MAPS SHOWING METALLIC MINERAL RESOURCES OF THE BENDELEBEN AND SOLOMON QUADRANGLES, WESTERN ALASKA

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INTRODUCTION

This report summarizes the potential for metallic mineral resources in the Bendeleben and Solomon quadrangles, central Seward Peninsula, Alaska (fig. 1), and was prepared as part of the AMRAP (Alaska Mineral Resources Appraisal Program) studies for these quadrangles, which were begun in 1981. Geologic mapping during this study (Till and others, 1986) included the southern part of the Kotzebue quadrangle. However, stream-sediment and panned-concentrate samples were not collected in that area, and the mineral resources of the southern part of the Kotzebue quadrangle are not assessed in this report.

Based on the geology (Till and others, 1986), rock geochemistry (Gamble and others, 1988), stream-sediment and panned-concentrate geochemistry (King and others, 1989a; Smith and others, 1989), geophysical data (Cady and Till, in press), and known mineral occurrences (Gamble, 1988), the Bendeleben and Solomon quadrangles are favorable for the following mineral deposit types: low-sulfide gold-quartz veins, sediment-hosted zinc-lead deposits, Besshi volcanogenic massive-sulfide deposits, tin veins, tin greisens, tin skarns, tin replacements, tungsten skarns, iron skarns, copper skarns, gold-bearing skarns, polymetallic veins, polymetallic- replacement deposits, Zn-Pb-Ag skarns, and low-fluorine stockwork molybdenum systems (see Cox and Singer, 1986; Eckstrand, 1984, for descriptions of mineral deposit models).

Several other mineral-deposit types are considered permissive based on certain geological characteristics (for example, lithologies) but are not further evaluated during this study because of a lack of supporting indicators such as appropriate geochemistry and geophysics. For example, active hot springs are present in two areas in the Bendeleben quadrangle, and these areas could be considered permissive for hot-spring gold-silver deposits. However, the lack of any other indicators such as silicification or anomalous geochemistry precludes evaluating the favorability of these areas. Other mineral-deposit types that are considered permissive are sedimentary rock-hosted Au-Ag ("Carlin"-type gold), Mississippi Valley-type Pb-Zn, sedimentary manganese, and bedded barite

The uranium resource potential of the Bendeleben and Solomon quadrangles was not evaluated during this study since

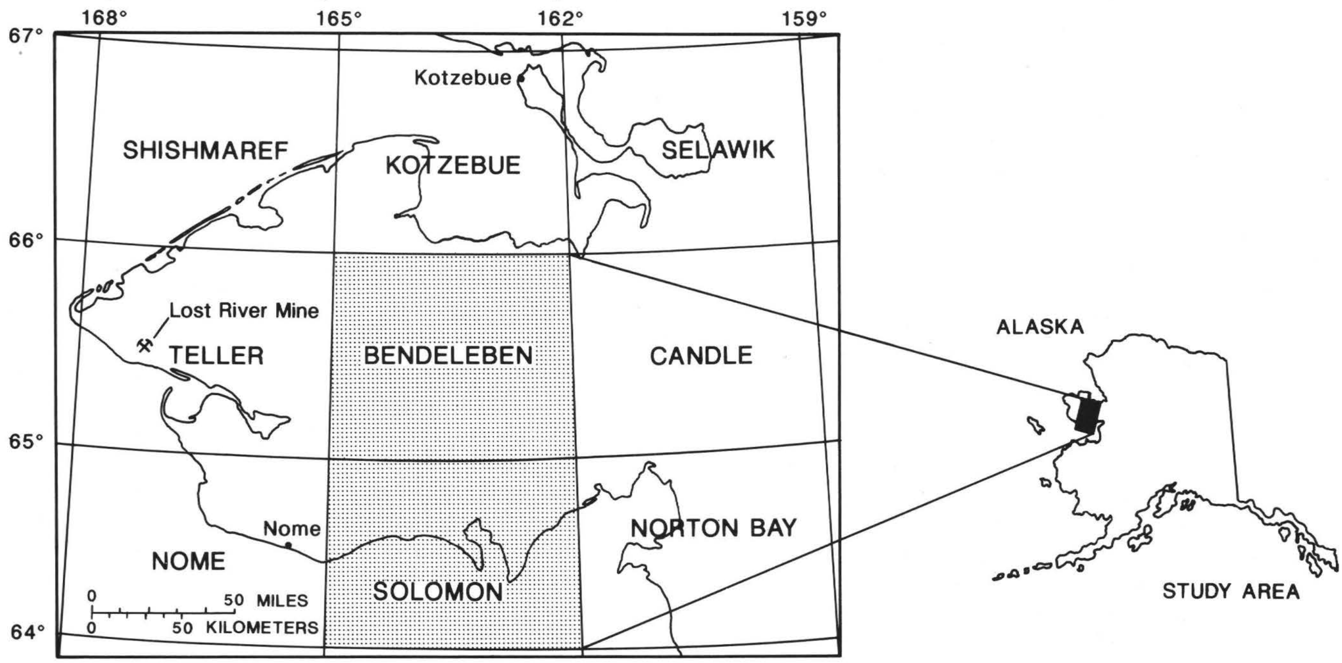

Figure 1. Index map showing location of Solomon and Bendeleben quadrangles, Seward Peninsula, Alaska.

a National Uranium Resource Evaluation (NURE) report by Hawley and Associates (1978) evaluated the uranium resource potential of the Seward Peninsula and the area to the east.

Sheets 1, 2, and 3 delineate areas favorable for several classes of mineral deposits. These are low-sulfide gold-quartz veins (sheet 1); sediment-hosted zinc-lead and Besshi-volcanogenic massive-sulfide deposits (sheet 2); and magmatic-hydrothermal deposits (sheet 3). A mineral-deposit model approach was used to prepare these maps. Features of the area being examined were compared with characteristics (including host rock lithologies, structure, geochemistry, among many others) of mineral deposit types (for example, Eckstrand, 1974; Cox and Singer, 1986; Roberts and Sheahan, 1988). The presence of a critical feature or combination of features is taken to indicate potential for the occurrence of a mineral-deposit type. Some features are better positive indicators than others and are given greater weight in this assessment. Conversely, the absence of certain critical features, chiefly appropriate lithologies, indicates that an area probably does not show potential for a given deposit type.

In this report, permissive is used to imply that an area has potential for a given type of mineral deposit based on the presence of the appropriate geologic environment. Favorable means that within a permissive area, a domain is outlined that we believe has greater potential and is more likely to contain a mineral deposit than the remainder of the permissive area.

PREVIOUS WORK

Geologic studies

The Omilak Mine (fig. 2), worked in the 1880's, was the first productive mineral deposit on the Seward Peninsula (Smith and Eakin, 1911). However, interest in the mineral resources of the Seward Peninsula began in earnest with the discovery of placer gold in 1898 and the subsequent gold rush of the late 1800's and early 1900's. In response to this discovery, the U.S. Geological Survey started a series of investigations of the geology and mineral resources of the gold fields. The earliest report (Brooks and others, 1901) includes detailed descriptions of placer gold occurrences and the observation that lode gold is present in quartz veins and stringers and in "impregnated zones." Investigations by the U.S. Geological Survey continued on a yearly basis until the 1920's. Among the more significant reports on mineral deposits from this period are the descriptions of the placer gold deposits of the Seward Peninsula and the gold-quartz veins on Big Hurrah Creek (Collier and others, 1908) and a summary report on lode deposits of the southern Seward Peninsula (Cathcart, 1922).

Between 1926 and 1957, the Alaska Territorial Department of Mines published reports on lode, placer, and coal occurrences on the Seward Peninsula. These include examinations of the Wheeler deposit (Wimmler, 1926), the gold lodes and placers at Bluff (Reed, 1933), the Foster prospect (Jones, 1953), and the Hannum Creek prospect (Burand, 1957).

Several studies have been conducted on uranium and thorium resources on the Seward Peninsula. In the 1940's, the U.S. Geological Survey conducted a series of investigations of radioactive mineral occurrences (Gault and others, 1953; West, 1953; Moxham and West, 1953). Miller and Bunker (1976) and Miller and others (1976) reported on the radioactive and rare-earth contents of plutonic rocks in the eastern part of the Seward Peninsula. Hawley and Associates (1978) evaluated the uranium resource potential of the Seward Peninsula and the area to the immediate east. Dickinson and Cunningham (1984) reported on a uranium deposit at Death Valley in the eastern part of the Bendeleben quadrangle.

U.S. Bureau of Mines personnel have examined a number of mineral deposits on the Seward Peninsula, including the Hannum Creek prospect (Mulligan, 1957), the Omilak Mine area (Mulligan, 1962) and the lode gold occurrences at Bluff (Mulligan, 1971). These reports detail the results of some of the earliest drilling and trenching of these deposits, and include the first multi-element chemical analyses published.

The Alaska Division of Mines and Minerals (later the Alaska Divisions of Mines and Geology, and currently the Alaska Division of Geological and Geophysical Surveys) has examined many of the mineral deposits on the Seward Peninsula. Those in the Bendeleben and Solomon quadrangles are the Bluff lode and placer gold deposits (Herreid, 1965a); the Omilak Mine (Herreid, 1965b); the Hannum Creek prospect (Herreid, 1966); the Big Hurrah Mine area (Asher, 1969a); and the Iron Creek deposits (Asher, 1969b). Two other reports (Asher, 1970; Bundtzen, 1974) present the results of detailed geochemical sampling in the western and central parts of the Bendeleben Mountains.

A number of regional geologic studies include descriptions of mineral deposits. Miller and others (1971) described molybdenum, lead, and zinc mineralization in the Windy Creek pluton. Sainsbury and others (1973) reported on several small base-metal prospects in the western part of the Bendeleben Mountains. A map of the Bendeleben quadrangle shows the location of several previously unknown occurrences (Sainsbury, 1974). The geology and mineral resources of the Serpentine Hot Springs area was discussed by Sainsbury and others (1970) and Hudson (1979). A geochemical sampling program in the southeastern part of the Seward Peninsula (Miller and Grybeck, 1973) identified several new occurrences of metalliferous minerals. Several geochemical anomalies and new occurrences of metalliferous minerals were identified during work in the western part of the Bendeleben and eastern part of the Teller quadrangles (Sainsbury and others, 1969).

Compilations of mineral occurrences and relevant literature include Cobb (1972a, b, 1975, 1978, 1981a, b, c, d), Hudson and others (1977), Hummel (1975), Sainsbury (1975), and Gamble (1988).

The first modern mineral resource evaluation for the Seward Peninsula was made by Lu and others (1968). This report describes known mineral resources and uses spatial and statistical analysis of cells (areas) to arrive at a total tonnage and dollar value for the mineral resources. Hudson and DeYoung (1978) took a different approach to assessing the resource potential of the Seward Peninsula; knowledge of the geology, geophysics, and geochemistry of the Seward Peninsula and grade and tonnage models for mineral-deposit types were used to arrive at estimates of undiscovered mineral resources that may be present.

Several reports on mineral deposits or occurrences in the Bendeleben and Solomon quadrangles have already been

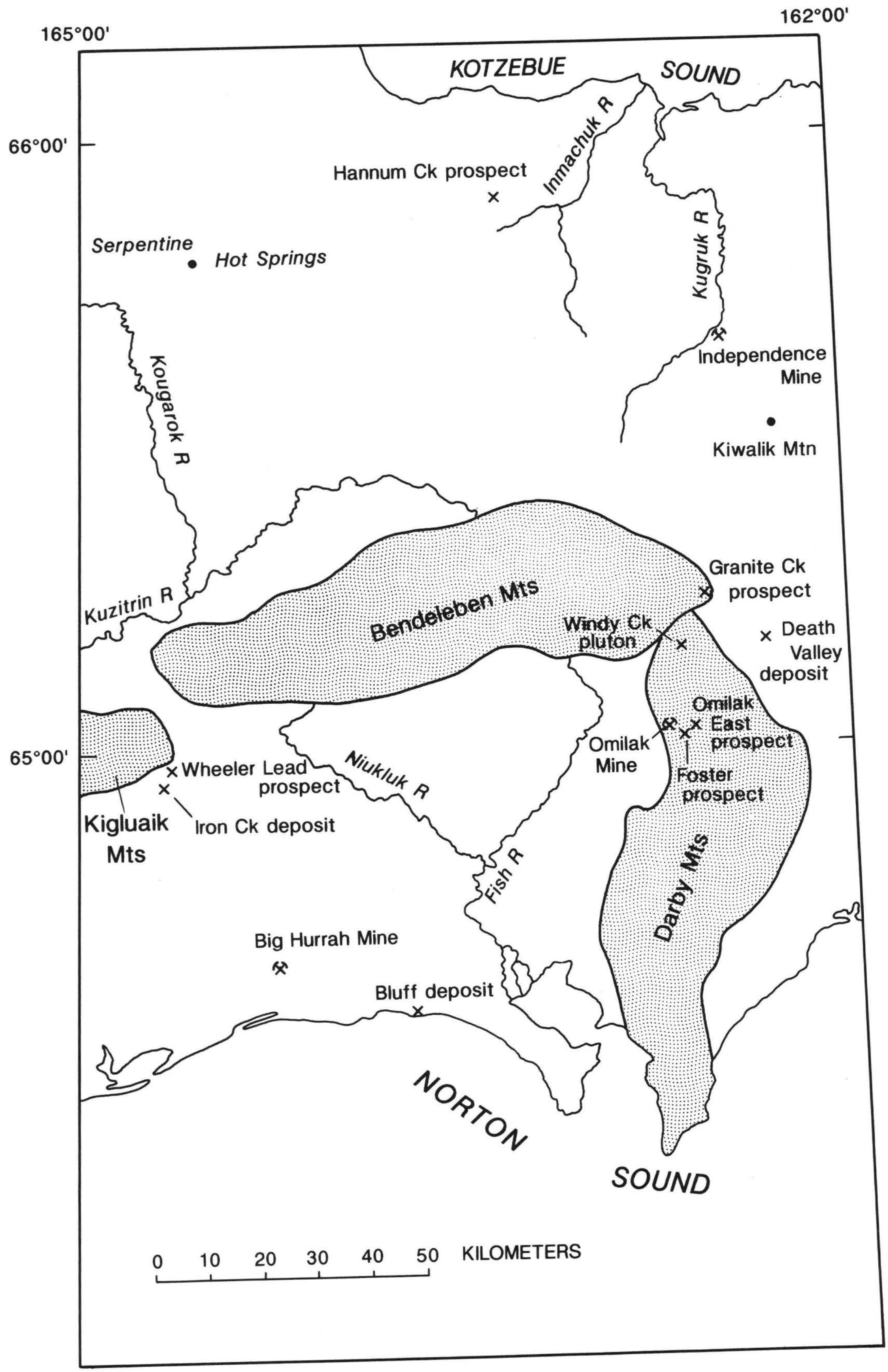

Figure 2. Index map showing location of geographic features and areas discussed in this report.

published as a result of this AMRAP study. These reports present the results of examinations of lode gold deposits (Gamble and others, 1985; Gamble, 1987), a lead-isotope study of base-metal deposits (Church and others, 1985), and descriptions of significant lode deposits of the Seward Peninsula (Gamble and others, 1987).

Geochemical studies

Many of the above-mentioned geologic reports include rock and (or) stream-sediment geochemical data. In particular, the Alaska Division of Geological and Geophysical Survey reports, and many later reports of the U.S. Geological Survey (post 1969) include geochemical analyses of rock and (or) stream-sediment samples. Hummel (1977) compiled a review of geochemical surveys on the Seward Peninsula. Arbogast and others (1985) present analytical data for 1,590 stream-sediment and 1,400 heavy-mineral-concentrate samples collected as part of this AMRAP investigation. Smith and others (1989), and King and others (1989a) reported on the distribution of anomalies for selected elements in these stream-sediment and panned-concentrate samples. The distribution and abundance of minerals in the panned-concentrate samples is presented by King and others (1989b). Gamble and others (1988) list analytical data for rock geochemical samples collected during this AMRAP study.

Geophysical studies

The Alaska Division of Geological and Geophysical Surveys (1973a, b, 1984) published 1:63,360-scale maps of aeromagnetic surveys of most of the Bendeleben and Solomon quadrangles. The remaining parts of these quadrangles are covered by aeromagnetic surveys of the U.S. Geological Survey (1969) at a scale of 1:63,360. An aeromagnetic map (Decker and Karl, 1977a), aeromagnetic profiles (Decker and Karl, 1977b), and aeromagnetic interpretation map (Cady, 1977) were published for the entire Seward Peninsula. A Bouguer gravity map (Barnes and Hudson, 1977) shows several anomalies that have possible relevance to mineral resources. A report by Anaconda Minerals Company (McDermott, 1982) details aeromagnetic, ground magnetic, and gravity surveys on the western part of Seward Peninsula, including the western part of the Bendeleben quadrangle. Aerial and ground radiometric surveys were conducted on the Seward Peninsula as part of the National Uranium Resource Evaluation program of the Department of Energy (Hawley and Associates, 1978). Cady and Till (in press) interpret aeromagnetic data in relation to the geology mapped by Till and others (1986).

GEOLOGY

The Solomon, Bendeleben, and southern Kotzebue quadrangles are underlain primarily by low- and high-grade metamorphic rocks and four suites of granitic rocks (fig. 3). Protoliths of the metamorphic rocks are mostly early Paleozoic in age; some Precambrian rocks may be present. A simplified geologic map, modified from Till and others (1986), provides the base for the sheets 1, 2, and 3.

The Precambrian(?) to Devonian Nome(?) Group and associated rocks are exposed in the low rolling hills of the southern part of the Solomon, northern part of the Bendeleben, and southern part of the Kotzebue quadrangles. These low-grade metamorphic rocks contain a mappable metamorphic lithostratigraphy (Till and others, 1986): the Precambrian(?) and Cambrian(?) Solomon Schist (ЄpЄs), which is a basal pelitic schist; a Cambrian(?) and Ordovician mixed rocks unit (OЄx), composed principally of interlayered marble and quartz-graphite schist; the Ordovician Casadepaga Schist (Oc), which is dominated by mafic and calcareous lithologies; and an Ordovician impure chlorite marble unit (Oim). Microfossils (conodonts) of Ordovician age were found in the mixed rocks and impure chlorite marble units by Till and others (1986). These four units have a minimum combined thickness of 4.5 km.

The protolith package of the Nome(?) Group and associated rocks includes submarine sedimentary and igneous rocks of Precambrian(?) to Devonian age. The Solomon Schist (ЄpЄs) is composed predominantly of pelitic rocks but includes small amounts of calcareous schist. The protoliths of this unit were probably shale or siltstone, locally limey. The mixed rocks unit (OЄx) is dominated by tens to hundreds of meters of marble in some areas and quartz-graphite schist in others. These two lithologies thicken and thin along strike on a scale of kilometers; this feature may be relict of depositional basin geometry. Interlayered with these lithologies are relatively thin, 1-m to tens of meters thick layers of pelitic schist, mafic schist, and calcareous schist. Protoliths of the mixed rocks unit (OЄx) are marine sediments; recrystallized radiolarians were found in quartz-graphite schist by Till and others (1986). The Casadepaga Schist (Oc) contains quartz-poor lithologies dominated by mafic and calcareous components. Metabasites are common. The impure chlorite marble (Oim) contains layers and lenses of chlorite and albite and rare metabasite lenses. Chlorite-albite lenses and metabasites are more common near the base of the unit. Because mafic and calcareous components are intimately interlayered in the Casadepaga Schist and the impure chlorite marble unit, these units probably record mafic volcanism on a carbonate platform. The major outpouring of mafic material formed the protoliths of the Casadepaga Schist during Ordovician time (Till and others, 1986).

The four lithostratigraphic units of the Nome(?) Group were metamorphosed and deformed in Late Jurassic time (at 160 Ma or earlier; Armstrong and others, 1986). Carbonate rocks of Cambrian to Devonian age, which were also metamorphosed and deformed, are spatially associated with the Nome(?) Group, although their relation to the four units described above is unclear (Till and others, 1986).

The foliation in the Nome(?) Group and associated rocks is a generally flat-lying to shallow-dipping schistosity. Although lithologic layering and foliation are commonly parallel, intrafolial isoclinal folds are abundant and some areas show lithologic layering at a high angle to schistosity. The foliation is therefore a transposition foliation, produced by penetrative ductile deformation that altered the original geometric relations between lithostratigraphic units. In the eastern part of the Bendeleben quadrangle, in the vicinity of Kiwalik Mountain, the lithostratigraphy is inverted relative to most exposures of the Nome(?) Group and may indicate that map-scale folding accompanied deformation.

Deformation in the Nome(?) Group and associated rocks took place at high pressure and temperature conditions that

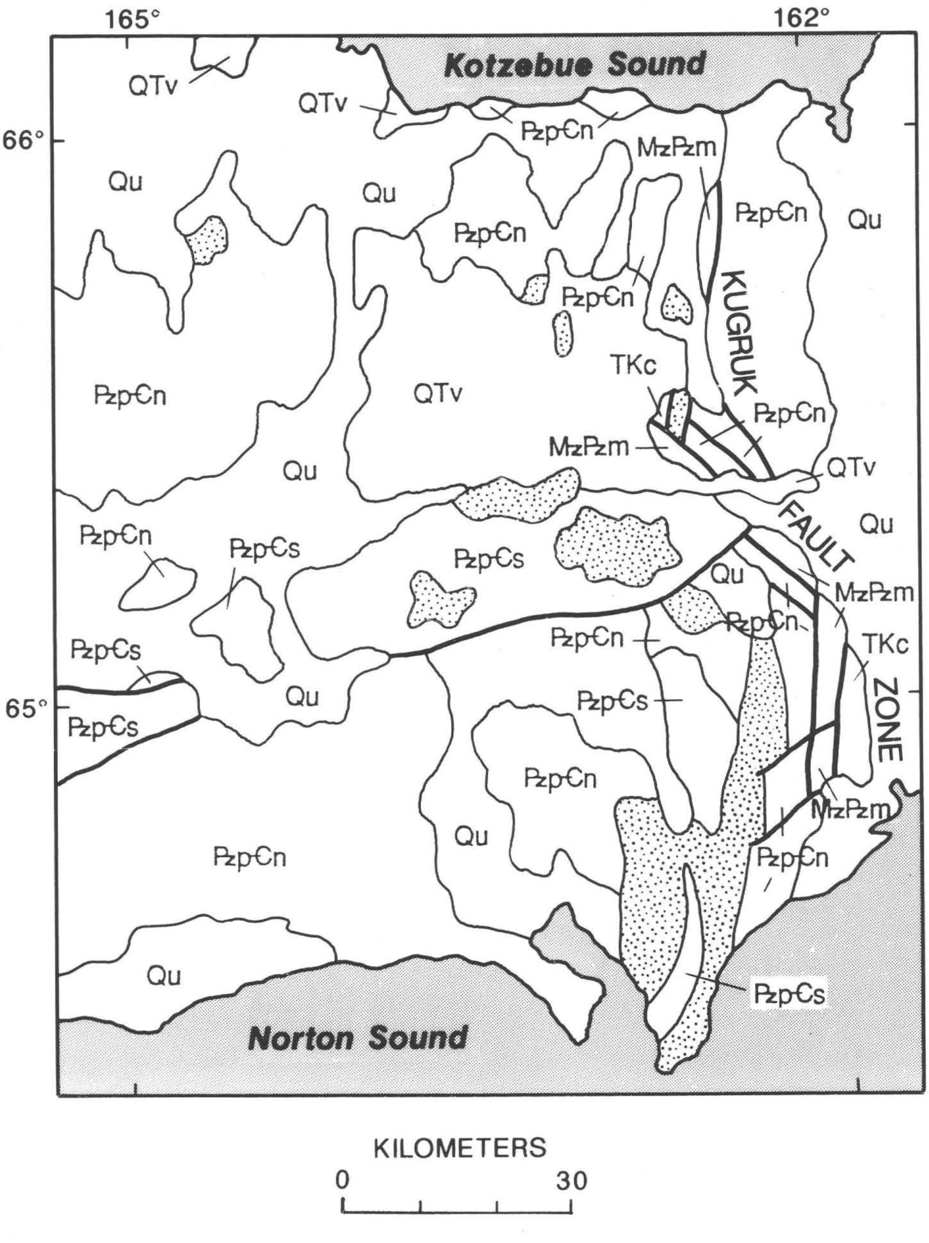

Figure 3. Simplified geologic map of Solomon, Bendeleben, and southern part of Kotzebue quadrangles. PzpЄn, Nome(?) Group; PzpЄs, high-grade metamorphic rocks; MzPzm, undifferentiated carbonate rocks; TKc, conglomerate; QTv, basalt flows; Qu, surfical deposits; stipple pattern, intrusions.

culminated in the blueschist facies (about 475°C and greater than 10 kb; Forbes and others, 1984; Thurston, 1985). Relatively few of the lithologies in the Nome(?) Group and associated rocks have appropriate compositions to crystallize minerals diagnostic of the blueschist facies, so that much of the unit may be mistaken for a greenschist-facies terrane.

High-grade metamorphic rocks crop out in the mountain ranges that transect the low-grade rocks from east to west (the Kigluaik and Bendeleben Mountains) and north to south (the Darby Mountains) (fig. 2). Most of the high-grade rocks are amphibolite facies in grade, but granulite facies assemblages were noted in the Kigluaik and Darby Mountains by Till and others (1986). Protoliths of the high-grade rocks are the same as the Nome(?) Group and associated rocks; locally high-grade equivalents of the four lithostratigraphic units of the Nome(?) Group are discriminated at mapping scale of 1:250,000 (Till and others, 1986). Cretaceous intrusive rocks intrude the high-grade rocks in all three mountain ranges. The amphibolite-to-granulite metamorphic events took place around 110-100 Ma (Till, written communication, 1989).

Several suites of granitic rocks intruded the low- and high-grade metamorphic rocks during the Cretaceous. The oldest intrusive suite consists of alkaline stocks and plutons, chiefly syenite, monzonite, and granodiorite. These range in age from 96.3 to 108.3 Ma (K-Ar) in the study area, where they are restricted to the eastern part of the Bendeleben quadrangle. These are the westernmost exposures of a 300-km belt of alkaline intrusive rocks that extends from the Shiniliaok Creek pluton in west-central Alaska to the Kachauik pluton in the Darby Mountains (Miller, 1970, 1972; Miller and Bunker, 1976).

A second intrusive suite consists of alkalic to alkali-calcic granite, granodiorite, quartz monzonite, syenite, and monzonite plutons ranging in age from 90.5 to 96.4 Ma (Miller and Bunker, 1976; Till and others, 1986). These are present chiefly in the eastern parts of the Bendeleben and Solomon quadrangles. A third intrusive suite consists of three large alkali-calcic to calc-alkalic granodiorite, quartz monzodiorite, monzonite, and granite plutons. These are 81.8 to 83.0 Ma in age and are confined to the Bendeleben Mountains and adjacent lowlands (Miller and Bunker, 1976; Till and others, 1986). The youngest suite of intrusive rocks consists of calc-alkaline tin-bearing granites (Hudson and Arth, 1983). These range in age from 69.2 to 80.2 Ma and are present primarily in the Teller quadrangle to the immediate west of the Bendeleben quadrangle. The youngest of the tin granites, the Oonatut Granite Complex (Hudson, 1979), is present in the northwest corner of the Bendeleben quadrangle.

In addition to these four suites of intrusive rocks, numerous dikes, sills, and small stocks are present, chiefly in the mountain ranges. These range from alkali feldspar granite to quartz monzodiorite in composition. A K-Ar age of 84.0 Ma (Till, written communication, 1989), was obtained from muscovite from a pegmatite. Turner and Swanson (1981) obtained K-Ar ages of 69.0 and 74.5 Ma for intrusive rhyolites and 74.9 Ma for a basalt dike in the western Bendeleben Mountains. Rhyolite dikes were not found during our study. Quartz latite dikes are common, but those examined during this study are altered and not amenable to isotopic age-dating techniques.

The Kugruk fault zone (Sainsbury, 1974) trends north-south along the east boundary of the quadrangles (fig. 3). Within the fault zone, the Nome(?) Group and associated rocks are juxtaposed with mylonitic metabasite, serpentinite, tonalite, and carbonate-clast conglomerate. The Nome(?) Group and associated rocks bound the fault zone on both the east and west. Cretaceous or Tertiary sedimentary rocks are the youngest rocks cut by the fault zone. Bedrock exposures in the fault zone are poor, and the age or sense of motion in the fault zone are not known.

Tertiary and Quaternary basinal sedimentary deposits are present in the Solomon and Bendeleben quadrangles; voluminous tholeiitic and alkalic basalt flows of Tertiary and Quaternary age form a plateau in the central part of the Bendeleben quadrangle.

METHODOLOGY

This mineral-resource assessment is the result of our examination of geologic, geochemical, geophysical, and mineral-deposit information to determine the types of mineral deposits that might be present and the domains where they would be expected to occur. This was done, in part, by a panel composed of 6 geologists, 2 geochemists, and a geophysicist familar with the geology of the Bendeleben and Solomon quadrangles.

The first step was to examine the geologic map of the Bendeleben and Solomon quadrangles (Till and others, 1986) to identify environments where specific types of mineral deposits might be present. We then prepared mineral-deposit descriptions from available models (Eckstrand, 1974; Cox and Singer, 1986; Roberts and Sheahan, 1988) and from known deposits on the Seward Peninsula. The following section on mineral-deposit types summarizes the major characteristics of each deposit type considered in this report.

Using the data of Smith and others (1989) for stream-sediment samples and King and others (1989a) for panned-concentrate samples, we delineated areas containing anomalous amounts of the elements comprising the geochemical signature of each mineral-deposit type. For example, areas containing anomalous Au, As, Sb, and (or) W were delineated as permissive for low-sulfide gold-quartz veins.

Smith and others (1989) and King and others (1989a) report 3 levels of anomalies for each element. For this assessment, anomalies that corresponded to approximately the 90th percentile, or greater, were generally used. The actual anomalous values used for each element are compiled in table 1. Comparison of the rock geochemistry of 15 major lithologies in these quadrangles (Gamble, unpub. data, 1990) with the anomalous levels chosen for the stream-sediment and panned-concentrate data, shows that (1) the anomaly levels used for stream-sediment samples are well above the mean for almost all of the elements for each rock type and (2) the anomaly levels for panned-concentrate samples are exceeded by only the highest values obtained for some rock types.

We then compared these anomalous areas to the geologic map. Areas where geochemical anomalies coincided with appropriate lithologies were delineated as a first approximation of the tracts considered favorable for a given deposit type. For example, areas where Au, As, Sb, and (or) W anomalies coincided with rocks of the Nome(?) Group were delineated as favorable for low-sulfide gold-quartz veins.

Tract boundaries were then refined using other information such as the distribution of known lode and placer mineral occurrences, the presence of minerals such as galena or scheelite in concentrate samples, and in a few cases, the geophysical expression of a pluton or mineral occurrence. The features used to draw tract boundaries are summarized in tables 2, 3, and 4.

We assigned each tract a low, moderate, or high favorability for each deposit type based on our evaluation of its attributes. The attributes known to be present in a tract were considered and compared to the attributes present in other tracts delineated for the same deposit type. In general, the more attributes present in a tract, the higher a favorability is assigned. However, all attributes were not given equal weight. The presence of a mineral deposit or occurrence of the type under consideration is the single most important attribute taken to indicate that an area is favorable for a mineral deposit. The presence of appropriate anomalies in stream-sediment and (or) panned-concentrate samples is given less weight; in part to reflect our uncertainty as to the origin of those anomalies and in part to reflect the low sample density and reconnaissance nature of the geochemical sampling program. The area of the drainage basins sampled ranges from 1 to 120 km^2 and averages 12 km^2 (Arbogast and others, 1985).

Table 1. Stream-sediment and panned-concentrate anomaly levels used in this assessment [From Smith and others (1989) and King and others (1989a). All values in parts per million. As, Au, Bi, Sb, and Zn analyses of stream-sediment samples are by atomic-absorption methods. All other analyses are by semiquantitative 6-step emission-spectrographic methods. Percentile, upper percentile of data set represented by anomalous value shown; L, detected but less than value shown]

	Stream-sediment samples		Panned-concentrate samples	
Element	Anomaly level	Percentile	Anomaly level	Percentile
Ag	0.5L	14.6	1.5	13.1
As	30	10.3	500L	3.9
Au	-	-	20L	5.1
B	250	5.7	1000	9.8
Ba	1500	9.5	2000	10.7
Be	5	13.6	3	10.2
Bi	2	0.9	20	7.7
Co	50	6.3	50	8.9
Cu	50	12.3	20	13.0
Mn	2000	11.8	1000	7.7
Mo	5	11.5	20	9.3
Ni	100	7.0	50	9.7
Pb	70	9.0	200	9.7
Sb	3	11.3	200L	3.8
Sn	10	10.5	500	12.8
W	50	1.9	500	9.4
Zn	140	10.7	500	10.6

Low, moderate, and high are relative terms we used to compare tracts delineated for a given deposit type. A tract assigned a high favorability is more likely to contain a mineral deposit than one assigned a moderate favorability, which, in turn, is more likely to contain a mineral deposit than one assigned a low favorability. However, it must be emphasized that our knowledge of these attributes is not only dependent on whether or not they are present, but also on our ability to detect their presence.

The final step of this assessment was estimation of the number of undiscovered low-sulfide gold-quartz veins that might be present within each tract within approximately 1 km of the surface. Estimates were made at the 90th, 50th, and 10th percentile confidence levels (table 5).

MINERAL-DEPOSIT MODELS

This section describes the types of mineral deposits that are present, or are most likely to be discovered, in the Bendeleben and Solomon quadrangles. These descriptions are derived from (1) examinations of mineral occurrences in these and adjacent quadrangles, and (2) descriptions of mineral-deposit models in Eckstrand (1984), Cox and Singer (1986), and other sources cited. The names of the deposit types used here are generally the same as used by Cox and Singer (1986). Examples are given for each deposit type known in these quadrangles and their locations are shown on the appropriate sheet.

LOW-SULFIDE GOLD-QUARTZ VEINS

Low-sulfide gold-quartz veins consist of gold-bearing quartz veins along high-angle faults and joint sets in regionally metamorphosed rocks (Berger, 1986). Pyrite, galena, sphalerite, chalcopyrite, arsenopyrite, and other metallic minerals may also be present in small amounts.

Low-sulfide gold-quartz veins are the most abundant type of mineral deposit in the Bendeleben and Solomon quadrangles; there are nine known deposits and occurrences in these quadrangles, and nineteen other occurrences may belong to this deposit type. Only one of these, the Big Hurrah Mine, has recorded gold production; over 750 kg (27,000 oz) of gold were produced, chiefly between 1903 and 1907 (Read and Meinert, 1986).

In these quadrangles, these veins are commonly less than 10 cm wide, but range from a few millimeters to several meters wide. They typically contain about 85 to 90 percent quartz, 10 percent albite and (or) ankerite, and 5 percent arsenopyrite, pyrite, and (or) stibnite. They are present along high-angle fault and fracture zones and postdate the regional metamorphic event. On the Seward Peninsula, these veins are restricted to the Nome(?) Group and are present chiefly in the mixed rocks unit and the Casadepaga Schist. Gold is present as free gold grains rarely greater than 0.5 mm across and typically less than 0.1 mm across (Gamble, unpub. data, 1988). Au, As, Sb, and W are the most consistently anomalous elements in these veins and should be the most reliable pathfinder elements in a geochemical survey designed to find these deposits. Ag, Bi, Zn, and Pb are anomalous in some veins but are unlikely to be reliable as pathfinder elements.

The most notable examples of this deposit type in the Bendeleben and Solomon quadrangles are the Big Hurrah Mine and the Bluff deposits. In addition to these two deposits, many other prospects and occurrences are present in these quadrangles (Gamble, 1988). Low-sulfide gold-quartz veins in the Nome quadrangle, to the immediate west of the Solomon quadrangle, are present in the same host rocks along similar structures.

POLYMETALLIC VEINS

Polymetallic vein deposits contain a variety of metallic minerals, chiefly galena and sphalerite, and locally pyrite, chalcopyrite, and Ag-sulfides and -sulfosalts (Sangster, 1984). Native gold and electrum are present in some deposits (Cox, 1986a). These veins are generally present along high-angle faults and at fault intersections near felsic intrusions in sedimentary and metamorphic rocks (Cox, 1986a). The chief commodities produced from these deposits are Ag, Pb, Zn, and locally Au and Cu.

In the Bendeleben and Solomon quadrangles, polymetallic vein deposits are present in high-grade metamorphic rocks in the Bendeleben and Darby Mountain ranges and locally in Nome(?) Group and associated rocks. All veins are present near exposed intrusive rocks or in areas where concealed intrusions are

Table 2. Summary of features present in tracts shown on Sheet 1

Tract No.	Map units	Stream-sediment anomalies[1]	Panned-concentrate[1]		Mineral deposit[2]	Gold placers[3]	Favorability for low-sulfide gold-quartz veins
			Anomalies	Minerals			
1.	OCx, Oc	Sb, As	Sb, As	None	1	3	High
2a.	OCx	(As)	[Au, W] (As, Sb)	[sch] (gold)	None	3	High
2b.	OCx, CpCs, Oim	[As, Sb]	[Sb] (As, Au, W)	[gold]	1	2	Moderate
3a.	OCx, QTv, Oim	As [Sb] (W)	[As, Sb, W] (Au)	[sch] (gold)	None	3	High
3b.	Qtv, Oim OCx	[Sb, As]	Sb [As]	None	None	1	Moderate
4.	OCx, Oc	[As] (Sb, W)	[Au, As, W] (Sb)	(sch, gold)	None	3	Moderate
5.	OCx, Oc	As (Sb, Au, W)	[W]	sch	1	1	Low
6.	Oim, Od, Kgd, MzPzt, Sd, Pzm	None	As, Au	sch	None	1	Low
7a.	Oc, CpCs, OCx Pzm, Oim	[As, Sb] (Au)	(As, Sb, Au)	(sch, gold)	None	2	Moderate
7b.	OCx, CpCs, Oc,	Sb	(Sb, Au)	(gold, sch)	1	3	Moderate
7c.	OCx, CpCs, Oc	Sb [As, Au] (W)	[Au, Sb] (As, W)	[sch] (gold)	2	3	High
7d.	Oim, Oc	[Sb, As] (Au, W)	[Au] (As, Sb, W)	[sch] (gold)	None	2	Moderate
7e.	OCx, CpCs, Oc	Sb [As]	[As, Au, W]	[sch] (gold)	2	3	High
7f.	OCx, CpCs	[As, Au] (Sb, W)	[Sb, Au, W] (As)	[sch] (gold)	2	3	High

(1) Unqualified = present in more than 30% of samples; [ ] = present in 11-30% of samples; ( ) = present in 1-10% of samples
sch, scheelite; gold, native gold

(2) 1 = possible low-sulfide gold-quartz vein occurrence; 2 = known low-sulfide gold-quartz vein occurrence/deposit

(3) 1 = prospect; 2 = moderate gold production; 3 = major gold production

Table 3. Summary of features present in tracts shown on sheet 2

Tract No.	Map units	Stream-sediment anomalies[1]	Panned-concentrate[1] Anomalies	Panned-concentrate[1] Minerals	Mineral deposit[2]	Favorability
1.	OЄx, Oim, QTv	[As, Ag, Sb, Cu, Zn] (Ba, Co, Ni, Mn, Pb)	Ni, Co, Pb, Cu [Ba, Ag, Zn, As, Mn] (Sb)	(tour, gal, cass)	2-Sed	Sed - high Bes - low
2.	OЄx, Oim, Oc	Ba [Mn, Co] (Zn, Ag, As, Ni)	Zn, Cu [Pb, Ba, Ag] (Mn, Co, Ni, As)	None	None	Sed - moderate Bes - low
3.	ЄpЄs, OЄx, Oc, Pzg	[Ba, Cu, Co, Mn] (As, Ag, Ni, Pb Zn)	[Zn, Pb, Co, Ag, Ni, Cu] (As, Mn)	[tour] (gal, cass)	1-Sed	Sed - moderate Bes - low
4.	OЄx, PzpЄh, Kdg, Od, Oim	[As, Pb, Ag, Zn] (Cu, Sb, Mn, Ba, (Ni)	Pb [Zn, Ba, Ag, Mn, Cu] (Co, Ni, As, Sb)	[tour, gal] (cass)	1-Sed	Sed - moderate
5.	PzpЄh, Kbg, PzpЄm	Cu, Zn, Ni, Ba Mn, Ag [Co] (As)	[Ag, Mn, Pb, Zn] (Co, Cu, Ni)	tour (gal, cass)	1-Sed	Sed - moderate Bes - low
6.	OЄx, Oc	[Mn] (Ag, As, Sb, Cu)	Ag, [Cu, Ba, Ni, Sb] (Co, Pb, Mn, As)	(tour, cass, gal)	None	Sed - low
7.	ЄpЄs, OЄx, Oc, Oim Pzm	[Sb, Ag, Zn, Cu, As] (Ni, Co, Mn, Ba)	[Cu, Ba, Ni, Ag, Zn, Co] (Pb, As, Sb, Mn)	[tour] (cass, gal)	1-Sed 1-Bes	Sed - low Bes - moderate

(1) Unqualified = present in more than 30% of samples; [ ], present in 11-30% of samples; ( ), present in 1-10% of samples; tour, tourmaline; gal, galena; cass, cassiterite

(2) 1, possible occurrence; 2, known occurrence; Sed, sediment-hosted zinc-lead; Bes, Besshi massive-sulfide

Table 4. Summary of features present in tracts shown on sheet 3

Tract No.	Map units	Stream-sediment anomalies[1]	Panned-concentrate[1] Anomalies	Panned-concentrate[1] Minerals	Mineral deposit[2]	Favorability
1.	OЄx, ЄpЄs, Kog, Pzg	Sn [Be] (Ag, Mo, W, Zn, Cu, As, B)	W, Sn [Mo, Cu, Pb] (Ag, B, Au, Be, Zn, As)	sch [tour, gold]	2-Sn vein	Sn vein - High Sn greisen - High Sn skarn - Moderate Sn rep. - Moderate W skarn - Moderate Au skarn - Low
2a.	Kku, MzPzm, OЄx, QTv	Cu [Zn] (Ag, W, Be)	Mo, W, Sn [Sb, Ag, Au]	sch [cass]	2-Fe skarn 2-Pmv	Fe skarn - High Cu skarn - Moderate Pmv - High Pmr - Moderate Zn-Pb-Ag skarn - Moderate
2b.	QTv, MzPzt, TKc, Pzm, MzPzm, TKs	(Ag, Cu, Sn)	Zn [Cu] (Pb)	(gold)	1-Cu skarn	Fe skarn - Low Cu skarn - Low Pmv - Moderate Pmr - Low Zn-Pb-Ag skarn - Low
3.	PzpЄh, Kwc, Ocs, Oim, OЄx, Kb, Kgu	Ag, Be, Mo [Zn, Sn] (As, W, Au)	Mo [W, Sn] (Ag, Pb, Au)	[sch] (cass, gal)	2-Low-F Mo 1-Pmv	Low-F Mo - High Pmv - High Pmr - Moderate Zn-Pb-Ag skarn - Moderate
4.	Kdg, Pzm, PzpЄh, Oim	Sn, Be [Mo, As, Pb, W] (Ag, B)	Mo, W, Sn [Be, Ag, Pb, As, Cu Au, B)	sch (gold)	none none	Sn vein - Low Sn greisen - Low Sn skarn - Low Sn rep. - Low W skarn - Moderate Low-F Mo - Moderate
5.	Kkms, Kkg, PzpЄh, Oc, Oim, Kkgm, Kad	Sn, Pb [Be] (Mo, As, Sb, W)	Mo (Pb)	(sch)		Sn vein - Low Sn greisen - Low Sn skarn - Low Sn rep. - Low

Table 4. Summary of features present in tracts shown on Sheet 3--Continued

Tract No.	Map units	Stream-sediment anomalies[1]	Panned-concentrate[1] anomalies	Panned-concentrate[1] minerals	Mineral deposit[2]	Favorability
6a.	Pzp€h, Kbg, Kfg, Pzp€m	Be, Cu, Zn, Mo, Pb, Ag [B] (Sn, As, W)	B, Be [Ag] (Zn, Pb, W, Sn, Mo, Cu, Au)	[sch, tour] (cass, gal)	3-Pmv	Sn vein - Low Sn greisen - Low Sn skarn - Low Sn rep. - Low W skarn - Low Pmv - High Pmr - Moderate Zn-Pb-Ag skarn - Moderate Au skarn - Low
6b.	Pzp€h, Pzp€m, Kbg, QTv	Sn, Be [Ag, Pb] (Mo, W, B, As, Au)	[Be, W, Sn, B] (Mo, Ag, Cu)	sch [tour] (cass)	none	Sn vein - Low Sn greisen - Low Sn skarn - Low Sn rep. - Low W skarn - Low Pmv - Moderate Pmr - Low Zn-Pb-Ag skarn - Low
7.	Pzp€h, O€x, Kgu, Pzg	As, Ag, Cu, Mo, Zn, B [Sn, Pb] (Sb)	B, Be (As, As)	tour [sch]	1-Pmv	Sn vein - Low Sn greisen - Low Sn skarn - Low Sn rep. - Low Pmv - High Pmr - Moderate Zn-Pb-Ag skarn - Moderate

(1) Unqualified, present in more than 30% of samples; [ ], present in 11-30% of samples; ( ), present in 1-10% of samples
sch, scheelite; tour, tourmaline; gold, native gold; cass, cassiterite; gal, galena

(2) 1, possible occurrence; 2, known occurrence; Pmv, polymetallic vein; Pmr, polymetallic replacement

suspected to be present. The veins are vertical to subvertical, range from a few centimeters to about 3 m wide, and crosscut the regional metamorphic fabric. Galena, sphalerite, and pyrite±arsenopyrite are the most common metallic minerals, and quartz is the most common gangue mineral. Ag, Pb, and Zn are the most consistently anomalous elements in these deposits; Cu and As are important in some occurrences.

In the Bendeleben Mountains, galena-chalcopyrite-pyrite quartz veins less than 50 cm wide are present adjacent to, or near, altered quartz latite(?) porphyry dikes. These veins cut a variety of high-grade metamorphic rock types.

The Granite Creek occurrence consists of galena, sphalerite, chalcopyrite, and fluorite in quartz-aplite breccia filling in hornfelsed black slate (Miller and Grybeck, 1973).

The galena-sphalerite-quartz vein at the Independence Mine is as much as 3 m wide and is present in a fault zone in calc-schists of the Nome(?) Group and associated rocks. In 1921, 32 tonnes (35 tons) of ore containing over 900 g per tonne (33 oz per ton) Ag, 30 percent Pb, and 5 percent Zn were shipped from the Independence Mine.

Other occurrences in these quadrangles may also belong to this deposit type. The Omilak East prospect has been drilled and contains highly oxidized galena-bearing veins (Ron Sheardown, Greatland Exploration, Inc., Anchorage, Alaska, written commun., 1985). Other lead-zinc occurrences in the area are poorly exposed and were not studied in detail.

SEDIMENT-HOSTED ZINC-LEAD DEPOSITS

Sediment-hosted zinc-lead deposits are syngenetic, stratiform Zn-Pb-Ag-barite deposits in clastic and carbonate sedimentary and metasedimentary rocks (Briskey, 1986; Morganti, 1988). Some deposits are underlain by crosscutting feeder veins and veinlets (Lydon and Sangster, 1984). Sphalerite, galena, barite, pyrite, and pyrrhotite are the chief metallic minerals in these deposits; chalcopyrite, marcasite, arsenopyrite, cassiterite, and other metallic minerals may also be present (Briskey, 1986; Lydon and Sangster, 1984). The geochemistry of these deposits is dominated by Zn, Pb, Ag, Cu, Ba, and Mn (Briskey, 1986).

Sediment-hosted zinc-lead deposits on the Seward Peninsula are restricted to Nome(?) Group and associated rocks. The only known example of this type of deposit in the Bendeleben and Solomon quadrangles is the Hannum Creek deposit in the Bendeleben quadrangle. The Thompson, Quarry, Aurora Creek, and Galena prospects in the Nome quadrangle may also be this type of deposit (see Cobb, 1972c for locations and references). The occurrences on the Seward Peninsula consist of galena and sphalerite, and locally barite layers, disseminations, and stringers in schist, calc-schist and marble. Pb, Zn, Ag, and locally Ba are the most consistent and highly anomalous elements in these occurrences. Sb is moderately anomalous in several occurrences.

In addition to the Hannum-Harrys Creek deposit, several poorly exposed Pb-Zn-Ag occurrences in the Bendeleben and Solomon quadrangles may also be sediment-hosted zinc-lead deposits. These include the Wheeler Lead prospect, the Foster prospect, and the Omilak Mine deposit. The Foster prospect and Omilak Mine deposit occur in high grade metamorphic rocks derived from the same protoliths as the Nome(?) Group and associated rocks.

Relative to other rocks in these quadrangles, the graphitic quartz schist of the mixed rocks unit (O€x) has higher Ag, Ba, Mo, Sb, and Zn contents (Gamble, unpub. data, 1990); these contents are significantly higher than averages reported for nonmetalliferous shales (for example, Levinson, 1980; Clark, 1982). The graphitic quartz schist is an unusual lithology, and its protolith is unknown.

TIN VEINS

Tin vein deposits are quartz-cassiterite±wolframite and base-metal veins, stockworks, breccias, and replacement deposits in or near felsic plutonic rocks (Reed, 1986a). Cassiterite is the chief metallic mineral; wolframite, arsenopyrite, stannite, molybdenite, galena, sphalerite, chalcopyrite, and other metallic minerals may also be present (Reed, 1986a; Sinclair and Kirkham, 1984). Common gangue minerals include quartz, tourmaline, beryl, topaz, fluorite, muscovite, and zinnwaldite (Sinclair and Kirkham, 1984). Sn, As, W, and B are good pathfinder elements (Reed, 1986a) for these deposits.

In the Bendeleben quadrangle, tin-bearing galena-quartz vein mineralization is present in mixed unit schist on the east side of the Oonatut Granite Complex. The Oonatut Granite Complex is the easternmost of a suite of highly evolved tin-enriched granites on the Seward Peninsula (Hudson and Arth, 1983). Samples of mineralized rock have high Ag (as much as 5000 parts per million (ppm), Pb, Sb, and Sn contents; and moderate As, Au, Cu, and Zn contents (Sainsbury and others, 1970). These veins may represent the outer parts of zoned tin veins related to the granite (see Reed, 1986a, fig. 44, for metal zoning in tin veins).

IRON SKARNS

Iron skarns consist of magnetite±chalcopyrite, pyrite, pyrrhotite, hematite, and cobaltite in calc-silicate metasomatic rocks adjacent to intermediate to felsic plutonic rocks (Einaudi and Burt, 1982; Gross, 1984; Cox, 1986b). The deposits may be massive, disseminated, and veinlike in form (Gross, 1984). The calc-silicate assemblages of the host rocks consist of pyroxene, garnet, epidote, and late-stage amphibole, chlorite, and ilvaite (Einaudi and Burt, 1982). The geochemical signature consists chiefly of Fe, Cu, Co, and Au (Cox, 1986b).

In the Bendeleben quadrangle, a magnetite (+chalcopyrite) deposit is located in the subsurface on the northeast flank of the Kugruk pluton. A prominent, approximately 1 by 2.5 km aeromagnetic high of greater than 1,000 nanoteslas (gammas) is centered over this occurrence. The pluton has a measured magnetic susceptibility of 13-28x10^3 SI (Cady and Till, in press), and the magnetic susceptibility of the skarn was not measured. Brief examination of drill core indicates that the occurrence consists of massive to semimassive magnetite in calcschist. The magnetite contains less than 5 volume percent chalcopyrite in clots as large as 2 cm across. Typical skarn lithologies containing calc-silicate minerals were not observed, and geochemical analyses of this mineralization are not available.

LOW-FLUORINE STOCKWORK MOLYBDENUM SYSTEMS

Low-fluorine stockwork molybdenum systems consist of quartz-molybdenite-pyrite stockworks in felsic intrusive rocks and nearby country rocks (Theodore and Menzie, 1984; Westra and Keith, 1981; White and others, 1981). Scheelite, chalcopyrite, tetrahedrite, cassiterite, and other metallic minerals may also be present. Hydrothermal alteration of the intrusion is extensive and commonly grades outward from a core of potassic alteration through a quartz-sericite-pyrite zone, an argillic zone, and an outer propylitic zone (Westra and Keith, 1981). The geochemical signature of these deposits consist chiefly of Mo, Cu, W, Au, Zn, and Pb (Theodore, 1986).

In the Bendeleben quadrangle, veins and veinlets of quartz-pyrite-molybdenite±galena occur in zones as large asseveral hundred square meters in area on the west side of the Windy Creek pluton. These veinlets do not have the density or crosscutting nature of a stockwork. Alteration of the Windy Creek pluton is limited to incipient propylitization throughout most of the pluton. This occurrence has several features that do not agree with the low-fluorine deposit model--most notably the alkaline to alkali-calcic nature of the quartz monzonite intrusion and a fluorine content of about 0.16 percent (2 samples). Fluorite is also reported in veins and locally disseminated in the granite (Miller and others, 1971). However, Theodore (USGS, Menlo Park, CA, oral. commun., 1991) reports that some low-fluorine stockwork molybdenum systems contain locally abundant fluorite. The geology of the Windy Creek occurrence more closely matches the low-fluorine type than the Climax type of molybdenum deposits (White and others, 1981). Samples of mineralization show high contents of Mo, W, Pb, Zn, and Ag (Miller and others, 1971).

The following deposit types do not have known analogs in the Bendeleben and Solomon quadrangles. However, their geologic and geochemical characteristics suggest that they might be present. The deposit descriptions presented here are derived from the mineral-deposit model compilations of Cox and Singer (1986), Eckstrand (1984) and other sources cited.

TIN GREISEN, SKARN, AND REPLACEMENT DEPOSITS

Although not known in the studied quadrangles, tin greisen and tin skarn deposits are associated with several tin-enriched granites in the Teller quadrangle, to the immediate west of the Bendeleben quadrangle. In addition, a greisen veinlet and calc-silicate rocks, both containing anomalous Sn, are reported near the Oonatut Granite Complex (Sainsbury and others, 1970). Tin replacement deposits are not known to be associated with these tin granites but are considered permissible because of the presence of extensive carbonate rocks around the plutons. Other types of tin deposits have been described (for example, Taylor, 1979; Hoskings, 1988) but we consider these, and tin veins, to be the types most likely to be present in these quadrangles.

Tin greisens consist chiefly of disseminated and (or) vein(let) cassiterite±wolframite and molybdenite in granite. The greisen consists of quartz, muscovite, topaz±fluorite and tourmaline in which the original texture of the intrusive may or may not be preserved. The geochemical signature consists of Sn, F, Be, W, Mo, and other elements (Reed, 1986b).

Tin skarns consist chiefly of cassiterite, scheelite, and beryllium minerals in skarn near the contact of granite and carbonate rocks. Stannite, tin silicates, and tin borates may also be present. The skarn consists chiefly of prograde idocrase, garnet, and malayite, and retrograde amphibole, mica, tourmaline, and fluorite (Einaudi and Burt, 1982). A distinctive fluorite-magnetite-idocrase vein skarn stage is associated with the Lost River Mine tin deposit (fig. 1) in the Teller quadrangle (Dobson, 1982). The geochemical signature of tin skarn deposits consists chiefly of Sn, W, F, Be, and other elements (Reed and Cox, 1986).

Tin replacement deposits are stratabound cassiterite-sulfide replacements in carbonate rocks near a granite intrusion. Pyrrhotite, arsenopyrite, cassiterite, and chalcopyrite are the main metallic minerals in these deposits. These deposits have a geochemical signature dominated by S, As, Cu, B, W, and F (Reed, 1986c).

POLYMETALLIC REPLACEMENT DEPOSITS

Polymetallic replacement deposits are massive to semimassive, sheetlike to lens-shaped deposits developed in carbonate rocks near, or adjacent to, intermediate to felsic intrusions. Sphalerite, galena, argentite, chalcopyrite, enargite, and tetrahedrite are the main metallic minerals. The geochemical signature consists chiefly of Cu, Pb, Ag, and Zn (Morris, 1986). Polymetallic replacement deposits are closely associated with a variety of other mineral deposits, including polymetallic vein deposits, and Zn-Pb-Ag skarn deposits; several different types of deposits may be present in the same district if suitable host rocks are present. The presence of polymetallic vein deposits in the Bendeleben and Solomon quadrangles thus suggests that polymetallic replacement deposits may also be present in the area.

COPPER SKARN, ZINC-LEAD-SILVER SKARN, TUNGSTEN SKARN, AND GOLD-BEARING SKARN DEPOSITS

Copper skarns consist of disseminated to massive mineralization in skarn developed adjacent to mafic to felsic intrusions. Chalcopyrite, magnetite, bornite, molybdenite, and pyrite are the primary metallic minerals. The skarn mineralogy consists chiefly of pyroxene, garnet, wollastonite, and amphibole. The geochemical signature consists chiefly of Cu, Fe, and Mo; Au, Ag, and Zn may also be significant (Einaudi and others, 1981; Kirkham and Sinclair, 1984; Cox and Theodore, 1986). Copper skarns are considered permissible because of the presence of an iron skarn near the Independence Mine (the two deposit types may occur together) and because of a reported chalcopyrite vein occurrence in that same area.

Zinc-lead-silver skarns consist of sphalerite, galena, and other metallic minerals in calc-silicate skarn developed adjacent to, or near, intermediate to felsic intrusions. The calc-silicate skarn consists chiefly of prograde hedenbergite, garnet, bustamite, rhodonite, and idocrase, with retrograde actinolite, ilvaite, epidote, chlorite, and other minerals (Einaudi and others, 1981; Einaudi and Burt, 1982). The geochemical signature consists chiefly of Zn, Pb, Cu, and Ag (Dawson and Sangster, 1984; Cox, 1986c). Zinc-lead-silver skarn deposits may be found in areas where several other types of mineral deposit are present, including polymetallic vein deposits and polymetallic replacement deposits. Because of the association of these deposit types, the presence of known polymetallic veins, and widespread Zn, Pb, Ag, Cu anomalies in areas containing intrusive rocks and carbonate rocks, Zn-Pb-Ag skarns are permissible in these quadrangles.

Tungsten skarns consist of scheelite in calc-silicate skarn developed adjacent to felsic granitic intrusions. Molybdenite, chalcopyrite, sphalerite, pyrrhotite, and other metallic minerals may also be present. Skarn mineralogy consists of pyroxene, garnet, biotite, quartz, and carbonate minerals. The geochemical signature is dominated by W, Mo, Cu, Zn, and Bi (Einaudi and Burt, 1982; Dawson, 1984; Cox, 1986d). Tungsten skarns were chosen as a possible source for anomalies for W, Mo, and other elements in areas containing felsic granitoids and carbonate rocks.

Au-bearing skarn deposits are developed in reactive host rocks adjacent to, or near, intermediate to felsic intrusions. The most common pre-skarn host rocks are carbonate rocks, conglomerate, and felsic to intermediate tuff. Theodore and others (1991) subdivide Au-bearing skarns into two subtypes: those in which Au is the primary commodity and those in which Au is produced as a byproduct. The most common opaque minerals in these deposits are native gold, electrum, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, sphalerite, galena, bismuth minerals, and magnetite or hematite. Gangue mineralogy consists chiefly of garnet, pyroxene, wollastonite, chlorite, epidote, quartz, amphibole, and calcite (Theodore and others, 1991). The geochemical signature of Au-bearing skarns is highly variable, and can include Au, Ag, Cu, Pb, Zn, Fe, Mo, W, Sn, Sb, As, Bi, Te, Co, and Ni (Beddoe-Stephans and others, 1987; Theodore and others, 1991). Au-bearing skarns may be associated with a wide variety of other mineral deposits, including iron-skarns, copper skarns, and lead-zinc skarns (Beddoe-Stephans and others, 1987; Theodore and others, 1991), and there is a continuum between these types of skarn deposits and Au-bearing skarn deposits.

BESSHI VOLCANOGENIC MASSIVE-SULFIDE DEPOSITS

Besshi volcanogenic massive-sulfide deposits are thin stratiform bodies of massive to well-laminated pyrite, pyrrhotite, chalcopyrite, sphalerite, and other minerals in intercalated marine sedimentary rocks and locally mafic volcanic rocks. All known examples are within deformed quartzose and mafic schist (Cox, 1986e). The geochemical signature of these deposits consists chiefly of Cu, Zn, Co, Ag, Ni, and Cr (Cox, 1986e). Besshi-type deposits were selected as the most likely source for widespread Zn, Cu$\pm$Ag, Co, and Ni, anomalies in stream-sediment and panned-concentrate samples collected in areas underlain by Nome(?) Group and associated rocks.

Several occurrences in the western part of the Solomon quadrangle (Gamble, 1988; map nos. 97, 98, 124, 128, 129, 130) may be related to Besshi-type deposits, or alternatively, to sandstone-hosted Cu deposits. These consist of disseminated malachite and (or) chalcopyrite in quartzitic layers within marble or at a marble-schist contact. Some of these occurrences also contain anomalous Zn and (or) Ag. Sainsbury (1975) termed these deposits "tectonogenic copper deposits" and believed that they formed by fluid movement along thrust faults and that the quartzite is a silicified marble.

TRACTS

Tracts favorable for the various types of mineral deposits evaluated in this report are shown on sheets 1, 2, and 3. These tracts were drawn by (1) identifying areas that contain the appropriate geologic environment for the deposit type under consideration, and (2) identifying, within these areas, the presence of some other attribute or attributes normally associated with the deposit type.

For example, all of the intrusive bodies in the Bendeleben and Solomon quadrangle have some carbonate lithologies in their host rocks. Therefore, in a general sense, all contact zones around intrusive bodies are permissive for Zn-Pb-Ag skarn deposits. In order to further define this potential and to outline areas of favorability, some other attribute normally associated with Zn-Pb-Ag skarns must be present. The attributes that were most commonly chosen are anomalous concentrations of select elements in stream-sediment and (or) panned-concentrate samples; in this case Zn, Pb, Ag, and Cu. Additional attributes that were used to delineate the tracts include minerals present in panned concentrates, the presence of a known or suspected occurrence of appropriate type, the presence of gold placers, and, in a few cases, aeromagnetic and (or) gravity data. The attributes that are present within each of the tracts, which were used to draw the boundaries of the tracts, are summarized in tables 2, 3, and 4.

The favorability of each tract for a given deposit type is rated low, medium, or high based on our evaluation of the features that are present within each tract. The presence and absence of features were considered, as well as the strength or abundance of the feature. For example, for low-sulfide gold-quartz veins, not only was the presence of gold placers considered, but the size and distribution of gold placers as described by Yeend and others (1988) was also considered.

LOW-SULFIDE GOLD-QUARTZ VEINS

All parts of these quadrangles underlain by the Nome(?) Group have potential for low-sulfide gold-quartz veins. However, in order to delineate tracts that are favorable for these veins, some other feature common to this deposit type must be present. Anomalous Au, Sb, As, and W in stream-sediment and panned-concentrate samples were used to delineate the tracts shown on sheet 1. Other features, such as the presence of known or possible occurrences of this type, the presence of gold placers, and the presence of gold and (or) scheelite in concentrates were used to modify the boundaries of the tracts. The attributes that are present in each of the tracts delineated are listed in table 2.

Fourteen tracts delineated on sheet 1 are considered favorable for low-sulfide gold-quartz veins. On the basis of our evaluation of the features that are present in each of the tracts, we feel that 6 tracts (1, 2a, 3a, 6c, 6e, 6f) have high favorability and the remaining 8 have low to moderate favorability. In general, tracts that contain known low-sulfide gold-quartz veins and (or) gold placers of moderate to large production are assigned a high level of favorability.

POLYMETALLIC VEIN DEPOSITS

The presence of a known or suspected intrusive body is required for an area to be considered as having potential for polymetallic vein deposits. In addition, anomalous Ag, Pb, Zn, Cu, and (or) As concentrations in stream-sediment and (or) panned-concentrate samples, or the presence of a known polymetallic vein occurrence is required for an area to be delineated as a favorable tract. The presence of galena in panned-concentrates is a favorable feature but is not required for tract delineation.

Six tracts are considered favorable for polymetallic vein deposits (sheet 3); four of these are considered highly favorable and two moderately favorable. In general, those tracts containing a known polymetallic vein occurrence are assigned high favorability. Tracts with the appropriate geochemical anomalies but no known deposit are considered moderately favorable.

SEDIMENT-HOSTED ZINC-LEAD DEPOSITS

Both the Nome(?) Group and associated rocks and the high-grade metamorphic rocks of the Kigluaik, Bendeleben, and Darby Mountain Ranges contain lithologies that are permissible host rocks for sediment-hosted zinc-lead deposits. Anomalous Zn, Pb, Ag, and Ba in stream-sediment and panned-concentrate samples were used to delineate favorable tracts (sheet 2) within these units. The presence of a known or possible deposit of this type, and the presence of galena, tourmaline, and (or) cassiterite in panned-concentrate samples are features that were used to modify the tracts.

Seven tracts are favorable for this type of deposit. The tract with the only known sediment-hosted zinc-lead deposit in these quadrangles is assigned high favorability. The other tracts are ranked as low or moderate favorability on the basis of the strength and abundance of geochemical anomalies.

Within tract 4 (sheet 2), a metasedimentary rock with 35 percent golden yellow dravite (Mg-rich tourmaline) is present in the mixed rocks unit (O€x). South of tract 4, high-grade metasedimentary rocks locally contain tourmaline-rich laminae, and gold-colored dravite is found with Mg-rich silicates (cordierite, orthoamphibole, spinel) in lenses and layers. Tourmaline laminae are found in metasedimentary rocks at the Sullivan Mine in British Columbia, and tourmaline is found in Mg-lithologies at the Blackhawk Mine in Penobscot Bay, Maine (Slack, 1980). The Black Hawk deposit, however, has also been interpreted as a volcanogenic massive-sulfide deposit (Schmidt, USGS, Anchorage, Alaska, oral. commun., 1991). Slack (1980) considered both of these occurrences to reflect the presence of boron-rich hydrothermal fluids in the mineralizing system and noted that they could be used as prospecting guides. Stream-sediment, panned-concentrate, and rock geochemical samples collected in this area south of tract 4 did not show appreciable enrichment in Ag, Pb, Zn, or Ba. For this reason, this area is not included in tract 4; however, owing to the presence of tourmaline and Mg-rich silicates, this area may be worthy of further study.

TIN VEIN, GREISEN, REPLACEMENT, AND SKARN DEPOSITS

Tracts delineated as favorable for these deposits require the presence of a felsic intrusion and anomalous Sn$\pm$other elements in stream-sediment and panned-concentrate samples. In addition, carbonate rocks are necessary for Sn replacement and skarn deposits. Six tracts delineated on sheet 3 are favorable for these deposits. Tract 1 is the only tract considered highly favorable because of the presence of the Oonatut Granite Complex and known tin vein occurrences. The other tracts are thought to have low favorability because they contain felsic intrusions that are not the highly evolved granites normally associated with tin deposits (Taylor, 1979; Hoskings, 1988). The Sn anomalies in these tracts may be related to widespread granitic pegmatites, which are known to be slightly enriched (as much as 100 ppm) in Sn. Nonetheless, these tracts are considered as somewhat permissive because evolved granites may not be exposed or may have been missed by the relatively large-scale geologic mapping.

IRON SKARN AND COPPER SKARN DEPOSITS

Areas delineated as favorable for iron skarn and copper skarn deposits require the presence of a known or suspected intermediate to felsic intrusion, carbonate host rocks, and some other feature commonly associated with these deposit types. The feature used for iron skarn deposits to delineate the tracts on sheet 3 is the presence of a pronounced aeromagnetic high over, or adjacent, to an intrusion. For copper skarn deposits, anomalous Cu in stream sediment and (or) panned-concentrate samples is required.

Two adjacent tracts on sheet 3 are favorable for these deposits. Tract 2a contains a known Cu-bearing iron skarn deposit overlain by a prominent aeromagnetic high. Several other prominent aeromagnetic highs are present within this tract (Alaska Division of Geological and Geophysical Surveys, 1973a), and this tract is highly favorable for the discovery of additional Fe skarn deposits. Tract 2a has moderate favorability for copper skarn deposits owing to anomalous Cu in stream-sediment samples and also owing to the common association of iron skarns and copper skarns.

On the basis of several broad, less pronounced aeromagnetic highs (Alaska Division of Geological and Geophysical Surveys, 1973a), tract 2b has low favorability for iron skarn deposits. On the basis of a reported chalcopyrite vein occurrence, tract 2b has low potential for copper skarn deposits.

LOW-FLUORINE STOCKWORK MOLYBDENUM SYSTEMS

Tracts favorable for low-fluorine stockwork molybdenum systems require a felsic intrusion, carbonate host rocks, and anomalous Mo±W, Pb, Zn, Ag, and Cu in stream-sediment or panned-concentrate samples. Two tracts on sheet 3 have favorability for this deposit type. Tract 4 includes the Windy Creek molybdenum occurrence and has high favorability for this deposit type. Although mineralization is sporadic, and alteration is limited to propylitization, the Windy Creek occurrence, as exposed, might represent the outer parts of a low-fluorine stockwork molybdenum system. Tract 5 includes part of the Darby pluton, has widespread Mo and W anomalies in stream-sediment and panned-concentrate samples, and is assigned moderate favorability for this deposit type.

POLYMETALLIC REPLACEMENT DEPOSITS

Polymetallic replacement deposits require the presence of a known or suspected intrusion with carbonate lithologies among its host rocks. In addition, anomalous Ag, Pb, Zn, and (or) Cu in stream-sediment or panned-concentrate samples are necessary to delineate tracts favorable for this deposit type. The presence of a polymetallic vein deposit in the tract is a positive indicator for these deposits.

Six favorable tracts for this deposit type are shown on sheet 3. Our evaluation of the features present within each of these tracts suggests that 4 tracts have moderate favorability, and 2 have low favorability. Because of the association of polymetallic vein deposits and polymetallic replacement deposits, those tracts containing a known or possible polymetallic vein deposit are assigned the higher (moderate) favorability.

ZINC-LEAD-SILVER SKARN DEPOSITS

Areas considered favorable for Zn-Pb-Ag skarn deposits require an intermediate to felsic intrusion and the presence of carbonate rocks in the host rock sequence. In addition, anomalous Zn, Pb, Ag, and (or) Cu in stream-sediment and (or) panned-concentrate samples is required. Six tracts on sheet 3 have favorability for this deposit type. The favorability for Zn-Pb-Ag skarns is the same as for polymetallic replacement deposits: tracts containing known polymetallic veins have moderate favorability, and the others have low favorability.

TUNGSTEN SKARN DEPOSITS

These tracts require felsic granitic intrusions, carbonate host rocks, and stream-sediment and (or) panned-concentrate anomalies of W±other elements, chiefly Mo, Cu, and Zn. Four tracts on sheet 4 are favorable for this deposit type. Two are ranked as moderately favorable, and the others have low favorability on the basis of our evaluation of the attributes present in each tract. Typical calc-silicate skarn lithologies consisting of garnet, pyroxene, and other minerals, are surprisingly unusual in these quadrangles, given the number of intrusions that have carbonate host rocks. Skarns that are present are restricted to the immediate contact area of an intrusion, perhaps 20 m at most. This may reflect the fact that the carbonate rocks were recrystallized to marble before final emplacement of the granitoids and their associated fluids; the marbles would then be relatively impervious to fluid migration.

GOLD-BEARING SKARN DEPOSITS

The possibility of gold-bearing skarns in these quadrangles is difficult to evaluate because of the paucity of analyses for gold of stream-sediment and panned-concentrate samples. Arbogast and others (1985) analyzed, by atomic-absorption methods, 618 of 1500 stream-sediment samples collected for gold. Only 23 samples had detectable gold at a lower determination limit of 0.05 ppm. All 1500 samples were analyzed for gold by emission spectrographic methods, however, gold was not detected in any sample at a lower determination limit of 10 ppm. Arbogast and others (1985) did not analyze panned-concentrate samples for gold by the atomic-absorption method. However, 45 of 1400 samples analyzed by emission-spectrographic methods contain detectable gold at a lower determination limit of 20 ppm.

Most of these stream-sediment and panned-concentrate samples that contain Au are in areas of Nome(?) Group and associated rocks that lack mapped or suspected intrusions. However, a few of these gold anomalies are present in areas where intrusions are mapped, chiefly around the Oonatut Granite Complex (tract 1; sheet 3) and in the Bendeleben Mountains (tract 6a; sheet 3). These tracts have low favorability for Au-bearing skarn deposits. All tracts delineated on sheet 3 are permissive for Au-bearing skarn deposits because of the presence of intermediate to felsic intrusions and carbonate host rocks. Detailed Au geochemistry of stream sediments, panned concentrates, and rocks is required to further evaluate those areas.

BESSHI VOLCANOGENIC MASSIVE-SULFIDE DEPOSITS

Coincident Nome(?) Group and associated rocks lithologies (metamorphosed marine sedimentary and volcanogenic rocks) and anomalous Cu, Zn, Co, Ag, Ni in stream-sediment and panned-concentrate samples indicate areas permissive for Besshi volcanogenic massive-sulfide deposits. One tract (sheet 2), with copper-rich occurrences of unknown type, is moderately favorable for this type of deposit. Four other tracts are assigned low favorability.

ESTIMATES OF THE NUMBER OF UNDISCOVERED MINERAL DEPOSITS

Estimates are made, for each tract delineated on sheet 1, of the number of undiscovered low-sulfide gold-quartz vein deposits that might be present within 1 km of the surface. These estimates are limited to low-sulfide gold-quartz vein deposits because it is the only type of deposit in these quadrangles that we feel is sufficiently understood to allow such estimates to be made. It is also the only deposit type for which grade and tonnage data are available for deposits in these quadrangles. Two deposits have been explored in detail in recent years. The Big Hurrah Mine, which previously produced over 750 kg (27,000 oz) of gold, has reserves of 408,000 tons with a grade of 0.296 ounces of gold per ton (equivalent to about 371,000 metric tonnes grading 10 grams per tonne) (The Northern Miner, 1989). The bulk of the 750 kg extracted was produced between 1903 and 1907, and the ore was reported to be worth $10.00 to $14.00 per ton (Smith, 1910). This translates to a gold grade of approximately 13 to 18 g per tonne based on the then prevailing gold price of $20.67 per ounce. The Rock Creek deposit in the Nome quadrangle has drill-indicated reserves of 6.04 million tonnes with a grade of 2.4 grams per tonne. Both of these deposits fall well within the grade and tonnage curves for this type of deposit (Bliss, 1986) and, with the exception of the grade of the Rock Creek deposit, are well above the median grade and tonnages. The undiscovered deposits that are under consideration here are also expected to fall within the grade and tonnage curves for this type of deposit.

Estimates are made at the 10th, 50th, and 90th percentile confidence level (table 5). These represent our best guesses based on (1) our knowledge of the geology and geochemistry of low-sulfide gold-quartz vein deposits on the Seward Peninsula; (2) comparison of the area with other areas containing these veins; and (3) our familiarity with the mineral-deposit model.

Table 5. Estimates of the number of undiscovered low-sulfide gold-quartz vein deposits in the Bendeleben and Solomon quadrangles

Tract (sheet 1)	Probability that number of undiscovered deposits equals or exceeds a given number		
	.10	.50	.90
Tract 1	2	1	0
Tract 2a	2	1	0
Tract 2b	2	1	0
Tract 3a	3	2	1
Tract 3B	1	0	0
Tract 4	2	1	0
Tract 5a	2	1	0
Tract 5b	1	0	0
Tract 6a	2	1	0
Tract 6b	2	1	0
Tract 6c	4	2	1
Tract 6d	2	1	0
Tract 6e	5	3	2
Tract 6f	3	2	1

CONCLUSIONS

Mineral resource assessment of the Bendeleben and Solomon quadrangles is based on integration of geological, geochemical, and geophysical data and has led to delineation of 30 tracts having favorability for 15 types of mineral deposits. Evaluation of the features present within each of these tracts allows this favorability to be ranked as low, medium, or high.

Low-sulfide gold-quartz veins are the most common deposit type in these quadrangles and have the greatest potential for discovery of additional deposits. Fourteen tracts, most having moderate to high potential, are delineated for this deposit type. Besshi massive-sulfide deposits have not been discovered in these quadrangles and are perhaps the most speculative mineral-deposit type in this assessment. Five tracts, mostly having low favorability, are delineated for this deposit type. The remaining thirteen deposit types fall somewhere between low-sulfide gold-quartz veins and Besshi massive-sulfide deposits regarding their overall potential for discovery in these quadrangles.

Exploration for any of these deposits will require detailed stream-sediment and panned-concentrate sampling to locate the source of the anomalies discussed in this report. Soil sampling, and (or) ground geophysical surveys will probably be needed to further pinpoint the location of possible targets. Finally, trenching and (or) drilling will be needed to verify the presence of a mineral deposit.

This assessment is based on data and mineral-deposit models that were available as of 1991. Detailed geologic mapping, geochemical surveys, and geophysical investigations will refine our concepts regarding the geologic environments that existed at the time of mineral- deposit formation. Modification of existing mineral-deposit models, or creation of new models for deposit types as yet unrecognized, could have a profound effect on future mineral-resource assessments of the area. Finally, refined mineral-resource assessment techniques may also alter our perception of the metallic mineral-resource potential of the Bendeleben and Solomon quadrangles.

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