SUMMARY OF METALLIFEROUS MINERAL RESOURCE ASSESSMENT

This report assesses the metalliferous mineral resources of the Mount Hayes quadrangle based on extensive geologic, geochemical, and geophysical investigations, and on investigations of mineral deposits, prospects, and occurrences. The assessment consists of the following steps: (1) integrating geological, geochemical, and geophysical data to identify favorable geologic environments for undiscovered mineral deposits; (2) developing models for the types of mineral deposits; (3) defining recognition criteria for the types of mineral deposits; and (4) assigning potential, for example, the likelihood for undiscovered mineral deposits, for each type of deposit by area, based on the number and the quality of recognition criteria.

A major result of the assessment is that specific types of mineral deposits are restricted to specific geologic units, such as tectonometamorphic terrane, or younger granitic plutons. In particular, the following areas exhibit high potential for undiscovered mineral deposits: (1) The metavolcanic rock unit of the Jarvis Creek Belt has high potential for porphyry Cu-Mo deposits in the south-central and southeastern parts of the quadrangle; (2) The Slana River terrane of the Wrangellia terrane exhibits high potential for porphyry Cu-Ag deposits in the south-central part of the quadrangle; (3) The Slana River terrane of the Wrangellia terrane exhibits high potential for porphyry Cu-Mo deposits in small granitic plutons (areas K and M, sheet 4) in the south-central part of the quadrangle; (4) The Tanagaha terrane of the southwest part of the quadrangle exhibits high potential for W-Mo and Cu-Zn-Pb skarn deposits adjacent to a small granitic pluton (area L, sheet 4). Areas with moderate or low potential for various undiscovered types of mineral deposits are described in tables 1 to 14 and sheets 1 to 4.

INTRODUCTION

This report and the accompanying maps assess the metalliferous mineral resource potential of the Mount Hayes quadrangle, eastern Alaska Range, Alaska. The assessment is the major result of a five-year study done under the Alaskan Mineral Resource Assessment Program (AMRAP). Field work for the assessment was done during the summers of 1976 through 1982. Laboratory investigations and office synthesis of data started in 1979. This report is one part of a folio on the quadrangle. In adjacent quadrangles, mineral resource assessments have been completed for the Big Delta quadrangle (Monzie and Foster, 1978), the Nabesna quadrangle (Richter and others, 1975), the Talkeetna Mountains quadrangle (Singer and others, 1978), and the Talkeetna quadrangle (Singer and others, 1976).

Nonmetallic commodities in the quadrangle consist of sand and gravel, marbles, and quartzites. Although much of this material is suitable for construction uses, its remoteness from markets would result in high, uncompetitive development and transportation costs. Local granite and decomposed granite are obtained from one or two pits along the Alaska Highway in the northeast part of the quadrangle. The geologic environment in the quadrangle is unfavorable for oil, gas, or geothermal energy. Coal has been sparsely mined from the Jarvis Creek coalfield which has been studied and assessed by Warhafert and Holkox (1955). This mineral resource assessment is based on the following new geologic, geochemical, and geophysical data:

1. Geologic mapping of the quadrangle at scales of 1:63,360 and 1:250,000;
2. Petrographic study of 3,332 thin sections of rock samples;
3. Geologic mapping and sampling of known mineral deposits, prospects, and occurrences (Noldenberg and others, in press), including study of 128 polished thin sections of sulfide and oxide minerals from mineral deposits, prospects, and occurrences;
4. Semiquantitative emission spectrometric analysis for 31 elements and interpretation of 1,976 rock, mineral deposit, prospect, and occurrence samples for 31 elements (Singer and others, 1978);
5. Semiquantitative emission spectrometric analysis for 31 elements and interpretation of 976 stream-sediment, glacial-debris, and heavy-mineral-concentrate samples for elements (O'Leary and others, 1971, 1982; Curtin and others, in press);
6. Identification and interpretation of the distribution of heavy minerals in heavy-mineral-concentrate samples;
7. Examination of 52 panned samples of gravel and sand from, or in the vicinity of known or suspected placer miner deposits (Yeend, 1980, 1981a, b); and

This assessment is for undiscovered mineral resources that might be expected to occur in the quadrangle as of the time of publication. Subsequent new techniques may be developed or new mineral resources may be defined that are not envisioned in this assessment. The term "mineral resource" is defined as a natural concentration of elements in such form that economic extraction is currently or potentially feasible.

ACKNOWLEDGMENTS

We greatly appreciate the excellent published geologic studies for the quadrangle. The geology, mineral deposit, and deposit compilation studies of Rose (1965, 1966a, b,
types of mineral deposits, all occurring markedly from those fault is the Yukon-Tanana terrane (Jones and others, 1987). The tectonostratigraphic terrane in the southern part of the quadrangle, the bedrock geology dominated by the Mesozoic Wrangellia terrane (fig. 1; Jones and others, 1987; Aleinikoff and Nokleberg, 1985). Because of regional tilting toward the south near the Denali fault, the deeper granitic rocks of the arc occur to the north, and the shallower volcanic rock of the arc occur to the south. The Lake George, Matanuska, Jarvis Creek Glaciers, and Hayes Glaciers were initially defined as separate terranes (Nokleberg and Aleinikoff, 1985); however, these units are now defined as subterranes in order to emphasize their genetic relations as various structural levels of the Yukon-Tanana terrane.

GEOLeGIC SUMMARY

The Mount Hayes quadrangle is in the eastern Alaska Range, which forms a great, glacially sculptured, arcuate mountain wall extending approximately 1,000 km from the Canadian border on the east to the Seward Range on the west and southwest. The eastern Alaska Range is characterized by high peaks ranging to over 4,180 m in elevation and spectacular valley glaciers as long as 65 km. The range 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 of southern Alaska to the south.

The bedrock geology is subdivided into various tectonostratigraphic terranes (fig. 1). The term “tectonostratigraphic terrane” is defined as a fault-bounded geologic entity with a distinct geologic history, stratigraphy, structure, and (or) types of mineral deposits, all differing markedly from those of adjoining neighbors (Jones and Silberling, 1975). In the northern part of the quadrangle, north of the Denali fault, the bedrock geology is dominated by the Devonian and Mississippian subterranes (fig. 1; Jones and others, 1987; Aleinikoff and Nokleberg, 1985a, b). These subterranes are interpeted as various levels of metasedimentary rocks and the metamorphosed plutonic rocks of the arc.

In the southern part of the quadrangle, the bedrock geology is dominated by the Mesozoic Nvakpak and older Yukon-Tanana terrane, a complex of multiply deformed and metamorphosed sedimentary, volcanic, and plutonic rocks (fig. 1; Jones and others, 1987; Aleinikoff and Nokleberg, 1985a, b; Nokleberg and Aleinikoff, 1985). In the southern part of the quadrangle, the bedrock geology is dominated by the Mesozoic Nvakpak and Paleozone and Mesozoic Wrangellia terranes (fig. 1; Jones and others, 1987; Nokleberg and Lange, 1985). The Lake George subterrane, south of the Tana River fault.

Macomb Subterrane of Yukon-Tanana terrane

The Macomb subterrane (fig. 1; Nokleberg and Aleinikoff, 1985) occurs south of the Lake George subterrane in the northeastern part of the quadrangle. This subterrane is composed of: (1) older, polydeformed, medium-grained sedimentary rocks, and plutonic rocks derived from quartz-rich to clay-rich shale of Devonian or older age; and (2) a suite of relatively younger, shallow-level, fine- to medium-grained gneiss, granite, and granodiorite, and quartz diorite, and diorite of Devonian age. The metasedimentary rocks and the metasedimentary rocks are ductily deformed and partially metamorphosed at lower greenschist facies into mylonitic gneiss and schist (Nokleberg and others, 1986). The metasedimentary rocks are ductily deformed and partially metamorphosed at lower greenschist facies into mylonitic gneiss and schist (Nokleberg and others, 1986). These subterranes are interpeted as various levels of metasedimentary rocks and the metamorphosed plutonic rocks of the arc.
consist of various proportions of pelitic schist, quartzite, calcschist, quartz-polyspar schist, and marble. Probable for these rocks include shale, quartz sandstone, marl, sandstone, volcanic graywacke, and limestone. The metavolcanic rocks consist of various proportions of abundant meta-andesite and meta-quartz keratophyre, less abundant metadacite and meta-monzonite, and very sparse metagabbro. In the northern central part of the quadrangle at Donnelly Dome, the Jarvis Creek Glaciar subterrane is intruded by intensely deformed and schistose Devonian metagranodiorite, and sparse augen gneiss, quartz, and mica schist, carbonate, and quartzite.

The Jarvis Creek Glaciar subterrane is ductily deformed and regionally metamorphosed at greenschist facies into a mylonitic schist, or locally phyllonite (Nokleberg and others, 1986). Locally, large areas of upper greenschist facies and lower amphibolite facies metapelites occur in the northern part of the Jarvis Creek Glaciar subterrane in the area south of Granite Mountain and south of Donnelly Dome. The higher grade metamorphic minerals in the north are progressively retrogressively replaced by lower grade metamorphic minerals to the south. The Jarvis Creek subterrane is locally intruded by small to large plutons of granite and granodiorite of mid- or Late Cretaceous age, mainly in the Granite Mountain, Molybdenum Ridge, and Buchanan Creek areas. In the central part of the Jarvis Creek Glaciar subterrane in the intrusive complex of early Tertiary(? monzonite, alkali gabbro, lamprophyre, and quartz diorite, partly surrounded by a ring dike of granite. Local comagmatic lamprophyre dikes also occur in the eastern part of the Jarvis Creek subterrane. Locally, abundant quartz and metagabbro dikes also cut the metamorphic rocks of the Jarvis Creek Glaciar subterrane. The Jarvis Creek Glaciar subterrane is bounded to the south by the Hayes Glaciar and Mt. Ogakona faults.

Hayes Glaciar subterrane of Yukon-Tanana terrane

The Hayes Glaciar subterrane (Fig. 1; Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle. The subterrane consists of various proportions of pelitic phyllite, quartz-rich phyllite, quartz-polyspar phyllite, and minor calcschist and marble derived from shale, chert or less likely quartz allstone, volcanic graywacke, marl, and limestone. In the western part of the quadrangle, the metasedimentary rocks are predominantly of poly-deformed black to dark-gray pelitic schist, quartz-mica schist, and lesser quartzite, and calcschist derived from shale, quartz allstone and sandstone, and marble of pre-mid-Cretaceous age. The metamorphic rocks consist of varying proportions of abundant meta-andesite and metamorphosed quartz keratophyre, and sparse metadacite and metabasalt.

The Hayes Glaciar subterrane is ductily deformed and regionally metamorphosed at lower and middle greenschist facies into phyllonite and blastomylonite (Nokleberg and others, 1986). In the eastern part of the quadrangle, southeast of the Robertson River, the Hima Creek Fault, and the Jarvis Creek Glaciar and Hayes Glaciar subterrane are intruded and folded together by a Late Cretaceous granite pluton. In the western part of the quadrangle, the Hayes Glaciar subterrane is intruded by the nonchotrite granite pluton of Mount Hayes, of apparent Late Cretaceous or early Tertiary age. The Hayes Glaciar subterrane is also intruded by locally and locally abundant amphibolite, Late Cretaceous metagabbro and metadiabase dikes and sill. The Hayes Glaciar subterrane also contains sparse, nonchotrite lamprophyre dikes and one small alkali gabbro pluton of apparent early Tertiary age. The Hayes Glaciar subterrane is bounded to the south by the Henana Glaciar and Denali fault.

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. This terrane consists of: (1) fine- to medium-grained and polydeformed calc-schist, marble, quartzite, pelitic schist, of Silurian to Triassic age; and (2) lesser amounts of regionally metamorphosed and deformed Late Cretaceous plutonic rock consisting of schistose quartz diorite, granodiorite, and granite, and sparse amphibolite derived from gabbro and diorite. Probable for the metasedimentary rocks include marl, quartzite, and shale. The Aurora Peak terrane exhibits an older, upper amphibolite facies metamorphism associated with mylonitic schists, and a younger, regionally metamorphosed and deformed Late Cretaceous plutonic rock consisting of schistose quartz diorite, granodiorite, and granite, and sparse amphibolite derived from gabbro and diorite. Probable for the metasedimentary rocks include marl, quartzite, and shale. The Aurora Peak terrane is intruded by weakly to nonmetamorphosed Late Cretaceous to early Tertiary gabbro plutons and dikes, and granodiorite and granite plutons. The Aurora Peak terrane is bounded to the south by the Denali fault.

Windy terrane

The Windy terrane (fig. 1; Jones and others, 1984; Nokleberg, 1985) occurs south of the Hayes Glaciar subterrane and Aurora Peak terrane, north of the Denali fault. The Windy terrane consists of: (1) argillite, limestone, granite, mafic, quartz diorite, and Early Tertiary graywacke, conglomerate of Devonian or Silurian age; and (2) lesser andesite and dacite. Unlike terranes to the north, the Windy terrane exhibits primary bedding, and sedimentary or volcanic textures and structures. The Windy terrane is singly deformed with a weakly foliated crenulation cleavage.Metamorphism associated with the Windy terrane is mainly moderate to strongly retrogressed to greenschist facies with minor amounts of amphibolite facies metamorphism. The Windy terrane is intruded by dikes of Cretaceous metagabbro and diabase. The Windy terrane is bounded to the south by the Denali fault.

BEDROCK UNITS SOUTH OF DENALI FAULT

East Susitna batholith of Maclearen terrane

The Maclearen terrane (fig. 1; Jones and others, 1984) occurs south of the Windy terrane in the central and western parts of the quadrangle and consists of the East Susitna batholith to the north and the Maclearen Glaciar to the south (Nokleberg and others, 1981, 1982, 1985). The East Susitna batholith consists predominantly of regionally metamorphosed Late Cretaceous to early Tertiary granitoid, granodiorite, and granite. Locally, these granite gneiss and gneissic rocks grade into migmatite, migmatitic schist, schist and schistometric gneiss. Metamorphic rocks are highly country rock and are composed of older, more intensely metamorphosed and deformed gabbro and diorite. Small roof pendants of calc-schist, schist, and amphibolite occur in the East Susitna batholith near the west edge of the quadrangle. The contact between the East Susitna batholith and the Maclearen Glaciar is a faulted contact named the Meteor Peak fault (Nokleberg and others, 1982, 1985). The East Susitna batholith is ductily deformed into mylonitic gneiss and schist and regionally metamorphosed at the upper amphibolite facies, with local retrograde metamorphism to lower greenschist facies (Nokleberg and others, 1985). A pluton of younger, nonchotrite, middle Tertiary granite intrudes the northwest part of the East Susitna batholith immediately south of the Denali fault (Smith and Turner, 1973; Turner and Smith, 1974).

Maclearen Glaciar metamorphic belt of Maclearen terrane

The Maclearen Glaciar metamorphic belt (fig. 1) is located on the East Susitna batholith, 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 (Nokleberg and others, 1980, 1982, 1985). Contacts between the three map units are generally faults which have produced intense shearing and abrupt changes of metamorphic facies at each contact. The argillite and metagraywacke unit, the lowest-grade unit in the metamorphic belt, is composed predominantly of volcanic graywacke and siltstone, and sparse andesite and basalt, with lesser argillite and quartz siltstone. The Madsen Glacer amphibolite unit is a unit of basic to intermediate composition, and is intruded by the phyllolite in the argillite and metagraywacke unit, phyllolite in the phyllite unit, and molybdenite schist in the schist and amphibolite unit. A general increase in metamorphic grade occurs from the argillite and metagraywacke unit in the south to the schist and amphibolite unit in the north, grading from lower greenschist facies in the argillite and metagraywacke unit to lower or middle amphibolite facies metamorphism in the schist and amphibolite unit (Nokleberg and others, 1985). A very small pluton of nonmagnetic and hydrously altered biotite granite intrudes the argillite and metagraywacke unit. The Madsen Glacer metamorphic belt is bounded to the south by the Broom Creek thrust.

Clearwater terrane

The Clearwater terrane (Fig. 1; Jones and others, 1984; Nokleberg and others, 1982, 1985) occurs in the western part of the quadrangle as a narrow, fault-bounded lens along the Broom Creek thrust between the Madsen and Wrangellia terranes. The Clearwater terrane consists of small faults bounded block of highly deformed chlorite schist, muscovite schist, schistose rhyodacite, Upper Triassic marble, and greenstone derived from pillow basalt. The Clearwater terrane is a unit of weakly metamorphosed, greenstone facies, and is intruded by fault-bounded and weakly schistose dolomite and quartz diorite.

Wrangellia terrane

The Wrangellia terrane (Fig. 1; Jones and others, 1985) occurs across the southern part of the quadrangle and is subdivided into the Slana River subterrace to the north, and the Tangle subterrace to the south (Nokleberg and others, 1981, b, 1982, 1985). The Slana River subterrace is bounded to the north by the Broom Creek thrust and to the south by the Eureka Creek fault. The Slana River subterrace (Fig. 1) consists mainly of upper Paleozoic and andesite and volcanic rocks and disconformably overlying massive basalt flows of the upper Triassic Nikolai greenstone, younger Mesozoic flysch, and Tertiary continental sedimentary and volcanic rocks. The upper Paleozoic and andesite and dacite andesite flows, volcanic graywackes, and breccia, other phyllicic rocks, argillite, and limestone of the Pennsylvania Teton volcanics, Pennsylvanian and Permiian Slana Spur formation, and Permian Eagle Creek formation. The Teton volcanics and Slana Spur Formation are intruded by Permanian hypabyssal dacite stocks, sills, and dikes, and granite. The upper Nikolai greenstone greenstone consists of massive, subaerial, and subtilagoidal basalt flows about 1,500 m thick. Locally extensive actinolite dikes and cumulate mafic and ultramafic sills intrude the Nikolai greenstone and older rocks in the terrane; these dikes and sills probably formed from the same magma as were the basalt flows and flows. Relatively to the Slana River subterrace, the Tangle subterrace (Fig. 1) contains a thinner sequence of upper Paleozoic and Lower Triassic sedimentary and tuffaceous rocks, and a thicker sequence of the Nikolai Greenstone. The upper Paleozoic and Lower Triassic sedimentary rock consists of quartzite, dark-gray argillite, minor andesite and tuff, and very sparse light-gray limestone. The Nikolai Greenstone consists of a moderately thick basal member of pillow basalt, and a thick upper member of massive, subaerial, and subvolcanic flows. Sparse upper Triassic marble overlies the Nikolai; younger Mesozoic sedimentary rocks are lacking in the Tangle subterrace. Extensive gabbro and cumulate mafic and ultramafic sills and plutons, gabbro, and Nikolai Greenstone and older units, these sills and plutons are probably comagmatic with the basal protolith of the Nikolai (Nokleberg and others, 1985).

The Wrangellia terrane is weakly regionally metamorphosed at the lower greenschist facies (Nokleberg and others, 1985). The Wrangellia terrane is locally intruded by weakly deformed to nonmagnetic, small- to moderate-size granite plutons of apparent Late Jurassic and Late Cretaceous age. Locally some of the granite plutons are weakly to extensively hydrothermally altered.

Terrane of ultramafic and associated rocks

In the eastern part of the geologic map is a narrow terrane of ultramafic rock and sparse associated mafic rock and sparse associated granitic rock that represents part of a string of alpine peridotites that occur along or near the Denali fault (Fig. 1; Richter and others, 1977; Nokleberg and others, 1982). The ultramafic rocks are chiefly dark-green serpentinitized pyroxenite and peridotite, light-gray to green diabase, and dark-gray schistose amphibolite and light-gray hornblende-plagioclase rocks. The overlying andesite is derived from the gabbroic units and is not as common in the Wrangellia terrane. The ultramafic and mafic rocks are intruded by weakly schistose, light-gray hornblende and granite. The ultramafic and associated rocks are ductily deformed and regionally metamorphosed.

Summary of possible and known types of mineral deposits, prospects, and occurrences

Fourteen types of mineral deposits are known, or may occur, in the quadrangle. The type "type of mineral deposit" is defined as a set of mines, mineral deposits, prospects, or occurrences that share a common geologic origin. A "mineral deposit" is defined as a concentration of potentially economically valuable minerals. A "mineral prospect" is defined as a concentration of potentially economically valuable minerals that shows some sign of development, such as an exploration pit or drill hole. A "mineral occurrence" is defined as any other concentration of potentially economically valuable minerals. The mineral deposit modes in Erickson (1982), Cox (1983a, b), and Cox and Singer (1986), and the cited references were used to formulate the types of mineral deposits that we consider important for this assessment. These types of mineral deposits are described in the subsequent assessment sections and are listed below in order increasing of depth of formation.

1. Gold placer deposits
2. Platinum placer deposits
3. Hot-spring Au deposits
4. Kuroko massive sulfide deposits
5. Epithermal precious and base metal deposits
6. Gold quartz vein deposits
7. Cu-Ag quartz vein deposits
8. Kennecott Cu-Ag deposits
9. Porphyry Cu-Au-Ag deposits
10. Porphyry Cu-Mo deposits
11. W-Mo and Cu-In-Pb skarn deposits
12. Porphyry Sn deposits
13. Gabbroic Ni-Cu deposits
14. Podiform chrome deposits

This report assesses the mineral resources for the above types of mineral deposits that are known or inferred to exist in the quadrangle, based on the data accumulated at the time of publication. New deposits of known types of mineral deposits, or even new types may be discovered. In some
In both belts, the massive sulfide deposits occur in schist, usually with disseminated pyrite, and containing as much as 450 ppm Pb, 30 ppm Sn, and 0.10 ppm Au. Most occurrences are in quartz veins or in metasedimentary schist containing 30 ppm Sn, and 7 ppm Ag; and (3) one grab sample of pyroxene cumulate contains 0.25 ppm Au; and (2) a small altered aplite dike containing 2.8 ppm Au and 70 ppm Sn; and (3) two areas of altered pyrite-bearing aplite or quartz monzonite with values of as much as 720 ppm Cu, 5,000 ppm Pb, 530 ppm Sn, 70 ppm Ag, and 2.0 ppm Au. The Jarvis Creek subterrane, the mineral occurrences consist of three areas west of Hohydonus Ridge, in the western part of the quadrangle, where grab samples of grano&nite with molybdenite contain as much as 0.1 ppm Au, and 5 ppm Ag, and 70 ppm Sn. In both subterrane, these occurrences are interpreted as porphyry Cu-Mo or porphyry Cu-Au-Ag deposits.

**SUMMARY OF LODE MINERAL DEPOSITS, PROSPECTS, AND OCCURRENCES SOUTH OF DENVAIL FAULT**

**Slana River subterrane of Wrangellia terrane**

The Slana River subterrane contains abundant lode mineral prospects and occurrences. Most of the prospects and occurrences are related to igneous activity during late Paleozoic island-arc volcanism (Nokleberg and others, 1984). About 19 small- to moderate-size porphyry Cu-Au-Ag prospects and occurrences are located in the central-southern and eastern-southern parts of the quadrangle and consist of disseminated to local small masses of chalcopyrite, bornite, malachite, and pyrite in or near metamorphosed and altered dacite porphyry. Selected samples contain as much as 100,000 ppm Cu, 5,000 ppm Pb, 530 ppm Zn, 70 ppm Ag, 2.0 ppm Au, 1,500 ppm As, and 50 ppm Mo, and 30 ppm Sn. About nine small skarn prospects and occurrences occur in the south-central and southeastern parts of the quadrangle. The skarns are hosted in mafic-interlayered with late Paleozoic metavolcanic rocks that are intruded by gabro, diabase, or dacite. These skarn prospects and occurrences consist of disseminated to local small masses of chalcopyrite and pyrite. Selected samples contain as much as 56,000 ppm Cu, 720 ppm Zn, 300 ppm Ag, 1.2 ppm Au, and 2,000 ppm Cu. These skarn prospects and occurrences are commonly associated with porphyry Cu-Au-Ag prospects and occurrences, and probably formed during late Paleozoic island-arc volcanism and associated igneous activity.

Locally abundant occurrences of potassic chrome occur in mafic or ultramafic dikes and sills in the Upper Triassic Nikolai Greenstone, or in mafic and ultramafic rocks that are probably carbonatic with the basalt protolith of the Nikolai Greenstone. These occurrences consist of disseminated to small lenses and stringers of poikiloblastic chrome in cumulate ultramafic rock and are located in the central and eastern parts of the subterrane. These
occurrences contain as much as greater than 5,000 ppm Cr and 500 ppm Co and probably formed as during crystal setting of chromite in maria scoria.

Several small- to moderate-size prospects and occurrences of Cu-Ag quartz vein deposits occur in late Paleozoic meta-andesite and metadacite in the Upper Triassic Nikolai Greenstone. These prospects and occurrences consist of disseminated and small masses of chalcopyrite, bornite, malachite, and azurite. Selected samples contain as much as 56,000 ppm Cu, 5,000 ppm Pb, 5,000 ppm As, 4,200 ppm Zn, 300 ppm Ag, and 6.5 ppm Au. These prospects and occurrences are either in, or near quartz veins, or in areas of epidote-chlorite-aegirinite-quartz alteration of the Nikolai Greenstone, meta-andesite, metadacite, gabbro, or diabase. These prospects and occurrences are being tested during low-grade regional metamorphism of Wrangellia in the mid-Cretaceous (Nikolberg and others, 1984).

Four small- to moderate-size prospects and occurrences of gabbroic Ni-Cu deposits occur in late Paleozoic or Late Triassic gabbro and diabase, or in Late Triassic cumulate ultramafic rocks. These prospects and occurrences consist of disseminated pyrrhotite, chalcopyrite, and pyrite, and minor chalcopyrite in lenses and veins. Selected samples contain as much as 20,000 ppm Ni, 6,000 ppm Cu, 10 ppm Ag, and 1.5 ppm Au.

Miscellaneous, small mineral occurrences in the Slana River subterrane of Co. (1) minor disseminated pyrrhotite containing as much as 150 ppm Ag, and 2.3 ppm Au in sheared or altered, iron- or copper-stained volcanic or volcanioclastic rock or argillite; and (2) chalcopyrite and galena in quartz veins in limestone containing 1,000 ppm Cu, 2,600 ppm Pb, and 25 ppm Ag. These occurrences consist of disseminated pyrite in sheared or unaltered mafic and ultramafic rocks. Selected samples contain as much as 3,000 ppm Cu, 200 ppm Ag, and 0.5 ppm Au.

Tangle subterrane of Wrangellia terrane

The Tangle subterrane contains one lode mine and abundant prospects and occurrences, mainly in the Triassic Nikolai Greenstone, or in mafic and ultramafic rock that are probably cogenetic with the Nikolai Greenstone.

Eight small- to moderate-size mineral occurrences of podiform chromite deposits occur in cumulate ultramafic rock in the southwestern and southeastern parts of the quadrangle and consist of disseminated to local small lenses and stringers of podiform chromite mainly in olivine-proxene cumulate. Selected samples contain greater than 5,000 ppm Cr and formed as products of crystal settling of chromite in small to moderate-size quartz veins. The Kathleen Margaret mine, located in the western part of the quadrangle, and 3 small- to moderate-size prospects and occurrences of Cu-Ag quartz vein deposits occur in the Upper Triassic Nikolai Greenstone. The mine, prospect, and occurrences consist of disseminated and local small masses of chalcopyrite, bornite, malachite, and azurite. Selected samples contain as much as 130,000 ppm Cu, 300 ppm Ag, and 3.2 ppm Au. The mine, prospect, and occurrences are in or near quartz veins in or areas of epidote-chlorite-aegirinite-quartz alteration of the Nikolai Greenstone. These deposits are interpreted as having formed during low-grade regional metamorphism of Wrangellia in the mid-Cretaceous (Nikolberg and others, 1984).

Minor lode mineral occurrences in the Tangle subterrane include: (1) argillite containing 10 ppm Ag interbedded with metabasalt; and (2) pyrite in sheared, serpentinitized olivine cumulate containing as much as 3,200 ppm Cu. Insufficient data precludes classification of these occurrences.

Maclaren and Clearwater terranes, and terrane of ultramafic and associated rocks

A few minor lode mineral occurrences exist in the Maclaren Glacier metamorphic belt of the Maclaren terrane. These occurrences consist of: (1) meta-andesite with bornite and malachite and containing 24,000 ppm Cu and 5 ppm Ag; and (2) three small areas of pyrite-bearing pyrrhotite containing as much as 1,800 ppm Zn and 15 ppm Ag and (3) pyrite in cobalt containing 1,000 ppm Zn. Insufficient data precludes classification of these occurrences. The East Sukushna batholith does not contain any known mineral deposits, prospects, or occurrences.

Minor lode mineral occurrences in the Clearwater terrane are: (1) pyrite in mafic-stained pyrrhotite containing as much as 2,300 ppm Cu and (2) iron-stained magnetite with pyrite, galena, sphalerite, and malachite and containing 49,000 ppm Pb, 7,900 ppm Zn, 2,700 ppm Cu, and 50 ppm Ag. The latter occurrence may be a Kuroko massive sulfide deposit. Minor lode mineral occurrences in the terrane of ultramafic and associated rocks in the eastern part of the quadrangle are: (1) iron-stained hornblende-plagioclase gneiss with disseminated pyrite, pyrrhotite, and chalcopyrite, and (2) a podiform chromite deposit consisting of disseminated pyrrhotite in pyroxycline.

Mesozoic granitic rocks south of the Denali fault

A few lode mineral prospects and occurrences in or near late Mesozoic and early Tertiary intrusive rocks occur south of the Denali fault in the Maclaren and Wrangellia terranes. In the Maclaren Glaciar metamorphic belt of the Maclaren terrane, a porphyry Cu-Mo deposit contains pyrite, chalcopyrite, and pyrrhotite that occur either in quartz veins, in granite, or in disseminations in metatuff adjacent to granite. Selected samples contain as much as 2,500 ppm Mo.

In the Slana River subterrane of Wrangellia, porphyry Cu-Au-Ag deposits consist of 12 small- to moderate-size prospects and occurrences of fresh to altered Jurassic or Cretaceous quartz diorite, granodiorite, and granite or areas of granite dikes and adjacent quartz veins containing chalcopyrite, sphalerite, pyrite, or galena. Selected samples contain as much as 65,000 ppm Cu, 35 ppm Ag, 4.4 ppm Au, and 100 ppm Pb. Skarn deposits consist of limestone and marble containing chalcopyrite, sphalerite, malachite, and gold. Selected samples contain as much as 66,000 ppm Cu, 55,000 ppm Zn, 35 ppm Ag, and 4.4 ppm Au.

Placer mines and deposits

Three small placer deposits occur north of the Denali fault in the Jarvis Creek Glaciar subterrane of the Yukon-Tanana terrane. These deposits consist of small amounts of gold in alluvial gravels of streams draining areas of extensive glacial deposits, metasedimentary schists, and quartz veins.

Nineteen small- to medium-sized placer mines and deposits occur south of the Denali fault in the Slana River subterrane of Wrangellia. Several small- to moderate-size placer deposits occur in the Bromon Gulch, Rainy Creek, Eureka Creek, and Delta River areas. Known grades are as much as 13 colors per pan (Yeend, 1981b). Most of these placers occur in gravels eroded from Tertiary sedimentary rocks or Pleistocene glacial deposits. A few deposits occur in alluvial gravels deposited downstream from late Paleozoic island-arc rocks. The largest of these is the Bromon Gulch placer deposit, which occurs in gravels eroded from late Paleozoic island-arc rocks and from a fault-bounded unit of Tertiary sedimentary rocks (Rose, 1965; Yeend, 1981b).

Major, gold placer mines and deposits occur in the Slate Creek and Chitchochua areas and have produced gold since the late 1880s (Mendenhall, 1900, 1909, Moffitt, 1912, 1944, 1945; Rose, 1967; Yeend, 1981a). Approximately 4.4 million grams of gold have been produced through 1969. The major gold placer deposits in this area are the Quartz Creek, Slate Creek, Ruby Gulch, Limeston Creek, and Big Four deposits (Yeend, 1981). Known grades range from 0.1 to 1.6 g/t. No gold is mined at the Big Four and Slate Creek deposits.

SUMMARY OF EXPLORATION GEOCHEMICAL STUDIES

Methodology

Reconnaissance stream-sediment, geothermal, and mineralogical studies were completed to identify and outline
mineralized areas and to aid in defining the types of the mineral occurrences within these areas. The studies included the collection of stream-sediment samples at 795 sites on tributary streams with drainage basins ranging from 1 to 5 sq mi in area (O’Leary and others, 1981, 1982; Curtin and others, in press). In addition, composite samples of glacial debris were collected at 116 sites on tributary glaciers. These samples were subsequently concentrated to yield a minus-80-mesh fraction and a nongranitic heavy-mineral concentrate fraction with a specific gravity greater than 2.85. For the purposes of this study, analytical data from glacial-debris samples were combined with those of stream-sediment samples because statistical analysis of the analytical data showed that these two media are chemically similar.

In general, the analytical results from both the heavy-mineral concentrate samples and the minus-80-mesh fraction of the stream-sediment samples are useful in identifying and outlining areas of known or inferred mineral occurrences. The data from the heavy-mineral concentrate survey are especially useful for delineating the distribution and abundance of ore minerals, because the dilution effect of low-density, barren minerals has been removed. The analytical results of minus-80-mesh sediment samples reflect the metal content of ore-related minerals, barren low-density minerals, and metals that have been scavenged primarily by sorp-tion of manganese coatings on sediment grains. In addition to analysis of the exploration geochemical samples, the mineralogy of the heavy-mineral-concentrate samples was microscopically determined to identify ore minerals.

The geochemical data indicate that the individual terranes have distinctive geochemical characteristics. Consequently, the terranes are treated as separate populations in determining the distribution and abundance of ore minerals in the quadrangle, and separate data sets were prepared for each major terrane. The major areas of interest are described below.

**Summary of results**

A few notable associations of high-metal concentrations and areas of known Kuroko massive sulfide deposits occur in the Jarvis Creek subterrane (Nokleberg and others, in press). High values of Ag, Cu, Pb, and Sn occur in heavy-mineral concentrates and in stream-sediment samples in the metavolcanic rock unit of the Jarvis Creek subterrane. In addition, heavy-mineral-concentrate samples contain pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, and scheelite, and molybdenite, marmatite, pyrrhotite, pyrite, and arsenopyrite also occur in the metamafic-sedimentary rock unit. These data outline known mineral occurrences and undiscovered Kuroko massive-sulfide and epithermal precious-metal mineral occurrences in the metavolcanic rock unit.

Three areas north of the Denali-Cle fault underlain by granitic rocks are characterized by high concentrations of Sn, W, and, and Pb in heavy-mineral concentrates. In the Maceb Plateau area, especially in the Berry Creek drainage, high values of Sn and Ag occur in heavy-mineral concentrates. High values of Cu, Pb, Sn, and Ag occur in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates. In the area underlain by granitic rocks, high concentrations of Sn, W, and Pb in heavy-mineral concentrates.
related to specific types of mineral deposits. In particular, several U-shaped anomalies were identified, for example, strong, local equidimensional anomalies with reentrant or central lows. Multiblock intrusions, such as porphyry Cu-Mo deposits, are sometimes characterized by this aeromagnetic signature. The reentrant aeromagnetic low of the U-shaped anomaly may occur over the zone of most intense alteration, and hence, can be used to define exploration targets (Cunningham and others, 1981). However, U-shaped anomalies may arise from several other causes, and furthermore, not all porphyry systems have associated anomalies of this shape. For instance, the anomalies may be eroded to an appropriate level for the anomaly to occur.

Three U-shaped anomalies are of interest for delineating porphyry deposits in the quadrangle: (1) An area in the eastern part of the quadrangle, northeast of the headwaters of Rainy Creek in the Jarvis Creek granitic subterrane; (2) an area in the southwestern part of the quadrangle in the Nenana terrane; and (3) an area in the south-central part of the quadrangle in the Sana River subterrane of the Wrangellia terrane. More detailed geophysical surveys are needed in these areas to determine whether porphyry deposits are present.

Certain anomalies are probably not due to porphyry bodies. The granite of Granite Mountain intruding the Jarvis Creek granitic subterrane and the granite plutons intruding the Lake George and Mount Konocti subterrane have complex aeromagnetic signature, which can be explained by variations in susceptibility of and depth to the source rocks without requiring pervasive alteration of magnetic minerals. A strong U-shaped anomaly occurs in the headwaters of Rumble Creek in the northern part of the quadrangle. Field examination indicates that this anomaly is due to an eroded radially zoned granite pluton whose core exhibits no alteration.

Geophysical indications of skarn deposits

The aeromagnetic map (State of Alaska, 1974) also shows several local highs in areas of sedimentary or metamorphosed rocks. Such geographically small highs, of low to moderate amplitude, occur in low-magnetic environments. This type of anomaly is often associated with skarn deposits. This type of anomaly can reflect relatively magnetic plutons, the source of the magnetic highs, that intrude calcareous rocks which are non-magnetic. Commonly, the pluton may not be particularly magnetic, but the skarn zone may contain strong magnetic minerals. Generally, skarn deposits are small, and as a result, aeromagnetic surveys should be flown at closer than the one mile spacing, which were used for this assessment. If such deposits are to be delineated by this method. Clearly, not all such anomalies are due to skarns nor do all skarn exhibit such anomalies. As a result, this criterion merely indicates areas where plutonic rocks may intrude and alter carbonate rocks. The areas with this type of anomaly are: (1) an area in the southeastern corner of the quadrangle bounded to the north by the Denali fault and to the west by a north-trending magnetic lineament in the Sana River subterrane; and (2) an area of known volcanicogenic massive sulfide deposits in the central-eastern part of the quadrangle in the Jarvis Creek granitic subterrane.

METODOLOGY AND CRITERIA FOR MINERAL RESOURCE ASSESSMENT

Methodology

The method used in this mineral resource assessment is based on a report of a resource appraisal workshop held in Golden, Colorado, in December 1981, and on the subsequent work of Pratt (1981) and colleagues in the Rolls, Montana, quadrangle. This form of assessment was first applied by Richter and others (1975) in the Nisqually quadrangle. The method consists of the following steps: (1) Compilation of geologic, geophysical, and geophysical model data from the quadrangle to identify the known and inferred geologic environments favorable to mineral deposits; (2) Determination of types of mineral deposits that could be expected to occur in the quadrangle on the basis of known world-wide associations of certain mineral-deposit types with geologic environments and on known mineral types of deposits; (3) Derivation of descriptive models for the types of mineral deposits; (4) Derivation of recognition criteria each type of mineral deposit; (5) Systematic examination of the available data for the existence of the recognition criteria; (6) Evaluation of the geographic distribution and relative importance of various recognition criteria to appraise a low, moderate, or high potential for undiscovered deposits in specific areas, or to indicate areas where data are insufficient for a knowledge assessment, and (7) description of grade-tennage models for well-defined types of deposits to define the possible sizes and grades of undiscovered deposits. Further descriptions of the grade-tennage models are described by Singer and Kotel (1982a, b) and Cox and Singer (1986).

Recognition criteria

Recognition criteria, as defined by Pratt (1981), are those geologic parameters that affect the favorability for the presence of an undiscovered mineral deposit and may be either diagnostic, secondary, or negative. The term "secondary" is used in place of the term "permissive" used by Pratt (1981) because both diagnostic and secondary criteria can be regarded as permissive.

Diagnostic criteria are those that are present in nearly all known deposits and are generally considered to be required for the presence of a mineral deposit. Conversely, the known absence of such criteria may either severely limit or definitively rule out the possibility of the presence of a deposit. Diagnostic criteria are also favorable indicators that a deposit may be present, but do not guarantee that a deposit is present. For example, Kuroko massive sulfide deposits are characterized by rhyolite or dacite being such abundant. Thus, the presence of rhyolite or dacite in such greater amounts than basalt. The use of diagnostic criteria, without which, the existence of such deposits can be ruled out.

General examples of diagnostic criteria include: (1) a specific favorable geologic environment; (2) a known mine, deposit, prospect, or occurrence; (3) a specific geologic relation including stratigraphy and (4) age, petrology, structure, or erosional stage; (5) a specific rock type; (6) a specific geochemical association such as anomalous concentrations of associated elements in rocks; (7) occurrence of an associated mineral suite; and (8) a specific alteration pattern. The most important recognition criterion is a specific favorable geologic environment. This criterion is used to initially define an area on a geologic map with at least a low potential for the presence of a deposit. All other recognition criteria, whether diagnostic or secondary, are built upon the existence of a specific favorable geologic environment.

Secondary criteria are those that are present in enough known deposits that they may be considered to favor the presence of a deposit, although they are not required. Their presence enhances the possibility of a mineral deposit, but their absence does not lessen the possibility. Examples of secondary criteria are: (1) a specific geologic relation; (2) a general geologic-chemical association; (3) specific anomalous concentrations in rock samples; (4) specific anomalies in stream-sediment or heavy-mineral-concentrate samples; (5) a specific geophysical anomaly; and (6) pathfinder accessory elements in rock or stream-sediment samples.

Recognition criteria were developed from the descriptions of types of mineral deposits and are described in the following sections and listed in tables 1 through 14 on map sheets 1 through 4. Recognition criteria were developed only for existing data; for example, criteria for data not obtained are not listed. For some types of deposits, recognition criteria would not be separated into diagnostic and secondary criteria.

The following mineral abbreviations are used in tables 1-14:

- ar arsenopyrite
- gal galena
- cob cadmiite
- mo molybdenite
- cinn cinnabar
- py pyrite
important. The deposits occur in a high-energy alluvial depositional environment where gradients flatten and river velocities lessen. The major deposit minerals are Pt-group alloys, Os-Ir alloys, magnetite, chromite, and (or) ilmenite.

Recognition criteria

1. Geologically favorable environment consisting of stream gravels or conglomerates in a region containing cumulate mafic or ultramafic rocks or alpine peridotites.
2. Known deposit, prospect, or occurrence.

Assessment

(table 1, map sheet 1)

Areas 5, 8, and 10 (sheet 1) are geologically favorable for undiscovered platinum placer deposits because of containing stream gravels, conglomerates, or glauconitic deposits that occur downstream or downglacier from cumulate mafic or ultramafic rocks or alpine peridotites. These areas are assessed to have a very low potential for undiscovered platinum placer deposits because of not containing any known deposits (criterion 2). A grade-tonnage model suggests that one-half of platinum placer deposits contain 1.1 million tonnes or more and grades greater than 2.5 g/t or more in one-half of the deposits (B.A. Singer and N.J. Page in Cox and Singer, 1986).

3. HOT-SPRING Au DEPOSITS

(Reference: B.R. Berger in Cox and Singer, 1986)

General description

Hot-spring Au deposits consist of finely disseminated gold in subaerial, intermediate volcanic, or volcaniclastic rocks that are extensively altered and brecciated. The host rocks are generally dacite and andesite with lesser rhyodacite, rhyolite, or volcaniclastic sedimentary rocks. Finely-grained silica, particularly chalcedony, and quartz veins occur in the altered breccia with gold, pyrite, and Sb-As-SbFides. Extensive alteration occurs with formation of albite-feldspar, stockworks, veins, and cemented breccia usually controlled by a pervasive fracture system. The depositional environment consists of hot springs in a volcanic pile of an Andean-type or in a continental rift setting. This type of mineral deposit grades downward into epithermal precious- and base-metal deposits.

Diagnostic criteria

1. Geologically favorable environment of dacite and andesite with lesser rhyodacite and rhyolite formed at or near the surface.
2. Known deposit, prospect, or occurrence.
3. Large amount of felsic shallow-intrusive and extrusive rock.
4. Extensive areas of strong alteration.
5. Brecciated volcanic rock.
6. Disseminated pyrite or restricted disseminated pyrite.
7. Hot-spring deposits.

Secondary criteria

1. Stockworks formed by abundant quartz veins.
2. Local areas of argilic to advanced argillic alteration.
3. Anomalous values of As, Sb, Ag, or Au in rock samples.
4. Anomalous values of As, Sb, Ag, or Au in stream-sediment samples.
5. Anomalous values of As, Sb, Ag, or Au in heavy-mineral-concentrate samples.
6. Occurrence of pyrite, gold, or cinnabar in heavy-mineral-concentrate samples.

Assessment

(table 2, map sheet 1)

Areas through (sheet 2) are underlain by Tertiary sedimentary and volcanic rocks and are geologically favorable.

1. Geologically favorable environment consisting of stream gravels or conglomerates in a region containing cumulate mafic or ultramafic rocks or alpine peridotites.
2. Known deposit, prospect, or occurrence.

Assessment

(table 2, map sheet 1)

Areas 5, 8, and 10 (sheet 1) are geologically favorable for undiscovered platinum placer deposits because of containing stream gravels, conglomerates, or glauconitic deposits that occur downstream or downglacier from cumulate mafic or ultramafic rocks or alpine peridotites. These areas are assessed to have a very low potential for undiscovered platinum placer deposits because of not containing any known deposits (criterion 2). A grade-tonnage model suggests that one-half of platinum placer deposits contain 1.1 million tonnes or more and grades greater than 2.5 g/t or more in one-half of the deposits (B.A. Singer and N.J. Page in Cox and Singer, 1986).
for undiscovered hot-spring Au deposits. Area J is assessed to have a moderate potential for undiscovered deposits because of exhibiting all other diagnostic criteria (3 through 7), anomalous values of As, Sb, Ag, or Au in rock samples (secondary criterion 3), and pyrite, gold, or chalcopyrite in heavy-mineral-concentrate samples (secondary criterion 5, table 3). Areas K through N are assessed to have a low potential because of exhibiting only local areas of strong sulfidation (diagnostic criterion 4) and/or because of exhibiting, only locally, pyrite, gold, or chalcopyrite in heavy-mineral-concentrate samples (secondary criterion 6, table 3).

A grade-tonnage model for hot-spring Au deposits is not available. The few well-studied deposits contain more than 2 million tonnes and as much as 90 million tonnes. Gold grades probably range from 1 to 6 g/t. Silver may be present in grades higher than gold grades.

4. EPITHERMAL PRECIOUS- AND BASE-METAL DEPOSITS

General description

Epithermal precious and base-metal deposits consist of gold or silver in vuggy quartz veins and disseminated in wall rock and are associated with abundant pyrite, arsenopyrite, tetrahedrite, and locally sphalerite, chalcopyrite, enargite. The host rocks consist of andesite to rhyolite flows, ash flows, tufts, and associated volcanioclastic rocks, sometimes overlying older volcanic sequence or igneous intrusions. This deposit type consists of two subtypes, quartz-adularia and quartz-alunite. Both subtypes may grade upward into hot-spring Au deposits. The quartz-adularia subtype is further divided into three subtypes on the basis of rock type beneath the deposits. Here, all of these types are contained. The ore depositional environment is volcanic centers such as calderas generally with a through-going fracture or fault system in an Andean-type arc or subaerial continental-rift setting.

Diagnostic criteria

1. Geologically favorable environment of a large and thick volcanic field of andesite to rhyolite flows, ash flows, tufts, and volcanioclastic rocks locally with interbedded fluvial or lacustrine sedimentary rocks.
2. Known deposit, prospect, or occurrence.
3. Quartz veins, stockwork, or breccia pipes.
4. Open-space filling in veins and altered areas with banded veins, vuggy, fine-grained crystals, or possibly large zones of crystals.
5. Quartz, adularia, chalcocite, carbonate, barite, and (or) fluorite fillings of veins and open spaces.
6. Concurrent wall-rock alteration consisting of extensive replacement by propylitic, sericitic, and argillic assemblages and replacement by albite, sericite, or alunite, within or adjacent to veins.
7. Disseminated pyrite.

Secondary criteria

1. Anomalous values of Cu, Pb, Zn, As, Sb, Ag, or Au in rock samples.
2. Anomalous values of Cu, Pb, Zn, As, Sb, Ag, or Au in stream-sediment samples.
3. Anomalous values of Cu, Pb, Zn, As, Sb, Ag, or Au in heavy-mineral-concentrate samples.
4. Occurrence of gold, chalcopyrite, sphalerite, galena, danniter, arsenopyrite, tetrahedrite or fluorite in heavy-mineral-concentrate samples.

Assessment and grade-tonnage models

(table 4, map sheet 2)

The geological favorable areas for undiscovered epithermal precious- and base-metal deposits are the Tertiary sedimentary and volcanic rocks in the Siana River subterrane of the Wrangellia terrane (areas J through N, sheet 2, table 4). Area J is assessed to have a low potential for undiscovered deposits because of exhibiting quartz veins, stockwork, or breccia pipes (diagnostic criterion 3), and pyrite, gold, or chalcopyrite in heavy-mineral-concentrate samples (diagnostic criterion 5, and table 3). Areas K through N are assessed to have a moderate potential because of exhibiting only locally, pyrite, gold, or chalcopyrite in heavy-mineral-concentrate samples (diagnostic criterion 6, and table 3).

A grade-tonnage model for epithermal precious and base-metal deposits is not available. The few well-studied deposits contain more than 2 million tonnes and as much as 90 million tonnes. Gold grades probably range from 1 to 6 g/t. Silver may be present in grades higher than gold grades.

5. GOLD QUARTZ VEIN DEPOSITS
(References: Clark, 1959; Boyle, 1951; B. R. Berger in Cox and Singer, 1986)

General description

Gold quartz vein deposits consist of gold in veins of massive quartz, sometimes with minor pyrite and arsenopyrite. Gold quartz vein deposits, termed low-sulfide Au quartz vein deposits by Cox and Singer (1986), are generally hosted in greenschist facies metapelitic belts—regionally metamorphosed and penetratively deformed orogen strata, including graywacke, shale, and chert that are intruded by granitic plutons. Grade of metamorphism is usually greenschist facies. The ore depositional environment consists of a mobile belt of arc-terrane terranes along a continental margin, sometimes associated with an Andean-type volcanic arc and associated batholith.

Diagnostic criteria

1. Geologically favorable environment of regionally metamorphosed and penetratively deformed orogen strata, including graywacke, shale, and chert intruded by granitic plutons.
2. Known deposit, prospect, or occurrence.
3. Greenschist facies regional metamorphism.
4. Quartz veins, with or without carbonate, pyrite, arsenopyrite, and base-metal sulfides.

Secondary criteria

1. Intrusion of calc-alkaline plutons during or just after regional metamorphism and penetrative deformation.
2. Quartz vein emplacement along major faults, shear zones, and foliation axes.
3. Anomalous values of As, Sb, Cu, Mo, W, Au, Ag, or Hg in rock samples.
4. Anomalous values of As, Sb, Cu, Mo, W, Au, Ag, or Hg in stream-sediment samples.
5. Anomalous values of As, Sb, Cu, Mo, W, Au, Ag, or Hg in heavy-mineral-concentrate samples.
6. Occurrence of gold, pyrite, or arsenopyrite in heavy-
mineral-concentrate samples.

Assessment and grade-tonnage model (table 5, map sheet 3)

North of the Denali fault, the geologically favorable areas for undiscovered gold quartz vein deposits are the regionally metamorphosed metasedimentary and metavolcanic rocks in Maconch, Jarvis Creek Glacier, and Hayes Glader subterrane of the Yukon-Tanana terrane (areas 1 through 4, sheet 3, table 2). South of the Denali fault, the geologically favorable area is the Mudrane Glacier metasedimentary belt in the Mudrane terrane (area 4, sheet 3, table 2). These areas exhibit greenschist-facies regional metamorphism and quartz veins (diagnostic criteria 3 and 4).

In addition, these areas exhibit postmetamorphic granitic plutons, quartz-vein emplacement along major or minor structures, and anomalous values of appropriate elements in rocks, stream-sediment, and heavy-mineral-concentrate samples (secondary criteria 1 through 6; table 5).

The Maconch subterrane (area 1) and Jarvis Creek Glacier subterrane (area 2), both in the Yukon-Tanana terrane, and the Mudrane Glacier metasedimentary belt (area 4) of the Mudrane terrane are assessed to have a moderate potential for undiscovered deposits because of exhibiting gold, arsenopyrite, and pyrite in heavy-mineral-concentrate samples (secondary criteria 6) and in the case of the Jarvis Creek Glacier subterrane (area 2), a known deposit, prospect, or occurrence (diagnostic criterion 2; table 5). The Hayes Glader subterrane (area 3) is assessed to have a low potential for this type of deposit because of exhibiting only locally arsenopyrite in heavy-mineral-concentrate samples (secondary criteria 6; table 5).

A grade-tonnage model for low-sulfide Au quartz vein deposits was published by J.D. Blij in Singer and Mosier (1933b) and Cox and Singer (1986) from deposits of the Mother Lode of California. Gold grade is negatively correlated with tonnage. The plotted grades and tonnages of the prototype deposits demonstrate that if low-sulfide Au quartz vein deposits exist in the quadrangle, then one-half of the deposits would contain 41,000 tonnes or more. Gold grades range from 14 g/t or more in the richest half of the deposits to 3.8 g/t or more in the richest tenth of the deposits. Silver grades are low and contain 5.1 g/t or more in the richest tenth of the deposits.

6. Cu-Ag QUARTZ VEIN DEPOSITS

General description

Cu-Ag quartz vein deposits consist of quartz veins or adjacent altered areas containing chalcopyrite, bornite, chalcocite, and local high values of Ag and lesser Au and native copper. The veins and altered areas occur in regionally metamorphosed and weakly deformed basalt, diabase, or gabbro and in mafic to intermediate volcanic and hypabyssal rocks. Grade of metamorphism is either prehnite-pumpellyite or lower greenschist facies. The altered areas contain relict igneous and metamorphic minerals in the greenschist and volcanic rocks that are replaced by irregular aggregates of chlorite, epidote, actinolite, carbonate, or quartz. The ore depositional environment consists of simultaneous accretion, regional metamorphism, and deformed sedimentary basaltic terrains along a continental margin. Low-grade regional metamorphism and deformation appear to have generated hydrothermal fluids from which formed quartz veins and altered areas.

Diagnostic Criteria

1. Geologically favorable environment of regionally metamorphosed and penetratively deformed mafic or intermediate igneous rocks.
2. Known deposits, prospect, or occurrence.
3. Prehnite-pumpellyite to lower greenschist-facies metamorphism.
4. Quartz veins.
5. Areas of pervasively altered gneiss with chlorite, epidote, actinolite, or carbonate.

Secondary criteria

1. Quartz vein occurrence controlled by faults and shear zones.
2. Anomalous values of Cu, Ag, or Au in rock samples.
3. Anomalous values of Cu, Ag, or Au in stream-sediment samples.
4. Anomalous values of Cu, Ag, or Au in heavy-mineral-concentrate samples.
5. Occurrence of chalcopyrite, bornite, chalcocite, pyrite, native copper, or gold in heavy-mineral-concentrate samples.

Assessment (table 6, map sheet 3)

The geologically favorable areas for undiscovered Cu-Ag quartz vein deposits are the Siuna River and Tangle subterrane of the Wrangellia terrane (areas A-I, sheet 3, table 6). A grade-tonnage model for these deposits is not available.

Areas A through E are assessed to have a moderate potential for undiscovered deposits because of exhibiting or containing known deposits, prospects, or occurrences, lower greenschist-facies metamorphism, quartz veins, and altered gneiss (diagnostic criteria 2 through 5). In addition, most of these areas contain quartz veins formed along faults and shear zones, anomalous values of Cu, Ag, and (or) Au in rock, stream-sediment, and heavy-mineral-concentrate samples and gold, pyrite, and (or) chalcopyrite in heavy-mineral-concentrate samples (secondary criteria 1 through 5; table 6).

Area F is assessed to have a low potential because of exhibiting only regional metamorphism, quartz veins, and altered areas (diagnostic criteria 3 through 5) and emplacement of quartz veins along shear or faults (secondary criteria 1; table 6).

7. KENNECOTT Cu-Ag DEPOSITS
(References: Batesan and McLaughlin, 1920; Armstrong and Mackevett, 1975, 1982; D.P. Cox in Cox and Singer, 1986)

General description

Kennecott Cu-Ag deposits (revised from basaltic Cu deposit in Cox and Singer, 1986) consist of chalcopyrite, bornite, and minor covellite, enargite, pyrite, galena, and sphalerite in veins, pods, and large irregular masses along or above the unconformity between basalt and overlying limestone or dolomite. The host rocks are regionally metamorphosed at prehnite-pumpellyite or lower greenschist facies. The unconformity between gneiss and overlying limestone, and the development of a regional subhka facies are major structural controls for the deposits. The veins, pods, and masses crosscut structurally and replace relict igneous and metamorphic minerals in the gneiss. The ore depositional environment appears to be a combination of development of sattura facies, subaerial erosion, groundwater leaching, and (or) regional metamorphism that generate hydrothermal fluids from which the deposits formed.

Diagnostic criteria

1. Geologically favorable environment of metasediment, discontinuously overlain by limestone or dolomite.
2. Known deposits, prospect, or occurrence.
3. Prehnite-pumpellyite to lower greenschist-facies regional metamorphism.
4. Weathered subhka facies in carbonate rock overlying metasediment.
Secondary criteria

1. Amygdole in metasubae with calcite, chalcedony, quartz, epidote, zeolites, calcite, C-smudfedite, and rare native copper.
2. Anomalous values of Cu, Pb, Zn, or Ag in rock samples.
3. Anomalous values of Cu, Pb, or Ag in stream-sediment samples.
4. Anomaly values of Cu, Pb, Zn, or Ag in heavy-mineral-concentrate samples.
5. Occurrence of chlorite, biotite, coevalite, galena, sphalérite, or pyrite in heavy-mineral-concentrate samples.

Assessment (Table 7, map sheet 3)

The geologically favorable areas for undiscovered Kastnerite Cu-Ag deposits are parts of the Sana River and Tangie subterrane of the Wrangellia terrane. The only area where this relation occurs is in the eastern part of the Sana River subterrane. The ore depositional environment consists of intermediate to felsic composition containing lesser mafic alkaline composition, and associated tuffs, kaecias, and in some cases in felsic domes. The ore depositional environment is faulted against other bedrock units. Area F is assessed to have a moderate potential for undiscovered deposits because of exhibiting lower Zn-sulfide minerals, anomalous values of Zn and Ag in heavy-mineral-concentrate samples, and chalcopyrite and pyrite in heavy-mineral-concentrate samples. A lack of abundant deposits precludes construction of a grade-tonnage model.

8. KURUOKO MASSIVE SULFIDE DEPOSITS

(Referenced: Lambert and Sato, 1974; Scott, 1980; Franklin and others, 1981; D.A. Singer in Cox and Singer, 1986).

General description

Kurukoro massive sulfide deposits consist of Cu, Pb, and Zn-sulfides that occur in submarine volcanic rocks of intermediate to felsic composition containing lesser mafic volcanic rocks and locally abundant sedimentary rocks. The volcanic rocks occur as flows, ash flows, tuffs, breccias, and in some cases in felsic dikes. The ore depositional environment is mainly hot springs related to marine volcanism in island-arc or extensional rifting regimes. The deposits include pyrite, chalcopyrite, sphalerite, and lesser galena, tetrahedrite, telluride, and magnetite. Local zeolite, clay, sericite, chlorite, and silica alteration may occur.

Diagnostic Criteria

1. Geologically favorable environment of submarine volcanic rock of intermediate to felsic, generally calc-alkaline composition, and associated tuffs, breccias, and sedimentary rocks.
2. Known deposit, prospect, or occurrence.
3. Felsic pyroclastic deposits.
4. Silicic chemical sedimentary rocks.
5. Hydrothermally altered volcanic rocks.

Secondary criteria

1. Primary basalt or gabbro in volcanic or sedimentary rocks.
2. Hydrothermal alteration along a narrow stratigraphic interval.
3. Anomalous values of Cu, Pb, Zn, As, Ag, Au, Sn, or Sb in rock samples.

4. Anomalous values of Cu, Pb, Zn, Ag, Au, Sn, or Sb in stress-sediment samples.
5. Anomalous values of Cu, Pb, Zn, Ag, Au, Sn, or Sb in heavy-mineral-concentrate samples.
6. Occurrence of chalcopyrite, sphalerite, galena, arsenopyrite, tetrahedrite, or pyrite, in heavy-mineral-concentrate samples.

Assessment and grade-tonnage model (Table 8, map sheet 2)

North of the Denali fault, the geologically favorable area for Kurukoro massive sulfide deposits is the submarine mafic volcanic rocks of the Jarvis Creek Glade and Hayes Glade subterrane (areas F through E, sheet 2, Table 8) of the Yukon-Tanana terrane. South of the Denali fault, the geologically favorable areas are the Tottinna Volcanics and Slama Spur Formation of the Slana River subterrane of the Wrangellia terrane (areas G through I, sheet 2, Table 8).

Areas A and D are assessed to have a high potential for undiscovered deposits because of exhibiting moderately abundant known deposits, prospects, or occurrences, felsic pyroclastic deposits, and silicic chemical sedimentary rock (diagnostic criteria 2, 3, and 5; Table 8). In addition, these areas exhibit low hydrothermal alteration, anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 2 through 6; Table 8).

Areas B, E, and G are assessed to have a moderate potential because of exhibiting few, if any known deposits, prospects, or occurrences, silicic chemical sedimentary rock (diagnostic criteria 2 or 5; Table 8), and few anomalous values of appropriate elements in rock, stream-sediment and heavy-mineral-concentrate samples, and few base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 2 through 6; Table 8).

Areas F, H, and I are assessed to have a low potential because of exhibiting only a few anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate sample, and few base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 2 through 6; Table 8).

Area C is assessed to have a very low potential because of a few anomalous values of appropriate elements in stream-sediment samples. A grade-tonnage model was prepared by D.A. Singer and D.L. Hoesch in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if Kurukoro massive sulfide deposits exist in the quadrangle, then one-half of the deposits should contain 1.6 million tonnes or more and the largest tenth of the deposits contain 19 million tonnes or more. Fifty percent of the deposits have average copper grades of 1.3 percent or more and the richest tenth contain at least 1.9 percent lead. Precious metals are reported in over half the deposits with the richest tenth having at least 2.3 g/t gold; the median silver grade is 11 g/t whereas 10 percent of the deposits contain 98 g/t or more of silver.

9. PORPHYRY Cu(Au-Ag) DEPOSITS


General description

Porphyry Cu(Au-Ag) deposits consist of chalcopyrite, bornite, or pyrite, and minor molybdenite, sphalerite, galena, or arsenopyrite in stockwork veiinals in hydrothermally altered, shallowly emplaced porphyry and adjacent country rock. The granite host rocks include quartz diorite to quartz monzodiorite, syenite, and minor hypabyssal andesite to rhyodacite. The mesoperthite, trachyte, andesite, and andesite are the most common. Local disseminated and massive sulfide minerals may occur in coeval volcanic rocks, along with quartz veins, and dikes with sulfide minerals. The ore depositional environment consists of
of optional intrusive rocks with abundant dikes, breccia pipes, and cupolas of batholiths that are intruded to shallow levels in either an island-arc or Andean-type arc setting. In this study, porphyry Cu-Au deposits include associated polymetallic vein deposits.

Diagnostic criteria

1. Geological favorable environment of calc-alkaline and alkalic porphyritic granitic plutons and stocks and (or) dikes, dikes, or sills of andesite to rhyolite or trachyte.
2. Known deposit, prospect, or occurrence.
3. Coeval coeval granitic, hypabyssal, and (or) volcanic rocks.
4. Hydrothermal alteration in and adjacent to intrusive rocks.

Secondary criteria

1. Massive sulfide minerals in volcanic rocks or in skarns formed in carbonate layers in volcanic pile.
2. Anomalous values of Cu, Pb, Zn, As, Hg, or Au in rock samples.
3. Anomalous values of Cu, Pb, Zn, As, Mo, Ag, or Au in stream-sediment samples.
4. Anomalous values of Cu, Pb, Zn, As, Mo, Ag, or Au in heavy-mineral-concentrate samples.
5. Occurrence of chalcopyrite, bornite, pyrite, molybdenite, sphalerite, galena, arsenopyrite, magnetite, monoxide, and thiotite in heavy-mineral-concentrate samples.
6. Local equidimensional aeromagnetic highs, particularly with reentrant or central lows.

Assessment and grade-tonnage model

The geologically favorable areas for undiscovered porphyry Cu(Au)-type deposits are the Ternina Volcanics and Slana Spur Formation in the Slana River subterrane of the Wrangellia terrane (areas C through G, H, I, sheet 2, table 9). These areas are the only ones in the quadrangle that are intruded by hypabyssal granitic plutons in this case, shallow-level, andesite to dacite stocks, dikes, and sills. Areas D2 and J are assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences, coeval granitic granite, hypabyssal, and volcanic rocks, and hydrothermally altered intrusive rocks (diagnostic criteria 2 through 4; table 9). In addition, these areas exhibit massive-sulfide layers in volcanic rocks, anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, base-metal sulfides in heavy-mineral-concentrate samples, and a local, equidimensional aeromagnetic high (secondary criteria 1 through 6; table 9). Areas G1 and H are assessed to have a moderate potential because of exhibiting most of the same diagnostic criteria as above (2 through 5), but fewer anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and fewer base-metal sulfides in heavy-mineral-concentrate samples, and local equidimensional aeromagnetic high (secondary criteria 1 through 6; table 9).

Areas G3 and J are assessed to have a low potential because of exhibiting only coeval granitic, hypabyssal, or volcanic rocks and hydrothermally altered igneous rocks (diagnostic criteria 3 and 4; table 9), and locally chalcopyrite in heavy-mineral-concentrate samples and an appropriate aeromagnetic high (secondary criteria 5 and 6; table 9).

A grade-tonnage model was prepared by D.A. Singer and D.P. Cox in Cox and Singer (1986) for porphyry Cu-Au deposits. The plotted grades and tonnages of the prototype deposits demonstrate that if porphyry Cu-Au deposits exist in the quadrangle, then one-half of the deposits should contain 100 million tonnes or more, and the largest tenth of the deposits should contain 910 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.050 percent or more, and the richest tenth have at least 0.71 percent copper. Average molybdenite grades of 0.0036 percent or more occur in one-half or more of the deposits. Cold grades of 0.31 g/t occur in one-half or more of the deposits, and the richest tenth have at least 0.64 g/t.

10. PORPHYRY Cu-Mo DEPOSITS

(References: Lowry and Guldbrand, 1970; Sutherland Brown, 1976; White and others, 1981; D.P. Cox in Cox and Singer, 1986)

General description

Porphyry Cu-Mo deposits consist of pyrite with lesser chalcopyrite and molybdenite, and minor sphalerite or galena. The sulfides occur in stockwork veined in porphyry granitic rocks or hypabyssal intrusive rocks or in wall rocks adjacent to the igneous rocks. The intrusive rocks include quartz dikes to granite plutons and andesite to rhyolite stocks. Local replacement sulfide bodies may occur in coeval volcanic rock or in older wall rocks, sometimes associated with quartz veins or dikes that also contain sulfide minerals. Associated alteration consists of sodic, potassic, phyllic, argillic, and propylitic types. The ore depositional environment consists of shallowly emplaced plutonic plutons in either an island arc or Andean-type arc, or a rifted continental setting. The areas of favorable environment are either surface outcrops of granitic rocks, or areas adjacent to granitic rocks where geophysical data indicates favorable areas in the subsurface. In this study, porphyry Cu-Mo deposits include associated polymetallic vein deposits.

Diagnostic criteria

1. Geologically favorable environment of plutons of generally porphyritic quartz dikes to quartz monzonite or hypabyssal stocks of andesite to rhyolite.
2. Known deposit, prospect, or occurrence.
3. Coeval shallow-granitic, hypabyssal, or volcanic rocks.
4. Numerous faults and brecciated country rock.
5. Intrusion of igneous rocks controlled by regional-scale faulting.
6. Hydrothermal alteration.

Secondary criteria

1. Multiple intrusive phases, some porphyritic.
2. Volcanic or intrusive breccias, locally with disseminated or massive sulfides.
3. Dikes, quartz veins, or stockwork veined with sulfide minerals.
4. Replacement massive sulfide minerals or skarns in country rock.
5. Breccia pipes locally with sulfides.
6. Anomalous values of Cu, Mo, Pb, Zn, Ag, Au, or Sb in rock samples.
7. Anomalous values of Cu, Mo, Pb, Zn, Ag, Au, or Sb in stream-sediment samples.
8. Anomalous values of Cu, Mo, Pb, Zn, Ag, Au, or Sb in heavy-mineral-concentrate samples.
9. Occurrence of chalcopyrite, molybdenite, pyrite, sphalerite, galena, and sohoulite-pyrrhotite, and (or) fluorite in heavy-mineral-concentrate samples.
10. U-shaped aeromagnetic anomaly patterns, for example, strong, local equidimensional aeromagnetic highs with reentrant or central lows.

Assessment and grade-tonnage model

The geologically favorable areas for undiscovered porphyry Cu-Mo deposits are granitic plutons throughout the quadrangle (areas A through F, G1 through G4, H1 through H4, I through K, L1 through L4, and M through N, sheet 8, table 10). North of the Denali fault, abundant granitic plutons occur in the lake George, Wacoab, and Jarvis Creek Glades subterrane of the Yukon-Tanana terrane and the Aurora Peak terrane (areas A, C, E, G, H, sheet 8), and south of the Denali fault, in the Naidon terrane and the Slana
River subterrane of the Wrangellia terrane (areas J, N, O, sheet 9). For a detailed assessment, areas K, L, and M are divided into subareas (sheet 4, table 10).

Areas K and M, small isolated granitic plutons in the Wrangellia terrane, are assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences; coeval granitic, hypabyssal, or volcanic rocks; numerous faults and brecciated country rock; or hydrothermal alteration (diagnostic criteria 2 through 6; table 9). In addition, areas K and M exhibit anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 10).

Relative to the areas with moderate potential, areas A-0, F, O-3, H1, H3, H4, J, L2, L3, and O-8 are assessed to have only a low potential because of exhibiting fewer and sparser diagnostic criteria, mainly small and sparse areas with coeval granitic, hypabyssal, or volcanic rocks; numerous faults and brecciated country rock; and hydrothermal alteration (diagnostic criteria 3 and 4), and fewer and sparser secondary criteria, namely a few anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and a few base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 10).

A grade-tonnage model for porphyry Cu-Mo deposits was prepared by D.A. Singer, D.L. Hodder, and D.P. Cox in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if porphyry Cu-Mo deposits exist in the quadrangle, then one-half of the deposits would contain 140 million tonnes or more, and the largest tenth of the deposits would contain 1,100 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.5 percent or more, and the richest tenth have at least 1.0 percent copper. The richest tenth contain at least 0.03 percent molybdenum and having at least 0.4 wt% gold. Ten percent of the deposits contain 2.5 g/t or more of silver. For porphyry Mo deposits (W.D. Henriksen and T.G. Theodore in Cox and Singer, 1986), one-half of the deposits would contain 93 million tonnes or more, and the largest tenth would contain 630 million tonnes or more. Fifty percent of porphyry Mo deposits contain 0.004 percent or more molybdenum. The richest tenth contain 0.13 percent molybdenum.

11. W-Mo AND Cu-Zn-Pb SKARN DEPOSITS

(References: Elmaudi and others, 1981; D.P. Cox and T.G. Theodore in Cox and Singer, 1986).

General description


Area L2 is assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences. Skarn masses, and bleaching of calcareous wall rocks (diagnostic criteria 2 through 6; table 11). In addition, area L2 exhibits abundant structures in calcareous sedimentary rocks, anomalous values of appropriate elements in rock and stream-sediment samples, and oxides and base-metal sulfides in heavy-mineral-concentrate samples, and an appropriate aeromagnetic signature (secondary criteria 1, 5, 7, 8; table 11).

Relative to area L2, areas A, C, H2, K3, L1, L3, L4, and P-R are assessed to have a moderate potential because of exhibiting fewer and very sparse diagnostic criteria, mainly two sites of silicate skarn minerals, and one site of bleaching of calcareous wall rocks (diagnostic criteria 3 and 4; table 11). In addition, these areas exhibit, relative to area L2, fewer secondary criteria, mainly sparse anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, sparse oxides and base-metal sulfides in heavy-mineral-concentrate samples, and in some complex mineralogic zoning. Replacement minerals and textures are often extremely varied, with the most common minerals being andradite-grossularite garnet, diopside-hedenbergite clinopyroxene, wollastonite, epidote, ilocrase, hornblende, quartz, fluorite, white mica, and chlorite. The ore depositional environment consists of granitic plutons that intrude either continental shelf sedimentary rocks in an andean-type setting or platform or oceanic sedimentary rocks in an island-arc setting.

Diagnostic criteria

1. Geologically favorable environment of calc-alkaline plutonic rocks intruding calcareous or impure calcareous sedimentary rocks.
2. Known deposit, prospect, or occurrence.
3. Replacement of calcareous wall rocks by irregular masses of contact metasomatic minerals, including andradite-grossularite, diopside-hedenbergite, hornblende, wollastonite, epidote, actinolite, ilocrase, and quartz.
4. Bleaching of calcareous wall rocks, for example, disappearance of graphite and local diagenetic alteration.

Secondary criteria

1. Abundant fractures, folds, or faults in calcareous sedimentary rocks.
2. Replacement of granitic rocks adjacent to calcareous sedimentary rocks by andradite-grossularite, diopside-hedenbergite, epidote, hornblende or actinolite, chlorite, calcite, or quartz.
3. Hydrothermal alteration of plutonic rocks.
4. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, Au, or Sn in rock samples.
5. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, Au, or Sn in stream-sediment samples.
6. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, or Au in heavy-mineral-concentrate samples.
7. Occurrence of scheelite-powellite, molybdenite, chalcopyrite, bornite, sphalerite, galena, pyrite, arsenopyrite, gold, or fluorite in heavy-mineral concentrate samples.
8. Local aeromagnetic highs, particularly geographically small highs of low to moderate amplitude in regions of otherwise low-aeromagnetic fields.

Assessment and grade-tonnage model (table 11, map sheet 4)

The geologically favorable areas for undiscovered W-Mo and Cu-Zn-Pb skarn deposits are carbonate rocks intruded by granitic plutons in the Hooam and Jarvis Creek Glacer subterrane of the Yukon-Tanana terrane and the Aurora Peak terrane north of the Denali fault (areas A, C, H through J, L1, L4, sheet 4, table 11). For a detailed assessment, areas M and L are divided into subareas (sheet 4, table 11).
areas an appropriate aeromagnetic signature (secondary criteria 1 through 6; table 11).

Relative to the above areas with moderate potential, areas H1, H2, and J are assessed to have a low or very low potential because of exhibiting only a geologically favorable area (diagnostic criteria 1). In addition, these areas exhibit very few and sparse secondary criteria, for example, rare anomalous values of appropriate elements in rock, stream-sediment, and heavy mineral-concentrate samples, sparsely oxidized and base-metal sulfides in heavy-mineral-concentrate samples, and an appropriate aeromagnetic signature (secondary criteria 4 through 6; table 11).

Grade-tonnage models were prepared for Cu and W skarn deposits by G.M. Jones and W. D. Hendle in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that Cu skarn deposits exist in the quadrangle, then one-half would contain 0.5 million tonnes or more, and the largest tenth of the deposits contain 5.5 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.7 percent or more, and the richest tenth have at least 8.0 percent copper. The richest tenth contain at least 2.2 g/t gold and 0.67 percent W.

For W skarn deposits, one-half of the deposits would contain 1.1 million tonnes or more, and the largest tenth should contain 22 million tonnes or more. Fifty percent of the deposits have average tungsten grades of 0.67 percent W03 or more, and the richest have at least 1.1 percent W03.

12. PORPHYRY Sn DEPOSITS
(References; Mulligan, 1974; Smith and Turner, 1976; B.J. Reid in Cox and Singer, 1986).

General description
Porphyry Sn deposits consist of disseminated cassiterite and accessory tourmaline, topaz, and white mica in the upper, highly altered parts of leucocratic quartz monzonite or granite. The host granitoid rocks are generally intensely hydrothermally altered to various combinations of K-feldspar, albite, sericite, chlorite, fluorite, or arsenopyrite. The ore depositional environment consists of intrusion of dikeletic granitic rocks into a continental fold belt of tholeiitic rocks with minor volcanic rocks. This deposit type may be associated with Sn-greisen deposits. Howewer, no greisen occurrences were observed in the field, either because of poor exposure in geologically favorable areas or because of a lack of occurrence.

Diagnostic criteria
1. Geologically favorable environment of granitic intruded into continental platform sedimentary rocks.
2. Known deposit, prospect, or occurrence.
3. Continental fold belt of tholeiitic platform sedimentary rocks and minor volcanic rocks.
4. Epizonal multiphase stocks of granitic rocks.

Secondary criteria
1. Upper-level cupolas and roof zones of plutons.
2. Locally extensive alteration in granitoid rocks consisting of replacement K-feldspar, albite, sericite, chlorite, fluorite, or arsenopyrite.
3. Postorogenic intrusion of granitic rocks.
4. Associated tin greisen.
5. Associated tin placer deposits.
6. Anomalous values of Sn, Mo, As, or W in rock samples.
7. Anomalous values of Sn, Mo, As, or W in stream-sediment samples.
8. Anomalous values of Sn, Mo, As, or W in stream-sediment heavy-mineral-concentrate samples.
9. Occurrence of cassiterite, fluorite, and molybdenite, or arsenopyrite in heavy-mineral-concentrate samples.

Assessment (table 12, map sheet 4)

The geologically favorable areas for undiscovered porphyry Sn deposits are granitic plutons intruding folded, continental platform sedimentary rocks in the Haldenm and Jarvis Creek Glacial subterrane of the Yukon-Tanana terrane and the Aurora Peak terrane north of the Denali Fault (areas A, B, and P-N, sheet 4, table 12). For a detailed assessment, areas G and H are divided into subareas (sheet 4, table 12).

A grade-tonnage model is not available.

Areas A, D, F, and H2-H4 are assessed to have a moderate potential for undiscovered deposits because they exhibit folded continental-platform sedimentary rocks or local epizonal or multiphase granitoid rocks (diagnostic criteria 1 and 4; table 12). In addition, most of these areas exhibit locally extensively altered granitic rocks (secondary criterion 2). Although all areas show anomalous values of trace elements in rock, stream-sediment, and heavy-sediment concentrate samples, and oxides and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 12).

Relative to the above areas with moderate potential, areas G1 through G4 and E1 are assessed to have a low potential because of exhibiting fewer and sparser diagnostic criteria, mainly confined continental-platform sedimentary rocks, and in a few areas, epizonal granitoid rocks (diagnostic criteria 1 and 3; table 12). In addition, these areas exhibit fewer and sparser secondary criteria, mainly, local areas of a few anomalous values of appropriate elements in rock, stream-sediment, and heavy-sediment concentrate samples, and a very few oxides and sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 12).

13. GABROIC Ni-Cu DEPOSITS

General description
Gabbroic Ni-Cu deposits (adapted from synorogen-syntectonic Ni-Cu deposit of Cox and Singer, 1986) consist of porphyritic, pentlandite, or chromite cumulates in plutonic-gneissic ultramafic rocks and accessory pyrite that occur mainly as disseminations and lesser massive sulfide lenses in large slabs of cumulate mafic and ultramafic rocks and in smaller dikes, sills, and masses of gabbros and norites. The mafic and ultramafic rocks generally intrude greenstone belts and are locally intensely deformed and metamorphosed. The host rocks consist of various combinations of diabase-diorite gneisses, plagiodolerite-pegmatite cumulates, or diabase-gabbro-gneiss, gabbro, and norite. The ore depositional environment consists of a moderately large bodies of cumulate mafic and ultramafic rocks, and gabbro or norite dikes and sills intruded into greenstone belts, possibly associated with rifting, followed by a period of accretion, deformation, and regional-grade metamorphism.

Diagnostic criteria
1. Geologically favorable environment of cumulate mafic or ultramafic rock and gabbro or norite dikes and sills intruding or associated with greenstone belt.
2. Known deposit, prospect, or occurrence.

Secondary criteria
1. Anomalous values of Cu, Ni, or Co in rock samples.
2. Anomalous values of Cu, Ni, or Co in stream-sediment samples.
3. Anomalous values of Cu, Ni, or Co in heavy-mineral-concentrate samples.
4. Strong aeromagnetic gradient or high.

Assessment and grade-tonnage model (table 13, map sheet 4)

The geologically favorable areas for undiscovered gabbroic Ni-Cu deposits are intrusive gabbros, diabases, and cumulate mafic and ultramafic rocks in the Slana River and Tangle intrusive of the Wrangellia terrane (areas A-E,
sheet 1, table 13). These rocks are interpreted as being cumulates that formed during submarine and subaerial basaltic activity of the Upper Trincomalee Islands of Ceylon.

Areas A through D are assessed to have a moderate potential for undiscovered deposits because of exhibiting a favorable geologic environment (diagnostic criterion 1 and table 13) and because of exhibiting anomalous values of Cu, Ni, or Co in rock, stream-sediment, or heavy-mineral-concentrate samples and a strong aeromagnetic gradient or high (secondary criterion 1 through 4; table 13).

Areas B, C, and D are assessed to have a low potential for exhibiting only a favorable geologic environment (diagnostic criterion 1; table 13), and because of exhibiting few and sparse anomalous values of Cu, Ni, or Co in rock, stream-sediment, and heavy-mineral-concentrate samples and a strong aeromagnetic gradient or high (secondary criteria 1 through 4; table 13). The aeromagnetic survey (State of Alaska, 1974) indicates that the cumulative ultramafic rocks in areas B and C are present at shallow depths and form a continuous U-shaped bed open to the west. Areas peripheral to areas B and C may also have low potential for gabroic Ni-Cu deposits.

A grade-tonnage model was prepared by D.A. Singer, W.J. Page, and W.D. Munkie in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if gabroic Ni-Cu (pyrrhotite-nickel-sulfide) deposits exist in the quadrangle, then one-half should contain 2.1 million tonnes or more, and the largest tenth should contain 17 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.47 percent or more, and the richest tenth have at least 1.3 percent copper. Fifty percent of the deposits have average nickel grades of 0.77 percent or more, and the richest tenth have at least 1.6 percent nickel. Cobalt, gold, and the platinum-group elements are present in some of these deposits.

14. PODIFORM CHROMITE DEPOSIT

(References: Aldredt and Gebert, 1976; BP. Albers in Cox and Singer, 1986)

General description

Podiform chromite deposits consist of chromite and accessory platinum-group minerals that are found in podiform bodies in ultramafic rock in which these rocks are highly deformed and metamorphosed. The best rocks include dunite and harzburgite, associated with igneous rocks, and ultramafic rocks, sometimes extensively serpentinized. The ore deposition environment is that of tectonized ultramafic rock formed in the basal parts of ultramafic bodies in ultramafic rocks of the upper parts of ophiolites or ultramafic rock formed in the upper parts of ophiolites or along rifts.

Diagnostic criteria

1. Geologically favorable environment of metamorphic-textured mafic or ultramafic rocks, associated effusive rocks, or cumulate mafic or ultramafic rocks.
2. Known deposit, prospect, or occurrence.
3. Tectonic emplacement.

Secondary criteria

1. Anomalous values of Cr, Ni, or Co in rock samples.
2. Anomalous values of Cu, Ni, or Co in stream-sediment samples.
3. Anomalous values of Cr, Ni, or Co in heavy-mineral-concentrate samples.
4. Strong aeromagnetic gradient or high.

Assessment and grade-tonnage model (table 14, map sheet 1)

The geologically favorable areas for undiscovered podiform chromite deposits are the terrane of the Wrangell terrane (areas F-H, sheet 1) and the cumulative ultramafic and mafic rocks in the Blaine River and Tangle subterrains of the Wrangell terrane (areas A-B, sheets 1, 14).

Areas A through D are assessed to have a moderate potential for undiscovered deposits because of exhibiting known prospects or occurrences of tectonic emplacement (diagnostic criteria 2 and 3). In addition, these areas exhibit anomalous values of Cr, Ni, or Co in rock, stream-sediment, and heavy-mineral-concentrate samples and a strong aeromagnetic gradient or high (secondary criteria 1 through 4; table 13). The aeromagnetic survey (State of Alaska, 1974) indicates that the cumulative ultramafic rocks in areas B and C are present at shallow depths and form a continuous U-shaped bed open to the west. Areas peripheral to areas B and C may also have low potential for gabroic Ni-Cu deposits.

A grade-tonnage model was prepared by D.A. Singer, W.J. Page, and W.D. Munkie in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if podiform chromite deposits exist in the quadrangle, then one-half should contain 2.1 million tonnes or more, and the largest tenth should contain 17 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.47 percent or more, and the richest tenth have at least 1.3 percent copper. Fifty percent of the deposits have average nickel grades of 0.77 percent or more, and the richest tenth have at least 1.6 percent nickel. Cobalt, gold, and the platinum-group elements are present in some of these deposits.

REFERENCES CITED


Lehman, J.A., Church, S.E., and Nokleberg, W.J., 1985, Lead isotopes in sulfide deposits from the Jarvis Creek Glacier and Wrangellia terranes, Mount Hayes quadrangle, eastern Alaska Range, in Barton-Winkler, Susan, and Reed, K.M., eds., The United States


Figure 1. Tectono-stratigraphic terrane map of the Mount Hayes quadrangle, eastern Alaska Range, Alaska
Figure 1. Tectono-stratigraphic terrane map of the Mount Hayes quadrangle, eastern Alaska Range, Alaska—Continued