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METALLIFEROUS MINERAL RESOURCE ASSESSMENT OF THE MOUNT HAYES QUADRANGLE, EASTERN ALASKA RANGE, ALASKA

By

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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 that occur, 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-Ag deposits in the south-central and southeastern parts 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; in addition, the Maclaren Glacier metamorphic belt of the Maclaren terrane exhibits high potential for porphyry Cu-Mo deposits in the southwestern part of the quadrangle; and (4) The Tangle subterrane of the Wrangellia terrane in the southwest part of the quadrangle exhibits high potential for W-Mo and Cu-Zn-Pb skarn deposits adjacent to a small granitic pluton (area L2, sheet 4). Areas with moderate or low potential for various undiscovered types of mineral deposits are described in tables 1 to 14 and sheets 1 to 4.

INTRODUCTION

This report and the accompanying maps assess the metalliferous mineral resource potential of the Mount Hayes quadrangle, eastern Alaska Range, Alaska. The assessment is the major result of a five-year study done under the Alaskan Mineral Resource Assessment Program (AMRAP). Field work for the assessment was done during the summers of 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 Nabesna 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 uses, its remoteness from markets would result in high, uncompetitive development and transportation costs. Local granite and decomposed granite are obtained from one or two pits along the Alaska Highway in the northeast part of the quadrangle. The geologic environment in the quadrangle is unfavorable for oil, gas, or geothermal energy. Coal has been 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 128 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, 1981a, b);

And (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 deposit, and deposit compilation studies of Rose (1965, 1966a, b,

1967), Rose and Saunders (1965), Cobb (1972, 1979), and MacKevett and Holloway (1977) were particularly useful. Valuable tours of lode mineral deposits, prospects, and occurrences, were provided by Michael Ross, C.R. Nauman, and S.R. Newkirk, and of placer mines by William Beerman, Douglas Culp, Lewis Elmer, John Johnson, and Richard Osborne. Valuable discussions of geology and mineral deposits were held with H.C. Berg, Richard Cavalero, E.R. Chipp, Donald Grybeck, D.L. Jones, E.M. MacKevett, Jr., C.R. Nauman, S.R. Newkirk, D.H. Richter, Michael Ross, N.J. Silberling, and T.E. Smith. We are indebted to H.C. Berg, Donald Grybeck, T.P. Miller, A.T. Ovenshine, and G.R. Winkler who encouraged and supported this mineral resource assessment. This assessment benefited from the constructive reviews of Donald Grybeck and J.E. Case.

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 4,180 m in elevation and spectacular valley glaciers as long as 65 km. The range is bisected by the Denali fault, which is a major geologic and geographic boundary between the Yukon River basin in interior Alaska to the north, and the Copper River basin of southern Alaska to the south.

The bedrock geology is subdivided into various tectonostratigraphic terranes (fig. 1). The term "tectonostratigraphic terrane" (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 differing 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 Maclaren 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 (1968), Matteson (1973), Bond (1976), Stout (1976), Richter and others (1977), and Nokleberg and others (1982). Isotopic studies have been published by Smith and Turner (1973), Turner and Smith (1974), Wilson and Turner (1975), Aleinikoff and others (1981, 1983), Aleinikoff (1984), Aleinikoff and Nokleberg (1984a, b, 1985a, b), LeHurray and others (1985), 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 (1985). Summary studies of mineral deposits and metallogenesis have been published by Nokleberg and others (1984) and Nokleberg and Lange (1985). A geologic bibliography 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 Gromme (1984), and Campbell and Nokleberg (1985).

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 subterranes (fig. 1; Aleinikoff and Nokleberg, 1985a; Nokleberg and Aleinikoff, 1985; Nokleberg and others, 1986). These subterranes are interpreted as various levels of a complex and highly metamorphosed Devonian and Mississippian continental margin igneous arc (Nokleberg and Aleinikoff, 1985). Because of regional tilting toward the south near the Denali fault, the deeper granitic rocks of the arc occur to the north, and the shallower volcanic rock of the arc occur to the south. The Lake George, 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 subterranes 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 northeastern part of the quadrangle, and is composed of: (1) polydeformed, coarse-grained pelitic muscovite-quartz-biotite-garnet schist derived from quartz-rich to clay-rich shale of Devonian or older age; and (2) relatively younger Devonian and Mississippian medium-grained, gneissose granodiorite and diorite, and coarse-grained augen gneiss derived from granite and granodiorite. The pelitic schist and metamorphosed plutonic rocks are ductily deformed and regionally metamorphosed at middle or upper amphibolite facies into mylonitic schist and mylonitic gneiss, and exhibit local retrogression to the lower greenschist facies (Nokleberg and others, 1986). The pelitic schist and metamorphosed plutonic rocks are intruded by mid-Cretaceous to early Tertiary diorite, granodiorite, and granite. Small areas of some plutons are extensively hydrothermally altered. These plutonic rocks are locally slightly to moderate schistose and are weakly metamorphosed at lower greenschist facies. The Lake George subterrane is bounded to the south by the Tanana River fault.

Macomb Subterrane of Yukon-Tanana terrane

The Macomb subterrane (fig. 1; Nokleberg and Aleinikoff, 1985) occurs south of the Lake George subterrane in the northeastern part of the quadrangle. The Macomb subterrane is composed of: (1) older, polydeformed, medium-grained pelitic schist, calc-schist, and quartz-feldspar-biotite schist derived from shale, marl, and sandstone of Devonian or older age; and (2) a suite of relatively younger, shallow-level, fine- to medium-grained gneissose granite, granodiorite, quartz diorite, and diorite of Devonian age. The metasedimentary rocks and the metamorphosed plutonic rocks are ductily deformed and regionally metamorphosed at epidote-amphibolite to upper greenschist facies into mylonitic gneiss and schist (Nokleberg and others, 1986). The metasedimentary and metamorphosed plutonic rocks are intruded by younger and less deformed and metamorphosed mid-Cretaceous and possibly younger granitic rocks ranging in composition from quartz diorite to granite. These younger plutonic rocks are locally weakly to moderately deformed and metamorphosed. The Macomb subterrane is bounded to the south by the Elting Creek fault.

Jarvis Creek Glacier subterrane of Yukon-Tanana terrane

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-grained 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 consist of various proportions of pelitic schist, quartzite, calc-schist, quartz-feldspar schist, and marble. Protoliths for these rocks include shale, quartz sandstone, marl, sandstone, volcanic graywacke, and limestone. The metavolcanic rocks consist of various proportions of abundant meta-andesite and metaquartz keratophyre, less abundant metadacite and metabasalt, and very sparse metarhyodacite. In the north-central part of the quadrangle at Donnely Dome, the Jarvis Creek Glacier subterrane is intruded by intensely deformed and schistose Devonian metagranodiorite, and sparse augen gneiss, derived from granite and granodiorite.

The Jarvis Creek Glacier subterrane is ductily deformed and regionally metamorphosed at greenschist facies into mylonitic 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 Glacier 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, Molybdenum Ridge, and Buchanan Creek areas. In the central part of the Jarvis Creek Glacier subterrane is an intrusive complex of early Tertiary(?) monzonite, alkali gabbro, lamprophyre, and quartz diorite, partly surrounded by a ring dike of granite. Local comagmatic lamprophyre dikes also occur in the eastern part of the Jarvis Creek subterrane. Locally abundant gabbro, diabase, and metagabbro dikes also cut the metamorphic rocks of the Jarvis Creek Glacier subterrane. The Jarvis Creek Glacier subterrane is bounded to the south by the Hayes Glacier and Mount Gakona faults.

Hayes Glacier subterrane of Yukon-Tanana terrane

The Hayes Glacier subterrane (fig. 1; Nokleberg and Aleinikoff, 1985) occurs across the northern part of the quadrangle, south of the Jarvis Creek Glacier subterrane. The Hayes Glacier subterrane consists of polydeformed phyllite, 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 consist of various proportions of pelitic phyllite, quartz-rich phyllite, quartz-feldspar phyllite, and minor calc-phyllite and marble derived from shale, chert or less likely quartz siltstone, volcanic graywacke, marl, and limestone. In the western part of the quadrangle, the metasedimentary 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 marble of pre-mid-Cretaceous age. The metavolcanic rocks consist of varying proportions of abundant meta-andesite and metamorphosed quartz keratophyre, and sparse metadacite and 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, southeast of the Robertson River, the Hines Creek fault, and the Jarvis Creek Glacier and Hayes Glacier subterranes are intruded and welded together by a Late Cretaceous granite pluton. In the western part of the quadrangle, the Hayes Glacier subterrane is intruded by the nonschistose granite pluton of Mount Hayes, of apparent Late Cretaceous or early Tertiary age. The Hayes Glacier subterrane is also intruded by relatively older and locally abundant mid- or Late Cretaceous metagabbro and metadiabase dikes and sills. The Hayes Glacier subterrane also contains sparse, nonschistose lamprophyre dikes and one small alkali gabbro pluton of apparant early Tertiary age. The Hayes Glacier subterrane is bounded to the south by the Nenana Glacier and Denali faults.

Aurora Peak terrane

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

Windy terrane

The Windy terrane (fig. 1; Jones and others, 1984; Nokleberg and others, 1985) occurs south of the Hayes Glacier subterrane and Aurora Peak terrane, north of the Denali fault. The Windy terrane consists of: (1) argillite, limestone, marl, quartz-pebble siltstone, quartz sandstone, graywacke, conglomerate of Devonian or Silurian age; and (2) lesser andesite and dacite. Unlike terranes to the north, the Windy terrane exhibits primary bedding, and sedimertary or volcanic textures and structures. The Windy terrane is singly deformed with a weak schistosity; locally, however, the terrane contains sparse intensely deformed phyllonite and protomylonite in narrow shear zones and exhibits incipient greenschist facies metamorphism. The Windy terrane is intruded in the central part of the quadrangle by a fault-bounded Late Cretaceous pluton of locally slightly schistose diorite to granite. The Windy terrane is intruded by dikes of Cretaceous metagabbro and diabase. The Windy terrane is bounded to the south by the Denali fault.

BEDROCK UNITS SOUTH OF DENALI FAULT

East Susitna batholith of Maclaren terrane

The Maclaren terrane (fig. 1; Jones and others, 1984) occurs south of the Denali fault in the central and western parts of the quadrangle and consists of the East Susitna batholith to the north and the Maclaren Glacier metamorphic belt to the south (Nokleberg and others, 1981c, 1982, 1985). The East Susitna batholith consists predominantly of regionally metamorphosed, mid-Cretaceous to early Tertiary diorite and granodiorite, and lesser granite. Locally, these gneissose granitic rocks grade into migmatite, migmatitic schist, and schist and amphibolite composed of older, more intensely 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 contact between the East Susitna batholith and the Maclaren Glacier metamorphic belt is a faulted intrusive contact named the Meteor Peak fault (Nokleberg and others, 1982, 1985). The East Susitna batholith is ductily deformed into mylonitic gneiss and schist and regionally metamorphosed at the upper amphibolite facies, with local retrograde metamorphism to lower greenschist facies (Nokleberg and others, 1985). A pluton of younger, nonschistose, middle Tertiary granite intrudes the northwest part of the East Susitna batholith immediately south of the Denali fault (Smith and Turner, 1973; Turner and Smith, 1974).

Maclaren Glacier metamorphic belt of Maclaren terrane

The Maclaren Glacier metamorphic belt (fig. 1), south of the East Susitna batholith, is a prograde, Barrovian-type metamorphic belt formed in metasedimentary and metavolcanic rocks. From south to north, the principal units are pre-Late Jurassic argillite and metagraywacke, phyllite, and schist and amphibolite (Nokleberg and others, 1981c, 1982, 1985). Contacts between the three map units are generally faults which have produced intense shearing and abrupt changes of metamorphic facies at each contact. The argillite and metagraywacke unit, the lowest-grade unit in the metamorphic belt, is composed predominantly of volcanic graywacke and siltstone, and sparse andesite and basalt, with lesser calcareous and quartz siltstone. The Maclaren 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 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 Maclaren Glacier metamorphic belt is bounded to the south by the Broxson 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 Broxson Gulch thrust between the Maclaren 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 Broxson 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 disconformably overlying massive basalt flows of the Upper Triassic Nikolai Greenstone, younger Mesozoic flysch, 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 Pennsylvanian 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, amydgaloidal basalt flows about 1,500 m thick. Locally extensive gabbro dikes and cumulate mafic 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 graywacke of the Gravina-Nutzotin belt, and sparse deposits of Tertiary sandstone, conglomerate, and rhyolite 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 sedimentary rock consists of aquagene 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, amydgaloidal flows. Sparse Upper Triassic marble overlies the Nikolai; younger Mesozoic sedimentary rocks are lacking in the Tangle subterrane. Extensive gabbro and cumulate mafic 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 mafic rock and sparse associated granitic rock that represents part of a string of alpine peridotites that occur along or near the Denali fault (fig. 1; Richter and others, 1977; Nokleberg and others, 1982). The ultramafic rocks are chiefly dark-green serpentinized pyroxenite and peridotite, light-gray to green dunite, and dark-green schistose amphibolite and lighter hornblende-plagioclase gneiss derived from gabbro. Interlayered with the gneiss are rare thin lenses of light-green and gray marble and zones of dark-gray graphitic schist. The ultramafic and mafic rocks are intruded by weakly schistose, light-gray tonalite and granite. The ultramafic and associated rocks are 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, or occurrences that share a common geologic origin. A "mineral deposit" is defined as a concentration of potentially economically valuable minerals. A "mineral prospect" is defined as a concentration of potentially economically valuable minerals that shows some sign of development, such as an exploration pit or drill hole. A "mineral occurrence" is defined as any other concentration of potentially economically valuable minerals. The mineral deposit models in Erickson (1982), Cox (1983a, b), and Cox and Singer (1986), and the cited references were used to formulate the types of mineral deposits that we consider important for this assessment. These types of mineral deposits are described in the subsequent assessment sections and are listed below in order increasing of depth of formation.

(1) Gold placer deposits
(2) Platinum placer deposits
(3) Hot-spring Au deposits
(4) Kuroko massive sulfide deposits
(5) Epithermal precious and base metal deposits
(6) Gold quartz vein deposits
(7) Cu-Ag quartz vein deposits
(8) Kennicott Cu-Ag deposits
(9) Porphyry Cu-Au-Ag deposits
(10) Porphyry Cu-Mo deposits
(11) W-Mo and Cu-Zn-Pb skarn deposits
(12) Porphyry Sn deposits
(13) Gabbroic Ni-Cu deposits
(14) Podiform chromite 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 subterranes of Yukon-Tanana terrane

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 Elting 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) during intrusion of Cretaceous granitic plutons.

Jarvis Creek Glacier subterrane of Yukon-Tanana terrane

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 form two major belts; a western belt, west of the Delta River, between the Hayes and McGinnis 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, 23,000 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 meta-andesite, metadacite, metamorphosed quartz keratophyre flows and tuffs, metamorphosed volcanic graywacke and siltstone, and quartz schist, part of which may be derived from quartz exhalite. Preliminary studies of these deposits have been published by Nauman and others (1980), Anderson (1982), Culp (1982), Lange and Nokleberg (1984), and Nokleberg and Lange (1985). Field, petrographic, geochemical, and isotopic data indicate these deposits formed in a Devonian submarine island-arc environment and were subsequently deformed, metamorphosed, and remobilized in the mid-Cretaceous (Lange and Nokleberg, 1984; Nokleberg and Lange, 1985).

Other lode mineral occurrences in the metasedimentary rock unit of the Jarvis Creek Glacier subterrane are: (1) grab samples of quartz veins in iron-stained schist, usually with disseminated pyrite, and containing as much as 450 ppm Pb, 30 ppm Sn, and 7 ppm Ag; (2) grab samples of iron-stained schist, usually with disseminated pyrite, and containing as much as 350 ppm Pb, 300 ppm Sn, 30 ppm Mo; and (3) one grab sample of chalcopyrite and malachite in metagabbro containing 55,000 ppm Cu, 7 ppm Ag, and 0.10 ppm Au. Most occurrences are in quartz veins or in metasedimentary schist and are either probably gold quartz vein or epithermal precious- and base-metal deposits that formed during regional metamorphism and (or) intrusion of Cretaceous granitic plutons.

Hayes Glacier subterrane of Yukon-Tanana terrane, and Windy and Aurora Peak terranes

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 western part of the quadrangle; the other occurrence is 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 subterranes. In the Macomb subterrane, the mineral occurrences consist of: (1) altered quartz monzonite 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 Ag 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 subterranes, these occurrences are interpreted as porphyry Cu-Mo or porphyry Cu-Au-Ag deposits.

SUMMARY OF LODE MINERAL DEPOSITS, PROSPECTS, AND OCCURRENCES SOUTH OF DENALI FAULT

Slana River subterrane of Wrangellia terrane

The Slana River subterrane contains abundant lode mineral prospects and occurrences. Most of the prospects and occurrences are related to igneous activity during late Paleozoic island-arc volcanism (Nokleberg and others, 1984). About 19 small- to moderate-size porphyry Cu-Au-Ag prospects and occurrences are located in the central-southern and eastern-southern parts of the quadrangle and consist of disseminated to local small masses of chalcopyrite, bornite, malachite, and pyrite in or near metamorphosed and altered dacite porphyry. Selected samples contain as much as 100,000 ppm Cu, 5,000 ppm Pb, 530 ppm Zn, 70 ppm Ag, 2.0 ppm Au, 1,500 ppm As, 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 probably comagmatic with the basalt protolith for the Nikolai Greenstone. These occurrences consist of disseminated to small lenses and stringers of podiform chromite in cumulate ultramafic rock and are located in the central and western parts of the subterrane. These occurrences contain as much as greater than 5,000 ppm Cr and 500 ppm Co and probably formed as during crystal settling of chromite in mafic sills.

Seventeen small- to moderate-size prospects and occurrences of Cu-Ag quartz vein deposits occur in late Paleozoic meta-andesite and metadacite and in the Upper Triassic Nikolai Greenstone. These prospects and occurrences consist of disseminated and small masses of chalcopyrite, bornite, malachite and azurite. Selected samples contain as much as 56,000 ppm Cu, 5,000 ppm Pb, 5,000 ppm As, 4,200 ppm Zn, 300 ppm Ag, and 6.5 ppm Au. These prospects and occurrences are either in, or near quartz veins, or in areas of epidote-chlorite-actinolite-quartz alteration of the Nikolai Greenstone, meta-andesite, metadacite, gabbro, or diabase. These prospects and occurrences are interpreted as being 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 containing as much as 150 ppm Ag, and 2.3 ppm Au in 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 44 ppm Ag. These occurrences are probably gold quartz vein or epithermal precious- and base-metal deposits that formed either 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 chromite 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 chromite mainly in olivine-pyroxene 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 34 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, serpentinized olivine cumulate containing as much as 3,200 ppm Cu. Insufficient data precludes classification of these occurrences.

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

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

Minor lode mineral occurrences in the Clearwater terrane are: (1) pyrite in iron-stained phyllite containing as much as 2,300 ppm Cu; and (2) iron-stained metarhyolite 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 chromite deposit consisting of disseminated to podiform chromite in alpine peridotite.

Mesozoic granitic rocks south of the Denali fault

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

In the Slana River subterrane of Wrangellia, porphyry Cu-Au-Ag deposits consist of 12 small- to moderate-size prospects or occurrences of fresh to altered Jurassic or Cretaceous quartz diorite, granodiorite, and granite or areas of granitic 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 deposits, metasedimentary schists, and quartz veins.

Nineteen small- to medium-sized placer mines and deposits occur south of the Denali fault in the Slana River subterrane of the Wrangellia terrane. Several small- to moderate-size placer deposits occur in the Broxson Gulch, Rainy Creek, Eureka Creek, and Delta River areas. Known grades are as much as 13 colors per pan (Yeend, 1981b). Most of these placers occur in gravels deposited down drainage 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 Broxson 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 grams 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/m^2. 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 mi^2 in area (O'Leary and others, 1981, 1982; Curtin and others, in press). In addition, composite samples of glacial debris were collected at 116 sites on tributary glaciers. These samples were subsequently concentrated to yield a minus-80-mesh fraction and a 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-sediments 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, and separate data sets were prepared for each major terrane. The major areas of interest are described below.

Summary of results

A few notable associations of high-metal concentrations and areas of known Kuroko massive sulfide deposits occur in the Jarvis Creek subterrane (Nokleberg and others, in press). High values of Ag, Cu, Pb, and Zn occur in heavy-mineral concentrates 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 metasedimentary rock unit. These data outline 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, and Sb in heavy-mineral concentrates. In the Macomb 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 Macomb 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, thorite, 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, thorite, 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 in the southwest part of the quadrangle, another notable area exhibits high concentrations 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 mininum potential for Cu-Ag quartz vein deposits.

To the northwest in the East Susitna batholith of the Maclaren 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 Cu-Ag quartz vein deposits in mafic 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 data and surveying a short, very low-frequency, electromagnetic profile over the Miyaoka massive sulfide occurrence in the northwestern 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 density of 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) to: (1) separate magnetically distinct terranes; (2) delineate approximate boundaries of magnetic plutons and tabular bodies; 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) visiting outcrops and measuring magnetic suseptibilities; 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 cumulate 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 part of the quadrangle, a large granitic batholith trimmed by the Denali fault is exceptionally deep rooted (Campbell and Nokleberg, 1985).

Geophysical indications of porphyry deposits

Analysis and interpretation of an aeromagnetic features map 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 signatures. 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 eastern part of the quadrangle, northwest of the headwaters of Rumble Creek in the Jarvis Creek Glacier subterrane; (2) an area in the southwestern part of the quadrangle in the Maclaren terrane; and (3) an area in the south-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 Glacier subterrane and the granitic plutons intruding the Lake George and Macomb subterranes 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 part of the quadrangle. Field examination indicates this anomaly is due to an exhumed radially zoned granitic pluton whose core exhibits no alteration.

Geophysical indications of skarn deposits

The aeromagnetic map (State of Alaska, 1974) also shows several local highs in areas of sedimentary or metasedimentary rocks. Such geographically small highs, of low to moderate amplitude, occur in low-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 the 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. As a result, this criterion merely indicates areas where plutonic rocks may intrude and alter carbonate rocks. The areas with this type of anomaly are: (1) an area in the southeastern corner of the quadrangle bounded to the north by the Denali fault and to the west by a north-trending magnetic lineament in the Slana River subterrane; and (2) an area of known volcanogenic massive sulfide deposits in the central-eastern part of the quadrangle in the Jarvis Creek Glacier 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 Rolla, Missouri quadrangle. This form of assessment was first applied by Richter and others (1975) in the Nabesna 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 deposit; (4) Derivation of recognition criteria each type of mineral-deposit; (5) Systematic examination of the available data for the existence of the recognition criteria; (6) Evaluation of the geographic distribution and relative importance of various recognition criteria to appraise a low, moderate, or high potential for undiscovered deposits in specific areas, or to indicate areas where data are insufficient for a 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 Mosier (1983a, b) and Cox and Singer (1986).

Recognition criteria

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

Diagnostic criteria are 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 much 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 geochemical association such as anomalous concentrations of associated elements in rocks; (6) occurrence of an associated mineral suite; and (7) a specific alteration pattern. The most important recognition criterion is a specific favorable geologic environment. This criterion is used to initially define an area on a geologic map with at least low potential for a particular type of mineral deposit. All other recognition criteria, whether diagnostic or secondary, are built upon the existance of a specific favorable geologic environment.

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

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

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

ar	arsenopyrite	gn	galena
ca	cassiterite	mo	molybdenite
cin	cinnabar	py	pyrite

cp	chalcopyrite	pyrr	pyrrhotite
ep	epidote	sh	scheelite
fl	fluorite	sp	sphalerite

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, aeolin, 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 are 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
(table 1, map sheet 1)

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 glaciofluvial 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 geological favorable because of containing stream gravels, conglomerates, or glaciofluvial 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 mines or occurrences, gold in heavy-mineral-concentrate samples, and (or) anomalous values of Au in heavy-mineral-concentrate samples (criteria 2 through 4). Areas 6 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; Stumpfl 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, aeolin, 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-It alloys, magnetite, chromite, and (or) ilmenite.

Recognition criteria

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

Assessment
(table 2, map sheet 1)

Areas 5, 8, and 10 (sheet 1) are geologically favorable for undiscovered platinum placer deposits because of containing stream gravels, conglomerates, or glaciofluvial 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 at grades of 2.5 g/t or more in one-half of the deposits (D.A. Singer and N.J Page in Cox and Singer, 1986).

3. HOT-SPRING Au DEPOSITS

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

General description

Hot-spring Au deposits consist of finely disseminated gold in subaerial, intermediate volcanic, or volcaniclastic rocks that are extensively silicified 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 silicified 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 silification.
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 argillic to advanced argillic alteration.
3. Anomalous values of As, Sb, Ag, or Au in rock samples.
4. Anomalous values of As, Sb, Ag, or Au in stream-sediment samples.
5. Anomalous values of As, Sb, Ag, or Au in heavy-mineral-concentrate samples.
6. Occurrence of pyrite, gold, or cinnabar in heavy-mineral-concentrate samples.

Assessment
(table 3, map sheet 2)

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 silification (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

(References: Lindgren, 1933; Sillitoe, 1977; D.P. Cox, D.L. Mosier, Takeo Sato, N.J Page, D.A. Singer, and B.R. Berger in Cox and Singer, 1986)

General description

Epithermal precious- and base-metal deposits consist of gold or silver in vuggy quartz veins and disseminated in wall rock and are associated with abundant pyrite, arsenopyrite, tetrahedrite, and locally sphalerite, chalcopyrite, enargite, and galena. The host rocks consist of andesite to rhyolite flows, ash flows, tuffs, and associated volcaniclastic rocks, 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. Known deposit, prospect, or occurrence.
3. Quartz veins, stockworks, or breccia pipes.
4. Open-space filling in veins and altered areas with banded veins, vuggy, fine-grained crystals, or possibly large zoned crystals.
5. Quartz, adularia, chalcedony, carbonate, barite, and (or) fluorite fillings of veins and open spaces.
6. Conspicuous wall-rock alteration consisting of extensive replacement by propylitic, sericitic, and argillitic 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 Slana 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. Mosier and W.D. Menzie in Singer and Mosier (1983a) and Cox and Singer (1986). The data suggest that if quartz-adularia type deposits exist in the quadrangle, then one-half would contain 690,000 tonnes or more, whereas the quartz-alunite type would contain 460,000 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 19 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 600 g/t or more. Copper and zinc grades are low. Silver grades tend to be higher in the quartz-adularia 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, W, Au, Ag, or Hg in stream-sediment samples.
5. Anomalous values of As, Sb, Cu, Mo, W, Au, Ag, or Hg in heavy-mineral-concentrate samples.
6. Occurrence of gold, pyrite, or arsenopyrite in heavy-

mineral-concentrate samples.

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

North of the Denali fault, the geologically favorable areas for undiscovered gold quartz vein deposits are the regionally metamorphosed metasedimentary and metavolcanic rocks in Macomb, Jarvis Creek Glacier, and Hayes Glacier subterranes of the Yukon-Tanana terrane (areas 1 through 4, sheet 3, table 5). South of the Denali fault, the geologically favorable area is the Maclaren Glacier metamorphic belt in the Maclaren terrane (area 4, sheet 3, table 5). These areas exhibit greenschist-facies regional metamorphism and quartz veins (diagnostic criteria 3 and 4). In addition, these areas exhibit postmetamorphic granitic plutons, quartz-vein emplacement along major or minor structures, and anomalous values of appropriate elements in 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 Maclaren Glacier metamorphic belt (area 4) of the Maclaren 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 Hayes 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. Bliss 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 half 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
(References: Harper, 1977; Wilton and Sinclair, 1979; Lincoln, 1981; Nokleberg and others, 1987).

General description

Cu-Ag quartz vein deposits consist of quartz veins or adjacent altered areas containing chalcopyrite, bornite, chalcocite and local high values of Ag and lesser Au and 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 relict igneous and metamorphic 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 accretion, regional metamorphism, and deformation of oceanic basalts 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.
3. Prehnite-pumpellyite to lower greenschist-facies metamorphism.
4. Quartz veins.
5. Areas of pervasively altered greenstone with chlorite, epidote, actinolite, or carbonate.

Secondary criteria

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

Assessment
(table 6, map sheet 3)

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

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

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

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

General description

Kennecott Cu-Ag deposits (revised from basaltic Cu deposit in Cox and Singer, 1986) consist of chalcocite, bornite, and minor covellite, enargite, pyrite, galena, and sphalerite in veins, pods, and large irregular masses along or above the unconformity between basalt and overlying limestone or dolomite. The host rocks are regionally metamorphosed at prehnite-pumpellyite or lower greenschist facies. The disconformity 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 schistosity and replace relict igneous and metamorphic minerals in the greenstone. The ore depositional environment appears to be a combination of development of sabhka 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, disconformably overlain by limestone or dolomite.
2. Known deposit, prospect, or occurrence.
3. Prehnite-pumpellyite to lower greenschist-facies regional metamorphism.
4. Weathered sabhka facies in carbonate rock overlying metabasalt.
5. Quartz-epidote-sulfide-copper-carbonate veins in metabasalt.

Secondary criteria

1. Amydgules in metabasalt with chlorite, chalcedony, quartz, epidote, zeolites, calcite, Cu-sulfides, and rare native copper.

2. Anomalous values of Cu, Pb, Zn, or Ag in rock samples.

3. Anomalous values of Cu, Pb, or Ag in stream-sediment samples.

4. Anomalous values of Cu, Pb, Zn, or Ag in heavy-mineral-concentrate samples.

5. Occurrence of chalcocite, bornite, covellite, galena, sphalerite, or pyrite in heavy-mineral-concentrate samples.

Assessment
(table 7, map sheet 3)

The geologically favorable areas for undiscovered Kennecott Cu-Ag deposits are parts of the Slana River and Tangle subterranes of the Wrangellia terrane where the Nikolai Greenstone is overlain by Triassic limestone. The only area where this relation occurs is in the eastern part of the Slana River subterrane (area F, sheet 3, table 7). Farther west in the Tangle subterrane, Triassic limestone is faulted against other bedrock units. Area F is assessed to have a moderate potential for undiscovered deposits because of exhibiting lower greenschist-facies metamorphism and quartz-Cu-sulfide veins in metabasalt (diagnostic criteria 3 and 5; table 7). In addition area F exhibits amydgules in metabasalt with various silicate and Cu-sulfide minerals, anomalous values of Zn and Ag in heavy-mineral-concentrate samples, and chalcopyrite and pyrite in heavy-mineral-concentrate samples (secondary criteria 1, 4, and 5; table 7). A lack of abundant deposits precludes construction of a grade-tonnage model.

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 island-arcs 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, generally calc-alkaline 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)

North of the Denali fault, the geologically favorable areas for Kuroko massive sulfide deposits are the submarine metavolcanic rocks of the Jarvis Creek Glacier and Hayes Glacier subterranes (areas A through F, sheet 2, table 8) of the Yukon-Tanana terrane. South of the Denali fault, the geologically favorable areas are the Tetelna Volcanics and Slana Spur Formation of the Slana River subterrane of the Wrangellia terrane (areas G through I, sheet 2, table 8).

Areas A and D are assessed to have a high potential for undiscovered deposits because of exhibiting moderately abundant known deposits, prospects, or occurrences, felsic pyroclastic deposits, and siliceous chemical sedimentary rock (diagnostic criteria 2, 3 and 4; table 8). In addition, these areas exhibit relict hydrothermal alteration, anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 2 through 6; table 8).

Areas B, E and G are assessed to have a moderate potential because of exhibiting few, if any known deposits, prospects, or occurrences, siliceous chemical sedimentary rock (diagnostic criteria 2 or 4; table 8), and few anomalous values of appropriate elements in rock, stream-sediment and heavy-mineral-concentrate samples, and few base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 3 through 6; table 8).

Areas F, H, and I are assessed to have a low potential because of exhibiting only a few anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate sample, and a few base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 3 through 6; table 8).

Area C is assessed to have a very low potential because of a few anomalous values of appropriate elements in stream-sediment samples.

A grade-tonnage model was prepared by D.A. Singer and D.L. Mosier in Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if 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 have 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. Precious metals are reported in over half the deposits with the richest tenth having at least 2.3 g/t gold; the median silver grade is 11 g/t whereas 10 percent of the deposits contain 98 g/t or more of silver.

9. PORPHYRY Cu(Au-Ag) DEPOSITS
(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 veinlets 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 of epizonal intrusive rocks with abundant dikes, breccia pipes, and cupolas of batholiths that are intruded to shallow levels in either an island-arc or Andean-type arc setting. In this study, porphyry Cu(Au-Ag) deposits include associated polymetallic vein deposits.

Diagnostic criteria

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

Secondary criteria

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

Assessment and grade-tonnage model
(table 9, map sheet 2)

The geologically favorable areas for undiscovered porphyry Cu(Au-Ag) deposits are the Tetelna Volcanics and Slana Spur Formation in the Slana River subterrane of the Wrangellia terrane (areas G-1 through G3, H, I, sheet 2, table 9). These units are the only ones in the quadrangle that are intruded by hypabyssal granitic plutons in this case, shallow-level, andesite to dacite stocks, dikes and sills.

Areas G2 and I are assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences, coeval granitic granitic, hypabyssal, and volcanic rocks, and hydrothermally altered intrusive rocks (diagnostic criteria 2 through 4; table 9). In addition, these areas exhibit massive-sulfide layers in volcanic rocks, anomalous values of appropriate elements in rock, stream-sediment and heavy-mineral-concentrate samples, base-metal sulfides in heavy-mineral-concentrate samples, and a local, equidimensional aeromagnetic high (secondary criteria 1 through 6; table 9).

Areas G1 and H are assessed to have a moderate potential because of exhibiting most of the same diagnostic criteria as above (2 through 4), but fewer anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, and fewer base-metal sulfides in heavy-mineral-concentrate samples, and local equidimensional aeromagnetic highs (secondary criteria 1 through 6; table 9).

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

A grade-tonnage model was prepared by D.A. Singer and D.P. Cox in Cox and Singer (1986) for porphyry Cu-Au deposits. The plotted grades and tonnages of the prototype deposits demonstrate that if porphyry Cu-Au deposits exist in the quadrangle, then one-half of the deposits should contain 150 million tonnes or more, and the largest tenth of the deposits contain 910 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.50 percent or more, and the richest tenth have at least 0.71 percent copper. Average molybdenum grades of 0.0036 percent or more occur in one-half or more of the deposits. Gold grades of 0.31 g/t occur in one-half or more of the deposits, and the richest tenth have at least 0.64 g/t.

10. PORPHYRY Cu-Mo DEPOSITS

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

General description

Porphyry Cu-Mo deposits consist of pyrite with lesser chalcopyrite and molybdenite, and minor sphalerite or galena. The sulfides occur in stockwork veinlets in porphyritic granitic rocks 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 either surface outcrops of granitic rocks, or areas adjacent to granitic rocks where geophysical data indicates favorable areas in the subsurface. In this study, porphyry Cu-Mo deposits include associated polymetallic vein deposits.

Diagnostic criteria

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

Secondary criteria

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

Assessment and grade-tonnage model
(table 10, map sheet 4)

The geologically favorable areas for undiscovered porphyry Cu-Mo deposits are granitic plutons throughout the quadrangle (areas A through F, G1 through G4, H1 through H4, I through K, L1 through L4, and M through R, sheet 4, table 10). North of the Denali fault, abundant granitic plutons occur in the Lake George, Macomb, and Jarvis Creek Glacier subterranes of the Yukon-Tanana terrane and the Aurora Peak terrane (areas A, C, E, G, H, sheet 4), and south of the Denali fault, in the Maclaren terrane and the Slana

River subterrane of the Wrangellia terrane (areas J, N, O, sheet 4). For a detailed assessment, areas G, H, and L are divided into subareas (sheet 4, table 10).

Areas K and M, small isolated granitic plutons in the Wrangellia terrane, are assessed to have a high potential for undiscovered deposits because of exhibiting known deposits, prospects, or occurrences; coeval granitic, hypabyssal, or volcanic rocks; numerous faults and brecciated country rock; or hydrothermal alteration (diagnostic criteria 2 through 4 and 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 with high potential, areas E, G4, H2, I, L1, L4, and N are assessed to have a moderate potential because of exhibiting fewer diagnostic criteria, mainly coeval granitic, hypabyssal, or volcanic rocks; numerous faults and brecciated country rock; and 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, hypabyssal, 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 Cox and Singer (1986). The plotted grades and tonnages of the prototype deposits demonstrate that if porphyry Cu-Mo deposits exist in the quadrangle, then one-half of the deposits would contain 140 million tonnes or more, and the largest tenth of the deposits would contain 1,100 million tonnes or more. Fifty percent of the deposits have average copper grades of 0.5 percent or more, and the richest tenth have at least 1.0 percent copper. The richest tenth contain at least 0.03 percent molybdenum and having at least 0.4 g/t gold; 10 percent of the deposits contain 2.5 g/t or more of silver. For porphyry Mo deposits (W.D. Menzie 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 0.084 percent or more molybdenum. The richest tenth contain 0.13 percent molybdenum.

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

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

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 metasomatized calcareous rocks or in nearby metasomatized granitic rocks. The contact metasomatic 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 is 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 andradite-grossularite, diopside-hedenbergite, hornblende, wollastonite, epidote, actinolite, idocrase, and quartz.
4. Bleaching of calcareous wall rocks, for example, disappearance of graphite and local silicification.

Secondary criteria

1. Abundant fractures, folds, or faults in calcareous sedimentary rocks.
2. Replacement of granitic rocks adjacent to calcareous sedimentary rocks by andradite-grossularite, diopside-hedenbergite, epidote, hornblende or actinolite, chlorite, calcite, or quartz.
3. Hydrothermal alteration of plutonic rocks.
4. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, Au, or Sn in rock samples.
5. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, Au, or Sn in stream-sediment samples.
6. Anomalous values of W, Mo, Cu, Pb, Zn, Ag, or Au in heavy-mineral-concentrate samples.
7. Occurrence of scheelite-powellite, molybdenite, chalcopyrite, bornite, sphalerite, galena, pyrite, arsenopyrite, gold, or fluorite in heavy-mineral concentrate samples.
8. Local aeromagnetic highs, particularly geographically small highs of low to moderate amplitude in regions of otherwise low-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 Glacier subterranes of the Yukon-Tanana terrane and the Aurora Peak terrane north of the Denali fault (areas A, C, H1 through H4, sheet 4, table 11), the East Susitna batholith of the Maclaren terrane, and the Wrangellia 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 very sparse diagnostic criteria, mainly two sites of silicate skarn minerals, and one site of bleaching of calcareous wall rocks (diagnostic criteria 3 and 4; table 11). In addition, these areas exhibit, relative to area L2, fewer secondary criteria, mainly sparse anomalous values of appropriate elements in rock, stream-sediment, and heavy-mineral-concentrate samples, sparse oxides and base-metal sulfides in heavy-mineral-concentrate samples, and in some areas an appropriate aeromagnetic 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, sparse oxides and base-metal sulfides in heavy-mineral-concentrate samples, and an appropriate aeromagnetic 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. The richest tenth contain at least 2.2 g/t gold and 34 g/t silver. For W-skarn deposits, one-half of the deposits would contain 1.1 million tonnes or more, and the largest tenth should contain 22 million tonnes or more. Fifty percent of the deposits have average tungsten grades of 0.67 percent WO_3 or more, and the richest have at least 1.4 percent WO_3.

12. PORPHYRY Sn DEPOSITS

(References: Mulligan, 1974; Smith and Turek, 1976; B.L. Reed in Cox and Singer, 1986).

General description

Porphyry Sn deposits consist of disseminated cassiterite and accessory tourmaline, topaz, and white mica in the upper, highly altered parts of leucocratic quartz monzonite or granite. The host 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 siliceous 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 stocks 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 Macomb and Jarvis Creek Glacier subterranes of the Yukon-Tanana terrane and the Aurora Peak terrane north of the Denali 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 3 and 4; table 12). In addition, most of these areas exhibit locally extensively altered granitic rocks (secondary 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 oxides and base-metal sulfides in heavy-mineral-concentrate samples (secondary criteria 6 through 9; table 12).

Relative to the above areas with moderate potential, areas G1 through G4 and 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 fewer 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 9; table 12).

13. GABBROIC Ni-Cu DEPOSITS

(References: Naldrett, 1981; Ross and Travis, 1981; N.J Page in Cox and Singer, 1986)

General description

Gabbroic Ni-Cu deposits (adapted from synorogenic-synvolcanic Ni-Cu deposit of Cox and Singer, 1986) consist of pyrrhotite, pentlandite, chalcopyrite, platinum-group minerals and accessory pyrite that occur mainly as disseminations and lesser massive-sulfide lenses in large sills of cumulate mafic and ultramafic rocks and in smaller dikes, sills, and masses of gabbros and norites. The mafic and ultramafic rocks generally intrude greenstone belts and are locally intensely deformed and metamorphosed. The host rocks consist of various combinations of olivine-pyroxene cumulates, plagioclase-pyroxene cumulates, or olivine-plagioclase cumulates, gabbro, and norite. The ore depositional environment consists of moderate to large bodies of cumulate mafic and ultramafic rocks, and gabbro or norite dikes and sills intruded into greenstone belts, possibly associated with rifting, followed by a period of accretion, deformation, and regional-grade metamorphism.

Diagnostic criteria

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

Secondary criteria

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

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

The geologically favorable areas for undiscovered gabbroic Ni-Cu deposits are intrusive gabbros, diabases, and cumulate mafic and ultramafic rocks in the Slana River and Tangle subterranes of the Wrangellia terrane (areas A-E, sheet 1, table 13). These rocks are interpreted as being comagmatic with the magmas that also formed the submarine and subaerial basalts of the Upper Triassic Nikolai Greenstone.

Areas A and D are assessed to have a moderate potential for undiscovered deposits because of exhibiting a known prospect or occurrence (diagnostic criterion 2; table 13) and because of exhibiting anomalous values of Cu, Ni, or Co in rock, stream-sediment, or heavy-mineral-concentrate samples and a strong aeromagnetic gradient or high (secondary criteria 1 through 4; table 13).

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

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

14. PODIFORM CHROMITE DEPOSIT

(References: Naldrett and Cabri, 1976; J.P. Albers in Cox and Singer, 1986)

General description

Podiform chromite deposits consist of chromite and accessory platinum-group minerals that are occur in podlike masses in ultramafic rock that in some cases are highly deformed and metamorphosed. The host rocks include dunite and harzburgite, associated mafic igneous rocks, and cumulate mafic and ultramafic rocks, sometimes extensively serpentinized. The ore depositional environment consists of tectonized ultramafic rock formed in the basal parts of ophiolites or cumulate igneous rock formed in the upper parts of ophiolites or along rifts.

Diagnostic criteria

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

Secondary criteria

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

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

The geologically favorable areas for undiscovered podiform chromite deposits are the terrane of ultramafic and associated rocks in the southeastern part of the quadrangle (areas F-H, sheet 1, table 14) and the cumulate ultramafic and mafic rocks in the Slana River and Tangle subterranes of the Wrangellia terrane (areas A-D, sheet 1, table 14).

Areas A-D and H are assessed to have a moderate potential for undiscovered deposits because of exhibiting known prospects or occurrences or tectonic emplacement (diagnostic criteria 2 and 3). In addition, these areas exhibit anomalous values of Cr, Ni, or Co in rock, stream-sediment, and heavy-mineral-concentrate samples, and a strong aeromagnetic gradient or high (secondary criteria 1 through 4; table 14).

Areas F and G are assessed to have a low potential because of exhibiting only tectonic emplacement (diagnostic criteria 3) and because of exhibiting sparse and few anomalous values of Cr, Ni, or Co in stream-sediment or heavy-mineral-concentrate samples and a strong aeromagnetic gradient or high (secondary criteria 2 through 4; table 14).

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. Chromite grade is negatively correlated with tonnes. The plotted grades and tonnages of the prototype deposits demonstrate that if podiform chromite deposits exist in the quadrangle, then one-half should contain 130 tonnes or more, and the largest tenth of the deposits contain 2,000 tonnes or more. Fifty percent of the deposits have average chromite grades of 44.0 percent or more Cr_2O_3, and the richest tenth have at least 50 percent Cr_2O_3. Cobalt and the platinum-group elements are present in some of these deposits.

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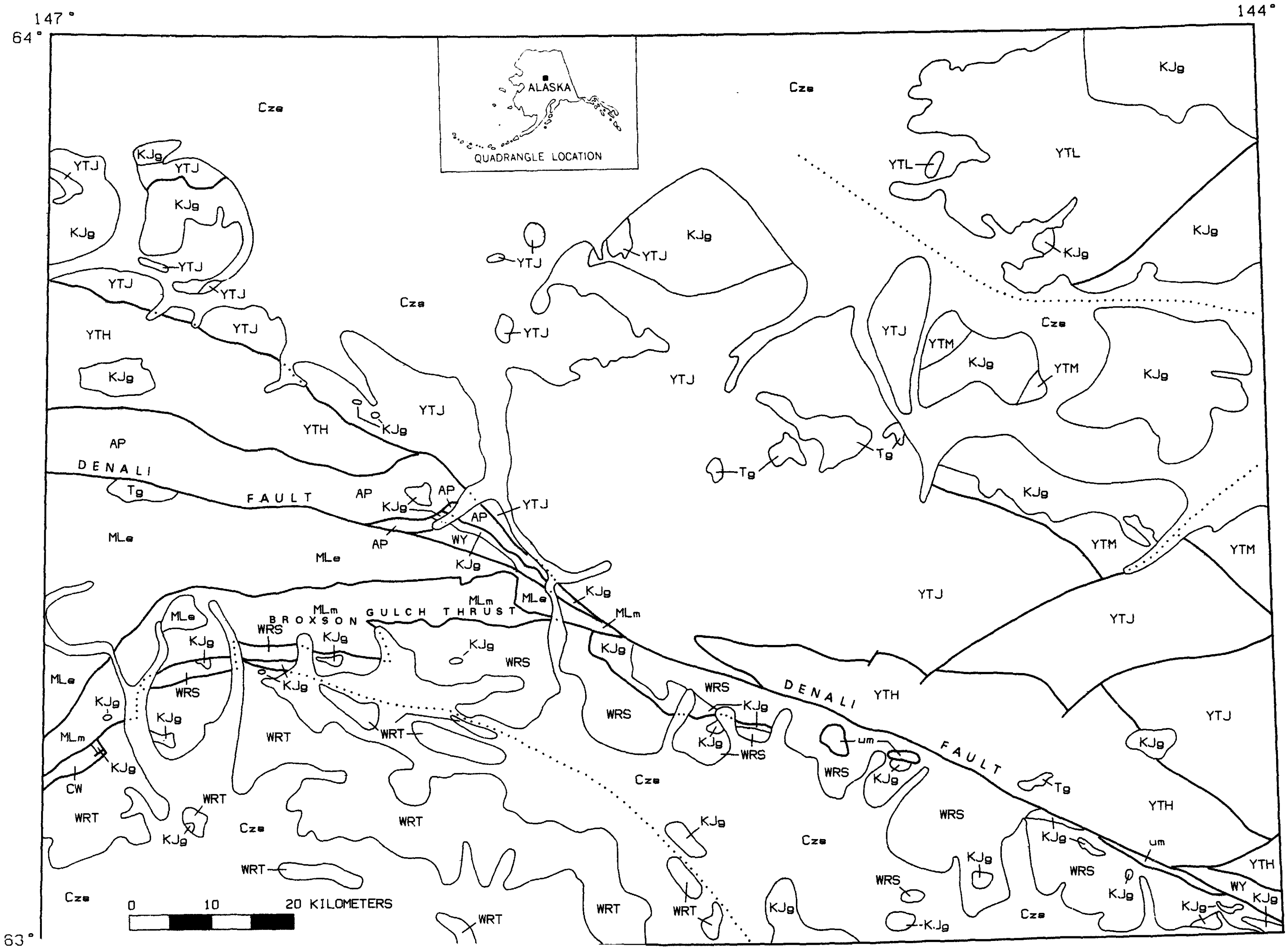

Figure 1. Tectono-stratigraphic terrane map of the Mount Hayes quadrangle, eastern Alaska Range, Alaska

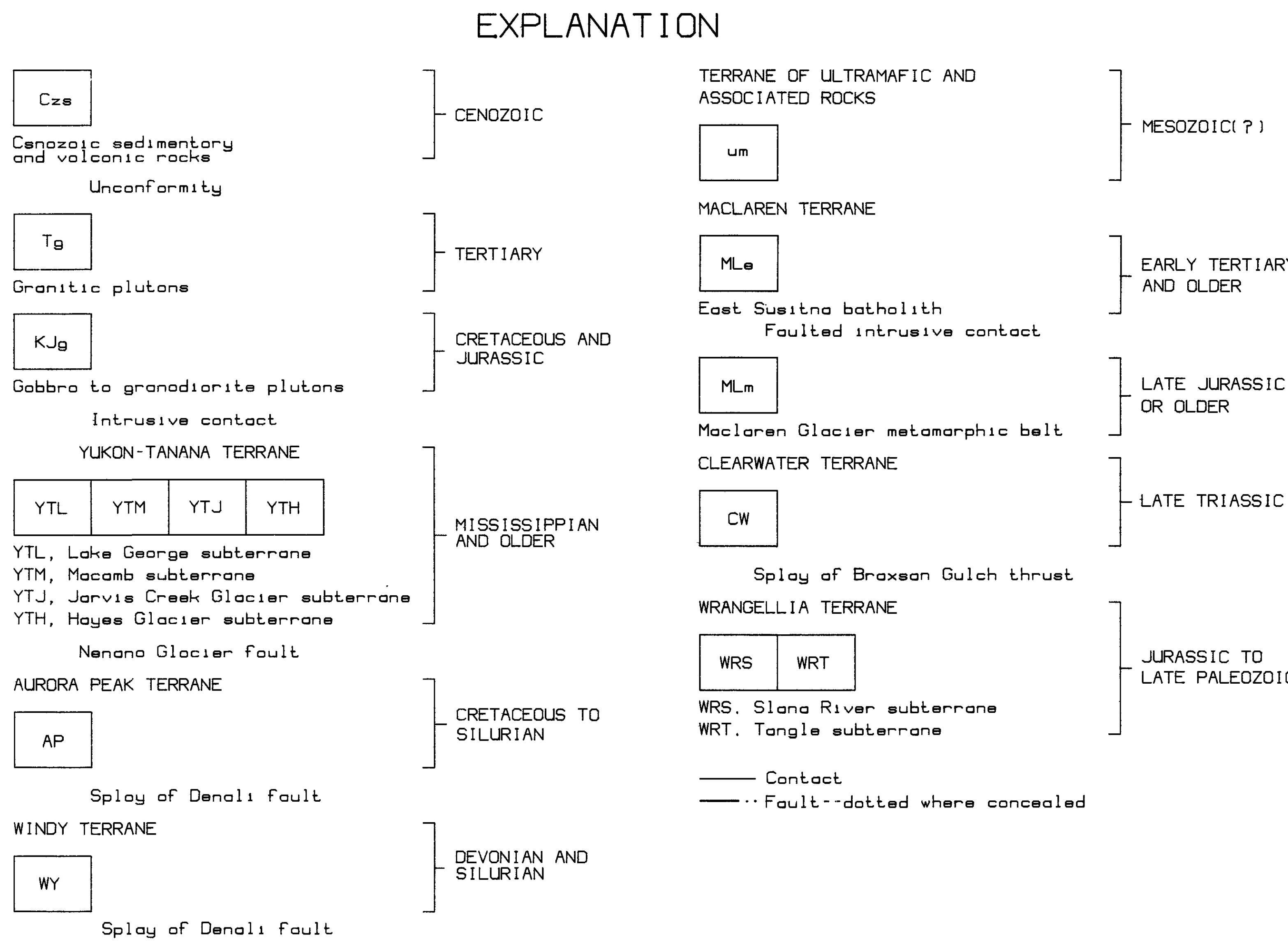

Figure 1. Tectono-stratigraphic terrane map of the Mount Hayes quadrangle, eastern Alaska Range, Alaska—Continued