The Alaska Mineral Resource Assessment Program

Background Information to Accompany Mineral-Resource and Geologic Maps of the Anchorage Quadrangle, South-Central Alaska

U.S. DEPARTMENT OF THE INTERIOR March 3, 1849

U.S. GEOLOGICAL SURVEY CIRCULAR 1094

Cover photograph. College Fiord, in the middle ground, was named in 1899 by G.K. Gilbert and other members of the Harriman Alaska Expedition after they had named many of the surrounding glaciers after American colleges. Bryn Mawr, Smith, and Radcliffe (from left to right, starting on the back) are the conspicuous tributary glaciers above the large tidewater glacier (far right), which is named after Harvard College. Mount Marcus Baker, in the background (far left, front cover), is the highest point (13,176 ft) in the Anchorage quadrangle and was named in honor of an early Alaskan topographer who charted much of the State's coastline and prepared the first geographic dictionary of Alaska. Photograph by G.R. Winkler, July 14, 1983.

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By D.J. MADDEN-McGUIRE *and* G.R. WINKLER

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By D.J. MADDEN-McGUIRE *and* G.R. WINKLER

ABSTRACT

The Anchorage 1°×3° quadrangle in south-central Alaska contains significant resources of gold, coal, and chromium, as well as resources of silver and base metals (including copper, lead, and zinc), platinum-group elements, strategic metals (nickel and cobalt), uranium, peat, zeolites, and even glacial ice. Hydrocarbons may be present in upper Cook Inlet. Mining of placer gold deposits between 1895 and 1906 preceded discovery of lode gold. Lode-gold mines produced more than 623,874 ounces (17.7 million grams) from the Willow Creek district between 1909 and 1950; production continued into the 1980's. The Willow Creek mining district contributed substantially to the development of south-central Alaska. Coal mines in the quadrangle were productive between 1915 and 1968, supplying coal for the Alaska Railroad and for construction and maintenance of military bases in Anchorage. Most production has come from the Wishbone Hill district; between 1916 and 1952 the district produced 3,284,723 short tons (3.7 million metric tons) of coal. The military bases converted to natural gas in 1967; coal mining ceased until the late 1980's and early 1990's, when exploration was renewed.

In 1898, the U.S. Geological Survey began field investigations in the Anchorage quadrangle; W.C. Mendenhall traversed the northern Matanuska Valley as part of a War Department expedition led by Captain Edwin F. Glenn and Lt. Joseph C. Castner. Studies by the U.S. Geological Survey continued in the area so as to provide information to the mining public, to provide mineral resource information as input for land-use planning and minerals-policy development, to guide mineral exploration, and to add to the geologic knowledge of the area.

The Anchorage quadrangle is underlain by three lithotectonic terranes, distinctive fault-bounded assemblages of rock that differ from each other in stratigraphy, age, structural style, and types of mineral and energy resources. The Peninsular terrane in the Anchorage quadrangle consists of Triassic(?) to Tertiary bedded volcanic and sedimentary rocks, Early Jurassic to Tertiary intrusive rocks, and Paleozoic(?) to Jurassic metamorphic rocks. To the south the Border Ranges fault separates the Peninsular and Chugach terranes. The Chugach terrane in the Anchorage quadrangle consists of a landward subduction assemblage of melange and broken formation called the McHugh Complex and seaward trench-fill and trench-slope deposits called the Valdez Group. To the south is the Contact fault, a northward-dipping thrust between the Chugach and Prince William terranes. The Prince William terrane consists of the Paleocene and Eocene Orca Group, which is 6–10 km of interbedded graywacke, siltstone, shale, conglomerate, and minor greenstone that lithologically resemble rocks of the Valdez Group. The terranes accreted successively to southern Alaska from Mesozoic to Tertiary time. The Valdez and Orca Groups are intruded by mafic to felsic plutons of Eocene and Oligocene age that are important in terms of mineral resources. Whereas the rocks that are older than the mid-Cretaceous are allochthonous, rocks younger than the mid-Cretaceous overlap the accretionary assemblages and cover much of the western part of the quadrangle, which includes upper Cook Inlet. The inlet is underlain by more than 12,000 m of Mesozoic marine sedimentary and igneous rocks and as much as 9,000 m of Tertiary estuarine and nonmarine sedimentary and minor volcanic rocks recording three Mesozoic cycles of marine sedimentation and two Tertiary cycles of estuarine and nonmarine sedimentation. Cycles

Table 1. Geologic, geochemical, geophysical, and mineral-resource maps of the Anchorage 1°×3° quadrangle, Alaska.

Reference	Subject
Cobb (1979)	Compilation of references on mineral resource occurrences.
Jansons and others (1984)	Compilation of mineral occurrences in the Chugach National Forest in the southeastern part of quadrangle.
Newberry (1986)	Compilation and interpretation of data from mineral prospects in the north-central Chugach Mountains, about 100 km east of Anchorage.
Arbogast and others (1986)	Geochemical analytical data from stream-sediment and concentrate samples.
Madden and others (1987)	Geochemical analytical data from rock samples.
Winkler (1992)	Geologic compilation and geochronologic summary of the quadrangle, scale 1:250,000.
Burns and others (1991)	Geologic map and report on the northern Chugach Mountains, between the Knik and Nelchina Rivers, scale 1:63,360.
Yehle and Schmoll (1987a, b, 1988, 1989)	Surficial geologic maps, Anchorage area (Anchorage B–7 quadrangle), scale 1:24,000.
Madden (1991a, b)	Geochemical interpretation; maps showing stream-sediment and concentrate sample geochemical anomalies, scale 1:250,000.
Tripp and Madden (1991)	Mineralogical interpretation; maps showing ore-related heavy minerals identified from concentrate samples, scale 1:250,000.
Burns and others (in press)	Interpretation of aeromagnetic data, scale 1:250,000.
Madden-McGuire and Tripp (in press)	Geochemical map showing the distribution of gold in heavy-mineral concentrate samples in the quadrangle, scale 1:250,000.

of deposition were interrupted by times of orogeny and corresponding shifts in the depositional center of the proto–Cook Inlet basin. The Tertiary strata contain most of the coal deposits in the Anchorage quadrangle and are reservoirs for most of the oil and gas produced in southern Alaska.

Geochemical studies were carried out in support of the U.S. Geological Survey Alaska Mineral Resource Assessment Program (AMRAP). Samples were collected and analyzed so as to supplement existing data for a regional and mineralogical study of the Anchorage quadrangle. Aeromagnetic studies were done in the quadrangle to evaluate petroleum-bearing strata and to evaluate the extent of geologic units having mineral resource potential. Published U.S. Geological Survey geologic, geochemical, and geophysical maps served as the basis for outlining and assigning a mineral resource potential to areas in the quadrangle. Mineral resource potential maps for the Anchorage quadrangle show areas containing known and undiscovered mineral and energy resources.

This report is a summary of the geological, geochemical, and geophysical field and laboratory studies that served as the basis for the assessment of the mineral resources of the Anchorage quadrangle. The results of the studies have been published in various forms, which are cited in this summary.

INTRODUCTION

PURPOSE AND SCOPE

Studies of the geologic setting and mineral and energy resources in the Anchorage 1°×3° quadrangle were carried out as part of the U.S. Geological Survey Alaska Mineral Resource Assessment Program (AMRAP) and mineral surveys of public lands within the Chugach National Forest. The objectives of the geologic, geochemical, and geophysical investigations were to provide mineral resource information for use as input to land-use planning and minerals-policy development, to guide minerals exploration, and to add to the geologic knowledge of the area. Table 1 is a list of maps and reports that provide

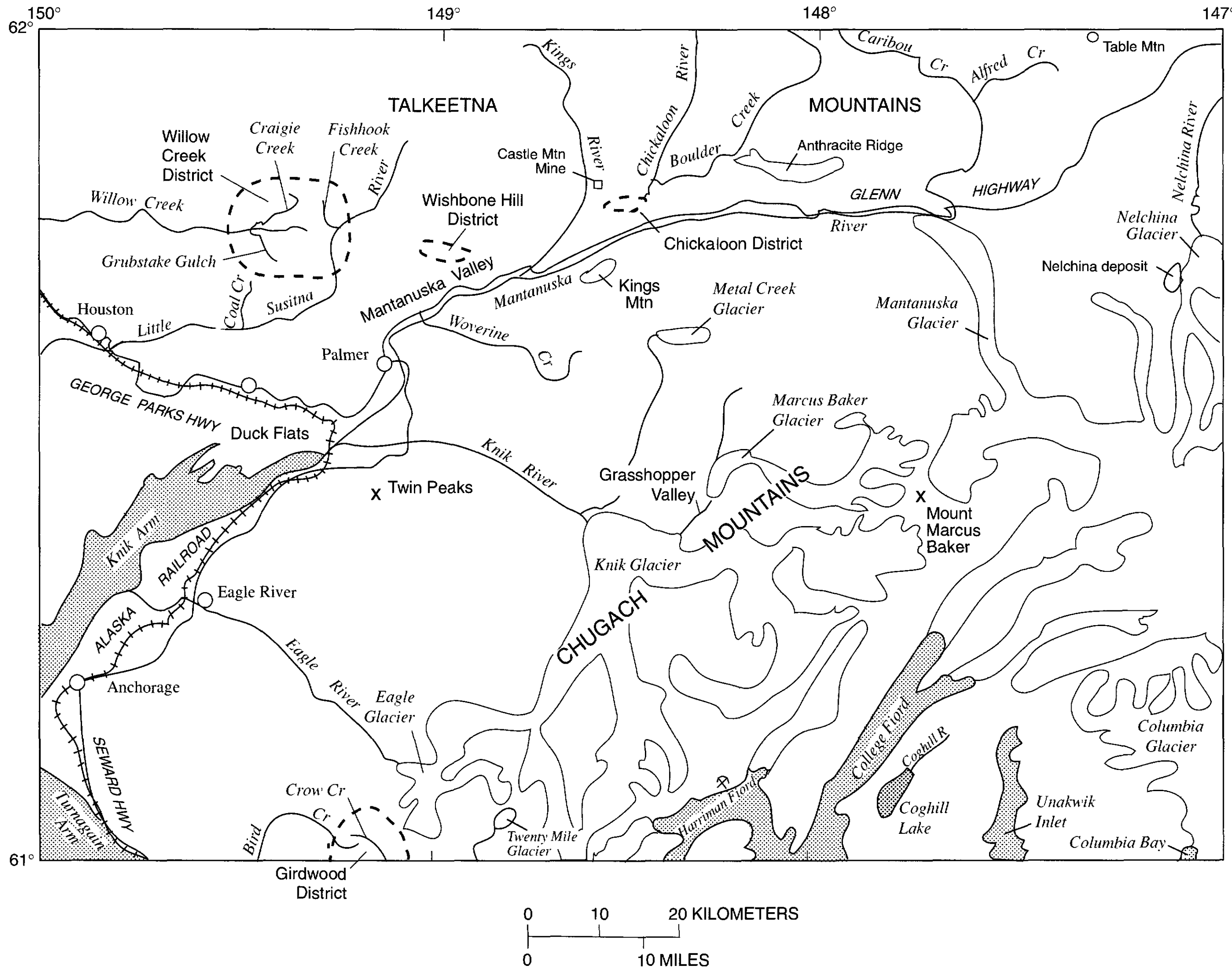


Figure 1. Map showing selected geographic features of the Anchorage 1°×3° quadrangle, Alaska.

the primary mineral resource data for the Anchorage quadrangle. Other sources for information on the geology and the mineral and energy resources in the quadrangle are cited in the text and listed in the accompanying references. The U.S. Geological Survey (USGS), the Division of Geological and Geophysical Surveys (DGGS) of the State of Alaska Department of Natural Resources, and students and faculty from the University of Alaska cooperated informally in field and laboratory studies in the Anchorage 1°×3° quadrangle.

GEOGRAPHY AND ACCESS

The Anchorage quadrangle encompasses about 18,000 km^2 of south-central Alaska, bounded by the 61° and 62° parallels and the 147° and 150° meridians (fig. 1). The quadrangle includes, from north to south, the southern Talkeetna Mountains, the Matanuska River Valley, ice fields and glaciers of the Chugach Mountains, and fjords and bays of the northwestern part of Prince William Sound.

Topographic relief in the Anchorage quadrangle exceeds 4,000 m. The highest point in the quadrangle is Mount Marcus Baker (4,016 m), in the Chugach Mountains. The top of Mount Marcus Baker is only 19 km from coastal fjords of Prince William Sound.

The Matanuska, Knik, and Susitna Rivers form the major watersheds to the north and east of Anchorage. The Knik and Matanuska Rivers flow westward and converge as they enter Knik Arm, a branch of upper Cook Inlet. The Susitna River (west of the quadrangle) flows southward and enters Knik Arm to the west of the Anchorage quadrangle. The rivers transport and deposit silt from upstream glaciers into upper Cook Inlet. The influx of silt is slowly filling the mouths of 64-km-long Knik Arm and

77-km-long Turnagain Arm and filling channels in upper Cook Inlet; annual dredging in the inlet keeps the shipping lanes open. The siltiness of the water limits the varieties of marine life in northern Cook Inlet. This area therefore supports less commercial and sport fishing than southern Cook Inlet.

In the southwestern part of the Anchorage quadrangle, the lowland coastal area (about 5,200 km^2) of the Municipality of Anchorage projects into the head of Cook Inlet. The Municipality is bounded by lower Knik Arm, lower Turnagain Arm, and the Chugach Mountains. The maximum tidal range in this particular area is about 10 m. Precipitation is only about 30–50 cm per year. Temperatures in the winter generally range between 10°F and 25°F (–12°C to –4°C), with occasional lows down to –20°F to –30°F (–29°C to –34°C); daytime temperatures in the summer are generally in the 60's and 70's (about 16°C to 26°C) (The Alaska Geographic Society, 1983). Summer daylight is from 14 hours to more than 19 hours long. In mid-June there are more than 19 hours of daylight; in mid-December there are less than 6 hours of daylight (The Alaska Geographic Society, 1983).

In the Municipality of Anchorage, Anchorage International Airport, Lake Hood float plane base, and Merrill Field serve air traffic. The municipality is connected by paved highways to smaller towns within and outside of the Anchorage quadrangle. The Glenn Highway connects Anchorage with the towns of Eagle River and Palmer. The Glenn Highway extends east-northeast through the Matanuska River Valley and beyond the quadrangle boundaries to the junction with the Richardson Highway at Glennallen, 304 km from Anchorage, providing access to Valdez and Delta Junction (fig. 1). The Glenn Highway extends an additional 224 km to Tok, which is on the Alaska (ALCAN) Highway. The Glenn Highway crosses almost the entire Anchorage quadrangle and follows one of the earliest trails from upper Cook Inlet to the interior of Alaska. The George Parks Highway branches off from the Glenn Highway 56 km northeast of Anchorage, passes through the town of Wasilla, leaves the Anchorage quadrangle, and follows the Susitna River on the way north to Denali National Park, Fairbanks, and other points in the interior of Alaska. The Seward Highway connects Anchorage with Seward, 204 km southward on Resurrection Bay on the eastern side of the Kenai Peninsula. The Sterling Highway branches off from the Seward Highway about 145 km south of Anchorage, outside the quadrangle, providing access to the town of Homer and to other communities of the western Kenai Peninsula.

The Alaska Railroad runs from Seward northward through Anchorage and the Matanuska and Nenana coal fields on its way to Fairbanks. The railroad was built between 1915 and 1923 to connect the ice-free port of Seward with coal fields of the interior of Alaska. The prospect of a railroad supplying nearby transportation increased interest in coal deposits of the Matanuska Valley area. Initially, the coal was tested to fuel the U.S. Navy's Pacific fleet. (The Navy never actually used this coal, however, due to insufficient supply from the local mines.) Construction of the 750-km-long railroad (the only railroad ever owned and operated by the Federal government) started in 1915. The beginning of construction brought job seekers and rapid population growth to Ship Creek, which was to become Anchorage. In 1914 only a handful of settlers lived at Ship Creek, but by April 1915 more than 2,000 people lived there in a ramshackle town of tents (The Alaska Geographic Society, 1983). With the increase in population, a post office opened and the Federal Government adopted the name of Anchorage for the new town. The name of Anchorage was shortened from Knik Anchorage, another name for Ship Creek (The Alaska Geographic Society, 1983).

The first priority in construction of the railroad was to build a spur to the Matanuska Valley coal fields so as to develop a supply of coal for construction of the south-central part of the Alaska Railroad and for other needs such as heating in Anchorage (Seager-Boss and Roberts, 1991). The spur (the Anchorage-Matanuska-Chickaloon Railroad Line) was completed in 1917. So as to ensure an adequate supply of coal for the railroad and the growing city of Anchorage, the Federal Government (through its Alaska Engineering Commission, AEC, created by the Alaska Railroad Act of 1914) bought and operated two mines in the area (Seager-Boss and Roberts, 1991).

Further reading on the Anchorage area includes Cohen (1982), Seager-Boss and Roberts (1991), Matanuska-Susitna Borough (1989), and The Alaska Geographic Society (1983).

Acknowledgments.—Many geoscientists participated in various studies of the Anchorage quadrangle, as summarized in this circular. We wish to thank the many people, too numerous to adequately list here, who contributed significantly to the mineral resource assessment of the quadrangle. In particular, we acknowledge the excellent and detailed geologic studies done by Bela Csejtey, Jr., Sandra H.B. Clark, Miles L. Silberman, and Arthur Grantz (USGS) and by Gar H. Pessel and his colleagues (DGGS); very comprehensive studies of mineral prospects by Rainer J. Newberry, University of Alaska, Fairbanks; chemical and spectrographic analyses of rocks and sediment by Richard M. O'Leary, James D. Hoffman, Belinda F. Arbogast, Robert R. Carlson, Allen L. Meier, and others (USGS); geochemical study by Richard J. Goldfarb (USGS) in the Chugach National Forest, which includes the southeastern part of the quadrangle; mineralogical study by Richard B. Tripp (USGS); and geophysical studies and interpretations by Laurel E. Burns (DGGS) and David F. Barnes (USGS).

SUMMARY OF MINERAL AND ENERGY PRODUCTION AND EXPLORATION

Gold in the Anchorage quadrangle has been produced from mines in the Talkeetna and Chugach Mountains, and coal has been produced from mines in the Matanuska Valley. Gold was produced principally from lode and placer deposits in the Willow Creek and Girdwood mining districts (fig. 1). Small amounts of gold also were produced from placer deposits in drainages outside of these districts: Alfred Creek, Caribou Creek, Boulder Creek, Chickaloon River, and Metal Creek. Coal was mostly produced in the Wishbone Hill and Little Susitna (near Houston) coal-mining districts. Chromite has been prospected in the informally named Eklutna (ultramafic) complex of Clark and Greenwood (1972b) (described by Rose, 1966) and the Wolverine Complex of Carden and Decker (1977) (first studied and described by Clark, 1972b), both along the Border Ranges fault (unit Jum, fig. 2). Base metals (zinc, copper, lead, and silver) resources have been examined in the southeastern part of the quadrangle, between Unakwik Inlet and Columbia Glacier. Plutonic rocks in the Willow Creek mining district have been prospected for copper and molybdenum.

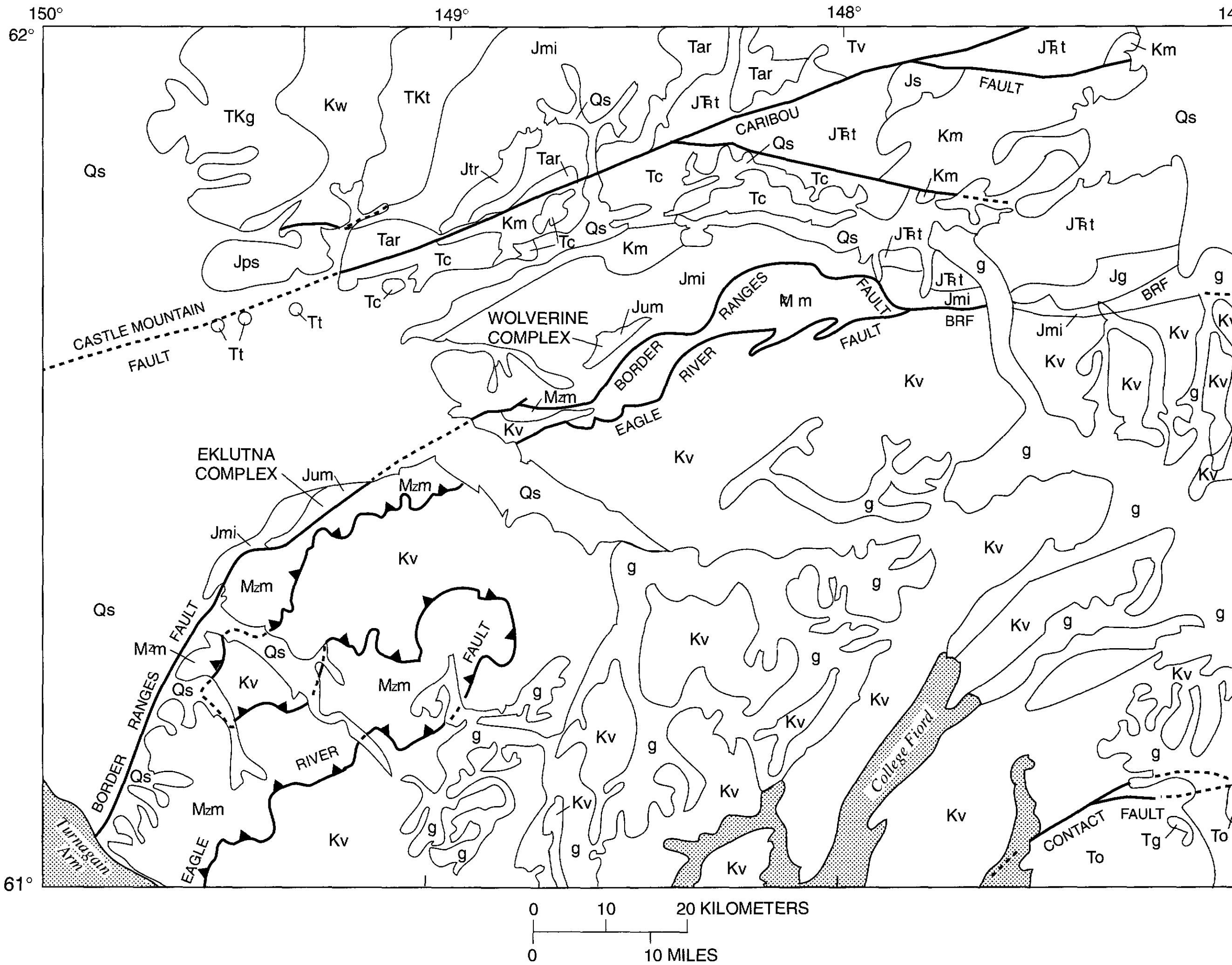
GOLD-BEARING QUARTZ-CARBONATE VEINS AND PLACER GOLD AND PLATINUM

The Willow Creek district is about 80 km northeast of Anchorage and encompasses about 290 km^2 of the southwestern Talkeetna Mountains. The first placer claims were staked on Willow Creek, at the mouth of Grubstake Gulch, in 1897; in 1898, 300 eager prospectors arrived by boat at nearby Tyonek (west of the Anchorage quadrangle) (Cohen, 1982). In 1899, two more claims were staked on lower Grubstake Gulch. In 1900, the claims were consolidated by one operator and mined for several years. In 1904 and 1905, after installing a hydraulic plant, placer production peaked; however, placer production fell far short of what was expected because the minable area proved to be very small. Subsequent placer mining was carried on erratically, with little production, while prospectors searched for lode deposits.

In 1906, the first lode was discovered and staked (Cohen, 1982). The ore was relatively rich: assay values were more than ten times higher than the values from gold mines near Juneau in southeastern Alaska. Around 1910, values from the Willow Creek district ranged from $30 to $40 per ton ($35–$45 per metric ton) (Katz, 1911), whereas values from the Treadwell mine near Juneau were about $2.50 per ton ($2.80 per metric ton) (Cohen, 1982). Also, most of the ore in the Willow Creek district was relatively simple to process: it was free milling and required only simple processing to release the gold (Cohen, 1982). More than 80 known mines, prospects, and mineral occurrences are within the district (Kurtak, 1986); at least 15 of these operations produced gold (Cohen, 1982). Production peaked during the interval from 1931 to 1943. Post–World War II production was limited because of increases in the expense of mining, and the last major production was in 1950. Ensearch Exploration produced gold from the Independence Mine during the early 1980's, but the mine closed in the fall of 1984. Today, the 270-acre Independence Mine State Historic Park preserves some of the old mining buildings along the East Fork of Fishhook Creek. Cohen (1982) is a good historical reference for further reading about the Willow Creek mining district.

Gold-enriched veins are in the 79–72-Ma, zoned, propylitically altered Willow Creek pluton (unit Kw, fig. 2) and in an adjacent unit of pelitic schist (unit Jps, fig. 2). (An adjacent unit of granite (unit TKg, fig. 2, 67 and 65 Ma) to the northwest is barren of gold-bearing quartz veins.) Mineralized veins are within about a kilometer of the contact between the zoned pluton and the pelitic schist. In the zoned pluton, the gold-quartz veins formed by open-space filling during shearing. The gold is concentrated in fractures within the quartz. Most of the gold is free-milling rather than physically bound up in sulfide minerals. Free-milling gold can be mechanically separated from the rock by crushing and gravity concentration and by amalgamation (the free gold adheres to and dissolves in mercury). Free-milling gold does not require removal from sulfide minerals by smelting or by solution in cyanide. The gold ore in quartz in the zoned pluton is present together with minor pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, galena, scheelite, stibnite(?), and telluride minerals including nagyagite (Ray, 1954). In the pelitic schist, gold is in shear zones of comminuted schist together with calcite, quartz, albite, chlorite, muscovite, pyrite, marcasite, arsenopyrite, chalcopyrite, sphalerite, and very fine grained cerrusite or anglesite (Madden-McGuire and others, 1989). Most gold production in the district has been from the veins cutting the zoned pluton. Total production (1909–1950) from the Willow Creek district was more than 623,874 ounces (17.7 million grams) (Dorff, 1984), mostly from lode deposits. A number of the gold mines reopened in the 1980's; in 1987, the Independence Mine produced 1,050 tons (952.6 metric tons) of ore.

A mineralized occurrence on the west side of the Nelchina Glacier, called the "Nelchina deposit," exposes sulfide-rich gold-bearing veins (Henning and Pessel, 1980; Newberry, 1986). Northwest-trending calcite-siderite-sulfide veins containing as much as 35.9 ppm Au, 150 ppm Ag, 1,279 ppm As, 9.3 percent Pb, 2.7 percent Zn, and 5,900 ppm Cu cut an irregular northeast-trending felsic aphanite-matrix breccia within a major dike system (Henning and Pessel, 1980; Newberry, 1986). The mineralogic



EXPLANATION

g	Glaciers and icefields (Holocene)
Qs	Surficial deposits (Quaternary)

PENINSULAR TERRANE

Bedded rocks

Tt	Tyonek Formation (Miocene)
Tv	Volcanic rocks (Miocene? to Paleocene)
Tc	Chickaloon Formation (Eocene and Paleocene)
Tar	Arkose Ridge Formation (Eocene and Paleocene)
Km	Matanuska Formation (Late and Early Cretaceous)
Js	Sedimentary rocks (Jurassic)
JŦt	Talkeetna Formation (Early Jurassic and Late Triassic?)

Intrusive rocks

TKg	Granite (Early Paleocene and Late Cretaceous)
TKt	Tonalite (Early Paleocene and Late Cretaceous)—Granite and tonalite
Kw	Willow Creek pluton (Late Cretaceous)—Altered, zoned granodiorite, quartz monzonite, and quartz diorite
Jtr	Trondhjemite (Late Jurassic)
Jg	Gabbronorite (Middle and Early Jurassic)
Jum	Ultramafic rocks (Middle and Early Jurassic)
Jps	Pelitic schist (Jurassic?)—Willow Creek mining district
Jmi	Metamorphic and igneous rocks (Jurassic)

CHUGACH AND PRINCE WILLIAM TERRANES

Bedded rocks

To	Orca Group (Eocene and Paleocene)
Kv	Valdez Group (Late Cretaceous)
Mzm	McHugh Complex (Mesozoic)

Intrusive rocks

Tg	Granite and granodiorite (Oligocene or Eocene)

Contact

Thrust fault—Dotted where concealed; sawteeth on upper plate

Steep fault—Dotted where concealed

Figure 2. Generalized geologic map of the Anchorage 1°×3° quadrangle, Alaska, showing selected geologic units, lithotectonic terranes, and major faults. Modified from Winkler (1992); Eklutna Complex of Carden and Decker (1977); Wolverine complex as informally named by Clark and Greenwood (1972). Peninsular terrane is north of the Border Ranges fault, Chugach terrane is south of the Border Ranges fault and north of the Contact fault, and Prince William terrane is south of the Contact fault.

source of the gold and silver was not determined (Henning and Pessel, 1980). Newberry (1986) estimated the occurrence of less than 500 tons (453.6 metric tons) of rock containing about 0.5 oz/ton (12.9 g/metric ton) silver and several percent zinc and lead; he made no estimate for gold.

In the Chugach Mountains, gold-enriched quartz veins are concentrated in areas underlain by metasedimentary rocks of the Valdez Group (unit Kv, fig. 2) that have been regionally metamorphosed to medium greenschist facies (characterized by incipient growth of biotite in graywacke) and, locally, that have been thermally metamorphosed adjacent to plutons where the pressure and temperature conditions were similar to those of medium-grade greenschist-facies metamorphism (Goldfarb and others, 1986). Rocks of the younger and structurally higher Orca Group (unit To, fig. 2), exposed to the southeast of the Valdez Group, generally have been metamorphosed under lower pressure-temperature conditions and do not contain significant gold occurrences in the Anchorage quadrangle. Gold-bearing veins cutting the Valdez Group consist mostly of quartz, injected in multiple stages, ankerite, gold, sulfide minerals, and later calcite. Arsenopyrite was the most abundant and earliest sulfide mineral to form and was followed by pyrite, pyrrhotite, sphalerite, galena, chalcopyrite, and sparse stibnite (Goldfarb and others, 1986).

The entire Valdez Group within the Anchorage quadrangle is permissive for gold- and silver-bearing quartz veins; however, the areas where anomalous amounts of gold are present in heavy-mineral concentrates from stream and glacial moraine sediment samples are more likely to contain gold-bearing quartz veins (Madden-McGuire and Tripp, in press). This is illustrated by the example of the Girdwood gold mining district.

The Girdwood district is on the north shore of Turnagain Arm, near the southern boundary of the Anchorage quadrangle. The district includes the drainage of Crow Creek and the headwaters of the Eagle River. Placer gold was discovered in 1895, and production began in 1898. In 1909 lode deposits of gold in quartz-carbonate veins were discovered in upper Crow Creek, and in 1910 development began (Park, 1933). Gold and silver are concentrated in quartz-carbonate veins in shear zones and joints within metasedimentary rocks of the Valdez Group. Quartz diorite intrusive bodies are present in the vicinity of the mines, and quartz diorite forms the wallrock along part of one vein (in a mine called the Bahrenberg; Park, 1933). Production from the veins has been small, consisting of about 5,000 ounces (141,750 g) of gold and 1,200 ounces (34,020 g) of silver (Hoekzema, 1984). Most of the abandoned mines are in upper Crow Creek, but a silver-rich prospect on the south bank of the Eagle River, just below the terminus of the glacier, contained 1.5 ppm Au and 855 ppm Ag (Cobb, 1979). Park (1933) described the Eagle River prospect as containing mineralized quartz stringers, all less than 0.3 m wide, within sheeted zones in massive, fine-grained graywacke.

Jansons and others (1984) presented data on the gold content from a few of the better known mines in the Girdwood district. Ten chip samples from Jewel Mine averaged 36 ppm Au, 17 ppm Ag, and as much as 4.7 percent As; 43 chip samples from "Monarch," including the Bruno-Agostino Mine, averaged about 10 ppm Au and 10 ppm Ag (with as much as 233 ppm Au); four samples from Bahrenberg Mine averaged 56 ppm Au and 58 ppm Ag (Jansons and others, 1984). M.L. Silberman (USGS, written commun., 1992) collected 12 grab samples of mineralized veins from several levels of one mine (Bruno-Agostino) in the Girdwood district and reported 0.1–550 ppm Au, as much as 70 ppm Ag, and 10–2,000 ppm As. For comparison, the Hope-Sunrise gold district, situated across Turnagain Arm to the southwest, also contains high-grade ore. On a district scale, the average ore grade in the Hope-Sunrise district is about 70 ppm Au; high-grade ore shoots average about 450–500 ppm Au. It is not certain if the average grade in this district is comparable to the average grade of ore in the whole Girdwood district. Although ore from the Girwood district has been considered to be high in grade, Park (1933) said that the host rock was not favorable for developing large and persistent veins; wallrocks are tight, and veins are lenticular and thin out in small and scattered stringers. The quartz diorite exposed in the area (Park, 1933; Jansons and others, 1984) could have formed a more competent host rock for the veins during mineralization; however, the quartz diorite has not been reported to host gold veins, and locally it is only present as part of the wallrock (Park, 1933). The character of the host rocks is only one of many possible reasons why the Girdwood lode deposits have not been more productive. In the Girdwood district, placer-gold production, as discussed below, has been more significant than lode-gold production.

Gold-quartz veins are exposed in two areas underlain by rocks of the Valdez Group near Prince William Sound: an area near Harriman Fjord and an area near the Coghill River. Near Harriman Fjord, the Alaska Homestake gold mine produced 83 oz (2,353 g) of gold and 33 oz (935.6 g) of silver (Jansons and others, 1984), and two prospects contained 2.4 ppm and 0.17 ppm Au. One of these occurrences is in a shear zone along the contact between a felsic dike and hornfels (Jansons and others, 1984). Heavy-mineral-concentrates from stream sediment samples in the area contained anomalous gold, silver, and arsenic (Madden, 1991a; Tripp and Madden, 1991). Near the Coghill River, outcrops of gold-quartz veins on the margin of a small granitic stock contained 16 ppm Au and 38 ppm Ag (Jansons and others, 1984). Heavy-mineral-concentrate samples contained anomalous gold and silver (Madden, 1991a; Tripp and Madden, 1991).

An area between the Marcus Baker Glacier and the Matanuska River contains exposures of mineralized base-metal- and gold-enriched quartz veins in altered, iron-stained metasedimentary and plutonic (quartz diorite) rocks (Richter, 1967; Cobb, 1979; Madden and others, 1988). The veins contained as much as 0.25 ppm Au, 5 ppm Ag, 2,000 ppm As, and 2,000 ppm Cu and more than 2,000 ppm Zn (Madden and others, 1988). Heavy-mineral-concentrate samples in the lower half of the Grasshopper Valley drainage contain chalcopyrite, sphalerite, galena, and arsenopyrite, as well as gold. Many heavy-mineral-concentrate samples in this area are enriched in silver, arsenic, and less commonly in antimony.

Placer gold has been mined in the Willow Creek district from Willow Creek and Grubstake Gulch and briefly, in 1906, from the lower part of Fishhook Creek, which proved to be uneconomical because of large boulders (Cobb, 1979). In 1990, the district supported several small placer operations, two on Willow Creek and one on the Little Susitna River (Swainbank and others, 1991). Heavy-mineral-concentrate samples contained gold from all the above-mentioned streams, as well as from Craigie Creek (Madden, 1991a; Tripp and Madden, 1991). During the early 1990's, placer gold was still being mined from Willow Creek, just below the mouth of Grubstake Gulch.

In the Alfred Creek drainage, placer gold was discovered in 1911; small-scale mining was continuing there during these investigations in the early 1980's. Only a few heavy-mineral-concentrate samples from Alfred Creek contained gold (5 samples from Alfred Creek and 2 tributaries, out of a total of 28 samples in the whole drainage; Madden, 1991a; Tripp and Madden, 1991). At the northeast end of the Alfred Creek drainage, near Table Mountain, placer gold was found in 1913 (Cobb, 1979); however, heavy-mineral-concentrate samples from that area lacked gold (Madden, 1991a; Tripp and Madden, 1991). Brooks (1925) and Cobb (1979) reported small quantities of platinum in the placers. The source of the platinum is uncertain. Perhaps it came from paleoplacer deposits in Jurassic sedimentary rocks in unit JTRt (fig. 2) in the Alfred Creek drainage.

Mining was reported in Caribou Creek in 1912 (Cobb, 1979), but no operations were seen during the early 1980's. Many heavy-mineral-concentrate samples in Caribou Creek were enriched in gold (Madden, 1991a; Tripp and Madden, 1991).

Mendenhall (1900) described small placer-gold prospects in the lower part of Boulder Creek (Cobb, 1979). Gold prospects were reported in the area, but there are no records of commercial production (Cobb, 1979) and no signs of operations during the early 1990's. Four of sixteen heavy-mineral-concentrate samples in the drainage contained gold, and some of these gold-bearing samples were enriched in arsenic and silver (Madden, 1991a; Tripp and Madden, 1991). The U.S. Bureau of Mines (USBM) includes platinum as a commodity in Boulder Creek placers (J.Y. Foley, written commun., 1991).

Placer mining was reported in the Chickaloon River in the early 1900's, but the mined placer deposits might have been north of the Anchorage quadrangle (Cobb, 1979). Gold also was reported from the lower part of the river, near the mouth of Boulder Creek. Only three of twenty heavy-mineral-concentrate samples in the Chickaloon River were enriched in gold (and silver; Madden, 1991a; Tripp and Madden, 1991). The source of the placer gold might be felsic volcanic rocks in the drainage north of the Anchorage quadrangle, which host copper and gold in veins(?) (Singer and others, 1978).

Placer gold is present in the Girdwood mining district, where the deposits on Crow Creek first were claimed in 1895. These deposits were mined continuously until World War II (Cobb, 1979) but have been mined only sporadically since. Most of the mining has been done near the southern boundary of the Anchorage quadrangle. Nuggets commonly weigh 0.025–0.05 ounces (0.71–1.42 g), but some weigh as much as 1 ounces (28.35 g). The gold content of six samples of placer gold averaged 72 percent Au, 22 percent Ag, and the remainder base metals (Hoekzema, 1984). Heavy-mineral-concentrate samples from Crow Creek and from surrounding drainages contain anomalous gold, silver, arsenic, and antimony (Madden, 1991a; Tripp and Madden, 1991). Crow Creek has been a large placer-gold-producing stream for south-central Alaska, producing almost 43,000 ounces (1.2 million grams) of relatively coarse gold (much of it >14 mesh) detritus between 1898 and 1982 (Hoekzema, 1984; Jansons and others, 1984). Production between 1979 and 1983 was 400 ounces (11,340 g); recreational placer mining remains popular. The inferred placer gold reserve in Crow Creek, within and south of the Anchorage quadrangle, was estimated at more than 1,000,000 cubic yards (764,600 m^3) of gold-bearing gravel (Jansons and others, 1984). Creeks other than Crow Creek may contain placer deposits with only subeconomic quantities of gold (Jansons and others, 1984).

Placer gold was discovered in Metal Creek in about 1906 and mined sporadically for about 20 years (Richter, 1967; Cobb, 1979). USGS heavy-mineral-concentrate samples from Metal Creek and four of its tributaries were enriched in gold (Madden, 1991a; Tripp and Madden, 1991). No placer-mining operations were seen in the early 1980's. The occurrence of platinum is disputable. Placer platinum was reported by Smith (1926), but it was not confirmed by Richter (1967).

PODIFORM CHROMITE AND PLATINUM-GROUP ELEMENTS

Podiform chromite is within two fault-bounded ultramafic complexes. The two complexes are the informally named Eklutna (ultramafic) complex of Clark and Greenwood (1972) (described by Rose, 1966) and the Wolverine Complex of Carden and Decker (1977) (first studied and described by Clark, 1972b). Chromite is a brownish- to iron-black mineral of the spinel group; chromitite is an igneous rock made up mostly of chromite. Chromitite generally is within dunite cumulate rocks and less commonly within harzburgite and wehrlite in the Eklutna (ultramafic) complex and in the Wolverine Complex. Stream-sediment samples from basins draining the exposed ultramafic complexes are enriched in chromium and nickel (Zinkl and others, 1981; Madden, 1991b). Because the lateral continuity of individual chromite-bearing horizons is poorly known, tonnages can only be estimated. A magnetic anomaly between the Eklutna complex and the Wolverine Complex suggests that ultramafic rocks also are present at shallow depth beneath unconsolidated deposits of the Knik River floodplain.

Following the signing of the 1939 Strategic Minerals Act, prospectors staked two Eklutna chromite occurrences between Anchorage and Palmer in 1940 and 1942. The Pioneer Creek occurrence is south of mile 32.8, on the south side of the road, and the Highway occurrence is near mile 31.8, more than 0.8 km south of the old Glenn Highway. The U.S. Bureau of Mines learned about these prospects in 1941–1942 and carried out geological investigations in 1943. They found the occurrences to be uneconomic due to small size and low grade. Foley and Barker (1985) noted that the chromite claims had all lapsed but that several of the well known occurrences contained recoverable chromite.

In the Eklutna (ultramafic) complex, an igneous stratigraphy of cumulate dunite and chromitite grades upward into wehrlite, clinopyroxenite, and gabbronorite (Newberry, 1986). Layers of chromitite (deformed by magmatic or early postmagmatic processes) are restricted to olivine cumulate rocks, and the area of abundant high chromitite apparently is quite limited; chromitite bands and layers cannot be extrapolated more than 100 ft (30.48 m) along strike or down dip (Newberry, 1986). At Twin Peaks ridge, which exposes the richest chromite concentrations in the Eklutna complex, Newberry (1986) estimated 50,000–100,000 tons (45,360–90,720 metric tons) of 8 percent Cr_2O_3.

In the Wolverine Complex, 40 km to the east-northeast of the Eklutna (ultramafic) complex, chromitite is in layers separated by dunite and minor wehrlite (in fault contact with gabbronorite) and in lenses and deformed nodules interlayered within harzburgite and dunite (Newberry, 1986). Chromitite layers are sheared into elongate bodies along faults; structural complexity suggests that effective exploration for chromite would be difficult here (Newberry, 1986). Newberry (1986) estimated 100,000–300,000 tons (45,360–272,160 metric tons) of 8 percent Cr_2O_3 and 20,000–40,000 tons (18,144–36,288 metric tons) of 10 percent Cr_2O_3 in the richest parts of the Wolverine Complex. Worldwide, cumulate ultramafic rocks comparable to the Eklutna complex and Wolverine Complex rarely contain significant chromite (Newberry, 1986).

Rocks from the Eklutna complex contained a maximum of 0.1 ppm Pt (mean 0.042 ppm Pt) and a maximum of 0.14 ppm Pd (mean 0.04 ppm), based on an analyses of Clark and Greenwood (1972). Analyses of 10 additional samples from the Eklutna (ultramafic) complex show similar results: an average of 46 ppb Pt and 40 ppb Pd, and maximums of 100 ppb Pt and Pd (J.Y. Foley, USBM, written commun., 1991). One sample of coarse-grained clinopyroxenite contained 94 ppb Pt and 91 ppb Pd (J.Y. Foley, USBM, written commun., 1991). Rocks sampled from the Wolverine Complex contained 0.007–0.05 ppm Pt and 0.002–0.04 ppm Pd, based on analyses of 16 samples (Clark, 1972b).

In the Willow Creek mining district, pelitic schist (unit Jps, fig. 2) contains serpentinized dunite and wehrlite-lherzolite enriched in chromium and nickel (as much as 5,000 ppm Cr and >5,000 ppm Ni, Csejtey and Evarts, 1979; Madden and others, 1988; Madden-McGuire and others, 1989). We did not observe chromitite in these rocks or chromium or nickel enrichment in stream sediment. The serpentinite contained a maximum of 0.03 ppm of both Pt and Pd, based on analyses of 10 samples from 6 different bodies; serpentinite was not analyzed for other platinum-group elements (Csejtey and Evarts, 1979). Two samples of talc schist from a soapstone occurrence within the pelitic schist (unit Jps, fig. 2) contained 0.001–0.003 ppm Pd and no detectable platinum, rhodium, ruthenium, or iridium (Madden and others, 1988).

BASE-METAL DEPOSITS—STRATIFORM, STRATABOUND, AND RELATED SYNGENETIC MINERALIZATION, MASSIVE SULFIDES AND VEINS, AND STRATEGIC METALS

Amphibolite schist (within unit Jmi, fig. 2) in the northern Chugach Mountains contains stratiform disseminated sulfide minerals along foliation and stratabound sulfide-bearing veinlets (Newberry, 1986). The protolith for the amphibolite is interpreted as mafic sills or flows in a sedimentary-volcanic sequence (Newberry, 1986). The amphibolite and syngenetic pyrite have been altered to varying degrees by retrograde metamorphism. Amphibole, biotite, and plagioclase are locally altered to chlorite and muscovite; in the sulfide zones pyrrhotite is altered to pyrite. The stratabound veinlets and the abundant retrograde pyrite formed during retrograde metamorphism (Newberry, 1986). Based on 13 samples from 5 localities, the sulfide zones are slightly enriched in copper (65–194 ppm), silver (as much as 0.2 ppm), and cobalt (13–40 ppm) and contain pyrrhotite, pyrite, lesser chalcopyrite, and minor chalcocite. Heavy-mineral-concentrate samples downstream from these exposures lacked chalcopyrite (Madden, 1991a; Tripp and Madden, 1991). The low metal grades and complex deformation (lack of continuity) indicate that these sulfide occurrences in the northern Chugach Mountains have low economic potential (Newberry, 1986).

Volcanic rocks of the Talkeetna Formation (unit J₹t, fig. 2) host numerous stratiform and stratabound zones of pyrite, slightly enriched in silver, that are restricted to intermediate to silicic volcanic rocks (Newberry, 1986). Sparse quartz veinlets contain bornite, chalcopyrite, epidote, and supergene chalcocite and covellite; locally these veinlets assay very high in copper, silver, and gold (Newberry, 1986). The veinlets are restricted to the volcanic rocks and do not cut overlying sedimentary rocks; thus the veins either had a volcanic (pre-sedimentation) origin or the volcanic rocks were more competent and served as better host rocks for the veinlets. No chalcopyrite was found in heavy-mineral-concentrate samples downstream from these prospects (Madden, 1991a; Tripp and Madden, 1991). The resource potential of these occurrences is low because of their low metal grades.

Two small tributaries north of Boulder Creek contain exposures of altered, metal-enriched, volcanic rocks of the Talkeetna Formation. These outcrops contained as much as 2 percent Cu, 5,000 ppm Pb, more than 2,000 ppm Zn, 3,000 ppm Ba, 0.1 ppm Au, and 10 ppm Ag (Madden and others, 1988). Heavy-mineral-concentrate samples downstream from these outcrops lacked chalcopyrite; one sample downstream in Boulder Creek contained gold (Tripp and Madden, 1991). These rocks are deformed and cut by numerous Tertiary porphyritic intrusive rocks.

Base-metal occurrences in the southeastern part of the Anchorage quadrangle are in an area between Columbia Bay and Unakwik Inlet, within the Orca Group (unit To, fig. 2). Shear zones are abundant in slate, sandstone, conglomerate, and greenstone of the Orca Group and cut felsic dikes that intrude the Orca Group. Chalcopyrite, pyrite, galena, and sphalerite are in quartz veins in the shear zones (Jansons and others, 1984). The U.S Bureau of Mines (Jansons and others, 1984) assigned a low mineral-development potential to all of the prospects except for one; a moderate development potential was assigned to Long Bay No. 1, in which mineralized shear zones cutting the Orca Group contained as much as 3.2 percent Zn, 2.6 percent Pb, and 273.6 ppm Ag. Rock samples from another prospect in this area, called the "Four-in-One," contained as much as 150 ppm Ag, more than 20,000 ppm Cu, 650 ppm Zn, 270 ppm As, and 0.15 ppm Au but were not enriched in lead (Madden and others, 1988).

In the upper part of the Grasshopper Valley drainage, mineralized metasedimentary rocks of the Valdez Group contained as much as 5 ppm Ag, 10,000 ppm Cu, more that 2,000 ppm Zn, more than 2,000 ppm As, and only 0.25 ppm Au in small veins (Madden and others, 1988). Chalcopyrite, sphalerite, galena, and gold were microscopically visible in heavy-mineral-concentrate samples and probably were derived from the known mineralized outcrops.

PORPHYRY DEPOSITS

Plutonic rocks of intermediate composition (diorite, quartz diorite, tonalite, and granodiorite) in the northern Chugach Mountains may have potential for porphyry-copper-gold deposits, based on comparison of these rocks with host rocks for the deposits described by Hollister (1978). Newberry (1986) observed minor malachite staining and pyritic zones in intermediate plutonic rocks in the northern Chugach Mountains in the Anchorage quadrangle but no sulfide-bearing quartz veins or copper sulfide minerals. Newberry (1986) found no significant gold enrichment in these rocks in the northern Chugach Mountains. Jurassic intermediate plutonic rocks are widespread along an east-trending belt on the north side of the Chugach Mountains and also within the southern Talkeetna Mountains.

The prospects studied by Newberry (1986) in the northern Chugach Mountains lack evidence for major hydrothermal systems (such as sulfide-bearing quartz veins, secondary biotite, potassium feldspar or muscovite, and copper sulfide minerals), contain low copper values (generally less than 100 ppm Cu, one value of 142 ppm Cu), and lack detectable gold in rock samples, altogether indicating a lack of significant metal deposition (Newberry, 1986).

Intermediate plutonic units sampled elsewhere in the quadrangle, in the southern Talkeetna Mountains and in other parts of the northern Chugach Mountains, are locally enriched in copper, containing as much as 2 percent, but the extent of mineralized rock is unknown (Madden and others, 1988; Madden-McGuire and Winkler, in press).

Within the Willow Creek mining district, rock samples contain as much as 8,000 ppm Cu (and more than 2,000 ppm Mo in one sample of quartz vein from a mine; Silberman, O'Leary, and others, 1978; Madden and others, 1988). Copper enrichment was first noted by Capps and Tuck (1935), who observed numerous small veins of glassy quartz containing chalcopyrite and bornite that grade into the plutonic host rock in the Willow Creek district. Ray (1954) noted that the most abundant veins in the Willow Creek district are vuggy, glassy quartz veins characterized by chalcopyrite, molybdenite, and minor pyrite and arsenopyrite. The chalcopyrite is altered to azurite and malachite at the surface. Silberman, Csejtey, and others (1978) and Silberman, O'Leary, and others (1978) sought evidence in the Willow Creek district for hypothesized porphyry-type disseminated copper deposits, which are present in similar granitic rocks in the eastern Alaska Range. They published geochemical data, interpretations, and isotopic ages for plutonism, metamorphism, and gold mineralization. Burleigh (1987 and 1988), while carrying out geochemical, stable-isotope, and fluid-inclusion studies of mineralization, noted widespread copper-molybdenum quartz veins in the plutonic host rocks of the Willow Creek district.

COAL

In the Anchorage quadrangle, coal has been mined from the Matanuska coal field (Wishbone Hill and Chickaloon districts) and from the area of Houston.

The occurrence of coal in the Matanuska Valley area was known as early as 1894, when prospectors and traders learned of it from the indigenous people. The Federal Government learned of the coal in the Matanuska Valley in 1898, as a result of the expedition by Captain Glenn and Lt. Castner, who were exploring for new routes from Cook Inlet to the gold fields of the Yukon. Prior to 1903, however, the Matanuska coal was not economic to explore and mine due to the lack of feasible transportation. The prospect of nearby transportation led to increased coal exploration in 1903 when construction of a private railroad from Seward to the Yukon Valley seemed certain. In 1904, construction began on the private railroad from Seward northward. The railroad was to depend on Matanuska coal for their engines. After 84 km of track were laid down, the Federal Government withdrew the availability of coal on public lands in Alaska in 1906 (Matanuska-Susitna Borough, 1989). In 1914, railroad and coal-leasing acts were signed and construction began on the Federally owned Alaska Railroad to link Seward with Fairbanks. The railroad was the primary market for local coal before World War II, after which the military bases built in Anchorage were the main coal consumers (Seager-Boss and Roberts, 1991). Local coal production was at a peak of 255,989 tons (232,233 metric tons) in 1944, and demand still exceeded supply. After 1944, local demand for coal diminished. By the 1950's, the train engines converted to diesel; in 1967, the military bases converted to natural gas (Seager-Boss and Roberts, 1991). Interest in coal has been renewed in the 1980's and 1990's.

During the late 1980's and early 1990's, open-pit mining was planned in the Wishbone Hill district, where high-quality, bituminous coal having low-moisture and low-sulfur content is in the Chickaloon Formation (unit Tc, fig. 2) (Schneider, 1989). Underground mining was recently planned for the old Jonesville Mine, but earthquake-induced landslide damage to the mine portal ended preparations. Open-pit mining is presently planned for the Wishbone Hill Mine (Wishbone Hill district) and for the Castle Mountain Mine (Chickaloon district). During 1990, mapping, trenching, and sampling were done at the Evan Jones Mine (Wishbone Hill district) and at the Castle Mountain Mine (Chickaloon district), in preparation for development (Swainbank and others, 1991), but no coal was produced from the Anchorage quadrangle (Swainbank and others, 1991).

In the Wishbone Hill district, coal has been mined from the Paleocene and Eocene Chickaloon Formation (unit Tc, fig. 2). Barnes and Payne (1956) called this the "only producing bituminous coal district in Alaska." Ranges for proximate values of raw coal are heating value, 10,400–12,500 Btu; ash, 5–24 percent; fixed carbon, 37–47 percent; volatile matter, 33–41 percent; and moisture, 3–7 percent (Conwell and others, 1982). Coal production was 3,284,723 million short tons (3 metric tons) between 1916 and 1952, with almost one-third of that total produced early within that period, between 1916 and 1934 (Barnes and Payne, 1956). Total coal reserves are 112.5 million tons (6.6 million tons measured, 48.6 million tons probable, and 57.3 million tons inferred; Barnes and Payne, 1956; Conwell and others, 1982). In metric units, total reserves are 126 million metric tons (measured, 6 million metric tons; probable, 44 million metric tons; inferred, 52 million metric tons). Though coal zones in the Chickaloon Formation are extensive, individual coal beds pinch out abruptly into clastic rocks.

Commercial production of coal in mines of the Chickaloon district has been limited by the structural complexity of the coal-bearing strata (Warfield, 1967). At present, there is interest in redeveloping the Castle Mountain Mine, northwest of Chickaloon (Swainbank and others, 1991). The Castle Mountain Mine produced about 6 million tons (5.4 million metric tons) of coal between 1920 and 1968; current reserves are estimated at about 22.4 million tons (20.3 million metric tons) (Swainbank and others, 1991) in small, broken-up beds, which are intruded by igneous sills that follow coal and carbonaceous shale.

In the area of Anthracite Ridge and adjacent areas, coal is exposed in the Chickaloon Formation (and locally in the Arkose Ridge Formation (unit Tar) and the Matanuska Formation (unit Km) (fig. 2) on both sides of the Matanuska Valley. There is no record of commercial coal production from the Anthracite Ridge area. Coal beds of the Chickaloon Formation have been locally heated by igneous intrusions to produce anthracite, which is exposed in a 1.3-km^2 (half-mile-square) area on the south side of the ridge (Waring, 1936). Proximate analyses of raw coal are heating value, 11,510–14,210 Btu; ash, 4–22 percent; fixed carbon, 46–81 percent; volatile matter, 8–32 percent; and moisture, 2–7 percent (Conwell and others, 1982).

In the Little Susitna coal district, including the coal mine near Houston, subbituminous and bituminous coal are in the Tyonek Formation (unit Tt, fig. 2). Ranges for proximate analyses of raw coal are 8,460–9,210 Btu; ash, 9.2–20.5 percent; fixed carbon, 34.1–38.9 percent; volatile matter, 31.3–32.5 percent; and moisture, 14.1–20.3 percent (Conwell and others, 1982). Mining produced about 10,000 tons (9,072 metric tons) of coal from a 3.5-ft-thick bed between 1917 and 1920 (Barnes and Sokol, 1959), and 65,000 tons (58,968 metric tons) between 1948 and 1952 (Conwell and others, 1982).

East of Houston, small areas in the Little Susitna coal district that expose the Tyonek Formation also expose coal beds (Barnes and Sokol, 1959). These areas include a small coal mine along Coal Creek, where coal was mined for local use in the gold mines (Barnes and Sokol, 1959).

URANIUM

Some areas in the Anchorage quadrangle contain geochemical evidence for uranium mineralization associated with granitic rocks. A few drainages in the southeastern part of the Anchorage quadrangle (west of Columbia Bay) yielded stream sediment samples enriched in uranium (2–22 ppm) (Zinkl and others, 1981). Heavy-mineral-concentrate samples in these areas are enriched in tin, lanthanum, yttrium, and thorium (Arbogast and others, 1986), a suite of elements that commonly accompanies uranium mineral deposits associated with granitic intrusive rocks. Biotite±hornblende granite having a granodiorite border phase (unit Tg, fig. 2) is exposed in the area (Nelson and others, 1985). These granitic rocks might be the source for uranium enrichment in stream sediment.

The upper part of Bird Creek contains stream sediment that are enriched in uranium (9–22.8 ppm). Ratios of uranium to thorium are greater than 1 in four stream-sediment samples; ratios range from 1.2 to 5.2. Heavy-mineral-concentrate samples contain only modest amounts of lanthanum (100 ppm), yttrium (500 ppm), tungsten (500 ppm), and niobium (50 ppm). Outcrops of small areas of unmapped felsic intrusive rocks might contribute anomalously high concentrations of uranium to stream sediment.

Northwest of the Willow Creek mining district, 10 samples of uranium-enriched stream sediment (5–44 ppm U) were collected from an area underlain by a large epizonal biotite- and muscovite-bearing granitic pluton of Late Cretaceous and early Paleocene age (unit TKt, fig. 2) (Csejtey and others, 1978; Winkler, 1992). One sample has a U:Th ratio as high as 10, and most samples have ratios greater than 2. Heavy-mineral-concentrate samples from drainages in this pluton are enriched in molybdenum (as much as 700 ppm), tin (100 ppm), tungsten (200 ppm), lanthanum (>2,000 ppm), yttrium (1,500 ppm), and thorium (500 ppm).

Several areas west of the Kings River drainage yielded two stream-sediment samples containing 46 ppm U (U:Th=25.6) and 26 ppm U (U:Th=7.9). The sediment was eroded, in part, from a Late Jurassic trondhjemite (unit Jtr, fig. 2) that consists of epizonal muscovite-biotite leucocratic plutonic rocks, including some quartz diorite, near the northern boundary of the quadrangle (Csejtey and others, 1978; Winkler, 1992). The leucocratic plutonic rocks might be the source for the uranium enrichment in the stream sediment.

OIL AND GAS

Commercial oil was discovered in Cook Inlet in 1957. The upper Cook Inlet region contains oil and gas fields producing mostly from upper Tertiary sedimentary rock units west and southwest of the Anchorage quadrangle. The Cook Inlet petroleum province is Alaska's main gas-producing area (Schneider, 1989). The closest gas fields to the Anchorage quadrangle are Beluga River and North Cook Inlet, about 50 km west of Anchorage and outside of the quadrangle; the closest oil field is Swanson River, about 35 mi southwest of Anchorage and also outside of the quadrangle. Most of the oil is produced from the Hemlock Conglomerate (Oligocene), which is not exposed in the quadrangle, and from the Tyonek Formation (Miocene), which is exposed in just a few places (unit Tt, fig. 2). Much of the dry gas is produced from sandstone within the upper part of the Beluga Formation and from the lower, Miocene part of the Sterling Formation of the Kenai Group (Kirschner and Lyon, 1973; Wolfe and Tanai, 1980).

Petroleum is in sandstone and conglomerate reservoirs in north-northeast-trending compressional folds. The source of the oil might be underlying Middle Jurassic siltstone; migration might have occurred along the Jurassic-Tertiary unconformity and along faults associated with the compressional folds (Gould and others, 1991). Gas in sandstone reservoirs is almost pure methane of biogenic origin and perhaps was derived from the subbituminous to lignitic coal in the Tertiary section (Gould, Karpas, and Slitor, 1991). In 1985, the State of Alaska began exporting Cook Inlet oil to the highest bidder, the Chinese Petroleum Company of Taiwan (Gould and others, 1990).

Within the Anchorage quadrangle, wells have been drilled through the Mesozoic and Cenozoic clastic units north of the Border Ranges fault system and both north and south of the Susitna segment of the Castle Mountain fault. Although several anticlines and likely fault traps were tested, no oil or gas fields were discovered; numerous dry holes were drilled in the quadrangle but no producing wells (Magoon and others, 1976). Apparently, well locations in the Anchorage quadrangle are near the margins of the Tertiary depositional basin of upper Cook Inlet, where unconformities, rapid facies changes, and structural deformation have prevented successful hydrocarbons discoveries.

GEOLOGIC INVESTIGATIONS

Field investigations by the U.S. Geological Survey in the Anchorage quadrangle began in 1898, when Mendenhall traversed the northern Matanuska Valley as part of a War Department expedition led by Capt. Edwin F. Glenn and Lt. Joseph C. Castner. The purpose of the expedition was to discover a route from Cook Inlet to the Tanana River and the gold fields of the Klondike and, along the way, to accumulate geographic and geologic information about the region. Mendenhall (1900) assigned the unmetamorphosed sedimentary rocks in the Matanuska Valley to his now-abandoned Lower Cretaceous Matanuska Series. Following the Glenn expedition, USGS field studies were carried out in the area in order to provide geologic information to the mining public.

Some of the geologic studies that were done in the Willow Creek gold-mining district are summarized following. Paige and Knopf (1907a, b) did geologic mapping in the Matanuska Valley with a topographic survey party in 1906. They visited the Willow Creek district during a general geologic reconnaissance of the Talkeetna Mountains, Matanuska Valley, and the northern Chugach Mountains. They noticed that the main source of the placer gold in Willow Creek was in a unit of schist: the paying placer deposits were in streams draining the schist and not in streams draining plutonic rocks in the area. They gave a long description of the hydraulic mining of placer gold in Grubstake Gulch (Paige and Knopf, 1907a). Katz (1911) examined lode deposits in the Willow Creek district and published references to telluride minerals in the gold veins. He described several mining properties, discussed vein characteristics, and reported assay values. Capps (1915) produced a comprehensive report on the general geology of the district, vein distribution and character, property descriptions, mining methods, mill design, and an account of mining developments through 1913. Capps (1919) described cyanide leaching of tailings in the district between 1914 and 1917.

Ray (1933), by invitation from the Alaska Railroad Board, made a detailed study of the gold veins, concentrating on the paragenesis of ore mineralogy, structural features of veins, and the faults that offset vein systems. He produced accurate maps for a number of the mines. Capps and Tuck (1935), working under a special appropriation made to the Alaska Railroad Board for mineral development, studied whether the gold mineralized rocks in the Willow Creek district extended to the northeast of the mined area. They observed numerous small veins of glassy quartz containing chalcopyrite and bornite grading into the plutonic host rock but no gold. They noted that, although all assays yielded at least a trace of gold, silver and copper, but not gold, increase in amount northward from the Willow Creek mining district. They suggested that veins to the northeast would contain a greater proportion of sulfide minerals and less free gold and that any veins north and northeast of the mining district would be of low grade. Stoll (1944) evaluated structural details of the Independence vein to produce a qualitative correlation of stress, brecciation, and the location of gold mineralization. Thorne and others (1948) studied the occurrence of scheelite in several mines in the Willow Creek district. Ray (1954) produced a comprehensive report on the geology and ore deposits in Willow Creek and supplied detailed maps, property descriptions, and production figures. As a result of increasing interest in exploration in the Willow Creek district in the early 1960's, Jasper (1962) discussed individual mining properties, exploration for gold in the schist, and placer mining in Grubstake Gulch.

Silberman, Csejtey, and others (1978) and Silberman, O'Leary, and others (1978) published the first isotopic ages for gold-vein formation in the Willow Creek district, in conjunction with reconnaissance geochemical data and interpretations from the district. They sought evidence for porphyry-type disseminated copper deposits, which are present in lithologically similar granitic rocks in the eastern Alaska Range. They found pegmatitic rocks containing as much as 8,000 ppm Cu. Burleigh (1987, 1988) carried out geochemical, stable isotope, and fluid-inclusion studies of mineralized rocks in the Willow Creek district. He noted that the gold veins transect copper-molybdenum quartz veins in the plutonic host rocks. The gold veins formed shortly after the widespread copper-molybdenum sheeted quartz veins. The gold veins contain pyrite, arsenopyrite, sphalerite, chalcopyrite, zoned arseno-tetrahedrite, galena, telluride minerals, bournonite, copper-lead-bismuth sulfosalts, gold, and hypogene chalcocite and hematite. Alteration consists of sericitization and carbonatization. Most of the quartz precipitated from earlier, CO_2-rich, higher temperature solutions (homogenization temperatures 300°C–325°C). Carbonate minerals, as well as gold, galena, telluride minerals, and sulfosalt minerals, precipitated from later, low-CO_2, cooler solutions (homogenization temperatures 167°C–267°C). Evolved formation and metamorphic solutions were thought to be the mineralizing solutions. Burleigh (1988) described the paragenetic relationship between gold, tetrahedrite, and telluride minerals in the quartz veins. Madden and others (1987) and Madden-McGuire and others (1989) discussed the relationship between mineralization, plutonism, and faulting in the Willow Creek district. They presented geochemical data, K-Ar ages, lead-isotope, strontium-isotope, and oxygen-isotope data, and several alternative hypotheses regarding how mineralization fits into the geologic history of the area.

Geologic studies done in the Girdwood mining district are described following. Moffitt (1905, 1906) studied gold deposits of Turnagain Arm and first reported on placer deposits in the Girdwood mining district. Crow Creek, with the largest hydraulic plant in Cook Inlet, had two grades of gold (one coarse and silvery and the other finer and yellow), as well as native copper and silver. Gold assays from Crow Creek were lower than assays from other streams in the Turnagain Arm area. In a report on the Kenai Peninsula, Martin and others (1915) described the general features of the Girdwood district and individual prospects. Capps (1916) included a comprehensive report on the Girdwood area in a general report on the Turnagain Arm–Knik region. He described what is now known as the McHugh Complex (unit Mzm, fig. 2) but did not name the unit. He observed that the rocks that comprise the McHugh Complex, as now defined, unconformably overlie the rocks that are now called the Valdez Group. Park (1933) studied the Girdwood mining district as part of an investigation of mineral resources near the route of the Alaskan Railroad. He noted that placer mining operated steadily on Crow Creek, whereas gold production from quartz veins in Girdwood was negligible. Although the ore was high grade, Park (1933) did not think that the host rocks were favorable for developing large, persistent veins. The geological reasons are not known as to why the Girdwood district never supported a high-tonnage mine, only small mines. After World War II, there was only minor lode mining. Hoekzema (1984) reported that Crow Creek was the largest placer-gold-producing stream in south-central Alaska, producing almost 42,500 ounces (1.2 million grams) of gold.

Geologic studies delineated the extent of coal-bearing strata in the Matanuska coal fields, as described following. Martin (1906) did a reconnaissance geologic study of the Matanuska coal field to determine coal resources of the lower Matanuska basin. Interest in coal resources had increased in 1903, when construction of a private railroad from Seward seemed assured. The prospect of nearby transportation made the coal deposits more valuable. Martin (1906) noted that the Matanuska Series of Mendenhall (1900) contained rocks of several ages not just Early Cretaceous. He described rock units without formal formational names and included detailed measurements of many coal beds and analyses of representative samples. Paige and Knopf (1907a, b) provided descriptions of coal beds in the Matanuska Valley. Martin and Katz (1912) were the first geologists to map, in detail, the geology of the lower Matanuska Valley on the north side of the Matanuska River. They recognized principal structural features and stratigraphic units, and they described and sampled many coal beds. Martin and Mertie (1914) studied the geology and occurrences of coal in the upper Matanuska Valley. Chapin (1921) correlated and studied the structure of coal beds of the Matanuska coal field. Capps (1927) visited all the working coal mines in the upper part of the Matanuska Valley. He noted that the area contained abundant coal of high quality but that mining would be a problem because the coal beds are so folded, faulted, and intruded by igneous rocks. Landes (1927) mentioned coal exposures in the northern Chugach Mountains. Waring (1936) examined the Anthracite Ridge area. Barnes and Payne (1956) made a detailed map of the Wishbone Hill coal district. Barnes and Sokol (1959) explored in the subsurface for coal in the western part of the Matanuska Valley near Houston, in the Little Susitna district. Barnes (1962) compiled a geologic map of the lower Matanuska Valley showing the latest and most complete information on the character, distribution, and structure of the coal-bearing Chickaloon Formation and associated rocks of the Matanuska coal field. Conwell and others (1982) discussed some coal districts in the Anchorage quadrangle, including Anthracite Ridge and Wishbone Hill. They examined well logs from dry holes to determine the distribution of coal beds, providing deep subsurface geologic information in the western part of the quadrangle. Merritt (1985) discussed the natural coking coal of the Castle Mountain Mine. He noted that the coal increases in rank from subbituminous and high-volatile bituminous in the lower Matanuska Valley, through medium- and low-volatile bituminous in the central part of the valley, to low-volatile bituminous, semianthracite, and anthracite in the upper (eastern) part of the Matanuska Valley. The degree of deformation is greater in the central and eastern parts of the coal field and igneous intrusions are more abundant.

Chromite has been discussed in several studies. Rose (1966) mapped and described chromite-bearing ultramafic rocks in the Anchorage quadrangle. Clark (1972b) discovered ultramafic rocks at the head of Wolverine Creek and noted layered olivine chromitite. The ultramafic rocks were later formally named the Wolverine Complex by Carden and Decker (1977). Foley and Barker (1985) sampled and described chromite at locations in the informally named Eklutna (ultramafic) complex of Clark and Greenwood (1972) (described by Rose, 1966) and in the Wolverine Complex. Four of the six Eklutna occurrences were considered recoverable, but no chromite has ever been produced from the Eklutna area and old claims were inactive. Wolverine occurrences were not considered recoverable. Newberry (1986) discussed in the most detail occurrences in both the Eklutna complex and the Wolverine Complex.

MacKevett and Holloway (1977), Cobb (1979), and Bottge and Northam (1986) have all provided compilations of known mineral prospects and mines in the Anchorage quadrangle. Cobb (1979) made a comprehensive compilation of locations and references for metallic and nonmetallic mineral occurrences in the quadrangle; the other two reports cover larger areas, including the Anchorage quadrangle.

Recent geologic mapping and topical studies have been done in various parts of the quadrangle. Winkler (1992) produced the most recent geologic compilation of the Anchorage quadrangle: a geologic map and summary geochronology. Earlier maps and studies are summarized following. Grantz (1960) mapped the eastern part of the Anchorage quadrangle and showed the relationship between the larger faults and outcrops of intrusive rocks. Some of the mapping was based on previous work by Capps (1927). Grantz (1964) studied the relatively complete section of Cretaceous strata of the Matanuska Formation (unit Km, fig. 2) (Martin, 1906) in the Nelchina area, where subunits are separated by unconformities and or gaps in the faunal succession. Richter (1967) investigated the Metal Creek placer occurrence, which had previously been reported on by Landes (1927). Barnes (1962) compiled a geologic map of the lower Matanuska Valley based on existing data and additional field checking so as to present, on a modern topographic base, the latest and most complete information on the character, distribution, and structure of the coal-bearing Chickaloon Formation and associated rocks of the Matanuska coal field. Clark and Bartsch (1971a, b), Clark and Yount (1972), and Clark (1972a) carried out reconnaissance geologic mapping at 1:63,360 scale and a stream-sediment and rock geochemical survey in the southeastern part of the Anchorage quadrangle, between the Knik River and Turnagain Arm. Clark (1972b) discovered what she informally called the Wolverine complex (=Wolverine Complex of Carden and Decker, 1977), a layered ultramafic complex near the headwaters of Wolverine Creek. Clark (1973) named the McHugh Complex near Anchorage, designating a type locality and a reference locality. Miller and Dobrovolny (1959) mapped and described surficial geology of the Anchorage area, and Yehle and Schmoll (1987a, b, 1988, 1989) mapped surficial deposits within the Municipality of Anchorage and in the Kenai-Chugach Mountains and the Cook Inlet–Susitna Lowland areas. Csejtey and others (1978) made a reconnaissance geologic map of the northern part of the Anchorage quadrangle and provided rock descriptions, isotopic ages, and tectonic and structural synopses of the region. Pessel and others (1981) and Burns and others (1983) made geologic maps of the northern Chugach Mountains in the eastern part of the quadrangle at a scale of 1:63,360. Burns and others (1991) discussed the geologic history of the Border Ranges fault system and the Peninsular and Chugach terranes (fig. 2). In the northern Chugach Mountains, Henning and Pessel (1980) briefly studied massive pyritic outcrops enriched in gold, silver, copper, and lead (referred to in their report as the Nelchina deposit). The deposit is an extensive iron gossan in ice-polished bedrock near the western edge of the Nelchina Glacier. Newberry (1986) studied 44 mineral prospects in the Peninsular terrane in the north-central Chugach Mountains, most of which are in the Anchorage quadrangle. He concluded that the occurrences are all too small, low in grade, or structurally disrupted to be economic deposits. Nelson and others (1984, 1985) presented an updated geologic map compilation and a mineral resource potential map of the Chugach National Forest, including the southeastern part of the Anchorage quadrangle. They identified potential for gold and other metals within the quadrangle. Jansons and others (1984) summarized metallic mineral occurrences in the southeastern part of the Anchorage quadrangle as part of the U.S. Bureau of Mines summary for the Chugach National Forest. They presented data on mines, prospects, mineral occurrences, and areas of mineralization.

Following the Alaskan earthquake in 1964, Grantz (1966) compiled available published and unpublished USGS field data and proposed some generalizations about strike-slip faults in Alaska. This was an outgrowth of detailed 1:63,360-scale geologic mapping in the Anchorage and Talkeetna Mountains quadrangles. The report includes a discussion of the Castle Mountain fault in the Anchorage quadrangle. Silberman and Grantz (1984) studied volcanic and sedimentary rocks of the Matanuska Valley, determined ages of the volcanic rocks, and concluded that volcanism and major strike-slip movement along the Castle Mountain Fault were both mostly Eocene events.

A series of reports was prepared as part of the Alaska Mineral Resource Assessment Program (AMRAP) that provided information on the geology, geochemistry, geophysics, and known and undiscovered mineral resources of the Anchorage quadrangle (table 1). The reports provide multidisciplinary, up-to-date mineral resource information as possible input for land-use planning and minerals-policy development and as guidance for minerals exploration.

In the mid-1980's, multidisciplinary geophysical investigations of the deep crustal structure of south-central Alaska were conducted along the southern part of the Trans-Alaskan crustal transect (TACT) corridor. Detailed surface geologic studies in the adjacent Valdez quadrangle were carried out in support of the geophysical studies. Many of these studies provide information that is relevant to the geologic and structural setting of the Anchorage quadrangle. The TACT surficial studies include geologic mapping and a variety of structural, geochemical, and isotopic studies near the transect. For example, Plafker and others (1989) and Nokleberg and others (1989) described the lithologic and structural features and the tectonic evolution of the four lithotectonic terranes that make up the adjacent Valdez quadrangle.

GEOLOGIC AND TECTONIC SUMMARY

The Anchorage 1°×3° quadrangle is underlain by three lithotectonic terranes (Silberling and Jones, 1984 (fig. 2)), distinctive fault-bounded assemblages of rock that differ from each other in stratigraphy, age, structural style, and types of mineral and energy resources. The Peninsular terrane underlies the Talkeetna Mountains, Matanuska Valley, and northern Chugach Mountains; the Chugach terrane underlies the rugged crest of the Chugach Mountains; and the Prince William terrane underlies the extreme southeastern part of the quadrangle in Prince William Sound (Burns and others, 1991; Winkler, 1992). The terranes accreted successively to southern Alaska from Middle Jurassic to middle Eocene time (Plafker and others, 1977, 1989; Csejtey and others, 1978; Tysdal and Case, 1979; Burns and others, 1991).

The Peninsular terrane in the Anchorage quadrangle is bounded on its south side by the Border Ranges fault system (Winkler, 1992). The terrane consists of Triassic(?) to Tertiary bedded volcanic and sedimentary rocks, Early Jurassic to Tertiary intrusive rocks, and Paleozoic(?) to Jurassic metamorphic rocks (Csejtey and others, 1978; Pavlis, 1983; Winkler, 1992). Rocks older than mid-Cretaceous are allochthonous; rocks younger than mid-Cretaceous overlap the accretionary assemblages and cover much of the western part of the quadrangle.

South of the Peninsular terrane is the Chugach terrane, which is bounded by the Border Ranges fault system on the north and by the Contact fault system on the south. In the Anchorage quadrangle, the Chugach terrane consists of a landward subduction assemblage of melange and broken formation called the McHugh Complex and seaward trench-fill and trench-slope deposits called the Valdez Group (Plafker and others, 1977; Burns and others, 1991).

Exposures of the Mesozoic McHugh Complex form a discontinuous band along the south side of the Border Ranges fault system within the upper plate of the Eagle River thrust fault. The McHugh Complex contains Carboniferous to mid-Cretaceous blocks of mafic metavolcanic and metaclastic rocks, bedded chert, and minor lenses of limestone and ultramafic rocks in an argillaceous matrix. These blocks were chaotically faulted together, metamorphosed to prehnite-pumpellyite facies, and accreted between Middle Jurassic and mid-Cretaceous time (Clark, 1973; Winkler and others, 1981; Plafker and others, 1989; Burns and others, 1991). The McHugh Complex overlies the Valdez Group along the Eagle River thrust fault.

The Upper Cretaceous Valdez Group consists of metamorphosed, rhythmically interbedded graywacke, siltstone, and argillite, minor pebble conglomerate, and very minor mafic tuff. The sedimentary rocks are interpreted as representing trench-fill and trench-slope deposits (Nilsen and Zuffa, 1982). The stratigraphic thickness of the metamorphosed and deformed Valdez Group is unknown in the Chugach Mountains. To the southeast, on Sanak, Shumagin, Afognak, and Kodiak Islands, correlative strata have been estimated to be 3–5 km thick (Moore, 1973; Nilsen and Moore, 1979). The age of the Valdez Group is Campanian(?) and Maastrichtian (Jones and Clark, 1973). The Valdez Group was accreted between latest Cretaceous and early Paleocene time. A thermal event comprising widespread intrusion of felsic plutons and regional metamorphism culminated in early middle Eocene time (48–52 Ma) (Hudson and Plafker, 1982; Sisson and Hollister, 1988; Plafker and others, 1989; Burns and others, 1991).

Southeast of the Valdez Group is the Paleocene and Eocene Orca Group of the Prince William terrane, which consists of 6–10 km of interbedded graywacke, siltstone, shale, conglomerate, and minor greenstone that lithologically resemble rocks of the Valdez Group (Nelson and others, 1985; Dumoulin, 1987). The Chugach and Prince William terranes are separated by the Contact fault, a northward-dipping thrust. Between Columbia Glacier and Unakwik Inlet, the Valdez and Orca Groups are intruded by mafic to felsic plutons of Eocene and Oligocene age (Nelson and others, 1985) that are significant in terms of mineral resources. The mafic Miners Bay pluton, host for base- and strategic-metal concentrations, contains disseminated pyrrhotite, pentlandite, pyrite, and (or) chalcopyrite, generally in small quartz veins or quartz breccia. The more felsic plutons contain fluorite, sphalerite, galena, and chalcopyrite (Nelson and others, 1984).

The Cook Inlet region includes the western part of the Anchorage quadrangle. Kirschner and Lyon (1973) discussed the stratigraphy and tectonics of the region. The inlet is underlain by more than 12,000 m of Mesozoic rocks and as much as 9,000 m of Tertiary estuarine and nonmarine rocks recording three Mesozoic cycles of marine sedimentation and two Tertiary cycles of estuarine and nonmarine sedimentation. Cycles of deposition were interrupted by times of orogeny and corresponding shifts in the depositional center of the proto– Cook Inlet basin. The Tertiary strata contain most of the coal deposits in the Anchorage quadrangle and are reservoirs for most of the oil and gas produced in southern Alaska.

SUMMARY OF GEOCHEMICAL DATA

The geochemical data base for the Anchorage quadrangle includes chemical analyses from a number of sources. Clark and Bartsch (1971a, b), Clark and Yount (1972), and Clark and others (1976) collected rock and stream-sediment geochemical samples while mapping bedrock geology in the southwestern part of the Anchorage quadrangle. Zinkl and others (1981) published the results of a National Uranium Resource Evaluation (NURE) hydrogeochemical survey of the Anchorage quadrangle, including geochemical data from 520 stream-sediment samples and 341 lake-sediment samples. Goldfarb and others (1984), Goldfarb and Tripp (1985), Goldfarb and others (1985), Goldfarb and Smith (1987), and Tripp and others (1985) published the results of a geochemical and mineralogical survey of the Chugach National Forest, including the southeastern part of the Anchorage quadrangle. They generated a large geochemical data base from stream-sediment, heavy-mineral-concentrate, and rock samples and delineated areas characterized by anomalous concentrations of selected elements and by occurrences of ore-related minerals in nonmagnetic heavy-mineral-concentrate samples. In the Anchorage quadrangle, Goldfarb and Smith (1987) delineated areas of anomalous iron-cobalt-copper-nickel to the northeast of Coghill Lake and southeast of Harriman Fjord. They identified areas of anomalous zinc and microscopically visible sphalerite in heavy-mineral-concentrate samples northwest of Twentymile Glacier and found anomalous amounts of gold within samples from the Valdez Group north of Harriman Fjord.

Geochemical studies were done in support of the Alaska Mineral Resource Assessment Program (AMRAP) between 1982 and 1985. The USGS collected 1,297 samples of stream sediment and panned 1,168 heavy-mineral-concentrate samples to supplement existing data for a regional geochemical and mineralogical study of the Anchorage quadrangle. Arbogast and others (1987) and Madden and others (1988) generated a geochemical data base of analyses from stream sediment, heavy-mineral-concentrate, and rock samples in the Anchorage quadrangle. Madden and Tripp (1987a, b), Madden (1991a, b), and Tripp and Madden (1991) delineated areas characterized by anomalous concentrations of selected elements and occurrences of ore-related minerals in stream-sediment samples.

The published multielement geochemical maps and mineralogical map of the Anchorage quadrangle show the locations of samples enriched in selected elements (Au, Ag, As, Zn, Cu, Pb, Bi, Sb, Ni, Cr, Cd, Mo, W, and Sn) and ore-related heavy minerals (gold, arsenopyrite, sphalerite, chalcopyrite, galena, cinnabar, cassiterite, and scheelite) (Madden, 1991a, b; Tripp and Madden, 1991; Madden-McGuire and Tripp, in press). Areas outlined on the geochemical maps generally encompass all likely source areas for the metal-enriched samples. The area boundaries generally correspond to ridge tops separating drainage basins, as do most of the boundaries of the mineral resource-potential areas outlined in the mineral resource assessment. The geochemical data from the various sources served as the basis for delineating and assigning a mineral resource potential to many areas (Madden-McGuire and Winkler, in press).

In summary, heavy-mineral-concentrate samples collected in the Willow Creek and Girdwood gold-mining districts were enriched in gold, silver, arsenic, tungsten, and lead, and stream-sediment samples were enriched in arsenic, silver, and lead. Heavy-mineral-concentrate samples from placer-gold-bearing streams in and near known placer districts (Boulder Creek, Chickaloon River, Alfred Creek, Metal Creek, Grasshopper Valley) were enriched in gold and silver, and stream-sediment samples commonly were enriched in arsenic. Sediment derived from the Wolverine Complex and Eklutna complex was enriched in chromium, nickel, copper and other metals. Additional areas enriched in gold and (or) base metals in nonmagnetic heavy-mineral-concentrate samples and stream-sediment samples are delineated on the published geochemical maps (Madden, 1991a, b).

GEOPHYSICAL INVESTIGATIONS

Aeromagnetic data were collected and aeromagnetic lines were compiled across Cook Inlet in 1954 and 1958 to evaluate the areal extent, structure, and thickness of Mesozoic and Tertiary coal and petroleum-bearing strata in an area covered by water and extensive glacial and alluvial deposits. From these data, Grantz and others (1963) recognized and named the Knik Arm anomaly, which underlies the southeast side of Cook Inlet in the Anchorage quadrangle. Grantz and others suggested that the anomaly was due to unexposed plutonic rocks. Decker and Karl (1977) compiled aeromagnetic data for eastern southern Alaska at a scale of 1:1,000,000. The compilation included the areas of the Talkeetna Mountains quadrangle and the northern part of the Anchorage quadrangle. The map by Decker and Karl (1977) clearly shows the location of the Knik Arm aeromagnetic anomaly. The State of Alaska made an aeromagnetic survey of the northern Anchorage quadrangle in 1972; at the same time, an aeromagnetic survey was flown in the southern part of the quadrangle for the mineral resource study of the Chugach National Forest. Barnes (1991) and Barnes and Morin (1990) compiled gravity and aeromagnetic data for the Chugach National Forest, including the southeastern part of the Anchorage quadrangle.

Burns and others (in press) compiled and interpreted an aeromagnetic map for the Anchorage quadrangle from three separate aeromagnetic surveys. The three surveys were flown over the Anchorage quadrangle at a barometric elevation of about 300 m above ground level (L.E. Burns, written commun., 1991). The data were corrected for the regional magnetic field before being contoured and interpreted. Burns and others related the geophysical anomalies to the main rock units causing the anomalies. The magnetic susceptibilities of various units in the adjacent Valdez quadrangle, to the east, were previously determined and reported in Burns (1982) and Case and others (1985). Because these rock units are continuous into the Anchorage quadrangle, their magnetic susceptibilities were not remeasured. Interpretations of aeromagnetic data in the western part of the Anchorage quadrangle were based in part on Grantz and others (1963), Csejtey and Griscom (1978), and Case and others (1979, 1985).

A discontinuous belt of ultramafic and mafic plutonic rocks of Jurassic age in the northern Chugach Mountains is exposed across the Anchorage quadrangle (Burns, 1985). The belt includes the informally named Eklutna (ultramafic) complex of Clark and Greenwood (1972), the Wolverine Complex of Carden and Decker (1977) and Clark (1972b), and the Nelchina River Gabbronorite (unit Jg, fig. 2) (Burns, 1985; L.E. Burns, written commun., 1988; Burns and others, 1991). Positive aeromagnetic anomalies suggest that large bodies of gabbroic and ultramafic rocks underlie the northern Chugach Mountains and Cook Inlet in the area between the Border Ranges and Castle Mountain–Caribou faults (L.E. Burns, written commun., 1991). The positive anomalies follow the oroclinal bend of the northern Chugach Mountains. The anomalies are about 1,000 gammas near the Border Ranges fault, due to the presence of ultramafic rocks or very sheared gabbro along the fault, and about 1,500 gammas to the north and northwest of the fault, possibly due to subsurface gabbro. An anomalous area at the head of Knik Arm (Duck Flats), measuring 1,348 gammas, is probably underlain by gabbroic rocks. Aeromagnetic and gravity modeling by Burns (written commun., 1991) suggests that the upper surface of the gabbroic rocks dips to the north and northwest at a shallow angle.

Mafic rocks of the Nelchina River Gabbronorite (unit Jg, fig. 2) create the greatest magnetic (L.E. Burns, written commun., 1991) and gravity (D.F. Barnes, written commun., 1990) anomalies in the quadrangle; their magnetic susceptibilities are as much as an order of magnitude higher than those of the ultramafic rocks (Case and others, 1985), with some overlap between various rock types. Some of the gabbroic rocks, particularly in the eastern part of the Anchorage quadrangle, contain 5–15 percent modal magnetite (L.E. Burns, written commun., 1988).

A magnetic anomaly near the Eklutna (ultramafic) complex extends along strike beneath the Knik River for a distance of 7 km northeast of the exposed body. The source for this anomaly is probably ultramafic rock at shallow depth, concealed by a thin cover of gravel of the Knik River. This anomaly suggests that there are additional areas of low potential for subsurface chromite beneath the surficial deposits.

Additional observations and conclusions of Burns and others (in press) include the following: (1) the Peninsular terrane has an aeromagnetic signature very different from that of the Chugach and Prince William terranes; (2) the signature of the Chugach and Prince William terranes suggests a relatively deep magnetic basement covered by a thick sequence of nonmagnetic rocks; (3) the largest positive aeromagnetic anomaly in the quadrangle was formed by the gabbroic and ultramafic rocks of the Peninsular terrane, near the Border Ranges fault; (4) many of the plutons in the Talkeetna Mountains can be distinguished from each other by distinctive aeromagnetic signatures, particularly positive anomalies associated with the gold-bearing pluton (unit Kw, fig. 2)in the Willow Creek mining district; and (5) small plugs of Tertiary age can be identified on the aeromagnetic map even though they are not exposed.

MINERAL RESOURCE POTENTIAL MAPS

Mineral resource potential maps for the Anchorage quadrangle show areas that contain known and potential resources (Madden-McGuire and Winkler, in press). The quadrangle contains significant resources of gold, coal, and chromium, as well as possibly significant resources of silver and base metals (including copper, lead, and zinc), platinum-group elements, strategic metals (nickel and cobalt), uranium, peat, zeolites, and even glacial ice. Hydrocarbons may be present in Cook Inlet. The mineral resource evaluation was based mostly on recent results of geological, geochemical, and geophysical field and laboratory studies in the southern part of the Talkeetna Mountains, the Matanuska Valley, the Chugach Mountains, and the northwestern part of Prince William Sound. These studies were done to provide mineral resource information as possible input for land-use planning and minerals-policy development, to guide minerals exploration, and to add to the geologic knowledge of the area.

The mineral resource maps and text include discussion and illustration of areas having known and undiscovered gold resources. For example, areas enclosing the Willow Creek and Girdwood mining districts are assigned a high potential for gold-bearing quartz-carbonate veins and for gold in placer deposits, based on known deposits, favorable geologic units, and geochemical anomalies in stream sediments. Areas within the Eklutna (ultramafic) complex and the Wolverine Complex are assigned a moderate potential for podiform chromite, based on known occurrences. Much of the Orca Group in the southeasternmost part of the quadrangle is assigned a moderate potential for base-metal vein and massive sulfide deposits, based on the locations of prospects and the presence of chalcopyrite and sphalerite in stream sediments. Parts of the Matanuska Valley and southern Talkeetna Mountains contain surface and near-surface coal deposits and are assigned high, moderate, and low potentials for coal, based on criteria such as the presence of coal mines, coal outcrops, and favorable geologic units.

REFERENCES CITED

The Alaska Geographic Society, 1983, Anchorage and the Cook Inlet Basin: Alaska Geographic, v. 10, no. 2, 168 p.

Arbogast, B.F., Madden, D.J., Hoffman, J.D., and O'Leary, R.M., 1987, Analytical results and sample locality map of stream-sediment, moraine-sediment, and heavy-mineral-concentrate samples from the Anchorage quadrangle, south-central Alaska: U.S. Geological Survey Open-File Report 87–151, 175 p., scale 1:250,000.

Barnes, D.F., 1991, Map showing geologic interpretation of aeromagnetic data for the Chugach National Forest, Alaska: U.S. Geological Survey Map Miscellaneous Field Studies MF–1645–H, scale 1:250,000.

Barnes, D.F., and Morin, R.L., 1990, Gravity contour map and interpretation of gravity data for the Chugach National Forest, Alaska: U.S. Geological Survey Map Miscellaneous Field Studies MF–1645–F, scale 1:125,000.

Barnes, F.F., 1962, Geologic map of lower Matanuska Valley, Alaska: U.S. Geological Survey Miscellaneous Field Investigations Map I–359, scale 1:63,360.

Barnes, F.F., and Payne, T.G., 1956, The Wishbone Hill district, Matanuska coal field, Alaska: U.S. Geological Survey Bulletin 1016, 88 p.

Barnes, F.F., and Sokol, Daniel, 1959, Geology and coal resources of the Little Susitna district, Matanuska coal field, Alaska: U.S. Geological Survey Bulletin 1058–D, p. 121–138.

Bottge, R.G., and Northam, M.J., 1986, Availability of land for mineral exploration and development in south-central Alaska, 1985: U.S. Bureau of Mines Special Publication, 45 p., scale 1:500,000.

Brooks, A.H., 1925, Alaska's mineral resources and production, 1923: U.S. Geological Survey Bulletin 773, p. 3–52.

Burleigh, R.E., 1987, A stable-isotope, fluid inclusion and ore petrographic study of the gold-quartz veins in the Willow Creek mining district, Alaska: Fairbanks, University of Alaska, M.S. thesis, 246 p.

———1988, Ore mineralogy and petrologic study of the gold-telluride-quartz veins in the Willow Creek mining district, Alaska, *in* Carson, D.J.T., and Vassiliou, A.H., Process mineralogy VIII—Applications of mineralogy to mineral beneficiation technology, metallurgy, and mineral exploration and evaluation, with emphasis on precious metal ores: Warrendale, Penn., The Minerals, Metals, & Materials Society, p. 159–177.

Burns, L.E., 1982, Analysis of gravity and magnetic anomalies over a layered gabbro complex, Chugach Range, Alaska: U.S. Geological Survey Open-File Report 82–460, 96 p.

———1985, The Border Ranges ultramafic and mafic complex south-central Alaska; cumulate fractionates of island arc volcanics: Canadian Journal of Earth Sciences, v. 22, p. 1020–1038.

Burns, L.E., Case, J.E., and Winkler, G.R., in press, Interpretation of the aeromagnetic map of the Anchorage quadrangle: State of Alaska, Department of Natural Resources, Report of Investigations, scale 1:250,000.

Burns, L.E., Little, T.A., Newberry, R.J., Decker, J.E., and Pessel, G.H., 1983, Preliminary geologic map of parts of the Anchorage C–2, C–3, D–2, and D–3 quadrangles, Alaska: State of Alaska, Department of Natural Resources, Report of Investigations 83–10, scale 1:25,000.

Burns, L.E., Pessel, G.H., Little, T.A., Pavlis, T.L., Newberry, R.J., Winkler, G.R., and Decker, John, 1991, Geology of the northern Chugach Mountains, south-central Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 94, 63 p.

Capps, S.R., 1915, The Willow Creek district, Alaska: U.S. Geological Survey Bulletin 607, 86 p.

———1916, The Turnagain-Knik region: U.S. Geological Survey Bulletin 642, p. 147–194.

———1919, Gold lode mining in the Willow Creek district: U.S. Geological Survey Bulletin 692, p. 177–186.

———1927, Geology of the upper Matanuska Valley, Alaska, with a section on the igneous rocks by J.B. Mertie, Jr: U.S. Geological Survey Bulletin 791, 92 p.

Capps, S.R., and Tuck, Ralph, 1935, The Willow Creek–Kashwitna district, Alaska: U.S. Geological Survey Bulletin 864–B, p. 95–113.

Carden, J.R., and Decker, John, 1977, Tectonic significance of the Knik River schist terrane, south-central Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 55, p. 7–9.

Case, J.E., Burns, L.E., and Winkler, G.R., 1985, Maps showing the aeromagnetic survey and geologic interpretation of the Valdez quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1714, scale 1:250,000.

Case, J.E., Tysdal, R.G., Hillhouse, J.W., and Gromme, C.S., 1979, Geologic interpretation of aeromagnetic map, Seward and Blying Sound quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–880–D, scale 1:125,000.

Chapin, Theodore, 1921, Lode developments in the Willow Creek district: U.S. Geological Survey Bulletin 714, p. 201–206.

Clark, A.L., and Greenwood, W.R., 1972, Geochemistry and distribution of platinum-group metals in mafic to ultramafic complexes of southern and southeastern Alaska [abs.]: International Geological Congress, 24th, Proceedings, sec. 10, p. 201.

Clark, S.H.B., 1972a, Reconnaissance bedrock geologic map of the Chugach Mountains near Anchorage, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–350, scale 1:250,000.

———1972b, The Wolverine complex, a newly discovered layered ultramafic body in the western Chugach Mountains, Alaska: U.S. Geological Survey Open-File Report 72–70, 10 p.

———1973, The McHugh Complex of south-central Alaska: U.S. Geological Survey Bulletin 1372–D, 11 p.

Clark, S.H.B., and Bartsch, S.R., 1971a, Reconnaissance geologic map and geochemical analyses of stream-sediment and rock samples of the Anchorage B–6 quadrangle, Alaska: U.S. Geological Survey Open-File Report 71–70, 63 p., 2 sheets, scale 1:63,360.

———1971b, Reconnaissance geologic map and geochemical analyses of stream-sediment and rock samples of the Anchorage B–7 quadrangle, Alaska: U.S. Geological Survey Open-File Report 71–71, 70 p., 2 sheets, scale 1:63,360.

Clark, S.H.B., and Yount, M.E., 1972, Reconnaissance geologic map and geochemical analyses of stream-sediment and rock samples of the Anchorage B–6 quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Investigations Map MF–351, 2 sheets, scale 1:63,360.

Clark, S.H.B., Yount, M.E., and Bartsch, S.R., 1976, Reconnaissance geologic map and geochemical analyses of stream-sediment and rock samples of the Anchorage A–7 and

A–8 quadrangles, Alaska: U.S. Geological Survey Miscellaneous Field Investigations Map MF–765, 2 sheets, scale 1:63,360.

Cobb, E.H., 1979, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Anchorage quadrangle, Alaska: U.S. Geological Survey Open-File Report 79–1095, 183 p.

Cohen, K.K., 1982, Independence Mine and the Willow Creek Mining District: State of Alaska, Department of Natural Resources, Division of Parks, Office of History and Archaeology, 169 p.

Conwell, C.N., Triplehorn, D.M., and Ferrell, V.M., 1982, Coals of the Anchorage quadrangle, Alaska: Alaska Division of Geological and Geophysical Surveys Special Report 17, 8 p.

Csejtey, Bela, Jr., and Evarts, R.G., 1979, Serpentinite bodies in the Willow Creek district, southwestern Talkeetna Mountains, Alaska: U.S. Geological Survey Circular 804–B, p. B92–B94.

Csejtey, Bela, Jr., and Griscom, Andrew, 1978, Text to accompany preliminary aeromagnetic interpretive map of the Talkeetna Mountains quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–558–C, 14 p., scale 1:250,000.

Csejtey, Bela, Jr., Nelson, W.H., Jones, D.L., Silberling, N.J., Dean, R.M., Morris, M.S., Lanphere, M.A., Smith, J.G., and Silberman, M.L., 1978, Reconnaissance geologic map and geochronology, Talkeetna Mountains quadrangle, northern part of Anchorage quadrangle, and southwest corner of Healy quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–558–A, 60 p., 1 sheet, scale 1:250,000.

Decker, John, and Karl, Susan, 1977, Preliminary aeromagnetic map of the eastern part of southern Alaska: U.S. Geological Survey Open-File Report 77–169–E, 1:1,000,000.

Dorff, A.C., 1984, Independence mine, *in* Blackford, Michael, Clardy, B.I., Dorff, A.C., and Visconty, Greg, eds., Guide to the Willow Creek gold mining district, with stops at the Castle Mountain fault and the Alaska Tsunami Warning Center: Anchorage, Alaska, Geological Society of America and Alaska Geological Society, 24 p.

Dumoulin, J.A., 1987, Sandstone composition of the Valdez and Orca Groups, Prince William Sound, Alaska: U.S. Geological Survey Bulletin 1774, 37 p.

Foley, J.Y., and Barker, J.C., 1985, Chromite deposits along the Border Ranges fault, southern Alaska—Part 1, Field investigations and descriptions of chromite deposits: U.S. Bureau of Mines Information Circular 8990, 58 p.

Goldfarb, R.J., Leach, D.L., Miller, M.L., and Pickthorn, W.J., 1986, Geology, metamorphic setting, and genetic constraints of epigenetic lode-gold mineralization within the Cretaceous Valdez Group, south-central Alaska, *in* Keppie, J.D., Boyle, R.W., and Haynes, S.J., eds., Turbidite-hosted gold deposits: Geological Association of Canada Special Paper 32, p. 87–105.

Goldfarb, R.J., Nelson, S.W., Dumoulin, J.A., and Miller, M.L., 1984, Data report and statistical summary for samples of moraine and stream sediment, nonmagnetic heavy-mineral concentrate, and rocks from the Chugach National Forest, Alaska: U.S. Geological Survey Open-File Report 84–355, 446 p., scale 1:250,000.

Goldfarb, R.J., and Smith, S.C., 1987, Geochemical map showing distribution of the anomalous element suites in nonmagnetic heavy-mineral concentrates from the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–G, scale 1:250,000.

Goldfarb, R.J., and Tripp, R.B., 1985, Geochemical map showing distribution of chalcopyrite within the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–E, scale 1:250,000.

Goldfarb, R.J., Tripp, R.B., and Smaglik, S.M., 1985, Geochemical map showing distribution of barite, galena, and sphalerite within the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–C, scale 1:250,000.

Gould, G.J., Karpas, R.M., and Slitor, D.L., 1990, Alaska update—September 1988–January 1990—Outer continental shelf oil and gas activities: U.S. Department of the Interior, Minerals Management Service, OCS Information Report MMS 90–0012, p. 46–47.

———1991, OCS Compendium—Outer continental shelf oil and gas information through October 1990: U.S. Department of the Interior, Minerals Management Service, OCS Information Report MMS 91–1132, p. 12–13.

Grantz, Arthur, 1960, Generalized geologic map of the Nelchina area, Alaska, showing igneous rocks and larger faults: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–312, scale 1:96,000.

———1964, Stratigraphic reconnaissance of the Matanuska Formation in the Matanuska Valley, Alaska: U.S. Geological Survey Bulletin 1181–I, 27 p.

———1966, Strike-slip faults in Alaska: U.S. Geological Survey Open-File Report 267, 82 p., scale 1:96,000.

Grantz, Arthur, and Eberlein, G.D., 1966, Anomalous Au and Cu at Sheep Mountain, Alaska: Unpublished U.S. Geological Survey, Branch of Alaskan Geology, Report to the Director, 2 p.

Grantz, Arthur, Zietz, Isidore, and Andreasen, G.E., 1963, An aeromagnetic reconnaissance of the Cook inlet area, Alaska: U.S. Geological Survey Professional Paper 316–G, p. 117–134.

Henning, M.W., and Pessel, G.H., 1980, Reconnaissance geology of the Nelchina Glacier gold-silver-copper-lead deposit, north-central Chugach Mountains, Alaska: State of Alaska, Department of Natural Resources Open-File Report 126, 5 p.

Hoekzema, R.B., 1984, Mineral deposits and mining history of the Valdez Group in the Kenai Peninsula area, *in* Winkler, G.R., Miller, M.L., Hoekzema, R.B., and Dumoulin, J.A., Guide to the bedrock geology of a traverse of the Chugach Mountains from Anchorage to Cape Resurrection: Anchorage, Alaska Geological Society, 40 p.

Hollister, V.F., 1978, Geology of the porphyry copper deposits of the western hemisphere: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, 219 p.

Hudson, Travis, and Plafker, George, 1982, Paleogene metamorphism of an accretionary flysch terrane, eastern Gulf of Alaska: Geological Society of America Bulletin, v. 93, p. 1280–1290.

Jansons, Uldis, Hoekzema, R.B., Kurtak, J.M., and Fechner, S.A., 1984, Mineral occurrences in the Chugach National Forest, south-central Alaska: U.S. Bureau of Mines MLA 5–84, 43 p., scale 1:250,000.

Jasper, M.W., 1962, Willow Creek gold district activity, Anchorage quadrangle, *in* Report for the year 1962: Alaska Division of Mines and Minerals, p. 75–84.

———1965, Geochemical investigations of selected areas in south-central Alaska, 1964: Alaska Division of Mines and Minerals Geochemical Report 4, 31 p.

Jones, D.L., and Clark, S.H.B., 1973, Upper Cretaceous (Maestrichtian) fossils from the Kenai-Chugach Mountains, Kodiak, and Shumagin Islands, southern Alaska: U.S. Geological Survey Journal of Research, v. 1, no. 2, p. 125–136.

Katz, F.J., 1911, A reconnaissance of the Willow Creek gold region: U.S. Geological Survey Bulletin 480, p. 139–152.

Kirschner, C.E., and Lyon, C.A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province: American Association of Petroleum Geologists Memoir 19, p. 396–407.

Kurtak, J.M., 1986, Results of 1984 Bureau of Mines site specific field studies within the Willow Creek mining district, Alaska: U.S. Bureau of Mines OFR–17–86, 17 p.

Landes, K.K., 1927, Geology of the Knik-Matanuska district: U.S. Geological Survey Bulletin 792, p. 51–72.

MacKevett, E.M., Jr., and Holloway, C.D., 1977, Table describing metalliferous and selected nonmetalliferous mineral deposits in eastern southern Alaska: U.S. Geological Survey Open-File Report 77–169–A, 99 p., scale 1:1,000,000.

Madden, D.J., 1991a, Geochemical maps showing distribution of anomalously abundant elements in the nonmagnetic, heavy-mineral-concentrate fraction of stream sediment from the Anchorage 1°×3° quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–1977, scale 1:250,000.

———1991b, Geochemical maps showing distributions of anomalous elements in stream-sediment samples from the Anchorage 1°×3° quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–1976, scale 1:250,000.

Madden, D.J., Arbogast, B.F., O'Leary, R.M., Van Trump, George, and Silberman M.L., 1988, Analytical results, statistical analyses, and sample-locality maps of rocks from the Anchorage quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 88–240, 125 p., scales 1:250,000 and 1:24,000.

Madden, D.J., Silberman, M.L., and Moore-Nall, Anita, 1987, Ages and geologic relationships in the Willow Creek gold-mining district, southwestern Talkeetna Mountains, Anchorage quadrangle: U.S. Geological Survey Open-File Report 87–143, 12 p.

Madden, D.J., and Tripp, R.B., 1987a, Geochemical signatures of mineral deposits and rock types as shown in stream sediments from the Peninsular terrane, Anchorage quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 87–129, 8 p.

———1987b, Geochemical signatures of mineral deposits and rock types as shown in stream sediments from the Chugach and Prince William terranes, Anchorage quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 87–131, 8 p.

Madden-McGuire, D.J., Silberman, M.L., and Church, S.E., 1989, Geologic relationships, K-Ar ages, and isotopic data from the Willow Creek gold-mining district, southern Alaska, *in* Keays, R.R., Ramsay, W.H.R., and Groves, D.I., eds., Geology of gold deposits—The perspective in 1988: Economic Geology Monograph 6, p. 242–251.

Madden-McGuire, D.J., and Tripp, R.B., in press, Geochemical map showing the distribution of gold in the Anchorage 1°×3° quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–2227.

Madden-McGuire, D.J., and Winkler, G.R., in press, Mineral resource potential maps of the Anchorage 1 by 3 quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–2393, scale 1:250,000.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossils localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–1019, 3 sheets, scale 1:250,000.

Martin, G.C., 1906, A reconnaissance of the Matanuska coal field, Alaska, in 1905: U.S. Geological Survey Bulletin 289, 36 p., scale 1:360,000.

Martin, G.C., Johnson, B.L., and Grant, U.S., 1915, Geology and mineral resources of Kenai Peninsula, Alaska: U.S. Geological Survey Bulletin 587, 243 p.

Martin, G.C., and Katz, F.J., 1912, Geology and coal fields of the lower Matanuska Valley, Alaska: U.S. Geological Survey Bulletin 500, 98 p.

Martin, G.C., and Mertie, J.B., 1914, Mineral resources of the upper Matanuska and Nelchina valleys: U.S. Geological Survey Bulletin 592, p. 273–299.

Matanuska–Susitna Borough, 1989, Survey of historic sites in the Matanuska coal field, Alaska: Matanuska–Susitna Borough Cultural Resources Division, 213 p.

Mendenhall, W.C., 1900, A reconnaissance from Resurrection Bay to the Tanana River, Alaska, in 1898: U.S. Geological Survey Annual Report 20, pt. 7 p. 265–340.

Merritt, R.D., 1985, Review of coking phenomena in relation to an occurrence of prismatically fractured natural coke from the Castle Mountain mine, Matanuska coal field, Alaska: International Journal of Coal Geology, v. 4, p. 281–298.

Miller, R.D., and Dobrovolny, Ernest, 1959, Surficial geology of Anchorage and vicinity, Alaska: U.S. Geological Survey Bulletin 1093, 128 p.

Mitchell, P.A., 1979, Geology of the Hope-Sunrise (gold) mining district, north-central Kenai Peninsula, Alaska: Palo Alto, Calif., Stanford University, M.S. thesis, 123 p., 2 pls.

Moffitt, F.H., 1905, Gold placers of Turnagain Arm, Cook Inlet: U.S. Geological Survey Bulletin 259, p. 90–99.

———1906, Gold fields of the Turnagain Arm region: U.S. Geological Survey Bulletin 277, p. 7–52.

Moore, J.C., 1973, Cretaceous continental margin sedimentation, southwestern Alaska: Geological Society of America Bulletin, v. 84, p. 595–614.

Nelson, S.W., Dumoulin, J.A., and Miller, M.L., 1985, Geologic map of the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–B, 16 p., 1 sheet, scale 1:250,000.

Nelson, S.W., Miller, M.L., Barnes, D.F., Dumoulin, J.A., Goldfarb, R.J., Koski, R.A., Mull, C.G., Pickthorn, W.J., Jansons, Uldis, Hoekzema, R.B., Kurtak, J.M., and Fechner, S.A., 1984, Mineral resource potential map of the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–A, 24 p., scale 1:250,000.

Newberry, R.J., 1986, Mineral resources of the north-central Chugach Mountains, Alaska: State of Alaska, Department of Natural Resources, Report of Investigations 86–23, 44 p.

Nilsen, T.H., and Moore, G.W., 1979, Reconnaissance study of Upper Cretaceous to Miocene stratigraphic units and sedimentary facies, Kodiak and adjacent islands, Alaska: U.S. Geological Survey Professional Paper 1093, 34 p.

Nilsen, T.H., and Zuffa, G.G., 1982, The Chugach terrane, A Cretaceous trench-fill deposit, southern Alaska, *in* Leggett, J.K., ed., Trench-forearc geology—Sedimentation and tectonics on modern and ancient active plate margins: Geological Society of London Special Publication 10, p. 213–227.

Nokleberg, W.J., Plafker, George, Lull, J.S., Wallace, W.K., and Winkler, G.R., 1989, Structural analyses of the southern Peninsular, southern Wrangellia, and northern Chugach terranes along the Trans-Alaska Crustal Transect, northern Chugach Mountains, Alaska: Journal of Geophysical Research, v. 94, no. B4, p. 4297–4320.

Paige, Sidney, and Knopf, Adolf, 1907a, Reconnaissance in the Matanuska and Talkeetna basins, with notes on the placers of the adjacent region: U.S. Geological Survey Bulletin 314, p. 104–125.

———1907b, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: U.S. Geological Survey Bulletin 327, 71 p.

Park, C.F., Jr., 1933, The Girdwood district, Alaska: U.S. Geological Survey Bulletin 849–G, p. 381–424.

Pavlis, T.L., 1983, Pre-Cretaceous crystalline rocks of the western Chugach Mountains, Alaska—Nature of the basement of the Jurassic Peninsular terrane: Geological Society of America Bulletin, v. 94, p. 1329–1344.

Pessel, G.H., Henning, M.W., and Burns, L.E., 1981, Preliminary geologic map of parts of the Anchorage C–1, C–2, D–1, and D–2 quadrangles, Alaska: Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, Alaska Open-File Report 121, scale 1:63,360.

Plafker, George, Jones, D.L., and Pessagno, E.A., Jr., 1977, A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin, U.S. Geological Survey Circular 751–B, p. B41–B43.

Plafker, George, Nokleberg, W.J., and Lull, J.S., 1989, Bedrock geology and tectonic evolution of the Wrangellia, Peninsular, and Chugach terranes along the Trans-Alaska Crustal Transect in the Chugach Mountains and southern Copper River Basin, Alaska: Journal of Geophysical Research, v. 94, no. B4, p. 4255–4295.

Ray, R.G., 1933, The Willow Creek gold-lode district, Alaska: U.S. Geological Survey Bulletin 849–C, p. 165–229.

———1954, Geology and ore deposits of the Willow Creek mining district, Alaska: U.S. Geological Survey Bulletin 1004, 86 p.

Richter, D.H., 1967, Geological and geochemical investigations in the Metal Creek area, Chugach Mountains, Alaska: State of Alaska, Department of Natural Resources, Division of Mines and Minerals, Geologic Report 25, 17 p., scale 1:63,360.

Rose, A.W., 1966, Geology of chromite-bearing ultramafic rocks near Eklutna, Anchorage quadrangle, Alaska: State of Alaska, Department of Natural Resources, Division of Mines and Minerals, Geologic Report 18, 22 p., scale 1:42,000.

Schneider, J.L., 1989, 1989 Annual report on Alaska's Mineral Resources: U.S. Geological Survey Circular 1040, 70 p.

Seager-Boss, Fran, and Roberts, L. E., 1991, Major coal towns of the Matanuska Valley—A pictorial history: Palmer, Alaska, Matanuska–Susitna Borough, 74 p.

Silberling, N.J., and Jones, D.L., 1984, Lithotectonic terrane maps of the North American Cordillera: U.S. Geological Survey Open-File Report 84–523, 106 p., scale 1:250,000.

Silberman, M.L., Csejtey, Bela, and Connor, C.L., 1979, K-Ar ages of metamorphic rocks, granitic rocks, and hydrothermal alteration-mineralization in the Willow Creek area, southwestern Talkeetna Mountains, Alaska: Geological Society of America Abstracts with Program, v. 11, no. 3, p. 128.

Silberman, M.L., Csejtey, Bela, Jr., Smith, J.G., Lanphere, M.A., and Wilson, F.H., 1978, New potassium-argon data on the age of mineralization and metamorphism in the Willow Creek mining district, southern Talkeetna Mountains, Alaska: U.S. Geological Survey Circular 751–B, p. B65–B69.

Silberman, M.L., and Grantz, A., 1984, Paleogene volcanic rocks of the Matanuska Valley area and the displacement history of the Castle Mountain fault: U.S. Geological Survey Circular 868, p. 82–86.

Silberman, M.L., O'Leary, R.M., Csejtey, Bela, Jr., Smith, J.G., and Connor, C.L., 1978, Geochemical anomalies and isotopic ages in the Willow Creek mining district, southwestern Talkeetna Mountains, Alaska: U.S. Geological Survey Open-File Report 78–233, 32 p.

Singer, D.A., Csejtey, Bela, and Miller, R.J., 1978, Map and discussion of the metalliferous and selected nonmetalliferous mineral resources of the Talkeetna Mountains quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–558–Q, 34 p., scale 1:250,000.

Sisson, V.B., and Hollister, L.S., 1988, Low-pressure facies series metamorphism in an accretionary sedimentary prism, southern Alaska: Geology, v. 16, p. 358–361.

Smith, P.S., 1926, Mineral industry of Alaska in 1924: U.S. Geological Survey Bulletin 783, p. 1–30.

Stoll, W.C., 1944, Relations of structure to mineral deposition at the Independence mine, Alaska: U.S. Geological Survey Bulletin 933–C, p. 201–217.

Swainbank, R.C., Bundtzen, T.K., and Wood, John, 1991, Alaska's mineral industry 1990: Alaska, Division of Geological and Geophysical Surveys, Special Report 45, 78 p.

Thorne, R.L., Muir, N.M., Erickson, A.W., Thomas, B.I., Heide, H.E., and Wright, W.S., 1948, Tungsten deposits in Alaska: U.S. Bureau of Mines Report of Investigations 4174, 22 p.

Tripp, R.B., Goldfarb, R.J., and Pickthorn, W.J., 1985, Geochemical map showing the distribution of gold within the Chugach National Forest, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF–1645–D, scale 1:250,000.

Tripp, R.B., and Madden, D.J., 1991, Mineralogical maps showing the distribution of ore-related minerals in the nonmagnetic, heavy-mineral-concentrate fraction of stream sediment from the Anchorage 1°×3° quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–1975, scale 1:250,000.

Tysdal, R.G., and Case, J.E., 1979, Geologic map of the Seward and Blying Sound quadrangles, Alaska: U.S. Geological

Survey Miscellaneous Investigations Series Map I–1150, 12 p., scale 1:250,000.

Warfield, R.S., 1967, Resume of information on Alaskan bituminous coals with particular emphasis on coking characteristics: U.S. Bureau of Mines Open-File Report 11–67, 20 p.

Warfield, R.S., and Landers, W.S., 1966, Sampling and coking studies of coal from Castle Mountain mine, Matanuska coalfield, Alaska: U.S. Bureau of Mines Open-File Report 7–66, 22 p.

Waring, G.A., 1936, Geology of the Anthracite Ridge coal district, Alaska: U.S. Geological Survey Bulletin 861, 57 p.

Winkler, G.R., 1992, Geologic map and summary geochronology of the Anchorage 1°×3° quadrangle, southern Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I–2283, scale 1:250,000.

Winkler, G.R., Silberman, M.L., Grantz, Arthur, Miller, R.J., and MacKevett, E.M., Jr., 1981, Geologic map and summary geochronology of the Valdez quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 80–892–A, 2 sheets, scale 1:250,000.

Wolfe, J.A., and Tanai, Toshimasa, 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper 1105, 52 p.

Yehle, L.A., and Schmoll, H.R., 1987a, Surficial geologic map of the Anchorage B–7 NW quadrangle, Alaska: U.S. Geological Survey Open-File Report 87–168, 11 p., scale 1:25,000.

———1987b, Surficial geologic map of the Anchorage B–7 NE quadrangle, Alaska: U.S. Geological Survey Open-File Report 87–416, 20 p., scale 1:25,000.

———1988, Surficial geologic map of the Anchorage B–7 SE quadrangle, Alaska: U.S. Geological Survey Open-File Report 88–381, 19 p., scale 1:25,000.

———1989, Surficial geologic map of the Anchorage B–7 SW quadrangle, Alaska: U.S. Geological Survey Open-File Report 89–318, 33 p., scale 1:25,000.

Zinkl, R.J., Shottel, D.L., Langfeldt, S.L., Youngquist, C.A., and D'Andrea, R.F., Jr., 1981, Uranium hydrogeochemical and stream-sediment reconnaissance of the Anchorage NTMS quadrangle, Alaska: U.S. Department of Energy National Uranium Resource Evaluation, GJBX–204 (81), on microfiche.

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