The Assessment of Metallic Mineral Resources in Alaska

by

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U.S. Geological Survey
Open-file report 78-1A

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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Introduction

In the last two decades federal and state governments have become increasingly preoccupied with classifying public lands according to the uses that may be made of them. One outcome of the classifying can be a change in the land's legal status from a type in which any use is tolerated to a type in which only selected activities are allowed. Since this change affects the economic and recreational opportunities of individuals and institutions, a variety of interest groups have developed to follow and influence the classifying process. Perhaps nowhere has the process been more closely scrutinized or more hotly debated than in Alaska, where land use decisions for much of the State's 375 million acres are being made.

Concomitant with the increased interest in land classifying has come an increasing requirement to document the reasons for the classification decision. One response has been the development of resource inventories or assessments of the different attributes of the land and the life it supports. In theory, once made, the assessments of different resources are weighed, and the qualities for which the land is most valuable determine the classification decision. Since synopses of resources are also a requirement of most environmental impact statements required by the National Environmental Policy Act of 1969, much of the contemporary workload of public scientific agencies involves making resource assessments.

In considering resource assessments for land classification, it is helpful to draw a distinction between surface and subsurface resources. Surface resources can be assessed quickly and accurately by methods that are well-proven if often quite complicated. Mammals and birds can be counted, water can be fished, its volume measured, its quality tested. Timber can be appraised by cruising, recreational uses and game harvests can be tallied, and even scenic values can be photographed and described. For most assessment methods dealing with surface resources there is a theoretical basis, decades of experience in application, and an understanding of accuracy and precision.

In contrast, resources of the subsurface estate are concealed in many cases and are very difficult to inventory or assess. Particularly troublesome have been undiscovered deposits of minerals because the difficulty of detecting them is such that oil and mining companies may require many years and many millions of dollars to find and prove new discoveries of metal or petroleum. Theories of mineral resource assessment are developing rather than established, and testing the accuracy and precision of the results lag even father behind.

Assessing undiscovered mineral deposits is difficult enough in areas that have been geologically mapped in detail (scales of one inch equals one mile or larger) and partially explored by drilling. The problem is compounded in Alaska because large regions have not been mapped in even reconnaissance fashion (typically at a scale of one inch equals four miles), geochemical and geophysical surveys are far from complete, and exploration by drilling is much less widespread than in western Canada or the western conterminous United States (DeYoung, 1975).

Our report concerns how we and numerous colleagues in the United States Geological Survey assessed Alaska's deposits of valuable metals during the years 1974-78. Some of the methods and concepts used were new and may be applicable elsewhere.

The Question of Total Metal Endowment

Although Alaska had a turn of the century gold rush, was a leading producer of copper during the 1910's and 1920's, and has accounted for much of the small U.S. platinum production, the State has not been a major supplier of minerals. In recent years it has had no large metal mines in production so there appears to be valid preliminary question: Is Alaska sparingly endowed with metallic mineral resources?

One approach to this question is to compare Alaska's total mineral production to the total production of a comparably sized, geologically similar region. This method, called the unit regional value concept, is further explained by Griffiths (1978). Because large regions, by virtue of their size alone, will tend to exhibit more production when completely explored and developed, the production data should be expressed in terms of production per unit area. Alaska, which has long been recognized as part of the Cordilleran belt of western North America, is geologically similar to western Canada and the western conterminous U.S.

Comparison of the total production of certain metals from the Western States and Provinces of Canada with Alaska's production demonstrates that for all metals but platinum, Alaska has produced less than the analogous region (Figure 1). Alaska has "overproduced" platimun by a factor of 30, but "underproduced" gold by a factor of 6, chromite by 20, mercury by 29, copper by 34, silver by 79, tungsten by 361, lead by 378, and zinc by 136,000. These comparisons, however, do not necessarily imply that Alaska is endowed with, or will produce, the exact amount yielded by the comparative region: production from western Canada and the U.S. is continuing, some differences in resource endowment doubtless stem from differences in local geology, and mining costs may always remain so high in Alaska that low-grade deposits of low-price metals may never be produced. But the underproduction of most metals, and the magnitude of the underproduction suggest that Alaska's mineral resource endowment is quite large and that further attempts to pinpoint its location are certainly warranted.

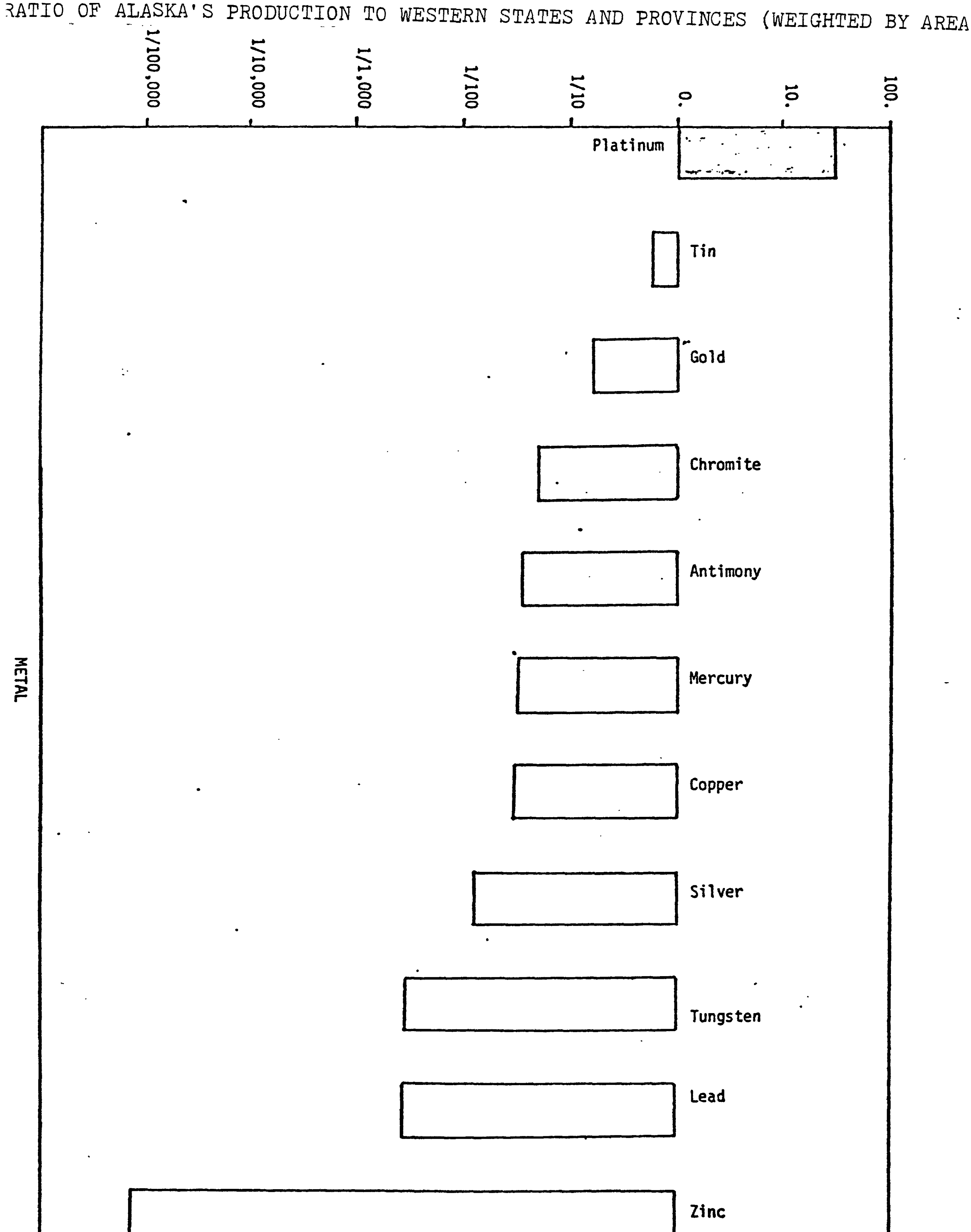
Figure 1. Near here

Areal Resource Assessment

Alaska's total metal endowment, as estimated by the unit regional value concept, is much larger than can be accounted for by the known deposits. This suggests that a resource assessment of Alaska requires careful consideration of undiscovered and incompletely explore mineral deposits. Because the assessments are intended for use in land

Figure 1.--Unit Regional Quantity of Metal Production for Alaska Divided by that from Western States and Provinces of the United States and Canada (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming, British Columbia, and Yukon).

(Production through 1974 in U.S. and 1975 in Canada; data compiled by J. C. Griffiths and M. L. Labovitz)


RATIO OF ALASKA'S PRODUCTION TO WESTERN STATES AND PROVINCES (WEIGHTED BY AREA
1/100,000
1/10,000
1/1,000
1/100
1/10
0.
10.
100.
Platinum
Tin
Gold
Chromite
Antimony
Mercury
Copper
Silver
Tungsten
Lead
Zinc
METAL

classification decisions, it is also necessary to delineate individual tracts of land and to differentiate the tracts on the basis of their potential for containing mineral resources. Mineral resources are defined as concentrations of naturally occurring solids, liquids, or gasses, discovered or only surmised that are or might become economic sources of mineral raw materials, whereas reserves are the part of resources that are both known and presently economic to mine. (U.S. Dept. of Interior, 1974). From this definition it is evident that mineral resources should be considered conditional supplies of mineral raw materials. The main conditions include existence of the material in appropriate forms and concentrations, discovery, prices that consumers might be willing to pay, and extraction costs and associated technologies that exist or might exist in the future. Thus, in principle, mineral resource estimates require the simultaneous estimation of the quality and quantity of mineral endowment and all of the economic and technological factors that can affect prices or costs such as exploration intensity and effectiveness, future demand, substitution, development of other supplies, development of new beneficiation methods, and government actions that affect mining. Even if a commonly accepted method of estimating mineral endowment is found, it is unlikely that consensus could be reached on assumptions and estimates of future economic and technologic conditions.

An assessment made with such economic assumptions and estimates would almost certainly become obsolete shortly after completion due to price fluctuations and new developments and could not be used to answer "what if" type questions. One way to eliminate some of these difficulties is to estimate mineral endowment in a disaggregate manner (Singer, 1975). This method requires the separate estimation of those variables related to the quality and quantity of mineralized areas that can affect possible economics and technologies of exploitation. The variables would include grade and tonnage estimates, the physical, chemical, and mineralogical features of the rock that could affect its metallurgical treatment and recovery, the geographical location, the geologic structure and hydrologic conditions, and the spatial distribution of mineralization and overburden.

Independent estimates of all of these variables is not now possible in Alaska. However, much of the desired information is conveyed if mineral deposit types rather than commodities are used as the basis for an assessement. In many cases deposits belonging to a single type occur in similar types of rock and have similar physical, chemical, and mineralogical features. Deposits of a single type do not necessarily share a common origin or age, although many do. The use of deposit types allows resource assessments to be performed in three basic steps:

1. Delineation of areas geologically permissive for various types of mineral deposits,
2. Estimation of the number of deposits of each type within each delineated tract,

3. Construction of grade-tonnage or contained-metal models for the deposit types.

The task of delineating tracts of land is facilitated by the use of deposit types because each type tends to occur in a characteristic geologic environment. In a broad sense information concerning the location of mineral resources is made available by the delineation process. Although each tract may be considered favorable for mineral resources, relative importance of a tract is not indicated by the delineation process. Relative importance of the tracts can be inferred from the economic viability of their contained mineral resources which in turn is largely dependent on the number of deposits and the qualities and tonnages of the deposits.

The difficulty of estimating the aforementioned variables increases dramatically as one moves from well-explored deposits to lesser known prospects to undiscovered deposits. Although single rare events such as the occurrence of an undiscovered mineral deposit are unpredictable, statistical averages of the number of deposits in large regions are quite regular and predictable. This suggests that the size of tracts delineated must be large so that estimates are stable. Just how large an area should be to produce stable estimates has not been determined; the size will vary with deposit type, the favorability of the tract for that deposit type, and with the extent of exploration in the tract.

Tonnages and average grades of incompletely explored deposits seldom are well known and are never known for unfound deposits. Variation of grades and tonnages of well-explored deposits is very large; much of this variation, however, is due to differences in deposit types. Variation of tonnages and average grades is much less within deposit types and can be represented by the proportion of well-explored deposits of each type that have different combinations of grades and tonnages. Average grades and tonnages of well-explored deposits of each type can be used as models for the grades and tonnages of yet to be discovered deposits, thereby conveying important information about the relative resource endowment of different areas.

Statistical distributions based upon well-explored deposits can serve as models for undiscovered or incompletely explore deposits. Estimates made from such statistical models must be tempered by geological conditions that might be related to the number, quality, or quantity of the undiscovered mineral deposits. It has long been recognized that tracts of land that are geologically only slightly different may have vastly different numbers of deposits. Recently documented are cases of significant regional differences in the grades and tonnages of deposits within types (Menzie and Singer, 1979). For some deposit types these differences may be predictable (Divi and others, 1979); for others differentiation factors have not yet been found. Where regional differences in grade or tonnage are suspected and a predictive model based on geology is not available, regional trends or tonnage and grade distributions from geologically similar areas near those for which the estimates are to be made are desirable. In either case, statistical models representing the proportion of deposits by type that have different grade and tonnage combinations are useful in demonstrating the relative importance of each deposit type and the variability that can be expected within types.

Precision of the tonnage-grade models probably cannot be increased without a thorough analysis of the geological, geochemical, and geophysical relationships near the deposits used to construct the models. However it should be noted that proper application of this technique might require more detailed data than is usually obtained by reconnaissance surveys of delineated tracts. The level of precision should, however, be stated explicitly because the probability that the actual resources are different than the expected value could have important implications for some policy decisions. Precision is represented in the grade and tonnage models by the proportion of deposits with different combination of grades and tonnages. Precision of the number of deposits estimates is shown by the probability levels associated with different estimates. A related problem, usually represented by a tendency to make conservative, "safe" estimates, is the possibility of biased estimates, such as the common neglect of undiscovered deposits in resource assessments of incompletely explored areas. For the studies reported here, every attempt was made to provide accurate estimates because biased estimates have the potential of adversely affecting the results of policy decision.

The Assessments

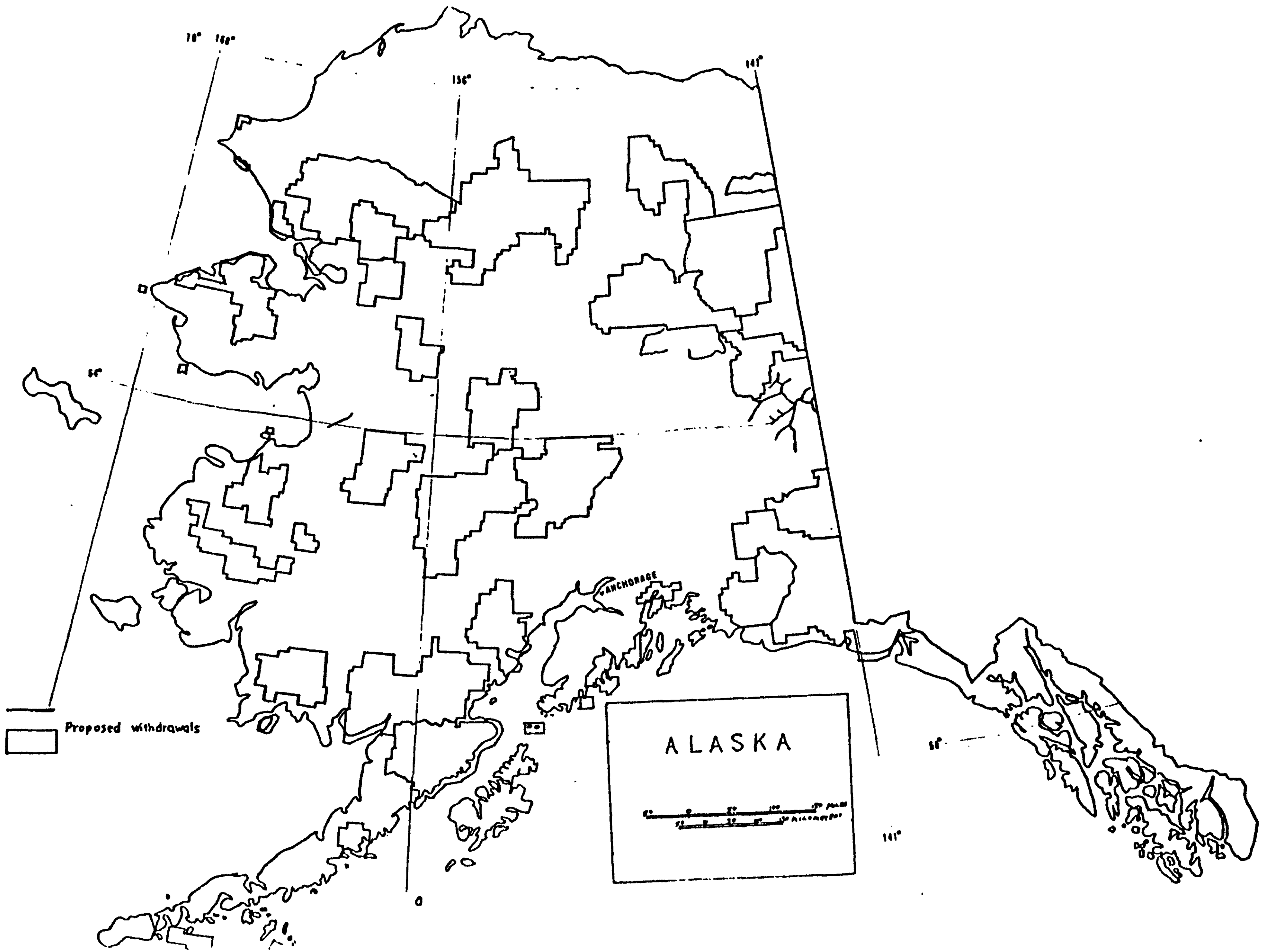
The Alaska Statehood Act of 1959 entitles the State to select 120 million of the 375 million acres of the State. The Alaska Native Claims Settlement Act of 1971 entitles the natives to select 44 million acres for ownership by the local or regional native corporations that are chartered by the Act. In addition, the Act authorizes the Secretary of the Interior to withdraw up to 80 million acres for possible inclusion in the four preservation systems (National Parks, Wildlife Refuges, Wild and Scenic Rivers, and National Forests). These 80 million acres are the "National Interest Lands" that are frequently called "d-2" lands after the section of the Act authorizing their withdrawal. Although the Act empowers the Secretary to withdraw lands and propose classifications, the final authority is the United States Congress which, under the Act, was required to complete classification by December 18, 1978.

In 1974 Congress requested that the United States Geological Survey assess the mineral potential of the "d-2" lands of Alaska in time for the December 1978 decision. One of the Statewide proposals, the 1972 Secretary of the Interior (Morton) withdrawals, is shown in Figure 2. Initially the Survey selected for study a group of 1:250,000-scale quadrangles that appeared to have significant mineralization and were being considerd at least in part for withdrawals. A multidiscipline approach was used to produce folios that include the geologic, geochemical, geophysical, mineral occurrence, and earth satellite maps and information along with the mineral resource assessment. By early 1976 it became evident that a systematic quadrangle-by-quadrangle approach could neither cover all of the "d-2" lands by 1978, nor could it adjust to the many boundary and area changes that were being proposed by Congress and the Interior Department. The first quadrangle assessment completed, Nabesna (Richter and other, 1975), became the model for resource assessment for the other quadrangles in Alaska and for the 1:1,000,000-scale assessments of 80 percent of Alaska that were completed by February 1978. The 1:250,000-scale quadrangles that were completed and those partially completed provided reconnaissance and in some cases detailed information for the 1:1,000,000-scale assessments. The large-region assessments of the metalliferous resources of Alaska are the prime topic of this paper.

Figure 2. Near here.

In preparation for the regional mineral resource assessments, a team of geologists with an average of 20 years of field and laboratory experience in investigating the geology and mineral deposits of Alaska prepared the following kinds of information that became the foundation of the assessments. Geologic maps at 1:1,000,000-scale were prepared from primary sources or revised from an existing compilation in order to emphasize rock units of metallogenic significance. New and comprehensive inventories of known mineral deposits were synthesized from existing government files, the mineral industry, and limited field studies. These inventories required experienced scientific judgment in discerning deposit types from data of variable age and authenticity.

Figure 2.--U.S. Department of the Interior National Interest Lands Proposal, 1973


141°
ANCHORAGE
ALASKA
Proposed withdrawals

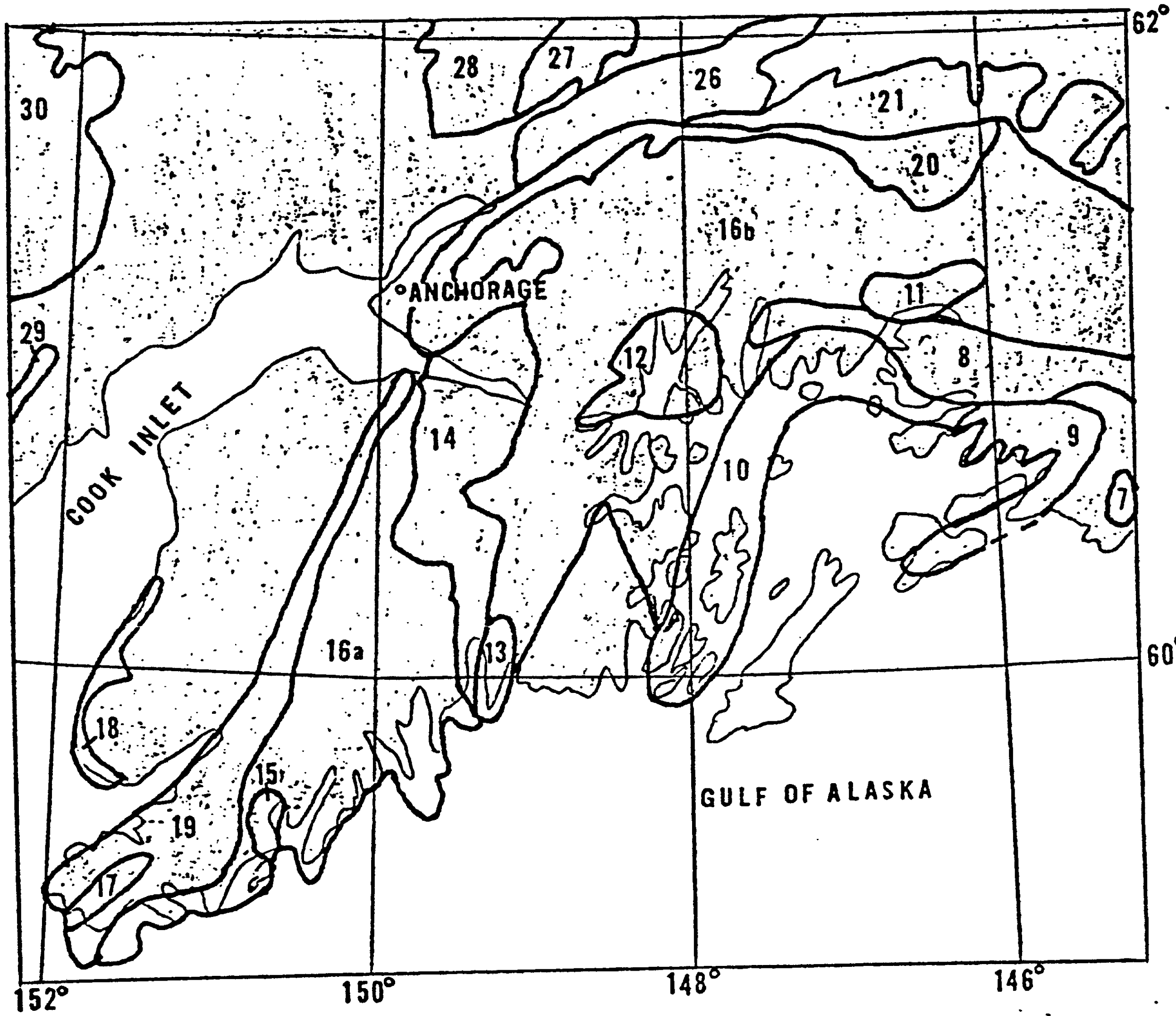
In addition, gravity and aeromagnetic maps were compiled at 1:1,000,000-scale, and geochemical data were assembled for local areas. The State was divided into four regions: Brooks Range, Seward Peninsula, central Alaska, and southern Alaska. Excluded were the north slope of Alaska, the Aleutian Islands, islands of the Bering Sea, and the "panhandle" or southeastern region of Alaska because none of the "d-2" proposals included these areas.

Tracts geologically permissive for the occurrence of various types of mineral deposits were delineated in each region. These tracts were outlined on the basis of their known deposits and their potential for undiscovered deposits. Speculative or suspected deposit types were inferred on the basis of occurrences in similar geologic settings elsewhere. The outer limit of delineated tracts was not allowed to extend beyond geologic units that are permissive for the occurrence of a deposit type. Tracts were restricted in areal extent if examination demonstrated absence of mineralization. Many of the intervening areas are mantled by thick covers of unfavorable rocks, glaciers, or unconsolidated surficial deposits; even though these areas may contain concealed deposits at depth the chances for discovering and exploiting such deposits are minimal. Several delineated tracts in the Brooks Range have open ends because not enough geologic information was available to close the boundaries. The scale of the maps required that many delineated tracts include more than one deposit type. An example showing several delineated tracts in southern Alaska is provided in Figure 3 (MacKevett and others, 1978).

Figure 3. Near here.

The relative importance of the tracts, that is the determination of which tracts are more favorable, should be based on the economic viability of the mineral resources within the tracts and may change with time because of changing economic conditions. Analysis of the economics of the resources requires information on the number of deposits and their quality and tonnage. Information concerning these geologic factors is provided in tables that accompany the maps. The 144 delineated tracts are keyed numerically in the tables to succinct descriptions of deposit types, contained metals, geologic settings, geologic, geochemical, and geophysical indications of favorability, extent and adequacy of exploration and geologic knowledge, and, for some deposit types, estimates of the number of deposits and indications of tonnages and grades extrapolated from models of better-known deposits. In most cases the basic data were insufficient to justify more than qualitative resource estimates. However, in some instances the data were adequate to permit quantitative estimates of the number of deposits of a specific type that may be present in a given area and their possible grades and tonnages. For approximately 17 percent of the 501 times that deposit types were listed, quantitative estimates of the number of deposits were provided and about 23 percent of the time, grade and tonnage models were used. If placer gold deposits and the various vein deposits that typically have low tonnages are excluded, the frequency of estimating the number of deposits rises to 32 percent and

Figure 3.--Map showing the tracts delineated in a part of southern Alaska. Numbers in the tracts are keyed to a table in the report (MacKevett and others, 1978).



62°
60°
152°
150°
148°
146°
30
28
27
26
21
20
16b
29
ANCHORAGE
11
8
12
COOK INLET
14
10
9
7
16a
13
18
15
19
17
GULF OF ALASKA

the usage of grade-tonnage models to 43 percent. Much of the information about the geologic factors that affect the economics of the resources thus was provided in tables, and for many of the deposit types that have larger tonnages, as estimates of the number of deposits and possible grades and tonnages. In Table 1, part of one resource table is provided for a delineated tract shown in Figure 3.

Table 1.--Near here.

Grade and tonnage models were based on well-explore deposits. Combinations of host and associated rock types, contained metals, ore minerals, geologic settings, and recognized mineral deposits of each type were used to identify deposits that belonged to the various deposit types. Only those deposits for which grade and tonnage estimates were available were included in the models. Average grades and total tonnages were calculated on the basis of past production plus estimated reserves or, if available, resources; deposits known to be incompletely explored were excluded to prevent obvious bias. Some types were not included because there were too few deposits with available grade and tonnage estimates to model, or because estimates were available for larger deposits only. Typically, any mineral deposit in the world that met the geologic requirements of a particular deposit type and had acceptable grade and tonnage estimates was used in a model. For porphyry copper and island arc porphyry copper deposit models, however, only deposits in western Canada or in Alaska were considered appropriate because of the consistent low grades of the

Table 1.--Metalliferous mineral resources of tract 10 shown in Figure 3.
(from MacKevett and others, 1978)

AREA OUT-LINED ON MAP	MAJOR TYPES OF KNOWN DEPOSITS	SUSPECTED OR SPECULATIVE TYPES OF MINERAL DEPOSITS (INCLUDES MINOR OCCURRENCES)	GEOLOGIC CONTROL(S) OF MINERAL RESOURCES	PRODUCTION AND RESOURCE INFORMATION	STATUS OF GEOLOGIC INFORMATION	ADDITIONAL COMMENTS	SUMMARY OF MINERAL RESOURCE POTENTIAL	ESTIMATED NUMBER OF DEPOSITS (PERCENT CHANCE THAT THERE ARE THE NUMBER PRESENTED OR MORE DEPOSITS)	GRADES AND TONNAGES FOR THIS DEPOSIT TYPE
10.	(a)Cu(Ag,Au,Zu)--submarine volcanogenic (b)Au--quartz lodes in Orca Group (c)Zn,(Au,Ag,Cu)--breccia cemented by sulfides	Cu--magmatic; occurrence of Tertiary gabbro that contains disseminated pyrrhotite and chalcopyrite	Contains the most important submarine volcanogenic deposits of the Prince William Sound area; area underlain by Orca Group (Tertiary) flysch and mafic volcanic rocks and scattered Tertiary felsic plutons (a)Consist of massive and disseminated sulfides, mainly pyrite, pyrrhotite, chalcopyrite, and sphalerite, in Orca Group; generally localized in or near shear zones; related to submarine volcanic processes (b)Small gold-bearing quartz veins, stringers, and veinlets in Orca Group near Tertiary felsic plutons (c)One small known deposit; on brecciated Tertiary pluton; breccia partly cemented by zinc and copper sulfides	Between 1900 and 1930 14 mines on the volcanogenic deposits produced about 97,000 tons (214 million pounds) of copper and subordinate amounts of gold, silver, and zinc; two mines, the Latouche and Ellemar, accounted for more than 96 percent of the production; the few gold mines in the area probably produced a total of not more than 31 kg (1,000) ounces) of gold; resource data are sketchy but the submarine volcanogenic deposits probably represent substantial copper resources; one prospect (Rua Cove) has estimated reserves of at least 1,020,000 tons (1,125,000 st) containing 1.25 percent copper	Modern reconnaissance mapping accompanied by geochemical and geophysical studies by U.S. Geological Survey for that part of area within Seward quadrangle; U.S. Geological Survey sponsored mapping and some sampling for remainder of area; topical studies of some volcanogenic deposits by Government agencies and industry; recent exploration of some volcanogenic deposits by industry	The resource potential of the submarine volcanogenic deposits dwarfs that of other deposit types in the area; some of the volcanogenic deposits contain large amounts of pyrite, which have been investigated as a possible source of sulfuric acid; the main concentrations of known submarine volcanogenic deposits are in three areas: Knight and Latouche Islands and east of Valdez Arm; despite fairly thorough prospecting these largely vegetation-covered areas are favorable for new discoveries particularly of concealed deposits; the less prospected terrain west of Valdez Arm is also favorable	(a) Over 50 mafic volcanogenic deposits are known; many have been incompletely explored and others probably remain to be found. Estimated number of deposits is only for deposits with tonnages comparable to those used in the grade-tonnage model. (b) Several small tonnage gold-quartz veins are known; others possible. (c) One small breccia cemented by zinc and copper sulfides is known.	(a) 90%: 2; 50%: 4; 10%: 8 chance that there are deposits or more	(a) mafic volcanogenic model

partially explored Alaskan deposits that have been found. Grade-tonnage models were constructed for the following deposit types:

1. Porphyry copper
2. Island arc porphyry copper
3. Porphyry molybdenum
4. Skarn copper
5. Mafic volcanogenic sulfide
6. Felsic and intermediate volcanogenic sulfide
7. Nickel and copper sulfides associated with small intrusions
8. Skarn tungsten

In some cases information on both grades and tonnages was not available, but information on the amount of contained metal within deposits was. Models based on metal contents were developed for the following deposit types:

1. Podiform chromite
2. Mercury
3. Vein gold

The chromite model was developed from deposits in California, the mercury model from deposits in Nevada, Oregon, Idaho, and Washington, and the gold model from deposits in British Columbia, Yukon, and Alaska.

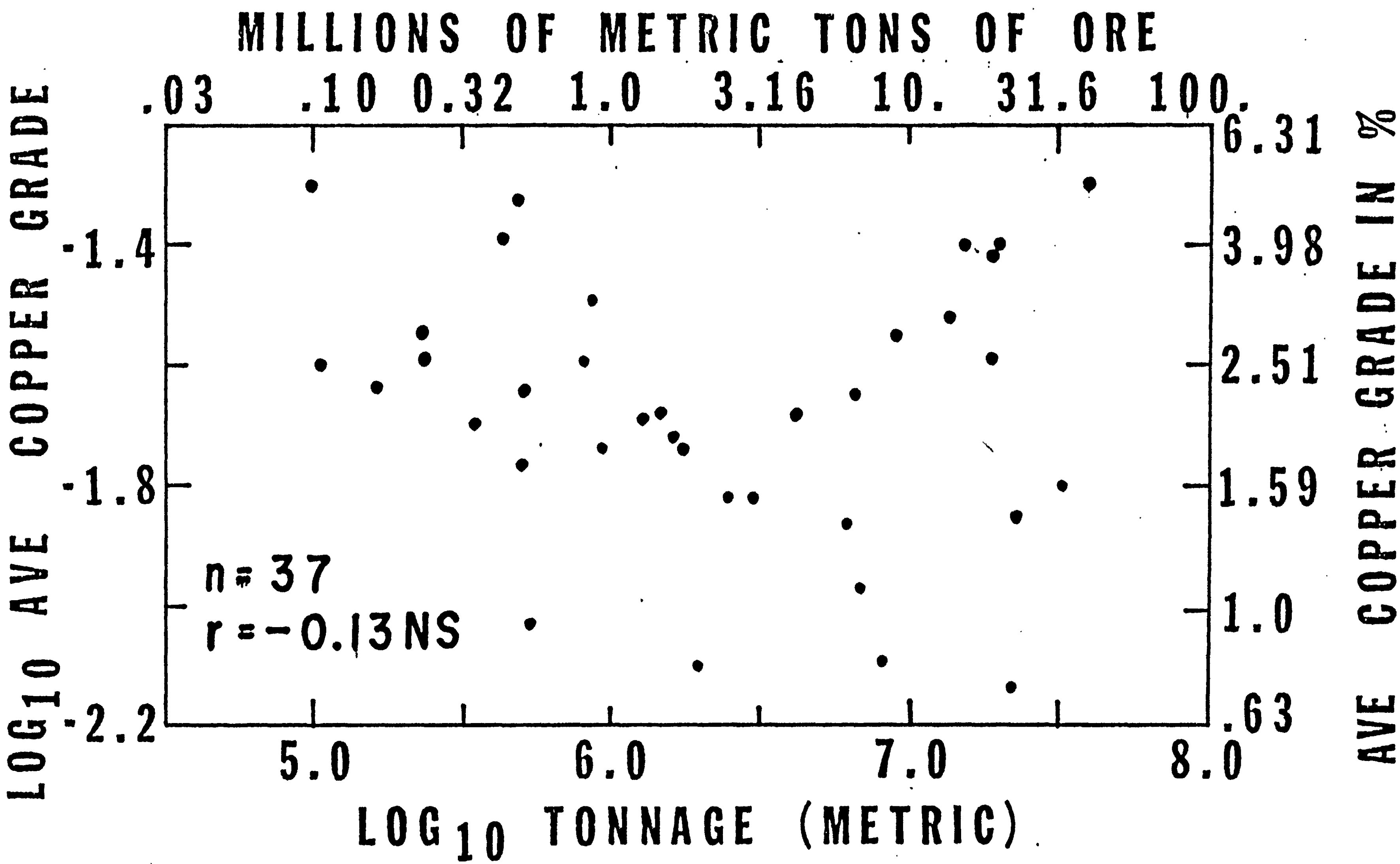
Oberved frequency distributions of average grade, tonnage, and in some cases, contained metal were compared to theoretical lognormal distributions which generally were found to represent adequately the shapes of the observed distributions. Statistical properties of the lognornal distribution are such that it is relatively easy to estimate proportions of deposits that should have different grade or tonnage characteristics. Thus, estimates of average grades that at least 90 percent of the deposits of each type would have were calculated using the lognormal distribution as were estimates at the 50 and 10 percent levels. This procedure was also used to estimate proportions of deposits that would have various tonnage and contained-metal characteristics. In Figure 4, average copper grades are plotted against their associated tonnages for those deposits used to construct the mafic volcanogenic grade-tonnage model.

Figure 4.--Near here.

Correlation coefficients among observed grades and tonnages were calculated in order to determine the degree of linear association of the logarithmic data. Correlation coefficients, along with the estimated probability of deposits having certain grade or tonnage characteristics, allow calculation of the chance that any combination of grades and tonnages occur, given that such deposits exist. For example, the mafic volcanogenic model indicated in Table 1 is provided in Table 2.

Table 2.--Near here.

Figure 4.--Average copper grade versus tonnage for the 37 deposits used to construct the mafic volcanogenic sulfide grade-tonnage model.



GRADES AND TONNAGES OF COPPER IN MAFIC VOLCANOGENIC DEP

Table 2.--Grade and tonnage model for mafic volcanogenic sulfide deposits (from MacKevett and others, 1978)

(metric units)

Variable (units)	Number of deposits used to develop model	Correlation Coefficients	90 percent of deposits have at least	50 percent of deposits have at least	10 percent of deposits have at least
Tonnage (millions of tons)	37		0.24	2.3	22.0
Average copper grade (percent)	37	with tonnage = -0.13 NS	1.1	2.2	4.1
Average zinc grade excluding deposits without reported grades (percent)	19	with tonnage = 0.03 NS	0.3	1.3	5.5
Average gold grade-locally significant but not determined					

NS, not significant

Probabilistic estimates of the number of deposits by type were made within each delineated area where such estimates were warranted by available information. Estimates were presented in a probabilistic form in order to show the degree of certainty concerning the number of deposits that might occur. The estimates were made subjectively; that is, exact rules whereby estimates were constructed cannot be precisely stated. Where it was possible to estimate the number of deposits, estimates were made by integrating a variety of pertinent considerations such as degrees of geologic, geochemical, and geophysical favorability, extent and adequacy of exploration and geologic knowledge, and extent of exploration of deposits already recognized.

Typically the estimated number of deposits associated with a 90 percent chance is closely related to the number of known deposits of that type in the delineated area. The actual estimate depends largely on the degree to which the "known" deposits have been explored; that is, not all "known" deposits will necessarily be found to belong to a particular deposit type when the deposits are completely explored. Consistent rules for estimating the number of deposits associated with a 50 percent chance are more difficult to define because, in some situations, the estimate was based on the number of known prospects or the number of prospects and completeness of exploration; in others it may have been based on the proportion of the area mantled by unconsolidated surficial deposits or ice. The estimate associated with a 10 percent chance can generally be considered speculative in the sense that it is limited by the number of deposits that could fit in an area and may be based on a variety of indicators such as the number of related deposits, altered areas, or geochemical anomalies. A few estimates were directly based on the number of deposits in well-explored geologically similar environments. Although each of the four regional resource assessments of Alaska share a common philosophy, methodology and format, details of individual assessments differ depending on the amount and mixture of information available for use in making the assessment. Typically, estimates of the number of deposits were made only for deposits with tonnages and grades comparable to those used in the grade-tonnage models, but a few were made for deposits that lack associated grade-tonnage models. In some cases, explored deposits were known to be much lower in tonnage or grade than the deposits used in the grade-tonnage models and therefore were excluded from the estimated number of deposits.

Consideration of Applications Elsewhere

Variations of the general procedures used in our assessments are being considered for several regional resource assessment programs in the United States and elsewhere. Problems that became evident in the Alaskan assessments or that might exist in other regions are considered here in order to aid those designing their own mineral resource assessments. Of prime importance is the recognition that the form and nature of the final products have a large effect on the choice of procedures and methods that can be used for resource assessment. In regional assessments of Alaska, tracts of land were delineated if their geology allowed certain mineral deposit types to occur; the basis for determining the favorability of each tract was indicated in tables; and where appropriate, we provided estimates of the number of deposits, and grade-tonnage models. It might appear that one of the multivariate methods would be suited for such assessments, but we found none that could provide unbiased estimates that combined the continuous, discrete, and spatial variables present in the Alaskan assessments.

The use of subjective estimates for the number of deposits may be criticized, but as Harris (1977, p.9-93) has noted, subjective methods may have some advantage over multivariate methods in that, "... the information on basic geoscience to which the field geologist has been exposed may exceed by a large margin the information available to the public for the construction of a multivariate model." In the fields of medicine and meteorology it has been shown that knowledgeable experts could increase the accuracy of predictions beyond those which could be achieved by the best available statistical model (Hogarth, 1975); no comparable study has been performed in mineral resources. Although we are not aware of any bias in the estimated number of deposits in the Alaskan assessments, we recognize the value of corroborative statistical models in order to ensure that the estimates are reproducible and to allow others to examine the methods critically.

In applying our method of mineral assessment in well-explored areas it may be necessary to adjust the grade-tonnage models to reflect the possibility that the largest deposits might be discovered first. In Alaska most larger-tonnage deposits are either undiscovered or incompletely explored; in better-explored areas the main concern might be the undiscovered deposits and an adjustment of the grade-tonnage models to prevent bias might be necessary. The possibility of regional differences in grades or tonnages within a deposit type must also be considered. In some cases construction of the grade-tonnage models can be difficult because of the lack of agreement among economic geologists on the basis for classifying deposits. Deposits of more than one type can inadvertently be placed in the same model. It became evident in constructing our grade-tonnage models that a need exists for consistent methods of classifying deposits based on their geologic characteristics.

Grade-tonnage models developed for our assessments were based on past production plus either reserves or resources. Therefore tonnage and average grades in the models are associated with cutoff grades that are typically lower than those that are now economic to mine but higher than the endowment of the deposits. It is possible in many deposits to increase the average grade and decrease the tonnage by raising the cutoff grade; therefore some deposits that appear to have grades too low to economically mine, based on the grade-tonnage models, may in fact have parts that are economic. Ideally such models would be constructed for all of the mineralized rock in deposits at a fixed low cutoff grade, and another model would be built to show how tonnage and average grade vary with cutoff grade. Unfortunately, information necessary to determine this relationship is not generally publicly available. The need for this information is paramount not only for the type of assessment considered here but in most mineral resource assessments to which more than one economic or technologic condition may be applied.

Many of the regional mineral resource assessments that are being considered or are being conducted now are for tracts of land that are small in areal extent. The direct application of the methods used in the Alaskan assessments is of questionable value because of the problem of estimating in a probabilistic manner the number of deposits in small tracts. Subjectively estimating a single event that has a very low probability of occurrence is a treacherous problem.

Conclusions

In order to provide information for decisions on Alaskan land, a different type of mineral resource assessment was developed. An attempt was made to present information concerning the geologic properties that can affect the economics of exploitation in a disaggregate manner. A variety of economic and technologic assumptions could be tested and the effects of the assumptions on the potential supply of the resources could be evaluated. To the extent possible the results were presented in a probabilistic manner in order to make explicit the uncertainty and variability that exists in such estimates.

The direct usefulness of these assessments can only be determined by the effect they have on the interested parties in determining the boundaries of certain parcels of Alaskan lands. These assessments may also have a large indirect effect on future mineral resource assessments elsewhere. The disaggregated nature of the Alaskan assessments admits identification of specific problems that require further research, and it facilitates the updating of the assessments. Many of the problems discussed in this paper have existed in previous mineral resource assessments but have not been explicitly recognized. The Alaskan assessments may be considered a useful first step in the improvement of mineral resource assessments.

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