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Gold mineralization related to Cretaceous-Tertiary magmatism in west-central Alaska - a geochemical model and prospecting guide for the Kuskokwim region

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ABSTRACT

The occurrence of hypabyssal to plutonic dikes, stocks, and volcano-plutonic complexes at the headwaters of streams bearing placer gold in the Kuskokwim region of west-central Alaska led to early conclusions that hydrothermal systems associated with igneous rocks are the metal sources of these ore deposits. Subsequent discovery of lode precious metal deposits at the Golden Horn and the Nixon Fork mines added more credence to this hypothesis. These early spatial relations are supplemented by recent geochemical evidence. Plutonic rocks associated with gold are metaluminous, alkali-calcic, generally quartz monzonitic in composition, and appear to be ilmenite-series granitoids. Common characteristics for most of the plutonic rocks in the Kuskokwim region, regardless of shape or size of the plutonic body, are a reduced nature, as indicated by a low Fe_2O_3/ FeO value of the bulk rock; and a subalkaline to alkaline character, as shown by a commonly used alkalinity index. These characteristics are contrary to other studies that propose that oxidized, felsic magmas or oxidized magnetite series granitoids are genetically related to precious-metal deposits in volcano-plutonic arcs.

Ore deposits in the Kuskokwim region can be related to a vertically zoned model, with direct application to gold exploration. Mercury-dominated epithermal deposits, such as the Red Devil Mine, typify the structurally controlled, upper part of this model with an estimated 1500 meter maximum depth of formation. Gold values up to 10 ppm are found in cinnabar separates from mercury-dominant deposits. Stibnite-gold±cinnabar±tungsten quartz veins, such as those at Donlin Creek and Granite Creek, are examples of slightly deeper and/or higher temperature mineralization.

Gold deposits, such as the Golden Horn and Nixon Fork mines, typify deeper levels of mineralization. Gold is found in arsenopyrite-pyrite-scheelite-gold-sulfosalt veins or chalcopyrite-bornite-bismuth-gold skarns restricted to Late Cretaceous-early Tertiary quartz monzonitic stocks. Temperatures of formation up to 400°C have been estimated from fluid inclusions for this type of mineralization.

Tight clustering of Pb isotopic data supports interpretations that mineralization events are related to similar formation processes. Mineral deposits in the Kuskokwim region appear to be genetically associated with plutonic rocks of the Late Cretaceous-early Tertiary magmatic belt. Plutonic rocks appear to be the source of gold and other metals, while faults, breccias, and rock contacts acted as conduits to localize the ore metals in concentrations of potential economic significance.

Mining in the Kuskokwim region has produced at least 74.6 metric tons (2.4 million ounces) of gold, with byproduct silver, mercury, tungsten, and antimony over the past ninety years, mostly from placer deposits. Granitoid plutons in the Kuskokwim region provide favorable exploration targets for additional gold-bearing lode deposits or related placer occurrences.

INTRODUCTION

Ore deposits are commonly intimately associated with plutonic bodies of all ages and tectonic settings. Studies of magmatic-hydrothermal systems have led to two contrasting explanations for the association of ore deposits with plutonic rocks. One explanation is that plutonic rocks are structural conduits for ore deposit fluids from nonmagmatic or unknown sources; or the igneous body primarily serves as a heat and fluid pump to leach metals and associated elements from surrounding country rocks (Newhouse, 1942; Titley, 1987; Roslyakova et al., 1988; Nesbitt and Muehlenbachs, 1989; Nesbitt et al., 1989; Wyman and Kerrich, 1989; Nesbitt, 1991). The other explanation is that igneous rocks are the source of fluids, gold and other metals (Gottfried et al., 1972; Tilling et al., 1973; Keith, 1983; Mutschler et al., 1985; Keith and Swan, 1987; Leveille et al., 1988; Newberry et al., 1988; Burrows and Spooner, 1989; Rock et al., 1989; Sillitoe, 1989). Plutons probably act in both of these roles in different areas, in places simultaneously, which adds much difficulty to paragenetic interpretations of the plutonic rocks and mineralization.

The basic premise of the present magmatic-hydrothermal theory is that as a magma crystallizes, fractionation or other processes produce melts progressively enriched in volatiles and metals. Processes that lead to fluid release and crystal-melt and fluid-melt fractionation of critical elements, mainly metal species and volatile complexing agents, are at least as important, if not more important, as the initial magma chemistry to ore formation (Burnham, 1979; Hannah and Stein, 1990; Newberry et al., 1990; Candela, 1992). For example, granitic plutons associated with W skarn or Sn greisen-skarn deposits in the Fairbanks, Alaska area were shown by Newberry et al. (1990) to represent magmas with similar origins and source materials, but differences in crystallization environment and timing of vapor loss produced different metallogenic signatures. Volatiles and metals exsolved from igneous rocks can form a variety of ore deposits, such as veins, disseminated, skarn, and replacement deposits, generally depending on factors such as local lithologic and structural regimes.

Some recent studies have begun to characterize the geochemistry of intrusions related to precious metal deposits. There appear to be two main contradictory schools concerning the geochemical characteristics of igneous rocks related to gold deposits. A high degree of alkalinity in conjunction with low oxidation state has been suggested to indicate gold favorability (Mutschler et al., 1985; Keith and Swan, 1987; Leveille et al., 1988; Newberry et al., 1988; Rock et al., 1989; Schwab and Keith, 1989). However, other authors argue that the most likely sources for Au-bearing fluids in Archean or porphyry gold deposits are oxidized, CO_2-rich, felsic magmas (Sillitoe, 1979; Cameron and Carrigan, 1987; Cameron and Hattori, 1987; Hattori, 1987; Blevin and Chappell, 1992). Also, magnetite series granitoids, characterized by relatively oxidized nature, are proposed to be genetically related to all significant base- and precious-metal deposits in volcano-plutonic arcs (Ishihara, 1981).

This paper explores possible genetic relations between gold deposits and their associated plutonic rocks in the Kuskokwim region of Alaska. The objectives are to document empirical relationships between gold mineralization and magma chemistry and to provide a model for ore deposits in the study area. This investigation covers about 25,900 km^2 (10,000 mi^2) in west-central and southwestern Alaska, and includes data from areas of the Medfra, Ophir, McGrath, Iditarod, and Russian Mission quadrangles (Fig. 1).

Interest in west-central Alaska has been stimulated by the occurrence of many intermediate to felsic plutons and abundant placer gold production over a 77,700 km^2 (30,000 mi^2) province. Mining in the Kuskokwim region of west-central Alaska (Fig. 2) has produced at least 74.6 metric tons (2.4 million ounces) of gold, about 12.4 metric tons (440,000 ounces) of byproduct silver, nearly 41,000 flasks of mercury, and significant byproduct tungsten, and antimony over the past ninety years, mostly from placer deposits (Bundtzen et al., 1986; 1987). The presence of igneous rocks (some with gold-quartz veins, or gold-bearing polymetallic sulfide-quartz veins) at the sources of placer gold (± other metals) -rich streams in the Kuskokwim area caused miners and early geologists to conclude that igneous rocks are the metal sources (including Eakin, 1913, 1914; Brooks, 1916; Mertie and Harrington, 1916, 1924; Mertie, 1936). This same reasoning is echoed in later work by Bundtzen and Miller (1989, 1992), Bundtzen et al. (1992a), and Miller et al. (1989). These conclusions are largely based on field relationships, with little additional support. However, at Flat (southwestern Iditarod quadrangle, Fig. 1), Bull (1988) concluded, by studying minor and trace element trends, that metals in the ore deposits were derived from the igneous system(s). Elements enriched in ore (Au, As, Sb, W) are also enriched in halos surrounding the plutons, and these elements increase with increasing SiO_2 content in the plutonic suite.

Despite recognition of an association between igneous rocks and placer gold deposits in the Kuskokwim region, very little geochemical data and limited descriptive data on this area are present in the literature. The limited previous work has concentrated on 15 minute scale quadrangles, with little synthesis of material from adjacent areas. This incomplete and dispersed database did not facilitate recognition of systematic patterns of mineralization present throughout the Kuskokwim Mountains. This paper relies upon the work of previous investigators in the Kuskokwim region and attempts to consolidate those data with new data to evaluate the premise that plutonic rocks are a major source of gold in this part of Alaska.

Few lode gold deposits are known in the Kuskokwim region of Alaska, partly because of lack of intensive exploration and difficult access. Commonly, placer gold deposits in streams and creeks draining plutonic-cored mountains define those plutons as gold producing. Placer exploration in western Alaska was probably most intense during the early 1900s. Historically, placer miners in the Kuskokwim region looked for frozen ground when considering placer mining because the preferred mining technique was drift (underground) mining in the early 1900s. Typical of placer districts throughout Alaska, gold was first recovered by hand methods; scraper plants and floating dredges were introduced later (by 1920), and bulldozer-dragline sluicing operations commenced in the 1930s (Bundtzen et al., 1987). This last phase has continued to be the principal extraction method. Permafrost areas were probably more extensively explored and drift mined, while mining of thawed ground was dominantly by large, floating dredges. This style of mining dominated gold production during the period from about 1920 to the late 1950s, with the last floating operation discontinued in 1968. Streams with low discharge were unfavorable for dredge mining and even today are difficult to work by various bulldozer-sluice box methods. Therefore, stream characteristics and geomorphology are often factors when considering past placer activity as indicative of gold potential or endowment of the Kuskokwim Region. From the preceding, it is apparent that factors affecting placer development also affect pluton discriminant criteria.

REGIONAL GEOLOGY

The regional geology of the study area (Fig. 3) is described by Decker et al. (1994) and Patton et al. (1994). Precambrian metamorphic rocks, including crystalline rocks of the Yukon-Tanana Terrane, occur in the northern Kuskokwim Mountains and serve as depositional basement for Paleozoic units of the Ruby, Innoko, and Farewell Terranes (Silberman, et al., 1979; Bundtzen and Gilbert, 1983; Dillon et al., 1985; Decker et al., 1994; Moll-Stalcup, 1994). The Farewell Terrane, a nearly continuous sequence of Paleozoic continental margin rocks over 5,500 m thick (Patton et al., 1980; Dutro and Patton, 1981) underlies much of the southwestern Alaska Range and northern Kuskokwim Mountains and unconformably overlies metamorphosed Early Proterozoic sedimentary and plutonic units. The predominantly Upper

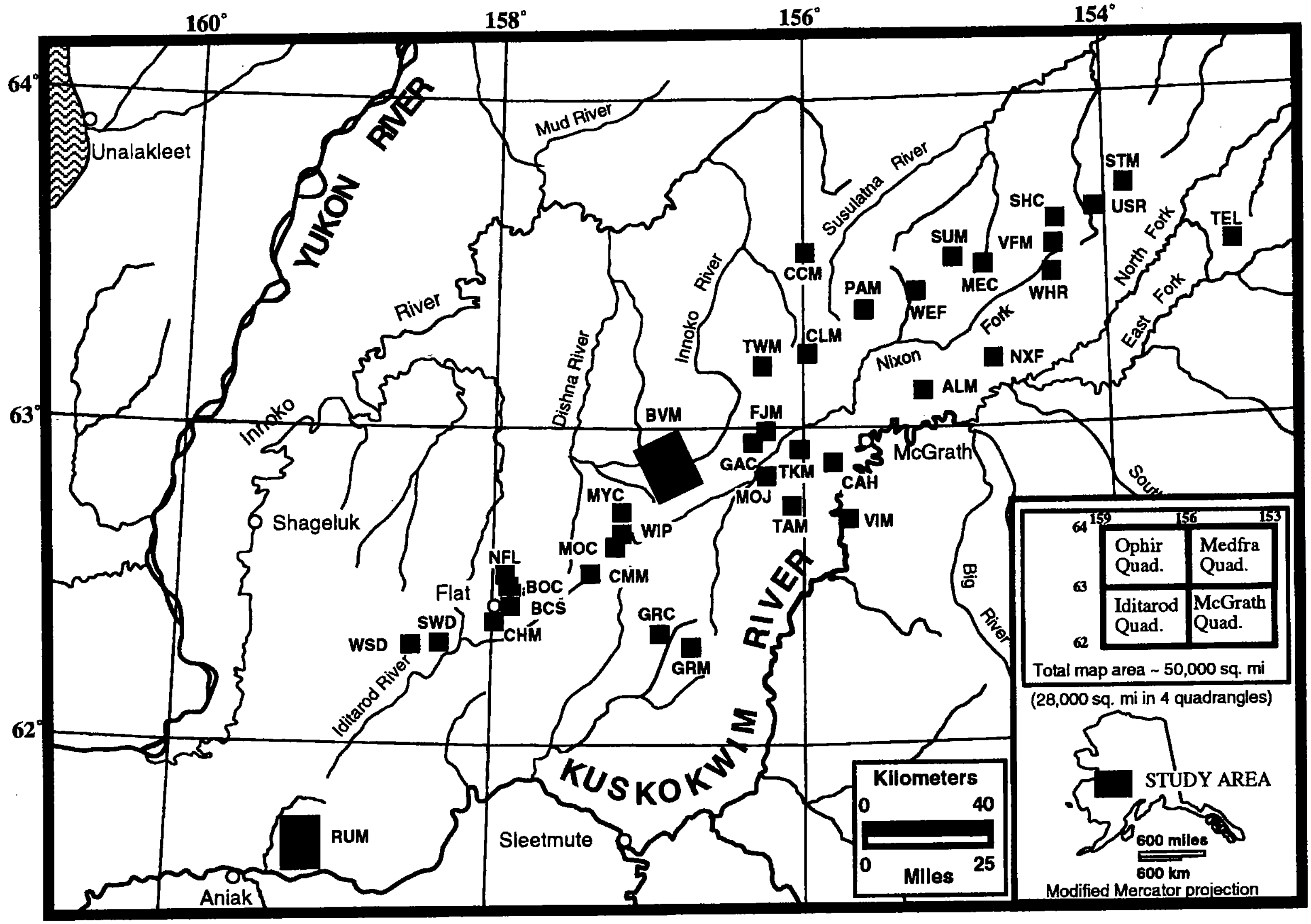

Figure 1–Location map of the Kuskokwim region. Black rectangles are plutonic areas mentioned in text and Table 1. Location abbreviations are defined in Appendix 1. Figure inset shows location of study area related to the State of Alaska and the main 1° by 3° quadrangles covered by this study. Map also includes the major rivers of the region and town locations.

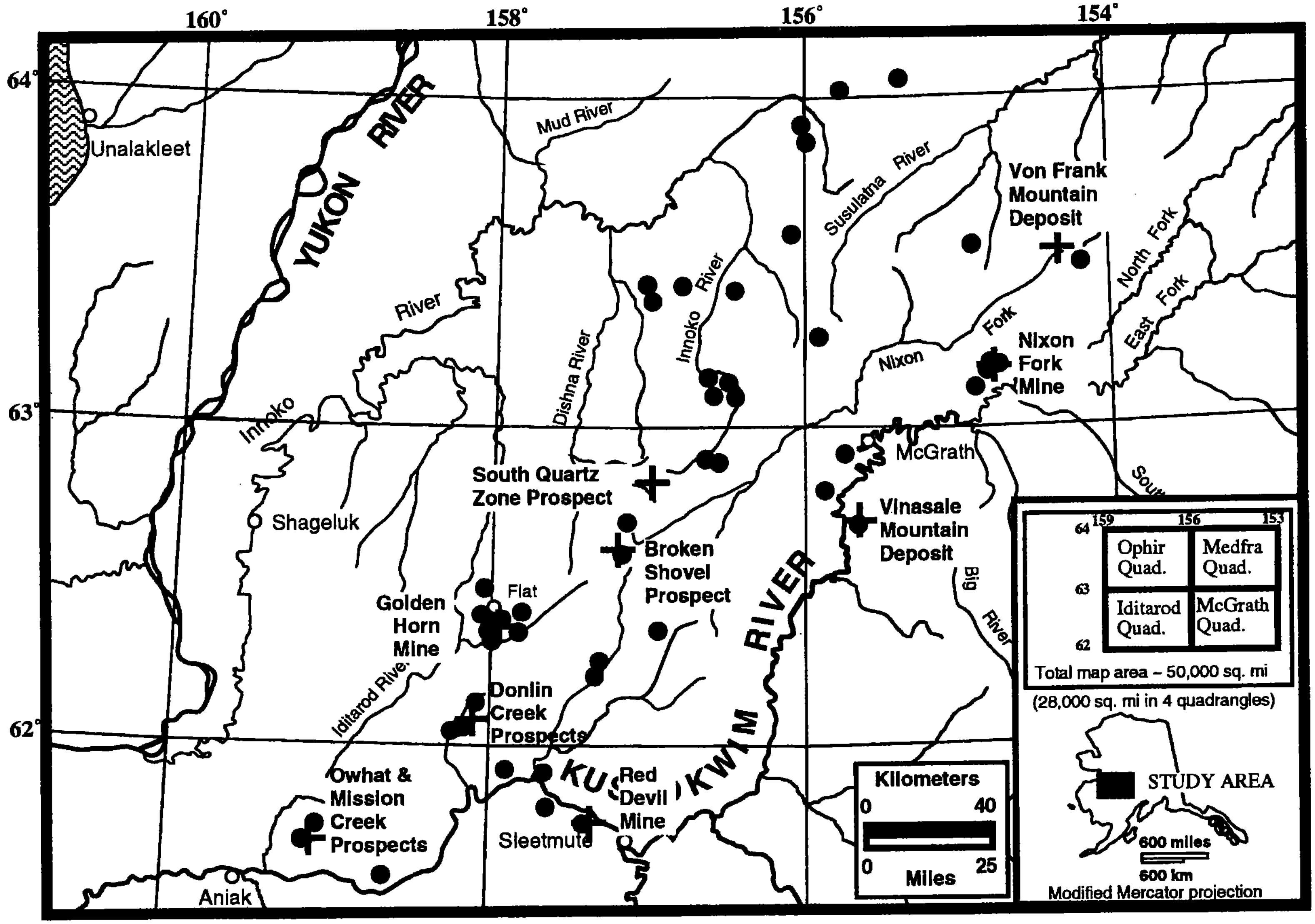

Figure 2–Locations of placer gold occurrences and important precious metal lode occurrences and mines in the Kuskokwim region. Base map is same as Figure 1. Shaded circles indicate locations of placer gold occurrences. Crosses indicate locations of lode prospects and mines mentioned in the text. Placer gold occurrences are from Maddren (1909, 1911) and Cobb (1973, 1974, 1976).

Cretaceous Kuskokwim Group, a post-accretionary basin-fill flysch sequence, is the most extensively exposed unit in the region (Fig. 3). The Kuskokwim Group consists largely of interbedded lithic sandstone and shale, and in large part rests unconformably on all older rock units of the region (Cady et al., 1955; Decker and Hoare, 1982; Bundtzen and Gilbert, 1983; Decker, 1984).

Two major northeast-trending faults traverse southwest Alaska, the Denali-Farewell fault system to the south, and the Iditarod-Nixon Fork fault to the north (Fig. 3). Late Cretaceous and Tertiary right-lateral offsets of 90 to less than 150 km characterize both faults (Bundtzen and Gilbert, 1983; Miller and Bundtzen, 1988).

The Kuskokwim Mountains are one of several Late Cretaceous to early Tertiary magmatic belts found throughout southern and western Alaska (Wilson, 1977; Hudson, 1979; Shew and Wilson, 1981). The Kuskokwim Mountains belt consists of calc-alkaline to alkaline andesitic to rhyolitic volcanic fields, isolated calc-alkaline stocks, and sub-alkaline to alkaline volcano-plutonic complexes (Moll-Stalcup, 1994). Plutonic rocks of the Kuskokwim Mountains magmatic belt extend over a northeast-trending area of approximately 900 km by 200 km (northern and central parts of this belt are shown in Fig. 3). Table 1 list selected plutonic rock analyses from the Kuskokwim Mountains. All igneous K-Ar age dates from the Kuskokwim Mountains range from 58 to 77 Ma, while plutonic K-Ar age dates range from 61 to 73 Ma (Szumigala, 1993).

Plutonic rocks of the Kuskokwim region have many typical geochemical characteristics of granites from volcanic arcs as defined by Pearce et al. (1984). These include: high-K or shoshonitic series affinity, biotite ± hornblende as the dominant ferromagnesian mineral(s), and variations from metaluminous to slightly peraluminous compositions. Major and trace element data are typical of arc-related calc-alkaline igneous rocks (Perfit et al., 1980; Gill, 1981) and suggest a common source for the Late Cretaceous to early Tertiary plutonic stocks and volcano-plutonic complexes. REE patterns are similar for plutonic and volcanic rocks from across a wide part of the Kuskokwim region, suggesting a common petrogenesis for many igneous centers.

Petrographic and chemical data for plutonic rocks of the Kuskokwim Mountains magmatic belt fit criteria for ilmenite series granitoids (Ishihara, 1981), including low Fe-Ti oxide content, ilmenite>magnetite, increasing Fe/Fe+Mg ratios in biotite with increasing SiO_2 content in the whole rock, and bulk Fe_2O_3/FeO ratios lower than 0.5. The plutonic rocks generally also have geochemical signatures compatible with I-type "granites": low Rb contents, Rb/Sr ratios, and $^{87/86}Sr$ values; and high K/Rb ratios, and Sr contents (Chappell and White, 1974).

Most plutons in the Kuskokwim area have quartz monzonitic to monzonitic compositions (Table 1) and are porphyritic. The fine-grained matrix texture of many plutonic rocks, well-developed contact metamorphic aureoles, sharp discordant contacts between igneous units, and common association of volcanic and plutonic rocks in igneous complexes indicate that intrusions were emplaced at shallow depths, probably within several kilometers of the paleosurface. Geobarometry calculations by Bull (1988) for plutonic rocks at Chicken Mountain (near Flat, Fig. 1) yield "maximum" emplacement depths of 1 to 4 km, which are probably representative for most plutonic areas throughout the Kuskokwim Mountains. Crystallization conditions calculated from coexisting biotite and ilmenite compositions (Bull, 1988) plot just below the quartz-fayalite-magnetite buffer assemblage (Wones and Gilbert, 1969).

KUSKOKWIM REGION GOLD DEPOSITS

Almost all plutons sampled for this study have minor to moderate amounts of propylitic alteration, dominated by secondary chlorite, epidote, and calcite. Clinopyroxene commonly has a halo of biotite, or is altered to a mixture of chlorite+opaques±amphibole±calcite. Many plutons in the Kuskokwim region also have secondary tourmaline replacing feldspar phenocrysts and matrix. Secondary tourmaline is commonly seen as spots and rosettes in most plutonic rocks, but tourmaline also occurs as almost complete replacements of plutonic rocks (examples include areas of the Beaver Mountains and the Russian Mountains) and as breccia matrix with plutonic rock clasts. Other types of alteration are minor, but locally important clay or sericite occur near veins and mineralized structures at numerous localities throughout the region. Also, replacement of feldspar phenocrysts by axinite in plutonic and volcanic rocks is common in parts of the Beaver and Russian Mountains (Bundtzen et al., 1988; Bundtzen and Laird, 1991; Szumigala, 1995).

Sixty three plutonic rock samples from the Kuskokwim region were analyzed for precious metal contents. Most of the plutonic rocks do not contain detectable gold or silver, at detection limits of 2 to 5 ppb Au and 0.2 ppm Ag. Gold was detected in samples from the Willow pluton (≤17 ppb), several sites in the Beaver Mountains (≤8 ppb), Granite Creek (≤29 ppb), and the Maybe Creek pluton (≤15 ppb). Determined values are at or near the detection limit, so accuracy is in doubt. Many of the plutonic rocks from the Flat area are reported to contain gold up to 58 ppb Au (Bull, 1988). The background concentration of Au in unaltered igneous rocks is generally less than 4 ppb (Tilling et al., 1973; Yingjun et al., 1983; Crocket, 1991), which is lower than the detection limits for analytical techniques reported in this study.

Gold has been found in polymetallic veins within plutons and along plutonic contacts in the Flat area, at the Broken Shovel prospect, and in the Beaver and Russian Mountains; in skarn at Nixon Fork; in shear zones at Granite Creek; and associated with hypabyssal and volcanic dikes at Donlin Creek and the Independence Mine (Cobb, 1976; Nokleberg et al., 1987; Nokleberg et al., 1994). The Nixon Fork mining district and the Golden Horn Mine (Fig. 2) have been chosen to characterize the regional style of mineralization because they are the best studied occurrences of lode gold mineralization, as well as having the most production. Gold deposits at Vinasale

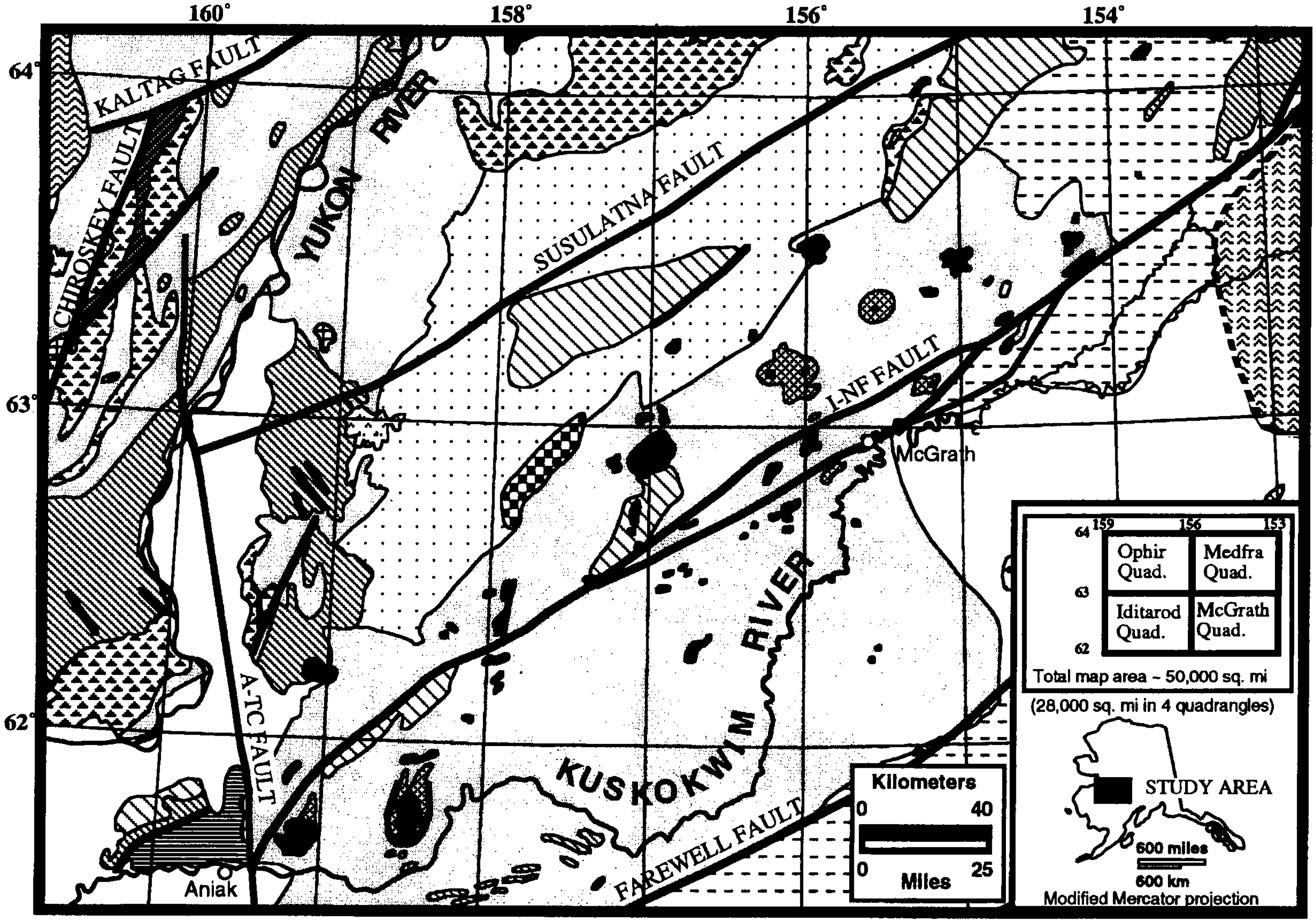

Figure 3—Kuskokwim region geologic map. Base map is same as Figure 1. Geology modified from Beikman (1980), with additions from Chapman et al. (1985), Patton et al. (1980), Gemuts et al. (1983), Miller et al. (1989), and Bundtzen et al. (1992a). Note the belt of Late Cretaceous-early Tertiary intrusive rocks and volcano-plutonic complexes trending from the upper right hand corner to the lower left hand corner of the figure.

Explanation of Map Symbols For Figure 3

- Quaternary Deposits
- Quaternary-Tertiary volcanic rocks
- Middle Tertiary continental deposits
- Late Cretaceous-Early Tertiary intrusive rocks
- Late Cretaceous-Early Tertiary volcanic rocks
- Late Cretaceous-Early Tertiary felsic volcanic rocks
- Late Cretaceous-Early Tertiary volcanoplutonic complexes
- Cretaceous intrusive rocks
- Cretaceous Kuskokwim Group
- Cretaceous and Jurassic rocks (black clastic turbidite)
- Jurassic, Triassic, and Permian volcanic rocks
- Mesozoic and Paleozoic rocks
- Farewell terrane (combination of Nixon Fork and Dillinger terranes)
- Paleozoic sedimentary and volcanic rocks (Ruby and Innoko terranes)
- Precambrian and early Paleozoic Yukon-Tanana terrane
- Early Proterozoic Idono Complex (metasedimentary and metaplutonic rocks)
- Fault
- Minchumina Suture
- Contact
- I-NF Iditarod-Nixon Fork Fault
- A-TC Aniak-Thompson Creek Fault

Mountain and Donlin Creek are recent discoveries and these deposits also provide important clues to understanding the regional metallogenesis. Gold prospects in the Beaver Mountains have been described in Szumigala (1995) and gold prospects associated with volcanic dikes have been discussed in Szumigala (1993).

Nixon Fork Gold Deposits

Gold skarns are associated with the 68 to 70 Ma Mystery Creek Stock at Nixon Fork in the Medfra quadrangle (Fig. 2), about 56 km (35 mi) northeast of McGrath. The deposits are adjacent to one of several plutons along the Iditarod-Nixon Fork Fault in an area largely covered by soil and vegetation. The skarn deposits were located by tracing placer gold (with native bismuth) deposits upstream to lode sources (Brown, 1926). This mineralization is one of few economically significant lode occurrences found within the Kuskokwim region.

The Nixon Fork mines produced approximately 1.8 metric tons (59,000 oz) of Au, with Cu, Ag, and minor Bi from 1917 to 1963 (Nokleberg et al., 1987; Newkirk et al., 1990; Bundtzen et al., 1992b). The total tonnage of ore mined has never been ascertained, but the average ore grade of several shipments in the 1920's was 46.9 g/t (1.5 oz/ton) gold, 2.6 percent copper, 62.5 g/t (2.0 oz/ton) silver, with bismuth credits (Bundtzen et al., 1986). Current measured and indicated resources at Nixon Fork are 114,995 short tons at 1.445 opt Au, containing 166,181 ounces of gold (unpublished 1994 Nevada Goldfields Inc. news release). Diluted recoverable reserves contain 154,517 ounces of gold.

Cretaceous age argillite and minor quartzite (metamorphosed lithic sandstone) of the Kuskokwim Group are found on the southwest edge of the Mystery Creek Stock. The dominant sedimentary units and hosts for skarn deposits are Middle and Upper Ordovician shallow water limestone and dolomite of the Telsitna Formation (Dutro and Patton, 1981). The Telsitna Formation in the Nixon Fork area consists predominantly of light gray to black limestone that ranges from thick-bedded and fine-grained to thin-bedded, silty, and micritic. Dolomite

Table 1—Major and trace element data of selected Kuskokwim plutonic rocks.

Location	Sample #	IUGS Rock Type	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI *	Total
STM (1)	78PA53E	quartz diorite	55.80	0.92	18.60	2.42	3.54	0.10	4.20	7.61	3.47	1.56	0.20	1.54	99.96
VFM (5)	79PA144	monzonite	56.20	0.87	17.30	1.67	5.06	0.12	3.60	5.76	3.71	3.94	0.40	0.70	99.33
CCM (6)	78PA7	monzonite	54.99	0.91	16.56	1.43	5.85	0.15	4.32	6.37	3.82	3.77	0.61	0.54	99.32
SUM (7)	75PA23E	granite	73.32	0.25	14.15	0.30	1.44	0.04	0.45	1.69	3.79	3.86	0.07	0.42	99.78
PAM (11)	79PA113C	quartz monzodiorite	59.80	0.71	15.20	1.11	4.71	0.07	4.10	5.26	3.24	2.76	0.30	1.93	99.19
NXF (12)	79PA46	quartz monzonite	61.10	0.91	16.40	2.23	2.73	0.08	2.90	4.74	3.77	4.02	0.30	0.72	99.90
NXF (12)	78NF20	quartz monzonite	64.18	0.83	15.89	0.96	3.36	0.07	1.81	3.21	3.48	4.27	0.23	0.68	98.97
NXF (12)	88ZNF02	granite	65.65	0.66	16.30	1.98	1.74	0.06	1.47	2.68	3.66	4.49	0.20	0.70	99.59
NXF (12)	89ZNF28	quartz monzonite	57.70	1.51	16.25	1.97	4.80	0.11	2.42	4.97	4.09	3.69	0.50	0.10	98.11
CLM (13)	79PA30C	quartz monzodiorite	58.70	1.02	17.20	0.66	6.39	0.14	3.80	5.05	2.70	2.39	0.30	0.71	99.06
TWM (14)	90ZTM1031	quartz monzodiorite	61.00	0.56	13.80	1.06	4.30	0.12	5.55	5.53	2.64	3.28	0.06	1.00	98.90
GAC (17)	89ZGA9152	granodiorite	64.30	0.49	16.06	1.23	2.65	0.09	1.87	3.97	3.31	3.01	0.36	1.38	98.72
CAH (18)	78BT379	monzonite	56.17	0.84	17.91	1.16	5.83	0.14	3.34	4.99	3.73	4.00	0.40	1.10	99.61
TKM (19)	78BT461	monzonite	56.20	0.93	17.17	1.65	5.17	0.13	4.43	6.12	3.47	3.79	0.48	0.47	100.01
BVM (20)	90ZBM1014	granite	64.00	0.63	14.80	1.47	3.40	0.10	2.85	3.60	2.67	4.55	0.30	1.08	99.45
BVM (20)	90ZBM1016	quartz monzonite	62.60	0.52	19.10	1.19	1.05	0.04	0.98	3.84	3.42	5.32	0.41	1.01	99.48
BVM (20)	90ZBM1024	granite	71.85	0.28	14.10	0.92	1.67	0.04	0.48	0.98	2.88	6.27	0.06	0.10	99.63
MOJ (21)	89ZMJ6466	quartz monzodiorite	61.59	0.61	17.28	1.56	3.09	0.10	2.87	4.66	3.48	3.17	0.25	0.40	99.06
MYC (23)	89ZMC6471	granodiorite	63.99	0.61	14.84	1.39	2.96	0.09	4.23	3.61	2.86	3.82	0.24	0.60	99.24
WIP (24)	89ZWP6470	granite	62.47	0.80	16.13	1.05	3.34	0.10	3.63	3.38	3.26	4.30	0.27	0.40	99.13
VIM (25)	90ZVM1000	granite	66.13	0.42	16.79	1.28	1.42	0.07	1.22	2.28	3.71	4.18	0.22	1.10	98.82
VIM (25)	77BT257	granodiorite	66.69	0.46	16.30	0.81	2.34	0.07	1.60	3.32	3.71	3.97	0.23	0.58	100.08
MOC (26)	89ZBS6474	quartz monzonite	61.20	0.68	14.50	0.99	4.10	0.13	4.46	3.92	3.09	4.30	0.28	1.71	99.36
CMM (27)	89ZCM6459	quartz monzodiorite	57.40	0.62	14.40	0.65	5.80	0.15	5.76	6.34	2.81	3.34	0.11	1.32	98.70
BCS (30)	89ZGH6452	monzonite	53.00	0.55	13.00	1.54	5.60	0.15	9.80	6.54	2.80	3.30	0.47	1.89	98.64
BCS (30)	81BTFM	quartz monzonite	60.96	0.50	15.74	0.78	3.44	0.08	4.24	3.29	3.93	4.47	0.30	1.27	99.00
BCS (30)	89BT2	monzonite	52.70	0.72	12.50	1.40	6.20	0.10	12.30	6.73	2.35	3.02	0.41	0.85	99.28
CHM (31)	86KB52	monzonite	57.14	0.73	16.67	5.81	T	0.10	4.77	4.78	3.91	5.16	0.72	0.70	100.49
CHM (31)	86KB1	granite	67.94	0.35	15.16	0.71	1.86	0.03	1.27	1.30	3.52	5.20	0.20	0.78	98.32
CHM (31)	88BT51	monzodiorite	49.90	0.82	10.90	0.79	8.30	0.21	14.00	8.63	1.50	2.14	0.42	0.00	97.61
CHM (31)	84MSL155	granodiorite	65.29	0.40	15.45	4.16	T	0.07	2.75	3.14	3.72	3.50	0.23	0.78	99.49
GRC (32)	89ZGC6433	granodiorite	65.04	0.55	15.68	1.51	2.77	0.09	2.68	3.95	2.78	3.17	0.18	0.90	99.30
RUM (36)	88BT73	quartz syenite	65.90	0.47	16.25	1.07	1.97	0.06	0.97	2.00	3.84	5.80	0.18	1.35	99.86

Location abbreviations listed in Appendix. All FeO analyses are by the titrametric method. T= all Fe given as Fe_2O_3. LOI*= loss on ignition.
(+) All CIPW Norms and differentiation index (diff. index) recalculated by author for consistency.

	Sample no.	Quartz	Corundum	Orthoclase	Albite	Anorthite	Nepheline	Diopside	Hypersthene	Olivine	Magnetite	Ilmenite	Apatite	Diff. index	References
CIPW	78PA53E	7.59	0.00	9.37	29.83	31.06	0.00	4.77	11.56	0.00	3.57	1.78	0.44	46.79	1
Norms	79PA144	1.46	0.00	23.61	31.83	19.18	0.00	5.85	13.01	0.00	2.46	1.68	0.89	56.89	1
(+)	78PA7	0.00	0.00	22.55	32.72	17.11	0.00	8.90	9.28	4.16	2.10	1.75	1.35	55.27	2
	75PA23E	31.68	0.84	22.96	32.27	7.98	0.00	0.00	3.20	0.00	0.44	0.48	0.15	86.91	1
	79PA113C	12.31	0.00	16.77	28.19	19.31	0.00	4.49	15.18	0.00	1.65	1.39	0.67	57.26	1
	79PA46	10.63	0.00	23.95	32.16	16.09	0.00	4.50	6.97	0.00	3.26	1.74	0.66	66.74	1
	78NF20	17.08	0.26	25.67	29.96	14.67	0.00	0.00	8.79	0.00	1.42	1.60	0.51	72.71	2
	88ZNF02	19.77	1.04	26.83	31.32	12.12	0.00	0.00	4.29	0.00	2.90	1.27	0.44	77.91	3
	89ZNF28	6.20	0.00	22.25	35.31	15.39	0.00	5.29	8.55	0.00	2.91	2.93	1.11	63.76	3
	79PA30C	14.00	1.74	14.36	23.23	23.48	0.00	0.00	19.55	0.00	0.97	1.97	0.67	51.59	1
	90ZTM1031	12.89	0.00	19.80	22.82	16.46	0.00	9.01	16.22	0.00	1.57	1.09	0.13	55.51	3
	89ZGA9152	22.39	1.03	18.27	28.77	17.82	0.00	0.00	8.08	0.00	1.83	0.96	0.81	69.43	3
	78BT379	1.11	0.00	23.99	32.04	20.62	0.00	1.54	16.43	0.00	1.71	1.62	0.89	57.15	4
	78BT461	1.59	0.00	22.50	29.50	20.17	0.00	5.85	15.10	0.00	2.40	1.77	1.05	53.59	4
	90ZBM1014	18.55	0.00	27.33	22.97	15.21	0.00	0.78	11.08	0.00	2.17	1.22	0.67	68.85	3
	90ZBM1016	13.96	1.74	31.93	29.39	16.63	0.00	0.00	2.64	0.00	1.75	1.00	0.91	75.27	3
	90ZBM1024	27.72	0.94	37.23	24.48	4.49	0.00	0.00	3.13	0.00	1.34	0.53	0.13	89.43	3
	89ZMJ6466	14.23	0.25	18.99	29.84	21.78	0.00	0.00	10.86	0.00	2.29	1.17	0.55	63.06	3
	89ZMC6471	18.05	0.01	22.88	24.53	16.57	0.00	0.00	14.17	0.00	2.04	1.17	0.53	65.47	3
	89ZWP6470	13.45	0.62	25.74	27.94	15.20	0.00	0.00	13.34	0.00	1.54	1.54	0.60	67.13	3
	90ZVM1000	22.54	2.60	25.28	32.12	10.10	0.00	0.00	4.12	0.00	1.90	0.82	0.49	79.94	3
	77BT257	19.80	0.42	23.58	31.55	15.04	0.00	0.00	7.02	0.00	1.18	0.88	0.50	74.93	4
	89ZBS6474	11.12	0.00	26.02	26.77	13.31	0.00	3.84	15.48	0.00	1.47	1.32	0.63	63.92	3
	89ZCM6459	5.29	0.00	20.27	24.42	17.27	0.00	11.66	18.66	0.00	0.97	1.21	0.25	49.98	3
	89ZGH6452	0.00	0.00	20.16	24.49	13.60	0.00	13.44	14.49	9.31	2.31	1.08	1.06	44.64	3
	81BTFM	6.84	0.00	27.03	34.02	12.39	0.00	1.87	15.01	0.00	1.16	0.97	0.67	67.89	5
	89BT2	0.00	0.00	18.13	20.20	14.87	0.00	13.05	16.82	12.51	2.06	1.39	0.91	38.33	5
	86KB52	0.00	0.00	30.73	33.35	12.80	0.00	5.18	7.27	6.75	0.85	1.40	1.59	64.08	6
	86KB1	22.97	1.90	31.50	30.53	5.27	0.00	0.00	5.61	0.00	1.06	0.68	0.45	85.01	3
	88BT51	0.00	0.00	12.96	13.00	17.10	0.00	19.27	17.14	16.78	1.17	1.60	0.94	25.96	5
	84MSL155	18.43	0.39	21.02	31.99	14.31	0.00	0.00	11.31	0.00	1.23	0.77	0.51	71.45	5
	89ZGC6433	23.76	0.94	19.04	23.90	18.72	0.00	0.00	9.93	0.00	2.23	1.06	0.40	66.70	3
	88BT73	15.44	0.46	34.79	32.98	8.88	0.00	0.00	4.55	0.00	1.57	0.91	0.40	83.21	7

References- (1) Moll, USGS unpublished data, (2) Moll et al., 1981, (3) Szumigala, 1993, (4) Bundtzen, ADGGS unpublished data, (5) Bundtzen et al., 1992a, (6) Bull, 1988, (7) Bundtzen and Laird, 1991.

interbeds are blue-gray in color, fine- to medium-grained, and range in thickness from 1 to 44 m (3 to 145 ft). Carbonate rocks near plutonic bodies are contact metamorphosed to a slightly coarser grained marble and contain trace to about ten percent fine-grained, disseminated pyrite and pyrrhotite.

The Mystery Creek Stock, a 68 to 70 Ma, alkali-calcic, metaluminous quartz monzonite/quartz monzodiorite stock intrudes the Telsitna Formation at Nixon Fork (Herreid, 1966; Moll et al., 1981; Szumigala, 1993). The ferric/ferrous ratio is quite low, primary opaque content is low (generally less than 1%) and most of the opaques are ilmenite rather than magnetite. These and other results from petrographic studies indicate dry, reduced conditions of crystallization for the Mystery Creek Stock.

The poorly exposed stock has a crude elliptical shape covering 39 km^2 (15 mi^2), with known skarn bodies restricted to its western edge. Drillhole data (Battle Mountain Exploration Company, unpublished report, 1988) indicate that either the Mystery Creek Stock thins to the west, or that a large sill ranging in thickness from 17 to over 100 m (55 to over 300 ft) occurs along the western margin where quartz monzodiorite is very irregular in outline and has numerous apophyses. Other intrusive units, cutting both sedimentary rocks and the Mystery Creek Stock, include dikes of quartz porphyry, monzodiorite, and dacite. Many dikes are extensively sericitized and K-Ar dates of fine-grained white mica from these dikes are equivalent to the Mystery Creek Stock age (Szumigala, 1993).

Surficial exposures of mineralization are quite limited. Drill results by several mining companies, as well as observations made during mining, indicate that skarn bodies and economic precious metal values are apparently restricted to the immediate area of plutonic/marble contacts and to marble pendants in the plutonic rocks. Geophysical and soil sampling programs have failed to identify any skarn bodies beyond sixty meters (200 ft.) of plutonic exposures (Reed and Miller, 1971; Szumigala, Battle Mountain Exploration Co. unpublished report, 1988). All mining and most of the recent exploration effort has been restricted to the western margin of the Mystery Creek Stock. The sill-like form of the intrusion possibly restricted metasomatic fluids to the western margin.

The richest gold grades at Nixon Fork occur in oxidized skarn consisting of iron oxides-bismuthinite-quartz-calcite-clay minerals, with some remnant garnet, pyroxene, amphibole, and micas (phlogopite and chlorite). The association of gold with intense retrograde hydrosilicate alteration is typical for gold-bearing skarns (Theodore et al., 1991). However, prograde pyroxene-dominant skarn also contains significant gold associated with chalcopyrite, pyrrhotite, bismuth-telluride, and native bismuth (Larry Freeman, written comm., 1995). Skarn assemblages at Nixon Fork are both calcic and magnesian (cf. Zharikov, 1970; Einaudi and Burt, 1982), but calcic skarn is by far the dominant skarn type, accounting for more than ninety volume percent of total skarn.

Local compositional differences in the carbonate protolith control the skarn type and local conditions control the ultimate skarn mineralogy. At Nixon Fork, limestone (calcium carbonate) is much more common than dolomite (magnesian carbonate). Therefore, the skarn assemblages tend to be garnet±pyroxene±epidote±calcite (calcic skarn assemblage), rather than olivine or humite±talc±serpentine±phlogopite (magnesian skarn assemblage). The dominant calc-silicates in prograde skarn at Nixon Fork are garnet, pyroxene, and epidote, with locally important wollastonite. In several drillholes, a progression can be observed from marble to a spotted skarnoid consisting of carbonate (dominant mineral)-olivine or humite (altering to serpentine)-fluorite-periclase (generally altered to brucite)±phlogopite to garnet-pyroxene-epidote skarn.

Chalcopyrite is the dominant ore mineral found in prograde skarn at Nixon Fork, but other ore minerals include bornite, pyrite, magnetite, native bismuth, native gold, and numerous supergene minerals (including limonite, tenorite, malachite, chrysocolla, and azurite). Some of the plutonic rocks host auriferous quartz veinlets near contacts with skarn deposits (Tom Bundtzen, 1991, oral comm.).

The principal controls on skarn mineralization are a combination of bedding and structures peripheral to the main plutonic contact or in areas adjacent to dikes and apophyses splaying outward from the stock (Brown, 1926; Herreid, 1966; Newkirk et al., 1990). Local structures with N30°E to N50°E trends appear to be significant for localizing skarn bodies and gold mineralization. Ore bodies were generally irregularly shaped with vertical or horizontal dimensions of less than 30 m (100 ft) (Mertie, 1936). Ore at the 460 foot depth in the Garnet shaft, on the west side of the Mystery Creek Stock, occurred as large slabs cemented by secondary copper minerals and limonite in chimney-like caverns near a "tongue of quartz monzonite" (Jasper, 1961). The largest deposit and principal producer at Nixon Fork was the Whalen Mine, located in a roof pendant or enclave of carbonate rock within the southern part of the Mystery Creek Stock (Brown, 1926; Herreid, 1966).

Although the Nixon Fork skarn deposits are one of the few lode gold deposits in the Kuskokwim region, the possibility of other similar mineralization is limited to areas with carbonate units. Outcropping carbonate units are restricted to the Medfra quadrangle, effectively restricting exploration for similar skarn occurrences to the area surrounding and north of the Nixon Fork deposits.

Golden Horn Deposit and Other Ore Occurrences at Flat

The Iditarod Mining District ranks as Alaska's third largest producer of placer gold (Bundtzen et al., 1992a), and most mining has occurred within 16 km (10 mi) of the town of Flat (Nokleberg et al., 1987). The Flat area, 132 km (82 mi) southwest of McGrath (Fig. 2), has yielded approximately 46.6 metric tons (1.5 million oz.) of gold since mining began in 1909. Most gold production is from placer deposits, although the Golden Horn lode deposit was mined from 1925 to 1937 and produced 535 tons of Au-Ag-W-Pb ore yielding 84.2 kg (2,706 ounces) of gold, 81.5 kg (2,620 ounces) of silver, and 4,243 kg (9,336 pounds) of lead (Bundtzen et al., 1992a). All placer operations are on creeks that either begin at or cross a monzonitic intrusion (Maloney, 1962). Lode mineralization in the Flat area consists of the Golden Horn quartz-scheelite-sulfide vein system in the Black Creek stock, auriferous quartz-sulfide veins in the Chicken Mountain igneous complex, and numerous quartz-antimony-mercury veins throughout the area (Brooks, 1916; Mertie and Harrington, 1924; Maloney, 1962; Kimball, 1969; Bull, 1988; Bundtzen et al., 1992a).

The following descriptions of the Iditarod Mining District and the Golden Horn Mine are synthesized from recent studies by Bull (1988) and Bundtzen et al. (1992a). The general geology of the Iditarod Mining District consists of clastic rock units of the Cretaceous Kuskokwim Group overlain and intruded by Late Cretaceous-early Tertiary subaerial volcanic rocks, comagmatic monzonitic plutons, peraluminous rhyolite/granite porphyry sills and altered mafic dikes (Bundtzen et al., 1992a). Four compositionally zoned plutonic bodies (Chicken Mountain, Boulder Creek, and Black Creek volcano-plutonic complexes; and the Swinging Dome pluton) are exposed in the Flat area (Figs. 1 and 3, Table 1) (Bundtzen et al., 1992a). The volcano-plutonic bodies at Chicken Mountain, Black Creek, and Boulder Creek are aligned in a N5°E direction over a distance of 15 km, which is nearly identical to an alignment of monzonitic plutons in the Moore-Moose Creek area 80 km (50 mi) northeast of Chicken Mountain (Bundtzen et al., 1992a). These authors postulate that a major structure with a trend of N15°W (referred to as the Granite Creek Fault) cuts the Chicken Mountain massif and acted as a locus for lode gold mineralization. All of the plutons in the Flat area have thermally metamorphosed host lithologies, forming hornfels for up to 2 km from plutonic-sedimentary rock contacts.

The Black Creek stock is exposed over 20 to 26 km^2 (8 to 10 mi^2) and is the center of a 65 ± 4 Ma, metaluminous, alkali-calcic volcano-plutonic complex intruding Kuskokwim Group sedimentary rocks (Bull, 1988; Bundtzen et al., 1992a). The Black Creek stock consists largely of biotite monzonite (core of pluton), that cuts an earlier olivine-pyroxene-biotite monzodiorite (rim) (Bull and Bundtzen, 1984; Bull, 1988). Late syenite and felsite quartz porphyry dikes cut the major phases. The Black Creek stock appears to have been emplaced at high crustal levels (1-4 km depth) and crystallized under conditions of low oxygen fugacity and low water content (Bull, 1988).

The Chicken Mountain stock is very similar to the Black Creek stock. This stock covers an elliptically shaped 15 km^2 (6 mi^2) area and is compositionally zoned from pyroxene monzodiorite and biotite olivine gabbro at the outer margin, through biotite monzonite with gradational contacts, to a core of leucocratic quartz monzonite (Bundtzen et al., 1992a).

Gold, As, Sb, W, and Ba are enriched in the Black Creek and Chicken Mountain stocks with increased differentiation of the magmatic series (Bull, 1988). The Golden Horn deposit is a series of generally en echelon, N10°E to N35°E striking, vertically dipping, quartz-gold-scheelite and cinnabar-stibnite veins that intrude monzonitic phases of the Black Creek stock (Bundtzen et al., 1992a). Mineralized structures appear to continue in a N5°E direction for at least 2.5 km (1.5 mi). Surface exposures at the Golden Horn deposit are a series of veins and shears with thicknesses ranging from 1 cm to 2 m that occur within a 38 m (125 ft) wide zone. Most auriferous mineralization at the Golden Horn open cut appears to be confined to the monzonite phase, especially within zones of ankerite-sericite alteration. Chlorite-calcite-quartz veins in joints of gabbro-monzodiorite are apparently devoid of gold and other metallic minerals.

Mineralization and alteration at the Golden Horn deposit occurred in six phases (Bull, 1988; and Bundtzen et al., 1992a). The earliest phase was 'greisen-like', with thin, en-echelon veinlets of muscovite-biotite-quartz±ilmenorutile cutting monzonite. Later, extensive sericite-ankerite-quartz veinlets or massive replacements with minor chrome phengite and fluorite occur in all igneous lithologies. This alteration is most intense in the pluton center, grading outwards to ankerite-sericite and finally to mild sericite alteration. The third phase of mineralization is black sulfide(?) clast-supported breccias and minor chalcopyrite with trace molybdenite in both monzonite and altered monzonite porphyry. Later arsenopyrite-scheelite-gold-quartz veins are accompanied by extensive chlorite alteration along structural conduits. The fifth phase of mineralization is lead sulfosalt-(gold?) introduced in shears and faults accompanied by sericite(?) alteration in monzonite. The last mineralization phase is quartz-stibnite±cinnabar veins (10 cm to 1 m wide), sometimes indistinguishable from phase 5 mineralization. Pyrite and arsenopyrite are the most common accessory minerals associated with gold mineralization.

Measurements of liquid-rich, subordinate solid-bearing fluid inclusions from quartz in phase 5 veins yield low NaCl, high CO_2 values with narrowly bracketed 148°C average homogenization temperatures (Bundtzen et al., 1992a). NaCl poor, liquid-rich inclusions in quartz from phase 1 mineralization yield homogenization temperatures averaging 272°C (Bundtzen et al., 1992a). Equilibrium temperatures of 300-350°C were calculated by Bull (1988) for arsenopyrite compositions associated with pyrite in phase 4 veins. Fluid inclusion studies of quartz from smaller, more distal cinnabar-quartz-stibnite veins indicate 150°C for the average homogenization temperature (Bull, 1988).

A number of en-echelon, centimeter wide, closely spaced, quartz-ankerite(?)-gold-stibnite-cinnabar veins and quartz-clay-iron oxide-sulfide veins occur in sericite and clay alteration zones (Nokleberg et al., 1987; unpublished WGM Inc. company report, 1988) within quartz monzonite on Chicken Mountain, but no production has occurred (Bundtzen et al., 1992a). Veins, veinlets, and stringers contain native gold, arsenopyrite, pyrite, stibnite, cinnabar, rare chalcopyrite and molybdenite. Scheelite has been identified in drill cuttings.

Vinasale Mountain

A significant new gold prospect was discovered in the late 1980's at Vinasale Mountain, about 26 km (16 mi) south of McGrath (Fig. 2). Recent drilling by a joint venture of Placer Dome U.S. Inc.-Central Alaska Gold Company, and later by ASA Inc., has outlined a significant resource of approximately

31 metric tons (one million ounces) of gold with an average grade of 4.7 g/t (0.15 oz/ton) within plutonic phases at Vinasale Mountain (Bundtzen et al., 1992b). The gold mineralization is metallurgically refractory (Bundtzen and Miller, 1992a; DiMarchi, 1993). Heavy mineral concentrates from gold placers on the south side of Vinasale Mountain contain scheelite, magnetite, and stibnite; with anomalous Bi, Sn and Nb values (Cobb, 1973; Bundtzen et al., 1987).

Vinasale Mountain is a resistant alkali-calcic monzonitic pluton rimmed by a thermally altered aureole of Kuskokwim Group sedimentary rocks. Four intrusive units are recognized: porphyritic quartz monzonite (most voluminous), rhyolite porphyry, monzonite intrusion breccia, and shonkinite (DiMarchi, 1993). Biotite-augite-quartz monzonite at Vinasale Mountain has a K-Ar age of 69.0 ± 2.0 Ma (Bundtzen and Swanson, 1984).

The monzonite intrusion breccia is the most significant intrusive unit for ore control. The intrusion breccia is characterized by subrounded clasts of porphyritic monzonite and minor vein quartz in a fine-grained equigranular monzonite matrix (DiMarchi, 1993). The breccia occurs as a series of steeply dipping and branching bodies that are central to slightly younger hydrothermal breccia and veining (McCoy et al., 1996). Gold mineralization and alteration occurs in a 0.3 km^2 zone spatially associated with the intrusion and hydrothermal breccias.

Three areas (0.7 km^2, 0.3 km^2, and 0.03 km^2) of coincident multi-element (Au, As, Sb, Bi, Pb, Mo, and others) anomalies in rock and soil samples dominate the surface geochemistry of Vinasale Mountain (DiMarchi, 1993). Hydrothermal alteration is centered on the intrusion breccias and extends outward for several hundred meters into the porphyritic quartz monzonite. Radiometric dating (K-Ar and fission track) indicates that the hydrothermal alteration age is the same as the crystallization age of the quartz monzonite stock (DiMarchi, 1993). Hydrothermal alteration consists of silicification, sericite alteration, and propylitic alteration, with propylitic alteration forming broad halos around zones of sericite and quartz alteration. The quartz monzonite phase also contains variable amounts of secondary tourmaline as isolated grains, rosettes, and veins with quartz (Bundtzen, 1986).

Dolomite and ankerite commonly occurs in veins and with silicification and sericite alteration. Pyrite and arsenopyrite, with lesser amounts of stibnite, sphalerite, and galena, occur as disseminated grains in areas of silica flooding or strong sericite alteration in breccias and quartz monzonite, and in quartz-dolomite veins and segregations (DiMarchi, 1993). Higher concentrations of gold are associated with areas of intense sericite alteration and silica flooding, where fine-grained disseminated arsenopyrite is abundant. Structural control appears important in the emplacement of the intrusion breccias and gold mineralization (DiMarchi, 1993). Fluid inclusion studies indicate boiling conditions, mean homogenization temperature of 225°C, very low CO_2 contents (3 mole percent), and a pressure estimate of formation of 0.23 kb (McCoy et al., 1996).

Donlin Creek

The Donlin Creek property, in the southwestern Iditarod quadrangle (Fig. 2), includes several lode gold targets situated along more than 6 km (3.7 mi) of a intensely mineralized rhyolite and monzonite dike system. A resource of nearly 12.5 metric tons (400,000 ounces) of gold at an average grade of 3.15 g/t (0.1 opt) has been drill-defined to a depth of 80 m (260 ft) (unpublished 1994 Calista Corp. report, 3 p.). Highly concentrated zones of 15 to over 50 ppm (0.4 to >1.5 opt) Au have been intercepted in several holes. Placer deposits in streams draining the lode deposits have a mineral suite including gold, stibnite, cinnabar, pyrite, garnet, scheelite, monazite, and possibly cassiterite (Cobb, 1976).

The Donlin Creek gold deposits are associated with an anastomosing swarm of early Tertiary (65 Ma), peraluminous rhyolite to monzodiorite dikes that cut graywacke, siltstone, and shale of the Cretaceous Kuskokwim Group. Dikes were emplaced along the steeply dipping, southwest-trending Donlin fault, a splay of the major Iditarod-Nixon Fork fault. Geophysics, structure, and metal suites suggest that dikes have originated from an intrusive center buried at a relatively shallow depth. Pervasive silicification, sericite alteration and petrographic textures indicate an epithermal or perhaps a distal porphyry environment during mineralization. In most of the area, gold mineralization occurs in steeply dipping linear trends, which are interpreted as zones of shearing. Mineralization is characterized by numerous, inconspicuous hairline quartz veinlets. Scattered larger quartz and quartz-sulfide veins ranging up to 10 centimeters (4 inches) wide occur locally. Mineralized zones typically contain 1 to 3 percent pyrite and trace to 2 percent other sulfides, including arsenopyrite and stibnite. Massive stibnite occurs locally. A pyrite-sericite-carbonate alteration assemblage, similar to alteration found at many Kuskokwim mercury deposits, is present near antimony-rich mineralization (MacKevett and Berg, 1963). Homogenization temperatures of primary fluid inclusions from Donlin Creek range from 147° to 196°C, primarily from 2-phase liquid-rich inclusions (McCoy et al., 1996).

Gold mineralization occurs in at least five separate zones. Some authors believe that the Lewis prospects have the best size potential in the Donlin Creek area (unpublished 1994 Calista Corp. report, 3 p.). An open-ended resource contains nearly 9.3 metric tons (300,000 oz) of gold. At the Lewis prospects, the extent and complexity of the intrusives increases, and significant amounts of coarser-grained, but chemically equivalent, granodiorite or monzodiorite are included in the intrusive mass. Dikes pinch and swell, forming small stock-like bodies, occasionally intruding subhorizontal bedding to form sills. These features indicate that the Lewis area may be within an extensional zone of a long, shallow, intrusive body.

Other Gold Occurrences

Mineralization in the Russian Mountains consists mainly of intrusion-hosted, copper-gold-arsenic deposits that contain anomalous amounts of antimony, tin, zinc, bismuth, lead, tungsten, uranium, and cobalt in tourmaline-quartz-axinite gangue (Bundtzen and Laird, 1991). Most lode prospects (examples include the Owhat and Mission Creek prospects, Fig. 2; Nokleberg et al., 1987) in the Russian Mountains share many similarities in structural style, geologic relationships, and metallic and mineralogic content. Almost all are hosted in N20-40°W trending joints and fractures in Late Cretaceous-early Tertiary plutonic rocks, commonly with axinite-bearing andesite porphyry dike rocks in the hanging walls and footwalls of the vein-fault structures. Andesite dikes may have a genetic association with the orebodies or may just intrude along the same structural channels (Bundtzen and Laird, 1991). The major sulfide minerals are arsenopyrite, chalcopyrite, and pyrite; with minor amounts of cassiterite, bornite, stephanite, tetrahedrite, and lead-bismuth sulfides.

Deposits in the Russian Mountains are relatively high-temperature veins emplaced along pre-existing structures. Fluid inclusion data from quartz at the Mission Creek Prospect indicate formation temperatures that range from 280 to 410°C (Bundtzen and Laird, 1991). Ore textures and field evidence from several prospects in the Russian Mountains indicate that intrusion-hosted polymetallic deposits formed during multiple events in the fracture systems. Sulfides appear to be deposited in later vein-forming stages, and replace earlier-formed fine-grained, banded tourmaline and euhedral quartz (Bundtzen and Laird, 1991).

Similar gold mineralization hosted by igneous phases of an alkalic volcano-plutonic complex is found in the Beaver Mountains (Fig. 1). The Beaver Mountains contain many areas with mineralized veins, stockworks, and breccias that have anomalous Au, Ag, Cu, Pb, and As values. Vein mineralization has a zoned distribution in plan view, with the most significant lode prospects found in a 13 km^2 (5 mi^2) area informally known as the South Quartz Zone (Fig. 2) (Szumigala, 1995). The veins are sometimes rhythmically banded and contain variable amounts of gangue minerals dominated by tourmaline, quartz, axinite, and subordinate carbonate.

Polymetallic veins that occur in sericite- and tourmaline-altered areas of the Moose Creek and Maybe Creek plutons are similar in style, mineral assemblage, and grade to the occurrences in the Russian and Beaver Mountains. Homogenization temperatures range from 254° to 380°C for quartz from the Broken Shovel prospect in the Moore Creek pluton (Bundtzen et al., 1988). The occurrences in the Moose Creek and Maybe Creek areas are relatively unexplored and their potential is unknown.

Recent mineral exploration near Von Frank Mountain (Fig. 1) found gold and very weak copper mineralization associated with chalcopyrite, pyrite, and rare molybdenite in quartz stockwork veining within a 69 Ma quartz diorite stock, which is the cupola of the Von Frank pluton. Drill intercepts include 131 meters (429 feet) with an average grade of 0.45 grams per tonne (0.013 ounces per ton), and up to 41 meters (135 feet) of 1.2 grams per tonne (0.035 ounces per ton) gold. Similar, low-grade gold mineralization discovered recently in plutonic hosts in the Candle Hills supports earlier conclusions that the rich placer gold deposits previously mined in Candle Creek were derived from the volcano-plutonic system.

INTERPRETATION OF PB ISOTOPE DATA

Lead isotopic studies are one method for comparing Kuskokwim ore deposits. Data presented in this discussion are from the Beaver Mountains (discussed in Szumigala, 1993), ten sulfide samples from other ore deposits in the Kuskokwim region, and two feldspar samples from Kuskokwim plutons. Lead isotope analyses of sulfides reported in this study were analyzed as part of the USGS Alaska Mineral Resource Appraisal Program (AMRAP), and Church et al. (1987) discuss chemical and analytical procedures. The samples considered in this section are from veins closely associated with Late Cretaceous-early Tertiary plutonic rocks. Sample locations, characteristics, and Pb isotopic values are given in Table 2. Data presented in this section are similar in range to values reported by Bergman and Doherty (1986).

The most noteworthy aspect of the Kuskokwim Pb isotopic data is the very narrow range in composition, especially in the $^{206}Pb/^{204}Pb$ ratio that ranges from 18.837 to 19.302 (Table 2 and Fig. 4). Overall, Late Cretaceous-early Tertiary plutons in the Kuskokwim Mountains magmatic belt have lead isotope compositions that are very similar to sulfide-bearing quartz veins found in plutonic rocks, or in volcanic and/or sedimentary rocks intruded by these plutons (Fig. 4). The Kuskokwim data are closely clustered, except for the Nixon Fork sample, and plot around the orogene curve of Doe and Zartman (1979) in the uranogenic diagram (Fig. 4a), on a mixing line between oceanic volcanics and pelagic sediments or non-cratonized crust. Data cluster along Doe and Zartman's (1979) upper crust curve in the thorogenic diagram (Fig. 4b), mostly within the non-cratonized crust field.

Pb isotopic data from the Beaver Mountains are more radiogenic than all other values from the Kuskokwim area, except for a mineralized sample from Nixon Fork (Fig. 4). The latter sample is much more radiogenic than the rest of the data, possibly because the Nixon Fork area is underlain by basement rock(s) with different characteristics than areas where other samples were collected.

Pb isotopic values for all Kuskokwim samples plot in the same region as the Beaver Mountain samples. Conclusions from the Beaver Mountain study (Szumigala, 1993), that correlations between vein and plutonic lead isotope data strongly imply that lead sources could be similar for magmas and ore fluids, are in agreement with this additional data. The limited range in Pb isotopic data may reflect the limited temporal range of ore deposition and homogeneous sources of Pb (along with other metals?) in the Kuskokwim region. Pb isotopic data from Kuskokwim epithermal mercury-antimony vein deposits are also homogeneous and plot in the same area of the upper crust field as the feldspar sample from the Beaver Mountains (Gray et al., 1992).

Table 2—Kuskokwim region Pb isotope data.

Locality	Sample #	Quadrangle	Latitude	Longitude	Host rock	Structure	Texture	Pb 206/204	Pb 207/204	Pb 208/204	Reference
Nixon Fork	88ZNF20	Medfra	63°14′	154°17′	marble hosted	manto	replacement	19.302	15.665	38.999	1
Maybe Creek	89ZMC9245	Iditarod	62°41′25″	157°09′	monzonite	magmatic	qtz vein	18.876	15.577	38.467	1
S. Cirque Prospect	90ZBM9505	Iditarod	62°50′20″	156°58′44″	basalt	sheeted-vein	qtz vein	18.887	15.564	38.428	1
S. Quartz Zone	90ZBM9516	Iditarod	62°49′40″	156°58′30″	basalt andesite	sheeted-vein	qtz vein	18.900	15.575	38.462	1
Sulfide Cirque	90ZBM9598	Iditarod	62°55′40″	156°58′50″	syenite	cross-cutting	qtz vein	18.914	15.595	38.512	1
Beaver Ridge	90ZBM9638	Iditarod	62°54′	156°53′	monzonite	shear zone?	qtz vein	18.892	15.566	38.434	1
Ax	90ZBM8453	Iditarod	62°51′50″	156°56′25″	andesite	cross-cutting	qtz vein	18.888	15.555	38.424	1
Cirque prospect	I-0096RC	Iditarod	62°50′45″	156°58′29″	monzonite	shear zone	qtz vein	18.923	15.607	38.583	2
Tolstoi Prospect	I-0099R	Iditarod	62°55′03″	156°58′45″	monzonite	shear zone	qtz vein	18.915	15.600	38.554	2
Broken Shovel	89ZBS6477	Iditarod	62°37′	157°10′	monzonite	shear zone	qtz vein	18.874	15.588	38.509	1
Snow Gulch	I-032	Iditarod	62°03′39″	158°11′15″	sed-hosted	cross-cutting	qtz vein	18.961	15.616	38.649	2
Willow Creek	I-280	Iditarod	62°21′25″	156°59′00″	sed-hosted	breccia	qtz vein	18.869	15.616	38.509	2
Decourcy Mine	I-036	Iditarod	62°03′34″	158°27′22″	sed-hosted	breccia	qtz/cal vein	18.854	15.605	38.580	2
Granite Creek	I-001RB	Iditarod	62°28′54″	157°54′41″	sed-hosted		qtz vein	18.838	15.592	38.429	2
Golden Horn	I-GHA	Iditarod	62°26′55″	157°55′05″	monzonite	concordant	contact	18.872	15.591	38.457	2
Independence Mine	I-122A	Iditarod	62°56′53″	156°28′42″	dacite dike	disseminated	qtz/cal vein	18.837	15.598	38.546	2
Beaver Mountains	unknown	Iditarod	62°51′	156°59′	monzonite	magmatic	phenocryst	18.976	15.640	38.692	3
Chicken Mountain	unknown	Iditarod	62°23′	158°00′	qtz monzonite	magmatic	phenocryst	18.888	15.605	38.461	3
Black Creek stock	unknown	Iditarod	62°29′	157°55′	monzonite	magmatic	phenocryst	18.845	15.590	38.407	3

References 1) This study 2)Gaccetta and Church, 1989 3) Unpublished data from J. Gray, USGS

GOLD MINERALIZATION INDICATORS

Alkalinity and Oxidation Parameters

For a potential mineralization indicator to have practical application, it must be based on easily obtainable information at a reasonable cost. Leveille et al. (1988) and Newberry et al. (1988) have shown in other mineralized regions of Alaska that favorable plutons in terms of gold deposits can be recognized by alkalinity and oxidation state. Their empirical discrimination line was determined by plotting over 660 whole rock analyses from a data base largely in the U.S.A. and Canada. The alkalinity index is similar to one proposed by Mutschler et al. (1985) and is given by equation (1):

$$A.I. = wt\% \; Na_2O + wt\% \; K_2O + 16 - (0.372) \; wt\% \; SiO_2 \quad (1)$$

The oxidation state index is simply the ratio wt% Fe_2O_3/ wt% FeO, a crude but useful indicator of the relative oxidation state (Blevin and Chappell, 1992). Other measurements of oxidation may be more accurate, such as biotite composition (Wones and Eugster, 1965), but iron analyses are more widespread in the literature.

Magnetite is an important gold sink in plutonic rocks, with the highest gold concentrations of common rock forming plutonic minerals (Tilling et al., 1973; Korobeynikov, 1980; Crocket, 1991). Processes that affect magnetite crystallization therefore may affect gold concentrations in residual melts. Newberry et al. (1988) propose that the abundance of crystallized magnetite is a product of both alkalinity and oxidation states and that plutons are gold-favorable because gold was partitioned into residual liquids, not into early crystallizing mineral phases. Gold concentrated in this manner is available for further partitioning into hydrothermal fluids and possible later deposition in ore deposits. Similar conclusions for gold partitioning toward a dissolved volatile phase under reducing conditions (indicated by Fe_2O_3/ FeO <0.6 in plutonic rocks) have been noted by Keith and Swan (1987), Schwab and Keith (1989), and Schwab et al. (1989).

Discrimination between gold-associated and non-gold associated plutons was attempted by plotting alkalinity versus oxidation values (data from Szumigala, 1993). When this technique is applied to plutons in west-central Alaska, almost all plutonic samples plot within the gold associated region (Fig. 5). Some plutonic samples that do not fit in the gold-associated region of Newberry et al. (1988) are from plutons with known gold deposits. Examples include several samples from the Mystery Creek Stock and a sample from Vinasale Mountain. Samples of pegmatite and aplite dikes from Twin Mountain and the Beaver Mountains fall in the gold-devoid region of Figure 5 and are oxidized compared to other plutonic samples from the same area. This indicates that more than one sample should be taken from a plutonic area to characterize that pluton by this method and that dike samples with significantly different compositions from the average plutonic composition should not be used to characterize the plutonic bodies.

Alkalinity and oxidation state parameters suggest that all analyzed plutons are potential hosts for gold deposits in the Kuskokwim Mountains plutonic belt. Plutonic areas with no known placer or lode gold occurrences, such as Takotna Mountain and Twin Mountain, plot in the gold favorable region. This suggests that the parameters for Figure 5 may not be good discriminators for the occurrence of gold in plutons of the Kuskokwim region or a significant number of gold deposits remain to be discovered. There also remain other

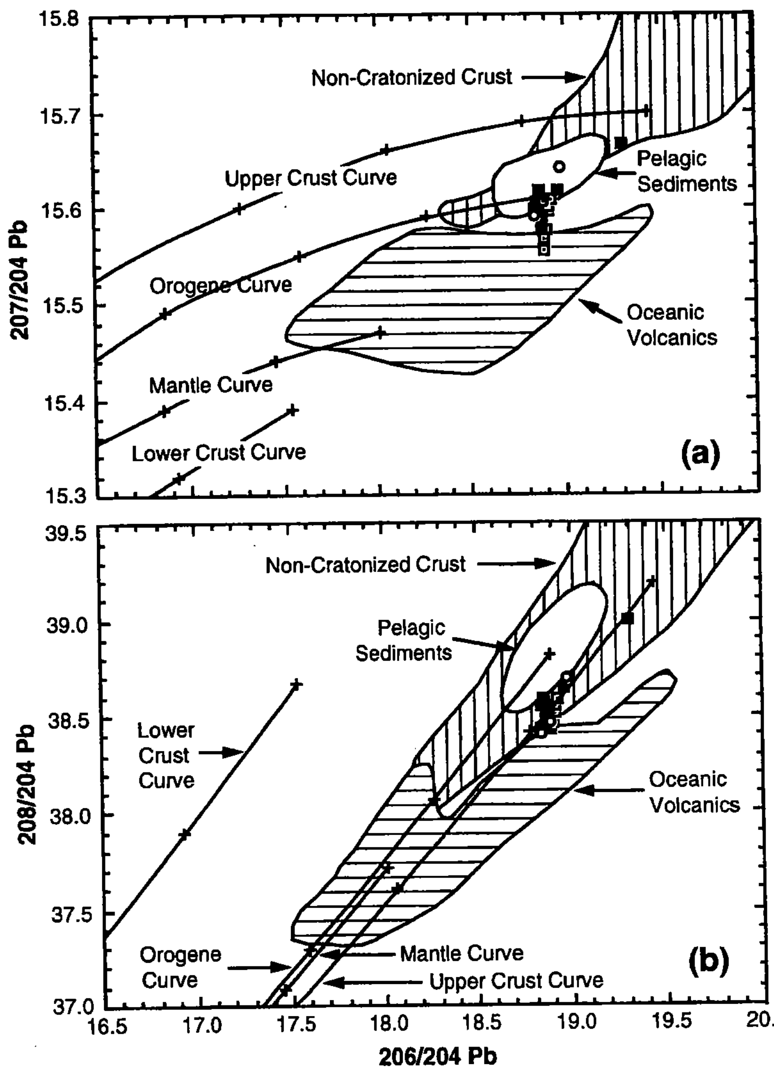

Figure 4—Lead isotopic plots of Kuskokwim data. Black squares are mineralization samples exclusive of the Beaver Mountains, open squares are vein mineralization samples from the Beaver Mountains, and open circles are feldspar samples from plutonic rocks. All data listed in Table 1. Fields and curves from Doe and Zartman (1979). Tick marks on curves are at 400 My intervals.

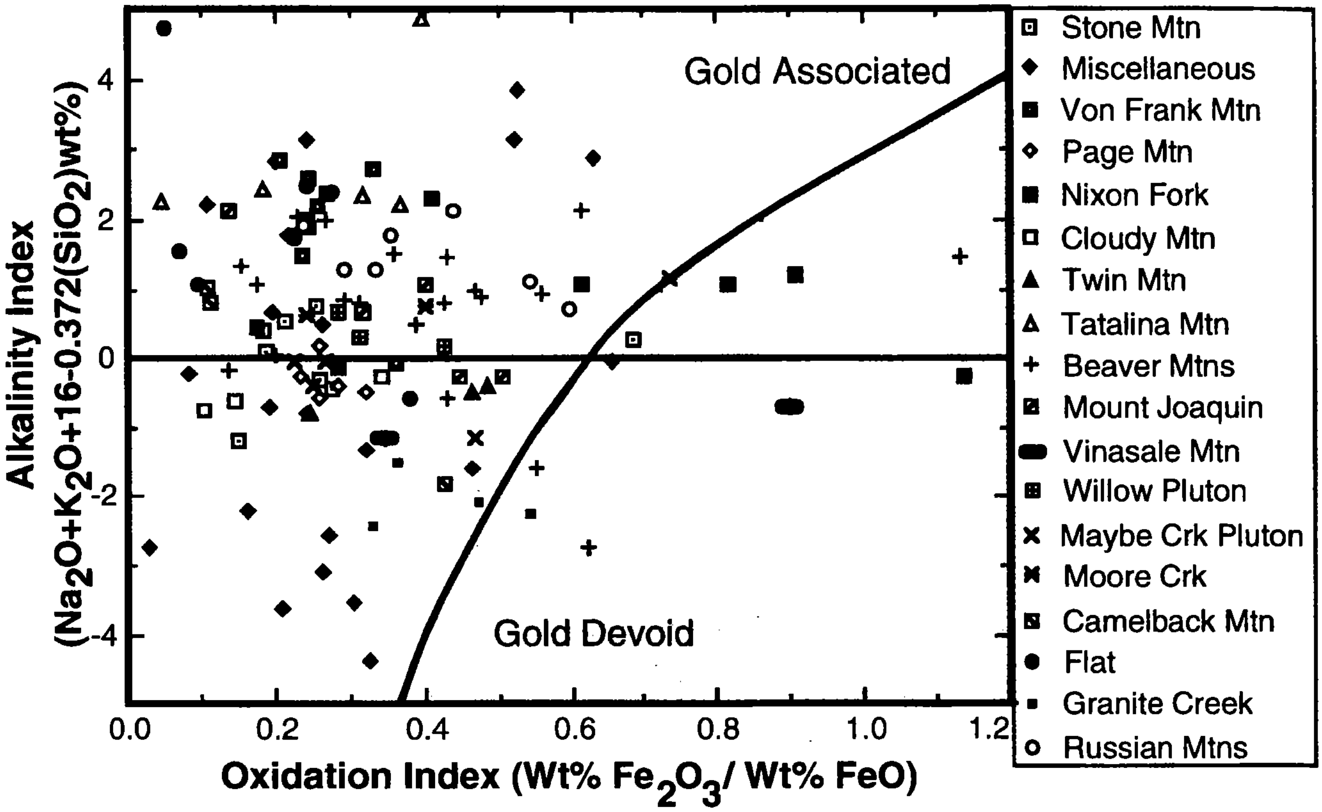

Figure 5—Plutonic rocks discriminated into gold-associated and gold-devoid areas on an alkalinity versus oxidation graph. Alkalinity and oxidation indices from Newberry et al. (1988), as is the empirically determined discrimination curve. Points above 0 are alkaline and points below 0 are subalkaline, after criteria by MacDonald and Katsura (1964). Plutonic area abbreviations are explained in Appendix 1.

plutonic rocks in the region that can be tested by this discrimination scheme.

Other Potential Discriminators

A strong correlation between magma chemistry and metal contents of associated ore deposits has been emphasized by Keith (1983) and Schwab et al. (1989). Keith (1983) concluded that economically important gold deposits are related to calcic, calc-alkalic, and alkalic rocks, but are absent from alkali-calcic magmatic rocks. Limited analytical data presented by Sillitoe (1989, 1991) for the principal gold deposits in the western Pacific tend to corroborate Keith's proposal. However, this correlation is not supported by the Kuskokwim data presented in this study. The two principal gold deposits in the Kuskokwim Region, the Nixon Fork mines and the Golden Horn Mine, are associated with alkali-calcic plutonic rocks (Szumigala, 1993). As presented in Figure 6, plutonic rocks from the Kuskokwim region plot from the alkaline to the calc-alkaline field. Plutonic rocks from Vinasale Mountain are confined to the alkali-calcic field in Figure 6. Figure 6 and the fields presented there may not best represent the plutonic data and should be discarded in favor of alkali-lime plots. The chemical data for the Kuskokwim region show that alkali-calcic rocks are important in terms of the overall character of the magmatic belt, as well as for some of the rocks associated with gold deposits. The different correlations between the Kuskokwim data set and those mentioned above may be due to scale problems, tectonic setting differences, or some other factor(s). Sillitoe (1989) notes that alkali-calcic suites may be associated with precious metal deposits characterized by high Ag/Au ratios, which may be consistent with precious-metal grades from Kuskokwim polymetallic vein mineralization.

Other parameters may be potential discriminators between barren and productive plutons and/or the type of mineralization associated with a certain pluton. One possibility may be tourmaline composition. Koval et al. (1991) demonstrate that major and trace element compositions and unit cell parameters can be used to distinguish between hydrothermal tourmalines from gold-bearing systems and those found with tin and rare-element deposits. With further study, tourmaline compositions may be expanded to be a discriminator between barren and gold-bearing systems. Tourmaline characteristics could be used as an exploration tool in the Kuskokwim region because most of the plutonic rocks, and numerous areas of volcanic rock, contain at least trace amounts of tourmaline.

It may be possible to use regional aeromagnetic surveys as an exploration tool for lode gold deposits in west-central Alaska. The larger known plutonic bodies in the Nixon Fork district can be correlated with either negative or positive magnetic anomalies (Anderson et al., 1970). However, plutons associated with known mineral deposits have negative magnetic anomalies. Anderson et al. (1970) conclude that the Mystery Creek Stock has no magnetic expression and the negative magnetic anomaly results from displacement of more magnetic units at depth.

The Anderson et al. (1970) study is the only published geophysical study for the Kuskokwim region. The aeromagnetic results fit well with geochemical data and petrographic observations of the Mystery Creek quartz monzonite. The ferric/ferrous ratio is quite low, opaque content is quite low (1-3%) and most of the opaques are ilmenite rather than magnetite, probably resulting in a small or negative magnetic signature. Aeromagnetic surveys could be used to identify buried plutons and possibly be used to provide a three-dimensional view of the intrusions. These surveys could be used in conjunction with knowledge about the known gold deposits and perhaps lead to further geophysical models of barren versus gold-productive plutons. Aeromagnetic surveys such as those conducted as a primary gold exploration tool in Western Australia (Isles et al., 1989) should help highlight geologic elements pertinent to the localization of gold mineralization in the Kuskokwim region.

ORE DEPOSIT MODEL

Known mineral endowment of the Kuskokwim region is dominated by precious metal lode and placer deposits. Mining, mostly placer, has produced at least 74,600 kg (2.4 million ounces) of gold, roughly 13,700 kg (440,000 ounces) of byproduct silver, nearly 41,000 flasks of mercury, and significant byproduct tungsten and antimony over the past ninety years (Bundtzen et al., 1986; 1987; Nokleberg et al., 1987). Mineral deposits in the Kuskokwim region appear to be genetically related to Late Cretaceous-early Tertiary plutonic rocks. A simple metallogenic model, similar in aspects to models proposed by Woodsworth et al. (1977), Panteleyev (1986) and Nesbitt et al. (1989) for the Canadian Cordillera,

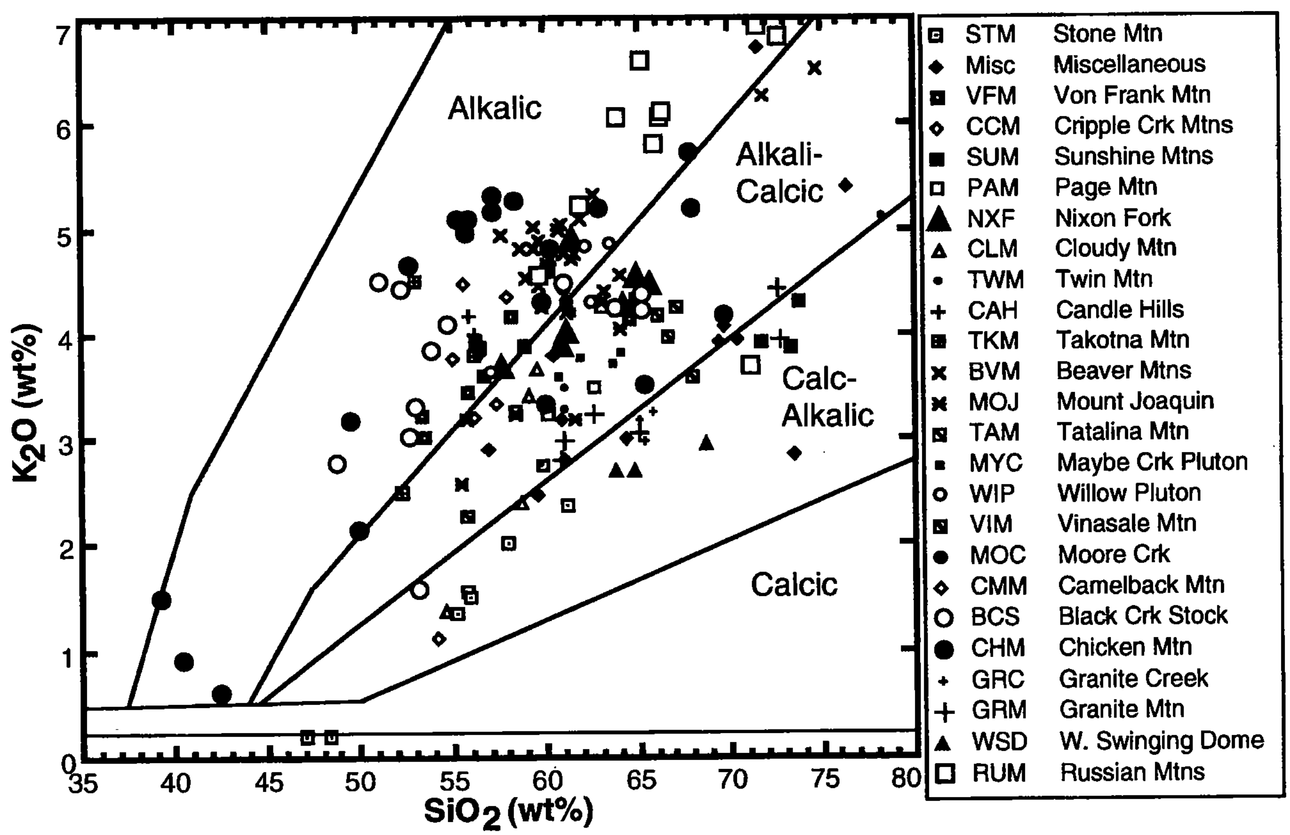

Figure 6—K_2O versus SiO_2 plot of Kuskokwim region plutonic rocks. Values in weight percent. Plutonic area abbreviations are explained in Appendix 1. Boundaries for alkali-lime fields after Keith (1985).

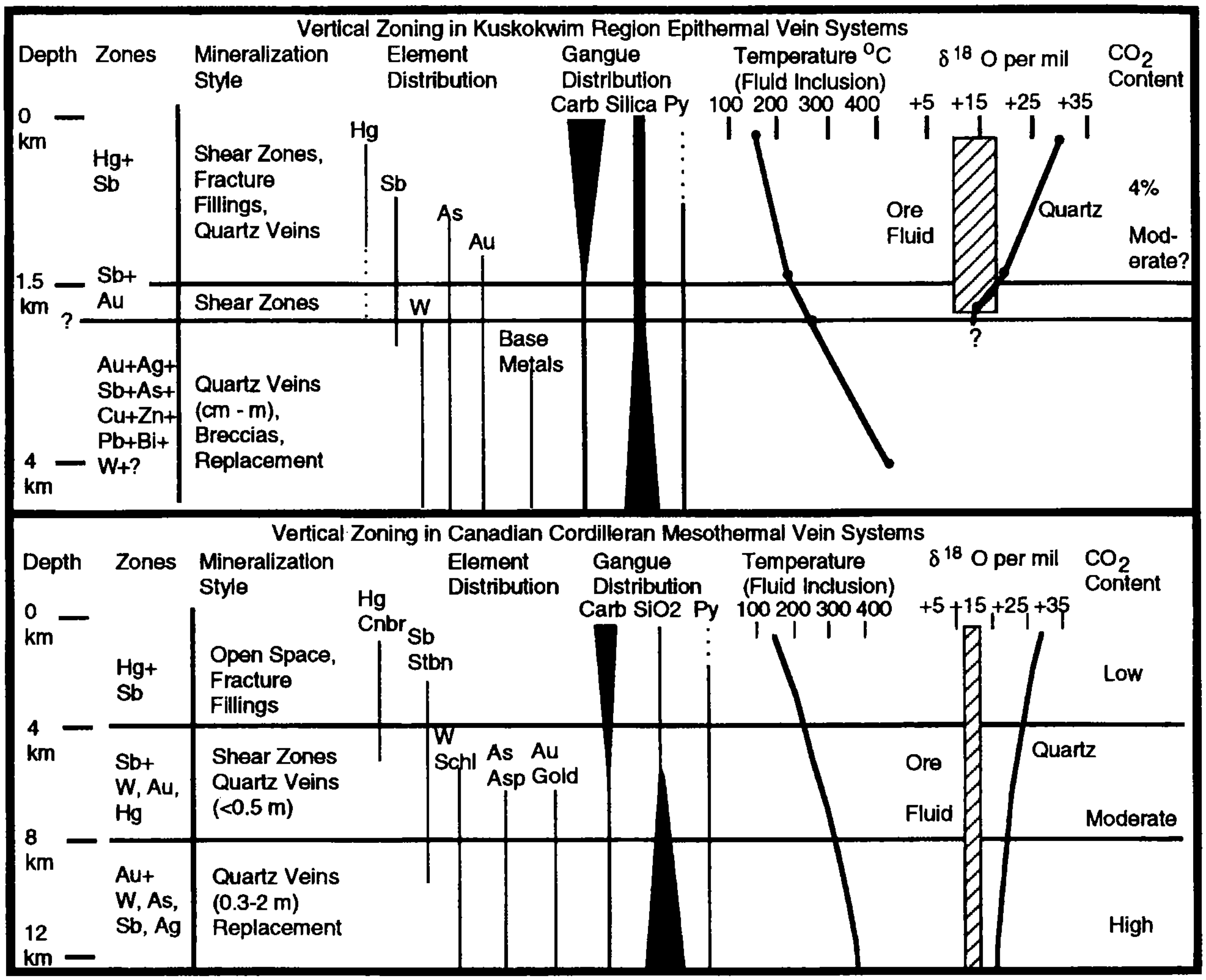

Figure 7—Model for mineralization in the Kuskokwim region as compared to Canadian Cordilleran vein systems. Diagram patterned after Nesbitt et al. (1989). Criteria for all characteristics are explained in text.

appears applicable to the Kuskokwim region and is presented in Figure 7. Bundtzen and Miller (1989, 1992) have also suggested that polymetallic mineral deposits associated with Cretaceous-early Tertiary igneous rocks in the Kuskokwim region represent vertically zoned hydrothermal systems now exposed at several erosional levels.

Epithermal mercury-antimony vein deposits are interpreted to represent the uppermost levels of hydrothermal systems exposed in the Kuskokwim region. Mineralization in epithermal systems can be vertically zoned from mercury dominant systems above, through antimony-rich systems at intermediate levels, to gold-rich systems at deeper levels, and then into base-metal dominant systems (Buchanan, 1981; Berger and Eimon, 1983; Silberman and Berger, 1985). Trace element zoning in hydrothermal systems typically progresses from elevated contents of As, Sb, Ba, F, Hg, B, and Tl in the upper levels to higher concentrations of Cu, Pb, Zn, Mo, Au, Ag, Bi, Te, and Co at greater depths (Grigoryan, 1974; Clarke and Govett, 1990). These vertical trends in elemental zoning are seen in various deposits in the Kuskokwim region which represent different levels of exposure.

Vertical mineral zonation, from cinnabar dominant at the surface to stibnite dominant at 180 meters depth, occurs at the Red Devil Mine, the largest mercury producer in Alaska, located approximately 160 km (100 mi) southwest of McGrath (Fig. 2) (Herreid, 1962; MacKevett and Berg, 1963; Nokleberg et al., 1987). About 75,000 tons of 1.55 percent mercury ore was produced from the Red Devil Mine, with antimony grade estimated to be roughly twice the mercury content (The Red Devil mercury district, southwestern Alaska, unpublished 1994 Calista Corp. pamphlet). Homogenization temperatures of fluid inclusions from vein quartz and cinnabar range from 160 to 210°C, with low uniform salinities (average 3.7 wt% NaCl equivalent) (Miller et al., 1989), and up to 4% CO_2 (Gray et al., 1992). Pressure estimates from CO_2-rich fluid inclusions suggest a maximum depth of formation of 1500 m (Miller et al., 1989).

Radiometric ages for hydrothermal sericite from several Kuskokwim mercury-antimony deposits are approximately

72 Ma, indicating that mineralization is coeval with the onset of Late Cretaceous magmatism (Gray et al., 1992). The common denominator in all Kuskokwim mercury-antimony deposits and prospects is adequate structural preparation of competent host rocks to form fractures and shears capable of conducting ore fluids upward from deeper sources (Miller et al., 1989). Recent geochemical studies indicate that several epithermal mercury-antimony vein deposits in the Kuskokwim region contain anomalous gold concentrations, up to 10 ppm in cinnabar concentrates (Gray et al., 1990, 1991).

The Donlin Creek prospects, Granite Creek prospect, and the Fisher Dome occurrences are good examples of antimony-quartz-(gold) prospects found throughout the Kuskokwim region. Gold associated with stibnite and pyrite at Donlin Creek and Granite Creek occurs in silicified breccias, quartz stockworks, and quartz veins along sheared contacts of rhyolite dikes and in tight shear zones within and adjacent to dikes in Cretaceous Kuskokwim Group sandstone (Szumigala, 1993). Quartz-stibnite veins at Fisher Dome occur in a Cretaceous-Tertiary granite pluton intruding rocks of the Kuskokwim Group (Gray et al., 1991). The $\delta^{18}O$ values from quartz at Fisher Dome are lighter relative to the mercury dominant systems (Goldfarb et al., 1990). This suggests that stibnite-rich quartz was deposited under higher temperature conditions, assuming a similar ore fluid isotopic composition for all epithermal mercury-antimony lode occurrences (Goldfarb et al., 1990).

The polymetallic gold-bearing deposits, prospects, and occurrences hosted by Late Cretaceous-early Tertiary plutons and volcano-plutonic complexes in the Kuskokwim region represent the deepest exposures of gold mineralization. Structural style, alteration, and mineralogical composition of mineralization in plutonic hosts is very similar throughout the Kuskokwim region. Mineralization consists of phases rich in varying amounts of Au, Ag, As, Sb, Cu, Zn, Bi, Sn, W, and B. Fluid inclusion homogenization temperatures for quartz from several of these deposits range from 250 to 410°C (Bundtzen and Laird, 1991; Bundtzen et al., 1988, 1992a). Table 3 summarizes the general characteristics between plutonic- and volcanic-hosted gold deposits in the Kuskokwim region.

The lode deposits at the Golden Horn Mine provide a temporal framework for various components of the mineralization model. The Iditarod-Flat district is the only locality where mineralization and alteration spans most of the mineralogic and geochemical transitions presented in the above model. The earliest ore-mineral assemblages have formation temperatures around 400°C and salinities of 1.8 wt% NaCl; with later assemblages ranging from 250 to 300°C; the latest stages consist of cinnabar-stibnite-quartz veins with homogenization temperatures averaging 150°C and salinities averaging 5.5 wt% NaCl (Bundtzen et al., 1992a; Bundtzen and Miller, 1992a).

The characteristics of mineral deposits in the Kuskokwim region of Alaska are similar to those of deposits in the Canadian Cordillera described by Nesbitt et al. (1989). These similarities are summarized in Figure 7. Even though the Kuskokwim deposits are not as well-studied as mesothermal vein systems in Canada, and the Canadian deposits are not obviously related to magmatism, vertical transitions of the models for the two areas appear nearly identical. For example, the proposed elemental distribution for the Kuskokwim

Table 3—General characteristics of Kuskokwim Region precious metal prospects.

Characteristics	Plutonic	Volcanic
Geochemistry	Au with base metals As important, low Hg, Sb	Au ± Hg, Sb, As low base metal content
Alteration	propylitic alteration of host rocks dominant, local ankerite, sericite	silicification, sericite, and local clay alteration of host rocks
Tourmaline	tourmaline common	tourmaline generally not present, but some deposits contain local disseminated tourmaline
Structure	mineralization commonly structurally controlled, brecciation locally important	mineralization in shear zones brecciation locally important
Associated Ore minerals	chalcopyrite, arsenopyrite, pyrite, tetrahedrite	stibnite, ± cinnabar, pyrite
Au/Ag Average	0.17 @ Beaver Mountains (Szumigala, 1993), 0.45 @ Golden Horn Mine, Flat (Bundtzen et al., 1992)	0.47-1.68 (Szumigala, 1993, 1995)
Quartz	massive to coarsely crystalline	massive, silica flooding, drusy crystalline
Deposit Zoning	Lateral zoning seen in the Beaver Mtns on a district scale (Szumigala, 1993), vertical zoning at the Golden Horn deposit (Bundtzen et al., 1992)	Zonation unknown, but may be like the vertical zonation seen in Hg-Sb ores at the Red Devil Mine (Miller et al., 1989)

region from Hg-Sb at the near surface to Au-W-base metals at deeper levels is matched by a consistent increase in homogenization temperatures for fluid inclusions, as seen in the Canadian Cordillera model. Clustering of Pb isotopic data in both regions supports interpretations from British Columbia mineral deposits by Leitch et al. (1989) that mineralization is related to a single protracted but episodic mineralizing event. Even though the geological characteristics of the Kuskokwim ore deposits and the Canadian Cordillera ore deposits are quite different, the only major disagreement between the two models presented in Figure 7 are the proposed depths of formation. The maximum depth calculated for the Kuskokwim deposits is 4 km (Bull, 1988), while the Nesbitt et al. (1989) model suggests depths in the Canadian deposits up to 12 km. Data for the Kuskokwim deposits are quite limited, and this is one area where further work would improve the constraints on the proposed model.

Gold deposits in the Kuskokwim Region are localized in areas with favorable plutonic host rocks and structure. In several locations it appears that pluton emplacement was controlled by regional faults, and later ore fluids were also localized along structures, particularly in plutonic rocks or along plutonic and other rock contacts. Gold deposits in the Kuskokwim region are integral parts of the volcano-plutonic arc comprising the Kuskokwim Mountains magmatic belt. The relationship between precious metal mineralization and igneous rocks in the Kuskokwim region is comparable to that noted in western Pacific island arcs by Sillitoe (1989). Plutonic rocks appear to be the source of gold and other metals; while faults, breccias, and rock contacts localize the ore metals in concentrations great enough to warrant exploration. Notwithstanding questions as to the origin of the gold deposits, granitoid plutons in the Kuskokwim region provide favorable exploration targets for additional gold-bearing lode deposits or related placer occurrences.

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