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PROBABILISTIC ESTIMATE OF MINERAL RESOURCES IN THE COLVILLE MINING DISTRICT, ALASKA

By

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PROBABILISTIC ESTIMATE OF MINERAL RESOURCES IN THE COLVILLE MINING DISTRICT, ALASKA

by
M.B. Werdon,[1] R.J. Newberry,[1] L.E. Burns,[2] and C.G. Mull[2]

INTRODUCTION

Mineral resources in the southeastern part of the Colville mining district, Alaska, were assessed by using a computer simulation model. On the basis of results of fieldwork by the U. S. Bureau of Mines (USBM) and the Alaska Division of Geological & Geophysical Surveys (DGGS), the probabilistic resource assessment covers that part of the Colville mining district within the Howard Pass, Killik River, and Chandler Lake Quadrangles. The assessment committee was composed of geologists and engineers from the USBM, DGGS, and the University of Alaska Fairbanks (UAF). Committee members were participants in geologic mapping and in the collection and analysis of samples during the field-investigation part of the Colville mining district study and are intimately familiar with the district.

The use of probabilistic methodologies for estimating the possible quantities of undiscovered mineral resources in large areas is well established (for example, Harris, 1984; Drew and others, 1986). The mineral endowment of the Colville mining district was assessed by using a modified version of ROCKVAL, a computer simulation model developed jointly by the USBM and DGGS (White and others, 1987).

Probabilistic resource modeling requires that an assessment group supply probabilistic estimates of deposit favorability, occurrence density, tonnage, and grades for all mineralization thought to occur in a study area. For early studies, estimates were made by "consensus guessing," a method of uncertain reliability and documentability (Harris, 1984). The experience of DGGS in making probabilistic resource estimates (1984 to present) was that reproducible, documentable estimates could be made in a shorter time period if (a) potential mineral deposits were classified as specific deposit "types" (for example, Cox and Singer, 1986) and (b) worldwide based "generic" data were used to make first-pass estimates for the various model parameters. Consequently, data required before conducting a probabilistic assessment session include: (a) a knowledge of the actual grades and potential tonnages present in the known prospects in the study area; (b) a knowledge of which deposit types best describe the known and likely prospects in the study area, (c) a rational basis for assigning the various poorly known mineral occurrences in the study area to various deposit types, and (d) worldwide "generic" data sets for estimating deposit characteristics such as densities, cutoff grades, and tonnages. The first data set was largely acquired by USBM as part of the Colville district study, the second by USBM, DGGS, and UAF personnel, and the last two sets by DGGS as part of both this project and previous mineral assessments.

The ROCKVAL assessment session (July 1994) performed by geologists from the DGGS and the USBM, used all the data generated by both field and laboratory studies. Deposits were modeled using worldwide "generic" data for the applicable deposit types, modified as deemed appropriate by the assessment group. The session was led by R.J. Newberry, UAF economic geologist.

GEOLOGIC CONTEXT FOR ROCKVAL ANALYSIS

FIELD STUDIES AND SAMPLING PROGRAMS

Field investigations by USBM and DGGS within the Colville mining district were restricted to the southern part of the district. The northern part contains sparse outcrops (mostly of Cretaceous age), is largely covered by Quaternary sediments and tundra vegetation, and is not considered to contain surface exposures of nonfuel, mineral-favorable host rocks. Likewise, the Misheguk Mountain Quadrangle was not included in the study because of an absence of geochemical anomalies and a lack of known mineral occurrences; it is deemed to have very little potential. Thus, this probabilistic resource assessment covers only that part of the Colville mining district within the Howard Pass, Killik River, and Chandler Lake Quadrangles.

In addition to the detailed geochemical sampling programs carried out by the USBM in the Colville study area (Meyer, 1994), DGGS was contracted to carry out several field studies. These studies included regional geologic mapping and sampling for three field seasons by DGGS geologists. Results and samples from previous DGGS studies, and detailed deposit-scale mapping and research from a University of Alaska Ph.D. dissertation in the Colville district were also used for the ROCKVAL study. Several large-scale maps were made and ultimately incorporated

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into the Colville district geologic map (Mull and Werdon, 1994).

DATA COMPILATION AND ANALYSIS

A few prospects and deposits adjacent to the study area (for example, the Red Dog deposit) have had sufficient drilling, trenching, mapping, and laboratory work for definitive mineral-deposit assignments to be made. These deposits serve as models for mineralization within the Colville district. Other deposits and prospects were intensively studied as part of this investigation. On the basis of past and current investigations in the area, we have identified eight major deposit types as present or likely in the Colville district: (a) sediment-hosted, stratabound (sedex) Zn-Pb, (b) vein-breccia Zn-Pb-Ag, (c) bedded barite, (d) sedimentary phosphate, (e) disseminated, arenite-hosted Zn-Pb, (f) sedimentary manganese, (g) placer platinum-group-metals (PGM) ± Au, and (h) Cyprus-type massive-sulfide deposits. The defining characteristics of these deposit types are briefly presented in table 1. Major examples of each deposit type and references are given in table 2.

Assignment of the various lesser-known prospects to the deposit types of table 2 was based on matching characteristics of the known to the poorly known prospects.

COMPUTER SIMULATION, ROCKVAL PROGRAM

PRELIMINARY ASSESSMENT STRATEGY

REGIONAL FAVORABILITY (F)

The ROCKVAL process was started with the systematic interpretation of favorability within the region for each of the deposit types. For the resource estimation process, an area of interest is divided into distinct geologic trends known as "plays" in the model terminology. A play is an area of relatively consistent geologic character that is favorable to a consistent degree for the occurrence of a single deposit type. The area for each play was chosen on the basis of existing geologic, geochemical, geophysical, and prospect distribution maps.

Regional favorability (F) was semiquantitatively

Table 1. *Characteristics of lode and placer deposits modeled, Colville mining district, based on worldwide and local data*

Deposit type	Major geochemical signature	Geologic characteristics	Age of host rock
Sediment-hosted, stratabound (sedex) Zn-Pb	Zn, Pb, Ag, ± Ba, ± F	Massive- to semimassive-sulfide mineralization	Carboniferous
Vein-breccia Zn-Pb-Ag	Zn, Pb, Ag, ± Cu, ± Au	Fault-controlled breccias and (or) veins; not pluton related	Devonian to Lower Carboniferous
Bedded barite	Ba	Bedded, massive texture	Carboniferous
Sedimentary phosphate	P, U, V	Bedded, pisolitic textures	Carboniferous, Triassic
Disseminated, arenite-hosted Zn-Pb	Zn, Pb, Ag	Low-grade disseminated sulfides, ± in concretions	Devonian to Lower Carboniferous
Sedimentary manganese	Mn, Fe ± P	Bedded manganese oxides	Cretaceous (known), Carboniferous hypothetical)
Placer platinum-group-metals (PGM) ± Au	Cr	Placers derived from mafic-ultramafic rocks	Quaternary, Cretaceous
Cyprus-type massive-sulfide deposits	Cu, Zn	Volcanogenic massive sulfides associated with mafic oceanic rocks	Devonian to Jurassic

Table 2. *Examples of modeled deposit types, Colville mining district (CMD)*

Deposit type	Examples	References
Sediment-hosted, stratabound (sedex) Zn-Pb	Drenchwater prospect; Red Dog deposit[a] (145 km west of CMD)	Moore and others, 1986; Nokleberg and Winkler, 1982
Vein-breccia Zn-Pb-Ag	Story Creek, Safari Creek, W & E Ipnavik River, W & E Kivliktort, W & E Koiyaktot, Vidlee, Kady	Ellersieck and others, 1990
Bedded barite	Abby Creek, Bion, Ekakevik, Lakeview, Longview, Stack, Tuck; Nimiuktuk (72 km west of CMD)[a]	Kelley and others, 1993; Mayfield and others, 1979
Sedimentary phosphate	Ivotuk Hills, Monotis Creek,[a] Skimo Creek,[a] Tiglukpuk Creek[a]	Patton and Matzko, 1959
Disseminated, arenite-hosted Zn-Pb	Ipnavik River, West Kivliktort; Ginny Creek[a] (72 km west of CMD)	Mayfield and others, 1979
Sedimentary manganese	Cobblestone Creek area[a] (eastern Chandler Lake Quadrangle)	Meyer, 1994
Placer platinum-group-metals (PGM) ± Au	None	Nelson and Nelson, 1982
Cyprus-type massive sulfide	None	

[a]Deposit is near, but outside of Colville mining district.

assessed by comparing assays and geologic data for known prospects in a play area to comparative data for mineral deposits known outside of the Colville district in the Brooks Range, including worldwide deposits. This number is an expression of the certainty that drillable prospects are present, at least one of which will be large enough to meet the minimum (cutoff) tonnage (that is, F=1 if there is a known deposit in the play area and F=0 if there is no potential for a deposit in the play area).

High favorability (F=1.0–0.9) implies that a specific deposit type is known to be present. Moderate favorability (F=0.9–0.55) implies that some geological, geochemical, or geophysical indicators are present but no prospects are known. Low favorability areas (F=0.55–0.1) are broadly similar geologically and geophysically to moderate and high favorability areas, but lack strong geochemical indicators or prospects.

DEPOSIT DENSITIES

For each ROCKVAL play, a prospect-density-probability distribution (that is, number of prospects likely to be present at a given probability level) must be created. For those plays with known prospects, the number of known prospects would be the 100 percent probability level. Numbers of prospects for other—less certain—plays and for other probability levels were first estimated by using generic "prospect density" curves developed for this and previous ROCKVAL studies (for example, Newberry and Burns, 1989). An internally self-consistent set of deposits and prospects from a series of worldwide locales was used to generate (a) the deposit favorability, (b) the deposit densities, (c) the deposit cutoff parameters, and (d) the deposit grade-tonnage models. The prospect density curves were prepared by determining the number of prospects per unit area of geologically favorable terrane for a large number of worldwide districts of a particular deposit type. The generic prospect density curve for a particular deposit type is thus the number of expected prospects per unit area for each probability level. The size of a given play times the generic prospect density value for a particular probability level yields a trial value for number of prospects. Finally, where applicable, calculated values for number of prospects were modified to reflect known geological considerations.

CUTOFF LIMITS

Cutoff limits represent the minimum values for grade and tonnage that will be considered as potential resources by the simulation process. Cutoff values for grade and tonnage are deliberately set below those that are likely to be produced at current commodity prices. Cutoffs are based on the minimum size and grades found in the literature data for a given deposit type. Cutoff limits for the different deposit types are given in table 3.

Table 3. *Cutoff limits used for deposit types in assessment*

Deposit type	Cutoff tonnage (million tons)	Cutoff grades
Sediment-hosted, stratabound (sedex) Zn-Pb	0.4	Zn 1.3 % Pb 0.3 % Ag 0.1 oz/ton
Vein-breccia Zn-Pb-Ag	0.01	Zn 1.3 % Pb 0.1 % Cu 0.01 % Ag 0.1 oz/ton Au 0.005 oz/ton
Bedded barite	0.1	Ba 52.5 %
Sedimentary phosphate	2.0	U 0.005 % P 5.0 % V 0.01 %
Disseminated, arenite-hosted Zn-Pb	0.14	Zn 0.4 % Pb 0.01 % Ag 0.01288 oz/ton
Sedimentary manganese	0.03	Mn 6.0 % P 0.01 %
Placer platinum-group-metals (PGM) ± Au	0.0001	Pt 0.002 oz/ton Au 0.00001 oz/ton
Cyprus-type massive sulfide	0.01	Pb 0.03 % Zn 0.4 % Cu 0.23 % Ag 0.1288 oz/ton Au 0.00805 oz/ton

DEPOSIT FAVORABILITIES

Not all the Colville district prospect grades and tonnages calculated or estimated from the criteria above would necessarily exceed the minimum grade and tonnage cutoff criteria for ROCKVAL. The proportion of prospects likely to meet the cutoff criteria (that is, deposit favorability) was estimated by noting the proportion of worldwide prospects used in generating the prospect distribution curve that would meet the ROCKVAL cutoff. These generic deposit favorability values were modified as appropriate by the appraisal committee.

GRADE AND TONNAGE DISTRIBUTIONS

Probability distributions for grade and tonnage were estimated from compilations of applicable worldwide literature data for each deposit type. Cox and Singer (1986) and Laznicka (1985), which are excellent references for deposit data, were widely used. Generic distributions were modified where local geological or geochemical features indicated that a given prospect in the study area deviated strongly from the average.

PLAYS AND ENDOWMENTS

SEDIMENT-HOSTED STRATABOUND (SEDEX) Zn-Pb-Ag DEPOSITS

World-class sedex Zn-Pb-Ag deposits (for example, Red Dog) occur in the northwestern Brooks Range, about 145 km west of the Colville mining district. The deposits are hosted by rocks of Mississippian to Pennsylvanian(?) age that are also present within the Colville mining district. Lithologic continuity, drainage geochemistry anomalies, and massive sulfide outcrops (for example, the Drenchwater prospect) indicate a high favorability of the Colville district for this deposit type.

Although the Drenchwater prospect has been previously described as a volcanogenic massive-sulfide prospect (Nokleberg and Winkler, 1982), detailed mapping shows the presence of laterally extensive silicification and the absence of typical VMS-style mineralization and alteration (Werdon, in press). Additionally, similarities in isotopic ratios, metal contents and ratios, ore mineralogy, and ore-mineral compositions indicate that the sedex Red Dog deposit is the most likely analogy to stratiform Zn-Pb-Ag mineralization in the Colville mining district. The favorability of Mississippian host rocks decreases to the east (from Red Dog) because the favorable black shale and chert host rocks grade eastward into platform carbonate rocks in the eastern part of the Colville mining district.

Four plays of differing regional favorability were assessed (fig. 1, table 4). Reasons for the differing potential include: play A (F=1) contains the Drenchwater prospect; play B (F=0.75) is defined by geochemical anomalies, favorable Mississippian black shale and chert of the Kuna Formation, and coeval, more basinal units, which are broadly favorable for hosting sedex mineralization; play C (F=0.55) outlines areas of broadly permissible Mississippian host rocks that are geochemically anomalous or contain extrusive volcanic rocks, and which to the west are spatially associated with sedex mineralization; and Play D (F=0.2) is defined by permissible Mississippian host rocks. Plays B, C, and D have variably favorable geology, but no known prospects.

We have used worldwide grade, tonnage, and

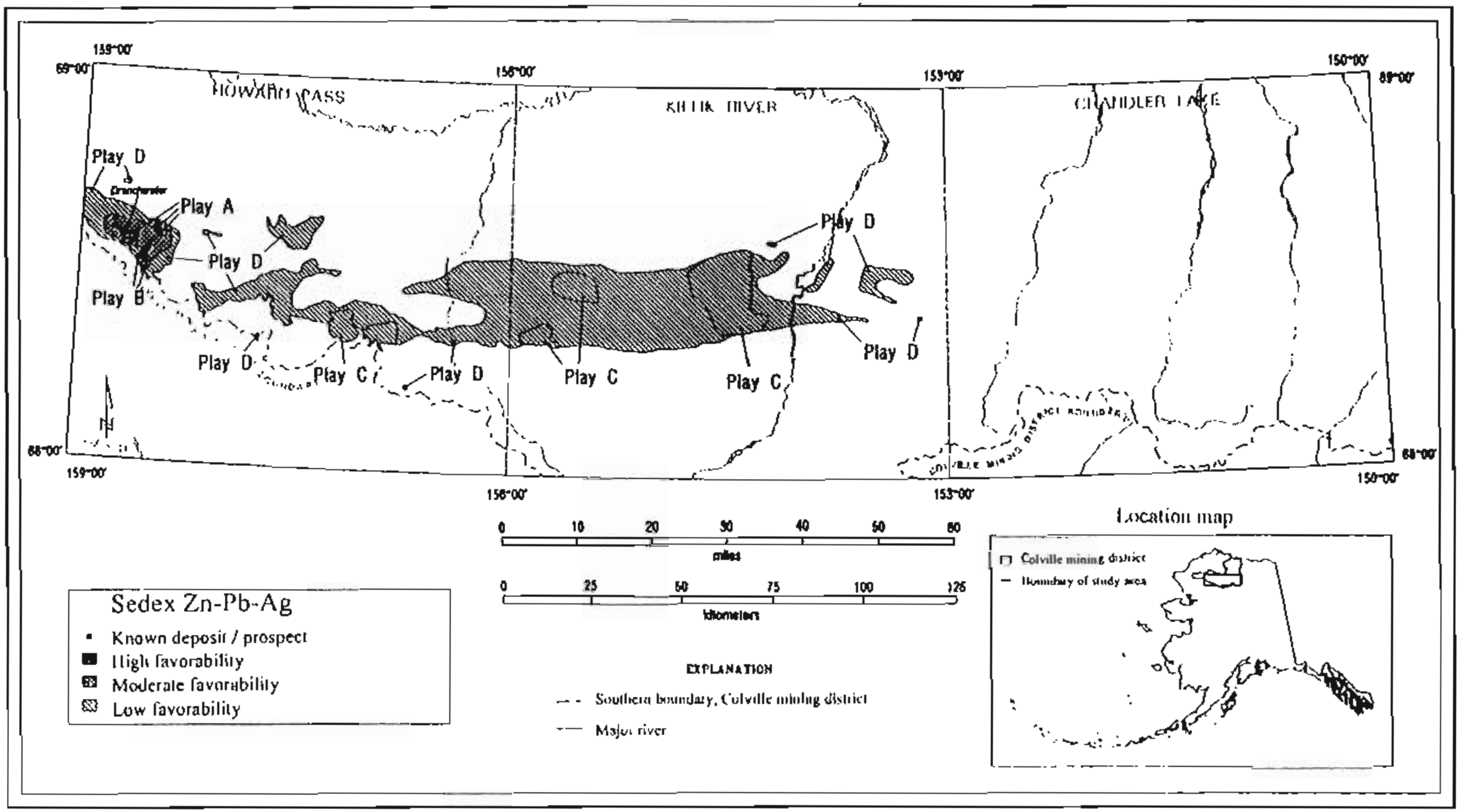

Figure 1. *Regions favorable for sediment-hosted stratabound (sedex) zinc-lead-silver.*

Table 4. *Calculated endowment from sediment-hosted stratabound (sedex) Zn-Pb-Ag deposits: plays A-D*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.74	62	430
Zinc (thousand tons)	46	4500	36,000
Lead (thousand tons)	21	2400	18,000
Silver (thousand oz)	0.00	66,000	840,000
PLAY B			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	190
Zinc (thousand tons)	0.00	0.00	14,000
Lead (thousand tons)	0.00	0.00	7,600
Silver (thousand oz)	0.00	0.00	300,000
PLAY C			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	35
Zinc (thousand tons)	0.00	0.00	2,800
Lead (thousand tons)	0.00	0.00	1,400
Silver (thousand oz)	0.00	0.00	38,000
PLAY D			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	27
Zinc (thousand tons)	0.00	0.00	2,200
Lead (thousand tons)	0.00	0.00	1,200
Silver (thousand oz)	0.00	0.00	29,000

prospect density information (appendix) to compile generic distribution curves for sedex deposits (Newberry and others, 1994). Numbers of prospects were based on sedex district models for plays A and B. Lower favorability plays C and D were modeled by using "large regionally favorable" areas. The regional model differs from the district model in that it has fewer prospects per given area. The number of prospects in each area is compatible with that seen in a Yukon sedex district (plays A and B) and with that seen in the Selwyn Basin (plays C and D) (Abbott and Turner, 1990).

VEIN BRECCIA Zn-Pb-Ag DEPOSITS

Vein-breccia prospects have been known in the western Brooks Range since the late 1970s (Jansons, 1982; Ellersieck and others, 1990). The prospects are hosted by the clastic Endicott Group of Late Devonian to Lower Mississippian age. Detailed mapping and isotopic analyses (Werdon, unpublished data) indicate that most of the vein-breccia mineralization in the district is of probable Lower Mississippian to Pennsylvanian(?) age and is related to faulting at that time. However, some of the vein-breccia prospects have been remobilized and are related to Mesozoic faulting (Werdon, unpublished data). Our geologic model for these prospects is based on the recently recognized basin-vein "type," which includes deposits of Coeur d'Alene, Idaho; Harz Mountains, Germany; Shawangunk Mountains, New York; and Silvermines, Ireland. These deposits may include several generations of vein formation, as appears to be the case in the western Brooks Range.

Four plays of differing regional favorability were assessed (table 5, fig. 2). Reasons for the differing potential include: play A (F=1) outlines two favorable trends that contain the nine known vein-breccia deposits in the Colville mining district; play B (F=0.9) includes lithologies similar to play A and contains drainage geochemistry anomalies, but lacks known vein-breccia occurrences; and plays C and D (F=0.6 and 0.3, respectively) possess variably favorable host rocks, but lack significant drainage geochemistry anomalies. Minor quartz-carbonate veinlets with trace sulfides have been reported within the area of plays C and D (Duttweiler, 1986).

Table 5. *Calculated endowmenet from vein-breccia Zn-Pb-Ag deposits: plays A-D*

PLAY A			
Percentile	5th	50th	95th
Ore tonnage (million tons)	7.2	14	32
Zinc (thousand tons)	570	1,300	2,400
Lead (thousand tons)	370	910	1,900
Silver (thousand oz)	13,000	34,000	69,000
Copper (thousand tons)	0.00	0.29	3.3
Gold (thousand oz)	0.00	0.48	18
PLAY B			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	4.1	16
Zinc (thousand tons)	0.00	320	1,500
Lead (thousand tons)	0.00	220	1,000
Silver (thousand oz)	0.00	8,000	41,000
Copper (thousand tons)	0.00	0.00	0.86
Gold (thousand oz)	0.00	0.00	7.5
PLAY C			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	1.2	12
Zinc (thousand tons)	0.00	81	1,100
Lead (thousand tons)	0.00	50	810
Silver (thousand oz)	0.00	1,200	31,000
Copper (thousand tons)	0.00	0.00	0.47
Gold (thousand oz)	0.00	0.00	2.6
PLAY D			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	9.1
Zinc (thousand tons)	0.00	0.00	830
Lead (thousand tons)	0.00	0.00	590
Silver (thousand oz)	0.00	0.00	18,000
Copper (thousand tons)	0.00	0.00	0.11
Gold (thousand oz)	0.00	0.00	0.12

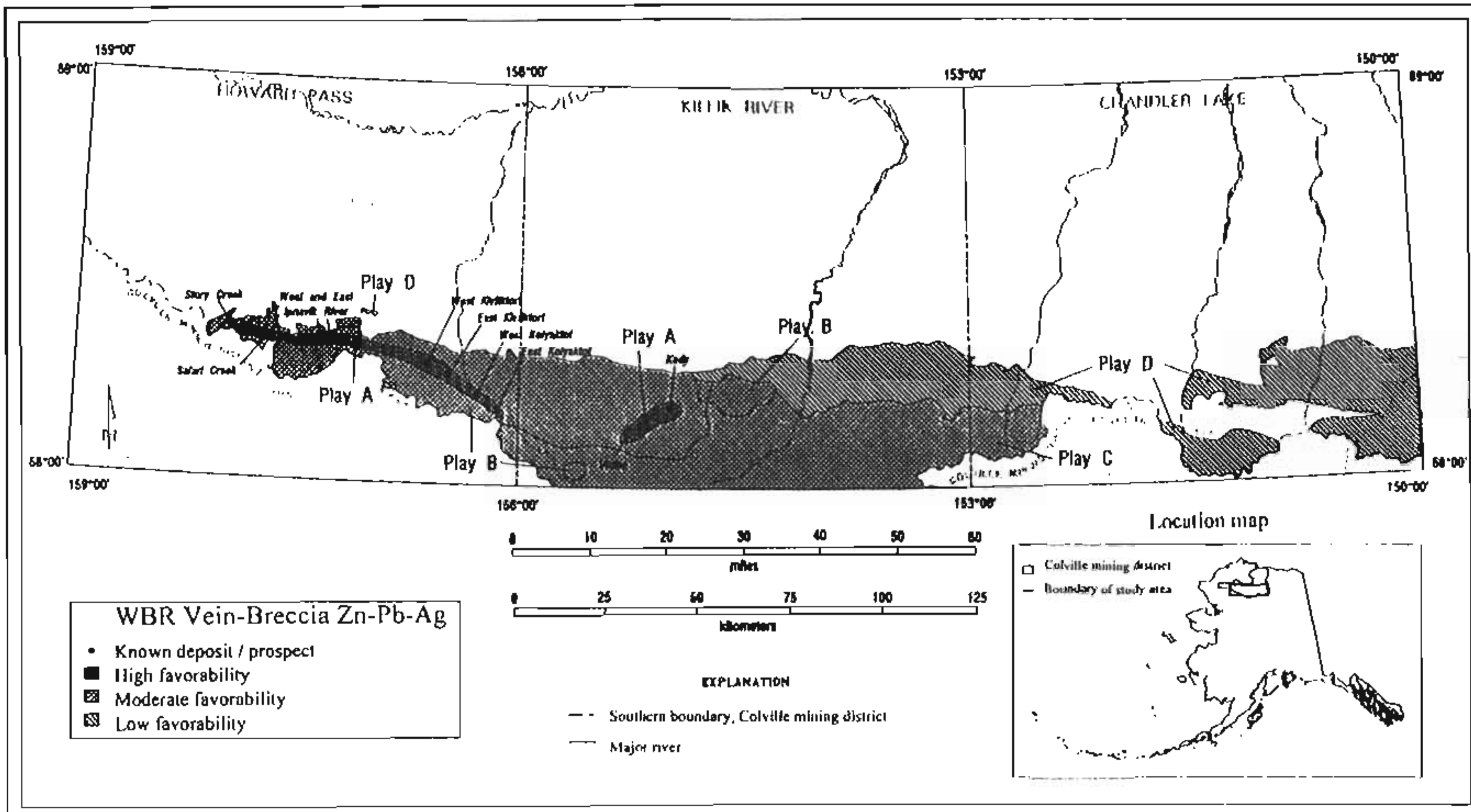

Figure 2. *Regions favorable for western Brooks Range vein-breccia zinc-lead-silver.*

The grade, tonnage, and prospect-density distributions (appendix) were built from worldwide basin-vein occurrences. The number of prospects in play A was estimated by using the known prospects for the high probability fractiles and a size-modified generic curve for the low probability fractiles. Play B was size adjusted to a similar distribution as used in play A. Number of prospects in C and D were estimated from large areas of broadly favorable geology and reflect a lower prospect density than plays A and B. The generic data are compatible with the size and occurrence density observed in the Colville mining district.

BEDDED BARITE DEPOSITS

There are seven known bedded barite deposits in the Colville mining district—six in the Cutaway Basin area and one near Ekakevik Mountain in the Howard Pass Quadrangle. The seven barite deposits have an estimated total indicated resource of 49,008,000 tonnes (Kelley and others, 1993). Individual deposits and their estimated resource in tonnes(t) include: Abby Creek, 406,000t; Bion, 10,051,000t; Ekakevik, 2,276,000t; Lakeview, 3,774,000t, Longview, 29,494,000t; Stack, 2,851,000t; and Tuck, 155,000t (Kelley and others, 1993). All deposits are high grade and have a mean specific gravity (4.23 to 4.27 gm/cc) that exceeds the minimum standard (4.20 gm/cc; API, 1981) required for barite used in oil-well drilling fluid (Kelley and others, 1993). The barite deposits are hosted by Mississippian bedded chert in the Cutaway Basin area and by Mississippian limestone and chert in the Ekakevik Mountain area (Kelley and others, 1993). There are no base metals associated with any of the barite deposits. The Nimiuktuk bedded barite deposit (Barnes and others, 1982), is located near, but outside of the study area in the Misheguk Mountain Quadrangle.

Kelley and others (1993) state that the barite deposits are hosted by Mississippian bedded chert in the Cutaway Basin area and by Mississippian limestone and chert in the Ekakevik Mountain area. Although the barite deposits are spatially associated with Mississippian rocks, our studies (Mull, unpubl. mapping) show that the deposits are localized along major thrust faults. The barite deposits may represent tectonic remobilization or emplacement of barite derived from some external source.

Bedded barite also occurs in spatial and genetic association with Carboniferous stratiform massive-sulfide deposits (for example, Red Dog) in the western Brooks Range. Although the stratiform Drenchwater Zn-Pb deposit in the Colville mining district contains only minor barite, there is the potential for bedded barite deposits in the area. Additionally, the Permian Siksikpuk Formation is regionally geochemically anomalous in barium, indicating the possibility of barite deposits in the unit. Although barite occurs as fine disseminations, concretions and lenses within the Siksikpuk Formation, no bedded barite deposits have been found.

Four plays of differing regional favorability were assessed (table 6, fig. 3). Reasons for the differing potential include: play A (F=1) contains the known barite deposits and outlines their Mississippian host rocks, which continue along strike; play B (F=0.55) includes Mississippian units near the stratiform Drenchwater Zn-Pb deposit and areas with geochemically anomalous amounts of barium in Mississippian or Permian host rocks (or both), but no known barite bodies; and plays C (F=0.35) and D (F=0.2) contain broadly favorable geology, broadly time-equivalent host rocks, and no known barite bodies; play C is distinguished by the presence of barium anomalies.

Stratiform, sediment-hosted barite bodies occur worldwide in a variety of host rocks and sedimentary-volcanic settings, and range in size from very small (10,000 tons) to very large (>100 million tons). Deposits hosted by chert and limestone in the western Brooks Range are large enough to have significant associated gravity anomalies and semiquantitative resource estimates (Kelley and others, 1993). We have modified a worldwide barite tonnage distribution to reflect known western Brooks Range occurrences by raising the cutoff size to 100,000 tons (the smallest occurrence in the belt) and lowering the maximum size to 90 million tons; the structural dismembering prohibits superlarge, continuous orebodies. Hypothetical barite ores of plays B, C, and D are in somewhat different facies or age units (or both) and the generic tonnage distribution is probably more appropriate.

The prospect distribution for play A is built around

Table 6. *Calculated endowment from bedded barite: plays A-D*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	53	110	290
Barite (thousand tons)	34,000	85,000	230,000
PLAY B			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.25	60
Barite (thousand tons)	0.00	62	45,000
PLAY C			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	8.5
Barite (thousand tons)	0.00	0.00	6,300
PLAY D			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	59
Barite (thousand tons)	0.00	0.00	44,000

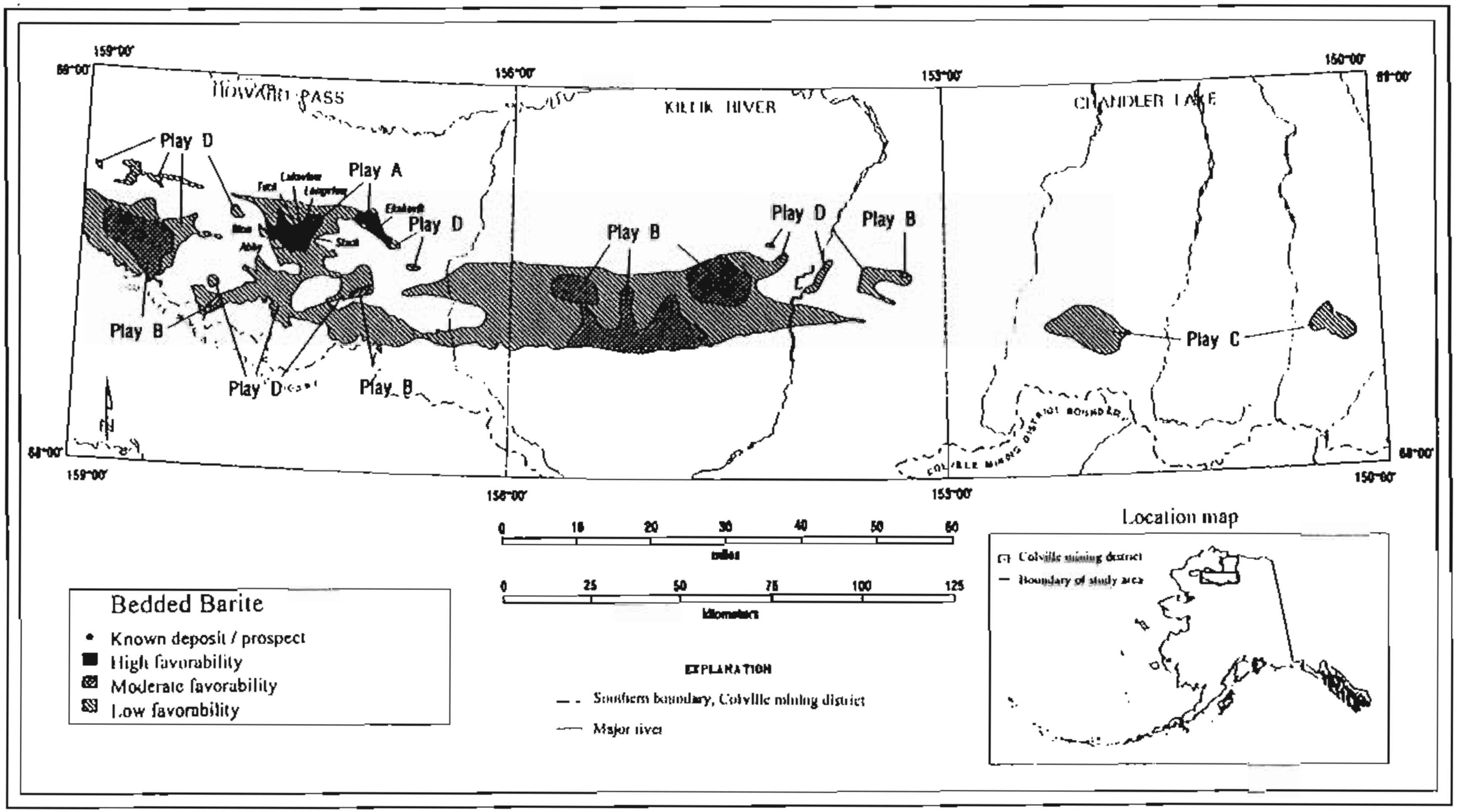

Figure 3. *Regions favorable for bedded barite.*

the number of known large occurrences for the high-probability fractiles and size-modified generic distributions for low-probability fractiles. Numbers of prospects for the hypothetical plays are built from size-adjusted generic curves describing barite-prospect densities in large regions of broadly favorable geology (appendix). The number of prospects is comparable to similar-sized areas in the Paleozoic basinal facies of Yukon and northern British Columbia, Canada (Abbott and Turner, 1990).

SEDIMENTARY PHOSPHATE DEPOSITS

Abundant bedded phosphate rock of the "upwelling type" is present over long strike intervals (up to 16 km) in the western Brooks Range. Known significant bedded phosphate occurs near the Ivotuk Hills, and along Monotis Creek, Kiruktagiak River, Skimo Creek, and Tiglukpuk Creek. This material has been sampled and described by a variety of workers over the last few decades (for example, Patton and Matzko, 1959). Phosphate-rock occurrences in the Colville mining district are mainly hosted by Mississippian carbonates of the Lisburne Group, but smaller amounts occur in Triassic units as well.

Two plays of differing regional favorability were assessed (table 7, fig. 4). Reasons for the differing potential include: play A (F=1) contains known occurrences with significant quantities of bedded phosphate, and outlines Mississippian and Triassic phosphate-bearing host rocks, and play B (F=0.2) contains lithologically similar host rocks as Play A, but only very thin beds or sparse nodules of phosphatic material are known within the area.

Much of the tonnage information available for worldwide phosphate deposits is derived from districts having linear dimensions of over 160 km, rather than from individual deposits (Mosier, 1986a). Given the structural dislocations in the Brooks Range, such enormous, contiguous districts are not reasonable models for the Colville mining district. We went back to the original literature (Krauss and others, 1984) and generated a tonnage distribution that consisted of deposits only (no districts), especially from structurally complex areas (appendix). The size cutoff for this distribution is 2 million tons, which reflects the economics of mining phosphate. The grade distribution is based on worldwide data and such data are compatible with observed grades in the Brooks Range. The number of prospects (play A) is based on the number of known large (>1 million ton) phosphate occurrences in the district at high probability fractiles and on a size-modified generic prospect-density curve for low-probability fractiles. The number of prospects for Play B is based on worldwide data for very large areas broadly favorable for phosphate rock. The prospect distributions generated are similar to those seen in the western United States.

Table 7. *Calculated endowment from sedimentary phosphate: plays A and B*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	110	430	1,300
Phosphate (thousand tons)	23,000	100,000	310,000
Uranium (tons)	11,000	44,000	110,000
Vanadium (tons)	77,000	330,000	940,000
PLAY B			
Percentiles	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	120
Phosphate (thousand tons	0.00	0.00	31,000
Uranium (tons)	0.00	0.00	12,000
Vanadium (tons)	0.00	0.00	88,000

DISSEMINATED, ARENITE-HOSTED Zn-Pb DEPOSITS

Several of the vein-breccia prospects in the western Brooks Range are surrounded by zones of low-grade, disseminated Zn-Pb mineralization in arenite host rocks of the Endicott Group. This mineralization style resembles that of the sandstone-hosted Pb-Zn deposits, as described by BjØrlykke and Sangster (1981).

Two plays of differing regional favorability were assessed (table 8, fig. 5). Reasons for the differing potential include: play A (F=1) contains both vein-breccia and disseminated occurrences within the clastic Endicott Group, and play B (F=0.8) contains the same host rocks as Play A and outlines areas with sphalerite ± galena concretions, geochemical anomalies, and trace disseminated sulfides.

The tonnage distributions for the two plays are based on worldwide disseminated, sandstone-hosted deposit data

Table 8. *Calculated endowment from disseminated arenite-hosted Zn-Pb deposits: plays A and B*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.25	20	160
Zinc (thousand tons)	3.2	530	4,400
Lead (thousand tons)	0.00	52	1,300
Silver (thousand oz)	0.00	1500	48,000
PLAY B			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	28	370
Zinc (thousand tons)	0.00	0.00	3,100
Lead (thousand tons)	0.00	0.00	68
Silver (thousand oz)	0.00	0.00	2,600

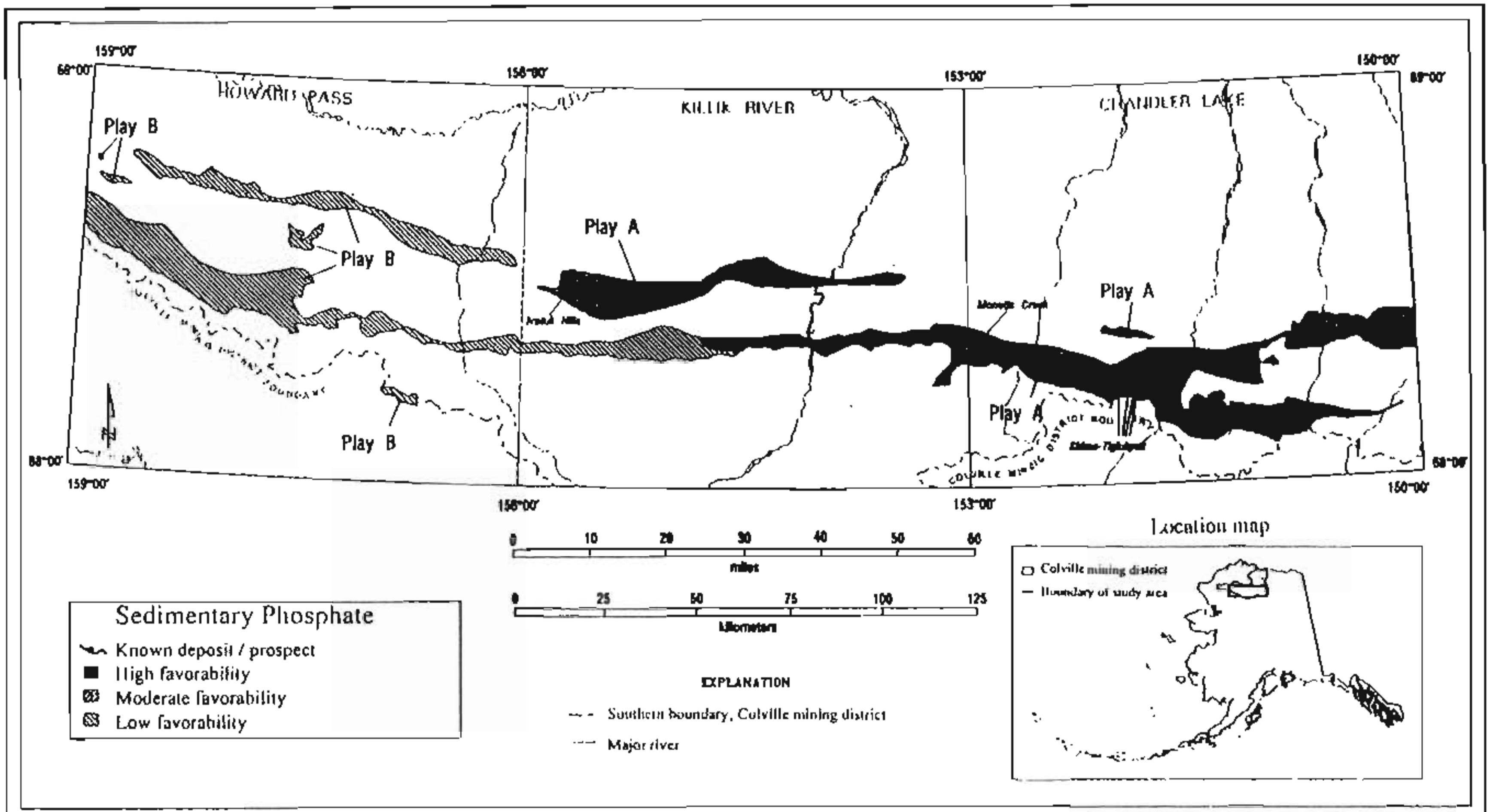

Figure 4. *Regions favorable for sedimentary phosphate.*

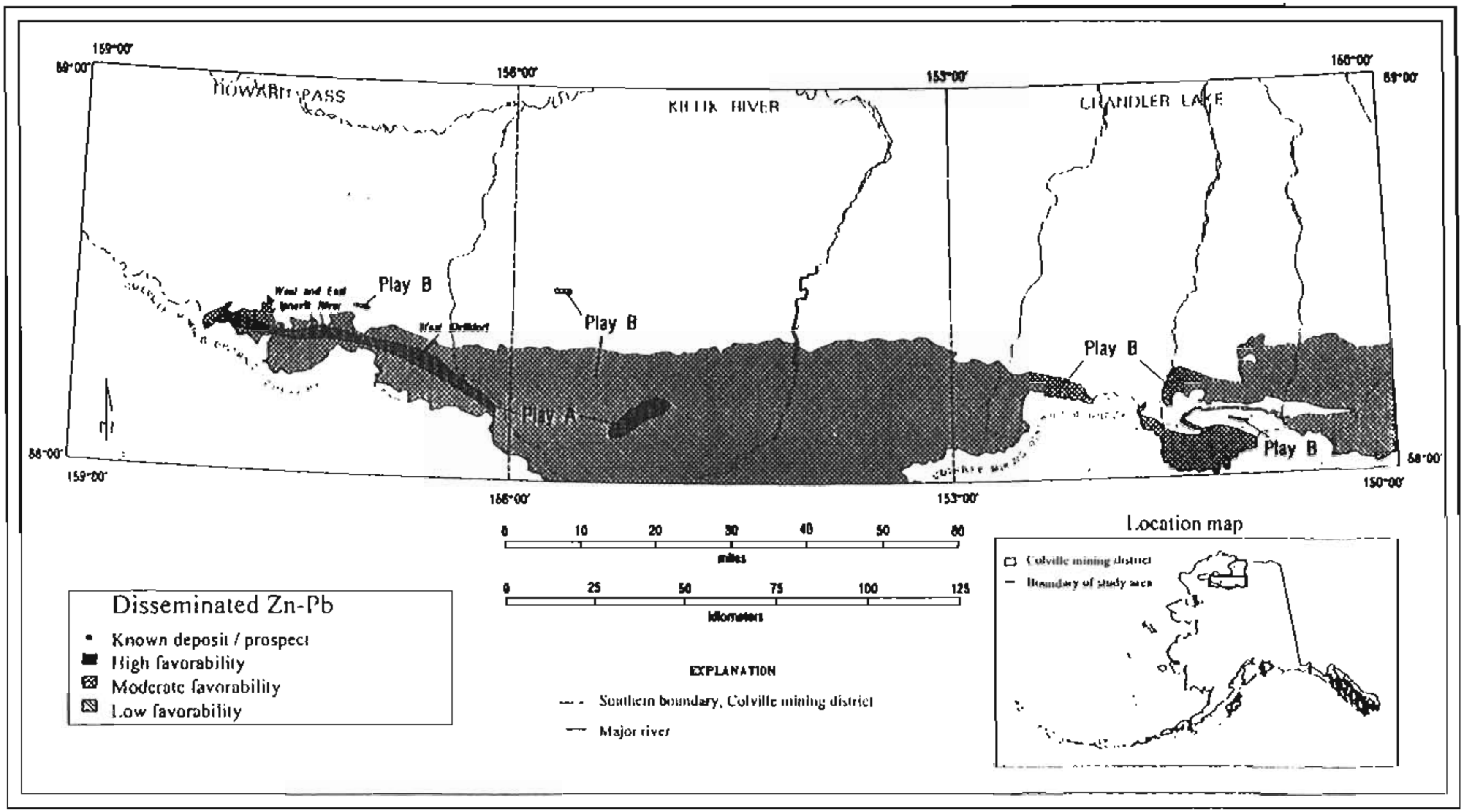

Figure 5. *Regions favorable for disseminated arenite-hosted zinc-lead-silver.*

(appendix). The grade distributions for Pb and Zn were adjusted to reflect the higher Zn:Pb ratios seen in western Brooks Range deposits relative to the generic lead-dominant disseminated deposit data. The number of prospects for each play is built from a size-adjusted prospect-density curve. The prospect density for play A is for districts and play B is for large areas of regionally favorable host rocks.

SEDIMENTARY MANGANESE DEPOSITS

The Lower Cretaceous Torok Formation in the Cobblestone Creek area contains a 6.4-m-thick silty mudstone and shale section with assays ranging from 11.9 to 0.5 percent MnO (Meyer, 1994). Cretaceous, shallow marine rocks in this eastern part of the Colville mining district are geologically similar to those hosting giant Cretaceous to early Tertiary "bathtub ring" Mn deposits known around the world. Additionally, upper Paleozoic rocks of the district are locally anomalous in Mn (drainages contain sediments with >2 percent Mn), and the setting is permissible for both sedex-associated Mn deposits and Mn deposits associated with bedded phosphate deposits. However, no Mn-rich occurrences are currently known in Paleozoic rocks of the district.

These two areas were separately modeled as a Cretaceous high-favorability play A (F=1) and a Paleozoic low-favorability play B (F=0.1) (table 9, fig. 6).

Worldwide, several Cretaceous-Tertiary Mn districts occur in simple structural settings with tremendous strike lengths and enormous tonnages. We reasoned that such giant deposits could not occur in the structurally dismembered stratigraphic units in the Brooks Range; thus, we modified worldwide deposit data by taking out the structurally simple, giant Mn deposits and districts (appendix). Because Brooks Range Mn grades are less than 12 percent (Meyer, 1994), worldwide grade distributions were modified by removing those deposits with exceptionally high supergene-enriched Mn grades.

Table 9. *Calculated endowment from sedimentary manganese: plays A and B*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	1.2	39	420
Manganese (thousand tons)	340	10,000	150,000
Phosphate (thousand tons)	0.00	0.97	96
PLAY B			
Percentile	90th	50th	10th
Manganese (thousand tons)	0.00	0.00	0.00
Phosphate (thousand tons)	0.00	0.00	0.00

The number of prospects was built from the size-adjusted prospect-density curves by using bathtub-ring types for play A and sediment-volcanic types for play B.

PLACER PLATINUM-GROUP-METALS (PGM) ± Au DEPOSITS

Mafic-ultramafic rocks of the Angayucham terrane were thrust over sedimentary and granitic rocks of the Brooks Range in Mesozoic time. Most of these mafic-ultramafic rocks have been subsequently eroded, but local klippe are still preserved. These klippe contain chromite and minor local platinum-group-metal (PGM) enrichments. PGM enrichments are typically associated with chromite, making chromium a potentially useful tracer for platinum-group metals. Extensive areas in the Colville mining district contain anomalous chromite in present-day (Quaternary) stream drainages and in paleostream drainages (Cretaceous). On this basis, we postulate PGM-bearing placer deposits in the district.

The area favorable for PGM placers (play A) is that which contains anomalous drainage chromite (fig. 7). We estimate the regional favorability as 0.1, a number typical of hypothetical plays with favorable geologic setting but lacking direct geochemical evidence. The grade, tonnage, and prospect distributions are generic, developed from worldwide data for typical nonmarine districts (appendix). The estimated endowment is shown in table 10.

Table 10. *Calculated endowment from placer platinum-group-metal* (PGM) ± *Au deposits: play A*

PLAY A			
Percentile	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	0.00
Platinum (thousand oz)	0.00	0.00	0.00
Gold (thousand oz)	0.00	0.00	0.00

CYPRUS MASSIVE-SULFIDE DEPOSITS

Basaltic volcanic rocks of an ophiolite package crop out in a small area of the Colville mining district. Such rocks are associated with copper-rich volcanogenic massive-sulfide (VMS) deposits worldwide. Basaltic rocks are inevitably enriched in copper, and the streams draining these basalts are mildly anomalous in copper. There is no direct evidence for VMS deposits in the district—that is, massive sulfide outcrops, major drainage anomalies, extensive quartz-pyrite veining in basalt, and so forth; consequently, the regional favorability for the deposit type is rated very low (F=0.1). We used generic size, grade, and prospect-density curves for basalt-associated copper-rich VMS deposits to model this hypothetical play (appendix). The play area is shown in figure 8 and the

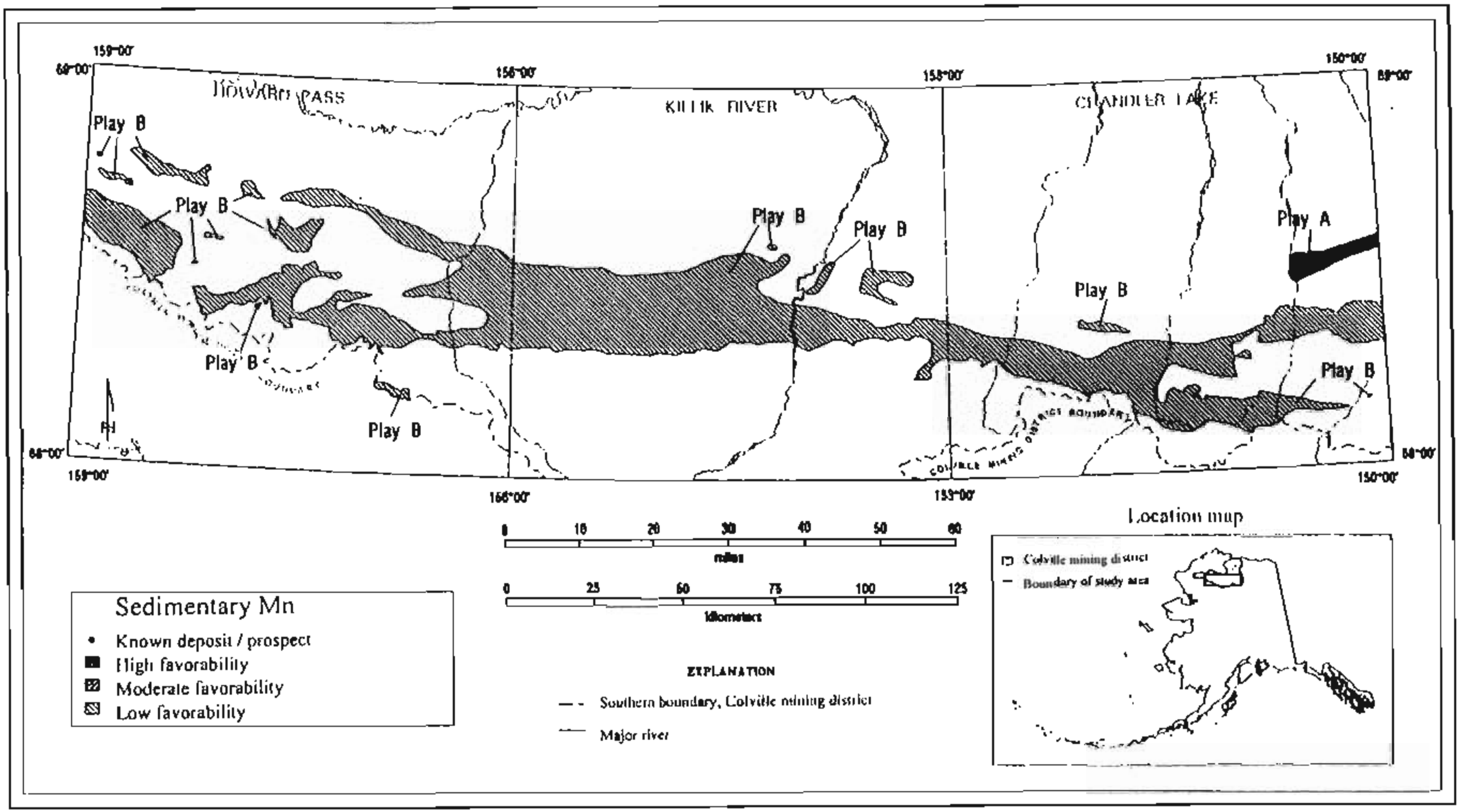

Figure 6. *Regions favorable for sedimentary manganese.*

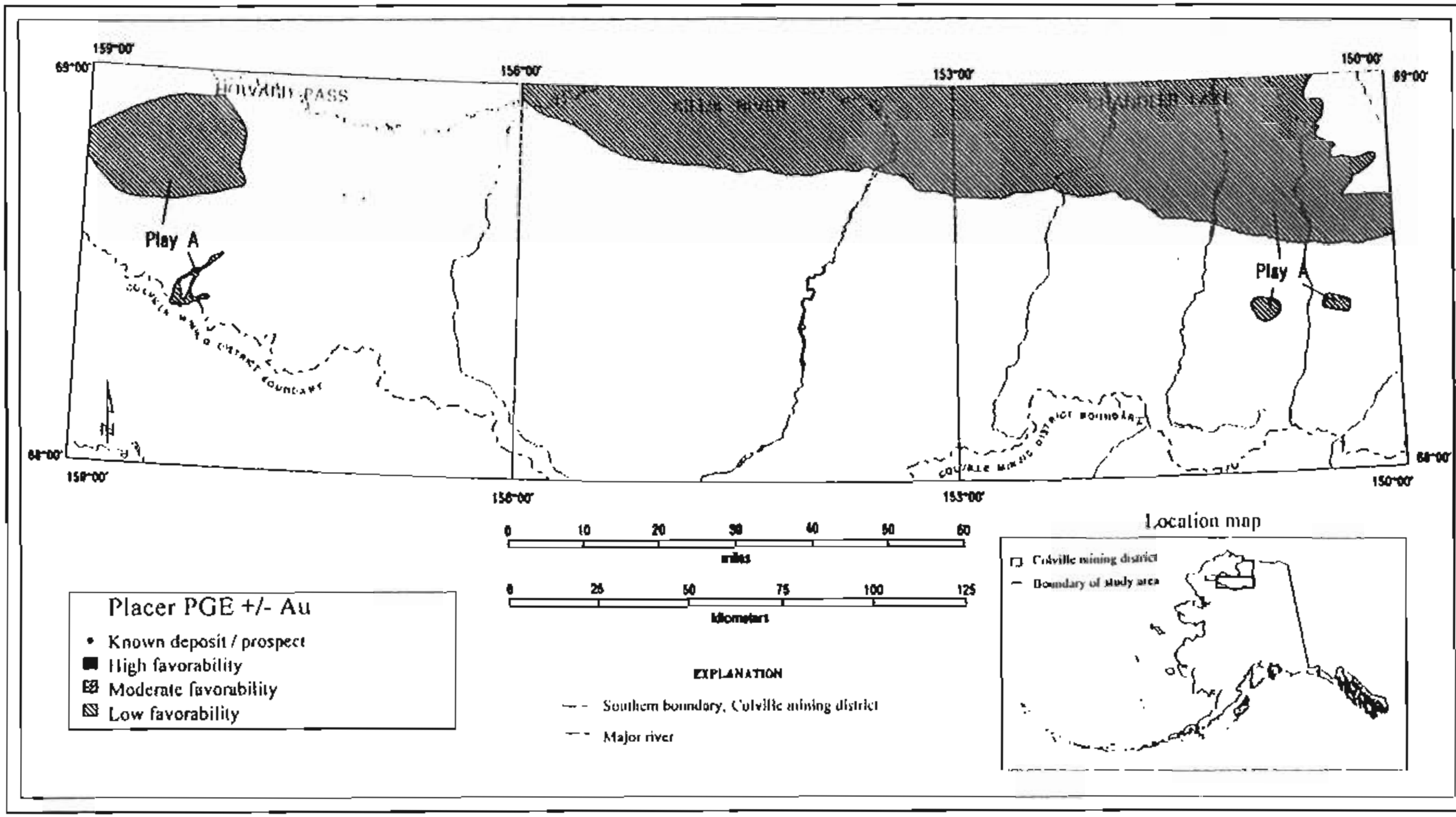

Figure 7. *Regions favorable for placer platinum-group elements (PGM) ± Au.*

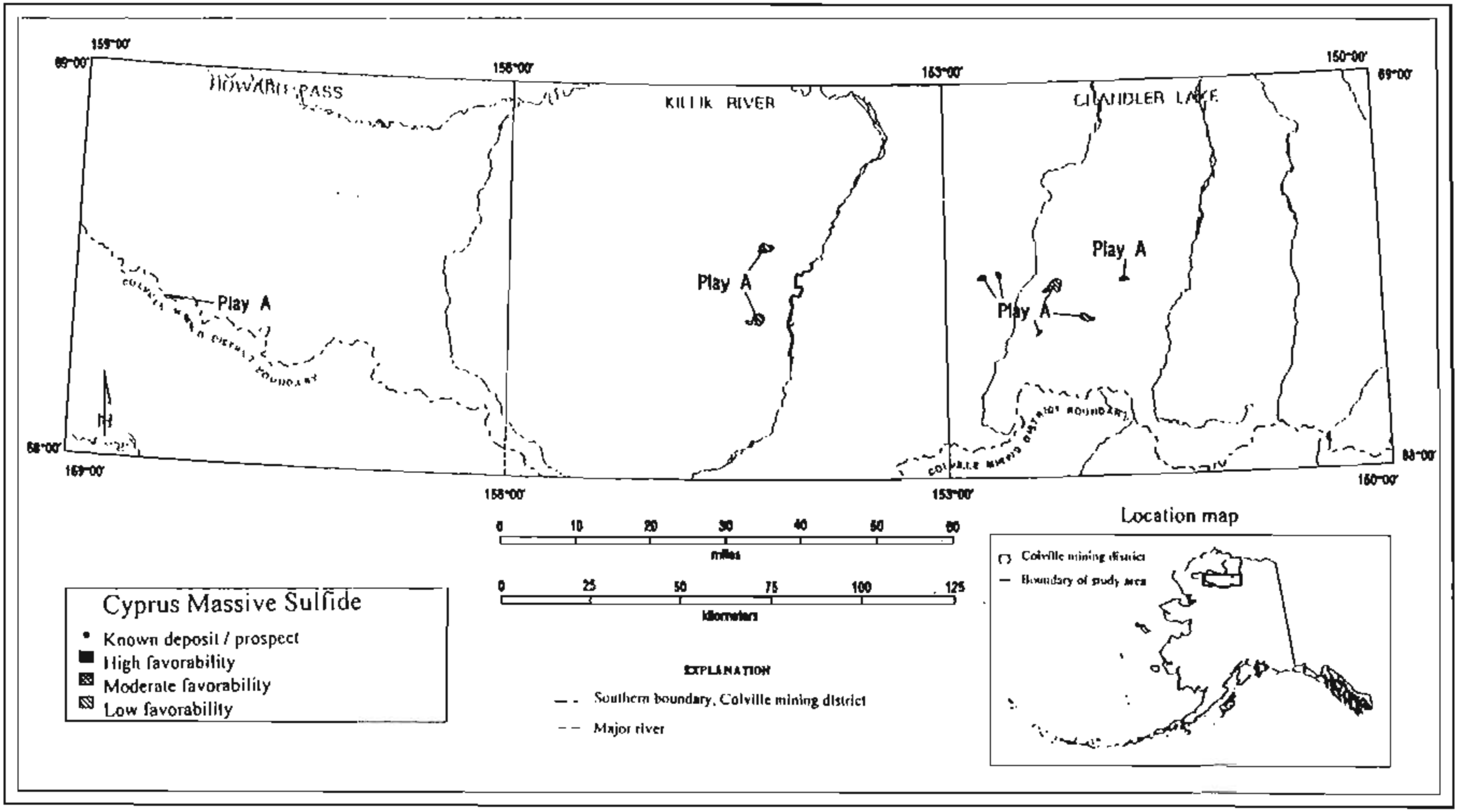

Figure 8. *Regions favorable for Cyprus-type massive sulfide.*

estimated endowment is shown in table 11.

Table 11. *Calculated endowment from Cyprus massive-sulfide deposits: play A*

PLAY A			
Percentiles	90th	50th	10th
Ore tonnage (million tons)	0.00	0.00	0.00
Zinc (thousand tons)	0.00	0.00	0.00
Copper (thousand tons)	0.00	0.00	0.00
Gold (thousand oz)	0.00	0.00	0.00

SUMMARY AND CONCLUSIONS

The results of the ROCKVAL analysis can be described in several ways. To show and compare the contribution of the various deposit types to the overall metal endowment of the Colville mining district, contained metals are presented on a deposit-type by deposit-type basis (table 12). This tabulation provides a measure of the relative value of each deposit type, highly simplified because the elements are not necessarily present in high enough concentrations or appropriate mineralogy for current economic extraction and beneficiation. The results shown in table 12 are arranged in descending order of endowment (using current commodity prices) for the 90-percent probability level. Because of statistical requirements, the summary endowment by deposit type (table 12) does not equal the sum of contained individual plays.

The estimated endowment at the 90-percent probability level, as presented in table 12, is biased toward those deposit types with the greatest certainty of existence, that is, known prospects with mapped areal extent and sampled grades. These include massive-sulfide and vein-breccia zinc deposits and sedimentary phosphate and barite deposits. Manganese is not a major contributor because raw Mn ores have a low unit value (present metal prices) relative to the other commodities in the Colville mining district. At the lower probability levels, more speculative deposit types, especially those with potentially large tonnages (for example, arenite-hosted, disseminated Zn-Pb deposits), play a significant role in the endowment.

As a summary of the metal endowment of the Colville mining district, table 13 gives the total estimated endowment for each major element present in major concentration at three probability levels. Figure 9 shows the locations of the highest endowment areas (90-percent-probability fractile) for the Colville mining district. Table 13 indicates that zinc is the element of greatest significance (at present-day metal values), accounting for about half of the present-day gross mineral value of the Colville mining district. This is a reasonable conclusion, given the Colville mining districts proximity to the world-class Red Dog Zn-

Table 12. *Estimated summary endowment for the Colville mining district by deposit type*

	Probability fractile		
Deposit type/Contained metal	90th	50th	10th
Sedex Zn-Pb			
Tonnage (10^6 tons)	5.4	140	530
Lead (10^6 tons)	0.2	5.4	30
Zinc (10^6 tons)	0.4	11	50
Silver (10^6 oz)	3	190	1,300
Vein - Breccia Zn-Pb-Ag			
Tonnage (10^6 tons)	13	24	59
Lead (10^6 tons)	0.7	1.6	3.6
Zinc (10^6 tons)	1.0	2.5	5.3
Copper (10^6 tons)	0.000	0.001	0.007
Silver (10^6 oz)	24	62	130
Gold (10^6 oz)	0.0	0.004	0.027
Bedded Barite			
Tonnage (10^6 tons)	55	150	310
Barite (10^6 tons)	40	110	60
Sedimentary Phosphate			
Tonnage (10^6 tons)	120	460	1,400
Phosphate (10^6 tons)	27	110	330
Uranium (10^6 tons)	0.01	0.05	0.12
Vanadium (10^6 tons)	0.09	0.36	1.00
Disseminated Zn-Pb			
Tonnage (10^6 tons)	3.6	100	740
Lead (10^6 tons)	0.00	0.09	1.5
Zinc (10^6 tons)	0.04	1.1	11
Silver (10^6 oz)	0.01	2.8	130
Sedimentary Manganese			
Tonnage (10^6 tons)	1.4	44	440
Phosphate (10^6 tons)	0.00	0.001	0.1
Manganese (10^6 tons)	0.4	13	160

Table 13. *Estimated total endowment for most significant metals, Colville mining district*

	Probability fractile		
Element	90th	50th	10th
Zinc (10^6 tons)	4.1	18	59
Lead (10^6 tons)	2.1	8.7	31
Phosphate (10^6 tons)	27	110	290
Barite (10^6 tons)	39	120	210
Silver (10^6 oz)	66	300	150
Manganese (10^6 tons)	0.36	11	160
Uranium (10^6 tons)	0.012	0.046	0.11
Vanadium (10^6 tons)	0.08	0.34	0.87
Gold (10^6 oz)	0.00	0.006	0.047
Copper (10^6 tons)	0.000	0.001	0.006

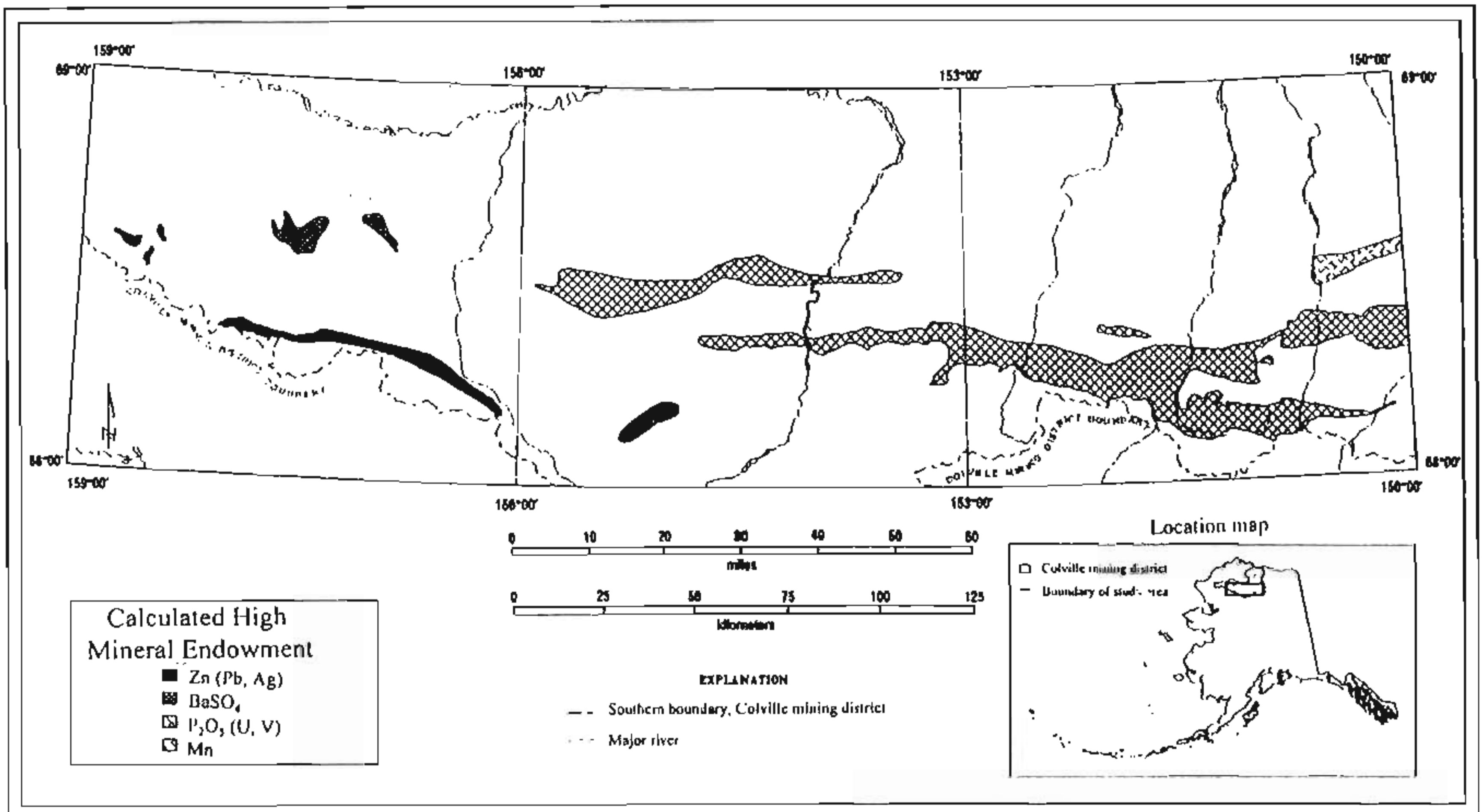

Figure 9. *Regions of calculated high mineral endowment.*

Pb-Ag deposit. Drilling indicates that the Red Dog deposit contains reserves of 77 million metric tons of 17.1 percent zinc, 5.0 percent lead, and 82 g per metric ton silver; Moore and others, 1986). The occurrence of host rocks with ages and lithologies similar to both Red Dog and a major Red Dog-type zinc prospect within the Colville mining district suggests a very likely zinc endowment. At high-probability fractiles (high levels of certainty), barite ($BaSO_4$) and phosphate (P_2O_5) deposits also make an appreciable contribution to the district mineral endowment. Secondary (by-product) commodities such as lead (Pb) and silver (Ag) in zinc deposits, and vanadium (V) and uranium (U) in phosphate deposits also add significantly to the endowment. Finally, there is a small (in worldwide terms) manganese endowment. In terms of present-day mineral prices, about two-thirds of the mineral endowment is derived from Zn-(Pb-Ag) deposits; the remainer is equally split between barite and phosphate deposits; manganese (Mn) and platinum (Pt) make little contribution.

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APPENDIX A
SUPPORTING DATA

NOTE: Numbers in ***bold italics*** are modified values for this study.

SEDIMENT-HOSTED STRATABOUND (SEDEX) Zn-Pb-Ag DEPOSITS

MODEL 29 DISTRICTS	Cutoff tonnage (million tons)	0.4
MODEL 30 LARGE AREAS	Probability that the prospect makes the cutoff tonnage	0.5

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 500 SQUARE MILE (1,295 KM^2) AREA								
MODEL 29:								
No. of prospects	1	2	6	15	25	42	48	50
MODEL 30:								
No. of prospects	1	1	2	2	3	4	5	7
MILLION TONS OF ORE	0.4	1	3	15	75	300	350	400
ZINC GRADE (%)	1.3	2.5	5	8	12	19	21	22
Occurrence probability of zinc	1							
LEAD GRADE (%)	0.3	0.85	2.8	4.4	6.5	10	11.5	12
Occurrence probability of lead	1							
SILVER GRADE (OZ/TON)	0.1	0.2	1	2	3	7	8	9
Occurrence probability of silver	0.85							

MODIFICATIONS: None

REFERENCES:

Newberry and others, 1994

VEIN-BRECCIA Zn-Pb-Ag DEPOSITS

MODEL 74a DISTRICTS	Cutoff tonnage (million tons)	0.01
MODEL 74b LARGE AREAS	Probability that the prospect makes the cutoff tonnage	0.7

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 100 SQUARE MILE (259 KM^2) OR 500 SQUARE MILE (1,295 KM^2) AREA								
MODEL 74a:								
No. of prospects per 100 square miles	1	1	2	6	20	38	48	50
	9	***10***	***11***	***12***	***13***	***14***	***15***	***16***
MODEL 74b:								
No. of prospects per 500 square miles	0	1	2	2	14	29	35	36
	0	***1***	***2***	***2***	***5***	***8***	***10***	***11***
MILLION TONS OF ORE	0.01	0.1	0.26	1.3	2.1	5.125	5.375	5.75
ZINC GRADE (%)	1.3	2.7	5.5	6.3	12.5	23	25	26
Occurrence probability of zinc	1							
LEAD GRADE (%)	0.1	1	3	5.72	8.8	14	16	17
Occurrence probability of lead	1							
COPPER GRADE (%)	0	0	0	0	0.01	0.05	0.5	1.5
Occurrence probability of copper	0.4							
SILVER GRADE (OZ/TON)	0.1	0.2	1	2	3	7	8	9
Occurrence probability of silver	0.95							
GOLD GRADE (OZ/TON)	0	0	0	0	0	0.005	0.01	0.03
Occurrence probability of gold	0.4							

MODIFICATIONS:

Revised prospect density to reflect the number of known occurrences. Reduced the number of deposits expected at low probabilities because the prospect-density curve overestimates these values when the number of districts used to calculate it are limited. Silver values are not consistently reported in the literature and so silver values were assumed to be about the same as sedimentary exhalative deposits. The low probability value was modified to reflect the higher silver values seen in a few of the vein-breccia deposits. Copper and silver grades estimated from the ratios seen with respect to zinc. Cumulative probability curves are shown in figures 10-14.

REFERENCES:

Fryklund, 1964; Gray, 1961; Ohmoto and Rye, 1970; Pattrick and Russell, 1989; Umpleby and Jones, 1923; Walther, 1986; Wilbur and others, 1990.

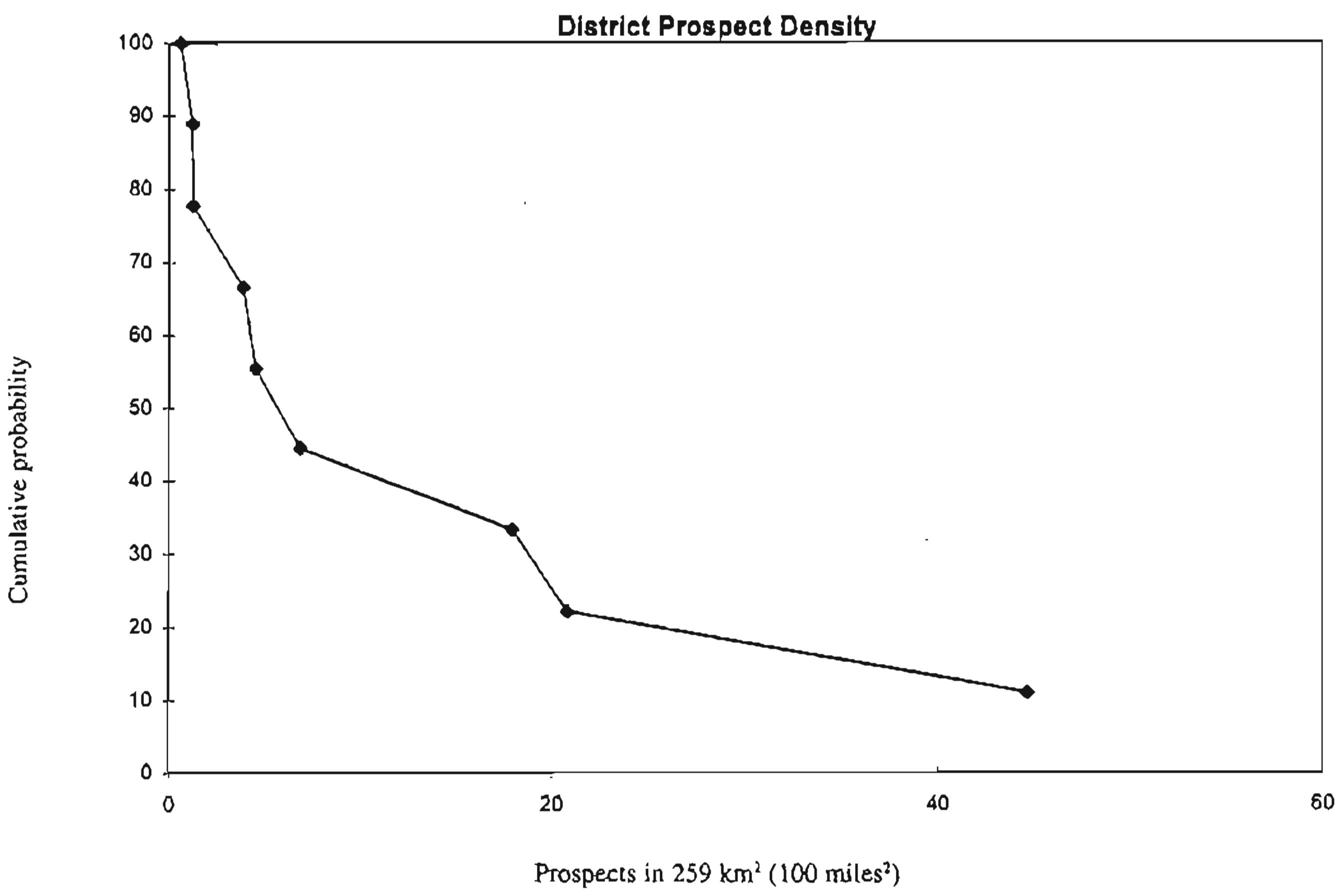

Figure 10. *Prospect density for vein-breccia districts.*

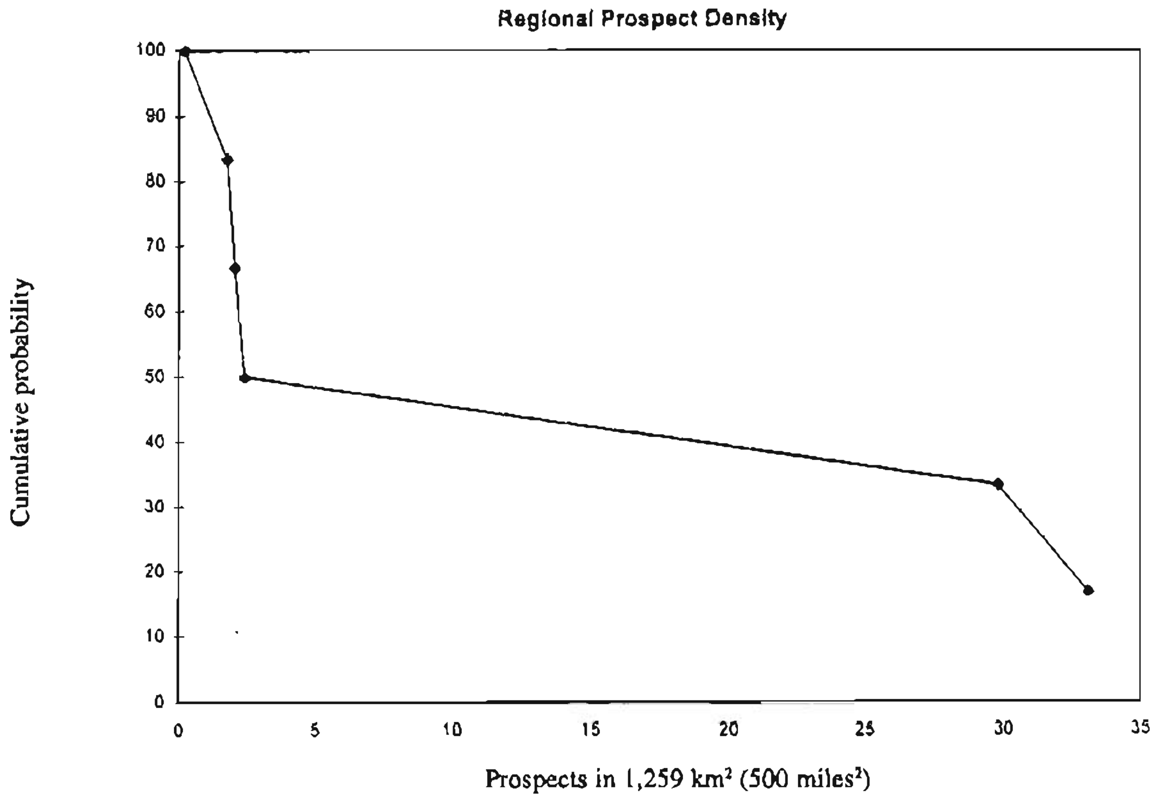

Figure 11. *Prospect density for vein-breccia regional areas.*

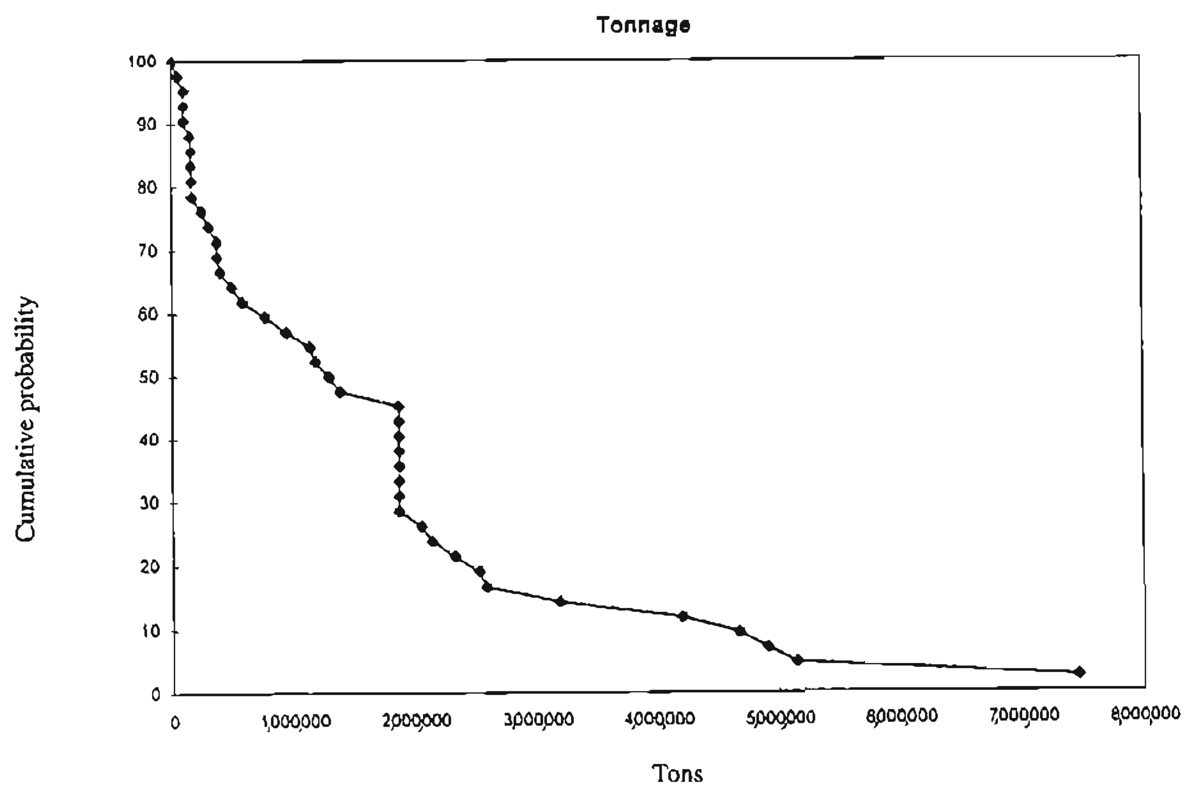

Figure 12. *Tonnage curve for vein-breccia deposits.*

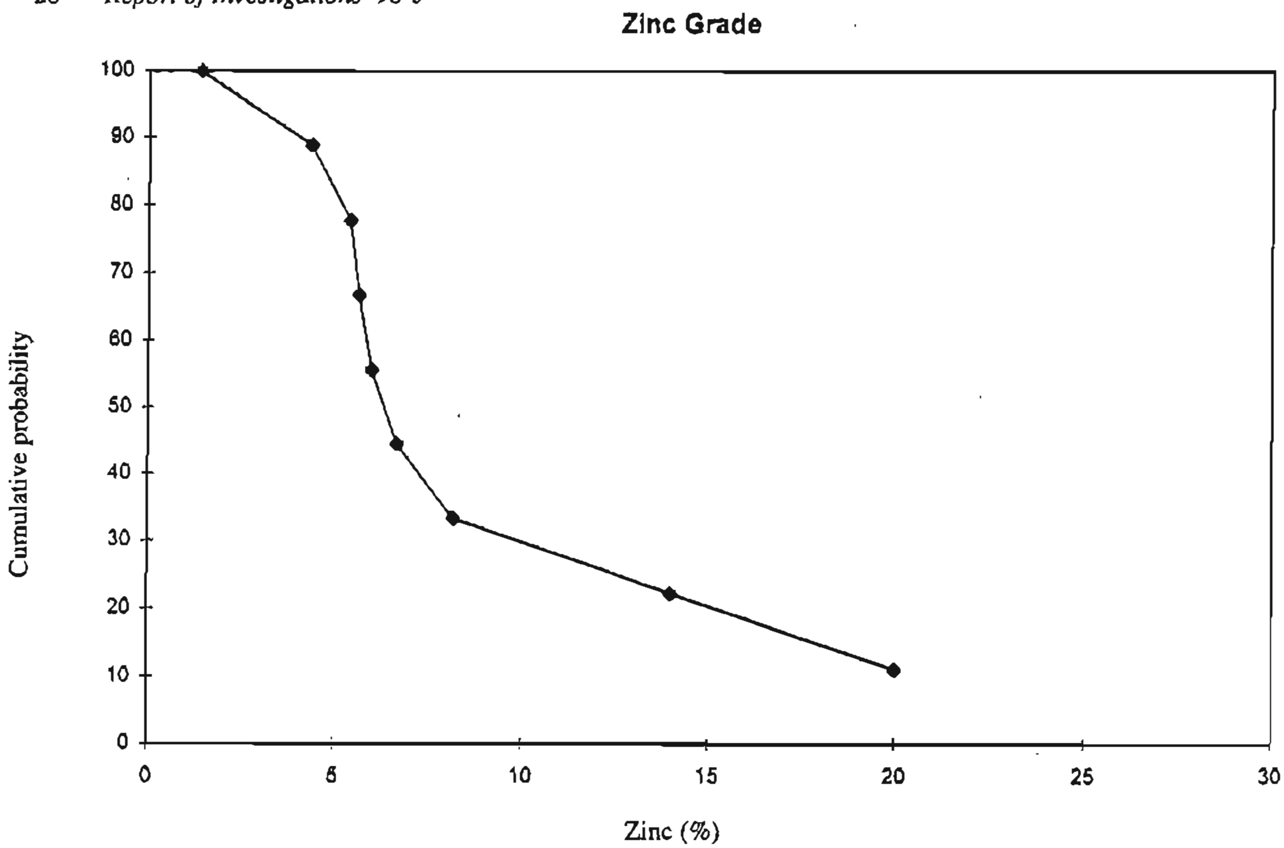

Figure 13. *Grade curve for zinc in vein-breccia deposits.*

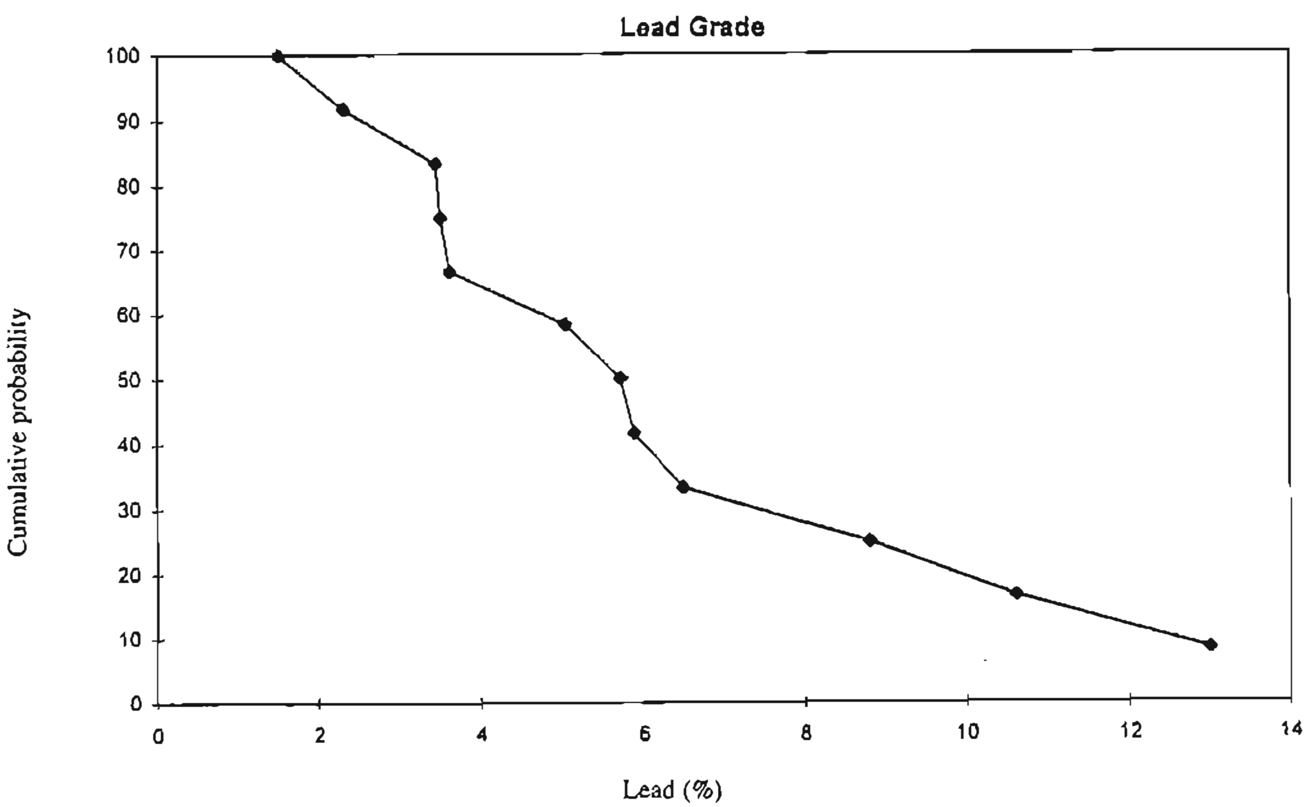

Figure 14. *Grade curve for lead in vein-breccia deposits.*

BEDDED BARITE DEPOSITS

MODEL 70a DISTRICTS	Cutoff tonnage (million tons)	0.1
MODEL 70b LARGE AREAS	Probability that the prospect makes the cutoff tonnage	0.9

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 100 SQUARE MILE (259 KM²) OR 500 SQUARE MILE (1,295 KM²) AREA								
MODEL 70a:								
No. of prospects	0	1	3	4	9	17	18	20
	14	*18*	*18*	*20*	*20*	*22*	*22*	*24*
MODEL 70b:								
No. of prospects	0	0	1	2	7	12	13	14
	0	*1*	*1*	*1*	*2*	*3*	*3*	*4*
MILLION TONS OF ORE	0.04	0.08	0.42	1.8	8	10	95	105
(modified for play A only)	*0.1*	*0.5*	*2.0*	*5.0*	*10*	*50*	*70*	*90*
BARIUM GRADE (%)	52.5	60	76	88	93	97.5	100	100
Occurrence probability of barium	0.9							

MODIFICATIONS:

Raised cutoff size to 100,000 tons and reduced maximum to 90 million tons to account for the large average size of the Brooks Range deposits and the structural complexity of the area. Changed high-probability prospect-density values to reflect the number of known barite deposits for play A. Modified regional prospect density because the curve overestimates the number of deposits expected in the low-probability fractiles. Cumulative probability curves are shown in figures 15 and 16.

REFERENCES:

Abbott and Turner, 1990; Cox and Singer, 1986; Kelley and others, 1993; Ketner, 1963; MacIntyre, 1983; Mills and others, 1971; Nuelle and Shelton, 1986; Orris, 1992; Shawe and others, 1969.

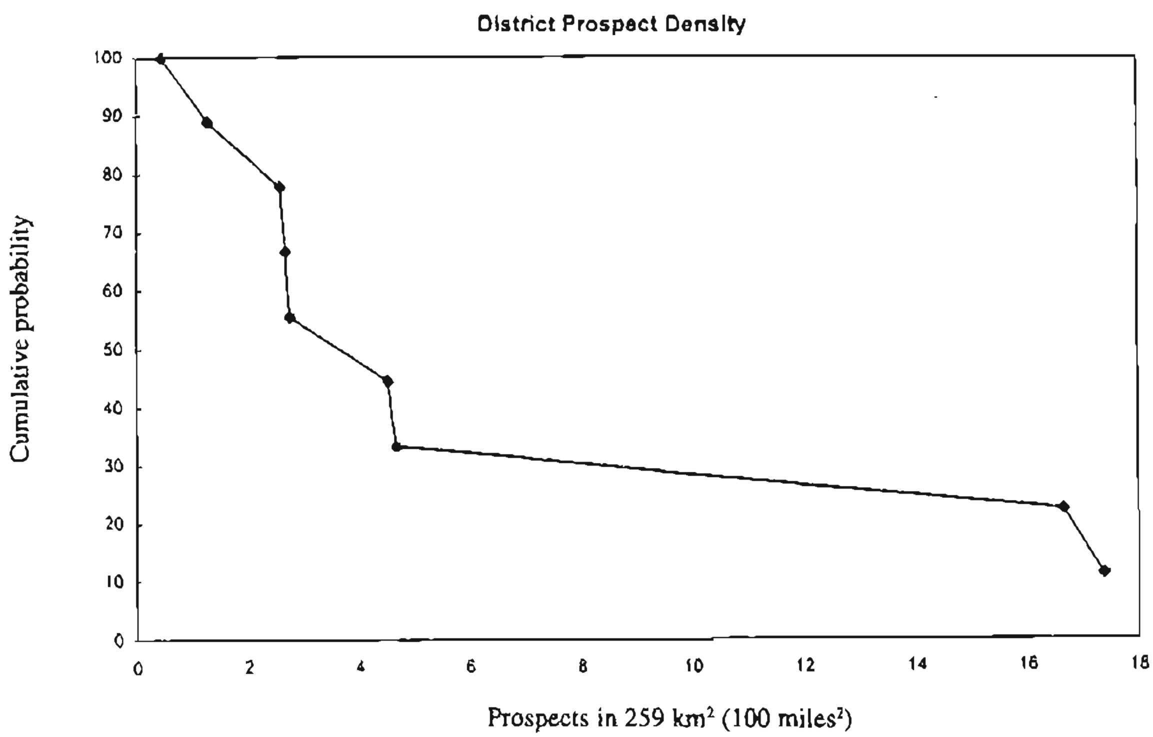

Figure 15. *Prospect density for bedded barite districts.*

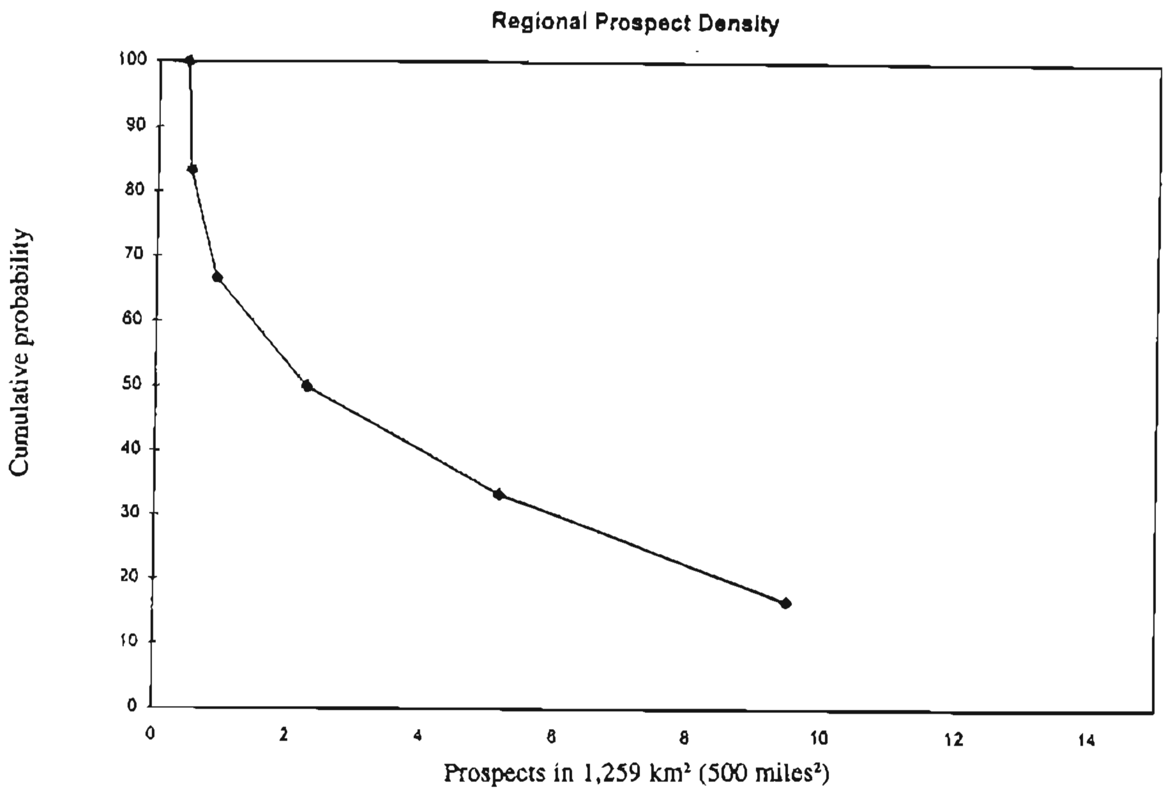

Figure 16. *Prospect density for bedded barite regional areas.*

SEDIMENTARY PHOSPHATE DEPOSITS

	Cutoff tonnage (million tons)					2		
	Probability that the prospect makes the cutoff tonnage					0.8		
PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN PLAY AREA								
MODEL for PLAY A:								
No. of prospects	3	3	4	4	5	5	6	7
MODEL for PLAY B:								
No. of prospects	1	1	2	2	2	3	3	4
MILLION TONS OF ORE	2	6	27	65	190	420	620	840
P_2O_5 GRADE (%)	10	11	19	25	29	33	33.5	34.5
	5							
Occurrence probability of phosphate	1							
U_3O_8 GRADE (%)	0.005	0.007	0.008	0.01	0.013	0.015	0.02	0.04
Occurrence probability of uranium	1							
V_2O_3 GRADE (%)	0.01	0.03	0.05	0.08	0.1	0.15	0.2	0.3
Occurrence probability of vanadium	1							

MODIFICATIONS:

Modified the high-probability fractile for low-grade phosphate to account for the low grade of Brooks Range occurrences. The minimum prospect density for play A is built around the known number of occurrences in the Brooks Range. The modified cumulative probability curve for tonnage is shown in figure 17.

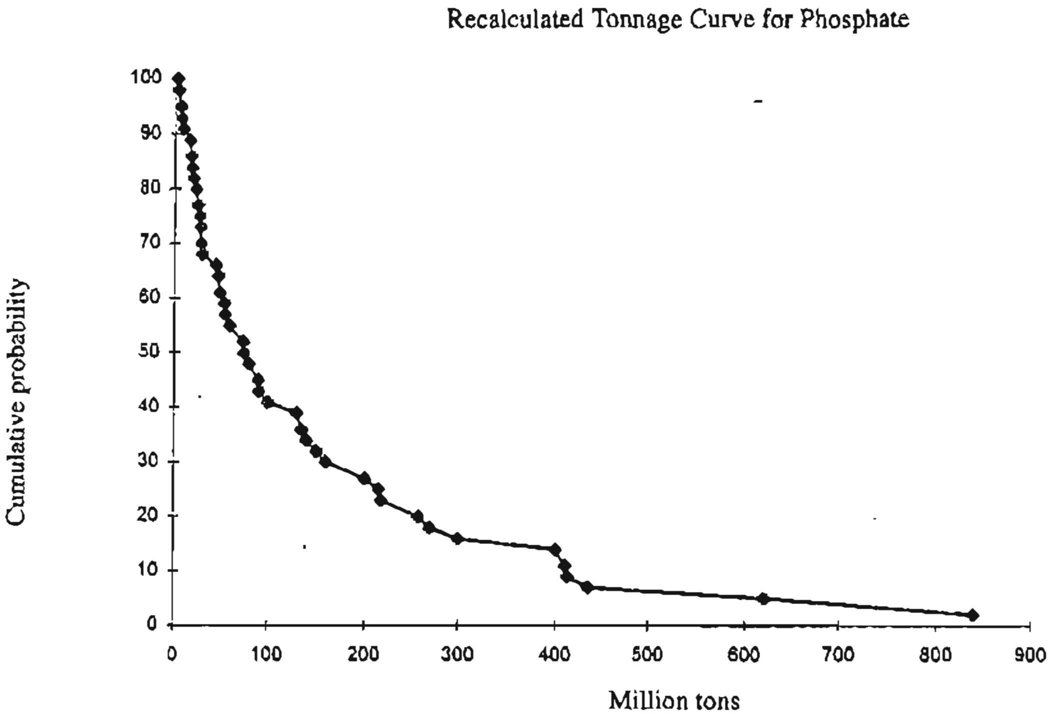

Figure 17. *Recalculated tonnage curve for phosphate deposits.*

Tonnage data:

Data used in calculating tonnage distribution curve for deposits are from Krauss and others, 1984. District data have been removed from those presented in Mosier, 1986a-c. Uranium and vanadium grades from Everhart, 1983.

Deposit name	Tonnage (million tons)	Deposit name	Tonnage (million tons)
Al-Hasa/Oatrana	621.9	Mrata	23
Arad	40	Mzaita	28
Beersheva	200	Nahal-Zin	130
Chilisai	269	Oronta	140
Eastern A & B	413	Oulad-Abdoun	160
El Hamrawein	410.65	Oulad-Abdoun	130
Hahotoe	91	Patos de Minas	435.3
Haikou	60	Qusseir	48
Hubsugul	400	Redeyef	200
Idfu-Qena	217.48	Ruseifa	218
Kalaa Khasba	6	Safagar	9
Khneifiss	17.68	San Juan de la Costa	45.4
Kondonakasi	20.3	Sehib	54.43
Kun Ming	400	S.E. Idaho	150
Lee Creek	2	S.E. Idaho	29
Lee Creek	300	S.E. Idaho	74
Le Kouif	27	S.E. Idaho	17.6
Makhtesh	3	Shediyah	838
P_2O_5 tonnage data continued			
Mazidagi	258	Taiba	75
Mdilla	80	Thamar-Kotra	49.2
Metalaoui	54.6	Thies	100
Moulares	25	unlabeled	90

REFERENCES: Krauss and others, 1984; Mosier, 1986a

DISSEMINATED ARENITE-HOSTED Zn-Pb DEPOSITS

MODEL 73a DISTRICT	Cutoff tonnage (million tons)				0.14		
MODEL 73b LARGE AREAS	Probability that the prospect makes the cutoff tonnage				0.35		

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 100 SQUARE MILE (259 KM²) OR 500 SQUARE MILE (1,295 KM²) AREA								
MODEL 73a:								
No. of prospects	0	1	2	3	4	5	6	6
MODEL 73b:								
No. of prospects	0	0	3	9	14	17	18	18
MILLION TONS OF ORE	0.14	0.38	1.5	5.4	22	100	225	325
ZINC GRADE (%)	0.01	0.01	0.01	0.23	1.15	5.5	7.5	9.5
	0.4	***0.65***	***1.5***	***2.2***	***3***	***8***	***9***	***10***
Occurrence probability of zinc	1							
LEAD GRADE (%)	0.04	0.65	1.5	2.2	3	8	9	10
	0.01	***0.01***	***0.01***	***0.23***	***1.15***	***5.5***	***7.5***	***9.5***
Occurrence probability of lead	0.9							
SILVER GRADE (OZ/TON)	0.01288	0.01288	0.01288	0.0322	0.2576	2.093	3.22	4.186
Occurrence probability of silver	0.9							

MODIFICATIONS:

Switched lead and zinc grades reported in Mosier, 1986b. On the basis of field observations and geochemical data, Brooks Range deposits contain more zinc than lead, often considerably more. Cumulative probability curves are shown in figures 18 and 19.

REFERENCES:

Mosier, 1986b

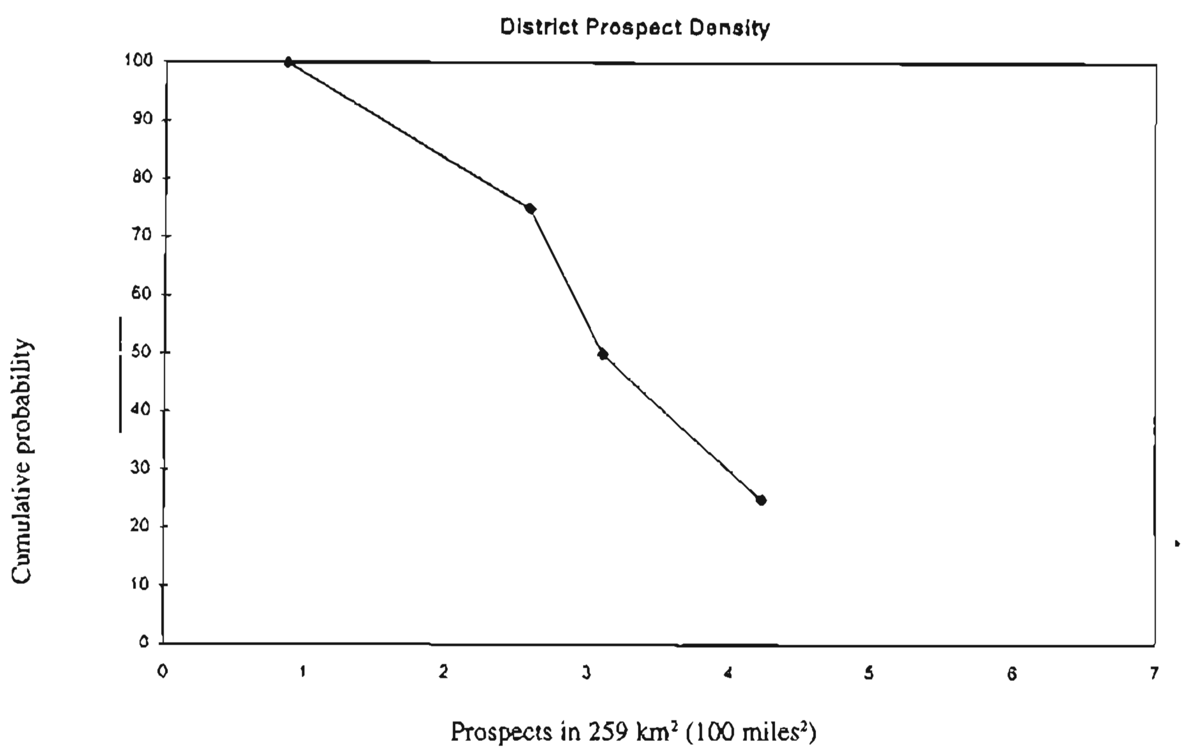

Figure 18. *Prospect density for disseminated Zn-Pb districts.*

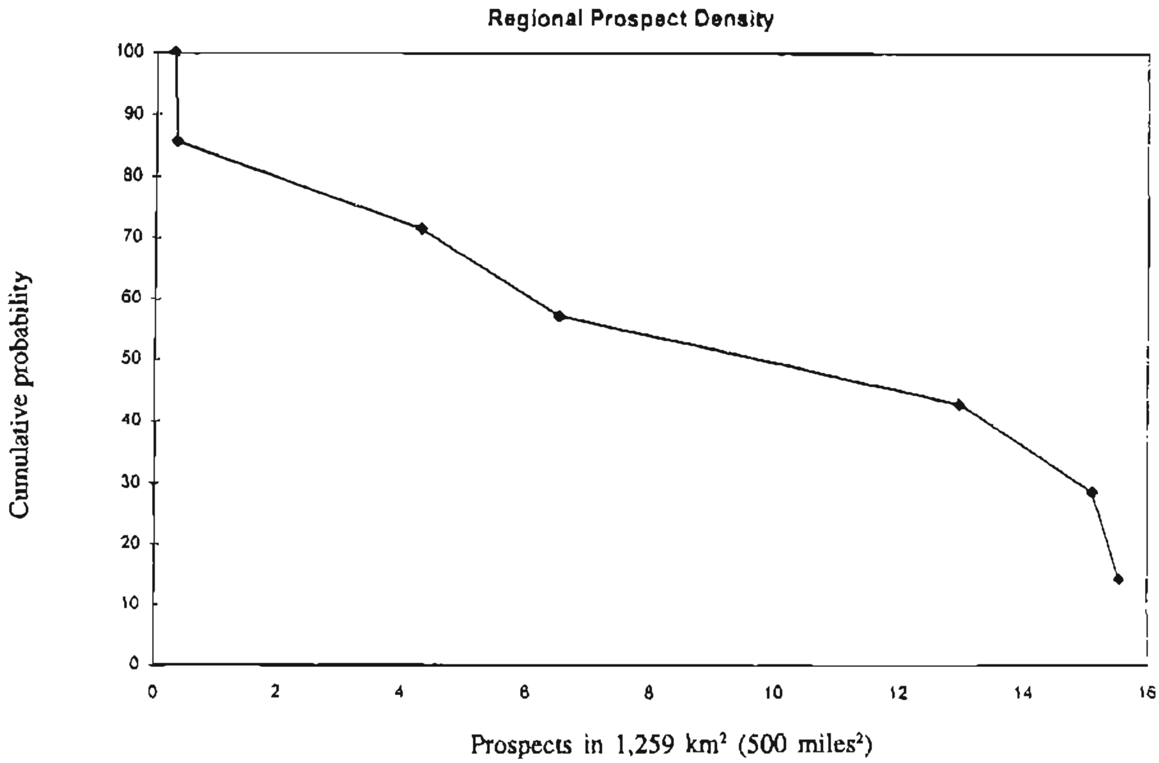

Figure 19. Prospect density for disseminated Zn-Pb regional areas.

SEDIMENTARY MANGANESE DEPOSITS

Cutoff tonnage (million tons)	0.03
Probability that the prospect makes the cutoff tonnage	1

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 500 SQUARE MILE (1,295 KM²) AREA								
MODEL 72:								
No. of prospects	1	1	1	1	1	1	1	2
MILLION TONS OF ORE	0.03	0.08	0.7	7.3	60	600	1600	2000
MANGANESE GRADE (%)	6 5	10	21	31	40.5	52	55	57
Occurrence probability of manganese	1							
P_2O_5 GRADE (%)	0.01	0.01	0.01	0.01	0.085	0.32	0.45	0.6
Occurrence probability of phosphate	0.5							

MODIFICATIONS:

Changed cutoff grade of manganese to 5 percent from 6 percent to reflect the relatively low grade of the Brooks Range deposits. The modified cumulative probability curve for tonnage is shown in figure 20.

REFERENCES:

Laznika, 1985; Mosier, 1986c

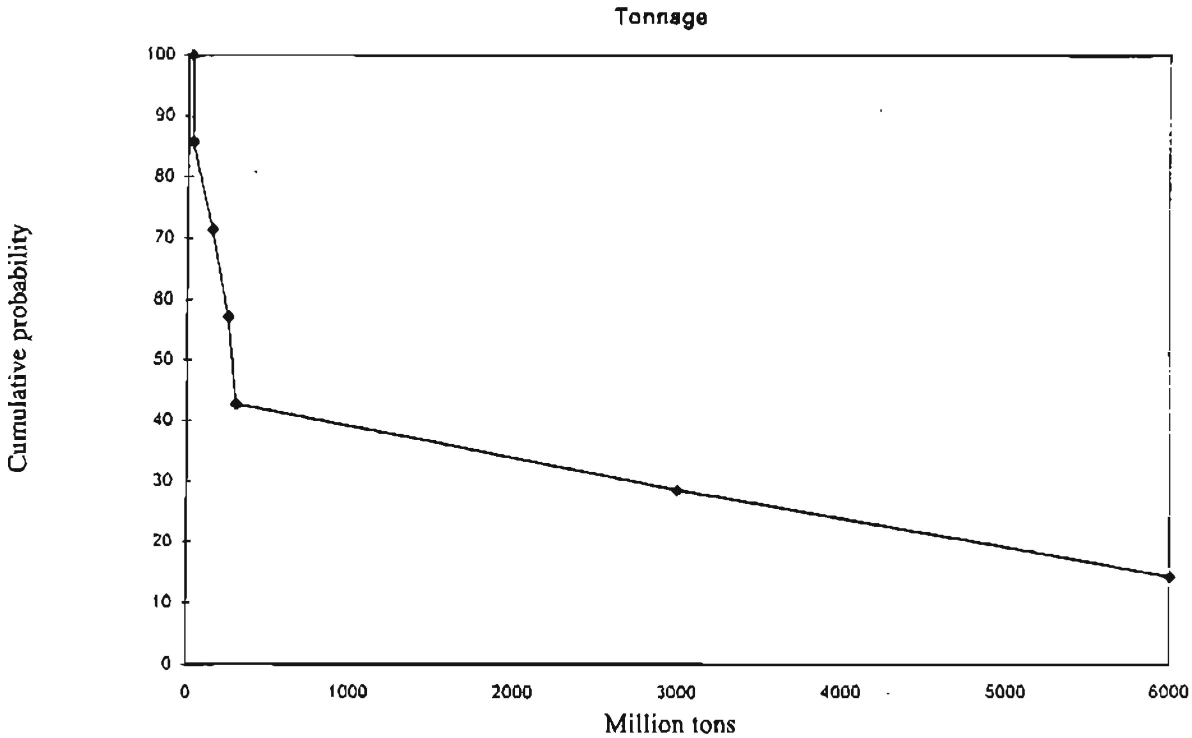

Figure 20. Tonnage curve for sedimentary manganese deposits.

PLACER PGM ± AU DEPOSITS

Cutoff tonnage (million tons)	0.0001
Probability that the prospect makes the cutoff tonnage	1

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 100 SQUARE MILE (259 KM²) AREA								
MODEL 49:								
No. of prospects	0	0	1	2	5	9	11	11
MILLION TONS OF ORE	0.0001	0.0014	0.003	0.11	0.4	4	9.5	10
PLATINUM GRADE (OZ/TON)	0.002	0.006	0.025	0.05	0.09	0.23	0.42	0.47
Occurrence probability of platinum	1							
GOLD GRADE (OZ/TON)	0.00001	0.00003	0.0003	0.0007	0.003	0.005	0.07	0.074
Occurrence probability of gold	0.5							

MODIFICATIONS: None

REFERENCES:

Newberry and others, 1994

CYPRUS MASSIVE SULFIDE DEPOSITS

Cutoff tonnage (million tons)	0.01
Probability that the prospect makes the cutoff tonnage	0.8

PROBABILITY	100	95	75	50	25	5	1	0
PROSPECT DENSITY WITHIN 500 SQUARE MILE (1,295 KM^2) AREA								
MODEL 40:								
No. of prospects	0	1	2	2	5	18	35	40
MILLION TONS OF ORE	0.01	0.075	0.33	1.6	6.3	29	40	50
ZINC GRADE (%)	0	0	0	0	0.4	4.3	8	13
Occurrence probability of zinc	0.9							
COPPER GRADE (%)	0.23	0.56	1.1	1.7	2.7	4.8	8	10
Occurrence probability of copper	1							
LEAD GRADE (%)	0	0	0	0	0	0.03	0.16	0.4
Occurrence probability of lead	0.1							
GOLD GRADE (OZ/TON)	0	0	0	0	0.00805	0.1932	0.5152	0.7406
Occurrence probability of gold	0.8							
SILVER GRADE (OZ/TON)	0	0	0	0	0.1288	2.415	3.864	5.152
Occurrence probability of silver	0.5							

MODIFICATIONS: None

REFERENCES:

Singer and Mosier, 1986