MINERAL RESOURCE ESTIMATION THE MINERAL POTENTIAL PROJECT: AN EVALUATION OF ESTIMATOR RESPONSES FOR SELECTED MINERAL DEPOSIT TYPES FOR THE PROVINCE

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KEYWORDS: mineral potential, probability, confidence, mineral deposit model, resource assessment

INTRODUCTION

The Mineral Potential project has completed resource assessment for all areas of British Columbia with the exception of the Queen Charlotte Islands. During the past year, the northwestern portion of the province was covered as described by Kilby (1996, this volume). Resource assessment is carried out on specified tracts of land, known as, Mineral Assessment tracts which are generalizations of contiguous geological tracts that share a common tectonic assemblage and metallogeny. The boundaries between tracts reflect differences in lithology, structure and/or geological history (*see* Grunsky *et al*, 1994; Church, 1995; Massey, 1995). This report provides a partial summary of results from estimates obtained from the Mineral Resource Assessment Workshops held throughout the province.

The overall potential value of a mineral assessment tract is the sum of known and predicted mineral resources. Known resources have been compiled from a number of sources (Kilby, 1995). Predicted resources were obtained using a method adapted from the three-part assessment methodology of the United States Geological Survey (Singer, 1993). The modified methodology used in the Mineral Potential project is described in this paper.

The Mineral Assessment tracts were created to define areas that contain specific characteristics related to metallogeny (*see* Kilby, 1995). Each tract is evaluated by a geologist who has knowledge about the area and the types of mineral deposits that might be expected there.

GRADE AND TONNAGE MODELS

Grade and tonnage data are required by the estimator in order to provide information on the range of the grade and tonnage that is typical for a mineral deposit type. Estimators were asked to base their estimates on the median values of the grade and tonnage ranges for each deposit type in order to standardize the process. Grade and tonnage data were obtained from three sources; the BC Geological Survey Branch, United States Geological Survey, and the Geological Survey of Canada. In several cases, grade and tonnage models assembled by the USGS were not considered to be applicable for British Columbia. In those cases, grade and tonnage data were compiled by the BC Geological Survey Branch (Lefebure and Hoy, 1996). The Geological Survey of Canada contributed a tungsten skarn model which was considered preferable for use in the estimation process for British Columbia.

In many cases, grade and tonnage data do not exist for many of the deposit types that were predicted. Grade and tonnage data were available for some of the USGS deposit models (Cox and Singer, 1986) but, in many cases the data was not publicly available. In these cases, "simulated" grade and tonnage data were generated by using data from the USGS Bulletin 1693 (Cox and Singer, 1986).

For the industrial mineral deposit models, a median grade and tonnage were provided by GSB staff (D. Hora and G. Simandl, personal communication). These median grade and tonnage data were used as substitutes for actual grade and tonnage data. Tables 1 and 2 provide a list of metallic and industrial mineral deposit models used across the province for the Mineral Potential Project. The tables are subdivided based on the sources of the information

ESTIMATE OF EXPECTED UNDISCOVERED DEPOSITS

The resource assessment process is based on subjective probability applied to the prediction of undiscovered resources. Added to the assessment is the value of known resources. The subjective approach to resource estimation requires that geologists make estimates on the likelihood of finding deposits based on their knowledge of the geology and other pertinent information within a specific mineral assessment tract. These assessments were carried out in Mineral Resource Assessment Workshops (*see* Kilby, 1995, 1996; Grunsky 1996).

For each estimate, estimators were asked to provide, on a scale from 0 to 100, the likelihood of finding at least one or more deposits for a specific mineral deposit model and, the degree of confidence of their estimate (see Grunsky 1996). Estimators worked in groups of 2 to 4 as outlined by Grunsky (1996). For each estimate, each estimator was asked to indicate a level of confidence on a scale of 0 to 100 for their own estimate. The estimators were also asked to base their "estimate of confidence" on their confidence of their own knowledge, not on the likelihood of the presence of a mineral deposit. Thus, the confidence and the

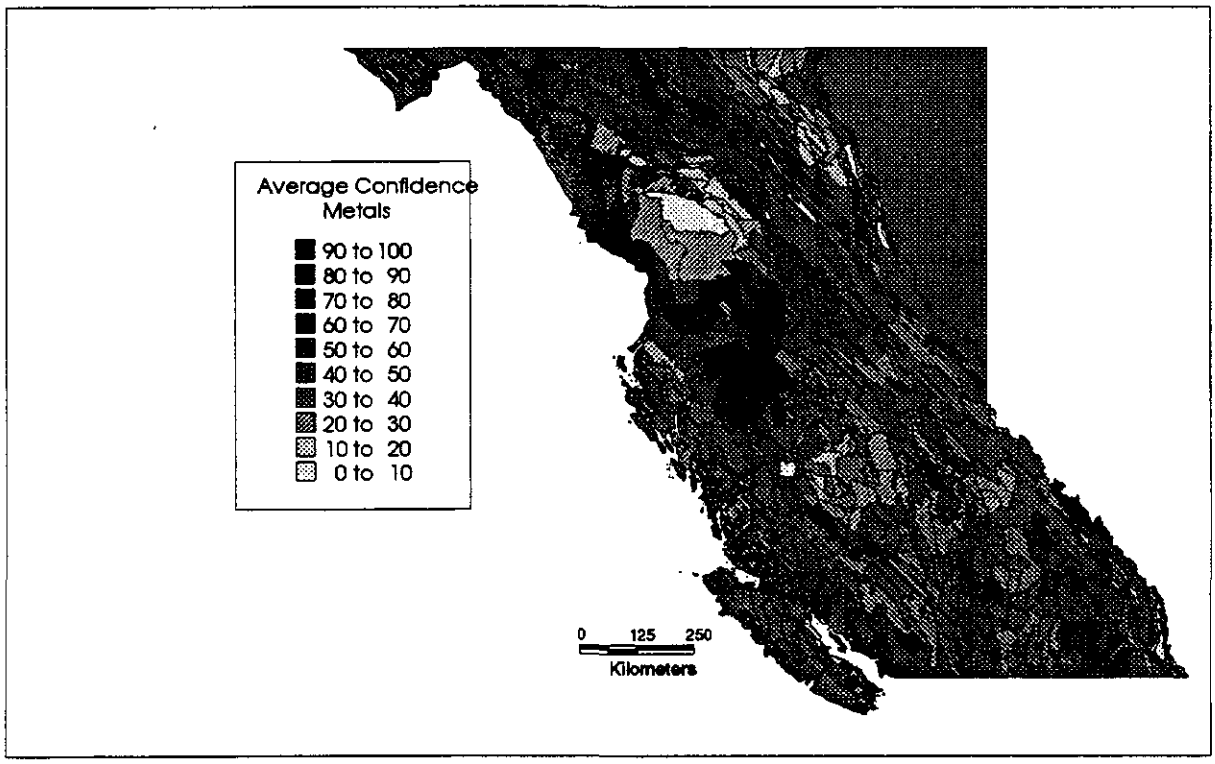

Figure 1. Map of mineral assessment tracts indicating the average confidence expressed for each tract for all metallic deposits.

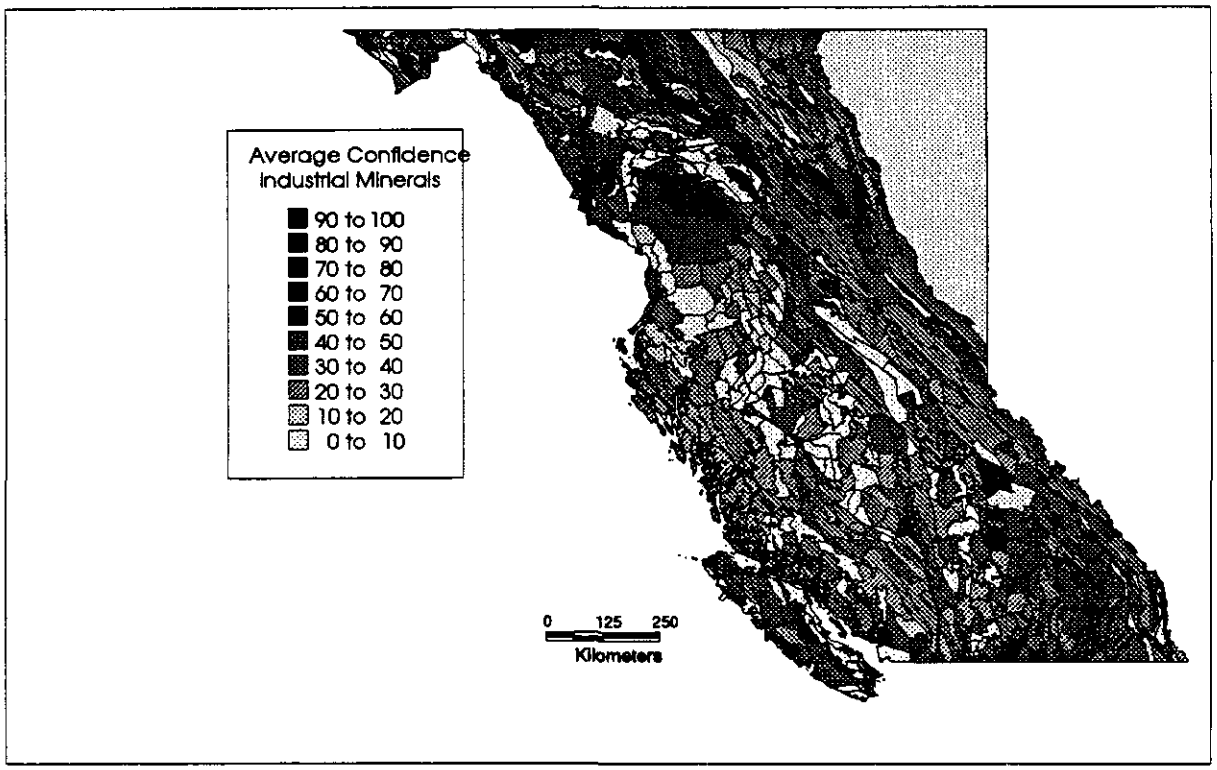

Figure 2. Map of mineral assessment tracts indicating the average confidence expressed for each tract for all industrial mineral deposits.

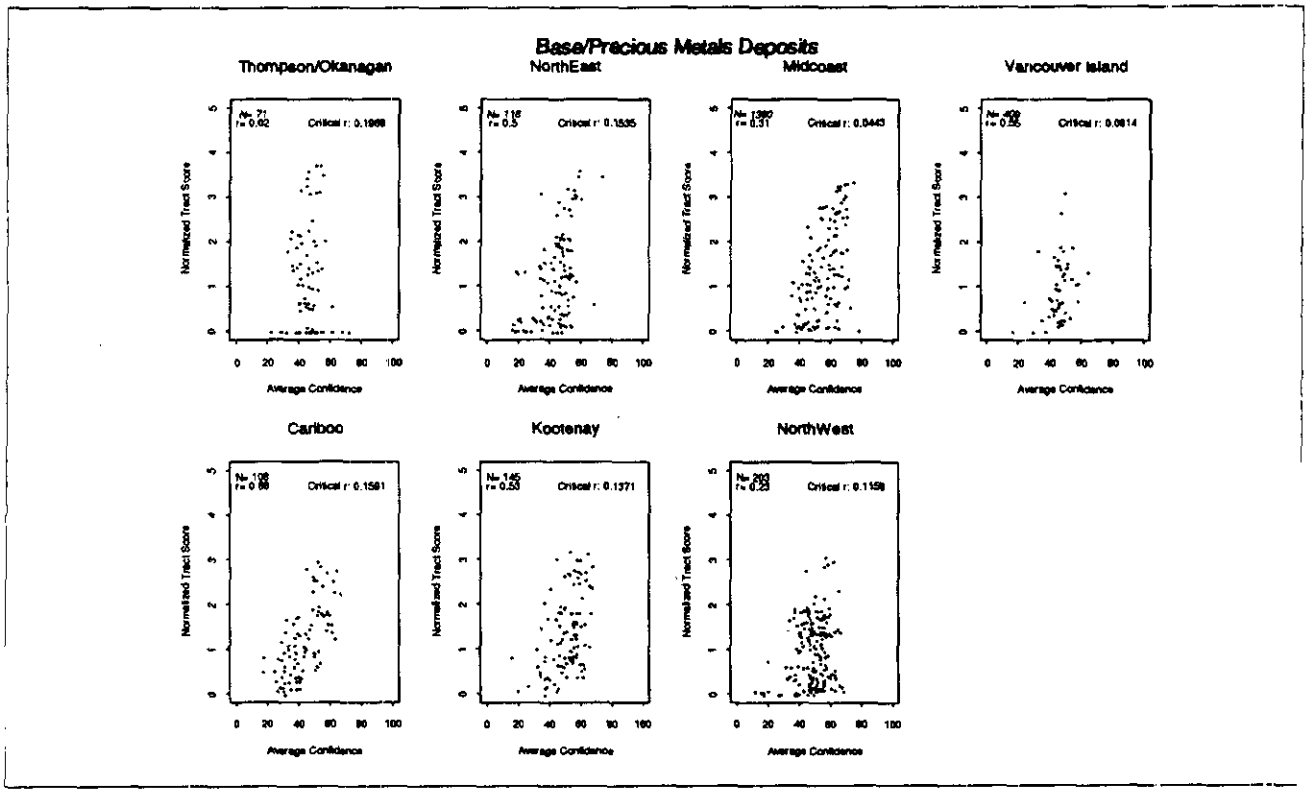

Figure 3. Plot of normalized tract score versus average confidence expressed by the estimators for each tract for precious and base metal deposits within each workshop area. See text for explanation.

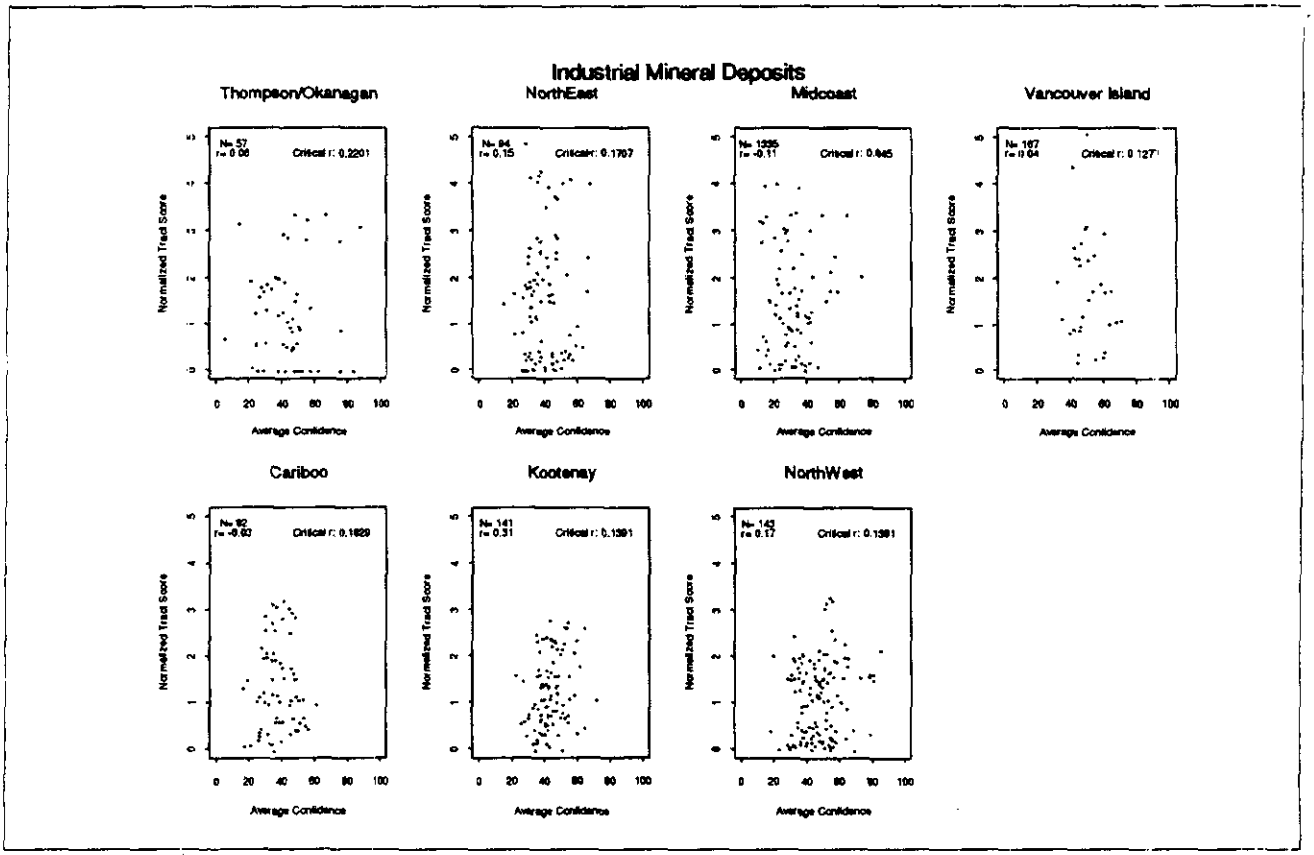

Figure 4. Plot of normalized act score versus average confidence expressed by the estimators for each tract for industrial mineral deposits within each workshop area. See text for explanation.

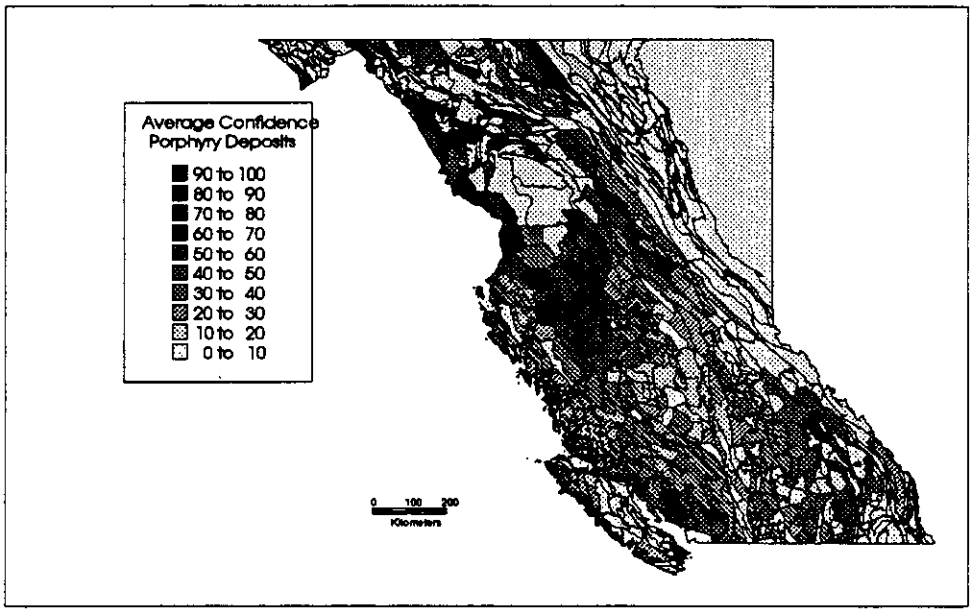

Figure 5. Map of average confidence for each tract for porphyry deposit types. Tracts with a value of 0 to 10 indicate tracts in which no porphyry deposit types were estimated.

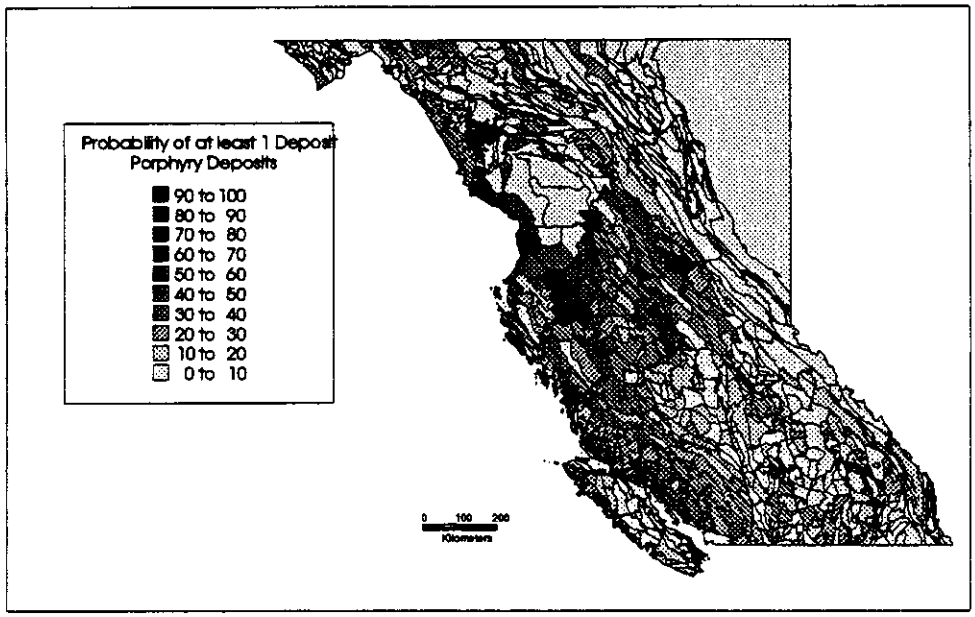

Figure 6. Map of the probability of at least one porphyry deposit occurring in each tract. Tracts with a value of 0 1o 10 indicate tracts in which no porphyry deposit types were estimated.

estimate of deposit probability were assumed to be independent.

Estimators were also asked to "weight" their confidence with respect to each other. The probability estimates for the likelihood of finding deposits were used as input in a Monte Carlo computer simulation program, Mark3, which was provided by the USGS (Root *et al*, 1992). The output of the Mark3 computer program consisted of a probability curve indicating the tonnes of commodity based on the input probabilities. The weights assigned to each estimator were then applied to the output values so that the confidence of each estimator with respect to each other was factored into the results.

A total of 19023 estimates were made for 762 tracts. The estimates associated with each region, in order of the date the workshop was carried out, are as follows:

Region	*# of Estimates*
Thompson/Okanagan	1836
Northeast BC	2855
Midcoast/Skeena-Nass	3460
Vancouver Island	1475
Cariboo	2203
Kootenay	2913
Northwest BC	4281

The following sections summarize and present a preliminary interpretation of the responses covering the entire province.

AN EVALUATION OF 'CONFIDENCE OF THE ESTIMATE'

For each mineral assessment tract, a summary confidence value was calculated based on the average of confidences expressed by all estimators for all deposit models. These values are summarized in Figures 1 and 2.

Figure 1 is a map of the mineral assessment tracts across the province. The tracts are shaded according to the average confidence for all of the base and precious metal deposit models. The map combines the results from the 7 different workshop regions (Thompson-Okanagan, Northeast BC, Skeena-Nass-Midcoast, Vancouver Island, Cariboo, Kootenay, and Northwest BC areas (*see* Kilby, 1995). Areas of very low confidence (0 to 10) reflect tracts in which there were very low estimates and/or no estimates for metallic deposits.

Figure 2 shows a map of the same tracts but is shaded according to confidences expressed for industrial minerals. In both figures there are areas in which relatively low

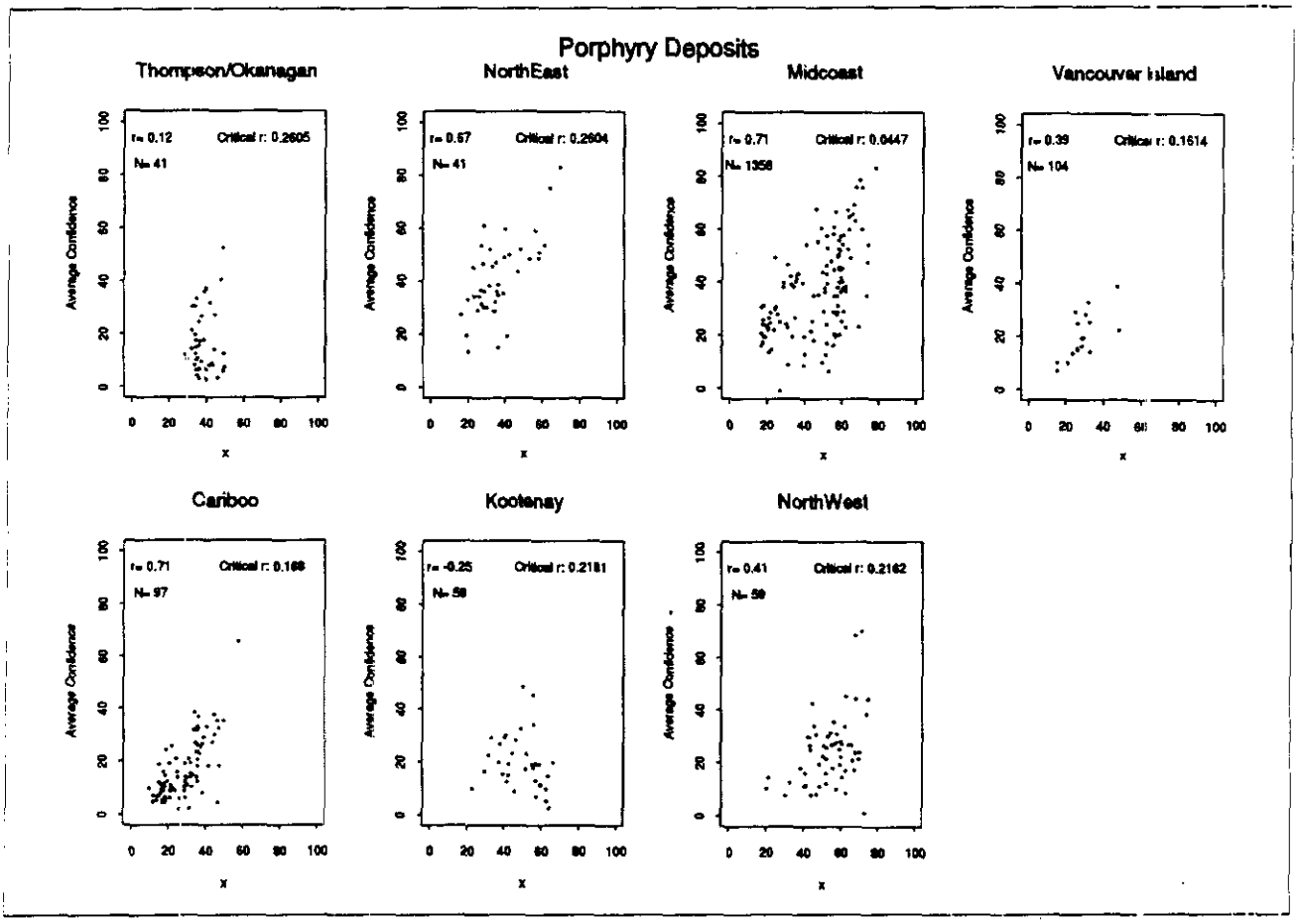

Figure 7. Plot of the average probability of at least one deposit versus the average confidence for each tract for porphyry deposits. There is a positive correlation for all seven areas however the Midcoast area indicates higher probabilities of at least one deposit with a corresponding high level of confidence.

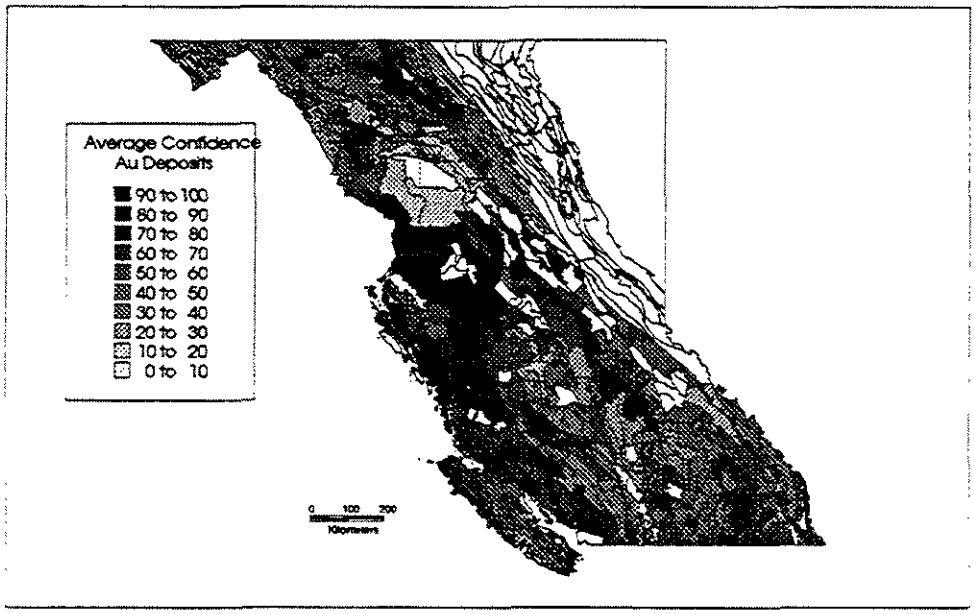

Figure 8. Map of average confidence for each tract for Au deposit types. Tracts with a value of 0 to 10 indicate tracts in which no vein deposits types were estimated.

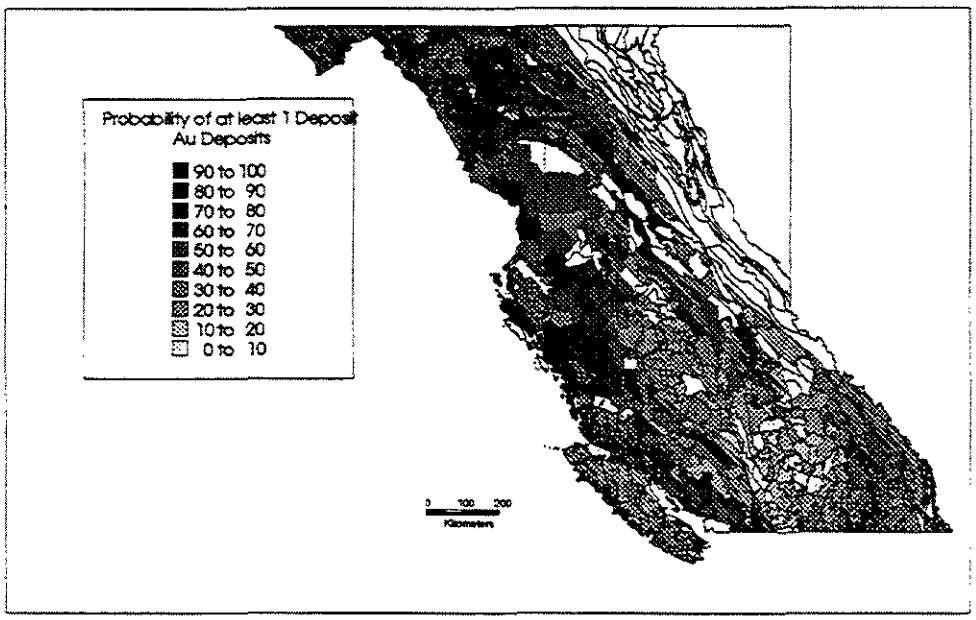

Figure 9. Map of the probability of at least one Au deposit occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no Au deposits were estimated.

confidences were expressed by workshop participants. For the metallic deposits, areas of low confidence were expressed for the Bowser basin area and the northeast of the province. For the industrial mineral deposits there were many more tracts that were either not assessed or had very low confidences.

An attempt to explain the variation of confidence was made by examining the relationships between the final tract score and the probability of at least one deposit being present for each tract and deposit model. Figures 3 and 4 show plots of average confidence for each tract with the tract score. The tract score is assigned by combining known reserves with predicted reserves (Kilby, 1996). As the tract score is dependent on the area and number of tracts within each assessment area (Vancouver Island, Kootenay, Cariboo, Midcoast, Thompson-Okanagan, Northeast, Northwest), the tract score is normalized so that the scores between areas can be compared.

Figure 3 contains plots by area, of average confidence for each tract plotted against the normalized tract score for precious and base metal deposits. Each plot contains a value N, indicating the number of points; the value, r, the correlation coefficient; and, the value Critical r, the value of the correlation coefficient at which the value is significant at the 95% confidence level. This statistic can only be considered reliable if the population being tested are normally distributed. The data analyzed here have not been examined for the nature of their distributions.

Areas with a significant correlation between the normalized mineral tract score and the average confidence include, the Northeast, Midcoast, Vancouver Island, Cariboo, Kootenay, and Northwest. Only the Thompson/Okanagan area fails to show any significant correlation. Tract scores are a combination of known reserves and estimated reserves from the mineral potential workshops. The relationship between mineral inventory and average confidence was examined for both the metal and industrial mineral deposit groups. No significant correlation was noted. This lack of correlation suggests that any observed correlation between average confidence and tract score is due primarily to the predictive estimates.

The positive correlation between tract score and confidence can be interpreted as the estimators placing more confidence in tracts where they believe there is a greater

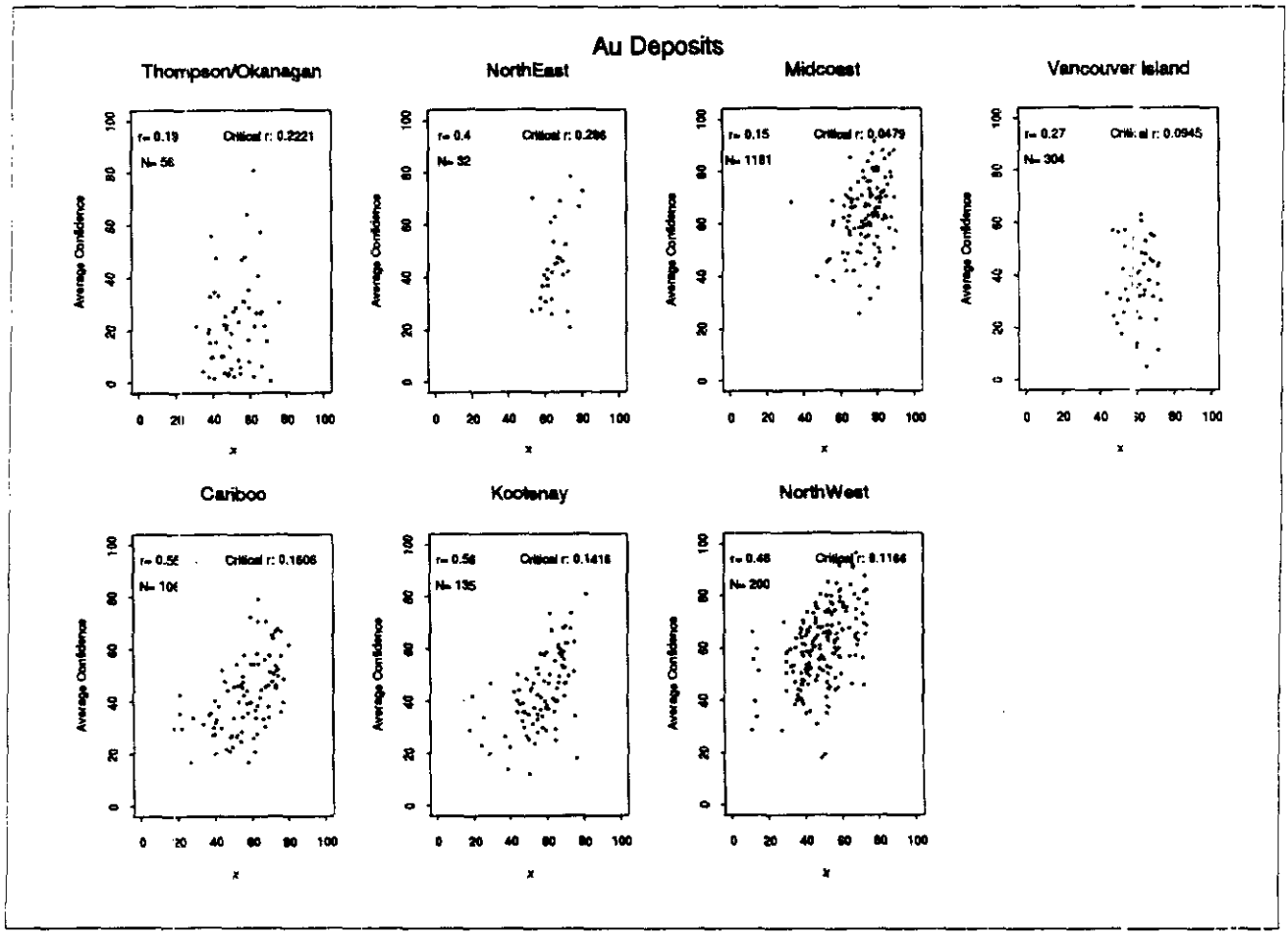

Figure 10. Plot of the average probability of at least one deposit versus the average confidence for each tract for Au deposits. There is a positive correlation for the Midcoast, Cariboo, Kootenay and Northwest areas. Vancouver Island, the Thompson/Okanagan and the Northeast areas display a poor to no correlation.

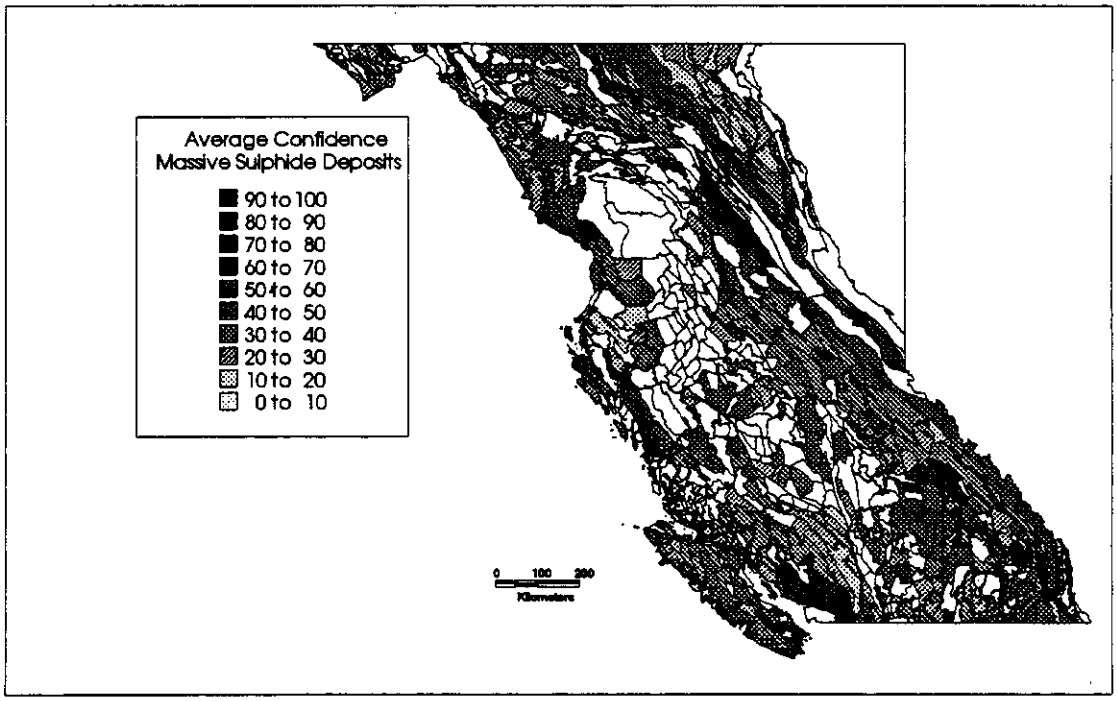

Figure 11. Map of average confidence for each tract for massive sulphide deposit types. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

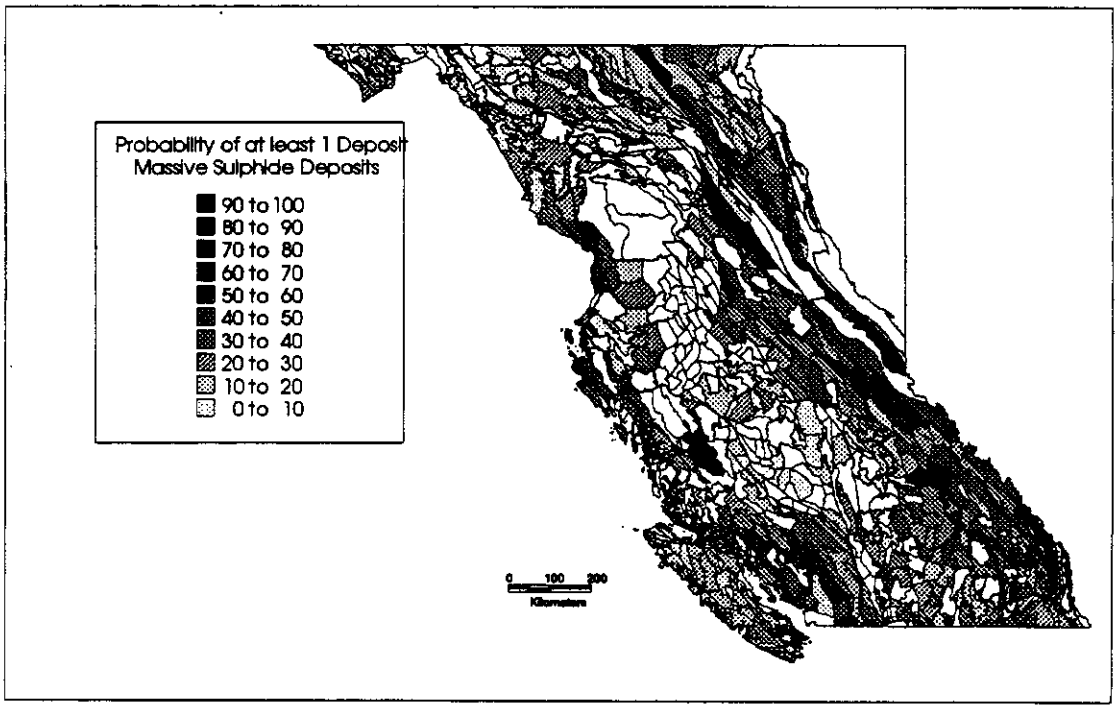

Figure 12. Map of the probability of at least one massive sulphide deposit occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

likelihood of finding additional deposits. In areas where there is a low tract score, the estimators also show a low degree of confidence. This also implies that rarely do the estimators place a high confidence on tracts where they do not believe there are additional metallic deposits. This also implies that areas of low confidence also indicate a degree of uncertainty of finding additional metallic deposits. It does not suggest that there are no additional deposits.

In Figure 3, although most areas show a positive correlation between normalized tract score and average confidence it is difficult to explain the variation in slope. In the areas where there is a poor correlation, it can only be inferred that the estimators did not use their measure of confidence as an indicator of resource potential. In almost all cases, there was no indication that high confidences were placed on areas of low metal resource potential.

Figure 4 shows plots of normalized tract score with average confidence for each tract over each workshop area for the industrial minerals suite of deposits. Areas in which significant correlations occur include the Midcoast, Kootenay, and Northwest regions. The correlations are not as strong as those shown for the base metal and precious metal deposit types of Figure 3. This suggests that the estimators did not consider their measure of confidence in assigning the industrial mineral potential of a tract.

AN EVALUATION OF DEPOSIT TYPE GROUPS

A number of deposit types were grouped together to study the areas in which specific mineral deposit types were predicted to occur with associated estimator confidences. Deposit type groups that were studied were porphyry deposits, Gold deposits, massive sulphide and skarn deposits. A measure of resource potential can be made by examining the probability for the presence of at least one deposit for each tract for each of the porphyry models. This measure was used in place of the tract score which indicates the resource potential for all metallic or all industrial mineral deposit types.

PORPHYRY DEPOSITS

Figure 5 shows a map of the average confidence associated with each tract that was estimated to contain porphyry deposits. The porphyry deposits include (calcalkalic

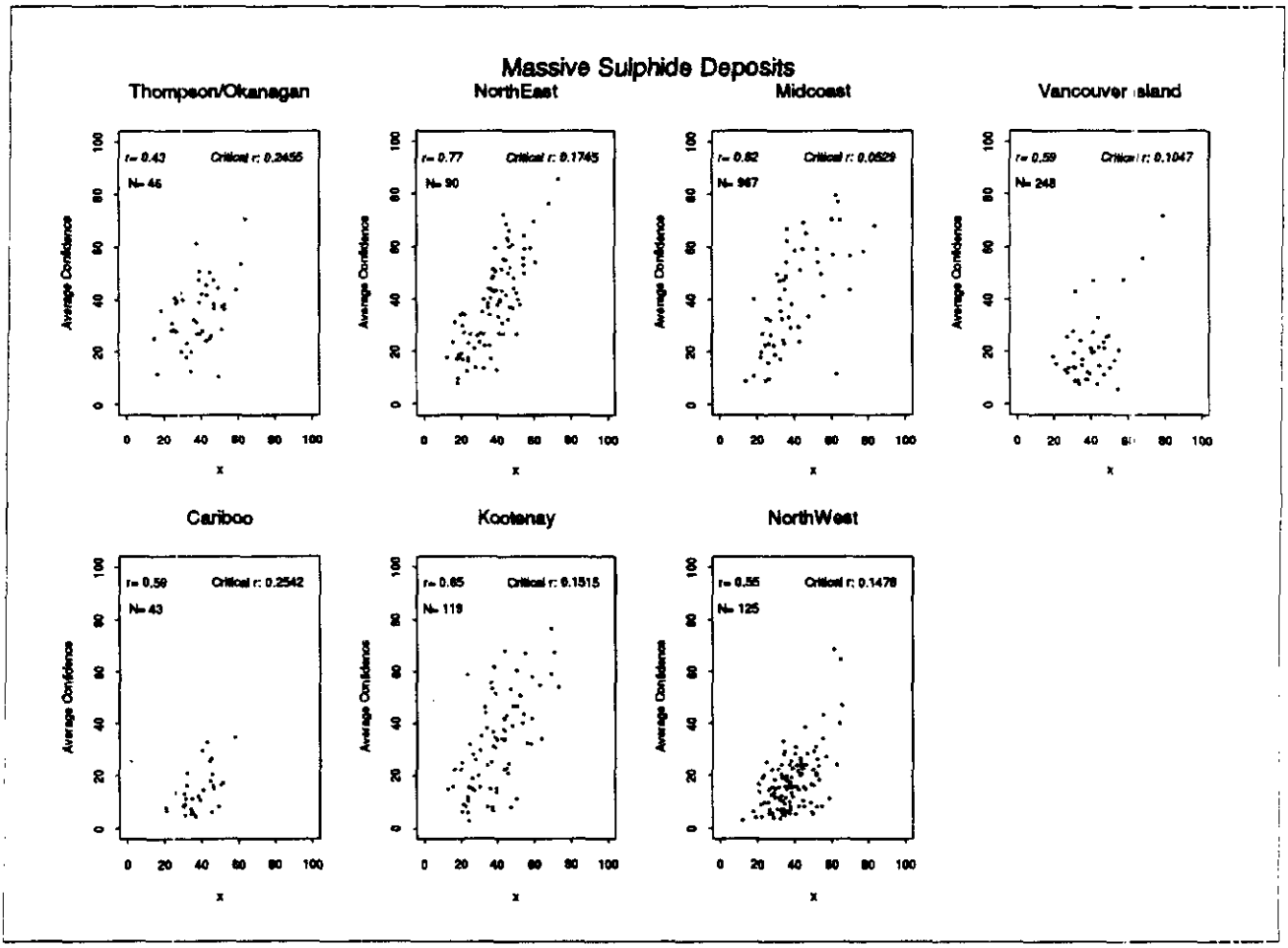

Figure 13. Plot of the average probability of at least one deposit versus the average confidence for each tract for massive sulphide deposits. There is a positive correlation for the Midcoast, Cariboo, Thompson Okanagan, Kootenay and Northwest areas.

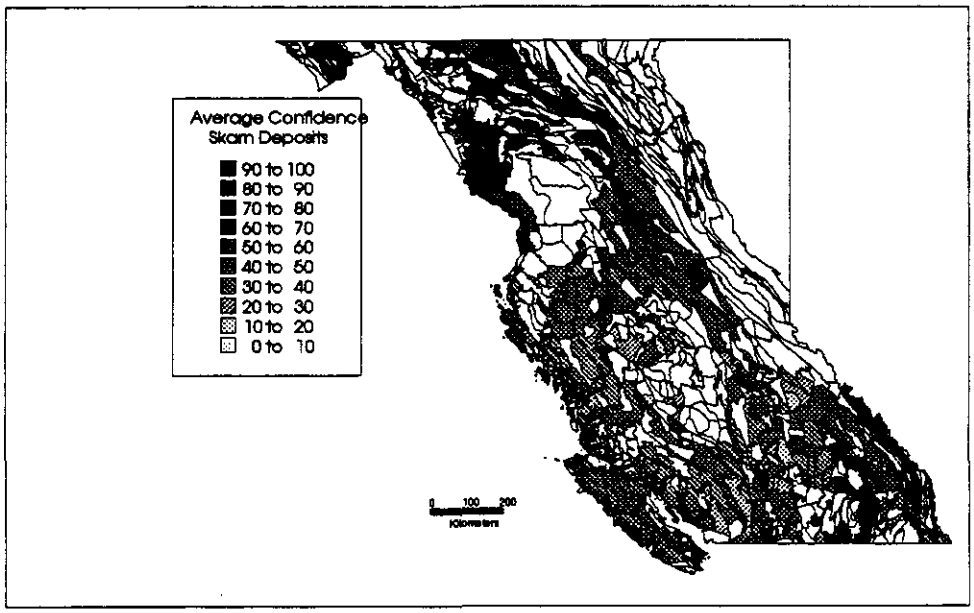

Figure 14. Map of average confidence for each tract for skarn deposit types. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

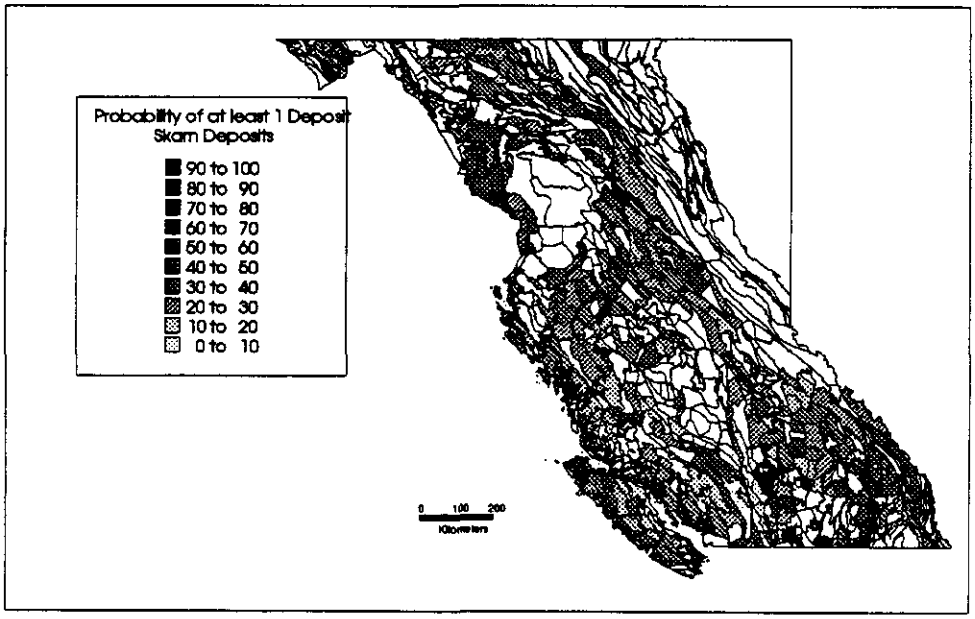

Figure 15. Map of the probability of at least skarn depost occurring in each tract. Tracts with a value of 0 to 10 indicate tracts in which no deposits were estimated.

Cu, alkalic Cu, Cu-Au, and Mo deposits). As well, for each tract, the average probability at which at least one deposit was estimated was also summarized as shown in Figure 6. Areas with high confidences in Figure 5 correspond with areas of high probabilities of at least one deposit in Figure 6.

Figure 7 shows a positive correlation between average confidence and the average probability of at least one deposit within each tract. Areas with significant correlation coefficients between confidence and the probability of at least one deposit include Northeast, Midcoast, Vancouver Island, Cariboo and Northwest areas. The Kootenay area results exhibit a negative relationship between confidence and the probability of at least one deposit. This result is possibly an artifact of what appears to be two clusters. The detailed investigation required to explain the differences between the areas is beyond the scope of this report. In part these differences may be explained by the workshop dynamics and attitudes of the estimators about their placing confidences with their estimates.

GOLD DEPOSITS

The following gold deposits were grouped together for this report: subvolcanic shear hosted veins, gold quartz veins, Eskay Creek type, hot spring Au-Ag, iron formation Au, and epithermal Au-Ag (high sulphidation). Figure 8 is a map of the average confidence expressed for these deposits for each tract. Figure 9 is a plot of the probability of at least one deposit occurring in each tract. Areas that indicate a lack of confidence and low probabilities of occurrence include the Bowser Basin area, the northeast. Figure 10 shows plots of the probability of at least one deposit versus the average confidence for each of the assessment areas. In contrast with the porphyry estimates, overall probabilities are higher. Figure 10 shows plots of average confidence versus the average probability of at least one deposit for the 7 areas. Significant correlations occur for the Northeast, midcoast, Vancouver Island, Cariboo, Kootenay and Northwest areas. The Thompson/Okanagan area data show no definitive relationship.

MASSIVE SULPHIDES

Massive sulphide deposits were grouped as follows: Mississippi Valley type Pb-Zn, Shushwap type, Kootenay arc type, Broken Hill type, Sullivan type, Besshi type, Kuroko type and Cyprus type. The average confidence and the associated probability of at least one deposit occurring in each tract is shown in Figures 11 and 12. These two

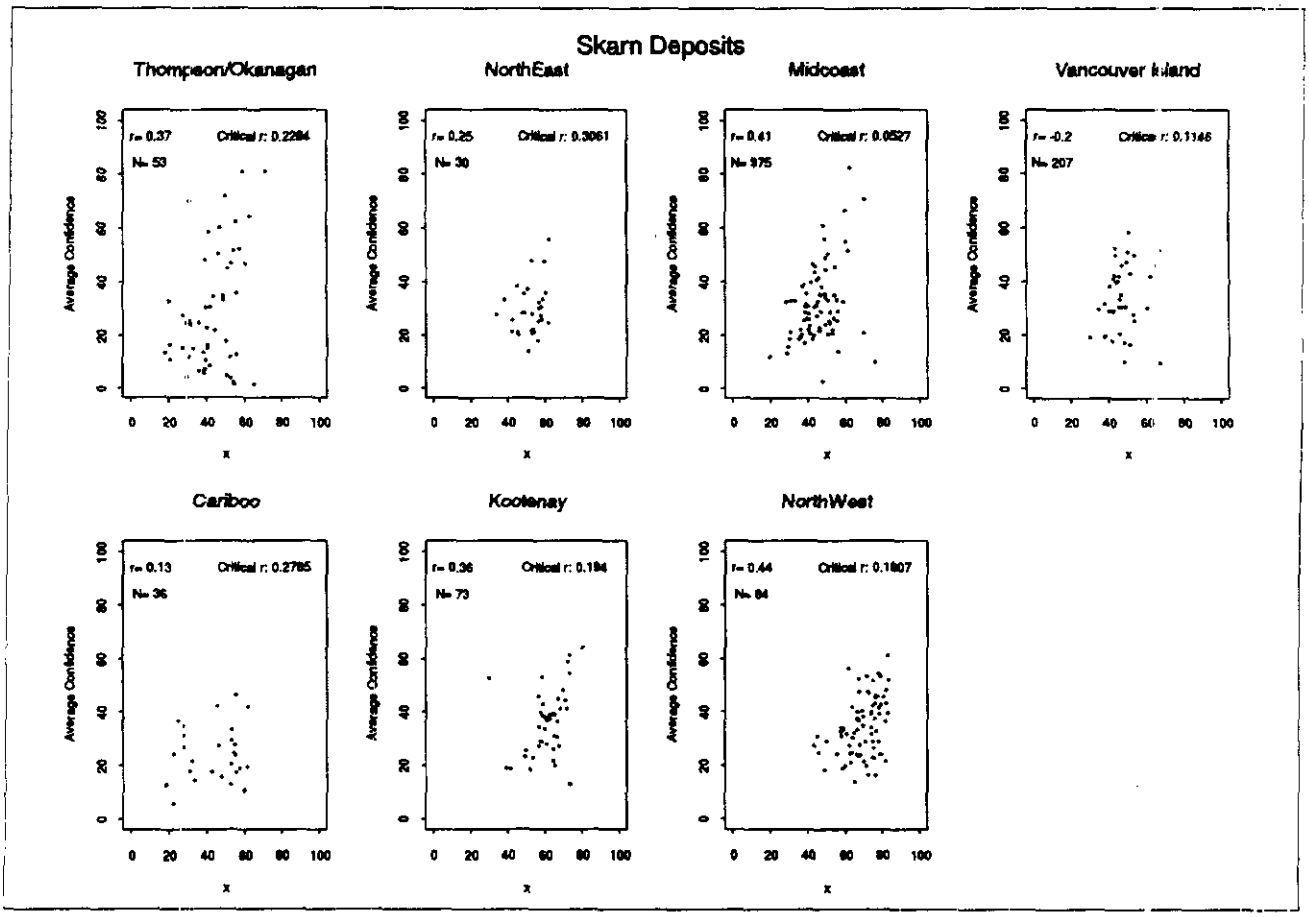

Figure 16. Plot of the average probability of at least one deposit versus the average confidence for each tract for skarn deposits. There is a positive correlation for the Midcoast, Cariboo, Thompson Okanagan, Kootenay and Northwest areas.

TABLE 1
METAL DEPOSIT MODELS USED IN THE MINERAL POTENTIAL PROJECT

Model No.		Commodities					
Metallic/Precious Minerals BC Deposit Grade/Tonnage Data							
5	Basaltic	Cu	Ag	Au	Cu		
7	Unconformityl U	U3O8					
9	Mississippi Valley Type Carbonate Hosted	Au	Ag	Cu	Pb	Zn	
80	Mississippi Valley/Kootenay Arc Type	Au	Ag	Cu	Pb	Zn	
84	Shushwap Mississippi Valley Type	Au	Ag	Cu	Pb	Zn	
109	Broken Hill Type Massive Sulphide	Ag	Cu	Pb	Zn		
21	Sullivan Type Massive Sulphide Zn-Pb-Ag	Au	Ag	Pb	Zn		
22	Besshi Type Massive Sulphide	Au	Ag	Pb	Zn		
23	Kuroko Type Massive Sulphide	Au	Ag	Cu	Pb	Zn	
28	Epithermal Au-Ag Low Sulphidation	Au	Ag				
30	Almaden Hg	Hg					
38	Silica-Hg Carbonate	Hg					
33	Subvolcanic Shear Hosted Gold Veins	Au	Ag	Cu			
108	Au deposits blended	Au	Ag	Cu	Pb	Zn	
34	Gold Quartz Veins	Au	Ag	Cu	Pb	Zn	
43	Polymetallic Ag-Pb-Zn	Au	Ag	Cu	Pb	Zn	
45	Polymetallic Manto Ag-Pb-Zn	Au	Ag	Cu	Pb	Zn	
47	Cu Skarn	Au	Ag	Cu	Pb	Zn	
49	Fe Skarn	Au	Ag	Cu	Fe		
50	Au Skarn	Au	Ag	Cu			
79	Transitional	Au	Ag	Cu	Pb	Zn	
54	Porphyry Cu (calcalkalic)	Au	Ag	Cu	Mo		
55	Porphyry Cu	Au	Ag	Cu	Mo		
56	Porphyry Cu (Alkalic)	Au	Ag	Cu			
59	Porphyry Mo (Low F)	Mo					
Metallic/Precious Minerals Simulated Deposit Grade/Tonnage Data							
106	PaleoPlacer Au	Au					
4	Placer U-Au-PGE-Sn-Diamond-Magnetite-Garnet	Au	Ag				
103	Eskay Creek Type	Au	Ag				
85	U-Th Pegmatite	U3O8					
102	Cu-Ag Veins						
83	Li in Pegmatite	Li					
104	Mississippi Valley Type	Zn	Pb	Ag			
78	Mo Skarn	Mo					
87	Alaskan PGE	PGE					
98	Nb/Ta Hosted Carbonatites	Nb					
105	Serpentinite Cu Ni	Cu	Ni				
Metallic/Precious Minerals GSC Deposit Grade/Tonnage Data							
51	W Skarn	W					
Metallic/Precious Minerals USGS Deposit Grade/Tonnage Data							
2	Terra Rosa Au-Ag	Au	Ag				
6	Sediment Hosted Cu	Cu	Co	Ag			
8	Volcanic Hosted U	U	Mo				
10	Sediment Hosted Au-Ag [Carlin type]	Au	Ag				
11	Sandstone Pb	Au	Ag	Cu	Pb	Zn	
14	Sedimentary Mn	Mn					
18	Volcanogenic Mn	Mn					
20	Algoma Fe	Fe	P				
24	Cyprus Type Massive Sulphide	Au	Ag	Cu	Pb	Zn	
25	Hot Spring Hg	Hg					
26	Hot Spring Au-Ag	Au	Ag				
27	Epithermal Au-Ag High Sulphidation	Au	Ag	Cu	Pb	Zn	
29	Epithermal Mn	Mn					
32	Sitbnite Veins and Disseminations	Sb	Au	Ag			
35	Iron formation -hosted Au	Au	Ag				
36	Volcanic Hosted magnetite	Fe	P				
39	Mn Veins and Replacements	Mn	Fe	P	Cu		
40	W Veins	W					
41	Sn Veins	Sn					
42	Sn Greisens	Sn					
46	Zn-Pb Skarn	Sn					
53	Wollastonite Skarn	Wollastonite					
48	Zn-Pb Skarn	Au	Ag	Cu	Pb	Zn	
52	Sn Skarn	Sn					
58	Porphyry Mo	Mo					
60	Basaltic subvolcanic Cu-Ni-PGE	Cu	Ni	Co	Pd	Au	Pt
61	Gabbroid Ni-Cu	Cu	Ni	Co	Pd	Ir	Au
62	Podiform chromite	Cr2O3	Pd	Pt	Rh	Ir	Ru
63	Carbonatite nephelinite hosted deposits	Nb	REE	P	Zr		
64	Carbonatite nephelinite hosted deposits	Nb	REE	P	Zr		
65	Au-Ag-Te-F Veins	Au	Ag				
67	Diamonds	Diamond					
Metallic/Precious Minerals Combined USGS/BC Grade/Tonnage Data							
57	Porphyry Au	Au					
107	Blended vein deposits	Au	Ag	Cu	Pb	Zn	

TABLE 2
INDUSTRIAL MINERAL DEPOSIT MODELS USED IN THE MINERAL POTENTIAL PROJECT

Model No.	Descriptions	Commodities (%)			
Industrial Minerals: BC Deposit Grade/Tonnage Data					
15	Bedded Gypsum/Anhydrite	Gypsum			
Industrial Minerals: USGS Deposit Grade/Tonnage Data					
3	Silica Sand	SiO2			
1	Residual Kaolin	SiO2	Al2O3	Fe2O3	Kaolin
13	Sedimentary Kaolin	SiO2	Al2O3	Fe2O3	
12	Bentonite	SiO2	Al2O3	Montmorillonite	
16	Lacustrine Diatomite	SiO2	Quartz		
17	Phosphate Upwelling Type	P			
19	Sedimentary Bentonite	SiO2	Al2O3	Montmorillonite	
31	Hydrothermal Kaolin	SiO2	Al2O3	Fe2O3	Kaolin
82	Silica Veins	SiO2			
66	Kyanite-Silliminate-Andalusite schists	Al2SiO5	Al2O3	SiO2	Kyanite
74	Silica Sandstone	SiO2			
Industrial Minerals: Simulated Deposit Grade/Tonnage Data					
86	Lamproite Hosted Diamonds	Diamond			
89	Placer Garnet	Garnet			
91	Zeolites	Clinoptilolite		Chabazite	
81	Sediment Hosted Stratiform Barite	Barite			
96	Kuroko Barite	Barite			
101	Anhydrite/Gypsum	Gypsum			
37	Vein Barite	Barite			
92	Feldspar Pegmatite	Feldspar			
88	Garnet Skarn	Garnet			
93	Asbestos	Asbestos			
94	Ultramafic Magnesite/Talc	Magnesite	Talc		
44	Alkalic Flourite Veins	Flourite			
95	Alkalic Flourite Veins	Flourite			
90	Metamorphic Mica	Mica			
68	Cement Shale	Shale			
99	Nepheline Syenite	Nepheline Syenite			
97	Lava Rock	Volcanic Cinder			
69	Expanding Shale	Shale			
70	Dimension Stone Granite	Granite			
71	Dimension Stone Marble	Marble			
100	white Marble	Marble			
72	Dimension Stone Andesite	Andesite			
73	Dimension Stone Sandstone	Sandstone			
75	Flagstone	Flagstone			
77	Limestone	Limestone			
76	White Limestone	Limestone			

figures indicate that massive sulphides are more likely to occur in the Vancouver Island and south coast regions, the northwest and the tracts west of the Rocky Mountain Trench. The Kootenay and Thompson/Okanagan areas also show a higher probability of massive sulphide (Mississippi Valley Type) deposit potential. Figure 13 shows plots of average confidence versus the probability of at least one deposit for each of the assessment areas. Significant correlations occur for all of the regions. The plot for Vancouver Island shows two clusters of points which perhaps indicates different perspectives used by the workshop participants in that area.

SKARN DEPOSITS

Figures 14-16 show the results of grouped skarn deposits which include, Cu, Fe, Ag, W, Mo, Zn-Pb, wollastonite and Sn skarns. Figure 14 is a map of the average confidence expressed for these deposit types over all of the tracts. Figure 15 shows the average probability of the presence of at least one of these deposit types for each tract. The confidence and probability of at least one deposit is lowest in the Interior Plateau, Bowser Basin, and northeast parts of the province. Higher confidence and estimates occur in the Kootenay, Vancouver Island, Midcoast, Iskut, Quesnel and portions of the northwest regions. Figure 16 shows the relationship between confidence and probability of at least one deposit for each of the areas. Significant correlation coefficients occur for the Thompson/Okanagan, Midcoast, Kootenay, and Northwest areas. The data for Vancouver Island exhibit a negative correlation that represent clusters of data points associated with different workshop estimators and/or skarn deposits.

DISCUSSION

An exhaustive summary and analysis of the data cannot be presented in this report. However an overview and summary of selected areas and mineral deposit type groups provides some insight into the data collected for the Mineral Potential Project.

The maps presented in this report summarize the following features of the mineral potential project:

- Confidence of the estimators in their estimates as a function of tract for metallic and industrial mineral deposits.
- Confidence by tract for porphyry, massive sulphide, gold and skarn deposit types.
- Maps of the probability of at least one deposit for each deposit type group for each tract.
- Plots of estimator confidence versus the probability of at least one deposit for each deposit type group.

Comparison between Figures 3 and 4 indicates that there is a better correspondence between average confidence for each tract versus normalized tract score for precious and base metal deposits than with the industrial mineral deposits. The patterns of Figure 4 suggest that the estimators did not have the same degree of confidence with respect to tracts where higher estimates of probability were assigned.

Figures 5, 8, 11 and 14 indicate the confidence that the estimators have in their assessment of the mineral assessment tracts. This can be interpreted as a measure of the state of knowledge that exists for those deposit types over the province.

Figures 6, 9, 12 and 15 highlight where workshop participants believe there is additional potential for the four mineral deposit groups. Almost all areas show perceived potential for mineral resources. Exceptions are the Bowser Basin area and the northeast area of the province.

Figures 7, 10, 13 and 15 which show the plots of average confidence versus the average probability of at least one deposit for each tract, provide some insight into the confidence for specific areas and deposit model groups. Where a positive correlation between confidence and the probability of at least one deposit exists, the estimators have knowledge about the area and the potential resources. In the case of poor correlation it would appear that the estimators are not confident about their knowledge of the area and the possible resources. The lack of any correlation may also be the result of uncertainty of the estimation process and the application of confidence. It is possible that both explanations may account for the observed patterns in the data.

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