologic inference. A summary of glacial advances is shown in figure 13.

The oldest till (Qgt_1) consists of isolated patches of diamicton on two planated, north-facing pediment surfaces northeast of the Russian Mountains (sheet 1) at about 400 m (1,300 ft) elevation. Isolated plutonic erratics on these surfaces and a series of similar flat ridge crests northwest and southeast of the Russian Mountains (sheet 1) are probably associated with these deposits. Till exposed on planated summits dissected by erosion is primarily composed of plutonic clasts to $\leq$20 cm (8 in.) diam nested in a silt-rich matrix; erosion has erased the glacial-moraine topography. The oldest till correlates with till of the Beaver Creek glaciation (pre-Wisconsin–probably pre-Illinoian) in the northern Iditarod Quadrangle (Bundtzen, 1980). Judging from the wide, fan-like configurations of the till and associated elevated terrace levels, the Russian Mountains may have supported a small, 310 km^2 (120 mi^2) ice cap during Beaver Creek time.

The next youngest till (Qgt_2) appears as distinct terminal and recessional moraines on Mission and Cobalt Creeks and on the east fork of Owhat River and as less extensive moraines on seven unnamed streams that originate in the Russian Mountains. During the glaciation in which this till was deposited, ice occupied at least 24 cirques and all drainages contained some ice (Kline and Bundtzen, 1986, p. 147). The largest trunk glacier occupied the Cobalt Creek drainage and was fed by two main tributary forks to the south. It measured almost 12 km (7.2 mi) long and up to 2 km (1.2 mi) wide during glacial maximums. This till is essentially identical to that of the Bifurcation Lake glaciation of early Wisconsin age in the Beaver Mountains (Bundtzen, 1980).

Still younger till (Qgt_3) appears as several arcuate, steep-fronted terminal moraines at the headwaters of Cobalt Creek and the east fork of Owhat River; these deposits mark a maximum ice advance of 3 km (1.8 mi) long. Unit Qgt_3 is also present in at least 13 north-oriented cirques, but absent from south- and west-facing valleys and cirques. In contrast to the well-dissected moraines of the next older till unit (Qgt_2), unit Qgt_3 is largely undissected by stream erosion. We correlate this till with the late Wisconsin

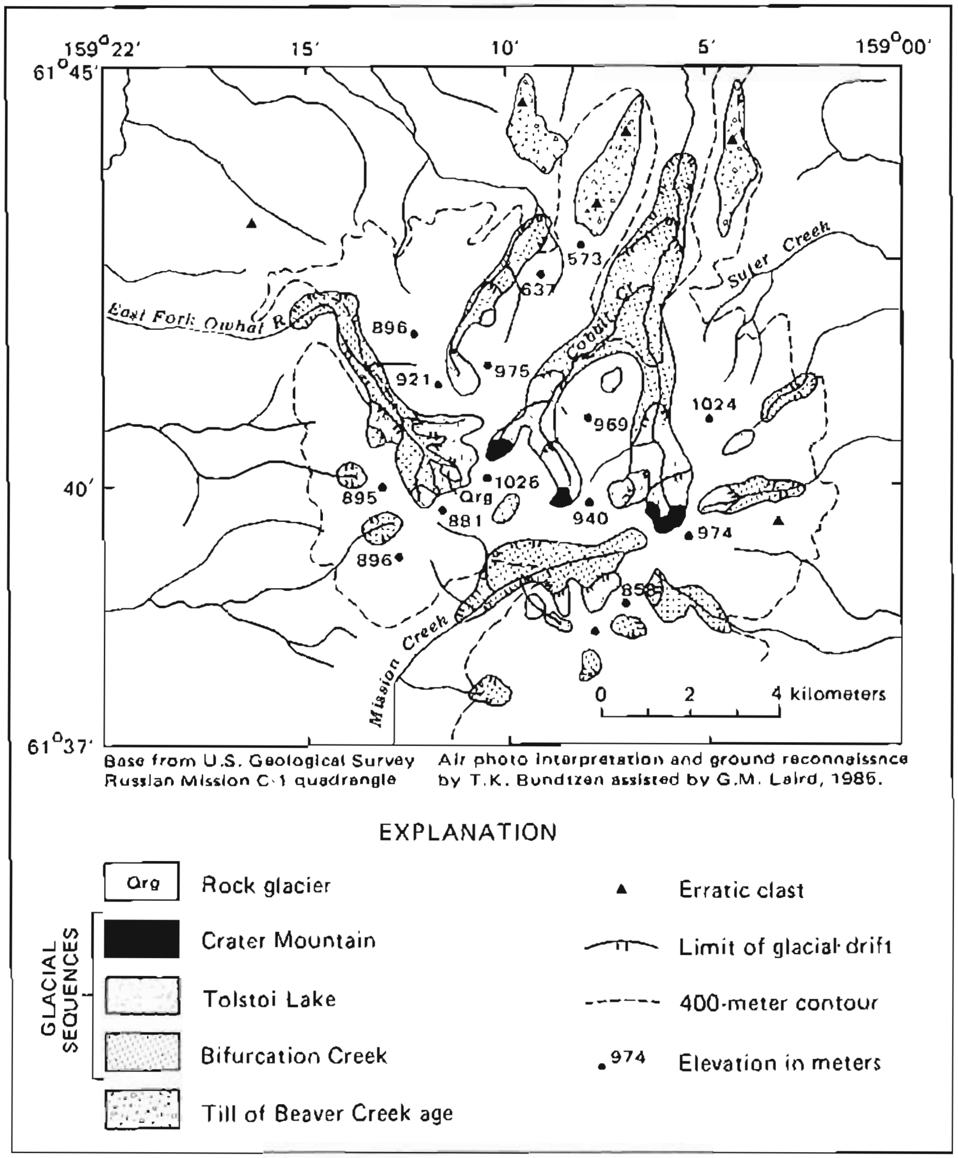

Figure 13. *Map showing extent of Quaternary glacial advances in Russian Mountains, Alaska. Modified from Kline and Bundtzen (1986).*

Tolstoi Lake glaciation in the northern Iditarod Quadrangle (Bundtzen, 1980).

The youngest till (Qgt_4) is confined to two or three unusually high north-facing cirques at the extreme headwall of the Cobalt Creek drainage. Twenty-four cirques in the Russian Mountains average 610 m (2,000 ft) elevation; the Holocene(?) cirques average 690 m (2,265 ft) elevation. Unit Qgt_4 is essentially unmodified by stream erosion, and cirque headwalls exhibit little colluvial modification. No soil is developed on Qgt_4 deposits. Qgt_4 deposits may be correlative with similar deposits of presumed Holocene age in the Beaver Mountains and Alaska Range (Kline and Bundtzen, 1986).

Eight dormant rock glaciers (Qrg) occupy cirques in the Russian Mountains. These spatulate-shaped deposits are composed of poorly sorted angular boulders and smaller rock fragments of intrusive origin. In contrast, on the East Fork Owhat River, a cirque headwall composed completely of more platy volcanic detritus has formed rock glaciers. All rock glaciers probably formed in cirques of Tolstoi Lake (Late Wisconsin) age at altitudes of 550 to 610 m (1,800 to 2,000 ft) immediately following deglaciation.

During an Early or pre-Wisconsin glacial maxima, several large outwash fans (Qgf) were deposited along the flanks of the Russian Mountains. This outwash is composed of almost equal amounts of plutonics, volcanics, and hornfels that appear as 20 ft to 150-m-thick (65 to 490 ft) terraces above modern dissected drainages. The largest Qgf deposits on Mission Creek and East Fork Owhat River are 5 to 7 km (3 to 4 mi) long, about 6 km (3.6 mi) wide, and average about 25 m (82 ft) thick, based on Kuskokwim River cuts of the outwash fan. Similar fan-shaped outwash plains have been reported in the Beaver, Horn, and Chuilnik Mountains (Bundtzen, 1980; Cady and others, 1955; Waythomas, 1984).

COLLUVIAL DEPOSITS (Qca, Qct, Qctf)

Following each successive glacial maxima and ice recession, valley walls collapsed and were rapidly modified by slope processes that built colluvial-alluvial fans (Qca) and colluvial-talus deposits at slope apices (Qct). Along the southern limit of the Russian Mountains, poorly sorted composite alluvial-colluvial aprons of fluvial fans and slope colluvium (Qctf) probably formed in part from the reworking of Early or pre-Wisconsin glacio-fluvial deposits of the Mission Creek outwash fan (Qgf).

Poorly stratified, organic-rich, bog silt (Qsp) covers glacio-fluvial deposits in the Russian Mountains and along the floodplains of the Kuskokwim and Aniak Rivers in the southern part of the study area. In both instances, Qsp deposition reflects stagnation of the previous higher energy fluvial environment that existed in these areas. Peat deposits (Qsp) in the Russian Mountains consist of well-stratified, frozen, peat layers 2 cm to 2 m (1 in. to 6.5 ft) thick in lenticular, mound-like palsas that reach thicknesses of 10 m (33 ft).

ALLUVIAL DEPOSITS (Qat, Qas, Qag, Qa)

Older fluvial deposits (Qat) are relict paleostreams and parallel modern drainage patterns. These deposits are composed of limonitically stained clasts of igneous and sedimentary rocks from local sources. Most deposits are presumably of Quaternary age, but high-level deposits may be Late Tertiary terraces. Sandy to cobble-sized floodplain alluvium (Qa, Qag) continues to be deposited in rivers and streams in the study area. The alluvium in upland areas is mainly coarse cobble-sand-silt derived from local bedrocks (Qag). Fluvial deposits in the Kuskokwim River valley are finer grained sand-silt-clay in part derived from bedrock and glacial debris that originated from upstream sources (Qa). During seasonal flooding, overbank muds up to 1 m (3.3 ft) thick cap floodplain deposits up to 3 m (10 ft) above normal high water levels; mappable overbank deposits are depicted as Qas.

STRUCTURE

Pre-Cretaceous layered rocks have undergone at least two episodes of northeast-trending, subisoclinal to open folding (sheet 1, cross sections A, B). The comparative nature and timing of the fold deformation between the Gemuk Group and the Kuskokwim Group were not accurately determined during this study. In outcrop, axes of F_1 folds trend from N. 10° E. to N. 60° E. and plunge steeply to the northeast. Locally, secondary low-angle cleavage has cut the folds, suggesting significant low-angle compressional stress in the layered rocks. Bedding attitudes in the Kuskokwim Group appear to all be right-side-up in the study area, but overturned beds were observed by Bundtzen and others (1989) at Gibraltar Point about 20 km (12 mi) upriver in the Sleetmute Quadrangle. The timing of most fold deformation in the MzPzus, Kus, and Kls units probably coincides with Late Cretaceous compressional tectonic activity documented in the McGrath, Lime Hills, and Iditarod Quadrangles north of the study area (Bundtzen and Gilbert, 1983).

The Upper Cretaceous andesitic lavas and tuffs in the Russian Mountains have been warped into broad, north-south trending synclines, which suggests that a mild compressional episode followed Late Cretaceous-early Tertiary igneous activity.

Several prominent, N. 25-30° W.-trending vertical faults cut the Russian Mountains volcanic-plutonic complex in Cobalt Creek and East Fork Owhat River. These fractures parallel a prominent joint orientation mapped throughout the pluton (sheet 1). Hydrothermal fluids and polymetallic sulfide mineralization have bled into the northwest-trending fractures–probably shortly after crystallization of the pluton–and created the mappable sericite-ankerite alteration zones described briefly in the Economic Geology section of this report. In the valley of East Fork Owhat River, syenomonzonite appears to be juxtaposed against porphyritic quartz monzonite along a N. 20° W.-trending fault.

Curvilinear high angle faults juxtapose andesitic lavas against quartz monzonite in the eastern Russian Mountains (sheet 1). Previous workers (Cady and others, 1955) suggest that this contact relationship represents caldera collapse into a rising magma chamber; however, this circular fault relationship is not typical of most volcanic-plutonic contacts in the Russian Mountains.

The north-northeast-trending high-angle "Owhat fault" juxtaposes the Kuskokwim Group against older Gemuk Group lithologies west of Owhat River (sheet 1). Movement along the "Owhat fault"–probably a splay of the Iditarod-Nixon Fork fault (INF)–appears to predate a 6.2 Ma old basaltic flow section (Tvb) previously described. However, lower Quaternary terrace deposits in the Moore Creek area about 100 km (62 mi) northeast of the study area may be offset by the INF fault (Bundtzen and others, 1988a).

Miller and Bundtzen (1988) proposed a Late Cretaceous to Present right-lateral offset solution of 88 to 94 km (53 to 56 mi) for the INF fault based on an offset restoration of the Upper Cretaceous Iditarod volcanic complex in the Beaver Mountains northwest of the fault with the same unit in the DeCourcy Mountain area southeast of the fault. This offset solution places the Russian Mountain complex (in Late Cretaceous time) directly south of similar but more mafic volcanic-plutonic complexes at Flat in the Iditarod mining district.

ECONOMIC GEOLOGY

INTRODUCTION

Mineralization in the Russian Mission C-1 Quadrangle consist mainly of several intrusive-hosted, copper-gold-arsenic deposits that contain anomalous amounts of antimony, tin, zinc, bismuth, lead, tungsten, uranium, and cobalt. Two deposits have been explored with pits, shafts, and drifts, but no commercial production has been recorded (sheet 2). Heavy-mineral placer deposits have been identified in immature high-energy glacial outwash on Cobalt and Mission Creeks, but no gold production is known. Modest amounts of sand and gravel have been mined for local projects, and riprap prospects have been recently identified in the Russian Mountains and along the Kuskokwim River.

LODE DEPOSITS

OWHAT PROSPECT

The Owhat quartz-gold-sulfide deposit was first discovered by Native prospectors near the head of Cobalt Creek (sheets 1, 2) shortly before 1900 (Cady and others, 1955; Holzheimer, 1926). Upon receiving information from the discoverers, Gordon Bettles prospected the Owhat property for gold shortly after 1900. Maddren (1915, p. 359-360) reported that by 1914, four claims of the "February Group" covered about 1,220 m (4,000 ft) of strike length along a "vein deposit of the fissure type." Early prospectors drove a 12 m (39 ft) shaft to explore the deposit. Holzheimer (1926) showed three shafts (the number observed during our investigations) on the vein along the eastern edge of the "Mary" and "Louise" claims.

The Owhat Prospect occurs in a bedrock lip that separates two distinct cirque levels at the head of Cobalt Creek [average elevation 480 m (1,570 ft)] (sheets 1, 2). Sulfide-bearing veins strike N. 24-28° W., dip 75-83° NE., and can be traced for 265 m (870 ft) before disappearing under talus and glacial till. Isolated mineralized float found along strike to the northwest and southeast suggests that the zone runs additional 200 m (650 ft) in both directions.

The mineralized zone consists of 8 to 10, closely spaced sulfide-tourmaline-axinite-quartz "greisens," each several centimeters to 1 m (3.3 ft) thick over widths that range from 1.5 to 8 m (5 to 26 ft); the total griesen zone averages about 2.5 m (8 ft) thick. Near the northwest end of the zone, the vein-fault splays into two distinct zones that are separated by host syeno-monzonite country rock. The mineralization is exposed from its lower northwest end at 442 m (1,450 ft) elevation to its higher upper end at 527 m (1,730 ft) elevation for a total vertical extent of 86 m (280 ft). Axinite-bearing andesite porphyry (TKdi) makes up most of the eastern hanging wall of the orebody, while syeno-monzonite comprises all of the western footwall and some of the eastern hanging wall.

Mineral species in the vein include major arsenopyrite, chalcopyrite and arsenopyrite, and pyrite and minor bornite, galena, sphalerite, tetrahedrite, and marcasite in a gangue of quartz, tourmaline, and axinite. Microprobe analyses have identified stephanite (silver-antimony sulfide), native bismuth, silver-free tetrahedrite, pekoite or gladite (lead-bismuth sulfide), free gold, aramayoite (silver-bismuth-antimony sulfide), bismuthite, and stetefeldite (silver-antimony hydroxide) (figs. 14, 15). Ore textures and field evidence indicate that the intrusive-hosted polymetallic deposits formed during multiple events in the fracture system.

The earliest mineralizing event distinctly banded, fine-grained, black schorl (tourmaline) that is frequently attached to the hanging-wall andesite porphyry. The tourmaline bands (or greisen) contain small xenoliths of syenite-monzonite plutonic rock. The distinctly red-stained, euhedral quartz crystals that formed along the footwall side of the tourmaline greisen during the second mineralizing event have no associated sulfides or free gold.

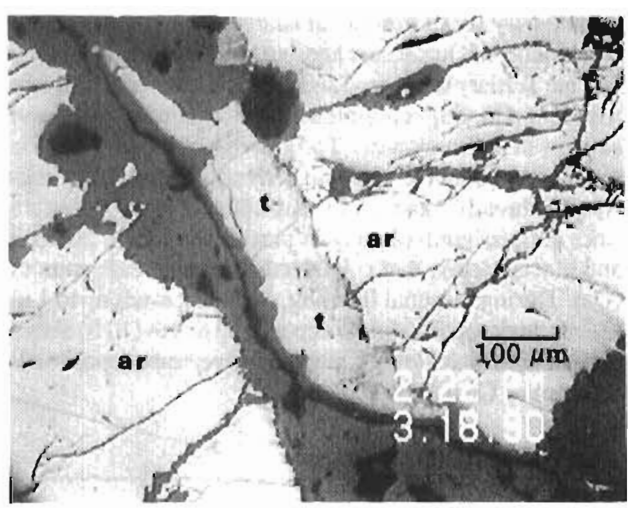

Figure 14. *Photomicrograph of silver-free tetrahedrite (t) along fractures in arsenopyrite (ar) from Owhat Prospect (88BT67u), crossed nicols. Photograph by Cannon Microprobe, Inc.*

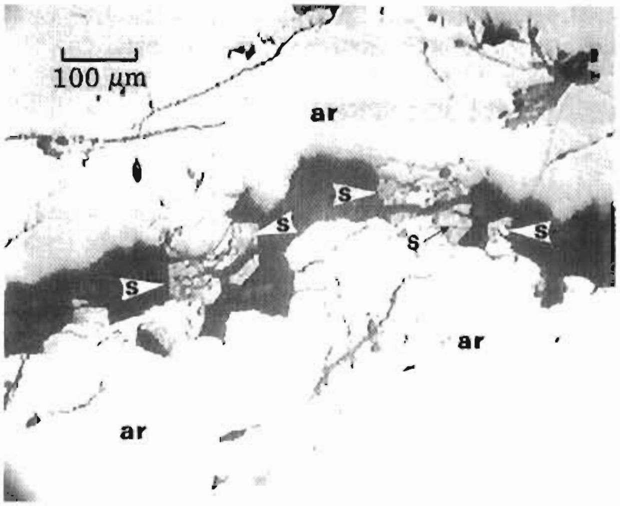

Figure 15. *Photomicrograph of stephanite (silver-antimony sulfosalt) (s) along fracture in arsenopyrite (ar) from Owhat Prospect (88BT67t), crossed nicols. Photograph by Cannon Microprobe, Inc.*

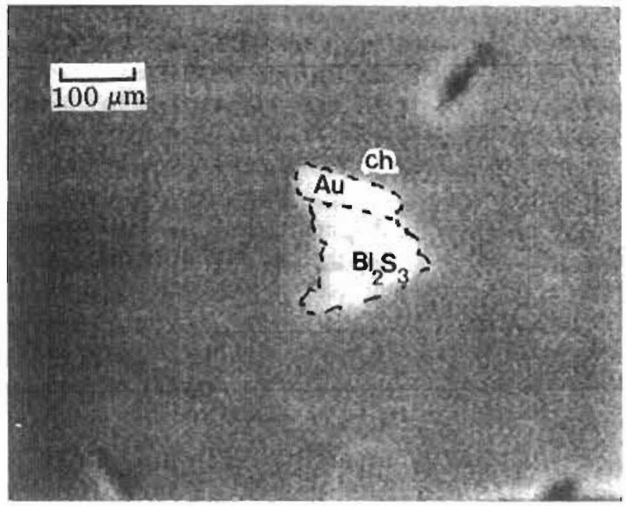

Figure 16. *Photomicrograph of 920 fine gold (Au) and bismuthinite (Bi_2S_3) in chalcopyrite (ch) from Owhat Prospect (88BT67t), crossed nicols. Photograph by Cannon Microprobe, Inc.*

A third mineral stage introduced base-metal sulfides (chalcopyrite, auriferous arsenopyrite, and pyrite) and cassiterite, all replacing vugs and sheets of replaced tourmaline greisen and quartz. Pyrite distinctly infills interstices between euhedral, second-stage quartz crystals. Some chalcopyrite forms finely laminated bands in the tourmaline-rich zones. A mineralizing fourth stage introduced bornite, stephanite, tetrahedrite, sphalerite, and lead-bismuth sulfides that clearly crosscut previous sulfides (figs. 14, 15). A fifth and final stage of ore formation introduced minor arsenopyrite subsequent to brecciation and fault movement along the Owhat structure.

Holzheimer (1926) reported that "three 40-ft-deep (13 m) shafts sunk on massive arsenopyrite kidneys bottomed out in gold-barren chalcopyrite." However, we noted no obvious vertical termination of arsenopyrite mineralization in the 90 vertical meters (295 ft) of the system that we examined. Moreover, microprobe analyses indicate that gold occurs as at least two distinct phases at the Owhat Prospect: As blebs of 900-to-920 fine free gold and bismuthinite in both chalcopyrite and arsenopyrite (fig. 16) and as local lattice contamination in arsenopyrite. The latter mode of occurrence was determined by comparing "count rates" for gold (Ma) in a standard gold-free arsenopyrite with arsenopyrite from the Owhat Prospect. The results indicate that arsenopyrite from the Owhat Prospect contains 0.1 to 0.2 weight percent gold in lattice structures.

Because no cobalt minerals were identified, trace analysis using the same prospecting method as that used for gold was also performed on two Owhat Prospect samples. Results show 1.2 to 3.4 percent cobalt in arsenopyrite lattice structures (fig. 17).

We collected 16 chip-channel samples over an average width of 1.4 m (4.4 ft) and a total strike length of 262 m (860 ft). All samples were analyzed for 22 elements, but some samples were not analyzed for copper, lead, tungsten, and tin; unfortunately none were analyzed for bismuth

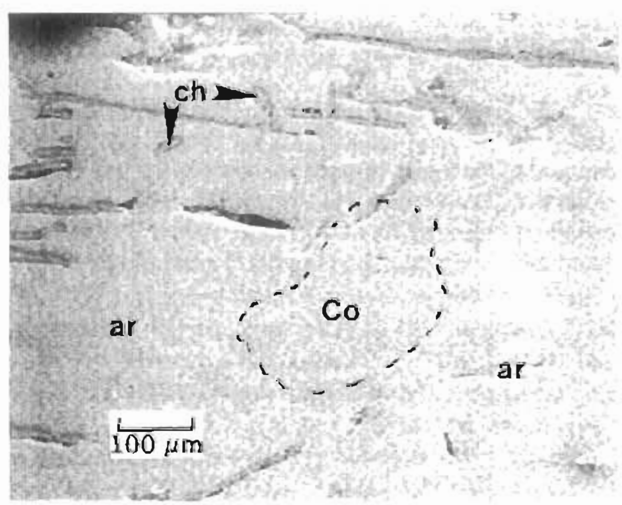

Figure 17. *Photomicrograph of arsenopyrite (ar) that contains zone of 3.4 percent cobalt (Co). Secondary chalcopyrite (ch) intrudes fractures. Samples from Owhat Prospect (88BT67t), crossed nicols. Photograph by Cannon Microprobe, Inc.*

(table 3). Holzheimer (1926) provided copper, gold, and silver analyses of channel samples; these analyses are also keyed to sample locations in our study (sheet 2).

Anomalous gold was detected in all but one submitted sample; with values range from 380 ppb (0.012 oz/ton) to 19 ppm (0.41 oz/ton) gold. Thirteen of 16 samples contained anomalous antimony, four contained anomalous tin, and three contained anomalous tungsten. All samples contained anomalous lead and copper. High gold values clearly follow increases in the arsenic content of the ores at a remarkably consistent ratio of 390 ppb gold for every 1 percent arsenic.

The following reserve calculations assume that the assay data from our 16 samples and from those reported by Holzheimer (1926) are representative of the mineralized system. We also assume that 0.25m³ (8.5 ft³) of mineralization weighs 0.907 metric ton (1 short ton). Two reserve estimates can be calculated: (1) a minimum inferred reserve based on the volume calculation of a triangular-shaped block of ore defined by known strike length, average width, and vertical extent of mineralization observed on the surface; and (2) a 'half square' estimate that assumes the vertical extent of mineralization is equal to half the known strike length of the ore body along segments of the deposit (Harding, 1923; Patterson, 1959). Using an average width of 1.4 m (4.4 ft), a strike length of 265 m (870 ft), and vertical control of 86 m (280 ft), the Owhat Prospect contains an inferred reserve of 57,000 metric tons (63,000 short tons) that grade 5.3 ppm gold (0.156 oz/ton gold), 13.4 percent arsenic, 0.21 percent antimony, 0.39 percent copper, 0.07 percent tin, 0.05 percent zinc, and 0.017 percent cobalt. The Owhat deposit contains a half-square reserve estimate of 120,200 metric tons (133,000 short tons) of similar grade.

LOUISE PROSPECT

The Louise Prospect was first reported by Holzheimer (1926) as a 320-m-long (1,000 ft) arsenic-gold deposit exposed in the lower cirque basin west of the lowest shaft at the main Owhat Prospect. The old "Louise" claim also includes shafts sunk on the Owhat Prospect. The prospect contains arsenopyrite, chalcopyrite, quartz, and black tourmaline in a poorly exposed vein that trends N. 25-35° W. for at least 80 m (245 ft) along strike; no vein widths could be estimated, and the occurrence was not sketched. As at the Owhat Prospect, altered andesite porphyry dike rock apparently forms part of the hanging wall of the vein; the remaining vein is hosted in syenite. One grab sample from the Louise Prospect (table 3, no. 10, 88BT68) contained 4.1 ppm gold (0.12 oz/ton gold), 10 percent arsenic, 0.99 percent antimony, and 0.12 percent tin. This sample contains 410 ppb gold per 1 percent arsenic-a ratio in remarkable agreement with results from the Owhat Prospect. Cady and others (1955) reported that "two samples from a short shaft 1,000 ft west of the Owhat Prospect are reported to assay 1.40 percent and 1.22 percent tin respectively;" these samples are probably from the Louise Prospect.

HEADWALL PROSPECT

The herein named Headwall Prospect (table 3, no. 14, and sheets 1, 2) is located along the steep western headwall of a cirque basin about 1 km (0.6 mi) south of the Owhat Prospect. Although we found the remains of tools and shovels, there are no published references for the deposit. The Headwall Prospect consists of a wide tourmaline-quartz-sulfide greisen that trends N. 32-34° W. and dips steeply southwest with a minimum strike of 240 m (790 ft). The northwest extension of the zone disappears under talus and till in a glacial cirque, but may continue southeast for an unknown distance into the cliff face of the cirque headwall.

Sulfide mineralization and paragenesis are similar to that of the Owhat and Louise deposits but more disseminated in nature. Several, 3 m-thick (10 ft) banded tourmaline greisen zones are well developed in southeast exposures and are partly replaced by euhedral quartz and sericite. Arsenopyrite, pyrite, and minor chalcopyrite cut the quartz and tourmaline, and xenoliths of the former gangue minerals are nested in sulfides. Additionally, native bismuth, pekoite (lead-bismuth sulfide), galena, bindheimite (antimony hydroxide), and scorodite were identified in microprobe analyses (fig. 18). Post-mineral movement has broken up the sulfide zone, suggesting fault movement subsequent to mineralization. No copper, bismuth, or lead assays are available from the prospect.

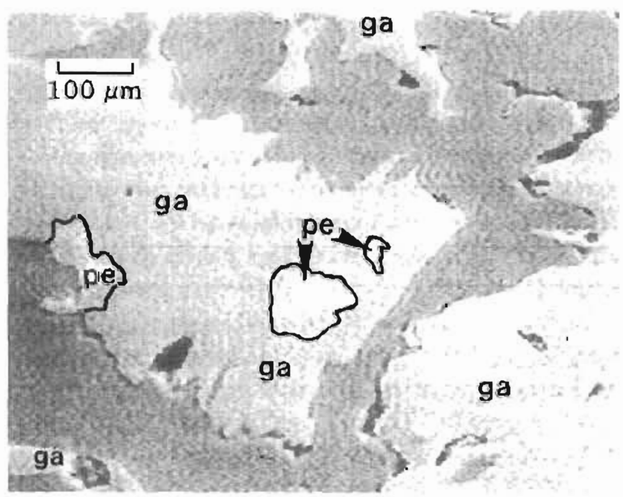

Figure 18. *Photomicrograph of pekoite (pe) in galena (ga). Headwall Prospect (88BT89e), crossed nicols. Photograph by Cannon Microprobe, Inc.*

Although vertical assay and geologic control of about 120 m (400 ft) are somewhat uncertain due to the extensive talus that covers more than 40 percent of the strike of the vein, we assume the same assay and geologic criteria calculations as used on the Owhat Prospect. Volume and grade calculations use an assay width of 1.36 m (4.45 ft), a strike length of 240 m (790 ft), and a vertical extent of 120 m (400 ft). Six channel samples indicate an inferred reserve of 75,000 metric tons (82,900 short tons) that grade 3.3 ppm (0.09 oz/ton) gold, 7.32 percent arsenic, 0.16 percent antimony, and 0.04 percent tin. A "half square" reserve estimate is essentially the same as the surface calculated reserve. Gold values clearly correlate with high arsenic content (450 ppb gold for every 1 percent arsenic), which is similar to results from the Owhat and Louise deposits.

MISSION CREEK OR "KONECHNEY" PROSPECT

A complexly mineralized quartz-sulfide-tourmaline greisen vein has been explored by trenching and by two levels of underground drifts at the head of Mission Creek about 1.2 km (0.7 mi) south of the Headwall Prospect on the south side of the Russian Mountains drainage divide (sheets 1, 2). The "Konechney" Prospect, which was described by Holzheimer (1926) and briefly by Cady and others (1955), has undergone more development than other prospects in the Russian Mountains (fig. 19).

Nine claims were located in 1921 and 1924 by prospectors Joseph Konechney and Charles Warden following their discovery of sulfide float on a low saddle above Mission Creek. Prior to 1926, a 100-m-long (360 ft) drift was driven at the 648-m (2,150 ft) elevation about 60 m (196 ft) below the discovery outcrops. A sketch of the underground workings from Holzheimer (1926) is included in the mine map on sheet 2. Holzheimer's original sketch refers to a S. 25° W. strike direction of the vein whereas the true direction is N. 30° W. Another drift (located about 62 m (204 ft) vertically below the 648 m drift) was completed by Konechney, probably between 1937 and 1942 (Ken Dahl, oral commun., 1988). We were unable to locate underground mapping control from this drift. A rock cabin and blacksmith shop, both in a state of disrepair, were still visible at the 595 m (1,950 ft) elevation below the mine workings. The portals of both drifts were caved and inaccessible (fig. 19).

The Konechney deposit consists of quartz-sulfide-tourmaline greisen veins similar to those observed at the Owhat, Louise, and Headwall prospects. Axinite-bearing andesite-porphyry dike rock parallels the N. 30° W. average strike of the mineralized zone in the upper levels, but splays off to the north in the lower workings. The zone dips 75-80° southwest in most surface exposures and in old sketches of underground workings.

Sulfide-gangue paragenesis differs somewhat from the Owhat and Headwall deposits in that chalcopyrite, tourmaline, and quartz appear to be introduced simultaneously, followed by arsenopyrite, pyrite, metazeunerite (a copper-uranium-arsenic mineral), free gold, and cassiterite. The cassiterite occurs as small, nearly black crystals interspersed in the quartz-tourmaline gangue on the structure's hanging wall. The last mineral species introduced into the structure are the low temperature sulfosalts and sulfides [chalcocite, bornite, stibnite(?), stephanite and covellite]. Abundant cuprite, azurite, malachite, goethite, and chrysocolla are found on the mine dumps. Wedow (1953) and West (1954) investigated the Konechney deposit because of its anomalous uranium content, and analyses of our

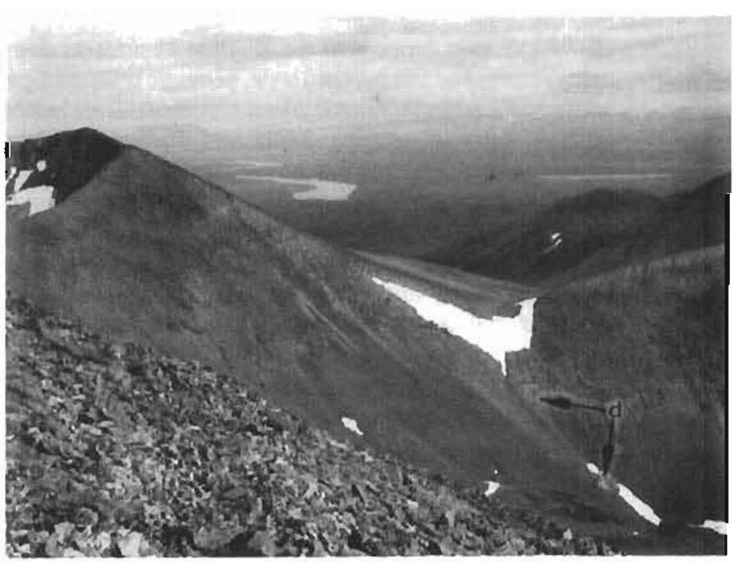

Figure 19. *"Konechney" or Mission Creek Prospect area showing mine dumps (d) and discovery area (low saddle); view southeast toward Kuskokwim River, Alaska.*

samples indicate up to 106 ppm uranium (table 3, 85BT184A).

The zone was traced for 150 m (470 ft) along strike before it disappeared under valley talus and vegetation on its northwest limit. The mineralized zone is truncated on its southeast limit as trenching and sampling failed to locate it beyond the high saddle.

To infer reserves, we used geologic and geometric assumptions similar to those employed on the Headwall and Owhat deposits. Assuming an average assay width of 1.05 m (3.4 ft), a minimum vertical extent of 120 m (400 ft), and a strike length of 150 m (470 ft), the 12 channel samples we collected and five channels samples collected by Holzheimer (1926) suggest an inferred reserve of 34,000 metric tons (37,600 short tons) that average 4.44 ppm (0.13 oz/ton) gold, 1.64 percent copper, 1.14 percent arsenic, 0.24 percent antimony, with anomalous levels of tin, cobalt, uranium, and silver. One sample (85BT184D) contained 112 ppm Bi-the only one analyzed for that element. Holzheimer (1926) reported up to 317 ppm (9.3 oz/ton) silver, our maximum analysis for silver is 182 ppm (5.3 oz/ton). Volume estimates using the 'half square' method understate vertical dimension and overall tonnage based on the surface calculations.

Evidence of a gold-arsenic association in the Konechney deposit is less convincing than the association shown at the Headwall and Owhat deposits. Examination of limited underground assay data from Holzheimer (1926) might suggest a gold-copper as well as a arsenic-gold correlation as documented in microprobe analyses of samples from the Owhat Prospect. If gold is only associated with arsenic, then there are 1,140 ppb gold for every 1 percent arsenic, which is about three times the ratio calculated for the other deposits.

OTHER LODE PROSPECTS IN THE RUSSIAN MOUNTAINS

Isolated and generally poorly exposed quartz-sulfide occurrences were noted during our work in the Russian Mountains. Gossan-rich quartz veins occur in N. 30° W.-trending fractures and joints in quartz syenite about 2.5 km (1.5 mi) southeast of the Konechney deposit (table 3, nos. 16, 17, and sheet 1). The two occurrences, each about 0.5 m (1.5 ft) wide and 150 m (490 ft) apart, contain up to 0.30 percent arsenic, 1.50 percent antimony, and 353 ppm neodymium. No sulfides were recognized in the oxidized zones. The dimensions of the occurrence are severely obscured by rubble and vegetation, but both may be associated with nearby andesite porphyry dikes. The occurrences project northwesterly along strike toward the Konechney deposit.

A small drift (now caved) was found in a gossan-rich quartz vein in hornfels within 100 m (330 ft) of the hornfels/intrusive contact zone in the southern Russian Mountains (table 3, no. 9, and sheet 1). Euhedral quartz crystals are particularly well developed in vugs in a sheeted vein, but poor exposure prevented measurement of the dimensions of the occurrence. The quartz vein contains anomalous gold (250 ppb), arsenic (250 ppm), and tin (62 ppm).

A poorly exposed amethyst-bearing vein that contains anomalous uranium (38 ppm) occurs at 365 m (1,200 ft) elevation about 8 km (5 mi) north of Chuathbaluk (sheet 1, no. 20). This prospect, which was discovered in 1960 by C. Abruska and N. Philip, has been referred to as the Ptarmigan Prospect (Ken Dahl, oral commun., 1985). Rubble material indicates that the crystals have grown in small vugs in a brecciated quartz-flooded zone in hornfels. Amethyst crystals range from 1 to 5 cm (0.4 to 1.8 in.) long and is frequently double-terminated in crystal habit. Colors vary from light purple to blue and average a moderate purple. Lack of exposure prevented further examination of the mineralized zone.

A discontinuous sulfide-quartz vein is hosted in the syeno-monzonite intrusive cupola zone immediately below thermally altered andesite flow rocks (TKvm) in the western Russian Mountains (table 3, no. 2, and sheet 1). Vein mineralization appears to be confined to the intrusive host rock and does not extend upward into the hornfelsed volcanic cap rocks. Two 1- to 3-cm-thick (0.4 to 1 in.) veins have intruded along N. 40° W.-trending joints in the plutonic rocks for a total tracable length of about 20 m (65 ft). Malachite-stained rubble-crop contains minor chalcopyrite, arsenopyrite, and galena in quartz gangue. One grab sample contained anomalous arsenic (0.46 percent), antimony (0.30 percent), 0.94 percent lead, 0.09 percent cadmium, and silver (45 ppm), but no gold. The occurrence, although small, is similar to those of the Owhat, Louise, Headwall, and Mission Creek Prospects.

LODE DEPOSIT PARAGENESIS

Most lode deposits in the Russian Mountains share many similarities in structural style, geologic relationships, and metallic and mineralogic content. Almost all are hosted in N. 20-40° W.-trending joints and fractures in host plutonic rocks and exhibit a ubiquitous association of axinite-bearing andesite porphyry dike rocks in the hanging walls and footwalls of the vein-fault structures. The andesite dikes may have a genetic association with the orebodies or may be intruding along the same structural channels. Deposits in the Russian Mountains are relatively high-temperature, "greisen-like" vein-faults. Fluid inclusion data from quartz in the Mission Creek Prospect (N=4) indicate formation temperatures that range from 280 to 410° C. Limited microprobe analyses from the Owhat Prospect show 29.0 to 33.0 atomic percent arsenic in arsenopyrite. Compositional plots using techniques described by Kretschmar and Scott (1976) show arsenic crystallization temperatures of about 320° C. If cassiterite, arsenopyrite, and chalcopyrite formed synchronously at the Mission Creek deposit, then temperatures of formation were probably ≥400° C for these mineral species. Tetrahedrite, bismuth, silver minerals, and free gold probably formed at lower temperatures.

The mesothermal to hypothermal(?) quartz-sulfide deposits of the Russian Mountains are similar to those of the Bolivian tin-silver belt—specifically deposits in the Cordillera Quimsa Cruz near LaPaz (Lindgren, 1936; Sillitoe and others, 1975). However, the deposits in the Russian Mountains exhibit an uncommon association of gold and tin. In many hydrothermal mineral deposits, the presence of gold usually indicates the absence of anomalous tin and vice versa, and gold is not a noteworthy occurrence in the Bolivian tin deposits (Lindgren, 1936; Cox and Singer, 1986). Similar auriferous deposits rich in copper and arsenic are described in the Beaver Mountains and at Golden Horn Prospect area near Flat (Bundtzen and Laird, 1982; Bull, 1988; Bundtzen and others, 1988b).

Although the deposits in Cobalt and Mission Creeks are modest in size, all four occurrences represent a definable structurally controlled zone of vertically dipping, intrusive-hosted ore shoots that strike N. 25-35° W. and are discontinuously exposed over a strike distance of 5 km (3 mi) and a strike width of 3 km (1.8 mi). Limited channel sampling at the four deposits shows a minimum inferred reserve of 229,200 metric tons (253,500 short tons) that grade 3.7 ppm (0.12 oz/ton) gold, 0.19 percent antimony, 9.59 percent arsenic, 0.61 percent copper, 0.014 percent tin with anomalous bismuth, silver, cobalt, tungsten, thorium, uranium, and zinc. It is probable that a larger resource exists in these mineral zones.

Miller and Bundtzen (1988) suggest that when right-lateral translation along the Iditarod-Nixon Fork Fault is restored, the Russian Mountains align in a north-south configuration with the volcanic-plutonic complexes in the Iditarod mining district. We note similarities between the arsenic-enriched, intrusive-hosted gold deposits in the Russian Mountains and the Golden Horn arsenic-scheelite gold deposits hosted in the Black Creek monzo-gabbro in the Iditarod mining district. However, tourmaline enrichments that typify the Russian Mountains system are generally lacking in the Iditarod district deposits.

Bundtzen and Miller (1989) presented a metallogenic model for ore deposits associated with meta-aluminous and peraluminous, alkali-calcic, Late Cretaceous to early Tertiary stocks, volcanics, and sills in the Kuskokwim Mountains. The model classifies polymetallic deposits formed in epithermal to hypothermal conditions by comparing temperature-pressure, mineralogical, alteration, structural, and geological data. These workers suggest that all deposits represent similar vertically zoned systems found in several erosional levels in the Kuskokwim Mountains. Intrusive-hosted polymetallic deposits in the Russian and Beaver Mountains and the Black Creek stock are part of the highest temperature-pressure, mesothermal to hypothermal(?) intrusive-hosted ore deposits of the "Kuskokwim mineral belt."

PLACER DEPOSITS

Despite the presence of gold-bearing lode sources for placer concentrations in streams of the Russian Mountains, there is no record of placer-gold or other heavy-mineral production in the study area. Multiple glaciofluvial cycles may have buried or diluted placer mineral concentrations in the Russian Mountains. Prospectors have searched for but not found economic concentrations of placer gold in the adjacent Owhat Upland (Maddren, 1915).

The two known placer occurrences in the Russian Mountains are described below. According to Maddren (1915, p. 339), "prospects of placer gold are present in the gravels of Mission Creek below the (Konechney) prospect, and the placer gold is presumed to be derived from the mineralized zones." We did not investigate these placer deposits. We panned placer gold in Cobalt Creek about 1.5 km (2.5 mi) below the Owhat gold-arsenic-copper deposit (table 3, no. 12, and sheet 1); concentrates from three panned samples yielded 68 ppm (2.0 oz/ton) gold, 0.042 percent arsenic, 0.15 percent tin, and 0.013 percent tungsten. The samples were obtained by extracting fine sands and gravels from a coarse boulder pavement of syeno-monzonite float up to 1 m (3.3 ft) in diam. Hence, despite positive gold values, the nature of the placer deposit could pose significant engineering obstacles.

Bundtzen and others (1987) reported anomalous placer gold below dissected till of Early Wisconsin age on Tolstoi Creek in the Beaver Mountains about 120 km (75 mi) north of the Russian Mountains. Both the Beaver and Russian Mountains contain similar hardrock metallic lodes, have similar glacial histories, and lack exploited placer deposits. Early or pre-Wisconsin auriferous till, if reworked by Holocene streams, might produce economic concentrations of heavy minerals. We suggest that sites below the terminuses of Qgt_2 and Qgt_1 till on Cobalt and Mission Creek deserve to be prospected for placer gold and other heavy minerals.

INDUSTRIAL MINERALS

AGGREGATE

Coarse cobble- or boulder-bearing outwash deposits form large fans on the East Fork Owhat River and in the Mission Creek drainage (sheet 1). The Mission Creek fan includes a multimillion cubic meter aggregate resource accessible by the Kuskokwim River. Gravel at the river edge consists of 20- to 35-m-thick (65 to 115 ft) zones of interbedded coarse cobble gravel and sand containing equal amounts of volcanic and intrusive float from the Russian Mountains. Sieve analysis of a 20-kg (44 lb) gravel sample (after selective removal of cobbles), indicates a coarse silty-sandy gravel aggregate. Approximately 35 percent of this material was coarser than 9.5 m (3/8 sieve), and nearly 10 percent was coarser than a 37.5 mm (1-1/2 in.) sieve (fig. 20). In 1987, 14,570 metric tons (16,100 short tons) of outwash from the Mission Creek fan was used in Chuathbaluk for road repairs, airport maintenance, and foundation preparation. More production occurred in 1988 and 1989.

Several hundred thousand tons of channel lag sands and pea gravels in the Kuskokwim River [Birch Tree crossing about 40 km (24 mi) below Chuathbaluk] have been dredged and shipped to Bethel for construction needs. Similar resources are present beneath the active flood plain and in oxbow bends (Qag) of the Kuskokwim River within the map area, but none (to our knowledge) have been developed (Krause, 1984).

RIPRAP

Bundtzen and others (1989) assessed three river-front bedrock sites in the study area for riprap. Because the City of Aniak, immediately downstream from the study area in the Russian Mission C-2 Quadrangle, has experienced severe bank erosion during spring flooding and migration of the active channel of the Kuskokwim River, the location of a local riprap source is a high priority.

At the "southcentral Russian Mountain site, 87MDT32" (Bundtzen and others, 1989) 8 km (4.8 mi) upriver from Chuathbaluk, a steep bluff of coarse sandstone, was tested and determined to be a submarginal riprap source. At "Chuathbaluk site, 87MDT33," prominent mafic dikes and hornfels contain 11,000 m^3 (13,500 short tons) Class I and Class II riprap (Bundtzen and others, 1989). However, the site's Alaska T-13 degradation testing value of 10 is below that recommended for riprap.

According to Bundtzen and others (1989), the quartz monzonite exposures at the southwest toe of the Russian Mountains contain the best local riprap resources. Almost 2,000,000 m^3 (6 million short tons) of shallow, near surface Class I-III riprap is accessible from Chuathbaluk 4 km (2.4 mi) south of the site. A T-13 degradation value of 86 was obtained for the quartz monzonite, the highest quality exhibited by any sample analyzed during the Kuskokwim riprap study. Although the quartz monzonite could be influenced by groundwater weathering (Bundtzen and others, 1989), we believe that shallow surface reserves alone constitute an adequate resource for riprap projects in the area. Further site evaluation should include drilling and blasting for conformatory testing.

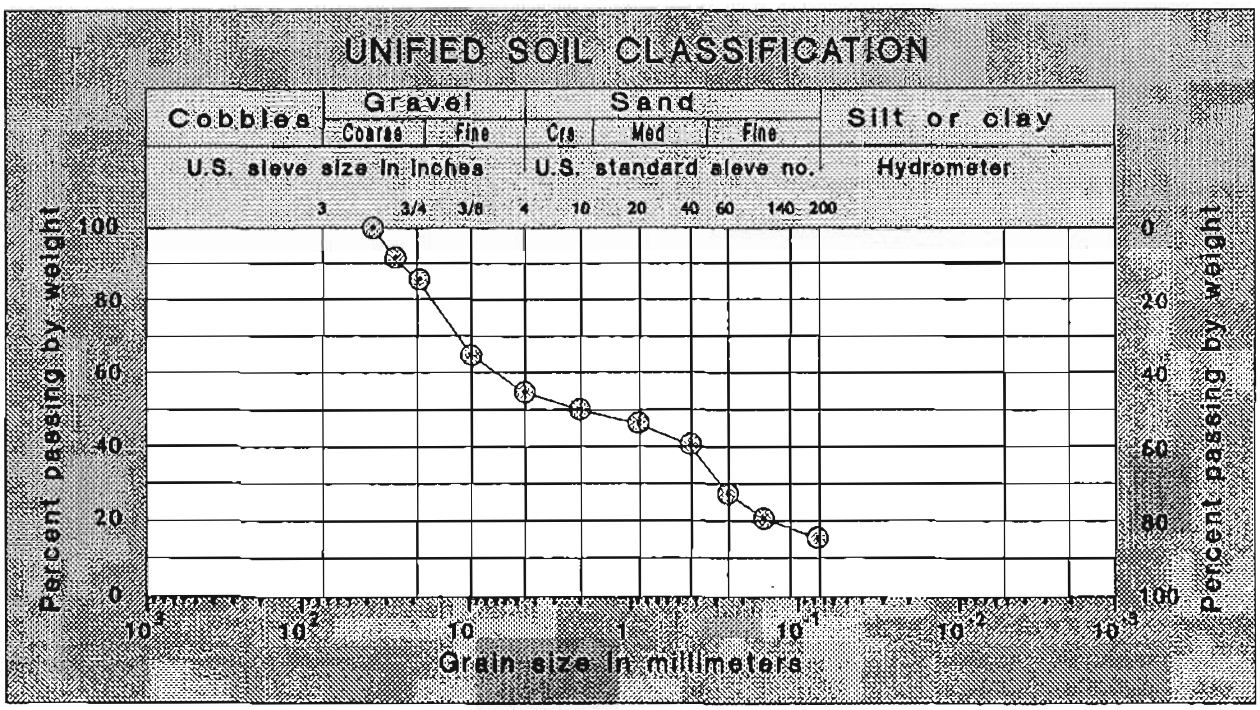

Figure 20. *Plot showing grain-size distribution of outwash of Mission Creek fan, Russian Mission C-1 Quadrangle, Alaska.*

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