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 14 types of mineral deposits, or may occur in the quadrangle; (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 tectonostratigraphic terranes, 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 Glacier subterrane of the Yukon-Tanana terrane has high potential for Kuroko massive sulfide deposits (areas A and D, sheet 2); (2) The Slana River subterrane of the Wrangellia terrane exhibits high potential for porphyry Cu-Au deposits in the southwestern part of the quadrangle (areas G2 and I, sheet 2); (3) The Slana River subterrane 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; and (4) The Tangle subterrane of the Wrangellia terrane in the southwestern part of the quadrangle exhibits high potential for Cu-Mo deposits in the southwestern part of the quadrangle, and (H) The Tangle subterrane of the Yukon-Tanana terrane has high potential for porphyry Cu-Au-Ag deposits in the southwestern part of the quadrangle; and (H) The Tangle subterrane of the Yukon-Tanana terrane exhibits high potential for porphyry Cu-Mo deposits in the southwestern part of the quadrangle.

Furthermore, 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 (AMRAPP). Field work for the assessment was done during the summers of 1978 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 (Menzie and Foster, 1978), the Nabena quadrangle (Richter and others, 1975), the Talkeetna Mountains quadrangle (Singer and others, 1978), and the Tanacross quadrangle (Singer and others, 1976).

Nonmetallic commodities in the quadrangle consist of sand and gravel, marble, and quartzite. Although much of this material is suitable for construction use, 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 sporadically mined from the Jarvis Creek coalfield which has been studied and assessed by Wahrhaftig and Hickox (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 (Nokleberg and others, in press), including study of 126 polished thin sections of sulfide and oxide minerals from mineral deposits, prospects, and occurrences;
(4) Semiquantitative emission spectrographic analysis for 31 elements and interpretation of 1,976 rock, mineral deposit, prospect, and occurrence samples for 31 elements (Zehner and others, 1985);
(5) Semiquantitative emission spectrographic analysis for 31 elements and interpretation of 976 stream-sediment, glacial-debris, and heavy-mineral-concentrate samples for elements (O’Leary and others, 1981, 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 mines or deposits (Yeend, 1980, 1988 a, b);
(8) Analysis and interpretation of the aeromagnetic map for the quadrangle (State of Alaska, 1974).

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 geologic, mineral deposits, and deposit compilation studies of Rose (1965, 1966a, b,
terrane) is defined as a fault-bounded geologic entity with 
tectonostratigraphic terranes (fig. 1). The term 
has been the focus of many bedrock geologic studies. 
and structural studies have been published by Bond (1973, 
1976), Richter and others (1977), and Nokleberg and others 
(1982). Isotopic studies have been published by Smith and 
(1976), Richter and Dutro (1975), Stout (1976), Nokleberg and 
others (1985). Summary studies of mineral deposits and 
prospects, and geophysical studies have been published by 
Holmes (1965), Rose (1965; 1966a; b; 1967), Holmes and 
Saunders (1965), Cobb (1972, 1979), and 
MacKevett and Holloway (1977) were particularly useful. 
Valuable reviews of Donald Grybeck and J.E. Case. 
In the last two decades, the Mount Hayes quadrangle has 
been the focus of many bedrock geologic studies. Bedrock 
geologic maps have been published by Holmes (1965), 
Rose (1965; 1966a; b; 1967), Roser and Saunders (1965), 
Holmes and Foster (1966), Matheson (1973), Bond (1976), 
Stout (1976), Richter and others (1977), and Nokleberg and others 
(1982). Isotopic studies have been published by Smith and 
Aleinikoff and Nokleberg (1981, 1983), LeHurray and others 
(1985b, 1985a), and Nokleberg and others (1985). Stratigraphic 
and structural studies have been published by Bond (1973, 
1976), Richter and Dutro (1975), Stout (1976), Nokleberg and 
others (1981a, b; c; 1983; 1985); and Nokleberg and Aleinikoff 
(1985b, 1985a). Summary studies of mineral deposits and 
metallogenesis have been published by Nokleberg and others 
bedrock geology north of Denali Fault 
Yukon-Tanana terrane 

The most extensive bedrock unit north of the Denali 
fault is the Yukon-Tanana terrane (Jones and others, 1987), which 
in this report is subdivided from north to south, into 
the Lake George, Macomb, Jarvis Creek Glacier, and Hayes 
Glacier subterrane (fig. 1; Aleinikoff and Nokleberg, 1985a; 
Nokleberg and Aleinikoff, 1985; Nokleberg and others, 1986). These subterrane are interpreted as various levels of 
a complex and highly metamorphosed Devonian and 
Mississippian continental margin igneous arc (Nokleberg and 
Aleinikoff, 1985). Because of regional tilting toward the south 
nean the Denali fault, the deeper granitic rocks of the arc 
occur to the north, and the shallower volcanic rock of the arc 
occurs to the south. The Lake George, Macomb, Jarvis Creek 
Glacier, and Hayes Glacier units were initially defined as 
separate terranes (Nokleberg and Aleinikoff, 1985); however, 
these units are now defined as subterrane in order to 
emphasize their genetic relations as various structural levels of 
the Yukon-Tanana terrane.

Lake George Subterrane of Yukon-Tanana terrane 
The Lake George subterrane (fig. 1; Aleinikoff and 
Nokleberg, 1985a, b; Nokleberg and Aleinikoff, 1985) occurs 
in the northern part of the quadrangle, south of the Macomb 
subterrane. The Jarvis Creek Glacier subterrane (fig. 1; 
Nokleberg and Aleinikoff, 1985) occurs across the northern part of 
the quadrangle, south of the Macomb subterrane. The Jarvis 
Creek Glacier subterrane consists of fine-grained, polydeformed schist derived from Devonian or older 
sedimentary and volcanic rock. This unit is subdivided into 
two major units: a metasedimentary rock unit rich in fine- 
grainet metasedimentary rocks with minor metavolcanic rocks, 
and a metavolcanic rock unit rich in fine-grained 
metavolcanic rocks with moderate amounts of fine-grained 
metasedimentary rocks. The metasedimentary and 
metavolcanic rocks are almost totally recrystallized 
(Nokleberg and others, 1986). The metasedimentary rocks 

BEDROCK GEOLOGY NORTH OF DENALI FAULT 
Yukon-Tanana terrane 

GEOLOGIC 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 Aleutian Range on the 
west and southwest. The eastern Alaska range is 
characterized by high peaks ranging to over 4,500 m in 
elevation and spectacular valley glaciers as long as 65 km. 
The range is bisected by the Denali Fault, which is a major 
geoologic and geographic boundary between the Yukon River 
basin in interior Alaska to the north, and the Copper River 
basin in southcentral Alaska to the south. 
The bedrock geology is subdivided into various 
tectonostratigraphic terranes (fig. 1). The term "tectonostratigraphic terrane" (hereafter referred to as 
terrane) is defined as a fault-bounded geologic entity with a 
distinct geologic history, stratigraphy, structure, and (or) 
types of mineral deposits, all different markedly from those 
of adjoining neighbors (Jones and Silberling, 1979). In 
the northern part of the quadrangle, north of the Denali fault, 
the bedrock geology is dominated by the Devonian and 
Mississippian or 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 Macomb and Paleozoic and 
Mesozoic Wrangellia terranes (fig. 1; Jones and others, 1987; 
Nokleberg and others, 1982, 1985). A moderate number of 
granitic and lesser gabbroic plutons, chiefly of Mesozoic age, 
occur both north and south of the Denali fault. 

In the last two decades, the Mount Hayes quadrangle 
has been the focus of many bedrock geologic studies. Bedrock 
geologic maps have been published by Holmes (1965), 
Rose (1965; 1966a; b; 1967), Rose and Saunders (1965), 
Holmes and Foster (1966), Matheson (1973), Bond (1976), 
Stout (1976), Richter and others (1977), and Nokleberg and others 
(1982). Isotopic studies have been published by Smith and 
Aleinikoff and Nokleberg (1984a, b; 1985a, b; LeHurray and others 
(1985b, 1985a), and Nokleberg and others (1986). Stratigraphic 
and structural studies have been published by Bond (1973, 
1976), Richter and Dutro (1975), Stout (1976), Nokleberg and others 
(1981a, b; c; 1983; 1985); and Nokleberg and Aleinikoff 
(1985b, 1985a). Summary studies of mineral deposits and 
metallogenesis have been published by Nokleberg and others 
bedrock geology of the Mount Hayes quadrangle was published by 
Zehner and others (1980). Geophysical studies have been 
published by the State of Alaska (1974), Barnes (1977), 
Hillhouse and Grooms (1984), and Campbell and Nokleberg 
(1985).
lamprophyre dikes and one small alkali gabbro pluton of intruded and welded together by a Late Cretaceous granite southeast of the Robertson River, the Hines Creek fault, and regionally metamorphosed at lower and middle greenschist the Jarvis Creek Glacier and Hayes Glacier subterranes are schist, quartz-mica schist, and lesser quartzite, and calc-schist derived from shale, quartz-siltstone and sandstone, and

the North Central part of the quadrangle at Donnelly Dome, the Jarvis Creek Glacer subterrane is intruded by intensely deformed and schistose Devonian metagranodiorite, and sparse augen gneiss, derived from granite and granodiorite. The Jarvis Creek Glacer subterrane is ductily deformed and regionally metamorphosed at greenschist facies into mylonite schist, or locally phyllonite (Nokleberg and others, 1986). Locally, large areas of upper greenschist facies and lower amphibolite facies metamorphism occur in the northern part of the Jarvis Creek Glacer subterrane in the area south of Granite Mountain and south of Donnelly Dome. The higher grade metamorphic minerals to 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, Polydenum Ridge, and Buchanan Creek area. In the eastern part of the Jarvis Creek Glacer subterrane it is an intrusive complex of early Tertiary(? ) monzonite, alkali gabbro, lamprophyre, and quartz diorite, partly surrounded by a ring dike of granite. Local cogenetic lamprophyre dikes also occur in the eastern part of the Jarvis Creek subterrane. Locally abundant gabbro, diabase, and metagabbro dikes also cut the metamorphic rocks of the Jarvis Creek Glacer subterrane. The Jarvis Creek Glacer subterrane is bounded to the south by the Hayes Glacier and Mount Gakona faults.

The Hayes Glacier subterrane (fig. 1; Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle, south of the Jarvis Creek Glacer subterrane. The Hayes Glacier subterrane consists of polydeformed phyllite, derived from Devonian or older sedimentary and volcanic rock, that is subdivided into two major units (1) a metasedimentary rock unit containing sparse metavolcanic rocks; and (2) a metavolcanic rock unit containing moderate to substantial amounts of metasedimentary rocks. Rocks in both units are almost totally recrystallized with few to no relict minerals. The metasedimentary rock unit in the eastern part of the quadrangle consists of various proportions of net bedded quartz-feldspar schist and quartz-mica schist, and minor calc-schist and marble derived from shale, chert or less likely quartz siltstone, volcanic graywacke, marl, and limestone. In the western part of the quadrangle, the metasedimentary rock unit consists predominantly of poly-deformed black to dark-gray pelitic schist, quartz-mica schist, and lesser quartzite, and calc-schist derived from shale, quartz-siltstone and sandstone, and merrle of pre-mid-Cretaceous age. The metavolcanic rocks consist of varying proportions of abundant meta-andesite and metamorphosed quartz keratophyre, and sparse metamorphosed metabasalt.

The Hayes Glacier 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, the Madaren terrane (fig. 1; Aleinikoff, 1984) is intruded by a Late Cretaceous granite pluton of locally slightly schistose gabbro and diorite, partly surrounded by a ring dike of granite. The Madaren terrane is locally intruded by dykes of gabbro and diorite. Small roof pendants of calc-schist, quartzite, and amphibolite composed of older, more intense metamorphosed and deformed gabbro and diorite. Small roof pendants of calc-schist, quartzite, and amphibolite occur in the East Susitna batholith near the west edge of the quadrangle. The basement contact between the East Susitna batholith and the Madaren terrane consists predominantly of regionally metamorphosed, mid-Cretaceous to early Tertiary quartzite and granodiorite, and lesser granite. Locally, these gneissose granite rocks grade into migmatite, migmatitic schist, and schist and amphibolite composed of older, more intense metamorphosed and deformed gabbro and diorite. The Hayes Glacier subterrane is located at the north of the Denali fault.
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 at least one change in metamorphic facies at each contact. Locally, the argillite and metagraywacke unit, the lowest-grade unit in the metamorphic belt, is composed predominantly of volcanic graywacke and sillstone, and sparse andesite and basalt, with lesser calcareous and quartz siltstone. The Madalen Glacier metamorphic belt is ductily deformed into protomylonite and phyllonite in the argillite and metagraywacke unit, phyllonite in the phyllite unit, and mylonitic schist in the schist and amphibolite unit. 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, the lowest-grade unit in the metamorphic belt, to lower or middle amphibolite facies metamorphism in the schist and amphibolite unit (Nokleberg and others, 1985). A very small pluton of nonschistose and hydrothermally altered biotite granite intrudes the argillite and metagraywacke unit. The Madalen Glacier metamorphic belt is bounded to the south by the Broxon Gulch 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 Broxon Gulch thrust between the Madaren and Wrangellia terranes. The Clearwater terrane consists of a small fault-bounded block of highly deformed chlorite schist, muscovite schist, schistose rhyodacite, Upper Triassic marble, and greenstone derived from pillow basalt. The Clearwater terrane is weakly deformed and metamorphosed at greenschist facies, and is intruded by fault-bounded and weakly schistose diorite 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 subterrane to the north, and the Tangle subterrane to the south (Nokleberg and others, 1981a, b, 1982, 1985). The Slana River subterrane is bounded to the north by the Broxon Gulch thrust and to the south by the Eureka Creek fault. The Slana River subterrane (fig. 1) consists mainly of upper Paleozoic island arc sedimentary and volcanic rocks and deformed and overlying massive basalt flows of the Upper Triassic Nikolai Greenstone, volcanic andesite and Tertiary continental sedimentary and volcanic rocks. The Upper Paleozoic island arc rocks consist of andesite and dacite flows, volcanic graywacke and breccia, other epiclastic rocks, argillite, and limestone of the Pennsylvaniaian Tetelna Volcanics, Pennsylvanian and Permian Slana Spur Formation, and Permian Eagle Creek Formation. The Tetelna Volcanics and Slana Spur Formation are intruded by Permian hypabyssal dacite stocks, sills, and dikes, and granite. The Upper Triassic Nikolai Greenstone consists of massive, subaerial, andysidal basalt flows about 1,500 m thick. Locally extensive gabbro dikes and cumulates and ultramafic sills intrude the Nikolai Greenstone and older rocks in the subterrane; these dikes and sills probably formed from the same magma as were the basalts that formed the Nikolai. Locally overlying the Nikolai Greenstone in the eastern part of the Slana River subterrane are Triassic limestone, Jurassic to Cretaceous argillite and metagraywacke of the Gravina-Nutzotin belt, and sparse deposits of Tertiary sandstone, conglomerate, and phyllite to dacite tuff, breccia, and flows. Relative to the Slana River subterrane, the Tangle subterrane (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 rocks in the Tangle subterrane consist of andysidal tuff, dark-gray argillite, minor andesite tuff and flows, 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, andysidal basalt flows. Sparse Upper Triassic marble overlies the Nikolai younger Mesozoic sedimentary rocks lacking in the Tangle subterrane. Extensive gabbro and cumulate maflc and ultramafic sills and plutons intrude the Nikolai Greenstone and older units; these sills and plutons are probably comagmatic with the basalt protolith of the Nikolai (Nokleberg and others, 1985).

The Wrangellia terrane is weakly regionally metamorphosed at the lower greenschist facies (Nokleberg and others, 1985). Metamorphic minerals are generally sparse, and abundant relict minerals occur in most rocks. The Wrangellia terrane is locally intruded by weakly deformed to nonschistose, small- to moderate-size granitic plutons of apparent Late Jurassic and Late Cretaceous age. Locally some of the granitic 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 maflc 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; Ricner and others, 1977; Nokleberg and others, 1982). The ultramafic rocks are chiefly dark-green serpentinitized pyroxenite and peridotite, light-gray to green dunite, and dark-green schistose amphibolite and lighter hornblendite-plagioclase gneiss derived from gabbro. Interspersed with the gneisses are rare thin lenses of light-gray and green marble and zones of dark-gray graphitic schist. The ultramafic and maflc rocks are intruded by weakly schistose, light-gray tonalite 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 term "type of mineral deposit" is defined as a set of mines, mineral deposits, prospects, and occurrences that share a common geologic origin. A "mineral deposit" 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 nodes 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-Au quartz vein deposits
8. Kennecott Cu-Au deposits
9. Porphyry Cu-Au deposits
10. Porphyry Cu-Mo deposits
11. W-Mo and Cu-Zn-Pb-Sb 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 variants of known types of mineral deposits, or even new types may be discovered. In some
cases, the type of deposit could not be defined because the available data are not sufficient for classification.

**SUMMARY OF LODE MINERAL DEPOSITS, PROSPECTS, AND OCCURRENCES NORTH OF DENALI FAULT**

Lake George and Macomb subterrane of Yukon-Tanana terrain

A minor lode mineral occurrence in the Lake George subterrane is on the south shore of Lake George, where a grab sample of silicified, iron-stained pyrite-quartz-actinolite schist contains 30 ppm Sn. Minor lode mineral occurrences in the Macomb subterrane occur: (1) on the north side of Elliott Creek, where a grab sample of pyrite-bearing iron-stained quartz-biotite schist contains 3.2 ppm Au; and (2) on the northwest side of the West Fork of the Robertson River, where a grab sample of pyroxene cumulate contains greater than 5,000 ppm Cr. Except for the latter, these occurrences are associated with quartz veins, or occur in metasedimentary schist near granitic plutons. These occurrences are probably either gold quartz vein or epithermal precious- and base-metal deposits that formed during regional metamorphism and (or) intrusion of Cretaceous granitic plutons.

Jarvis Creek Glacier subterrane of Yukon-Tanana terrain

The Jarvis Creek Glacier subterrane locally contains substantial lode mineral deposits, prospects, and occurrences. The major lode mineral deposits and occurrences are in the metavolcanic rock unit and consist of 15 small- to moderate-size Kuroko massive sulfide deposits. These deposits, prospects, and occurrences occur in two major belts: a western belt, west of the Delta River, between the Hayes and McFarland Glaciers, and an eastern belt in the area southeast of the West Fork of the Robertson River.

Five prospects and occurrences comprise the western belt, which is about 32 km long. The western belt prospects and occurrences generally contain disseminated to massive chalcopyrite, galena, sphalerite, pyrite, pyrrhotite. Selected samples contain as much as 9,200 ppm Cu, 2,500 ppm Pb, 3,200 ppm Zn, 5,000 ppm As, 50 ppm Ag, 0.20 ppm Au, and 100 ppm Sn. Ten deposits and occurrences comprise the eastern belt, which is about 26 km long. The eastern belt of deposits and occurrences contain the same sulfide minerals as the western belt. Selected samples contain as much as 110,000 ppm Cu, 110,000 ppm Zn, 15,000 ppm Pb, 10,000 ppm As, 300 ppm Ag, 1.9 ppm Au, 300 ppm Sn, and 2,000 ppm Sb. In both belts, the massive sulfide deposits occur discontinuously as irregularly shaped, generally fault-bounded pods, lenses, and stringers. The deposits and occurrences are hosted in mainly mafic and ultramafic rocks in the Upper Triassic Nikolai Greenstone. These occurrences 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, 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 marble interlayered with late Paleozoic volcanic rocks that are intruded by gabbro, 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 Co. 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.

Summary of lode mineral deposits, prospects, and occurrences south of Denali fault

Siana River subterrane of Wrangellia terrain

The Siana 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. 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. These occurrences 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, 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 marble interlayered with late Paleozoic metavolcanic rocks that are intruded by gabbro, 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 Co. 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 podiform chromite occur in mafic or ultramafic dikes and sills in the Upper Triassic Nikolai Greenstone, or in mafic and ultramafic rocks that are intruded by gabbro, diabase, or dacite. These 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 Co. These 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.

Mineral occurrences in the Hayes Glacier subterrane consist of three areas of grab samples of altered quartz-mica-graphite schist containing disseminated pyrite and quartz veins. Selected samples contain as much as 720 ppm Zn, 30 ppm Mo, and 3 ppm Ag. Two occurrences are on the northwest side of the Trident Glacier, in the southeastern part of the quadrangle. A minor lode mineral occurrence in the Windy terrane, in the southeastern part of the quadrangle, consists of a grab sample of metamorphosed quartz-white mica graywacke that contains 5,000 ppm As. Most of these occurrences are in quartz-rich schist or phyllite. These occurrences are probably either gold quartz vein or epithermal precious- and base-metal deposits that formed during regional metamorphism and (or) intrusion of Cretaceous granitic plutons.

Cretaceous granitic plutons north of the Denali fault

Sparse lode mineral prospects and occurrences in, or near Cretaceous and early Tertiary granitic plutons occur north of the Denali fault in the Macomb and Jarvis Creek Glacier subterrane. In the Macomb subterrane, the mineral occurrences consist of (1) a small- to moderate-size Kuroko massive sulfide deposit containing 0.25 ppm Au; (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 7 ppm Au and 110 ppm Pb. In the Jarvis Creek Glacier subterrane, the mineral occurrences consist of three areas west of Molybdenum Ridge, in the western part of the quadrangle, where grab samples of granodiorite with molybdenite contain as much as 0.1 ppm Au, and 5 ppm Ag, and 70 ppm Mo. In both subterrane, these occurrences are interpreted as porphyry Cu-Mo or porphyry Cu-Au-Ag deposits.
occurrences contain as much as greater than 5,000 ppm Cr and 500 ppm Co and probably formed as during crystal settling of chromite in mafic sills.

Five small- to moderate-size prospects and occurrences of Cu-Ag quartz vein deposits occur in Late Triassic cumulate ultramafic rocks. These prospects and occurrences consist of disseminated and local 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-actinolite-quartz alteration of the Nikolai Greenstone, or in mafic and ultramafic rock that are sheared or altered, iron- or copper-stained volcanic or volcaniclastic rock or argillite; and (2) chalcopyrite and galena in quartz veins in limestone containing 4,000 ppm Cu, 2,600 ppm Pb, and 48 ppm Ag. These occurrences are probably gold quartz veins or epigenetic pyrite- and base-metal deposits that formed during low-grade regional metamorphism of Wrangellia in the mid-Cretaceous (Nokleberg 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 to massive pyrite and pyrrhotite 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 consist of (1) minor disseminated pyrite occurring as much as 150 ppm Ag and 2.3 ppm Au in sheared or altered, iron- or copper-stained volcanic or volcanoclastic rock or argillite; and (2) chalcopyrite and galena in quartz veins in limestone containing 4,000 ppm Cu, 2,600 ppm Pb, and 48 ppm Ag. These occurrences are probably gold quartz veins or epigenetic pyrite- and base-metal deposits that formed during low-grade regional metamorphism of Wrangellia in the mid-Cretaceous or during intrusion of Mesozoic granitic plutons.

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 comagmatic with the Nikolai Greenstone.

Eight small- to moderate-size mineral occurrences of podiform chrome deposits occur in cumulate ultramafic rock in the south-central and southwestern parts of the quadrangle and consist of disseminated to local small lenses and stringers of podiform chrome mainly in ophiolitic ultramafic cumulate. Selected samples contain greater than 5,000 ppm Cr and formed as products of crystal settling of chromite in small- to moderate-size ultramafic sills.

The Kathleen Margaret mine, located in the western part of the quadrangle, and 24 small- to moderate-size prospects and occurrences of Cu-Ag quartz vein deposits occur in the Upper Triassic Nikolai Greenstone. The mine, prospects, 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, prospects, and occurrences are in or near quartz veins or in areas of epidote-chlorite-actinolite-quartz alteration of the Nikolai Greenstone. These deposits are interpreted as having formed during low-grade regional metamorphism of Wrangellia in the mid-Cretaceous (Nokleberg and others, 1984).

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

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

A few minor lode mineral occurrences exist in the Macedon Glacier metamorphic belt of the Macedon 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 pyrite containing as much as 1,800 ppm Zn and 15 ppm Ag.

Minor lode mineral occurrences in the Clearwater terrane are: (1) pyrite in iron-stained pyrite containing as much as 2,300 ppm Cu; and (2) iron-stained metahotypholite with pyrite, galena, sphalerite, and malachite and containing 94,000 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 chrome deposit consisting of disseminated to podiform chrome in alpine peridotite.

Mesozoic granite 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 Madlaren and Wrangellia terranes. In the Madlaren Glacier metamorphite belt of the Madlaren terrane, a porphyry Cu-Mo deposit consists of pyrite, chalcopyrite, and molybdenite that occur either in quartz veins in granite, or in quartz replacements in altered 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 60,000 ppm Cu, 35 ppm Ag, 4.4 ppm Au, and 250 ppm Pb. Skarn deposits consist of two skarns in limestone or 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 Glacier subterrane of the Yukon-Tanana terrane. These deposits consist of small amounts of gold in alluvial gravels of streams draining areas of extensive glacial sedimentary rocks, metasedimentary schists, and quartz veins.

Nineteen small- to medium-sized placer deposits occur south of the Denali fault in the Slana River subterrane of the Wrangellia terrane. Several small- to moderate-size placer deposits occur in the Bronson Gulch, Rainy Creek, Eureka Creek, and Delta River areas. Known grades are as much as 13 colors per pan (Yeend, 1981b). Most of these placer occur in gravels deposited downstream 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 Bronson 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 Chistochina areas and have produced gold since the late 1800's (Mendenhall, 1903, 1905; Moffit, 1912, 1944, 1954; Rose, 1967, Yeend, 1981a, b). Approximately 4.4 million ounces of gold have been produced through 1966. The major gold placers in this area are the Quartz Creek, Slate Creek, Ruby Gulch, Limestone Creek, and Big Four deposits (Yeend, 1981b). Known grades range from 0.5 to 1.1 g/m³. Minor platinum is mined at the Big Four and Slate Creek deposits.

SUMMARY OF EXPLORATION GEOCHEMICAL STUDIES

Methodology

Reconnaissance stream-sediment, geochemical, 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 mi² in area (O'Leary and others, 1981, 1982; Curtin and others, in press). In addition, coarse-grained glacial-debris were collected at 116 sites on tributary glaciers. These samples were subsequently concentrated to yield a minus-80-mesh fraction and a nonmagnetic 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 amorphous-iron and manganese-oxide 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 the elements in the quadrangle. Separate datasets 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 Zn occur in heavy-mineral deposits and in stream sediments in the metavolcanic rock unit of the Jarvis Creek Glacier subterrane. In addition, heavy-mineral-concentrate samples contain pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, and scheelite. Arsenopyrite, chalcopyrite, pyrite, galena, and sphalerite also occur in the metamorphosed terrane; these elements reveal known mineral occurrences and undiscovered Kuroko massive-sulfide and epithermal precious- and base-metal mineral occurrences in the metavolcanic rock unit.

Three areas north of the Denali fault underlain by granitic rocks are characterized by high concentrations of Sn, W, and Sb in heavy-mineral concentrates. In the Maconb subterrane, especially in the Berry Creek drainage, high values of Sn together with those of Cu, Pb, Zn, and Mo outline an area that has a moderate potential for undiscovered porphyry Sn, porphyry Cu-Mo, and skarn mineral deposits. Similar high concentrations of Sn and W in the Maconb Plateau area also suggest local areas that are favorable for undiscovered porphyry Sn and W-skarn mineral deposits. Mineralogical examination of the heavy-mineral-concentrate samples confirmed the presence of cassiterite, scheelite, and fluorite, all common minerals in porphyry Sn deposits, together with gold, chalcopyrite, and galena.

The granite of Granite Mountain in the central part of the quadrangle is characterized by high concentrations of Sn, W, and Sb and high concentrations of Ag, Cu, Pb, and Mo. Chalcopyrite, cassiterite and arsenopyrite, monazite, thortveit, molybdenite, and powellite occur in the heavy-mineral concentrates in this area. These relations indicate at least a low potential for undiscovered porphyry Cu-Mo and porphyry Sn deposits. The granite of Molybdenum Ridge is also characterized by high values of Sn, W and Sb in heavy-mineral concentrates. Monazite, thortveit, molybdenite and powellite also occur in the heavy-mineral concentrates from Granite Mountain and Molybdenum Ridge. These data indicate at least a low potential for undiscovered porphyry Sn deposits.

South of the Denali fault, in the Wrangellia terrane, another notable area exists of Ag, Cu, Pb, As, Mo, and local Sn and W in heavy-mineral concentrates and in stream-sediment samples, except for Sn and W. Gold, cinnabar, scheelite, chalcopyrite and arsenopyrite occur in heavy-mineral-concentrate samples from several sites in this area. These high concentrations occur in an area of known Cu-Ag quartz vein occurrences (Nokleberg and others, in press), and the exploration geochemical data outline areas with minimum potential for Cu-Ag quartz vein deposits.

To the northwest in the East Susitna batholith of the Madison terrane, abundant molybdenite, powellite and scheelite occur in heavy-mineral concentrates. These occurrences correlate with moderately high concentrations of W, Cu, and Sn in heavy-mineral concentrates and may indicate local small areas with a minimum potential for porphyry Mo or skarn mineral deposits.

Gold and cinnabar were identified in a number of heavy-mineral concentrates from the Wrangellia terrane. The source of the gold may be epithermal precious- and base-metal deposits associated with Mesozoic granitic rocks intruding the Wrangellia terrane or Cuzn mineral deposits in sialic and intermediate igneous rocks of the Wrangellia terrane. The source of cinnabar may be Tertiary volcanic rocks that occur within the Wrangellia terrane in the central and eastern parts of the quadrangle.

Summary of Geophysical Investigations

Methods

Geophysical investigations consisted of collecting and analyzing gravity and aeromagnetic surveys and mapping a short, very low-frequency, electromagnetic profile over the Miyakof massif occurrence in the northwest part of the quadrangle. Gravity measurements were made at 80 new stations in the quadrangle and augment 300 gravity measurements made by Barnes (1977). These gravity measurements greatly aid the tectonic interpretations of the region in the quadrangle. However, the gravity survey over most of the quadrangle is too sparse to define small anomalies that might indicate known or undiscovered mineral deposits.

Aeromagnetic fields were analyzed by Campbell and Nokleberg (1984, 1985) on the aeromagnetic map of the quadrangle published by the State of Alaska (1974) for (1) separate magnetically distinct terranes; (2) define approximate boundaries between these units; (3) identify lithological units and economic features; (4) identify areas of known or inferred mineral deposits; and (3) identify lineaments that may represent faults. Probable magnetic source rocks were identified by: (1) comparing detailed aeromagnetic and geologic maps at 1:63,360 scale; (2) investigating outcrops and measuring magnetic susceptibilities; and (3) performing new aeromagnetic surveys using a helicopter-borne magnetometer.

Subsurface models were also calculated of magnetic structures along six profiles, five of which were constructed from the aeromagnetic map of the quadrangle, and one of which was surveyed by the helicopter-borne magnetometer. These models show that the major magnetic anomalies of the Tangle subterrane of the Wrangellia terrane are probably due to thick tabular bodies of igneous ultramafic rock. The Nikolai Greenstone, which occurs at the surface, is less magnetic and results in lesser anomalies. The models also indicate: (1) that deep-rooted granitic plutons probably cause most of the anomalies of the Slana River subterrane of the Wrangellia terrane; (2) the major pluton in the Lake George subterrane is steep sided and deep seated; and (3) that in the central quadrangle, a large granitic batholith trimmed by the Denali fault is exceptionally deep rooted (Campbell and Nokleberg, 1985).

Geophysical indications of porphyry deposits

Analysis of interpretation of an aeromagnetic features maps reveals plutons and tabular magnetic bodies that may be
related to specific types of mineral deposits. In particular, several U-shaped anomalies were identified, for example, strong, local equidimensional aeromagnetic highs with reentrant or central lows. Multistage 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, 1984). 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 system must 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 southeastern corner of the quadrangle bounded by the Denali fault and to the west by a north-trending magnetic lineament in the Slana River subterrane. (2) An area in the southwestern part of the quadrangle in the Wrangellia terrane. (3) An area in the north-central part of the quadrangle in the Slana 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 Glaciated subterrane and the granite plutons intruding the Lake George and Mazama 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 Mount Hajdukovich area in the central east of the quadrangle. Its association with this anomaly is due to an eroded radial zoned granite pluton whose core exhibits no alteration.

Geophysical indications of skarn deposits

The aeromagnetic map (State of Alaska, 1979) also shows several local highs in areas of sedimentary or metasedimentary rocks. Such geographically small highs, of low to moderate amplitude, occur in low- to high magnetic fields. 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 strongly magnetic minerals. Generally, skarn deposits are small, and as a result, aeromagnetic surveys should be flown at closer than one-mile spacing, which were used for this assessment, if such deposits are to be defined by this method. Clearly, not all such anomalies are due to skarns nor do all skarns exhibit such anomalies; 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 Slana River subterrane. (2) A region of known volcanogenic massive sulfide deposits in the central-eastern part of the quadrangle in the Jarvis Creek Glaciated subterrane.

**METHODOLOGY 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 Bolia, Missouri quadrangle. This form of assessment was first applied by Richter and others (1975) in the Nabeana quadrangle. The method consists of the following steps: (1) Compilation of geologic, geochemical, and geophysical maps of 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 for 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 knowledgeable assessment. And, (7) description of grade-tonnage models for well-defined types of deposits, to define the possible sizes and grades of undiscovered deposits. Further descriptions of the grade-tonnage models are described by Singer and Mosher (1983a, b) and Cox and Singer (1986).

**Recognition criteria**

Recognition criteria, as defined by Pratt (1971), 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 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 a favorable indication 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 much more abundant than basalt. Thus, the presence of rhyolite or dacite in such greater amounts than basalt is a diagnostic criterion, 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 (or) age, petrology, structure, or erosional stage; (4) a specific rock type; (5) a specific geochronological age; (6) a specific geophysical signature; (7) an associated element return geochemical anomaly; (8) an associated element geochemical anomaly; and (9) a specific geologic feature that may be present. For example, Kuroko massive sulfide deposits are characterized by rhyolite or dacite being much more abundant than basalt. Thus, the presence of rhyolite or dacite in such greater amounts than basalt is a diagnostic criterion, without which, the existence of such deposits can be ruled out.

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 absence 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 including stratigraphy and (or) age, petrology, structure, or erosional stage; (2) a specific rock type; (3) a specific geochronological age; (4) a specific geophysical signature; and (5) a specific geologic feature that may be present. For example, Kuroko massive sulfide deposits are characterized by rhyolite or dacite being much more abundant than basalt. Thus, the presence of rhyolite or dacite in such greater amounts than basalt is a diagnostic criterion, without which, the existence of such deposits can be ruled out.

Examples of secondary criteria include: (1) a specific favorable geologic environment; (2) a known mine, deposit, prospect, or occurrence; (3) a specific geologic relation including stratigraphy and (or) age, petrology, structure, or erosional stage; (4) a specific rock type; (5) a specific geochronological age; 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 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 could not be separated into diagnostic and secondary criteria.

The following mineral abbreviations are used in tables 1-4:

- ar arsenopyrite
- ca cassiterite
- cin cinna bar
- gn galena
- molybdenite
- mo molybdenite
- py pyrite
1. GOLD PLACER DEPOSITS

(References: Lindgren, 1933; Yeend, 1980, 1981a, b; Warren Yeend in Cox and Singer, 1986)

**General description**

Gold placer deposits consist of elemental gold in grains and rarely nuggets in gravel, sand, silt, and clay and their consolidated equivalents, in alluvial, beach, aeolian, and rarely glacial deposits. The most common host rocks are alluvial gravel and conglomerate with white quartz clasts and heavy minerals that are indicative of low-grade metamorphic rocks containing quartz veins or of quartz veins in the upper-level exposures of granitic plutons. Sand and sandstone are of secondary importance. The deposits occur in a high-energy alluvial depositional environment where gradients decrease and river velocities lower. The major deposit minerals are gold, sometimes with attached quartz, magnetite, and (or) ilmenite.

**Recognition criteria**

1. Geologically favorable environment consisting of stream gravels or conglomerates in a region containing gold-bearing lode deposits.
2. Known mine, deposit, prospect, or occurrence.
3. Occurrence of gold and cinnabar in heavy-mineral-concentrate samples.
4. Anomalous values of Au in heavy-mineral-concentrate samples.

**Assessment**

Areas 1 and 2 in the northern part of the quadrangle, and area 3 in the southwestern part of the quadrangle (sheet 1) are geologically favorable for undiscovered gold placer deposits because they contain stream gravels, conglomerates, or glacial fluviatile deposits occurring downstream or downglacier from areas with anomalous values of Au in bedrock and gold in heavy-mineral-concentrate samples. Areas 4, 6, 7, 9, and 11 (sheet 1) in the south-central and southeastern part of the quadrangle are also geologically favorable because of containing stream gravels, conglomerates, or glacial fluviatile deposits that occur downstream or downglacier from Tertiary sandstone and conglomerate in the Wrangellia terrane that exhibit gold in panned samples.

Areas 1 through 4, 9, and 11 are assessed to have a moderate potential for undiscovered gold placer deposits, because of containing mine occurrences, gold in heavy-mineral-concentrate samples, and (or) anomalous values of Au in heavy-mineral-concentrate samples (criteria 2 through 4). Areas 5 and 7 are assessed to have a low potential because of containing only occurrences of gold and cinnabar in heavy-mineral-concentrate samples (criterion 3). A grade-tonnage model suggests that one-half of gold placer deposits contain 1.1 million tonnes or more and gold grades greater than 0.2 g/t for one-half of the deposits (G.J. Orris and J.D. Bliss in Cox and Singer, 1986).

2. PLATINUM PLACER DEPOSITS

(References: Lindgren, 1933; Stumpf and Tarkian, 1976; Warren Yeend and N.J. Page in Cox and Singer, 1986)

**General description**

Platinum placer deposits consist of elemental platinum and Pt-group minerals in grains and rarely nuggets in alluvial, beach, aeolian, and rarely glacial deposits. The most common host rocks are alluvial gravel and conglomerate with clasts of cumulate mafic or ultramafic rock or alpine type peridotite and heavy minerals indicative of mafic or ultramafic terrane. 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**

Areas 5, 8, and 10 (sheet 1) are geologically favorable for undiscovered platinum placer deposits because of containing stream gravels, conglomerates, or glacial fluviatile 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 gold grades greater than 0.2 g/t or more in one-half of the deposits (D.A. Singer and N.J. Page in Cox and Singer, 1986).

3. HOT-SPRINGS Au DEPOSITS

(References: 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. Fine-grained silica, particularly chalcedony, and quartz veins occur in the silica breccia with gold, pyrite, and Sb- and As-sulfides. Extensive alteration occurs with formation of siliceous sinter, stockworks, veins, and cemented breccia usually controlled by a pervasive fracture system. The ore-depositional environment consists of hot springs in a volcanic pile of an Andean-type arc 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 relict disseminated pyrite.
7. Hot-spring deposits.

**Secondary criteria**

1. Stockworks formed by abundant quartz veins.
2. Local areas of argillite to advanced argillite 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**

Areas J through N (sheet 2) are underlain by Tertiary sedimentary and volcanic rocks and are geologically favorable.
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 cinnabar in heavy-mineral-concentrate samples (secondary criterion 6; 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 cinnabar 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, locally sphalerite, galena, and cinnabar. The host rocks consist of andesite to rhyolite flows, ash flows, sometimes overlying older volcanic sequences 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 combined. 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, tuffs, and volcaniclastic rocks locally with interbedded fluvial or lacustrine sedimentary rocks.
2. Quartz-vein emplacement along major faults, shear zones, axial planes, and fold axes.
3. Greenschist facies regional metamorphism.
4. Open-space filling in veins and altered areas with banded veins, vuggy, fine-grained crystals, or possibly large zoned crystals.
5. Quartz veins, stockworks, or breccia pipes.
6. Conspicuous wall-rock alteration consisting of extensive replacement by propylitic, sericitic, and argilotic assemblages and replacement by silica, 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, cinnabar, 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 Sliau 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, stockworks, or breccia pipes (diagnostic criterion 3), conspicuous wall-rock alteration and disseminated pyrite (diagnostic criteria 6 and 7), and cinnabar and chalcopyrite in heavy-mineral-concentrate samples (secondary criterion 4; table 4). Areas K through N are assessed to have a very low potential because of exhibiting no secondary criteria, or only locally anomalous values of Cu in rock samples (secondary criterion 1) and or cinnabar, epidote, sphalerite, and galena in heavy-mineral-concentrate samples (secondary criterion 4; table 4).

Grade-tonnage models for the quartz-adularia and quartz-alunite subtypes of epithermal precious- and base-metal deposits are published by D.L. Mosler and W.D. Mendle in Singer and Mosler (1985a) and Cox and Singer (1985b). The data suggest that if quartz-adularia type deposits exist in the quadrangle, then one-half would contain 900,000 tonnes or more, whereas the quartz-alunite type would contain 450,000 tonnes or more.

For the quartz-adularia deposits, gold grades range from 4.3 g/t or more for the richest half of the deposits to 1.9 g/t or more in the richest tenth of the deposits. Silver grades vary from 130 g/t or more in the richest half, while ten percent of the deposits contain 500 g/t or more. Copper and zinc grades are low. Silver grades tend to be higher in the quartz-alunite type. Lead and zinc are present in some quartz-adularia deposits. Copper is present in less than one-half of the deposits. For the quartz-alunite deposits, gold grades range from 5.6 g/t or more for the richest half of the deposits to 12 g/t or more in the richest tenth of the deposits. Silver grades vary from 13 g/t or more in the richest half, while ten percent of the deposits contain 62 g/t or more.

5. GOLD QUARTZ VEIN DEPOSITS
(References: Clark, 1969; Boyle, 1961; 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 greenstone belts—regionally metamorphosed and penetratively deformed oceanic 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 accreted 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 graywacke, shale, or chert intruded by granitic plutons.
2. Known deposit, prospect, or occurrence.
3. Greenschist facies regional metamorphism.
4. Quartz veins, with or without, with Fe-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, axial planes, and fold 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, Au, Ag, or Hg in stream-sediment samples.
5. Anomalous values of As, Sb, Cu, Mo, 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 Macomb, Jarvis Creek Glacier, and Hayen Glacier subterrane of the Yukon-Tanana terrane (areas 1 through 4, sheet 3, table 5). South of the Denali fault, the geologically favorable area is the Macdonald Glacier meta-sedimentary belt in the Macdonald terrane (area 5, sheet 3, table 5). These areas exhibit greenstone-facies regional metamorphism and quartz veins (diagnostic criteria 3 and 4). In addition, these areas exhibit post-metamorphic granitic plutons, quartz-vein emplacement along major or minor structures, and anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples (secondary criteria 1 through 6; table 5).

The Macomb subterrane (area 1) and Jarvis Creek Glacier subterrane (area 2), both in the Yukon-Tanana terrane, and the Macdonald Glacier meta-sedimentary belt (area 4) of the Macdonald terrane, are assessed to have a moderate potential for undiscovered deposits because of exhibiting gold, arsenopyrite, and pyrite in heavy-mineral-concentrate samples (secondary criterion 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 Hayen Glacier 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 criterion 6; table 5). A grade-tonnage model for low-sulfide Au quartz vein deposits was published by J.D. Biles in Singer and Mosier (1983b) 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 tenth of the deposits to 38 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 in sparse 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 relic igneous and metasomatic minerals in the greenstone and volcanic rocks that are replaced by irregular aggregates of chlorite, epidote, actinolite, carbonate, or quartz. The ore depositional environment consists of simultaneous alteration, regional metamorphism, and deformation of oceanic basalt in terranes 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 deposit, prospect, or occurrence.

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

(References: Bateman and McLaughlin, 1920; Armstrong and Mackevey, 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 chalcocite, bornite, and minor covellite, enargite, pyrite, galesite, 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 greenstone and overlying limestone, and the development of a regional sabkha facies, are major structural controls for the deposits. The veins, pods, and masses crosscut sedimentology and replace relic igneous and metasomatic minerals in the greenstone. The ore depositional environment appears to be a combination of development of sabkha 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 metabasalt, conformably overlain by limestone or dolomite.
2. Known deposit, prospect, or occurrence.
3. Prehnite-pumpellyite to lower greenschist-facies regional metamorphism.
4. Weathered sabkha facies in carbonate rock overlying metabasalt.
5. Quartz-epidote-sulfide-copper-carbonate veins in metabasalt.
Secondary criteria
1. Anomalous values of Cu, Pb, Zn, or Ag in rock samples.
2. Anomalous values of Cu, Pb, Zn, or Ag in stream-sediment samples.
3. Anomalous values of Cu, Pb, Zn, or Ag in heavy-mineral-concentrate samples.
4. Anomalous values of Cu, Pb, Zn, or Ag in stream-sediment samples.
5. Occurrence of chalcopyrite, bornite, covellite, galena, sphalerite, or pyrite in heavy-mineral-concentrate samples.

Assessment (table 7, map sheet 3)
The geologically favorable areas for undiscovered Kenncott Cu-Ag deposits are parts of the Slana River and Tangle subterrane of the Wrangellia terrane (areas G through I, map sheet 2). North of the Denali fault, the geologically favorable areas are the Tetelna Volcanic- and Slana Spur Formation of the Slana River subterrane of the Wrangellia terrane (areas G through I, 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 dacitic to andesitic volcanic rocks. Areas B, E and G are assessed to have a moderate potential because of exhibiting few, if any known deposits, prospects, or occurrences, dacitic to andesitic volcanic rocks, and dacitic to andesitic pyroclastic rocks.

Diagnostic Criteria
1. Geologically favorable environment of submarine volcanic rock 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 domes. The ore depositional environment is mainly hot springs related to marine volcanism in inland-arc or extensional rifting regimes. The deposit minerals include pyrite, chalcopyrite, sphalerite, and lesser galena, tetrahedrite, tennantite, and magnetite. Local zeolite, clay, sericite, chlorite, and silica alteration may occur.

Secondary criteria
1. Primary barite or gypsum 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.

3. KUROKO MASSIVE SULFIDE DEPOSITS
(References: Lambert and Sato, 1974; Scott, 1980; Franklin and others, 1981; D.A. Singer in Cox and Singer, 1986).

8. KUROKO MASSIVE SULFIDE DEPOSITS
(References: Lambert and Sato, 1974; Scott, 1980; Franklin and others, 1981; D.A. Singer in Cox and Singer, 1986).

General description
Kuroko 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 domes. The ore depositional environment is mainly hot springs related to marine volcanism in inland-arc or extensional rifting regimes. The deposit minerals include pyrite, chalcopyrite, sphalerite, and lesser galena, tetrahedrite, tennantite, 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 composition, and associated tuffs, breccias, and sedimentary rocks.
2. Known deposit, prospect, or occurrence.
3. Felsic pyroclastic deposits.
4. Siliceous chemical sedimentary rocks.
5. Hydrothermally altered volcanic rocks.

Secondary criteria
1. Primary barite or gypsum 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 stream-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)
The geologically favorable areas for Kuroko 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 3.5 percent copper. Average zinc grades of 2 percent or more occur in one-half or more of the deposits. The richest tenth contain at least 1.9 percent lead. Previous 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
(References: Titley, 1975; Sutherland Brown, 1976; Colley and Greenbaum, 1980; D.P. Cox in Cox and Singer, 1986).

General description
Porphyry Cu(Au-Ag) deposits consist of chalcopyrite, bornite, or pyrite, and minor molybdenite, sphalerite, galena, or arsenopyrite in stockwork veins in hydrothermally altered, shallowly emplaced porphyry and adjacent country rock. The granitic host rocks include quartz diorite to quartz monzonite, syenite, and small, hypabyssal andesite to rhyodacite, and trachyte stocks, dikes, and sills. 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
The deposits have average copper grades of 0.50 percent or more 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: Lowell and Gubert, 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, chalcopyrite and molybdenite, and minor sphalerite or galena. The sulfides occur in stockwork veins in porphyritic granite or hypabyssal intrusive rocks or in wall rocks adjacent to the igneous rocks. The intrusive rocks include quartz diorite to granite plutons or 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 granitic plutons in either an island arc, Andean-type arc, or a rifted continental setting. The areas of favorable environment are generally porphyry quartz diorite to quartz monzonite or hypabyssal rocks and country rock.

Assessment and grade-tonnage model

(table 9, map sheet 4)

The geologically favorable areas for undiscovered porphyry Cu-Mo deposits are the Tetelina Volcanics and Siana Spur Formation in the Siana River subterrane of the Wrangellia terrane (areas G-1 through G3, H1 through H3, sheet 2, table 9). These areas are the only ones in the quadrangle that are intruded by porphyry granite plutons in this case, shallow-level, andesite to dacite stocks, dikes, and sills.

1. Multiple intrusive phases, some porphyritic.
2. Volcanic or intrusive breccias, locally with disseminated or massive sulfides.
3. Dikes, quartz veins, or stockwork veinlets with sulfide minerals.
4. Replacement massive sulfide minerals or skarn in country rock.
5. Breccia pipes locally with sulfides.
6. Anomalous values of Cu, Mo, Pb, Zn, Ag, Au, or Sn in rock samples.
7. Anomalous values of Cu, Mo, Pb, Zn, Ag, Au, or Sn in stream-sediment samples.
8. U-shaped aeromagnetic anomaly patterns, for example, strong, local equidimensional aeromagnetic highs with reentrant or central lows.

Assessment and grade-tonnage model

(table 10, map sheet N)

The geologically favorable areas for undiscovered porphyry Cu-Mo deposits are the quadrangle (areas A through F, G1 through G6, H1 through H4, I through K, L1 through L4, and M through R, sheet N, table 10). North of the Denali fault, abundant granitic plutons occur in the Lake George, Macomb, and Jarvis Creek subdivisions of the Yukon-Tanana terrane and the Aurora Peak terrane (areas A, C, E, G, H, sheet N, and south of the Denali fault, in the Mahonen terrane and the Siana...
River subterrane of the Wrangella terrane (areas J, N, O, sheet 4). For a detailed assessment, areas G, H, and I are divided into subareas (sheet 4, table 10).

Areas K and M, small isolated granitic plutons in the Wrangella terrane, are assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences; coeval granitic, pyroxenitic, 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 areas K and M, small isolated granitic plutons in the Wrangella terrane, are assessed to have a moderate potential because of exhibiting fewer diagnostic criteria, mainly coeval granitic, pyroxenitic, or volcanic rocks; numerous faults and brecciated country rock; or hydrothermal alteration (diagnostic criteria 3, 4, and 6). In addition, these areas relative to areas K and M, exhibit fewer secondary criteria, for example, a moderate number of anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and a moderate amount of base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 10).

Relative to the areas with moderate potential, areas A, D, F, G1-G3, H1, H3, H4, J, L2, L3, and O-R are assessed to have only a low potential because of exhibiting fewer and sparser diagnostic criteria, mainly small and sparse areas with coeval granitic, pyroxenitic, or volcanic rocks, and numerous faults and brecciated country rock (diagnostic criteria 3 and 4), and fewer and sparser secondary criteria, mainly 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. Mosier, and D.P. Cox in 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 have at least 0.4 g/t gold; 10 percent of the deposits contain 25 g/t silver. For porphyry Mo deposits (W.D. Menzies 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 0.08% percent or more molybdenum. The richest tenth contain 0.13 percent molybdenum.

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

General description

W-Mo and Cu-Zn-Pb skarn deposits consist of various combinations of scheelite-powellite, molybdenite, chalcopyrite, bornite, sphalerite, galena, pyrite, pyrrhotite, and (or) magnetite with accessory arsenopyrite, tetrahedrite, gold, or other ore minerals that occur in contact metamorphosed calcareous or impure calcareous rocks. The contact metamorphosed rocks or skarns are generally adjacent to granitic plutons ranging in composition from quartz diorite to granite. The extent of replacement of calcareous rocks varies from a few meters to a few hundred meters away from the granitic rocks. The extent of replacement is highly variable and often controlled by fractures, faults, and folds. Skarns commonly exhibit a complex mineralogic zonation. Replacement minerals and textures are often extremely varied, with the most common minerals being andradite-grossularite garnet, diopside-hedenbergite clinopyroxene, wollastonite, epidote, idocrase, 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 arc 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 ar-spatite, grossularite, diopside-hedenbergite, epidote, hornblende, wollastonite, epidote, actinolite, idocrase, and quartz.
4. Bleaching of calcareous wall rocks, for example, disappearance of graphite and local silification.

Secondary criteria

1. Abundant fractures, faults, 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, Sn, Ag, Au, or Sn in rock samples.
5. Anomalous values of W, Mo, Cu, Pb, Sn, Ag, Au, or Sn in stream-sediment samples.
6. Anomalous values of W, Mo, Cu, Pb, Sn, Ag, 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-magnetic 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 Macomb and Jarvis Creek Glade subterrane of the Wrangella terrane and the Nelson Peak terrane north of the Denali fault (areas A, C, H1 through H4, sheet 4, table 11), the East Susitna batholith of the Mad centre terrane, and the Wrangella terrane south of the Denali fault (areas J, L1 through L4, P-R, sheet 4, table 11). For a detailed assessment, areas H and L are divided into subareas (sheet 4, table 11).

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 4; 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, 4, 5, 7, 8; table 11).

Relative to area L2, areas A, C, H2, H3, L1, L3, L4, and P-R are assessed to have a moderate potential because of exhibiting fewer and 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, and base-metal sulfides in heavy-mineral-concentrate samples, and in some
areas an appropriate aero magnetic signature (secondary criteria 4 through 8; table 11).

Relative to the above areas with moderate potential, areas H1, H4, 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, minor oxides and base-metal sulfides in heavy-mineral-concentrate samples, and an appropriate aero magnetic signature (secondary criteria 4 through 8; table 11).

Grade-tonnage models were prepared for Cu and W skarn deposits by G.M. Jones and W.D. Menzie in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if Cu skarn deposits exist in the quadrangle, then one-half would contain 0.6 million tonnes or more, and the largest tenth of the deposits contain 9.6 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 4.0 percent copper. 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 0.57 percent WO3 or more, and the richest have at least 1.4 percent WO3.

12. PORPHYRY Sn DEPOSITS

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 granitic rocks are generally intensely hydrothermally altered to various combinations of K-feldspar, albite, sericite, chlorite, quartz, topaz, tourmaline, and fluorite. The ore depositional environment consists of intrusion of silicic granitic rocks into a continental fold belt of thick platform rocks with minor volcanic rocks. This deposit type may be associated with Sn-greisen deposits. However, no greisen occurrences were observed in the field, either because of poor exposures in geologically favorable areas or because of a lack of occurrence.

Diagnostic criteria

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

Secondary criteria

1. Upper-level cupolas and roof zones of plutons.
2. Locally extensive alteration in granitic 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 heavy-mineral-concentrate samples.
9. Occurrence of cassiterite, fluorite, 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 Macon and Jarvis Creek Glacier terrane of the Yukon-Tanana terrane and the Aurora Peak terrane north of the Bena fault (areas A, D, and F-H, 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 granitic rocks (diagnostic criteria 2) (areas A, D, and F). Although all areas show anomalous values of appropriate elements in rock, stream-sediment and heavy-mineral-concentrate samples, and minor oxides and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 8; table 12).

Relative to the above areas with moderate potential, areas G1 through G4 and H1 are assessed to have a low potential because of exhibiting fewer and sparser diagnostic criteria, mainly folded continental-platform sedimentary rocks, and in a few areas, epizonal granitic rocks (diagnostic criteria 3 and 4; table 12). In addition, these areas exhibit few and sparser secondary criteria, mainly, local areas of a few anomalous values of appropriate elements in rock, stream-sediment and heavy-mineral-concentrate samples, and a very few oxides and sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 8; table 12).

13. GABBROIC Ni-Cu DEPOSITS

General description

Gabbroic Ni-Cu deposits (adapted from synorogenetic-syngneogenic Ni-Cu deposit of Cox and Singer, 1986) occur as portions of pyrrhotite, pentlandite, chalcopyrite, pyrite, and accompanying sulfides. The host rocks consist of various combinations of olivine-spinel cumulates, plagioclase-spinel cumulates, olivine-plagioclase cumulates, gabbro, and norite. The ore depositional environment consists of moderately large bodies of cumulate olivine and plagioclase rocks, gabbroic rocks, and gabbro-norite rocks. The host rocks intrude into greenstone belts, possibly associated with rifts, followed by a period of accretion, deformation, and regional-grade metamorphism.

Diagnostic criteria

1. Geologically favorable environment of cumulate olivine 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 aero magnetic gradient or high.

Assessment and grade-tonnage model (table 13, map sheet 1)

The geologically favorable areas for undiscovered gabbroic Ni-Cu deposits are intrusive gabbros, diabases, and cumulate olivine and ultramafic rocks in the Flume River and Tangle subterrane of the Wrangellia terrane (areas A-E,
The geologically favorable areas for undiscovered podiform chrome deposits are the terrane of ultramafic and associated rocks in the southeastern part of the quadrangle.

A grade-tonnage model was prepared by D.A. Singer and N.J. Page in Cox and Singer (1986) based on podiform deposits from California and Oregon. Chrome grade is negatively correlated with tonnes. The plotted grades and tonnages of the prototype deposits demonstrate that if podiform chrome deposits exist in the quadrangle, then one-half should contain 130 tonnes or more, and the largest tenth should contain 2,000 tonnes or more. Fifty percent of the deposits have average chrome grades of 44.0 percent or more Cr₂O₃, and the richest tenth have at least 50 percent Cr₂O₃. Cobalt and the platinum-group elements are present in some of these deposits.

REFERENCES CITED


---1985b, Age of intrusion and metamorphism of a granodiorite in the Lake George terrane, northeastern Mount Hayes quadrangle, Alaska, in Bartsch-Winkler,


Lehurley, A.F., Church, S.E., and Nokleberg, W.J., 1985, Lead isotope in sulfide deposits from the Jarvis Creek Glacier and Wrangellia terranes, Mount Hayes quadrangle, eastern Alaska Range, in Bartsch-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.
**EXPLANATION**

- **Cenozoic sedimentary and volcanic rocks**
  - Unconformity

- **Granitic plutons**

- **Gabbro to granodiorite plutons**
  - Intrusive contact

**Yukon-Tanana Terrane**

- **YTL, Lake George subterrane**
- **YTM, Macamb subterrane**
- **YTJ, Jarvis Creek Glacier subterrane**
- **YTH, Hayes Glacier subterrane**
  - Nanana Glacier fault

**Aurora Peak Terrane**

- **Splay of Denali fault**

**Windy Terrane**

- **Splay of Denali fault**

**MacLaren Terrane**

- **Mississippian and Older**
  - **MLm**
    - MacLaren Glacier metamorphic belt
  - **CW**
    - Splay of Braxon Gulch thrust

**Clearwater Terrane**

**Wrangellia Terrane**

- **Jurassic to Late Paleozoic**
  - **WRS, Slana River subterrane**
  - **WRT, Tangle subterrane**
  - Contact
  - Fault--dotted where concealed

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