STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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September 1982

This is a preliminary publication of the Alaska Division of Geological and Geophysical Surveys and has not received final editing and review. The author will appreciate candid comments on the accuracy of the data and will welcome suggestions to improve the report.

Alaska Open-file Report 158

SOURCE OF LODE- AND PLACER-GOLD DEPOSITS OF THE CHANDALAR AND UPPER KOYUKUK DISTRICTS, ALASKA

By John T. Dillon

STATE OF ALASKA
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DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEY

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In addition, the Division shall collect, evaluate, and publish data on the underground, surface, and coastal waters of the state. It shall also file data from well-drilling logs.

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INTRODUCTION

Gold lodes and associated placer deposits of the upper Koyukuk and Chandalar districts of Alaska (pl. 1) have produced over 320,000 oz of gold since 1893. The gold placers were probably derived from the lode deposits.

This report discusses the spatial and geochemical relationship between the lodes and the placers and introduces hypotheses regarding the ultimate source of the gold. The hypotheses presented may be used as prospecting guides.

The Dalton Highway now provides access to the upper Koyukuk and Chandalar districts. This access will facilitate and increase minerals exploration and production. Much of the area consists of state lands which are open to mineral entry. Federal (BLM) lands in the outer pipeline corridor are also open to mineral entry, but those within both the inner pipeline corridor and the Gates of the Arctic National Park are not (U.S. BLM, 1980). Large areas of Native lands also lie within the district.

Geologic maps of the Chandalar and Wiseman quadrangles (Brosgè and Reiser, 1964, 1971) were used in preparing this report. Summaries of the valuable mineral occurrences of the Chandalar and upper Koyukuk districts published by Reed (1938), Grybeck (1977a,b), DeYoung (1978), and Cobb (1981) have been used extensively. Brosgè and Reiser (1970) published detailed geochemical studies of quartz-stibnite veins in the Wiseman area and concluded that Sb-rich gold veins were the source of nearby gold placer deposits.

The Alaska Division of Geological and Geophysical Surveys (DGGS) is mapping (at a 1:63,360 scale) parts of the Chandalar and Wiseman Quadrangles and studying the regional mineral potential of the area. DGGS geochemical surveys of the southwestern two-thirds of the Wiseman Quadrangle have been published (Dillon and others, 1981a,b), and geochemical surveys are now underway in the upper Koyukuk district. This report is one outgrowth of the Brooks Range mapping and resource assessment by DGGS.

REGIONAL GEOLOGY

The Chandalar and upper Koyukuk districts are underlain mainly by Devonian calcareous, carbonaceous, and siliceous clastic metasedimentary rocks with mafic and felsic metavolcanic interlayers. The Devonian metasediments are intruded by large, coeval plutons and may have a basement of early Paleozoic or Proterozoic metasediments. All of these rocks were regionally metamorphosed twice during Mesozoic time and later uplifted and faulted.

Lithologies

Silurian, Cambrian, and upper Proterozoic basement rocks can be traced into the Chandalar and Wiseman quadrangles from the northeastern Brooks Range. These rocks are exposed in the Doonerak area and probably are exposed near Ernie Lake and within the schist belt. Most of the basement rocks are polymetamorphosed quartzose clastic rocks with interbedded carbonaceous shale and local subunits of calcareous sandstones and mafic volcanic flows; there are also premetamorphic mafic and felsic plutons. One metamorphism probably produced the apparent pre-Devonian cleavage seen in these rocks.

Devonian and locally Mississippian metasedimentary rocks unconformably overlie and cover the lower Paleozoic and Proterozoic rocks in most parts of the study area (Dillon and others, 1980). The polymetamorphosed Devonian rocks consist of recrystallized limestone, sandstone, siltstone, and conglomerate with interbeds and intrusions of felsic and mafic volcanic and plutonic rocks. The oldest Devonian formation is unnamed; it consists of coarse-grained siliceous metaclastic rocks that are probably nonmarine and partly volcaniclastic.

Massive marbles overlying this older unit form the Upper and Middle Devonian Skajit Formation (Brosgè and Reiser, 1964). Skajit carbonate rocks were deposited in an intertidal environment. Interbedded with the Skajit marbles are many layers of graphitic and calcareous schists and metamorphosed felsic and mafic volcanic rocks.

The felsic and mafic volcanic rocks are particularly significant: not only are they extrusive equivalents of the granitic and mafic plutons they surround, but the copper-rich felsic schists have been tracked across the Brooks Range from the Ambler district, where they are the host rock for huge massive-sulfide ore deposits. The felsic plutons grade from meta-aplite to augen genesis and are surrounded by a rind of fine-grained mafic plutonic facies and by hornfelsed and altered country rocks. Injection migmatites and high-grade hornfelses are common along the contacts of the most deeply eroded plutons. Mafic rinds, aplite dikes, Cu-Mo porphyrys, skarns with metallic mineralization, and altered rocks are most common around the cupolas of partially unroofed plutons. Zircons obtained from several of these plutons yield preliminary U-Pb ages of 380 ± 15 m.y. Thick carbonate rocks of the Skajit Formation change facies both laterally (northward) and upsection to become the Upper Devonian Hunt Fork Shale, which is composed of polymetamorphic graphitic schist that had a protolith of carbonaceous argillite, siltstone, sandstone, and conglomerate. Within the study area the Hunt Fork Shale is locally unconformably overlain by schistose quartz-sandstone and graphitic mica schist of Mississippian(?) age.

Quaternary glacial, alluvial, and colluvial deposits unconformably overlie the polymetamorphic rocks (Hamilton, 1978, 1979). Quaternary deposits contain the placer gold mined in the upper Koyukuk and Chandalar districts.

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Devonian, Mississippian, Permian, and upper Triassic rocks of the central Wiseman Quadrangle were metamorphosed twice. The first event is shown by a penetrative cleavage defined by albite-epidote-amphibolite facies minerals. The second is evinced by a semipenetrative cleavage defined by upper-greenschist-facies minerals. This second post-upper Triassic metamorphism occurred during Early Cretaceous thrusting (Dillon and others, 1980). Therefore, the first metamorphism is limited to between Late Triassic and Early Cretaceous times.

Of the many ages of faulting recognized within the study area only two are mentioned here. Early Cretaceous thrust faults were first recognized by Brosgé and Reiser (1964, 1971). These thrust faults are typically shallow-dipping zones of mylonitic and phacoidal cataclastic rock, broken formations, and melanges. Postmetamorphic (post-Early Cretaceous) faults are generally steeply dipping zones of gouge with slickensided and brecciated walls which cut older metamorphic structures. Many are intruded by undeformed quartz and calcite veins. At three locations the quartz veins are gold bearing. Thus, the gold-bearing veins postdate the Late Cretaceous metamorphism.

GOLD DEPOSITS

Spatial, mineralogical, and geochemical similarities between lode and placer deposits provide evidence that the placer gold was derived from the lode deposits. The larger auriferous lode and placer deposits of the upper Koyukuk and Chandalar districts are described here, in plate 1, and in table 1.

Placer Deposits

Placer-gold deposits within the study area are discussed here to establish their connection with lode deposits. Reed (1938) provides a more complete description of the placer deposits.

Placer gold deposits have provided most of the gold produced in the upper Koyukuk and Chandalar districts. They are usually confined to Quaternary alluvial deposits just above bedrock in the deeply cut valleys. Rich placers have not been found in U-shaped glaciated valleys. Productive placer deposits are common around known lode gold deposits of the Little Squaw and Nolan Creek areas. Gold placers are also found close to smaller lode gold deposits at Sukakpak Mountain, at Jay Creek (pl. 1, loc. 43) and at Wild Lake (pl. 1, loc. 47).

Gold nuggets from the placer deposits are of two types: a) rounded and flattened pieces generally weighing less than 1 oz, and b) rough, coarse gold and wire gold; some nuggets with relict crystal shapes and attached pieces of quartz weigh up to 40 oz.

The second type is particularly common close to gold-bearing quartz veins. Some of the gold concentrates at Gold, Vermont, Lake, and Crevice Creeks contain angular pieces of gold-bearing stibnite-quartz vein material that must have been derived directly from the lode deposits (table 1; pl. 1, locs. 22, 25, and 47; pers. comm., Dennis Stacey and Pelham Jackson, 1982;

Table 1. Gold lode and associated placer mines and prospects in the Chandalar and upper Koyukuk districts. Information taken mainly from Cobb (1981), Reed (1938), Brosgé (1972), and Chipp (1970).

Map no.	Deposit name	Elements present	Deposit type	Description
1	Little Squaw Creek	Au, W, As	Placer	Gold mining and prospecting from about 1905-40. Two generations (preglacial and postglacial) of placer deposits. Concentrates contain gold, pyrite, hematite, arsenopyrite, scheelite, galena, and monazite. Production unknown but significant.
2	Little Squaw	Au, Sb, Cu, Pb, Ag, Zn	Vein	Development work from 1910-33 included about 100 m of underground workings on auriferous quartz veins in schist. Arsenopyrite lenses common. Only 38 to 62 g/t (grams/metric ton) of gold recovered on small stamp mill. Proven ore estimated at 1,800 m tons averaging 49 g/t gold in 1939. Recent trenching.
3	Star and Summit	Au, Ag, Sb, Cu, Pb, Zn	Vein	Quartz veins at Summit mine assayed at 90 ppm gold in 1913. Workings included 16-m shaft and 22-m drift on vein about 0.5 m wide. Dump samples assayed 0.5-6.6 ppm gold in 1970 with abundant arsenopyrite and scorodite. Some underground work in late 1950's. Nearby Star prospect has 1.8-m-wide quartz vein assayed at 11 ppm gold and with visible arsenopyrite and scorodite.
4	Big Creek	Au, Ag, As	Placer	Gold discovered in 1906. Production from Big Creek has been estimated as high as 440,000 g, of which two-thirds was after 1950. Gold, pyrite, hematite, limonite, monazite, scheelite, rutile, arsenopyrite, chalcopyrite, galena, and ilmenite are found in concentrates. Average grain size of gold is 1 mm with nuggets 2-3 mm.

Map no.	Deposit name	Elements present	Deposit type	Description
5	Big Squaw Creek	Au, Ag	Placer	Preglacial and postglacial placers contain gold, pyrite, arsenopyrite, stibnite, monazite, uranothorianite, galena, molybdenite, and zircon. Reports of mining as late as 1928, but no production data available.
6	Envelope	Au, Sb, Cu, Pb, Ag, Zn	Vein	Adit driven 50 m prior to 1913. Free gold (surface outcrop assayed 328 ppm) with minor galena and scorodite.
7	Mikado	Au, Sb, Cu, Pb, Ag, Zn	Vein	Steeply dipping (80° N.) auriferous quartz veins as much as 2 m thick exposed for over 900 m in schist. Highly faulted, gouged quartz vein structure with minor sulfides and visible gold. Assays of ore shoots range from 60 to 750 ppm gold. First underground workings in 1909-13 included a 60-m shaft and a 140-m crosscut. Over 200 m of workings were added in 1959-60, when the mine was reopened. About 260 m of drifting and crosscutting were done with Office of Minerals Exploration assistance in 1962 and 1963. Estimated reserves in 1968 were 11,000 m tons of ore averaging 75 g/t gold. Active exploration and small production through 1976.
8	Kelty	Au, Sb, Cu, Pb, Ag, Zn	Vein	Steeply dipping (65° SE.) auriferous quartz veins in schistose rocks.
9	Squirrel Creek	Au	Vein?	Thirty-four lode claims staked in 1973.
10	Big Joe Creek	Au, Ag	Vein	Gold in quartz vein in quartz-mica schist.
11	Arsine	Au, As	Vein?	Block of six lode claims staked in 1975.
12	Big Jim Creek	Au, Cu	Placer	Small-scale placer mining for gold; some native copper nuggets found.

Map no.	Deposit name	Elements present	Deposit type	Description
13	Sawlog Creek	Au	Placer	Recent placer mining reported in 1964.
14	Mule Creek	Au, Ag	Placer	Gold production of about 1,500 g from 1900-09 with small native silver and copper nuggets up to 3.2 kg. Shafts 23-24 m deep sunk in 1937.
15	Eightmile Creek	Au, Hg	Placer	Reports of mining prior to 1938 and of occurrence of placer gold and cinnabar.
16	Bettles River	Au	Placer	Drift mining on tributaries of Bettles River produced 5 g of gold/m^2 of bedrock in 1936-37. Mining reported as late as 1940. Placer claims relocated in 1976.
17	Lake Creek	Au	Placer	Gold discovered in 1915 and mined until recently (1964 report) from present stream channel and old buried channel.
18	California Creek	Au	Placer	From discovery in 1901 through 1909, about 4,500 g of gold were produced from 5.5-m shafts and stream gravels. Gravel containing rough but fine gold of 33-38 g/m^2 per meter of bedrock reported in 1938. Higher channel had 5 g of gold/m^2 of bedrock.
19	Matthews River	Cu, Pb, Zn, Au, Ag	Vein and coating	Sulfide mineralization in quartz veins in greenstone and greenschist. Iron-stained quartz float. Vein assayed 3.4 ppm gold and trace of silver.
20	Wiehl Mountain	Fe, Sb	Vein	Fine-grained pyrite and hematite in carbonate gangue with minor possible stibnite.

Map no.	Deposit name	Elements present	Deposit type	Description
21	Sukakpak Mountain	Sb, Hg, Mo, Au, Ag, Cu	Vein	Three quartz veins 10-30 cm thick grading 0-80% stibnite with high-grade selected grab samples containing up to 1.8 oz/ton Au, 17,000 ppm Mo, and 5,000 ppm Hg. Gangue is mostly quartz but some stibnite was found in calcite. Both calcite and quartz locally have vugs. Cinnabar and tetrahedrite found locally. Veins occur in and near fault at south contact of marble with schist. Veins exposed intermittently for nearly 1 km along contact. Placer-gold prospect downstream. Old working of "pre-chainsaw" vintage on both vein and placer deposits.
22	Gold Creek	Au	Placer	Gold discovered in 1900 with sporadic mining through 1974. Production of gold from 1900-09 was about 348,000 g. Angular fragments of stibnite with quartz stringers have been found in stream gravels.
23	Minnie Creek	Au	Placer	Heavily prospected, with some coarse placer gold recovered. Water on bedrock made prospecting and drift mining difficult.
24	Emma Creek	Au	Placer	Placer gold discovered in 1900. Mining has been on a small scale, mostly before 1930; most recently reported in 1974.
25	Vermont Creek	Au, Sb	Placer	Small tributary of Hammond River that heads against a fork of Nolan Creek in a mineralized area. Bedrock is phyllite, some mineralized with pyrite; quartz veinlets, one of which contains free gold and sulfides. Shallow creek gravels and deep (30-90 ft) channel in valley of Hammond River were mined from 1901 until as recently as 1969. Total production not known; production 1901-09 was about 8,325 oz. Gold coarse; some nuggets about 10 oz. A cobble of stibnite, with attached quartz and about 1% Au, was found by Dennis Stacey and Pelham Jackson.

Map no.	Deposit name	Elements present	Deposit type	Description
26	Union Creek	Au	Placer	Drains mineralized area east of Nolan Creek. A 32-oz nugget found in 1901. Production through 1909 was about 1,700 oz. Mining reported in 1934 and 1937.
27	Swift Creek	Au	Placer	Tributary of Hammond River; heads in mineralized area east of Nolan Creek. An old, high channel merged with that of Hammond River. Mining, all by hand methods, between 1901-12, in 1927, and possibly other years, when it was reported with following entry.
28	Hammond River	Au	Placer	Major tributary of Middle Fork, Koyukuk River; gold found only in lower 13 mi of its course; most mining within 3 mi of mouth. Most gold came from deep (up to 115 ft) channel that extends into valley of Middle Fork, where it is truncated, probably by a glacier. Pay gravel also in old channel 40-50 ft higher than present stream. Gold from mouths of tributaries such as Buckeye and Goldbottom Gulches and Steep Creek was probably from bench gravels of Hammond River, though some also came from mineralized areas near heads of tributaries. Much gold was very coarse (one 137-oz nugget reported). Gold was discovered in 1900 and mining continued with a few interruptions until World War II. Total placer gold production not known, but was substantial. Quartz vein near mouth of Swift Creek contains galena.

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29	Fay Creek	Au, As, Ag, Sb	Placer, vein	Tributary of Nolan Creek that drains a mineralized zone. By 1937 present channel and a deep (20-ft) channel near Nolan Creek were considered mined out. A high channel had been prospected and some mining was reported. Placer gold is rough and angular with quartz attached. Early (1901-09) production was about 1,450 oz. Some recent mining reported. Anomalously high amounts of Au, As, Ag, Sb in quartz veins near head of Tompsons Pup of Fay Creek.
30	Smith Dome	Au, Sb, As	Vein	At head of Fay Creek, on NW flank of Smith Dome, a 6-in. vein of stibnite and oxidation products was opened by a small pit. Samples contained as much as 9.2 ppm Au.
31	Ferguson Creek (Midnight Dome)	Sb, Au	Vein	Pit between heads of Smith and Union Gulches exposed 6-in.-wide vein that contains kernels of coarsely crystalline stibnite in earthy matrix of yellow antimony oxides. Samples of quartz-stibnite veins contain up to 14 ppm gold.
32	Unnamed	Au, As, Ag, Sb	Placer	See entry 29.
33	Archibald Creek	Sb, Au, As	Placer	Short, steep tributary of Nolan Creek cut in soft schist. Gravel is coarse, subangular, and frozen. In an old channel depth to bedrock is as much as 25 ft, decreasing upstream; gold all coarse, some smooth and some rough. Some gold in creek gravels is fine and smooth and some is coarse and rough. In bench deposits gold is fine and smooth. Stibnite vein reported exposed by drift mining; another reported on spur between Archibald and Archibald and Smith Gulches. Placer mining reported before 1909, in 1927, 1933-39, and 1974. No production data.

Map no.	Deposit name	Elements present	Deposit type	Description
34	Smith Creek	Au, Sb	Placer	Major gold-producing tributary of Nolan Creek; heads against Union Gulch. Bedrock is micaceous schist. Creek gravels are 5-20 ft thick. Deep (135 ft at mouth) channel was mined out. Remnants of high channels also mined. Intermittent production 1903-60. Quartz veins 3-4 m thick containing zones of stibnite 1.5-2 in. thick and detectable gold were exposed during placer gold mining. Five tons of stibnite (placer and lode) recovered during ground sluicing and shipped during World War II. Two stibnite-quartz veins on lower Smith Creek mined out by Vernie Pasqualli but ore has not been shipped.
35	Wannemaker and Wortman	Sb	Vein	Stibnite vein in fissure with walls lined with terminated quartz crystals; fissure cuts across cleavage of phyllite. Sample of stibnite contained 58.3% Sb.
36	Smith Creek	Au, Sb	Placer, vein	See entry 34.
37	Archibald Creek	Au, Sb, As	Placer, vein	See entry 33.
38	Washington Creek	Au	Placer	Gold discovered in 1902 and $5,000 worth (less than 250 oz) mined by 1905. None reported since. Results of prospecting high gravels not known.
39	Mascot Creek	Au	Placer	Thin (3 ft or less) creek gravels carry 0.2 or more oz per yd^3. Old channel 30 ft above creek also worked. Bedrock is mica schist with quartz stringers. Some nuggets about 5 fine oz. Gold discovered in 1902 and mined intermittently until 1950s; production well over 7,250 oz.

Map no.	Deposit name	Elements present	Deposit type	Description
40	Conglomerate Creek	Au	Placer	Gold prospects and some placer gold mining in early days of district. Many conglomerate boulders in creek hampered mining.
41	Unnamed	Sb	Vein	Antimony in quartz vein.
42	Jay Creek	Au	Placer, vein	Placer gold discovered in 1904, but mining did not begin until 1912. Production to 1935 was almost 10,000 oz. Lower part of stream flows in canyon 25-50 ft wide cut in schist; 3-12 ft of coarse angular gravel. Gold is coarse and unworn. Stibnite and quartz vein reportedly found upstream (John Cathrall, pers. commun., 1982).
43	Rye Creek	Au	Placer	Creek flows on limestone and schist and along contact (probably a fault) between them. No gold in paying quantities above Jay Creek. Both drift and hand mined. Placers found in 1915. Production through 1937 of $55,000. Concentrate samples contained ilmenite, andalusite, kyanite, pyrite, zircon, chalcopyrite, monazite, galena, sphalerite, scheelite, and gold.
44	Birch Creek	Au	Placer	Placer gold discovered in 1904. Mined for about 1 mi near mouth of Rye Creek in creek bed and in deposits 20 ft below a low left-limit bench. In early 1900s production was about 950-1,450 oz gold; last mining reported in 1933.
45	Spring Creek	Au	Placer	Bedrock is schist. Placer gold discovered in 1903. Production through 1937, about 2,785 fine oz, from open cuts and drift mines. Mining reported in 1938; and probably some since World War II.
46	Unnamed	Sb, Pb	Vein	Tetrahedrite in vein quartz; limonite also present.

Map no.	Deposit name	Elements present	Deposit type	Description
47	Lake Creek	Sb, Bi, Cu, Au, W	Placer, vein	Bedrock various schists cut by at least one greenstone dike; many quartz stringers near head of creek. Bedrock at head of delta into Wild Lake is 60-95 ft deep; gravel in stream bed above delta is only 3 ft thick. Placer concentrates contain gold, large pieces of stibnite, scheelite, native copper and bismuth, hematite, pyrite, and magnetite. A sample of vein quartz contained some chalcopyrite and tourmaline. Gold, both coarse and very fine, was mined intermittently from 1904 until at least 1938. Recorded production as of 1937 was $26,000.
48	Crevice Creek	Cu, Au, Pb, Sb	Placer	Placer gold production of 30 oz/yr. Stream said to run on bedrock and gold to be in crevices and potholes in schist-marble unit. Upstream from placer mine, galena and copper minerals occur in Devonian Skajit Limestone about 1/2 mi from small body of mafic rock. Probable stibnite found by Bill Fickus in placer concentrates.

Cobb, 1981). Other minerals found in placer concentrates such as arsenopyrite, pyrite, stibnite, sheelite, galena, cinnabar, and copper nuggets are typically associated with gold-bearing quartz veins. Anomalously high concentrations of Au, Sb, As, Ag, Pb, Cu, and Hg are also found in adjacent soil samples. Most of the placer deposits contain some gold that is extremely worn, which indicates it came from a distance source.

Lode Deposits

Gold-bearing quartz veins of the upper Koyukuk and Chandalar districts have been sought and mined since the turn of the century. The mineralogy, chemistry, and age of these lode deposits are described here with emphasis on evidence which links them to the productive gold-placer deposits and distinguishes them from barren quartz veins. The gold-bearing quartz veins are the key to identifying the primary source of the gold, which can in turn be used to predict the location of undiscovered lode and placer deposits.

The lode deposits occur in an east-trending belt from Wild Lake to Little Squaw Lake (pl. 1, table 1). Most are located between Nolan Creek and Little Squaw Creek and are surrounded by productive gold placer deposits. A typical vein is described in detail.

Individual veins are 10 to 40 cm thick and pinch and swell along strike for distances approaching 1 km. Many were emplaced along steeply dipping, postmetamorphic fault zones and are brecciated, displaced, slickensided, and boudinaged by fault movement but are not folded. Premetamorphic, isoclinally folded quartz veins are generally barren.

The gold-bearing veins are composed of quartz-calcite gangue with gold (Au), stibnite (Sb_2S_3), arsenopyrite (FeAsS), and scorodite ($FeAsO_4.H_2O$) as the principal ore minerals and with pyrite, tetrahedrite ($Cu_{12}Sb_4S_{13}$), cinnabar (HgS), molybdenite (MoS_2), and galena (Pbs) as accessory minerals.

Veins in the Nolan-Wiseman area of the upper Koyukuk district are extremely rich in stibnite with accessory arsenic-bearing minerals; those in the Chandalar district are rich in arsenopyrite and scorodite and contain small amounts of stibnite. Gold occurs as crystals, wires, and amorphous masses within the ore minerals and gangue. Stibnite forms elongate, euhedral, locally brecciated crystals. Quartz is the predominant gangue mineral, but calcite is abundant in some veins. Quartz and calcite are massive except in vugs where terminal crystal facies are preserved. Barren quartz veins are made entirely of quartz or quartz with siderite (or ankerite) and small amounts of pyrite.

The gold-bearing quartz veins are especially enriched in Sb and As, but also have anomalously high contents of Au, Mo, Hg, Ag, Pb, and Zn. These same elements are enriched in soils and placer deposits derived from the veins (Brosge' and Reiser, 1970; table 1). The veins of the Chandalar district are richer in As and poorer in Sb than those of the Koyukuk district. Gold is a native element that is concentrated in late-stage magmatic fluids and hydrothermal veins because of its inability to combine with other elements in the magma. As described by Marsh and others (1979), antimony is a chalcophile element which readily combines with sulfur and less so with Cu, Ag, Fe, Ni, or Co. It is also enriched in late-stage magmatic crystallates accompanied by Hg and is commonly found in metalliferous veins of volcanic regions. Antimony is a good geochemical indicator of Ag, Au, Cu, Pb, and Zn deposits. Arsenic is a chacophile element that separates in magmas at the highest temperatures after main-stage crystallization and is a useful pathfinder element for Au, Cu, Pb, and Zn deposits (Marsh and others, 1978b). Gold, arsenic, antimony, copper, molybdenum, mercury, and lead are all concentrated in hydrothermal solutions and late felsic liquid phases that crystallize into porphyrys, aplites, and pegmatities in the cupolas of granitic plutons. However, most of these elements are labile enough to be remobilized into quartz veins during post-magmatic thermal events.

The age of the quartz veins is estimated from the fact that both the veins and the fault zones into which they were emplaced postdate both the Devonian deposition and later metamorphism of the country rocks. The age of the youngest truncated metamorphic structures is Neocomian (Dillon and others, 1980). The veins themselves required modest emplacement temperatures (150°-300°C), a condition met if the host rocks were not completely cooled from their last metamorphism. Erosional unroofing and cooling from the Neocomian metamorphic event occurred during Albian time, the probable emplacement age of the veins.

Sukakpak Mountain

A gold-bearing quartz-stibnite vein found on Sukakpak Mountain (pl. 1, loc. 21) is described here as a typical example of the auriferous quartz veins in the upper Koyukuk district. The lode deposits of the Chandalar district have been described by Chipp (1970).

Sukakpak Mountain is composed of marble and dolomite overlying graphitic and calcareous quartz schists intrued by metabasite dikes (fig. 1). The marble is apparently the core of an anticline that is overturned to the west. A high-angle fault truncates this fold at its southern end. At the structural base of the marbles are interlayers of quartzite and graphitic schist.

All of the pre-Quaternary rocks of Sukakpak Mountain, except the gold-bearing veins, have been metamorphosed twice at greenschist-facies conditions. The high-angle fault and the veins apparently truncate metamorphic structures formed during the younger, Early Cretaceous metamorphism. As discussed above, these conditions require that the veins be emplaced during Albian time.

The auriferous stibnite-quartz veins are found at the contact of the marble with the schist on the south side of Sukakpak Mountain, both along the contact and within the basal marble layers (fig. 1). Another possibly related stibnite-bearing vein was found at the base of Wiehl Mountain (table 1; pl. 1, loc. 20).

At Sukakpak at least three stibnite-quartz veins are exposed intermittently along the strike of the contract for about 1 km and approximately 100 m down the dip (fig. 1). The veins are covered by colluvium at their western limit.

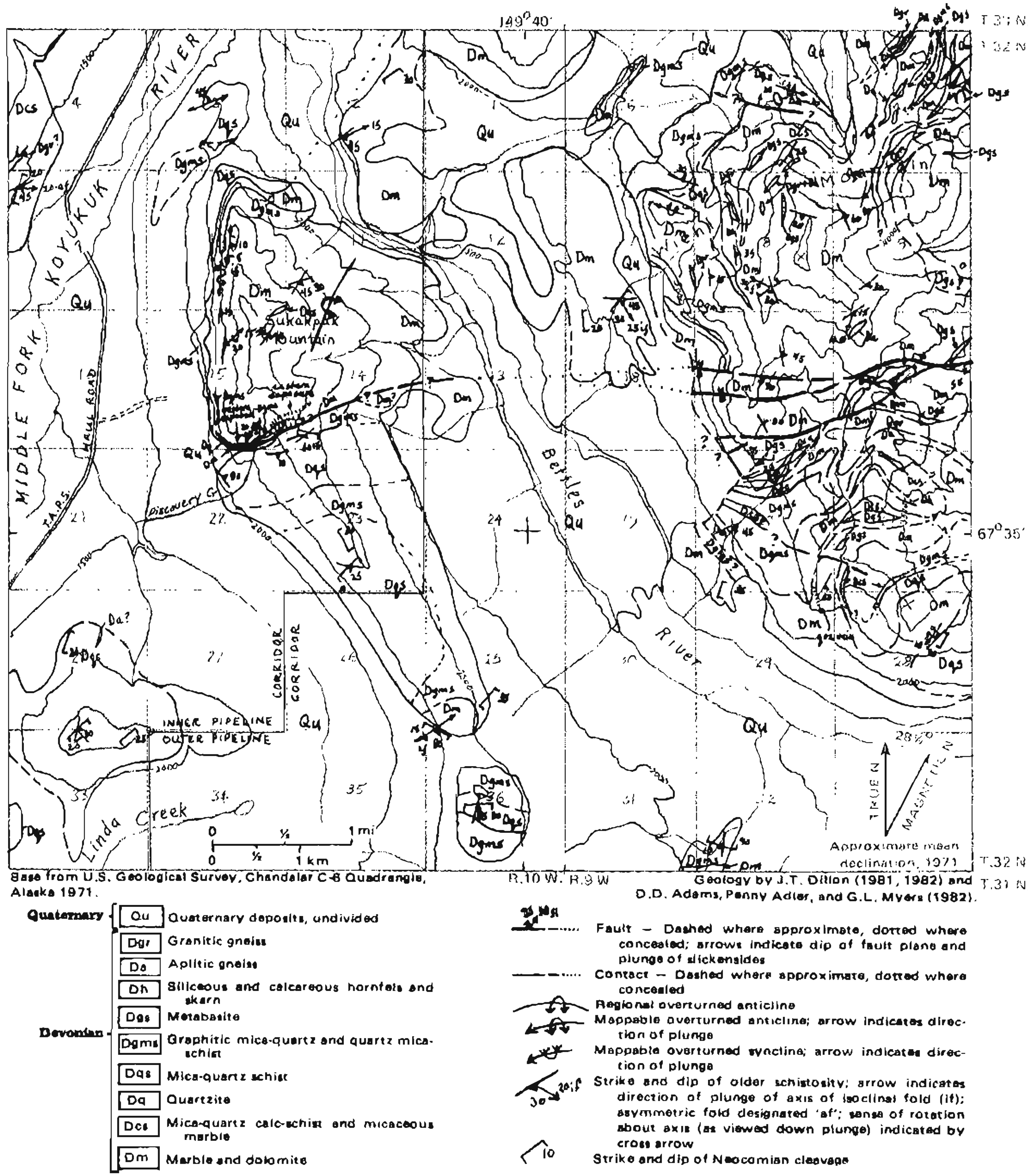

Figure 1. Geology of Sukakpuk Mountain area.

The westernmost vein is within marble at the base of a cliff at the 2,700-ft elevation, below which are slopes of talus and colluvium. Although no schist outcrops occur within 50 m of the base of the cliff, the horizon is believed to be about at the contact of the marble within the schist. Vein outcrops 10 cm or more thick were found in three places spaced about 10 m apart; however, in all cases the lower contacts of the vein(s) are obscured by talus so that the true thickness and individuality of the vein are uncertain.

The continuity of the vein(s) from the western to the eastern exposures could not be determined; they may be buried by colluvium. However, outcrops on the ridge west of 'Discovery Creek' are continuous across the contact and no vein material was found, which indicates the vein(s) is not continuous at the ridge elevation.

Three quartz-stibnite veins (10-40 cm thick) crop out on the east side of Discovery Creek at an elevation of 2,900 ft and are almost continuously exposed for about 300 m until they cross the ridge between the Koyukuk and Bettles Rivers. Here the southernmost vein is buried by colluvium. It may continue eastward along the schist-marble contact beneath the colluvium because large blocks of quartz-vein float were found near the contact. The blocks apparently lack stibnite, although they have gangue minerals and structures similar to the stibnite-quartz veins. Their source remains uncertain. The two northern veins change mineralogy and texture, grading into barren calcite veins as they cross eastward into the Bettles River drainage. Barren quartz veins occur both in the marble and the schist. Those in the marble crop out about 50-75 m north of the schist-marble contact and are structurally and mineralogically similar to the auriferous veins except that they lack stibnite. Those in the schist are abundant even close to the contact but are isoclinally folded and substantially predate the stibnite-quartz veins.

Structures in the auriferous veins are displayed best in the eastern exposures. The veins are not folded or metamorphosed. Some contacts of the veins are curviplanar and slickensided because of brittle deformation, but most contacts are not displaced. Anastomozing and boxwork vein structures are preserved. The larger veins are layered, presumably because of repeated periods of wall-rock dilation followed by vein crystallization. Many vugs with well-formed quartz and calcite crystals were found within the central layers.

There is evidence that the veins were emplaced along the high-angle fault while it was active. The veins strike and dip parallel to the fault and are found within the fault zone in most places. Quartz and calcite gangue minerals cement breccias of randomly oriented schist clasts locally within the fault zone. These facts are consistent with emplacement of the veins after faulting and metamorphism. However, the veins are slickensided and boudinaged and stibnite within the veins is locally bent and brecciated, which is consistent with emplacement before faulting. Apparently, the veins were emplaced along the high-angle fault during displacement. Movement was postmetamorphic, probably during cooling and uplift. Vertical separation along the fault on the west side of Wiehl Mountain is about 100 m.

The stibnite-rich quartz veins at Sukakpak Mountain are found within the fault zone. In the eastern exposures, where the northern quartz veins stray from the fault zone into the massive marble of the hanging wall, they grade into stibnite-poor, calcite-rich veins.

The stibnite-rich veins have a quartz gangue with 10 percent calcite. Small stibnite crystals were found in calcite but most occur in quartz as 2- to 10-cm-long euhedra that are elongate perpendicular to quartz vein walls. They compose 0-80 percent (average about 40 percent) of the stibnite-rich veins. Cinnabar forms a dusty coating on the high-grade stibnite, and wires and crystals of free gold have been found in a few samples. High molybdenum in assays of some high-grade stibnite-quartz samples (table 2) indicate that molybdenite is present.

Table 2. Analytical results from assay of selected high-grade grab samples of quartz-stibnite veins on the south flank of Sukakpak Mountain. Sample 2b is a replicate of 2a and samples 3b and 3c are replicate analyses of sample 3a. All values are in ppm, except Sb, which is in wt-%. Analyses of Sn, W, and Hg are by Bondar Clegg; all others are by DGGS.

Map No.	Cu	Pb	Zn	Au	Ag	Mo	Sb	Sn**	W	Hg
82 GE 1*	8	1	30	8.6	1.6	2	15.3	< 20	2	450
82 GE 2a	11	1	3	21.3	4.5	14	60.2	< 20	2	700
82 GE 2b	8	<1	2	27.2	0.4	17	62	ND	ND	ND
82 GE 2c*	5	1	2	13.1	3.6	12	60.6	< 20	2	900
82 GE 3a	38	26	109	< 0.1	< 0.1	17,000	0.37	ND	2	>5,000
82 GE 3b	36	30	105	< 0.1	0.1	309	0.35	ND	ND	ND

* Average of four determinations.
** Sn interference due to high Sb; Sn results on first three samples 20 ppm; not detected on the fourth.
ND = Not determined.

In the easternmost exposures, the stibnite-rich veins extend upward away from the contact into the marble. At this point the stibnite content decreases to $\sim$1 percent, and calcite increases to $\sim$25 percent of the vein within a distance of 10 m along strike. Tetrahedrite ($Cu_{12}Sb_4S_{13}$) is a disseminated accessory in this part of the vein. Farther eastward along strike calcite becomes the predominant gangue mineral, and no ore minerals are visible in hand specimens. Here the calcite vein is surrounded by a halo of oxidized country rock.

The auriferous veins of Sukakpak Mountain are enriched in Sb, Au, Hg, and Mo (table 2) similar to other gold-bearing veins of the upper Koyukuk and Chandalar districts (table 1). As explained above, these elements are common in hydrothermal deposits of granitic magmas and are labile enough to be remobilized during later thermal events.

Discovery Creek contains clasts of stibnite-quartz vein material. Old workings in the creek provide evidence of drift mining during the early days. Recent tests of the creek with a suction dredge establish the presence of recoverable placer gold derived from the deposit (Frank Creamer, pers. commun., 1982) as in streams near other gold lode deposits of the upper Koyukuk and Chandalar districts (table 1).

The Sukakpak lode deposit is so similar to other lode deposits of the upper Koyukuk and Chandalar districts in mineralogy, chemistry, and structure that studies of its characteristics may ultimately distinguish the mode of formation and primary source of most other lode deposits of the region.

The Sukakpak lode deposit is less than 2 km from the Dalton Highway. An abandoned materials-site road provides access to the base of the mountain within 1 km of the deposit. However, the land lies within the inner pipeline corridor and is not open to mineral entry (U.S. BLM, pers. commun., 1982). Nevertheless, most of the outcrop mineralization was recently staked and the validity of any claims there remains questionable.

PRIMARY SOURCES OF THE GOLD

Exploration for other gold deposits in the upper Koyukuk and Chandalar districts will be facilitated if the source of the gold can be identified. Significantly, the gold-bearing veins are younger than all the metamorphic supracrustal rocks exposed within the area. This means that the gold was either remobilized from a preexisting source within the supracrustal rocks or was a primary emanation of the mantle or deep crust. Of the possibilities, the most difficult to identify is a deep crustal source. There are three potential sources within the supracrustal rocks: granitic plutons, mafic plutons, and paleoplacer deposits. The geochemical characteristics and distribution of the deposits are the most helpful factors in distinguishing between the potential sources in the crust and mantle.

If it is assumed that the lode and placer deposits have the same primary source, the most significant aspect of the distribution of the lode and associated placer deposits in this regard is that they form a nearly east-west belt from Little Squaw Lake to the Wild River (pl. 1). The belt is broad enough to require a diffuse source if the source is shallow. On the other hand, even a localized source in the deep crust or mantle might form such a diffuse belt because of dispersal during transit to the supracrust. In either case, the source should be a west-trending geologic feature. Considering the structural and topographic relief in the study area, shallow sources should be exposed at the surface. Mantle and deep crustal sources will most likely remain hypothetical.

The gold-bearing veins are especially enriched in Sb, As, Au, Mo, Hg, Ag, Cu, Pb, and Zn. These elements, which are typically concentrated in the late crystallizing liquids and hydrothermal fluids of granitic magmas, are labile enough to be remobilized into early formed liquid and hydrothermal phases during strong metamorphic events. However, this elemental association is atypical of mantle-derived fluids and mafic magmas. If this geochemical argument against a primary mantle source of the gold is accepted, the gold and associated elements were probably remobilized during metamorphism of crustal rocks.

Abundant evidence for strong Neocomian metamorphism is found in the supracrustal rocks. Moreover, the metamorphic temperatures and pressures were probably higher and stayed higher longer in the deep crustal rocks. This is consistant with Albian emplacement of auriferous veins that were remobilized from a crustal source, especially a deep one. The lithology of deep crustal rocks in the study area is unknown but is thought to be continental. The problem with the hypothesis of a deep crustal source is that it does not explain the restricted distribution of the deposits. Neocomian metamorphism affected the entire southern Brook Range, but gold deposits are found in relatively limited districts. Moreover, the Devonian granitic plutons were apparently derived by anatexis of the deep crust (Dillon and others, 1980), which consequently should have been depleted in labile elements before Neocomian time. Nevertheless, a restricted---probably granitic---source in the deep crust cannot be eliminated because the present constitution of the deep crust has not been determined.

The possible supracrustal sources from which the gold may have been remobilized are paleoplacer deposits and mafic and granitic plutons. The former might be enriched in the elements now associated with the lode deposits during deposition. Within the western Wiseman Quadrangle is a fair correlation between exposures of potential paleoplacer deposits (quartz-rich metaconglomerates underlying the Skajit Formation) and the occurrence of present-day placers at Crevice, Jay, and Birch Creeks and Wild Lake (pl. 1; table 1; Brosgé and Reiser, 1970). However, the conglomerates apparently do not continue eastward into the productive Nolan Creek and Chandalar areas, and the paleoplacer hypothesis seems inadequate as an explanation for the belt of gold deposits as a whole.

Although there is good evidence that many of the granitic plutons within the study area are slightly younger magmatic facies that are genetically related to penecontemporaneaus mafic plutons, a presentation of these recently acquired data is beyond the scope of this paper. However, the genetic relationship allows the consideration of the granitic and mafic plutons together as potential sources for the gold. In any case, the mafic plutons are regarded as an atypical source geochemically and have a relatively poor spatial association with the deposits.

The locus of the deposits best corresponds geologically to a belt of shallowly eroded and buried Devonian granitic plutons (Brosgé and Reiser, 1964; Dillon and others, 1980). No lode deposits are found where the plutons are deeply eroded between Chandalar and Big Lakes, but are common adjacent to remaining cupolas and hornfelsed roofs. Anomalously high concentrations of Sb, As, Mo, and Cu in stream-sediment samples near the cupolas of granitic plutons in the Chandalar Quadrangle (Marsh and others, 1978a,b, 1979) support this geochemical association. The granitic plutons provide the expected diffuse, west-trending primary source in the shallow crust for the gold, whereas the overlying cupolas provide a depositional locus for hydrothermal fluids generated during late magmatic crystallization. In this case, metamorphic remobilization caused the gold to move only a small distance from the site of the magmatic deposition. Similar relationships occur in the Shungnak district of the western Brooks Range.

CONCLUSION

The most likely prospects for further gold deposits are in the roofs and cupolas of granitic plutons. Maps of the plutons are available from Brosgé and Reiser (1964, 1971) and from Dillon and others (1981a,b). Recent mapping in the Chandalar C-5 and C-6 Quadrangles has extended the distribution of the cupolas northward and westward from areas covered by existing geologic maps, and provides evidence for a genetic link between the mafic and granitic plutons. A primary mantle source for the gold seems extremely unlikely, but a deep crustal source is difficult to eliminate except on the basis of distribution.

Exploration programs that trace primary granitic or deep crustal gold sources would be most likely to succeed. The known distribution of granitic plutons and deep crustal rocks in the Brooks Range is illustrated in Dillon and others (1980) and in more detailed quadrangle maps of the U.S. Geological Survey. The deep crustal rocks can be identified on the basis of structural position and metamorphic grade. They tend to be found in the cores of anticlines and nappes in deeply eroded areas, and as country rocks around granitic plutons. These rocks are generally metamorphosed to amphibolitic facies.

Primary gold sources from granitic plutons are expected to occur a) where the plutons are shallowly covered by country rocks, b) in areas of hornfelsed rocks injected by felsic dikes and sills, and c) beneath the felsic volcanic rocks of the Chandalar C-5, C-6, D-5, and D-6 Quadrangles. Some of the highest potential for new gold deposits derived from primary granitic sources is along and north of the Bettles River and Roberts Creek in the Chandalar Quadrangle (pl. 1).

FURTHER WORK

An important method of characterizing vein lode deposits and discoverying the temperatures and pressures at which the veins are deposited is the study of fluid inclusions. DGGS is now completing such a study of the veins of the Chandalar districts. In addition, DGGS plans a comparative study of the geology of and the fluid inclusions in the veins of the Chandalar and upper Koyukuk districts. This project should further distinguish the possible primary sources of the gold and help define exploration objectives.

ACKNOWLEDGMENT

I thank G.R. Eakins for his manuscript review and S.A. Jacques for his cartography.

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