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SUMMARY AND INTERPRETATION OF GEOCHEMICAL MAPS FOR STREAM SEDIMENT AND HEAVY-MINERAL CONCENTRATE SAMPLES, MOUNT HAYES QUADRANGLE, EASTERN ALASKA RANGE, ALASKA

By

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INTRODUCTION

This report and accompanying maps summarize the results of geochemical exploration studies in the Mount Hayes quadrangle, Alaska. This is one of a series of maps and reports on the geological, geochemical, and geophysical studies of the quadrangle prepared as part of the Alaskan Mineral Resource Assessment Program (AMRAP) of the U.S. Geological Survey. These maps are part of the Mount Hayes 1:250,000-scale folio.

The geochemical studies were made in order to identify and define mineralized areas in the quadrangle and to aid in characterizing the nature of the mineral occurrences within these areas. The studies included the collection of composite samples of stream sediment or glacial debris and preparation of these samples, as described by O'Leary and others (1982), to yield a minus-80-mesh (0.2-mm) fraction and nonmagnetic heavy-mineral-concentrate fraction consisting of mineral grains having a specific gravity greater than 2.85. Samples were collected at 911 sites either from tributary streams or tributary glaciers with drainage basins ranging from 1 to 5 sq mi in area. The samples were analyzed for 30 elements by semiquantitative emission spectrography (O'Leary and others, 1982). The stream-sediment and glacial-debris samples also were analyzed for zinc by an atomic absorption method (Ward and others, 1969), and those results were used in preparing map A.

The maps in this report show drainage basins in which the stream sediment or glacial debris contained anomalously high amounts of selected metals. The geologic base map aids in showing the geologic terranes of the quadrangle. The accompanying tables give frequencies and cumulative percents of the selected metals for all major geologic terranes within the quadrangle.

SUMMARY OF BEDROCK GEOLOGY

The Mount Hayes quadrangle covers an area in the eastern part of the Alaska Range. This range is a glacially sculptured arcuate mountain chain extending approximately 1,000 km from the Canadian border in the east to the Aleutian Range in the west and southwest. The quadrangle is bisected by the Denali fault which is a major geologic and geographic boundary between the Yukon River basin in interior Alaska to the north and the Copper River basin in southern Alaska to the south.

The bedrock geology of the Mount Hayes quadrangle is varied and complex, and is subdivided into tectonostratigraphic terranes (fig. 1). The term "tectonostratigraphic terrane" (hereafter referred to as "terrane") is defined as a fault-bounded geologic entity with a distinct geologic history, stratigraphy, structure, and (or) mineral deposits, all differing markedly from those of adjoining terranes (Jones and Silberling, 1979). In the last two decades, the Mount Hayes quadrangle has been the focus of extensive geologic studies listed in Nokleberg and others (in press). A geologic bibliography of the Mount Hayes quadrangle was published by Zehner and others (1980).

NORTH OF DENALI FAULT

Yukon-Tanana terrane

The most extensive group of bedrock units north of the Denali fault is the Yukon-Tanana terrane (Jones and others, 1984) which is subdivided, from north to south, into the Lake George, Macomb, Jarvis Creek Glacier, and Hayes Glacier subterranes (fig. 1) (Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985; Nokleberg and others, 1986). These subterranes are interpreted as various levels of a complex and highly metamorphosed Devonian and Mississippian continental-margin igneous arc (Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985). Because of regional tilting towards the south near the Denali fault, the deeper, granite-rich levels of the arc occur to the north, whereas the shallower, volcanic-rich levels of the arc occur to the south. The Lake George, Macomb, Jarvis Creek Glacier, and Hayes Glacier subterranes were initially defined as separate terranes (Nokleberg and Aleinikoff, 1985); however, they are now defined as subterranes in order to emphasize their genetic relationships as various structural levels of the Yukon-Tanana terrane.

Lake George subterrane.—The Lake George subterrane (fig. 1) (Aleinikoff and Nokleberg, 1985a,b; Nokleberg and Aleinikoff, 1985) occurs in the northeastern part of the quadrangle and is composed of (1) polydeformed, coarse-grained, pelitic muscovite-quartz-biotite-garnet schist derived from quartz-rich to clay-rich shale (**lgs**) of Devonian or older age, and

(2) relatively younger Devonian and Mississippian medium-grained, gneissose granodiorite and diorite (**lgr**), and coarse-grained augen gneiss (**lga**) derived from granite and granodiorite.

Macomb subterrane.—The Macomb subterrane (fig. 1) (Nokleberg and Aleinikoff, 1985) occurs south of the Lake George subterrane in the northeastern part of the quadrangle. The Macomb subterrane is composed of (1) older, polydeformed, medium-grained, pelitic schist, calc-schist, and quartz-feldspar-biotite schist derived from shale, marl, and sandstone (**ms**) of Devonian or older age, and (2) a suite of relatively younger, shallow-level, fine- to medium-grained, gneissose granite, granodiorite, quartz diorite, and diorite (**mg**) of Devonian age.

Jarvis Creek Glacier subterrane.—The Jarvis Creek Glacier subterrane (fig. 1) (Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle, south of the Macomb subterrane. The Jarvis Creek Glacier subterrane consists of fine-grained, polydeformed schist derived from Devonian or older sedimentary and volcanic rock. This unit is subdivided into a metasedimentary rock unit (**jcs**) (rich in fine-grained metasedimentary rocks with minor metavolcanic rocks) and a metavolcanic rock unit (**jcv**) (rich in fine-grained metavolcanic rocks with moderate amounts of fine-grained metasedimentary rocks). The metasedimentary rocks consist of pelitic schist, quartzite, calc-schist, quartz-feldspar schist, and marble. The metavolcanic rocks consist of varying proportions of abundant meta-andesite and metaquartz-keratophyre, less abundant metadacite and metabasalt, and sparse metarhyodacite. In the north-central part of the quadrangle at Donnelly Dome, the Jarvis Creek Glacier subterrane is intruded by intensely deformed and schistose Devonian metagranodiorite and sparse augen gneiss derived from granite and granodiorite (**jcg**).

Hayes Glacier subterrane.—The Hayes Glacier subterrane (fig. 1) (Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle, south of the Jarvis Creek Glacier subterrane. The Hayes Glacier subterrane consists of polydeformed phyllite and blastomylonite, derived from Devonian or older sedimentary and volcanic rocks, that are subdivided into a metasedimentary rocks unit with sparse metavolcanic rocks (**hgs**) and a metavolcanic rocks unit with moderate amounts of metasedimentary rocks (**hgv**). The metasedimentary rocks unit in the eastern part of the quadrangle consists of pelitic phyllite, quartz-rich phyllite, quartz-feldspar phyllite, and minor calc-phyllite and marble derived from shale, chert, or less likely, quartz siltstone, volcanic graywacke, marl, and limestone. In the western part of the quadrangle, the metasedimentary rocks unit consists predominantly of polydeformed black to dark-gray pelitic schist, quartz-mica schist, and lesser quartzite and calc-schist derived from shale, quartz siltstone and sandstone, and marble. The metavolcanic rocks consist of meta-andesite and metaquartz-keratophyre, and sparse metadacite and metabasalt.

Metamorphism.—The metasedimentary, metavolcanic, and meta-igneous rocks of the Yukon-Tanana terrane are generally ductiley deformed and regionally metamorphosed. Metamorphic grade ranges from middle or upper amphibolite facies in the deeper-level Lake George subterrane, to lowest greenschist facies in the shallowest-level Hayes Glacier subterrane (Nokleberg and others, 1986). Medium-grained mylonitic schist and gneiss, in the deeper levels, grade upward into blastomylonite and phyllonite at shallow levels. Local extensive Cretaceous retrogression to the lower greenschist facies occurs in the shallow-level subterranes, particularly in the Jarvis Creek Glacier subterrane.

Cretaceous and early Tertiary plutonic rocks.—A variety of widely distributed Cretaceous and early Tertiary plutonic rocks intrudes the Yukon-Tanana terrane (fig. 1). Most common are granitic plutons (**gr**) of mid-Cretaceous to early Tertiary diorite, quartz diorite, granodiorite, and granite. Granodiorite and granite constitute most of the granitic plutons. Small areas of some plutons are extensively hydrothermally altered, and are locally slightly to moderately schistose and weakly metamorphosed at lower greenschist facies. In the central part of the Jarvis Creek Glacier subterrane is an intrusive complex of early Tertiary monzonite (**m**), alkali gabbro and lamprophyre (**la**), and quartz diorite (**gr**), all partly surrounded by a ring dike of granite. Local comagmatic lamprophyre dikes also occur in the eastern part of the Jarvis Creek Glacier subterrane. The Hayes Glacier subterrane also contains sparse, early Tertiary, nonschistose lamprophyre dikes, and one small alkali gabbro pluton. Locally abundant Cretaceous(?) gabbro, diabase, and metagabbro dikes and sills occur in the Jarvis Creek Glacier and Hayes Glacier subterranes.

Aurora Peak terrane

The Aurora Peak terrane (fig. 1) (Aleinikoff, 1984; Nokleberg and others, 1985) occurs north of the Denali fault in the western part of the quadrangle, and consists of (1) fine- to medium-grained and polydeformed calc-schist, marble, quartzite, pelitic schist (**as**) of Silurian to Triassic age, and (2) lesser amounts of regionally metamorphosed and deformed Late Cretaceous plutonic rock (**ag**) consisting of schistose quartz diorite, granodiorite, granite, and sparse amphibolite derived from gabbro and diorite. The Aurora Peak terrane exhibits an older, upper-amphibolite-facies metamorphism associated with mylonitic schist, and a younger, middle-greenschist-facies metamorphism associated with blastomylonite (Nokleberg and others, 1985). The Aurora Peak terrane is intruded by weakly to nonmetamorphosed Late Cretaceous to early Tertiary gabbro plutons and dikes (**gb**), and granodiorite and granite plutons (**gr**).

Windy terrane

The Windy terrane (fig. 1) (Jones and others, 1984; Nokleberg and others, 1985) occurs between the Aurora Peak and Maclaren terranes along the Denali fault and consists of Silurian(?) and Devonian argillite, limestone, marl, quartz-pebble siltstone, quartz sandstone, graywacke, conglomerate, and lesser andesite and dacite (**was**). The Windy terrane locally contains sparse phyllonite and protomylonite in narrow shear zones and exhibits incipient greenschist-facies metamorphism. The Windy terrane is intruded in the central part of the quadrangle by a fault-bounded Late Cretaceous pluton of locally slightly schistose diorite to granite. The Windy terrane also is intruded by dikes of Cretaceous(?) metagabbro and diabase (**gb**).

SOUTH OF DENALI FAULT

Maclaren terrane

East Susitna batholith.—The East Susitna batholith (fig. 1) occurs in the western part of the quadrangle and consists predominantly of regionally metamorphosed mid-Cretaceous to early Tertiary gneissose diorite and granodiorite and lesser granite (**gg**). The batholith forms the northern part of the Maclaren terrane (Nokleberg and others, 1982, 1985; Jones and others, 1984). Locally, the gneissose granitic rocks grade into migmatite (**mig**) and migmatitic schist (**mgsh**), and intrude coarse-grained schist and amphibolite (**sq**) derived from gabbro and diorite. Small roof pendants of calc-schist, quartzite, and amphibolite occur in the batholith near the western edge of the quadrangle. The East Susitna batholith is ductiley deformed into mylonitic gneiss and schist and is regionally metamorphosed at the upper amphibolite facies with local retrograde metamorphism to lower greenschist facies (Nokleberg and others, 1985). A pluton of younger, nonschistose, middle Tertiary granite (**gr**) intrudes the northwest part of the East Susitna batholith immediately south of the Denali fault.

Maclaren Glacier metamorphic belt.—The Maclaren Glacier metamorphic belt (**mmb**) occurs south of the East Susitna batholith and is a prograde Barrovian-type metamorphic belt formed in metasedimentary and metavolcanic rocks. From south to north, the principal units are pre-Late Jurassic argillite and metagraywacke, phyllite, and schist and amphibolite (fig. 1) (Nokleberg and others, 1982, 1985). Contacts between the three rock units are generally faults with intense shearing and abrupt changes of metamorphic facies at each contact.

The Maclaren Glacier metamorphic belt is ductiley deformed into protomylonite and phyllonite in the argillite and metagraywacke unit, phyllonite in the phyllite unit, and mylonitic schist in the schist and amphibolite unit. Metamorphic grade increases from south to north; lower-greenschist-facies metamorphism occurs in the argillite and metagraywacke unit whereas lower- or middle-amphibolite-facies metamorphism occurs in the schist and amphibolite unit (Nokleberg and others, 1985). A small pluton of hydrothermally altered biotite granite (**gr**) intrudes the argillite and metagraywacke unit.

Clearwater terrane

The Clearwater terrane (Nokleberg and others, 1982, 1985; Jones and others, 1984) occurs in the western part of the quadrangle in a narrow, fault-bounded lens (fig. 1). The Clearwater terrane consists of chlorite and muscovite schist, schistose rhyodacite, Upper Triassic marble, and greenstone derived from pillow basalt (**csv**). The Clearwater terrane is weakly deformed and metamorphosed at greenschist facies and is intruded by a fault-bounded pluton of weakly schistose diorite and quartz diorite.

Wrangellia terrane

The Wrangellia terrane occurs across the southern part of the quadrangle and is subdivided into the Slana River subterrane to the north and the Tangle subterrane to the south (fig. 1) (Nokleberg and others, 1982, 1985; Jones and others, 1984). The Wrangellia terrane is weakly regionally metamorphosed at lower greenschist facies (Nokleberg and others, 1985). Metamorphic minerals are generally sparse, but relict minerals are abundant in most rocks. The Wrangellia terrane is locally intruded by weakly deformed to nonschistose, small- to moderate-size granodiorite and granite plutons of Late Jurassic(?) and Cretaceous age. Some granitic plutons are weakly to extensively hydrothermally altered.

Slana River subterrane.—The Slana River subterrane consists of upper Paleozoic island-arc volcanic, volcaniclastic, and sedimentary rocks disconformably overlying massive basalt flows of the Upper Triassic Nikolai Greenstone, Upper Jurassic and Lower Cretaceous flysch of the Gravina-Nutzotin belt, and sparse deposits of Tertiary sandstone, conglomerate, and rhyolite to dacite tuff, breccia, and flows (Nokleberg and others, 1982, 1985). The upper Paleozoic island-arc rocks are intruded by Permian hypabyssal dacite stocks, sills, dikes, and granite. Locally extensive Late Triassic(?) gabbro dikes and cumulate mafic and ultramafic sills intrude the Nikolai Greenstone and older rocks.

Tangle subterrane.—Relative to the Slana River subterrane, the Tangle subterrane contains a thinner sequence of upper Paleozoic and Lower Triassic sedimentary and tuffaceous rocks, a thicker sequence of the Nikolai Greenstone (**TRnf** and **TRnp**), and a sparse, thin unit of Upper Triassic marble (**TRl**) (fig. 1) (Nokleberg and others, 1982, 1985). The upper Paleozoic and Lower Triassic rocks consist of aquagene tuff, dark-gray argillite, minor andesite tuff and flows, and sparse limestone. The Nikolai Greenstone is composed of a moderately thick basal member of pillow basalt (**TRnp**), and a thick upper member of massive, subaerial, amygdaloidal flows (**TRnf**). Extensive Late Triassic(?) gabbro and cumulate mafic and ultramafic sills and plutons intrude the Nikolai.

Terrane of ultramafic and associated rocks

A narrow terrane of ultramafic rocks and associated rocks (**um**) occurs in the eastern part of the quadrangle along and south of the Denali fault (fig. 1) (Richter and others, 1977; Nokleberg and others, 1982). The ultramafic rocks are chiefly dark-green serpentinized pyroxenite and peridotite, light-gray to green dunite, and dark-green schistose amphibolite and lighter hornblende-plagioclase gneiss derived from gabbro. Interlayered with the gneiss are rare thin lenses of light-green and gray marble and zones of dark-gray graphitic schist. The ultramafic and mafic rocks are intruded by weakly schistose, light-gray tonalite and granite. The ultramafic and associated rocks are ductiley deformed and regionally metamorphosed.

GEOCHEMICAL METHODS

Stream-sediment and heavy-mineral-concentrate samples were collected at 795 sites on tributary streams with drainage basins ranging from 1 to 5 sq mi in area. In addition, composite samples of glacial debris were collected at 116 sites on tributary glaciers that also had drainage basins ranging from 1 to 5 sq mi in area. The samples of glacial debris were processed to yield a minus-80-mesh fraction and a heavy-mineral concentrate. For this study, analytical data from glacial-debris samples were combined with those from stream-sediment samples because the mineralogy of the samples and frequency distributions of the analytical data for selected elements showed that the two media are chemically similar.

All samples were analyzed for the following 31 elements (O'Leary and others, 1982):

Antimony	Chromium	Manganese	Tin
Arsenic	Cobalt	Molybdenum	Titanium
Barium	Copper	Nickel	Tungsten
Beryllium	Gold	Niobium	Vanadium
Bismuth	Iron	Scandium	Yttrium
Boron	Lanthanum	Silver	Zinc
Cadmium	Lead	Strontium	Zircon
Calcium	Magnesium	Thorium	

The six-step semiquantitative emission spectroscopy method of Grimes and Marranzino (1968) was used. Stream-sediment and glacial-debris samples also were analyzed by an atomic absorption method (Ward and others, 1969). Analyses of the heavy-mineral concentrates reflect the presence or absence of detrital, ore-related mineral grains in the stream sediment and are especially useful for delineating the distribution and abundance of metals in these minerals because the dilution effect of low-density, barren minerals has been removed. In addition, the heavy-mineral concentrates were examined microscopically to determine which minerals contained metals of interest and therefore to better define the ore-related mineral suites. Analyses of the stream-sediment samples reflect the metal content of detrital, ore-related minerals (generally at lower levels than the concentrates because of the dilution effect of the barren, low-density minerals). These analyses also reflect metals that have been scavenged by organic material, clays, and the amorphous iron- and manganese-oxide coatings on sediment grains.

GEOCHEMICAL CHARACTERISTICS

The following fourteen selected metals were the most useful in identifying and defining areas favorable for mineral-resource occurrences in the Mount Hayes quadrangle:

Antimony	Lead
Arsenic	Molybdenum
Bismuth	Nickel
Chromium	Silver
Cobalt	Tin
Copper	Tungsten
Gold	Zinc

Host minerals for some elements (antimony, arsenic, copper, gold, lead, molybdenum, silver, tin, tungsten, and zinc) were most commonly ore or ore-related minerals such as stibnite, arsenopyrite, chalcopyrite or bornite, native gold, galena, molybdenite, tetrahedrite(?), cassiterite, scheelite, and sphalerite, respectively, or their weathering products. Locally abundant chromium, nickel, and cobalt concentrations occur mainly in, or are associated with, chromite and less often olivine and pyroxene. The few high concentrations of bismuth possibly are derived from bismuthinite.

Examination of the geochemical data for the metals showed that individual geologic units such as terranes, subterranes, or granitic plutons have distinctive geochemical characteristics. Consequently, the data were partitioned into twelve subpopulations based on samples collected from each of the major geologic units within the quadrangle. The distinct geochemical characteristics of the units are illustrated in the frequency tables (tables 1-8). Lower but significant metal concentrations in one unit can be masked by higher concentrations from another unit when both are lumped together. Partitioning permits emphasis of significant metal concentrations that otherwise would have been hidden within the background range of the total sample population. Although each geochemical data set is distinctive, there are some similarities among the subpopulations. For example, high concentrations of copper, lead, silver, and zinc occurred in stream-sediment and heavy-mineral-concentrate samples from major geologic map units. A correlation exists between high metal values in heavy-mineral concentrates and high concentrations in corresponding stream-sediment samples, although some anomalous areas are better defined by high metal values in one of the two sample types.

GEOCHEMICAL DISTRIBUTION MAPS

Drainage basins within the major geologic units which contain anomalous concentrations of the selected elements in stream-sediment or heavy-mineral-concentrate samples are depicted by the outlined areas on maps A through F. The drainage basins are defined by topography. On the maps, line patterns in the outlined basins are unique to a specific metal and to the strength of a particular anomaly. The line direction identifies a particular metal and the line weight of the pattern reflects the strength of the anomaly. Outlined but unpatterned areas represent an anomalous concentration of only one of the selected metals, and are not adjacent to other anomalous areas. Anomalously high metal concentrations are further identified by the chemical symbols for the metals. The symbols also are used to rank the anomalous concentrations as follows: (1) the chemical symbol by itself represents the lowest anomalous concentration (designated weakly anomalous) on the frequency tables, (2) the chemical symbol with a single underline represents the middle anomalous concentration (designated moderately anomalous), and (3) the chemical symbol with a double underline represents the highest anomalous concentration (designated strongly anomalous). Anomalous ranks (shown on the tables) were selected within the upper 10 percent (90th percentile and greater) of the metal populations, or as close to that percentage as possible. No anomalous rank was selected for populations in which the range of values was narrow (less than an order of magnitude, for example) and the values were relatively low, indicating that the entire population fell within the "background" range. The rankings were used to define drainage basins with anomalous concentrations of metals as shown in the explanation. To simplify the following discussion, the drainage basins containing anomalous metal concentrations were grouped into clusters, with each cluster enclosed by a dashed line and lettered on the appropriate map. The discussion interprets each cluster with respect to bedrock geology, known mines, and known and hypothetical mineral occurrences.

DISCUSSION OF GENERALLY ANOMALOUS AREAS

The geochemical results, together with geologic and mineral-occurrence data, indicate that there are at least 16 areas in the Mount Hayes quadrangle that are favorable for the existence of at least 14 types of mineral deposits or occurrences (Nokleberg and others, in press). These areas have been identified in all the major geologic units within the quadrangle except the Lake George subterrane. This section summarizes the anomalous areas within the quadrangle from north to south and describes them in detail.

NORTH OF DENALI FAULT

Four areas of plutonic rocks north of the Denali fault are characterized by high concentrations of antimony, bismuth, tin, and tungsten in heavy-mineral concentrates together with high concentrations of base and precious metals. The granite of Molybdenum Ridge in the northwestern part of the quadrangle is characterized by high concentrations of antimony, tin, and tungsten in heavy-mineral concentrates, and locally by copper and lead. Stream-sediment samples contain weakly to moderately anomalous values of copper, lead, molybdenum, silver, and zinc. The mineral sources for these metals in the concentrates are, in part, scattered occurrences of cassiterite, chalcopyrite, molybdenite, powellite, scheelite, and sphalerite (R.B. Tripp and others, unpub. data). These minerals and associated high metal values outline an area of discovered and hypothetical porphyry copper-molybdenum occurrences and copper-lead-zinc skarn and porphyry tin occurrences (R.C. Roback and others, unpub. data).

The granitic rocks of Granite Mountain, in the central part of the quadrangle, yield heavy-mineral concentrates that contain antimony, bismuth, tin, and tungsten as well as copper, lead, and molybdenum. The source minerals for these metals in the concentrates are arsenopyrite, cassiterite, chalcopyrite, galena, gold, molybdenite, monazite, thorite, and scheelite (R.B. Tripp and others, unpub. data). These minerals and associated metals outline an area of inferred porphyry tin and porphyry copper-molybdenum occurrences (R.C. Roback and others, unpub. data).

East of Granite Mountain, between the Johnson and Gerstle Rivers is another area characterized by strongly anomalous concentrations of bismuth, copper, lead, molybdenum, silver, tin, tungsten, and zinc in heavy-mineral concentrates. The source minerals for these high metal values are, in part, chalcopyrite, galena, and locally, arsenopyrite, cassiterite, and sphalerite, all of which are observed in the heavy-mineral concentrates from this area (R.B. Tripp and others, unpub. data). These anomalous occurrences are likely associated with the alkalic gabbro, monzonite, and granite ring dike complex located in this area. Furthermore, the high metal concentrations may reflect an area of inferred porphyry tin occurrences in granitic rocks (R.C. Roback and others, unpub. data).

Farther east, within and in the vicinity of the Berry Creek drainage, strongly anomalous concentrations of copper, lead, molybdenum, tin, and zinc define an area which may contain porphyry tin occurrences and possible skarn occurrences (R.C. Roback and others, unpub. data). High metal concentrations elsewhere on the Macomb Plateau suggest additional areas that are favorable for similar occurrences. Heavy-mineral concentrates from this area contain cassiterite, chalcopyrite, fluorite, galena, gold, and scheelite.

Some notable spatial relationships of high metal concentrations to both known and possible massive-sulfide deposits may be seen in the Jarvis Creek Glacier subterrane of the Yukon-Tanana terrane (Nokleberg and Lange, 1985; R.C. Roback and others, unpub. data). Strongly anomalous concentrations of copper, lead, silver, and zinc occur in heavy-mineral concentrates and sediments from streams draining the metavolcanic rocks unit of the Jarvis Creek Glacier subterrane in the western and southeastern parts of the quadrangle. Heavy-mineral concentrates from the western part of the quadrangle contain arsenopyrite, chalcopyrite, pyrite, and sphalerite. Heavy-mineral concentrates from the southeastern part of the quadrangle contain chalcopyrite, galena, gold, scheelite, and sphalerite. A striking feature of the mineralogy of the heavy-mineral concentrates in the Jarvis Creek Glacier subterrane is the pervasiveness of arsenopyrite, chalcopyrite, galena, pyrite, and sphalerite throughout the subterrane (R.B. Tripp and others, unpub. data). The high metal values in the samples and the abundance of sulfide and related minerals in the heavy-mineral concentrates target known mineral occurrences and help to define areas favorable for inferred massive-sulfide and epithermal precious- and base-metal occurrences (R.C. Roback and others, unpub. data).

SOUTH OF DENALI FAULT

South of the Denali fault, in the western part the quadrangle, heavy- mineral concentrates collected from the East Susitna batholith of the Maclaren terrane yield moderately high concentrations of copper, silver, tin, tungsten, and zinc. These samples also contain abundant amounts of molybdenite, powellite, and scheelite. The high metal values and the abundant ore minerals in the heavy-mineral concentrates aid in defining an area with known or inferred porphyry copper, molybdenum, or tungsten skarn occurrences (Nokleberg and others, in press).

In the Tangle subterrane of the Wrangellia terrane and in the Clearwater terrane in the southwest part of the quadrangle, heavy-mineral concentrates contain strongly anomalous concentrations of bismuth, copper, gold, lead, molybdenum, silver, tungsten, and zinc. Stream-sediment samples also contain anomalous concentrations of all these metals except tungsten and bismuth. Heavy-mineral concentrates from this area contain arsenopyrite, chalcopyrite, cinnabar, gold, and scheelite (R.B. Tripp and others, unpub. data). These minerals and associated high metal values define an area of known and possible inferred precious- and base-metal occurrences (R.C. Roback and others, unpub. data).

Several additional areas in which heavy-mineral concentrates contain moderately to strongly anomalous concentrations of copper, gold, lead, silver, zinc, and locally, molybdenum are defined in the Slana River subterrane in the south-central and southeastern parts of the quadrangle. Stream sediments from these areas also contain weakly to moderately anomalous amounts of copper, lead, and zinc. The source minerals for the high metal values in the concentrates are chalcopyrite, galena, gold, molybdenite, and sphalerite. The high metal concentrations define areas of known or possible inferred occurrences of (1) copper-silver-bearing quartz veins in the Nikolai Greenstone, (2) porphyry copper occurrences in hypabyssal dikes and sills, (3) copper skarn occurrences in marble, (4) Kuroko-type massive-sulfide and disseminated-sulfide occurrences, (5) porphyry copper occurrences in silicified quartz diorite and granodiorite, and (6) placer gold occurrences in units of Tertiary sandstone and conglomerate (Nokleberg and others, in press).

In three areas in the south-central part of the quadrangle, stream-sediment samples (and, in places, the heavy-mineral concentrates) contain moderately anomalous concentrations of chromium, cobalt, and nickel. These anomalous metal values reflect lenses and zones of disseminated chromite in cumulate mafic and ultramafic rocks that are comagmatic with the basalt protolith of the Nikolai Greenstone (Nokleberg and others, 1985).

DISCUSSION OF SPECIFIC AREAS OF METAL ANOMALIES—MAPS A-D

NORTHWESTERN PART OF THE QUADRANGLE

Cluster A on maps A and B, in the northwestern part of the quadrangle, is characterized by weakly anomalous concentrations of copper, molybdenum, and zinc in stream-sediment samples (table 1) and by weakly anomalous concentrations of copper and lead in the heavy-mineral concentrates (table 2). The copper was derived, at least in part, from chalcopyrite which was observed in two heavy-mineral concentrates from this area (R.B. Tripp and others, unpub. data). The area is underlain by the granite and granodiorite plutons of Molybdenum Ridge and Buchanan Creek, and adjacent Devonian or older metasedimentary schists of the Jarvis Creek Glacier subterrane. Sources for the chalcopyrite and these high metal values could be (1) a single area of altered, schistose granodiorite, (2) pyrite in an iron-stained shear zone in granodiorite near a contact with quartz schist, and (3) at Ptarmigan Creek, disseminated molybdenum-bearing quartz veins in shear zones in iron-stained granodiorite (R.C. Roback and others, unpub. data). The anomalous metal values likely reflect minor amounts of base-metal sulfides in these sources and in unknown scattered quartz vein occurrences together with scattered, disseminated base-metal occurrences in the granitic plutons.

High arsenic and silver values in this area occur with the base metals and are shown by cluster A on map C. The stream-sediment samples contain weakly anomalous concentrations of silver (table 4), and the heavy-mineral concentrates contain weakly anomalous concentrations of arsenic and silver. The high arsenic values reflect the presence of arsenopyrite which was observed in two heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The anomalous arsenic and silver values are likely derived from the same mineralized sources as are the base metals detected in this area.

In addition, heavy-mineral samples collected in this area yield high values of antimony, bismuth, tin, and tungsten (cluster A on map D). The samples contain cassiterite and scheelite (R.B. Tripp and others, unpub. data). These minerals, together with bismuthinite, stibnite, and the other sulfide minerals, are present in minor amounts either in quartz veins at the contact between the granitic plutons and the schist or in disseminated occurrences in the granitic rocks (R.C. Roback and others, unpub. data).

Additional anomalous values of copper, lead, molybdenum, and zinc in the northwestern part of the quadrangle are outlined by cluster B on both maps A and B. This area is underlain mainly by Devonian metavolcanic and metasedimentary schists of the Jarvis Creek Glacier and Hayes Glacier subterranes. The stream-sediment samples in this area contain weakly to moderately anomalous concentrations of copper, lead, molybdenum, and zinc (table 1), and the heavy-mineral concentrates contain moderately to strongly anomalous concentrations of copper, lead, and zinc (table 2). The mineral sources for the copper, lead, and zinc are chalcopyrite, galena, and sphalerite which are observed in varying quantities in heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The metal anomalies and the observed parent minerals mainly reflect the Miyoka, Hayes Glacier, Roberts, and McGinnis Glacier Kuroko-type massive-sulfide occurrences and similiar occurrences proximal to these in the metavolcanic rocks unit of the Jarvis Creek Glacier subterrane (Nokleberg and Lange, 1985; R.C. Roback and others, unpub. data). These occurrences consist of chalcopyrite, galena, pyrite, pyrrhotite, and sphalerite in massive layers, 0.2 to 2 m thick and 1 to several meters long, and in disseminations in meta-andesite and metakeratophyre submarine tuffs, flows, and less commonly in adjacent metavolcanic graywackes and pelitic schist.

The stream-sediment samples in this area also have weakly to moderately anomalous concentrations of arsenic and silver (table 4; map C, cluster B) and the heavy-mineral concentrates contain weakly to moderately anomalous concentrations of gold, silver, and arsenic (table 3). Arsenopyrite is common in heavy-mineral concentrates, and gold is contained in one of the samples (R.B. Tripp and others, unpub data). These high metal values, together with the observed gold and arsenopyrite, probably also are derived from Kuroko-type massive-sulfide deposits in this area.

WEST-CENTRAL PART OF THE QUADRANGLE

High arsenic and silver values are outlined by cluster C on map C. This cluster is characterized by weakly to moderately anomalous concentrations of arsenic and silver in both stream-sediment and heavy-mineral-concentrate samples (tables 3 and 4). Arsenopyrite, a common mineral in the heavy-mineral concentrates from this area (R.B. Tripp and others, unpub. data), is the probable source for the high arsenic values in the sediment. Weakly to strongly anomalous concentrations of copper, lead, molybdenum, and zinc also are measured in both stream-sediment and heavy-mineral-concentrate samples from this area (maps A and B). Chalcopyrite occurs with the arsenopyrite in the heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The area is underlain by Cretaceous(?) gabbro, the metasedimentary rocks unit of the Hayes Glacier subterrane, and metasedimentary schists of the Aurora Peak terrane. No mineral deposits or occurrences are known in this area (R.C. Roback and others, unpub. data). The anomalies, however, may reflect small lenses or disseminations of base-metal sulfides in the schists, or disseminated base-metal sulfides in gabbro.

In this same general area, heavy-mineral concentrates contain mainly weakly anomalous concentrations of bismuth, tin, tungsten. The main mineral source for tungsten is probably scheelite which is found in the heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The area of these anomalous values is underlain by Cretaceous(?) gabbro, the metavolcanic and metasedimentary rocks units of the Jarvis Creek Glacier and Hayes Glacier subterranes, metasedimentary schists of the Aurora Peak terrane, and a few small Cretaceous and early Tertiary(?) granitic plutons. These anomalous metal values probably reflect disseminations or lenses of bismuthinite, cassiterite, and scheelite in the granitic plutons or adjacent rocks. The metal anomalies also could be derived from the volcanogenic massive-sulfide occurrences, which are the major known mineral occurrences in this region.

To the east of cluster C on map C, in the central part of the quadrangle, are scattered, weakly anomalous concentrations of arsenic and silver (tables 3 and 4). Scattered, weakly anomalous concentrations of copper, lead, and zinc in both stream-sediment and heavy-mineral-concentrate samples also occur in this area (tables 1 and 2). Arsenopyrite is common, and chalcopyrite, galena, and sphalerite were observed in varying amounts in the heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The bedrock in the area is mainly the Devonian or older metasedimentary rocks unit of the Jarvis Creek Glacier subterrane. The presence of the high metal values and the sulfide minerals in the samples may reflect the occurrence of scattered known and probable small lenses or disseminations of base-metal sulfides, or quartz veins with base-metal sulfides in the metasedimentary schists. Small, scattered quartz veins in schist, and iron-stained schist containing pyrite were observed in this area (R.C. Roback and others, unpub. data).

NORTH-CENTRAL PART OF THE QUADRANGLE

Cluster C on map B, cluster D on map C, and cluster B on map D are associated with the Cretaceous granite and granodiorite pluton of Granite Mountain that intrudes the metasedimentary schists of the Jarvis Creek Glacier subterrane in the north-central part of the quadrangle. The clusters reflect weakly to strongly anomalous values of antimony, arsenic, bismuth, copper, gold, lead, molybdenum, silver, tin, tungsten, and zinc and roughly correlate spatially with each other, either within or in the vicinity of the pluton. These metals reflect the presence of arsenopyrite, cassiterite, chalcopyrite, galena, gold, powellite, and scheelite which were observed in the heavy-mineral concentrates from this area (R.B. Tripp and others, unpub. data). Locally abundant thorium also is present in the heavy-mineral concentrates (O'Leary and others, 1982) together with thorite and monazite; fluorite was observed in one sample near the area (R.B. Tripp and others, unpub. data). Two placer gold workings are known in the area as are occurrences of metasedimentary schist which contain as much as 30 ppm of molybdenum- and galena-bearing quartz stringers. The base metals as well as antimony, arsenic, bismuth, gold, and silver are likely derived from quartz stringers and veins, whereas the tin and tungsten may reflect minor amounts of cassiterite, scheelite, and other tungsten minerals in and along the contact between the granitic pluton and schist.

Gold was detected by chemical analysis in a heavy-mineral concentrate collected about 8 km to the east of cluster D on map C, and was subsequently visibly observed in the sample. The gold anomaly may indicate the existence of an undiscovered placer-gold occurrence in Tertiary sandstone and conglomerate which underlies the area.

Cluster D on map B, cluster E on map C, and cluster C on map D roughly correlate with each other and define weakly to strongly anomalous values of arsenic, bismuth, copper, lead, molybdenum, silver, tin, tungsten, and zinc (tables 2, 4, 5, and 6). The bedrock consists of a Cretaceous or early Tertiary granodiorite pluton; a small, partial ring dike of granite; and early Tertiary monazite and alkalic gabbro, all intruding metasedimentary schists of the Jarvis Creek Glacier subterrane. Arsenopyrite, cassiterite, chalcopyrite, galena, molybdenite, scheelite, and sphalerite were observed in one or more of the heavy-mineral concentrates collected in the area (R.B. Tripp and others, unpub. data). A sample of quartz-epidote garnet schist containing bands of pyrite and 300 ppm of tin was collected from a possible skarn zone (R.C. Roback and others, unpub. data). In addition, samples of granite and rhyolite containing pyrite and 30 ppm of tin were collected in the area (Zehner and others, 1985; R.C. Roback and others, unpub. data). The tin and other high metal values, together with the sulfide and related minerals observed in the heavy-mineral concentrates, probably are derived from mineralized rock found in the area and, possibly because of similar geologic characteristics, from mineralized quartz stringers and veins such as those found near the Granite Mountain pluton.

EAST-CENTRAL PART OF THE QUADRANGLE

Cluster C on map A and cluster E on map B, in the east-central part of the quadrangle, together with an area containing anomalous amounts of lead, molybdenum, and zinc, north of cluster C on map A, are underlain mainly by metamorphosed Devonian granitic plutons and Devonian or older metasedimentary rocks of the Macomb terrane, which have been intruded by Cretaceous(?) and early Tertiary(?) granite plutons. The moderately to strongly anomalous concentrations of copper, lead, molybdenum, and zinc in the stream sediment and heavy-mineral concentrates from this area (tables 1 and 2) most likely reflect the presence of chalcopyrite, galena, molybdenite, and sphalerite, which were observed in varying amounts in the heavy-mineral concentrates (R.B. Tripp and others, unpub. data). Weakly anomalous concentrations of arsenic and silver also were measured in the stream sediments and weakly to strongly anomalous concentrations of arsenic and silver were measured in the heavy-mineral concentrates from this area (tables 3 and 4; map C, cluster F). One heavy-mineral-concentrate sample from this area contains gold and a number of samples contain arsenopyrite (R.B. Tripp and others, unpub. data). Known mineral occurrences in this area are a zone of iron-stained quartz schist (near a schistose granodiorite dike) containing 3.2 parts per million (ppm) of gold, and iron-stained, pyrite-bearing aplite dikes and altered porphyritic granite containing up to 2.8 ppm of gold and 70 ppm of tin (Zehner and others, 1985; R.C. Roback and others, unpub. data). The metal anomalies and minerals probably reflect occurrences of disseminated sulfides in the metamorphosed Devonian granitic rocks or younger Cretaceous and early Tertiary plutons or, possibly, mineralized quartz veins (although none of these were observed).

In addition to the base and precious metals, stream-sediment samples in this area also contain mainly weakly to moderately anomalous concentrations of tin and tungsten, and heavy-mineral concentrates contain weakly to strongly anomalous concentrations of bismuth, tin, and tungsten (tables 5 and 6; map D, cluster D) together with locally abundant thorium (O'Leary and others, 1982). The mineral sources for tin and tungsten are cassiterite and scheelite which are present in the heavy-mineral concentrates in this area (Tripp and others, unpub. data). The anomalies and ore minerals probably reflect inferred occurrences of minor amounts of cassiterite, scheelite, and bismuthinite in veins or disseminated cassiterite, scheelite, and bismuthinite in or near the granitic rocks.

SOUTHEASTERN PART OF THE QUADRANGLE

Cluster D on map A and cluster F on map B, in the southeastern part of the quadrangle, are characterized mainly by weakly to moderately anomalous concentrations of copper, lead, molybdenum, and zinc in both stream sediment and heavy-mineral concentrates (tables 1 and 2). The host minerals for the high metal values are chalcopyrite, galena, and sphalerite which are abundant in the heavy-mineral concentrates from the area (R.B. Tripp and others, unpub. data). The metals and their parent minerals reflect the Kuroko-type massive-sulfide deposits and occurrences in the area, informally named "the Delta district" (Nauman and others, 1980; Nokleberg and Lange, 1985; R.C. Roback and others, unpub. data). The deposits and occurrences are hosted by the metavolcanic rocks unit of the Jarvis Creek Glacier subterrane. Archean-type gold occurrences (Newkirk, 1985) also exist here. The deposits consist of chalcopyrite, galena, pyrite, pyrrhotite, and sphalerite in massive layers and in zones of disseminated sulfides in meta-andesite and metakeratophyre submarine tuffs and flows, and to a lesser degree in adjacent metavolcanic graywackes and pelitic schist (Nokleberg and Lange, 1985; R.C. Roback and others, unpub. data). Similar Kuroko-type massive-sulfide occurrences may exist to the south in the local metavolcanic rocks of the metasedimentary rocks unit of the Hayes Glacier subterrane.

In the Delta district, stream-sediment and heavy-mineral-concentrate samples also contain mainly weakly to moderately anomalous concentrations of arsenic and silver (tables 3 and 4; map C, cluster G). Heavy-mineral concentrates from this area commonly contain arsenopyrite (R.B. Tripp and others, unpub. data). These anomalous metal values and arsenopyrite also reflect the Kuroko-type massive-sulfide deposits in the Delta district and possibly similar but inferred Kuroko-type occurrences in the Hayes Glacier subterrane.

Antimony, bismuth, tin, and tungsten also are present in the Delta district mainly as weakly anomalous concentrations, primarily in heavy-mineral concentrates (tables 5 and 6; map D, cluster E). Scheelite is the only associated parent mineral observed in the heavy-mineral concentrates (R.B. Tripp and others, unpub. data). The high metal values probably reflect the presence of bismuthinite, cassiterite, scheelite, and stibnite as minor constituents of the massive-sulfide deposits and possibly as zones of disseminated minerals in a granodiorite pluton that intrudes the metasedimentary rocks.

SOUTHWESTERN PART OF THE QUADRANGLE

Clusters E and E' on map A, a small area of anomalous lead and zinc values north of cluster E on map A, and clusters G and G' on map B, in the southwestern part of the quadrangle, are underlain by the Cretaceous and middle Tertiary East Susitna batholith and the Maclaren Glacier metamorphic belt of the Maclaren terrane. These anomalous areas are characterized by weakly to moderately anomalous concentrations of copper, lead, or zinc in stream sediments (table 1) and by moderately to strongly anomalous concentrations of copper, lead, molybdenum, and zinc in heavy-mineral concentrates (table 2). The mineral sources for the metals are chalcopyrite, galena, and molybdenite which are present in the heavy-mineral concentrates in varying quantities (R.B. Tripp and others, unpub. data). Likewise, the stream sediments in the area contain anomalous concentrations of silver and the heavy-mineral concentrates contain anomalous concentrations of arsenic, gold, and silver (tables 3 and 4; map C, cluster H). The parent mineral for the arsenic is arsenopyrite which, together with gold, was observed in the heavy-mineral concentrates. The sulfide minerals and gold are probably derived from scattered small mineral occurrences in the area (Zehner and others, 1985; R.C. Roback and others, unpub. data). These include (1) pyrite in meta-igneous rocks and phyllite, containing as much as 0.2 percent zinc and 15 ppm silver, (2) bornite and malachite in fractured meta-andesite with up to 2.4 percent copper and 5 ppm silver, and (3) altered granite and adjacent rocks with pyrite, molybdenite, and chalcopyrite containing up to 0.25 percent molybdenum. Base-metal sulfides may be present in quartz veins, although none were identified in the area.

Cluster F on map D, to the north, and scattered small bismuth anomalies to the east toward the Delta River and south of the Denali fault, also are underlain by the East Susitna batholith. Cluster F mainly defines weakly anomalous concentrations of bismuth, tin, and tungsten in heavy-mineral concentrates (table 5). Scheelite was the only parent mineral observed in the heavy-mineral concentrates in this area (R.B. Tripp and others, unpub. data). The anomalies may reflect minor amounts of disseminated cassiterite, scheelite, or bismuthinite in the granitic rocks, or minor amounts of the metals in veins in the plutons.

Cluster F on map A, and cluster H on map B are adjacent to the anomalous cluster H on map C just discussed, but are in a different geologic setting in the

Tangle subterrane of the Wrangellia terrane and in the Clearwater terrane. These clusters are underlain by four groups of rocks including (1) upper Paleozoic volcanic flows, tuff, and sedimentary rocks, the Upper Triassic Nikolai Greenstone (metabasalt), and small units of Upper Triassic marble in the Tangle subterrane, (2) Mesozoic diorite and quartz diorite plutons intruding the Tangle subterrane, (3) Triassic metabasalt, marble, metarhyodacite, and phyllite of the Clearwater terrane, and (4) a granitic pluton. Weakly to strongly anomalous concentrations of copper, lead, and zinc are defined by the clusters (tables 1 and 2).

Cluster I on map C roughly correlates with clusters F and H on maps A and B and is likely derived from the same bedrock source. This cluster defines weakly to moderately anomalous concentrations of silver in stream sediments (table 4) and weakly to moderately anomalous concentrations of arsenic, gold, and silver in heavy-mineral concentrates (table 2). Particulate gold and cinnabar are common constituents of the heavy-mineral concentrates from this area (R.B. Tripp and others, unpub. data).

These clusters of base- and precious-metal anomalies likely reflect the following known mines, and known or inferred mineral occurrences in the area (Nokleberg and others, 1984; R.C. Roback and others, unpub. data): (1) numerous copper-silver quartz-vein occurrences containing pyrrhotite, bornite, and chalcopyrite, such as the Kathleen-Margaret mine, hosted by the Nikolai Greenstone, (2) iron-stained metarhyolite, containing pyrite, galena, malachite, and sphalerite(?) in the Clearwater terrane, (3) chalcopyrite- and gold-bearing skarn in marble near a diorite pluton in the Tangle subterrane, and (4) pyrite in altered diorite porphyry intruding the Tangle subterrane.

Heavy-mineral concentrates from parts of this area yield weakly to strongly anomalous values of bismuth, tin, and tungsten (table 6; map D, cluster G). These high values were detected in an area underlain by upper Paleozoic sedimentary rocks and tuff, and the Upper Triassic Nikolai Greenstone of the Tangle subterrane, the Triassic marble, phyllite, metarhyodacite, and metabasalt of the Clearwater terrane, and by a small granitic pluton intruding the Clearwater terrane. A number of the heavy-mineral concentrates in the area contain 10 to 20 percent scheelite. These anomalies probably reflect minor amounts of bismuthinite, cassiterite, and scheelite in scattered zones of disseminated minerals in the granitic pluton or these metals may be present as minor constituents of minerals in the copper-silver quartz veins (Nokleberg and others, 1984; R.C. Roback and others, unpub. data).

Cluster I on map A also occurs in the southwestern part of the quadrangle and defines weakly to moderately anomalous concentrations of copper, lead, and zinc (table 1). The area is underlain by upper Paleozoic sedimentary rocks and tuff and the Upper Triassic Nikolai Greenstone of the Tangle subterrane. Heavy-mineral concentrates from the area do not yield base-metal sulfides (R.B. Tripp and others, unpub. data) possibly because of the destructive action of chemical weathering in this area of relatively gentle relief. The anomalies probably reflect small, scattered, known or inferred copper-silver quartz-vein occurrences, hosted in metabasalt of the Nikolai Greenstone, which contain pyrrhotite, bornite, and chalcopyrite (Nokleberg and others, 1984; R.C. Roback and others, unpub. data).

SOUTH-CENTRAL AND SOUTHEASTERN PART OF THE QUADRANGLE

Weakly to moderately anomalous concentrations of copper, lead, zinc, and molybdenum occur in the south-central and southeastern parts of the quadrangle (clusters G and H on map A and clusters I and J on map B). These clusters are underlain by the Slana River subterrane of the Wrangellia terrane which consists of (1) upper Paleozoic volcanic flows, tuff, marble, and sedimentary rocks, the Upper Triassic Nikolai Greenstone and small units of Triassic marble, (2) late Paleozoic hypabyssal andesite and dacite dikes and sills, and (3) Mesozoic granitic plutons. The stream-sediment and heavy-mineral-concentrate samples from this area contain weakly to moderately anomalous concentrations of copper, lead, molybdenum, and zinc (tables 1 and 2) which are derived from chalcopyrite, galena, molybdenite, and sphalerite observed in heavy-mineral concentrates (R.B. Tripp and others, unpub. data). Anomalous amounts of arsenic, gold, and silver also were measured in the heavy-mineral concentrates together with weakly to moderately anomalous concentrations of silver in stream sediments (tables 3 and 4; map C, clusters J, J', and J") in this area and in two isolated anomalous areas to the southeast. Gold was commonly observed in the heavy-mineral concentrates and cinnabar and arsenopyrite were observed in one sample (R.B. Tripp and others, unpub. data). These anomalous metal concentrations and their parent sulfide minerals probably reflect the following known or inferred mineral occurrences (Nokleberg and others, 1984; R.C. Roback and others, unpub. data): (1) numerous copper-silver quartz veins, containing bornite, chalcopyrite, and pyrrhotite hosted by the Nikolai Greenstone, (2) shallow disseminated occurrences of chalcopyrite and pyrite in the hypabyssal dikes and sills and Mesozoic granitic plutons, (3) bornite-, chalcopyrite-, and pyrite-bearing skarns in marble adjacent to late Paleozoic dikes and sills and Mesozoic granitic plutons, (4) massive-sulfide lenses and disseminated sulfides containing mainly chalcopyrite and pyrite, occurring adjacent to diorite and gabbro sills intruding the upper Paleozoic volcanic and sedimentary rocks, (5) porphyry copper occurrences consisting of silicified quartz diorite and granodiorite, locally with quartz veins containing chalcopyrite, galena, magnetite, and pyrite, and (6) placer gold in or near Tertiary sandstone and conglomerate.

A few scattered areas of weakly anomalous concentrations of bismuth, tin, and tungsten occur in heavy-mineral concentrates in the south-central and southeastern parts of the quadrangle (table 6). A few heavy-mineral concentrates from these areas contain scheelite (R.B. Tripp and others, unpub. data). The anomalies probably reflect cassiterite, scheelite, and rare bismuthinite occurring either in sparse, local, known or inferred copper-silver quartz veins or as disseminated minerals in the granitic pluton.

ANOMALOUS CHROMIUM, NICKEL, AND COBALT—MAPS E AND F

Weakly anomalous amounts of chromium, cobalt, and nickel occur in both stream-sediment and heavy-mineral-concentrate samples (tables 7 and 8) throughout most of the quadrangle. These anomalies mainly represent accumulations from disseminated chromite grains in (1) gabbro and diabase dikes and sills, and the larger gabbro plutons in the terranes and subterranes north of the Denali fault, and (2) metabasalt of the Nikolai Greenstone in the Wrangellia terrane south of the Denali fault. A few areas in the Wrangellia terrane contain moderately to highly anomalous concentrations of chromium, cobalt, and nickel.

Cluster A on maps E and F in the south-central part of the quadrangle, are underlain by cumulate ultramafic sills, and gabbro dikes and sills of the Slana River subterrane. The stream-sediment samples in this area contain moderately to strongly anomalous concentrations of chromium, cobalt, and nickel and heavy-mineral concentrates contain weakly anomalous concentrations of chromium, cobalt, and nickel (tables 7 and 8). The cumulate ultramafic rocks and most of the gabbro dikes and sills are comagmatic with the basalt protolith of the Nikolai Greenstone (Nokleberg and others, 1982, 1985). The anomalous chromium, cobalt, and nickel values probably reflect thin lenses of chromite in the ultramafic rocks. Known mineral occurrences in this area consist of chromite in thin, wispy lenses and as disseminations in olivine cumulate (Nokleberg and others, 1984; R.C. Roback and others, unpub. data).

Clusters B and C on maps E and F, also in the south-central part of the quadrangle, are similar to cluster A on maps E and F, just to the north, in that they are underlain by cumulate mafic and ultramafic sills, and sparse gabbro dikes and sills of the Tangle subterrane. Stream-sediment samples in these clusters contain moderately anomalous concentrations of chromium, cobalt, and nickel and heavy-mineral concentrates contain weakly anomalous concentrations of chromium and nickel (tables 7 and 8). The anomalies probably also reflect narrow, thin lenses of chromite in the ultramafic rocks.

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