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THE PROBABILISTIC ESTIMATION OF GOLD RESOURCES IN THE CIRCLE-FAIRBANKS-KANTISHNA AREA

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INTRODUCTION

A quantitative assessment of the gold resources present between Circle, Alaska and Kantishna, Alaska was performed by the Alaska Division of Geological and Geophysical Surveys (ADGGS), the U.S. Bureau of Mines (USBM), and the Department of Geology, University of Alaska, Fairbanks. The assessment was undertaken to evaluate the remaining gold potential of the area. The quantitative estimates of gold resource potential derived from this study will form the basis for an economic estimate of the value of those resources by the U.S. Bureau of Mines.

Although there has been considerable gold production from the Fairbanks area, the vast bulk of production has been from placers, not lodes. The endowment calculated for the report is only for lode sources, and we suggest that no corrections for past production be made to the endowment. Our reasoning for this conclusion is more fully discussed in appendix C.

BACKGROUND

A cooperative agreement between the Alaska Division of Geological and Geophysical Surveys and the U.S. Bureau of Mines was signed in 1987, requesting a quantitative assessment using a computer modeling process called ROCKVAL on the gold belt between Circle and Kantishna. This gold belt is referred to herein as the North Star gold belt (NSGB). The assessment was in part suggested to provide a methodology to quantitatively evaluate gold deposits outside of the immediate Fairbanks area. Dr. Rainer Newberry of the Dept of Geology, University of Alaska, Fairbanks, was contracted by the ADGGS to participate in the evaluation. The reader is referred to White and others (1987) for a description of the ROCKVAL methodology.

The current study included three phases in the assessment process; 1) field mapping, 2) analytical data acquisition and interpretation, and 3) the ROCKVAL analysis. Field and analytical work was designed specifically to address the problems of mineral potential and quantitative resource assessment. Two sources of gold, volcanogenic massive sulfide deposits and plutonic-hosted gold, were determined to be present in the area and are reported upon in detail elsewhere (Newberry and others, 1988; Newberry and Burns, 1988).

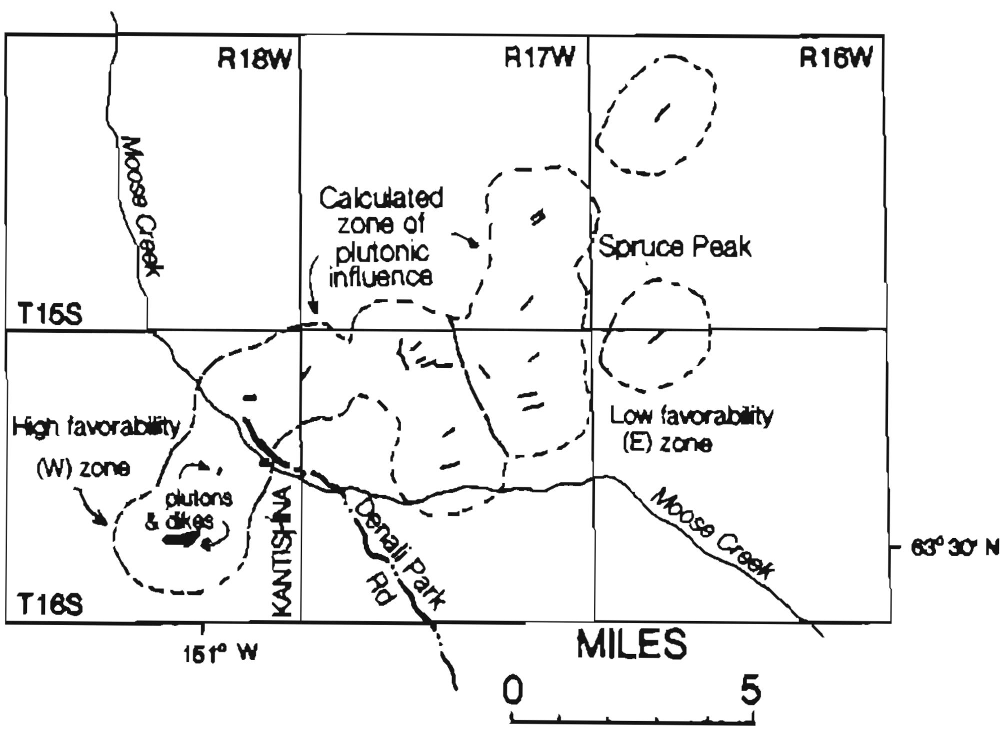
PRELIMINARY ASSESSMENT STRATEGY

1. Regional Favorability

The ROCKVAL process was started with the systematic interpretation for favorability within the region for each of the deposit types. For plutonic-related gold deposits, favorability was assessed through discriminant analysis. For volcanogenic-related deposits, favorability was semi-quantitatively assessed by comparing trace element signatures of metavolcanic rock from the NSGB with likely analog models.

For the purposes of 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 and geochemical maps and on rock geochemical data (Plate 1; Figs. 1-4).

FIGURE 1: Location of plutonic-related gold plays in the Kantishna area. See Plate 1 for location of Kantishna area.



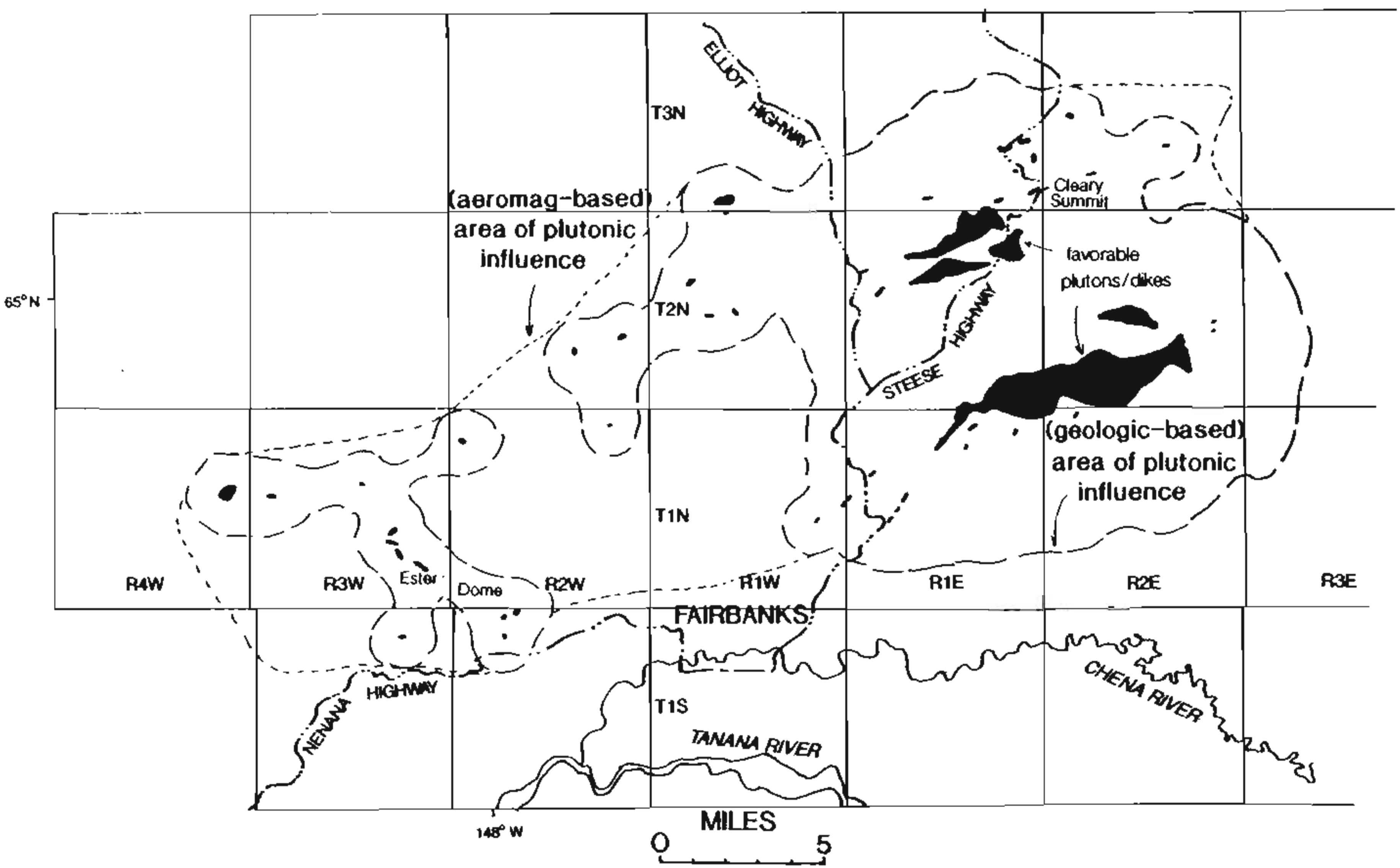


FIGURE 2: Location of plutonic-related gold plays in the Fairbanks area.

FIGURE 3: Locations of plutonic-related gold plays in the Steese area. See Plate 1 for general location.

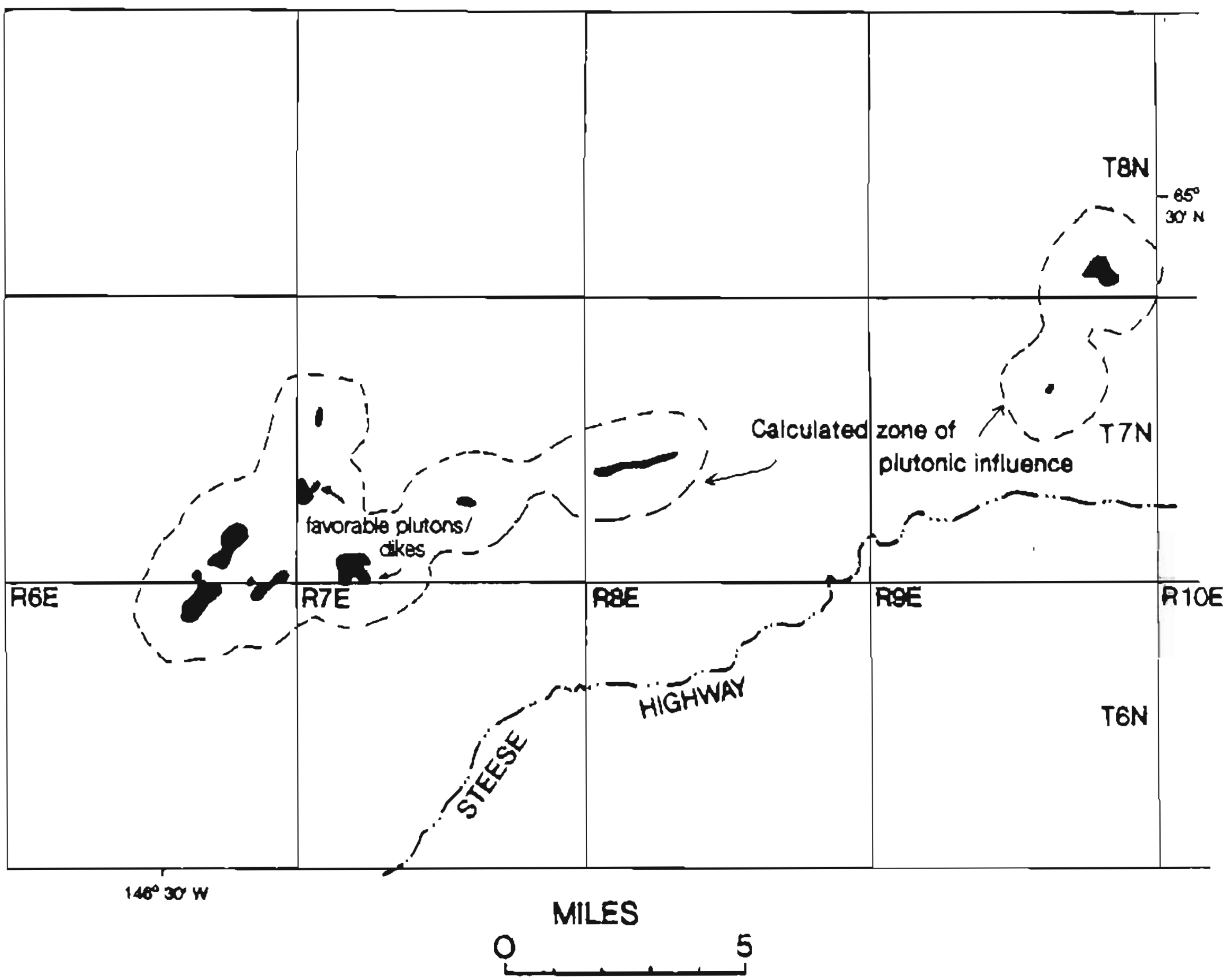
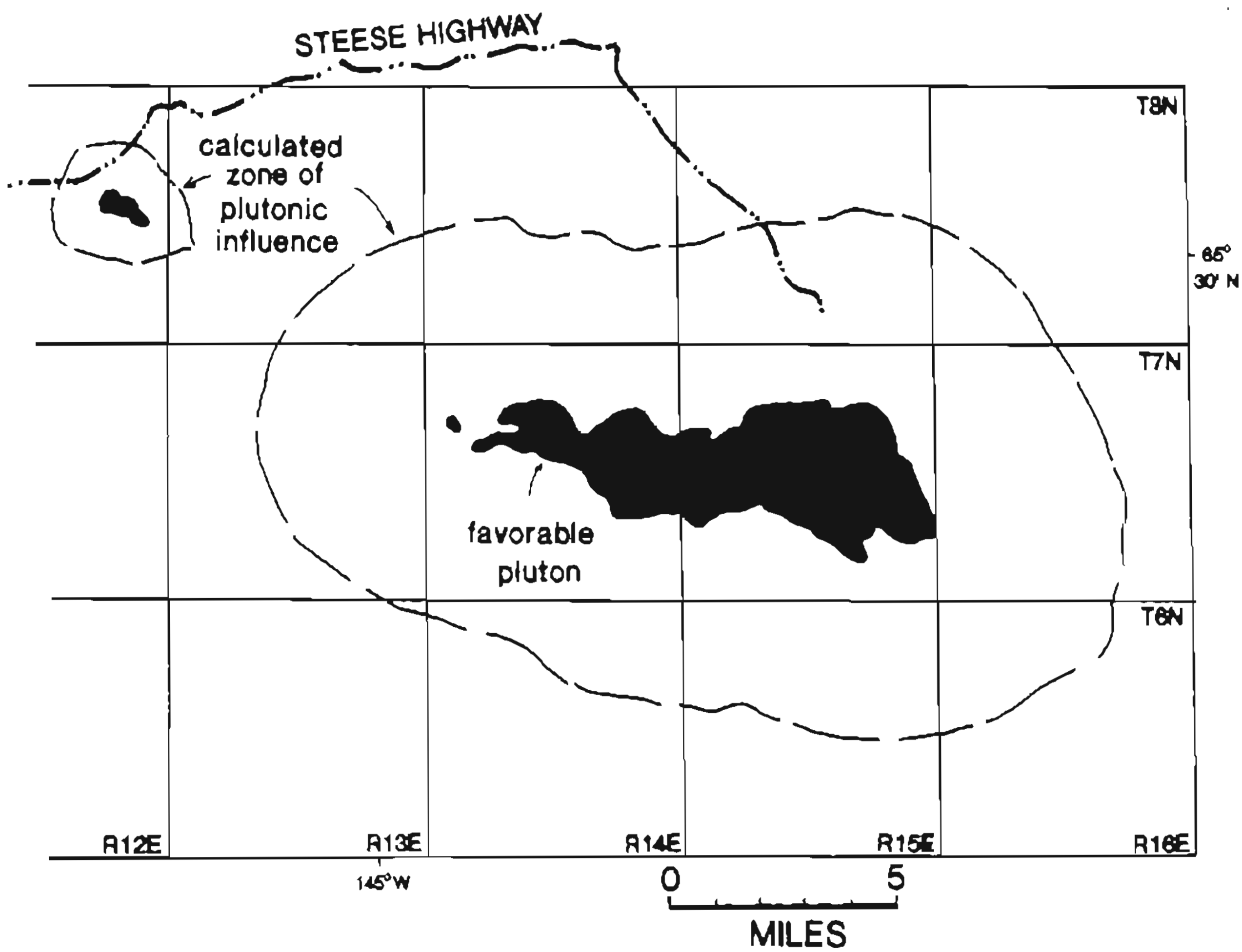


FIGURE 4: Location of plutonic-related gold plays in the Circle area.



The very high favorability plays encompass the least amount of area, and the low favorability plays encompass the largest tracts of land. Very high favorability implies that a specific deposit type is known to be present. Moderate favorability implies that some geological, geochemical, or geophysical indicators are present but no prospects are known. Low favorability areas are broadly similar geologically and geophysically to moderate and high favorability areas, but lack strong geochemical indicators or prospects. Favorability criteria for the deposit types are discussed in Appendix A.

2. Deposit densities

For each ROCKVAL play, a prospect probability distribution (i.e. 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 using generic "prospect density" curves (Appendix B), as described for the NORWAAP project (Pessel and others, 1987). For the current study, an internally self-consistent set of deposits/prospects was employed to generate a) the deposit favorability, b) the deposit densities, c) the deposit cut-off parameters, and d) the deposit grade-tonnage models. These generic curves were prepared by determining the number of prospects per square mile of geologically favorable terrane for a large number of world-wide districts of a particular deposit type. The generic prospect density curve for a particular deposit type is thus the number of expected prospects/square mile 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, calculated values for number of prospects were modified to reflect known geological considerations, where applicable.

3. Cut-off parameters

Cut-off parameters represent the minimum values for grade and tonnage which will be considered as potential resources by the simulation process. Cut-off values for grade and tonnage are deliberately set below those which are likely to be produced at current commodity prices. Cut-offs are based on the minimum size/grades found in the literature data for a given deposit type.

4. Grade and tonnage distributions

Probability distributions for grade and tonnage were estimated from compilations of applicable literature data for the appropriate deposit type. In particular, a plutonic-related gold deposit grade-tonnage model was created using those same districts employed as "gold-related" in the plutonic discriminant analysis. Cox and Singer (1986) and Laznicka (1985) are excellent references for deposit data and were widely employed. 'Generic' distributions were modified where geological or geochemical indicators made it necessary. Similarly, the early Paleozoic volcanogenic gold district of the southeastern U.S. Piedmont region, whose metavolcanic trace element signatures were used to estimate favorability, were used for grade-tonnage models.

5. Deposit favorabilities

Not all the prospects calculated/estimated from above would necessarily meet the grade/tonnage cutoffs. Estimation of the proportion likely to meet the cutoff was made by noting the proportion of prospects (used in generating the prospect distribution curve) which would meet the cutoffs. These 'generic favorabilities' were modified as appropriate by the appraisal committee.

DISCUSSION OF GOLD DEPOSIT TYPES

The available data suggest that 1) volcanogenic and remobilized volcanogenic, 2) plutonic-hydrothermal, and 3) mixed volcanogenic and plutonic-hydrothermal gold deposits are present in the NSGB (Newberry and Burns, 1988). The ROCKVAL parameters for each deposit type will be discussed below.

Volcanogenic massive sulfide deposits: Cleary Sequence gold

The Cleary Sequence (and equivalents) of the North Star gold belt contains both stratabound gold deposits and veins probably derived from stratabound(?) sources. Lithologies similar to the Cleary Sequence are assumed to be sources of some placer gold. Placer gold is not assessed herein.

Geologic mapping, and detailed geochemical and isotopic studies of the Cleary Sequence, the surrounding Fairbanks Schist lithologies, and the gold prospects and deposits show marked dissimilarities with typical early Proterozoic VPMS deposits of Canada and the northern U.S. (Newberry and others, 1988). The rocks of the study area are instead very similar in age, rock type, mineralogy, and ore and gangue mineralogy to the Early Paleozoic VPMS belt of the southeastern USA (Newberry and others, 1988; Newberry and Burns, 1988). A grade-tonnage model for deposits of the VPMS belt of the southeastern USA was constructed from the geologic literature (e.g. Pardee and Park, 1948; unpub. industry data) and was used in the present ROCKVAL assessment.

Prospect distribution for the NSGB was estimated from distribution of prospects in the Piedmont region, southeastern U.S. (e.g. Pardee and Park, 1948; unpub. industry data). Probabilities for exceeding grade and tonnage cutoffs for the NSGB were estimated from the fraction of southeastern U.S. prospects noted exceeding the cut-off values. The minimum size deposit in the southeastern Piedmont for which we had reliable data was 100,000 tons and that number was used for the cutoff tonnage.

Plutonic-related gold:

Many plutonic rocks in the NSGB are spatially associated with gold-bearing veins, hornfels, and skarns. Because of tellurium anomalies associated with some gold occurrences in the area and similarities of Pb isotope ratios between plutons and some veins/replacement bodies (see Newberry and others, 1988), the plutonic rocks were investigated as a possible major source of gold. Because all plutons are not gold-related, a discriminant analysis was computed that predicts which plutons in the NSGB are gold-related and estimates their corresponding favorability (discussed in more detail in Appendix A).

The discriminant was constructed from about 650 major oxide analyses from 150 geographic locations. Forty percent of the analyses were related to gold. Five quadratic discriminant equations were computed on random subsets of the data. The equations yield about a 5 percent TYPE II error, the probability that a gold pluton will be misclassified, and about a 10 percent TYPE I error, probability that a non-gold pluton will be classified as a gold pluton. These error rates are obviously low and make the discriminant analysis a useful approach.

Major oxide analyses of the plutonic rocks from the NSGB were run through the discriminant program. The two major suites of granitic plutons in the area have markedly different potential for gold production. The suite of plutons about 60 Ma old, including the Hope granite suite (Burns and Newberry, 1987) and the Circle Hot Springs pluton, have been attributed previously to being tin-related, and are predicted to be moderately non-gold by use of the discriminant function. Conversely, a suite of 90 Ma granites and granodiorites related to tungsten skarns are predicted by the discriminant function to be strongly gold-related. The tungsten-skarn plutons include Gilmore Dome (Blum, 1983;

Newberry and Swanson, 1986), and Table Mountain (Newberry, 1987), among others. More detailed results are shown in Appendix A.

Most of the other plutonic rocks in the NSGB are dikes. Compositions range from granite to gabbro to lamprophyre. Many of the dikes appear favorable for gold association (see Appendix A).

Computation of regional favorabilities for areas were based on the average posterior probability of the five discriminant functions per rock type and volume of that rock type. Where the average of the posterior probabilities for being related to gold was below 60 percent, the regional favorability was assumed to be extremely low.

The characteristics of the plutons in the area which appear to be favorable for gold concentration are typical of those related to "mesothermal veins". The characteristics include 1) only small amounts of pervasive hydrothermal alteration, 2) relatively deep emplacement, and 3) generally early Tertiary or older ages (Newberry and others, 1988). Hence, a model for "mesothermal veins/replacements" should be a proper analog to the plutonic-related deposits in the NSGB. Grade-tonnage curves based on literature data for mesothermal veins associated with the same plutonic rocks used for the discriminant analysis, were thus used in the ROCKVAL analysis.

Prospect distribution was estimated from generic distributions for plutonic-related gold veins, employing about 40 districts in Canada and the U.S. Favorable areas were determined by establishing four mile zones around favorable plutons greater than one mile in diameter, and one mile zones around favorable dikes/plugs that are less than one mile in diameter (see appendix B for more detail). Such favorability zones are approximately the same used by the U.S. Geological Survey in their estimation of favorable plutonic-related deposits of Nevada (Cox and others, 1989).

GEOLOGY AND RESOURCES OF THE AREA

Each major area of gold occurrences in the NSGB will be discussed briefly below in terms of the two end member deposit types, and the number of plays per deposit type. Locations for the volcanogenic plays are shown on Plate I. The plutonic-related plays occupy generally similar areas and are shown in figures 1-4. Results of the computer simulation are shown in table 1.

Kantishna area:

A volcanogenic and two plutonic-related plays were constructed and assessed for the Kantishna area. Some of the bedrock gold anomalies near Kantishna lack characteristics typical of the plutonic prospects (such as the presence of high Te and F; Newberry and others, 1988). S and Pb isotopic analyses from some ores in the Kantishna area (especially those in the northeast end) suggest that many of the veins/metal anomalies are most likely of volcanogenic origins. The presence of clearly strataform Au prospects with S and Pb isotopic signatures and trace element signatures that are all characteristic of the early Paleozoic, and metavolcanic rocks with appropriate trace element signatures, led to a favorability assignment of 1 for this volcanogenic play (Plate I).

Mafic and felsic dikes of Cretaceous age are also present in the Kantishna area. All of the mafic dikes (SiO_2 < 60 %) and several of the more silicic dikes classified in the discriminant analysis as strongly gold-related. Many of the Au-Ag veins, especially in the western part of the area, have Cretaceous plutonic Pb-S isotopic and trace element signatures. Geochemically 'favorable' dikes/plugs are also present in this area (Fig. 1). In contrast, geochemically 'unfavorable' dikes and a general dearth of Au-bearing veins are present in the eastern part of the Kantishna area (Fig. 1). Based on these data, two separate plutonic-related Au plays with favorabilities of 0.8 and 0.2 were estimated for the western and eastern portions, respectively, of the district.

TABLE 1: RESULTS OF THE ROCKVAL SIMULATION

KANTISHNA

Volcanogenic Au deposits (high - 1.00)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.16	.28	.90	2.2	8.7	22	37
Au (10E3 OZ)	6.0	10	33	88	320	790	1400

Plutonic-related Au (moderately high - 0.80)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.00	.00	.00	.17	1.3	3.4	4.9
Au (10E3 OZ)	.00	.00	.00	67	450	1200	1800

Plutonic-related Au (low - 0.20)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.00	.00	.00	.00	.00	.88	2.6
Au (10E3 OZ)	.00	.00	.00	.00	.00	250	940

TABLE 1, CONT: RESULTS OF THE ROCKVAL SIMULATION

FAIRBANKS

Volcanogenic Au deposits (high - 1.00)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	4.4	6.1	11	22	45	71	88
Au (10E3 OZ)	170	230	410	850	1700	2700	3600

Plutonic-related Au (high - 1.00)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	4.8	6.3	9.9	18	38	75	91
Au (10E3 OZ)	1500	2000	3300	6200	14000	26000	31000

TABLE 1, CONT: RESULTS OF THE ROCKVAL SIMULATION

STEESE AREA

Volcanogenic Au deposits (moderately high - 0.75)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.00	.00	.00	5.8	22	54	70
Au (10E3 OZ)	.00	.00	.00	210	830	2000	2800

Plutonic-related Au (high - 1.00)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.056	.14	.47	1.7	4.0	7.4	9.6
Au (10E3 OZ)	14	38	140	540	1400	2700	3500

TABLE 1, CONT: RESULTS OF THE ROCKVAL SIMULATION

CIRCLE AREA

Volcanogenic Au deposits (high- 1.00)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.76	1.3	2.5	7.8	23	49	69
Au (10E3 OZ)	28	47	95	290	870	1900	2800

Plutonic-related Au (moderately high - 0.80)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Tonnage (10E6 Tons)	.00	.00	.18	1.8	5.6	11	14
Au (10E3 OZ)	.00	.00	54	560	2000	4000	5300

TABLE 1, CONT: RESULTS OF THE ROCKVAL SIMULATION

HEALY AREA

Volcanogenic Au (low- .25)

	Fractile						
	.95	.90	.75	.50	.25	.10	.05
Ore Tonnage (10E6 Tons)	.00	.00	.00	.00	.11	3.8	10
Au (10E3 OZ)	.00	.00	.00	.00	2.8	140	380

Fairbanks area:

The Fairbanks Mining District has been the most productive placer gold district in the NSGB, having produced about 8 million oz (Bundtzen and others, 1988). Cleary Sequence containing known Au-bearing strata is present throughout the area (Plate I). Many plutons showing gold enrichment with fractionation (Newberry and others, 1988) intrude into and near the Cleary Sequence in the Fairbanks area. These plutons are classified by the discriminant analysis as having a strong gold-related potential (see Appendix A). ROCKVAL analysis suggests that about 80 percent of the gold is from plutonic sources, with the remaining gold predicted as coming from the Cleary Sequence.

A volcanogenic and a plutonic play, which each encompasses approximately the same area, were chosen for the area (Plate I; Fig. 2). The favorabilities were 1 for both of these plays ....

Steese area:

Birch Creek, a stream on which appreciable gold placer mining has occurred in the Circle mining district, drains the Steese-White Mountains area (near Table Mountain). Historic placer mining has also taken place on Hope, Faith, Charity, Sourdough, and Nome Creeks. Geologic mapping in the Steese-White Mountain recreation area indicated the presence of lithologies similar to the Cleary Sequence (Newberry, 1987) and several types of plutonic rocks.

Detailed sampling of the Cleary Sequence(?) lithologies indicated a few sulfidic stratabound zones slightly enriched in gold and some gold-bearing veins. Trace element data for metavolcanic rocks of this area are similar to those of the Piedmont region in the southeastern U.S. Based on lithologic similarities but the absence of known stratabound gold, Cleary Sequence(?) in the Steese area was assigned a regional favorability of 0.75 percent for stratabound gold deposits (Plate I). Only modest gold resources were estimated for Cleary Sequence(?) sources in the Steese area, due in part the uncertainty in their occurrence.

Two suites of plutonic rocks crop out in the Table Mountain area (Fig. 3), and include 1) granites and granodiorites related to tungsten skarns (Table Mountain monzogranite), and a 2) semi-alkalic suite containing lamprophyric dikes, and hornblende quartz monzonites (Burns and others, 1987; Newberry, 1987). Gold-bearing veins and hornfels zones spatially related to the gold-favorable plutonic rocks are present (Menzie and others, 1987; Newberry, 1987). Existing major oxide analyses were run through the discriminant equation. The discriminant analysis suggests that the Table Mountain monzogranite, the lamprophyric dikes, and the hornblende quartz monzonites are very likely associated with gold deposits. Due to the limited extent of these favorable plutonic rocks (Fig. 3), only modest gold resources were estimated for this area.

Circle area:

Nearly one million oz of gold has been produced from placer mining near Circle Hot Springs. The streams that are mined drain extensive exposures of Cleary Sequence, the Two-Bit pluton, and the Circle Hot Springs pluton. The Cleary Sequence in this area contains local low Te gold veins and stratabound sulfide zones, and shows trace element signatures similar to those of the Piedmont region. The Two-Bit pluton, largely granite and granodiorite of late Cretaceous age, yields moderate gold potential based on the results of the discriminant analysis. The Circle Hot Springs pluton, largely granite of early Tertiary age, yields low gold potential based on the results of the discriminant analysis. Based on these data, a volcanogenic play with a favorability of 1 and a plutonic play (Fig. 4) with a favorability of 0.8 were created.

Healy area:

Strata lithologically identical to the Cleary Sequence were located and sampled in the Healy area during 1987. Sulfide zones, but no significant Au concentration, were located at this time. No gold placers are known in drainages surrounding this area. Plutonic rocks are also apparently not present. Based on these data, a volcanogenic play with a favorability of 0.25 was modeled for the Healy area.

Cleary Sequence extension plays:

Due to the presence of magnetite-rich greenschists, Cleary Sequence is commonly characterized by an aeromagnetic "high" (Light and others, 1987). Several areas in the Fairbanks, Livengood, and Circle quadrangles contain linear magnetic highs corresponding to the positions of Cleary Sequence and most of these areas represent geologic extensions of known Cleary Sequence (Plate I). These extension plays are labeled on Plate I as Fairbanks east, Fairbanks west, and Steese west. In addition, preliminary mapping in an area south of the Circle play, combined with aeromagnetic data and the presence of some placer gold suggests the presence of Cleary Sequence (Circle south play, Plate I). There are no gold deposits unambiguously associated with these plays, nor is there sufficiently detailed mapping to conclusively demonstrate the presence of distinctive Cleary Sequence lithologies. Based on the evidence for the potential presence of Cleary Sequence, these plays were rated with a favorability of 0.2 to 0.75, depending on the persuasiveness of the evidence present. These low favorabilities resulted in very small estimated gold endowments for all the extension plays.

CONCLUSIONS

In summary, we estimate that the North Star gold belt contains significant amounts of gold at the 50 percent level for probability of occurrence. The Fairbanks area probably contains the most significant gold resource endowment, estimated at 7 million oz at the 50 percent level. The Circle and Steese areas are estimated to contain 0.85 and 0.75 million oz respectively also at the 50 percent level. The Kantishna area is only expected to contain 0.1 million oz, and the amount of gold estimated in the Healy area is negligible. These estimates indicate that parts of the Fairbanks, Circle, and Steese areas would probably make attractive exploration targets for gold resources.

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APPENDIX A: Favorability Criterion

1. VOLCANOGENIC GOLD PROSPECTS

During a search for analogy models for the Cleary Sequence, we noted several similarities between the Cleary Sequence and the Piedmont volcanogenic gold belts in the southeastern U.S. These include (Newberry and Burns, 1988)

1) late Precambrian to early Paleozoic age,
2) generally bi-modal volcanic rocks with island arc trace element signatures,
3) presence of compositionally zoned tourmalines, and
4) early Paleozoic Pb and S isotopic signatures.

Based on these similarities, we used prospect, grade, and tonnage models from the Piedmont belts for the North Star gold belt (NSGB) models. One feature of the Piedmont belts is that short portions, < 15 miles long, might lack deposits/prospects altogether due to the inhomogeneous distribution of such; whereas longer portions, e.g. > 40 miles, were large enough to contain a relatively uniform prospect distribution. In light of the inhomogeneity of the prospect distribution, shorter (< 15 mile long) plays within the NSGB were rated on their likelihood to contain any gold prospects based on their overall geochemical favorability. Criteria employed included:

1) known placer Au downstream of the play,
2) known lode deposits/prospects in the play, and
3) known Au-Ag geochemical anomalies in the play.

Similarly, the "extension" plays, i.e., those plays constituting extensions of known Cleary Sequence, but for which the presence of Cleary Sequence had not been documented, were qualitatively rated for favorability based on the above geochemical prospect indicators. Also, extensions of known favorable plays were rated more favorably than isolated plays with no known gold occurrences.

Based on these criteria, regional favorabilities for the plays were rated as follows:

qualitative favorability	numerical value
highly favorable	1.0
moderately favorable	.5 - .75
slightly favorable	.2 - .25

2. CLASSIFICATION OF GOLD- VS. NON-GOLD-RELATED PLUTONIC ROCKS BY DISCRIMINANT ANALYSIS

Background

Gold deposits are found in plutonic rocks spanning a wide range of compositions, basically from diorite to granite. Not all plutonic rocks spanning this composition, however, are associated with gold deposits. In order to assess the resources of the NSGB, we needed to determine which plutonic rocks in the NSGB area may be associated with gold. To determine this, discriminant analysis functions were formed on a database of gold- and non-gold-related plutonic rocks in an attempt to determine 1) what characteristics yield gold-producing plutonic rocks and 2) to predict which plutonic rocks in the NSGB would be likely to be associated with gold.

Database

Major oxide compositions of 665 plutonic rocks were collected into a database from about 150 geographic locations, largely in the U.S. and Canada. The rocks span a wide range of compositions (Fig. A.1a,b); rocks noticeably altered, with high CO_2, Rb, or F, or with nepheline in the norm were the only rocks not acceptable for inclusion in the database. Assignment of these rocks as gold-related was based on association with gold placers and/or lodes with Au:Ag > 0.1. Rocks classified as non-gold-related were those associated with no mineralization or very low Au-mineralization. About 40 percent of the rocks in the database were thus classified as gold-related.

Methodology

Before computing discriminant analysis, outliers were removed from the data. Univariate statistics and normal probability plots were computed, which indicated the samples gold and non-gold were both from normal populations. The data chosen to be used for discriminant function formation included SiO_2, Al_2O_3, FeO, Fe_2O_3, MgO, CaO, Na_2O, K_2O, Fe_2O_3/FeO, and an alkalinity term, $Na_2O + K_2O + 16 - SiO_2 \times 0.372$. A correlation matrix indicates that although the ratio Fe_2O_3/FeO and the alkalinity term are functions of major oxide variables, they are not highly correlated with the measured variables.

The discriminant functions were computed using a SAS program (DISCRIM: Sas Institute, 1982). Both linear and quadratic equations were tried. As the quadratic equations yielded a much lower error rate, only the results for the quadratic discriminants will be discussed here. Subsets of the data with smaller compositional ranges were used for trial discriminant analysis (e.g., Fig A.2a,b). Errors were found to be only slightly better than with discriminant functions computed from the entire data set, so the method of compositional subsetting was abandoned.

The data was randomly divided into a classifying group, composed of 60 percent of the data, and a test group, composed of the remaining 40 percent, every time the discriminant functions were calculated. The ratio of gold to non-gold in both the classifying and test groups were kept the same as in the total database, about 40 to 60 percent respectively. The process was repeated for a total of five times to get a more accurate estimate of the results.

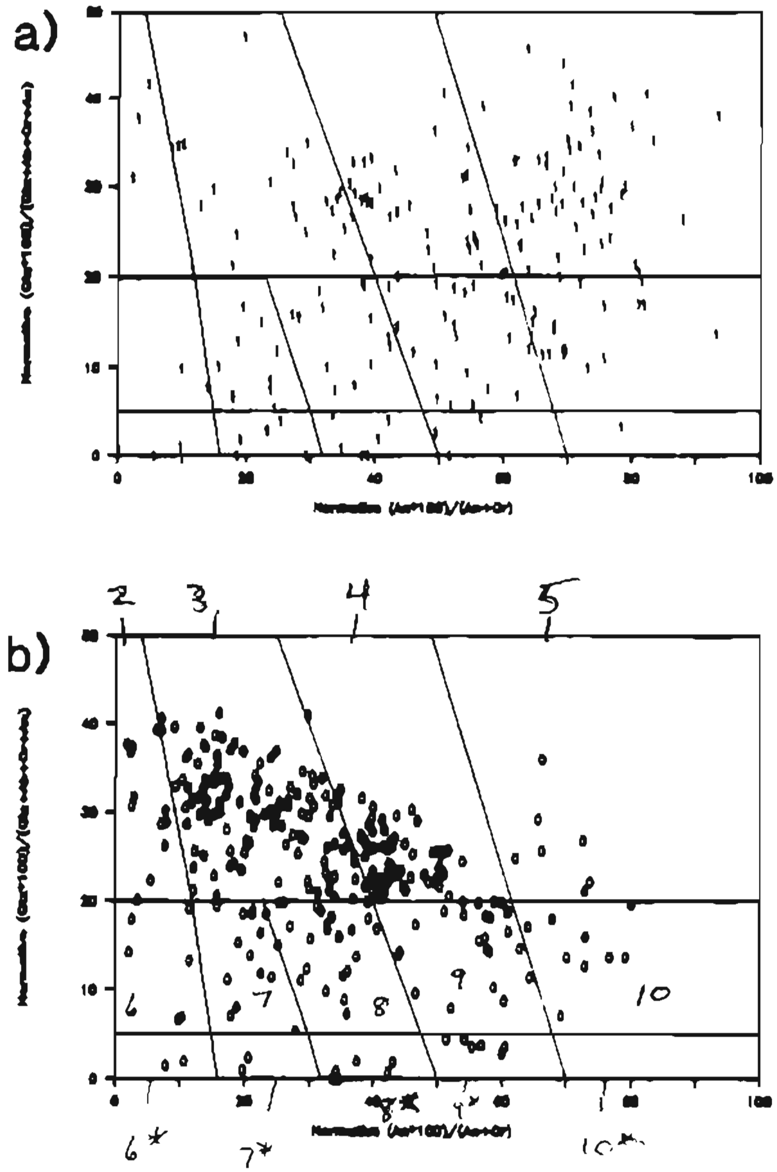


Fig. A1 The classification scheme by Streckeisen and LaMaitre (1979) which labels plutonic rocks based on their CIPW normative mineralogy shows the spread of compositions included in the database. The gold-related plutons are shown in plot A by the symbol 1; non-gold related plutons are shown in plot b by the symbol 0. Other symbols are as follows: Qtz-quartz, Ab-albite, An-anorthite, Or-orthoclase; 2-alkali granite, 3-granite, 4-granodiorite, 5-tonalite, 6-quartz alkali feldspar syenite, 7-quartz syenite, 8-quartz monzonite, 9-quartz monzodiorite, 10-quartz diorite, 6*-alkali feldspar syenite, 7*-syenite, 8*-monzonite, 9*-monzodiorite, 10*-diorite/gabbro

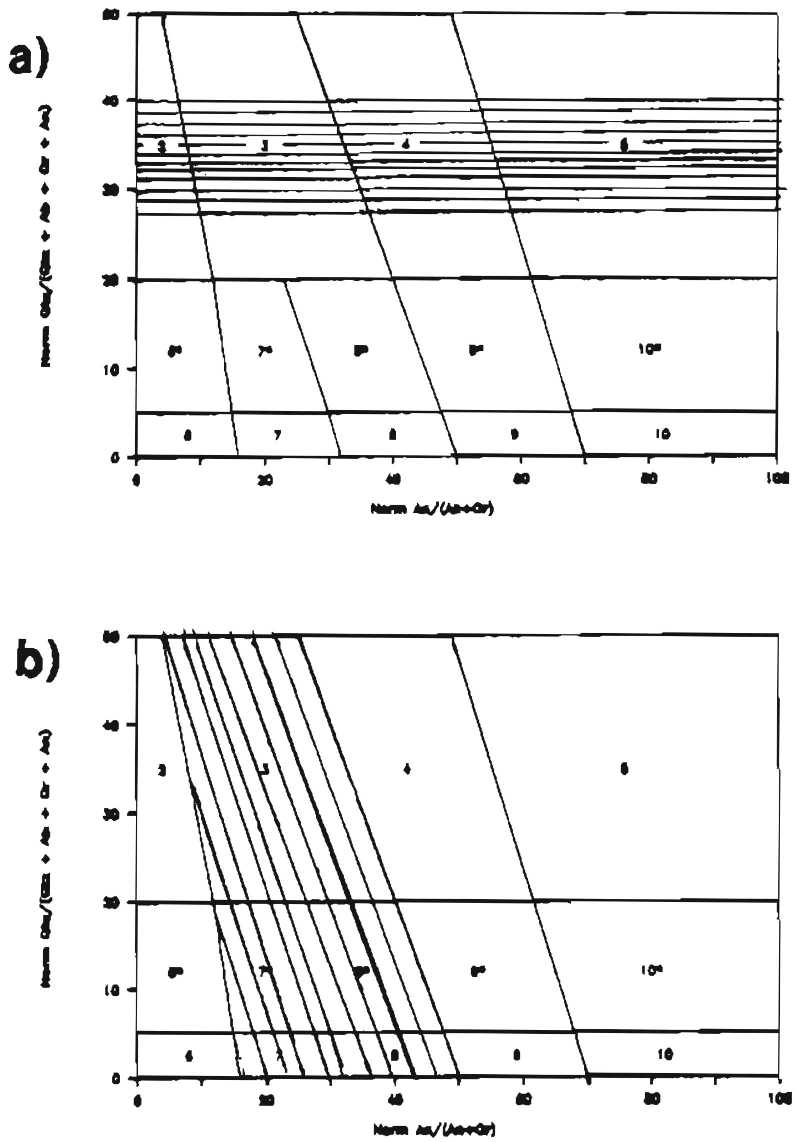


Fig. A2: Streckeisen and LeMaitre compositional plots showing examples of subsets of the plutonic data used for discriminant analysis: a) subsets based largely on normative quartz content, b) subsets based dominantly on feldspar compositions. Mixtures of the two methods, not shown, were also tried. The subsetting was found not to be exceptionally worthwhile and was abandoned.

The success of the discriminant function can be evaluated by several ways. An estimate of the overall effectiveness of the discriminant functions is the apparent error rate (APER) which is defined as

$$APER = \frac{n_{1m} + n_{2m} + \dots + n_{im}}{n_1 + n_2 + \dots + n_i}$$

where n_i = total # of observations in each group 1 - i

n_{im} = # of misclassified observations in each group.

For exploration purposes, however, the APER may not be the best number to minimize. Instead, the TYPE II error, which is the number of gold-plutons misclassified as non-gold plutons, should be kept low so that gold deposits are not overlooked. A discriminant function which yields a relatively low overall rate with a particularly low TYPE II error rate, particularly for the test group, would seem the most desirable.

The five discriminant functions computed from the randomized test data sets averaged a 10 percent APER rate with a standard deviation of about 1.7 (Table A.1). The discriminant functions on the test groups also had a 5 percent average TYPE II error rate, the percent of gold-related rocks misclassified as non-gold related rocks, with a standard deviation of about 1.4.

Major variables in the discriminant functions appear to be Fe_2O_3, FeO, and most importantly, the ratio Fe_2O_3/FeO. Although all these variables are related to some type of iron content, the correlation coefficients between any two of these three variables is less than 0.6. The gold-related rocks have very low oxidation states, recognizable as low Fe_2O_3/FeO. Other factors, such as Na_2O, K_2O, and the alkalinity term, are also important.

Classification of plutonic rocks in the North Star gold belt

Because the discriminant functions classified the known test groups reasonably well, the analyses of the plutonic rocks of the NSGB were run for classification. Analyses of plutonic rocks from the Circle, Steese, Fairbanks, and Kantishna areas were input as a test group.

Each analysis is rated with a posterior probability for each discriminant function. The average of the posterior probabilities for the five discriminant functions were computed for each compositional analysis (Fig. A.3;table A.2). A posterior probability from 95 to 100 is considered herein to be gold-related, 85 to 95 - strongly gold-related, 60 to 85 - moderately gold-related, and that below 60 is considered a poor candidate for association with gold.

The discriminant functions classified the Steese area lamprophyres, the Circle area Two-Bit pluton, and Gilmore Dome plutons as strongly gold-related. Most of the plutonic rocks in the Kantishna area and the Circle Hot Springs pluton classify as non-gold related.

Table A.1: Summary results of quadratic discriminant functions for predicting gold-related plutons vs. non-gold plutons:

	Classification Group		Test Group	
	APER (%)	TYPE II error (%)	APER (%)	TYPE II error (%)
Run 1)	7.4	3.8	9.5	4.6
Run 2)	8.4	4.4	9.9	3.7
Run 3)	9.5	1.9	12.5	5.6
Run 4)	9.7	6.3	7.6	7.4
Run 5)	8.7	1.9	9.9	4.6
Average:	8.7	3.7	9.9	5.2

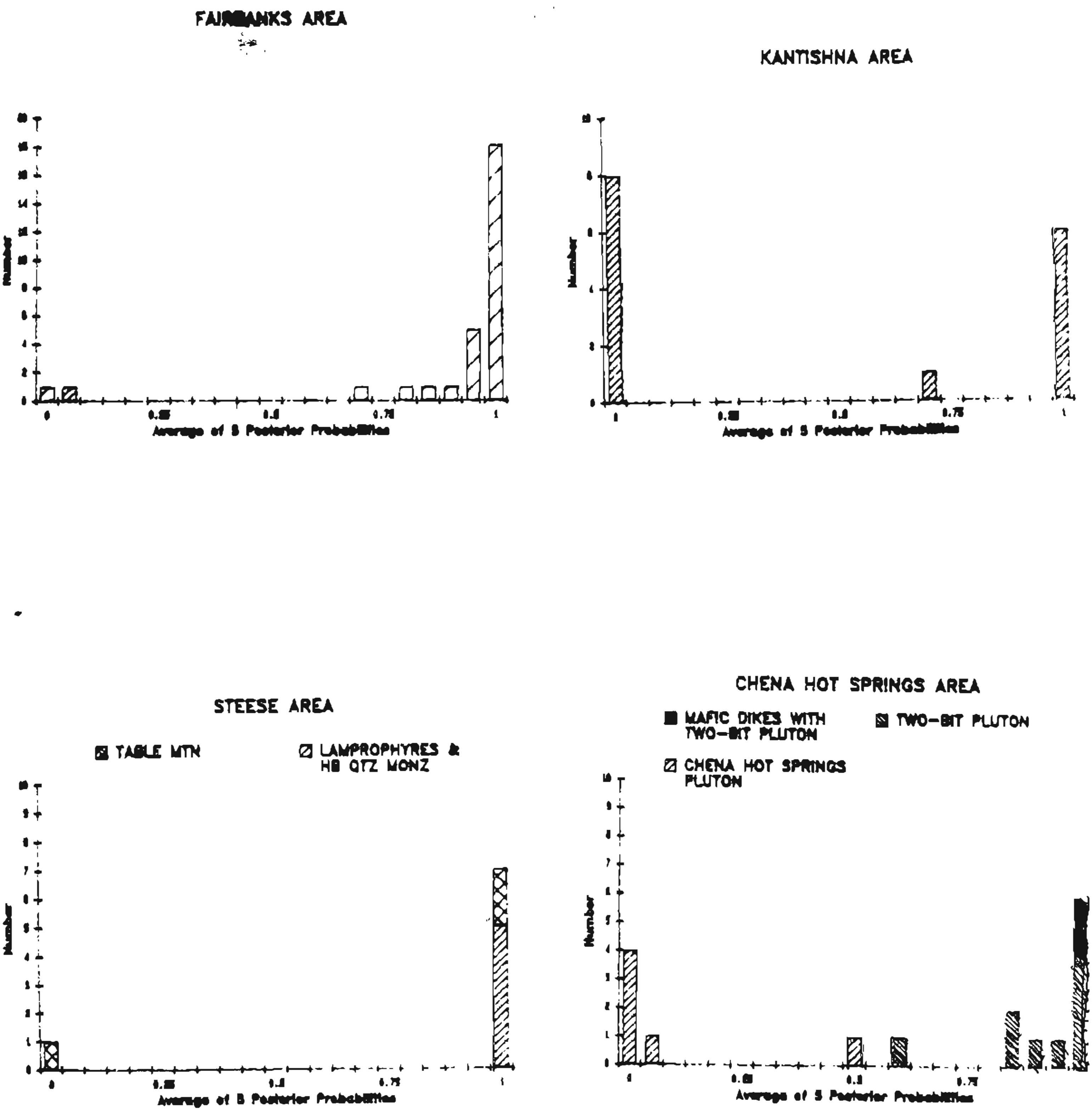


Fig A3: Histograms for the plutonic rocks from the four major areas of plutonic rock in the NSGB. The histograms show average posterior probability that the plutonic rocks are gold-related. A value of 1 is strongly gold-related, and 0 is non-gold-related.

Table A.2: Results of the discriminant analysis for gold vs. non-gold plutons: Results range from 1.00, analysis has characteristics typical of gold-related plutons, to 0 - analysis does not have characteristics typical of gold-related plutons.

KANTISHNA AREA

Sample	Rock Type	Run #1	Run #2	Run #3	Run #4	Run #5	AVE
K158	felsic dike	1.00	1.00	1.00	1.00	1.00	1.00
K159	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00
K162	intermediate dike	0.98	0.98	0.98	0.83	0.99	0.95
K1648	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00
K1859	intermediate dike	0.00	0.00	0.00	0.00	0.00	0.00
K1987	felsic dike	0.73	0.83	0.72	0.55	0.66	0.70
K276	mafic dike	1.00	1.00	1.00	1.00	1.00	1.00
K291	intermediate dike	1.00	1.00	1.00	1.00	1.00	1.00
K2922	mafic dike	0.00	0.00	0.00	0.00	0.00	0.00
K2922G	mafic dike	1.00	1.00	1.00	1.00	1.00	1.00
K3005	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00
K3055	felsic dike	1.00	1.00	1.00	1.00	1.00	1.00
K360	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00
K87	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00
K88	felsic dike	0.00	0.00	0.00	0.00	0.00	0.00

FAIRBANKS AREA

Sample	Rock Type	Run #1	Run #2	Run #3	Run #4	Run #5	AVE
JB106	porph. granodio.	1.00	1.00	1.00	1.00	1.00	1.00
JB108	porph. granodio.	0.93	0.90	0.91	0.91	0.94	0.92
JB116A	porph. granodio.	0.82	0.88	0.90	0.87	0.83	0.86
JB127	porph. granodio.	1.00	1.00	1.00	1.00	1.00	1.00
JB128	porph. granodio.	0.94	0.96	0.95	0.96	0.94	0.95
JB132	porph. granodio.	0.93	0.93	0.94	0.95	0.91	0.93
JB134	porph. granodio.	0.99	0.99	1.00	0.99	0.99	0.99
JB213	porph. granodio.	0.96	0.96	0.97	0.97	0.97	0.96
JB215	porph. granodio.	1.00	1.00	1.00	1.00	1.00	1.00
JB137	porph. granite	0.90	0.96	0.98	0.92	0.83	0.92
JB142	porph. granite	1.00	1.00	1.00	1.00	1.00	1.00
JB143	porph. granite	1.00	1.00	1.00	1.00	1.00	1.00
JB144	porph. granite	1.00	1.00	1.00	1.00	1.00	1.00
JB145	porph. granite	0.86	0.82	0.95	0.84	0.59	0.81
JB146	porph. granite	1.00	1.00	1.00	1.00	1.00	1.00
JB148	porph. granite	1.00	1.00	1.00	1.00	1.00	1.00
JB149	porph. granite	0.77	0.81	0.88	0.70	0.68	0.77
JB152	porph. granite	0.93	0.95	0.97	0.87	0.90	0.92
JB161	porph. granite	0.66	0.66	0.79	0.68	0.51	0.66
JB162	porph. granite	0.02	0.00	0.02	0.02	0.01	0.01
JB165	porph. granite	0.00	0.00	0.00	0.00	0.00	0.00
JB166B	porph. granite	0.98	0.96	0.99	0.98	0.99	0.98
JB201	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB203	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB205	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB207	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB211	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB216	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00
JB218	fine-gr granodio	1.00	1.00	1.00	1.00	1.00	1.00

STEESE AREA

TABLE MOUNTAIN PLUTON

Sample	Rock Type	Run #1	Run #2	Run #3	Run #4	Run #5	AVE
DA217C	granite	0.98	0.99	0.99	0.99	1.00	0.99
RN196	border phase	1.00	1.00	1.00	1.00	1.00	1.00
RN1835	aplite	0.00	0.00	0.00	0.00	0.00	0.00

LAMPROPHYRES AND HORNBLENDE QUARTZ MONZONITE DIKES

Sample	Rock Type	Run #1	Run #2	Run #3	Run #4	Run #5	AVE
GP282	h q monz	1.00	1.00	1.00	1.00	1.00	1.00
RS87	h q monz	1.00	1.00	1.00	1.00	1.00	1.00
GP283B	lamp	1.00	1.00	1.00	1.00	1.00	1.00
MA224	lamp	1.00	1.00	1.00	1.00	1.00	1.00
RS283B	lamp	1.00	1.00	1.00	1.00	1.00	1.00

CIRCLE AREA

CIRCLE HOT SPRINGS PLUTON

Sample	Rock Type	Run #1	Run #2	Run #3	Run #4	Run #5	AVE
4511	granodiorite	0.00	0.00	0.00	0.00	0.00	0.00
4512	granite	0.00	0.00	0.00	0.00	0.00	0.00
4514	granite	0.02	0.04	0.06	0.04	0.01	0.03
4515	granite	0.45	0.47	0.62	0.49	0.23	0.45
4523	granite	0.00	0.00	0.00	0.00	0.00	0.00
4524	granite	0.00	0.00	0.00	0.00	0.00	0.00
TWO-BIT PLUTON							
4517	granite	0.78	0.87	0.86	0.81	0.70	0.80
4518	granodiorite	1.00	1.00	1.00	1.00	1.00	1.00
4519	aplite	0.87	0.79	0.93	0.94	0.90	0.89
4520	granite	0.93	0.96	0.95	0.95	0.93	0.94
4521	granite	0.51	0.62	0.63	0.60	0.44	0.56
CH33	granite	1.00	1:00	1.00	1.00	1.00	1.00
CH54	granite	1.00	1.00	1.00	1.00	0.99	1.00
CH56A	granodiorite	1.00	1.00	1.00	1.00	1.00	0.82
KM114	granodiorite	1.00	0.99	1.00	0.99	1.00	0.998
MAFIC DIKES INTRUDING TWO-BIT PLUTON							
4522		1.00	1.00	1.00	1.00	1.00	1.00
4516		1.00	1.00	1.00	1.00	1.00	1.00

APPENDIX B: Prospect Distributions

1. Volcanogenic

Our analogy model for the North Star gold belt was the early Paleozoic Piedmont gold belts in the southeastern U.S. We began by dividing the Piedmont belts into 20-mile wide sub-belts, and then projected all known prospects and deposits onto a line running through the middle of a sub-belt (for example, fig. B.1). We then measured the distances between deposits and prospects along the line of projection within a sub-belt, and determined the prospect spacing for all prospects in all the sub-belts. This data was then compiled and smoothed, to form a generic curve for the number of prospects per linear mile of favorable belt.

Prospect distributions for the NSGB were determined by dividing the belt into plays, each of which were characterized by the presence of 'favorable' lithologies and each were < 20 miles in width. The lengths of these plays were then measured, and the length multiplied by the generic prospect distribution values to yield a preliminary prospect distribution curve. This curve was in practice not appreciably modified by the assessment panel, although some minor adjustments were occasionally made.

2. Plutonic related

The plutonic-related gold deposits which were employed in constructing the plutonic discriminant analysis are the same gold deposits used as the analog for prospect distribution and tonnage for the North Star gold belt. For each deposit/district examined, the number of prospects present was divided by the area favorable for deposits; the resulting values were statistically compiled and smoothed to yield a generic prospect density curve.

The area favorable for deposits was calculated based on the exposure area of favorable plutonic rocks and is similar to a scheme independently derived by the U.S. Geological Survey (Cox and others, 1989). For the current study, a one mile wide "zone of favorability" was drawn around the outer circumference of dikes and plugs less than one mile in diameter (for example, Fig. B.2). For plutons greater than one mile in diameter, a 4 mile diameter zone of favorability was constructed. For plutons greater than three miles in diameter, the area of the favorability zone was multiplied by 0.333, and for plutons greater than eight miles in diameter, the calculated area was multiplied by 0.2. These various favorability zones and factors were based on the observations that a) vein Au deposits could be found at greater distances from medium-sized plutons than from dikes and small plugs and b) deep exposures of plutons (large surface area) are less favorable more mesothermal veins than shallow levels of plutons, as the veins tend to be concentrated above major plutons.

Prospect distributions for the plutonic-related gold plays of the NS belt were calculated by

1) drawing appropriate "favorability zones" around favorable plutonic rocks,

2) calculating the resulting favorable areas,

3) multiplying these areas by the generic distribution curves. The resulting prospect distribution curves were not modified, except in the case of the Fairbanks area.

In the Fairbanks area, exposures are extremely poor (> 1 percent outcrop), there are extensive, but scattered exposures of dikes/plugs, and the aeromagnetic map shows an extensive low over the Fairbanks area. As the favorable plutons are low in magnetite and the surrounding country rock typically has a relatively high positive magnetic signature, such a magnetic low is probably an indication of a buried pluton. The data suggest that a major plutonic complex underlies the entire Fairbanks district at shallow depths, and consequently, the "favorable zones" around dikes and plugs were connected to make a continuous favorable zone. This calculation increased the zone of favorability in the Fairbanks district, hence the prospect distribution, by approximately 20 percent.

FIGURE B-1: Determination of volcanogenic gold prospect density for the North Carolina portion of the Carolina Slate belt, an example of such determinations for S.E. U.S. Piedmont gold belts. Aggregation of six areas like this one were used in constructing the "generic" volcanogenic gold prospect density curve. See text for details.

Volcanogenic prospects are identified by small black squares; projection of prospect locations onto the median lines is employed to convert the two-dimensional prospect distribution into a 1-dimensional distribution, based only on length of the belt.

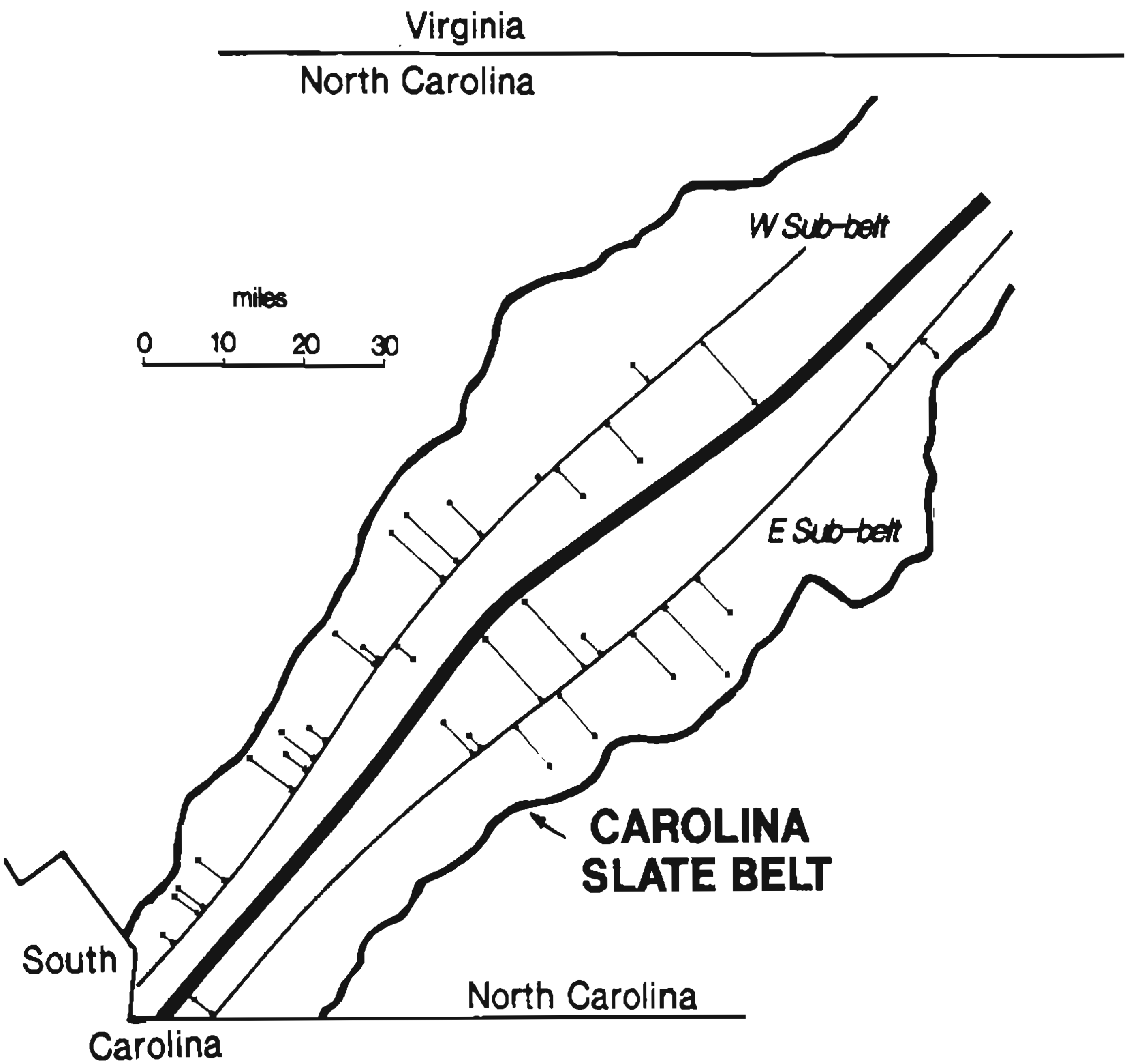
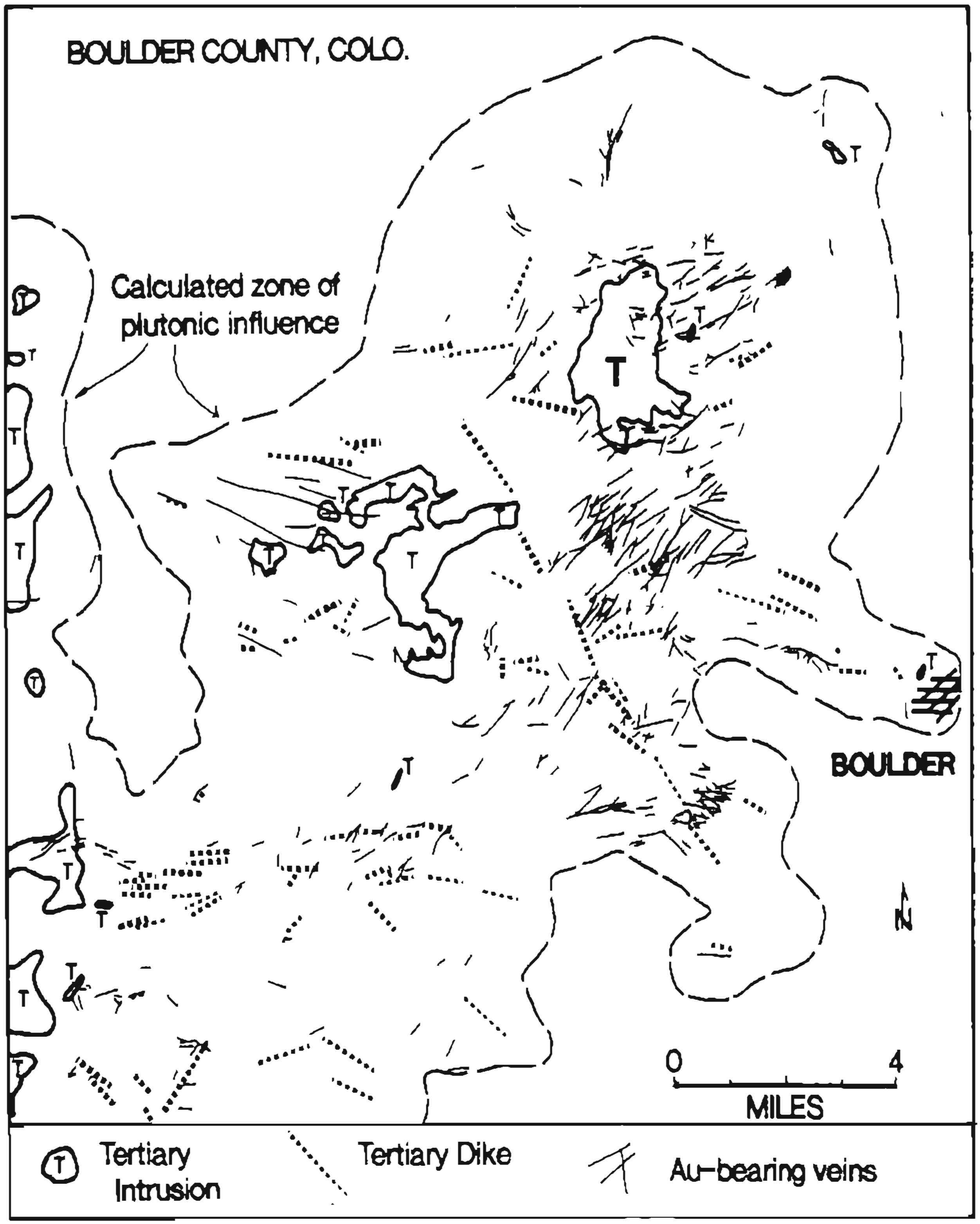


FIGURE B-2: Calculation of prospect density for the Boulder County Te-Au district, an example of a plutonic-related gold district. Favorability areas (dashed line) were calculated based on distribution and size of plutons/dikes (see text). Prospect density per unit area of "favorable area" was then calculated from total number of prospects divided by favorable area. The generic prospect density curve for plutonic-related gold deposits was constructed by aggregating the data from approximately 40 such districts. See text for details.



APPENDIX C: THE PRODUCTION AND ESTIMATED AU ENDOWMENT IN THE NORTH STAR GOLD BELT

The NSGB has produced approximately 10 million oz of gold to date. To what extent should this production be subtracted from the estimated gold endowment? We suggest that the estimated endowment not be modified to take into account previous production, based on the lines of reasoning discussed below.

1) More than 98 percent of the production of gold from the NSGB is from placers; hence, virtually all the lode gold present in the area prior to mining is still there. This small lode production only effects endowment estimates at very high probability fractiles (> 98 percent).

2) World-wide, known lode gold deposits have depth extensions of > 3000 feet; mining frequently stops due to economic factors and not changes in grade with depth. As the amount of placer gold present in the NSGB area could be derived from weathering of 500 to 1000 vertical feet of gold lodes, there is likelihood for abundant gold still present in the sub-surface.

3) The tonnage models for gold deposits were based on hundreds of lode deposits, for which erosion prior to mining has removed a variable amount of gold. Indeed, there are almost no known examples world-wide of gold veins for which some gold has not been eroded off the top. In consequence, the effects of variable removal of gold (by weathering) is implicitly addressed by the tonnage distribution model employed. Placer gold production was not incorporated into the grade-tonnage model from analogy districts.

4) In some districts, relatively recent glaciation and/or other unfavorable geomorphological factors have caused removal and dispersal of placer gold and/or never allowed placer gold to accumulate during weathering. It is clearly wrong to "penalize" the NSGB area relative to such other areas (by subtracting the gold production from the calculated endowment) simply because geomorphological factors have allowed for concentration of placer gold in this area.