MINERAL RESOURCE ESTIMATION: AN EVALUATION OF RESPONSES FROM NORTHEAST BRITISH COLUMBIA

E.C. Grunsky and W.E. Kilby

KEYWORDS: Mineral resource assessment, estimator evaluation, Northeast British Columbia

INTRODUCTION

The Mineral Potential Project is an initiative that provides predictions of resource abundance in the province and has been described by Kilby (1995). In this project, resource assessment is carried out on specified tracts of land, referred to as mineral assessment tracts. These tracts are generalizations of contiguous geological tracts that share a common tectonic history and metallogeny and whose boundaries reflect differences in lithology, structure and geological history (*see* Grunsky *et al.*, 1994; Church, 1995; Massey, 1995). Areas that have been covered to date include: Vancouver Island, Kootenay region, Cariboo region, Skeena-Nass region, Mid-coast, Thompson-Okanagan region, and northeast British Columbia (*see* Kilby, 1995, Figure 1).

The Mineral Potential Project adapted an approach similar to the methodology of the U.S. Geological Survey three-part assessment method as outlined by Singer (1993). The modified methodology used in British Columbia consists of:

- Creation of mineral assessment tracts;
- Grade and tonnage models are used that reflect the types of deposits that are expected in the area;
- An estimate of expected undiscovered deposits based on the grade and tonnage data.

In contrast to a purely statistical assessment based on a grid-cell approach, the mineral assessment tracts were created to reflect areas that contain specific characteristics related to metallogeny. The assessment is based on subjective probability applied to the prediction of undiscovered resources and 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 information within each tract. These assessments were carried out in Mineral Resource Assessment Workshops.

WORKSHOP METHOD

The workshop were introduced with lectures about the regional geology and known metallogeny. Geologists were assigned to working groups of three to four members. Each group represented knowledge and expertise with specific types of mineral deposits (e.g. industrial minerals, gold deposits, massive sulphide deposits). A facilitator was assigned to each group. The facilitator compiled the responses from the members and worked at resolving questions or difficulties that might be encountered in the group. Each group was given mineral resource assessment tract maps, geological maps, geochemical maps, geophysical maps, and a copy of the MINFILE database. Using these resources, the group members discussed the likelihood of mineral deposits of specific classes that might possibly be present. Through discussions, each member of the group was exposed to the other estimators' persnal knowledge of a given tract. Each member of the group would then, based on their knowledge, the information provided and the group discussion, make an independent confidential probabilistic estimation of undiscoveredl mineral deposits. This approach, modified from the RCON approach of Resource Science, Inc., (1994) weights the responses of individuals. The potential benefit of such weights is that an estimator who is highly respected (high scores) has more influence than an estimator who is considered to have less knowledge (lower scores) for a particular deposit model or mineral assessment tract.

ESTIMATOR RESPONSE

A cornerstone of accurate estimates is the correct understanding of how a geologist perceives the likelihood of **at least one or more undiscovered deposits** occurring in a tract. Each workshop covered the process of assessment with careful instructions of how the resulting estimates are translated into a frequency distribution that is used in the simulation process. The use of grade and tonnage models is crucial to a meaningful estimate of resources, as the estimator must consider the size and grade of a deposit in order to make an estimate (Grunsky, 1995; Resource Science, Inc., 1994). In this study geologists used the median grade and tonnage as the basis for their estimates (Kilby, 1995). The estimates were then used as input to a Monte Carlo simulation program that computes expected grades and tonnage, given the probability of finding at least one deposit. A typical response is as shown in Figure 1. The interpretation of this response is as follows:

The geologist decided that the probabilities of finding one or more copper skarn deposits are:

- 85% probability that there is at least one undiscovered deposit.
- 44% probability that there are at least two undiscovered deposits present.
- 21% probability that there are three undiscovered deposits present.

From these estimates a probability distribution can be constructed that indicates the likelihood of undiscovered

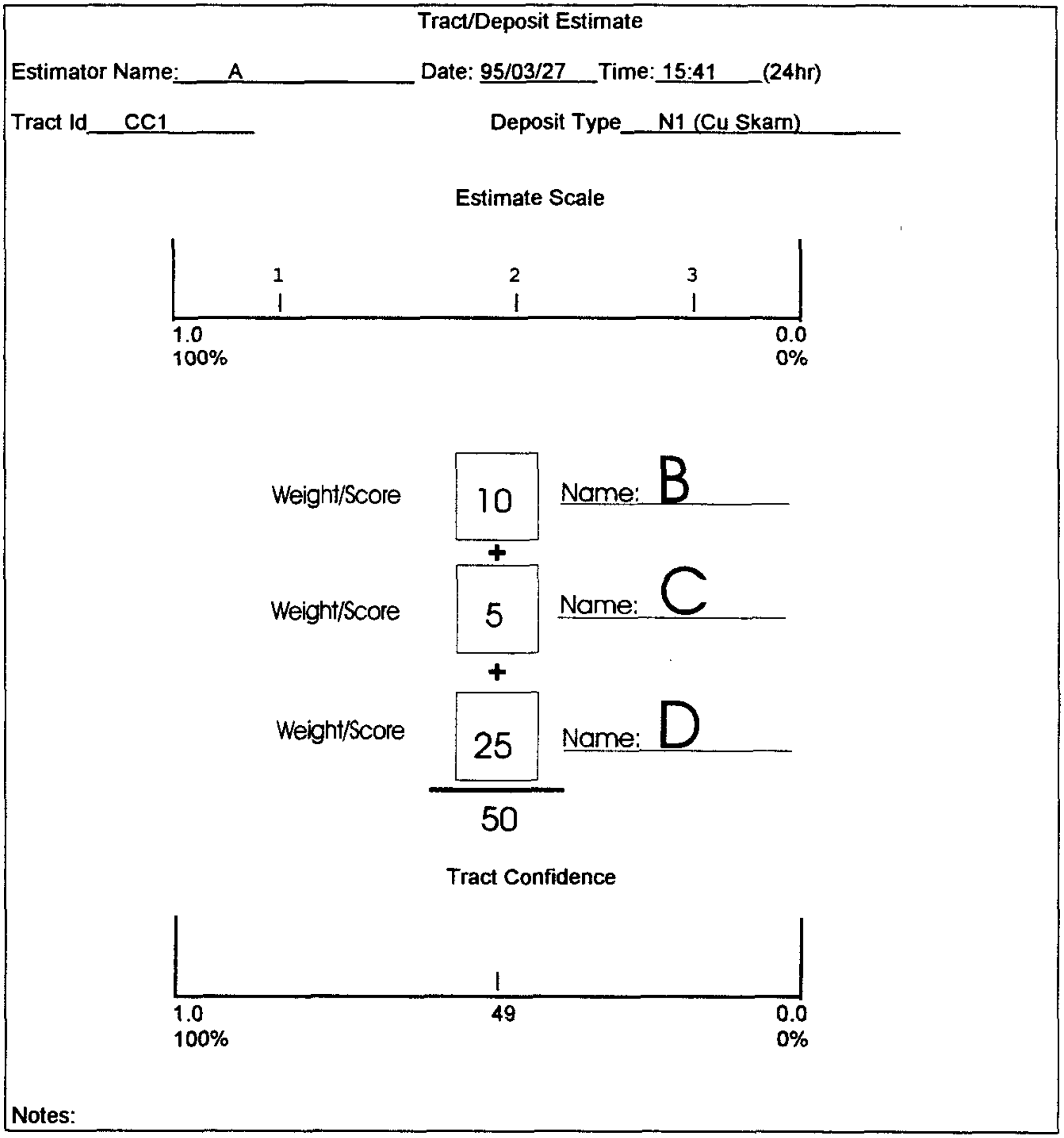

Figure 1. Estimator work sheet.

copper skarn deposits existing in this mineral assessment tract. A schematic of the initial estimate is shown in Figure 2. Using the procedure outlined by Root *et al.* (1992) the endpoints of the distribution can be defined and constructed so that probabilities and estimates are defined for the 99, 90, 50 and 10 percent probabilities. These computed values were used as a comparative basis between estimators, mineral deposit models and tracts. For each estimate, the geologist also assigned a weight to the other group members. The assigned weight may vary from 0 to 50 for the group members. The maximum score that any individual can assign another group member is 50. (As shown in Figure 1, the weights estimator A assigned to estimators B,C and D are 10, 5 and 25, respectively). Each estimator is automatically assigned a weight of 50. The total combined weight for any individual cannot exceed 100. For example if there are four members to a group, the maximum score that the group may obtain is a value of 400. Each group member will have individual weights that may vary from a minimum of 50 to a maximum of 200. Mathematically expressed, an estimate, P, made for a given tract, j, and mineral deposit model, k, with estimator, a, with weights from estimators i (i=1,2, ...,n-1) is defined as follows (equation 1):

$$E_a = 50*P_{ajk} + \sum_{i=1}^{n} w_{ijk}*P_{ajk} \quad (1)$$

where P represents the probability and w is the assigned weight.

Estimates were made for each tract, for each mineral deposit type considered likely to occur within it. For northeast British Columbia., a total of 2533 estimates were made. Figure 3 shows the locations of the mineral assessment tracts in the northeast region. The number of estimates made for each of the tracts varied greatly. The estimates were compiled and entered into a database that served as input for the Monte Carlo simulation program. Note that the references made to estimators G1A, G1B, G1C, and G1D represent estimators A, B, C and D for Group 1, respectively.

The Monte Carlo simulation program was adapted from the Mark 3 Simulation program that was kindly provided by the U.S. Geological Survey. It was modified to accept grade and tonnage data from British Columbia mineral deposit models (Lefebure *et al.*, 1995). The program was originally written to accept estimates at 90, 50 and 10% probabilities. This was modified to accept up to ten estimates with probabilities defined by the marks placed on the scale, as shown in Figure 1. The assigned weights of the estimators are applied to the results of the simulation.

The process of Monte Carlo simulation involves a random selection from the probability distribution that is determined from the estimates for a given tract and deposit model. The distribution curve is sampled 4999 times. Each time it is sampled, the resulting probability is multiplied by

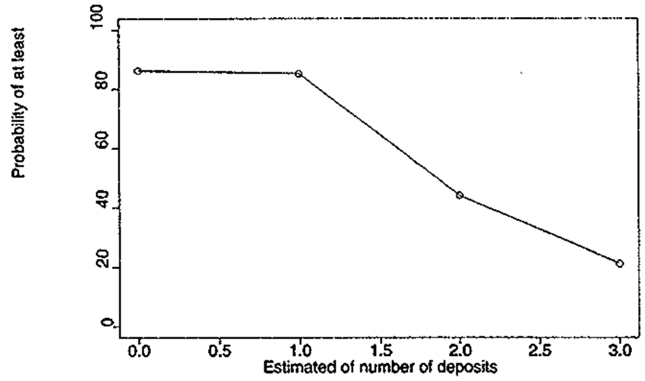

Figure 2. Cumulative probability distribution of estimator response for a specific tract and mineral deposit model.

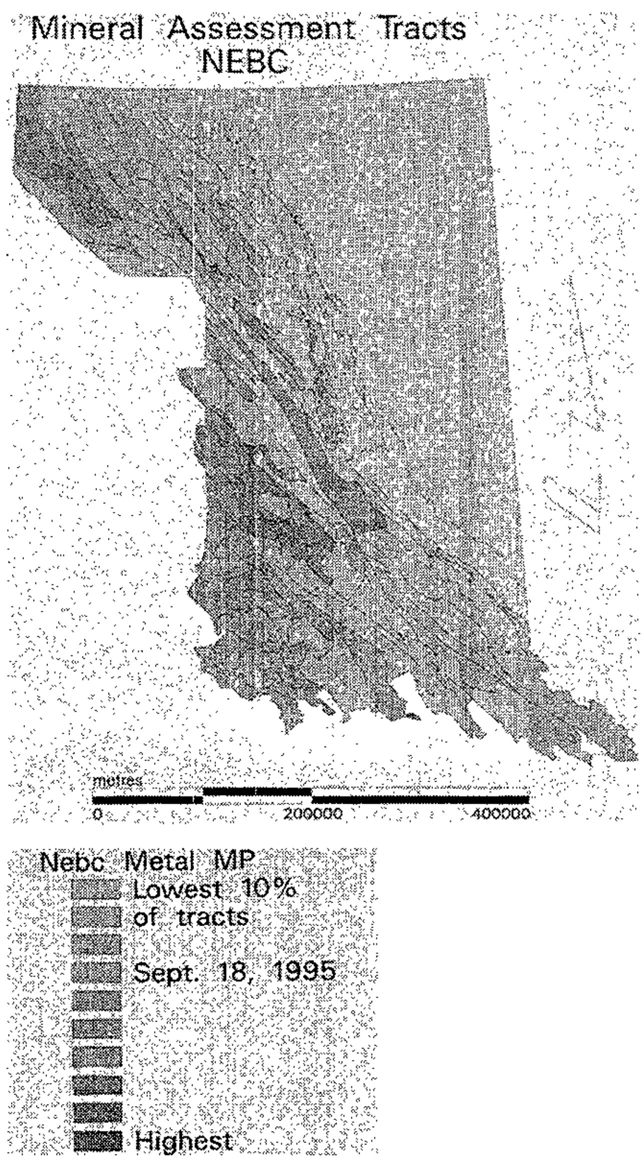

Figure 3. Map showing the Mineral Assessment Tract locations for Northeast B.C. The map is shaded according to mineral potential. Light areas have low mineral potential; dark areas have high mineral potential.

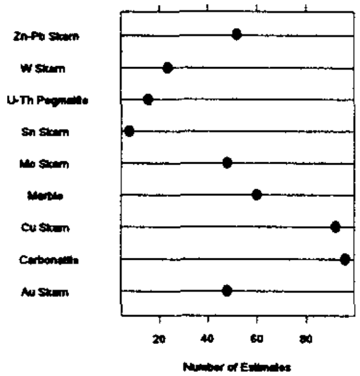

Figure 4. Number of estimates made by Group 1 for each mineral deposit model.

a randomly chosen grade and tonnage appropriate to the deposit model. This product is an estimate of the actual number of kilograms of metal. For each iteration, the product is summed. The final iteration produces a total expected number of kilograms of metal based on the distribution of the estimate.

COMPILATION OF RESPONSES

The estimates have been compiled and analyzed, in part, using a graphical display package. Not all features of the responses can be shown here. A total of five groups provided estimates for the northeast British Columbia region. The results from Group 1 are presented here. Group 1 had a total of four estimators and assessed the potential for the following models: U-Th pegmatite, Cu skarn, Pb-Zn skarn, Au skarn, W skarn, Sn skarn, marble skarn and carbonatite deposits. The group made 444 estimates. Figure 4 shows how the estimates were distributed over the mineral deposit models assessed by the group.

ESTIMATOR CONFIDENCE:

Figure 5 shows a plot of the overall confidences of estimates expressed by each estimator. Notice that most estimates are in the range of 25 to 60% for estimators A, B, and C. Estimator D displays a considerably higher amount of confidence relative to the others.. The interpretation that can be drawn from this figure is as follows:

- Estimators A and B share similar levels of confidence,
- Estimators C and D shows a more constrained range of confidences relative to estimators A and B,
- Estimator D shows a high degree of confidence relative to estimators A, B, and C.

One interpretation for very high confidences is that the estimator had some detailed knowledge about the mineral assessment tract and deposit model. Where confidences are very low, it can be inferred that the estimators did not feel comfortable with their level of knowledge or by what was discussed within the group for a given mineral assessment tract and deposit model.

A further analysis of confidence levels can be made by evaluating confidence as a function of mineral deposit model. This is illustrated in Figure 6 where the confidences of the estimators can be examined with respect to each of the mineral deposits. Estimators A and B show the greatest range in confidence. No clear comparisons or distinctions can be made between the four estimators, however, the figure clearly captures the range of confidence with respect to the mineral deposit models that were considered.

An important consideration is the confidence of estimators with respect to each other. Evaluation of the weight

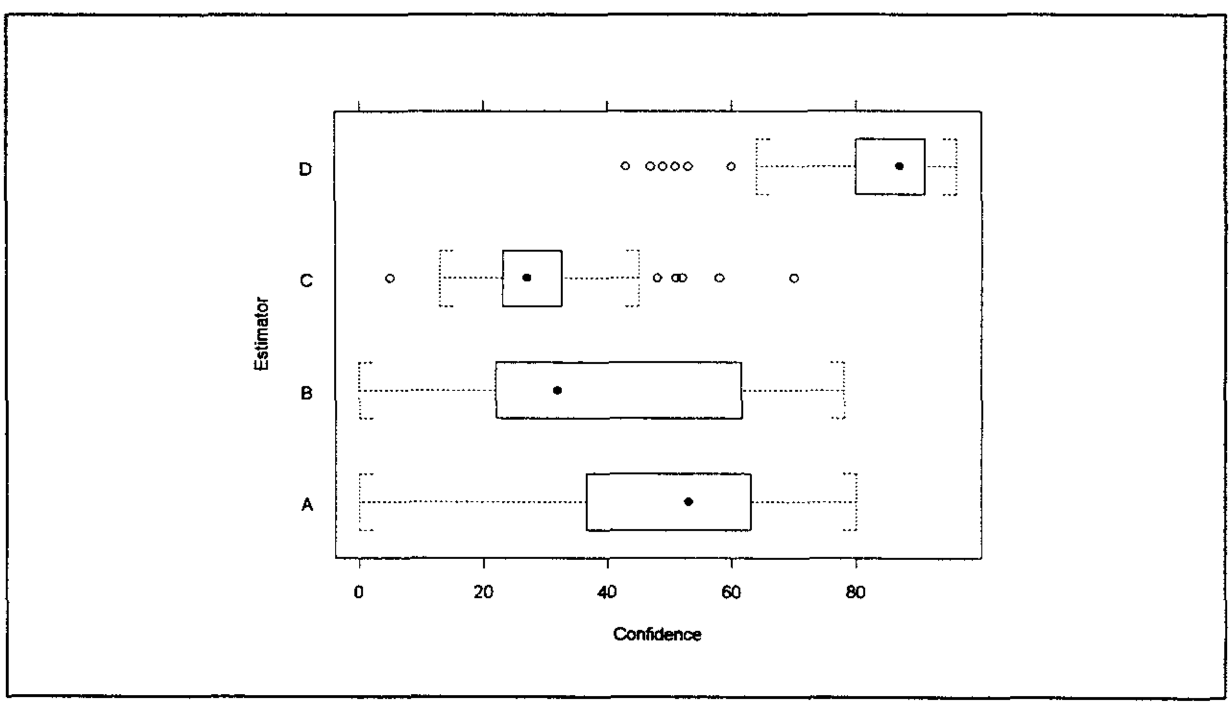

Figure 5. Boxplot showing the range of confidences expressed by each estimator for their own estimates.

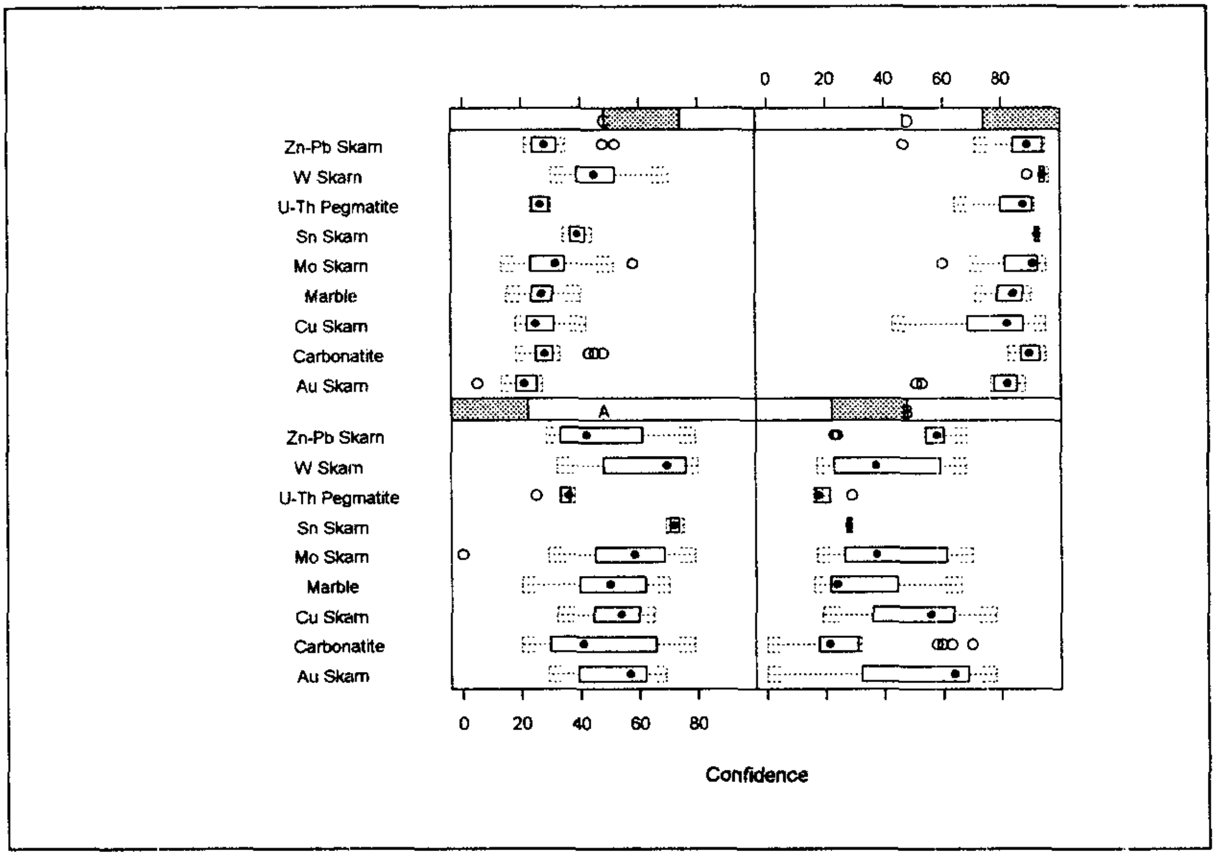

Figure 6. Boxplot showing confidence ranges for specific deposit types.

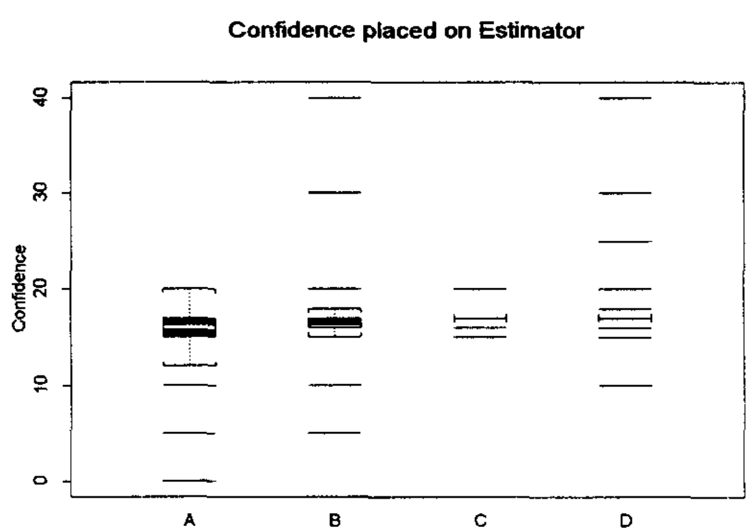

Figure 7. Boxplot showing how estimators were judged by each other. Each estimator can receive a maximum of 50 points from other group members,

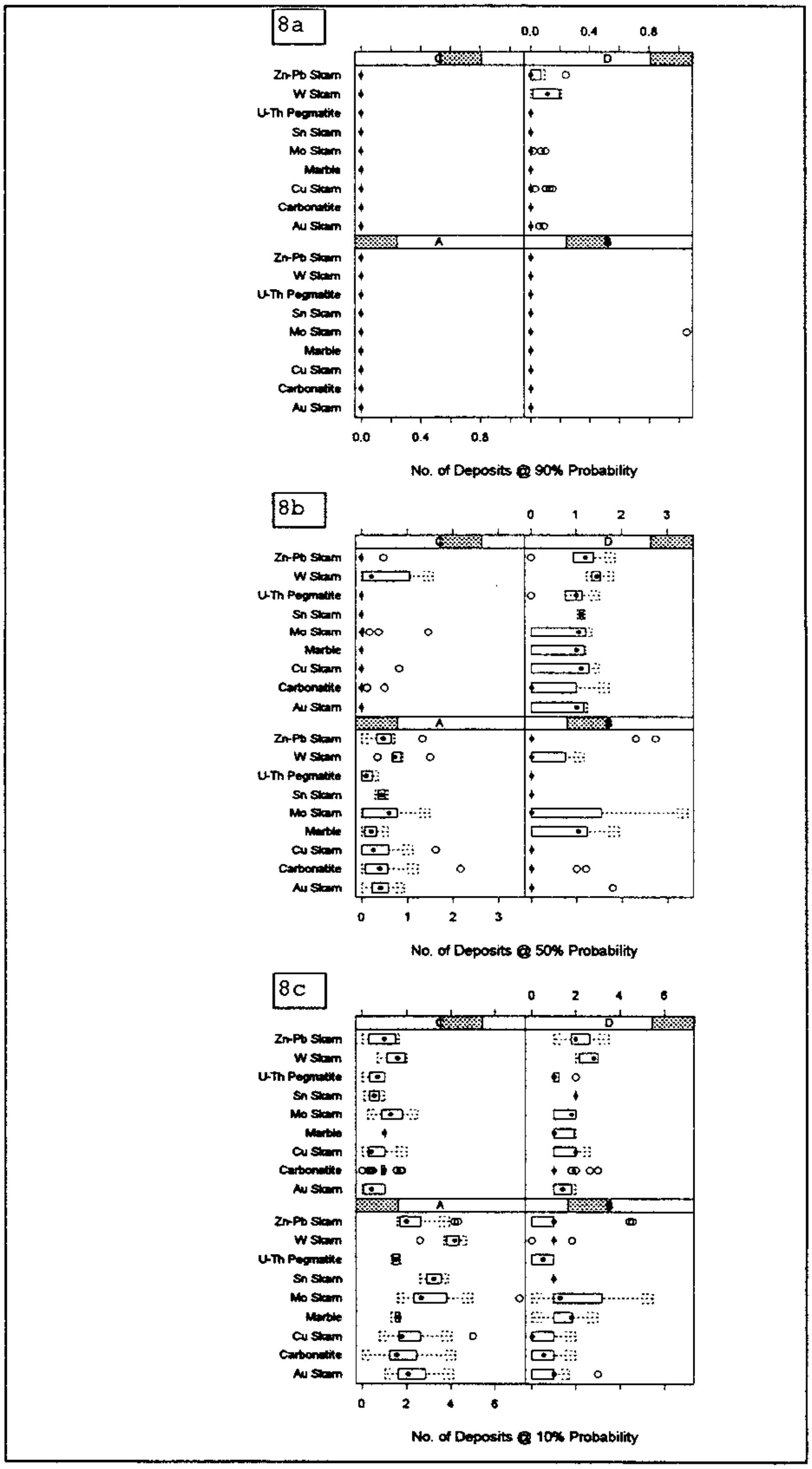

Figure 8. Number of estimates versus mineral deposit model for each of the estimators.

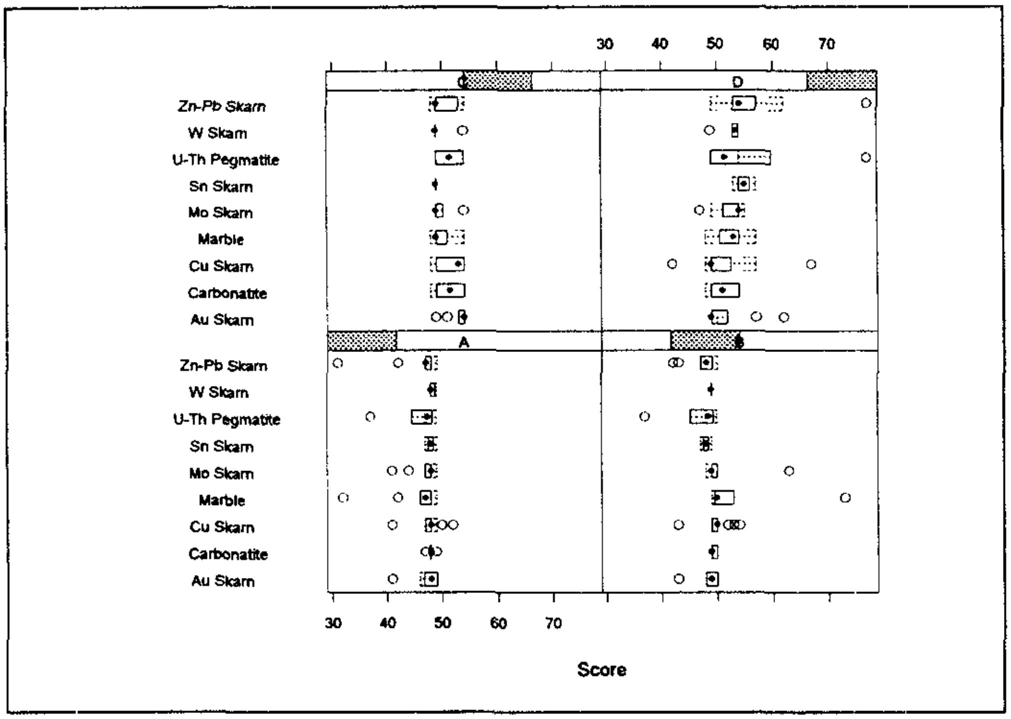

Figure 9. Scores assigned to each estimator for each deposit model. The maximum score that any estimator can obtain is 150. Note that most scores are in the range of 40 to 50. Estimator D obtained the highest scores. This suggests that the other estimators assigned more value to the estimates made by estimator D.

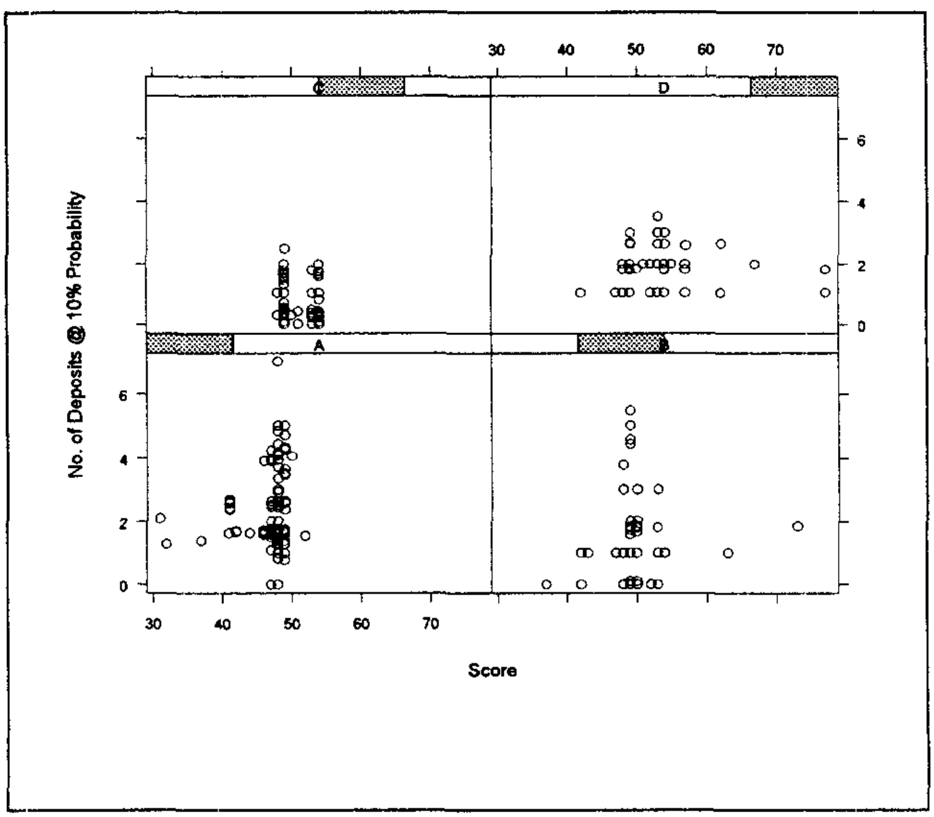

Figure 10. A plot of estimator scores versus the number of predicted deposits at the 10 % level of probability..

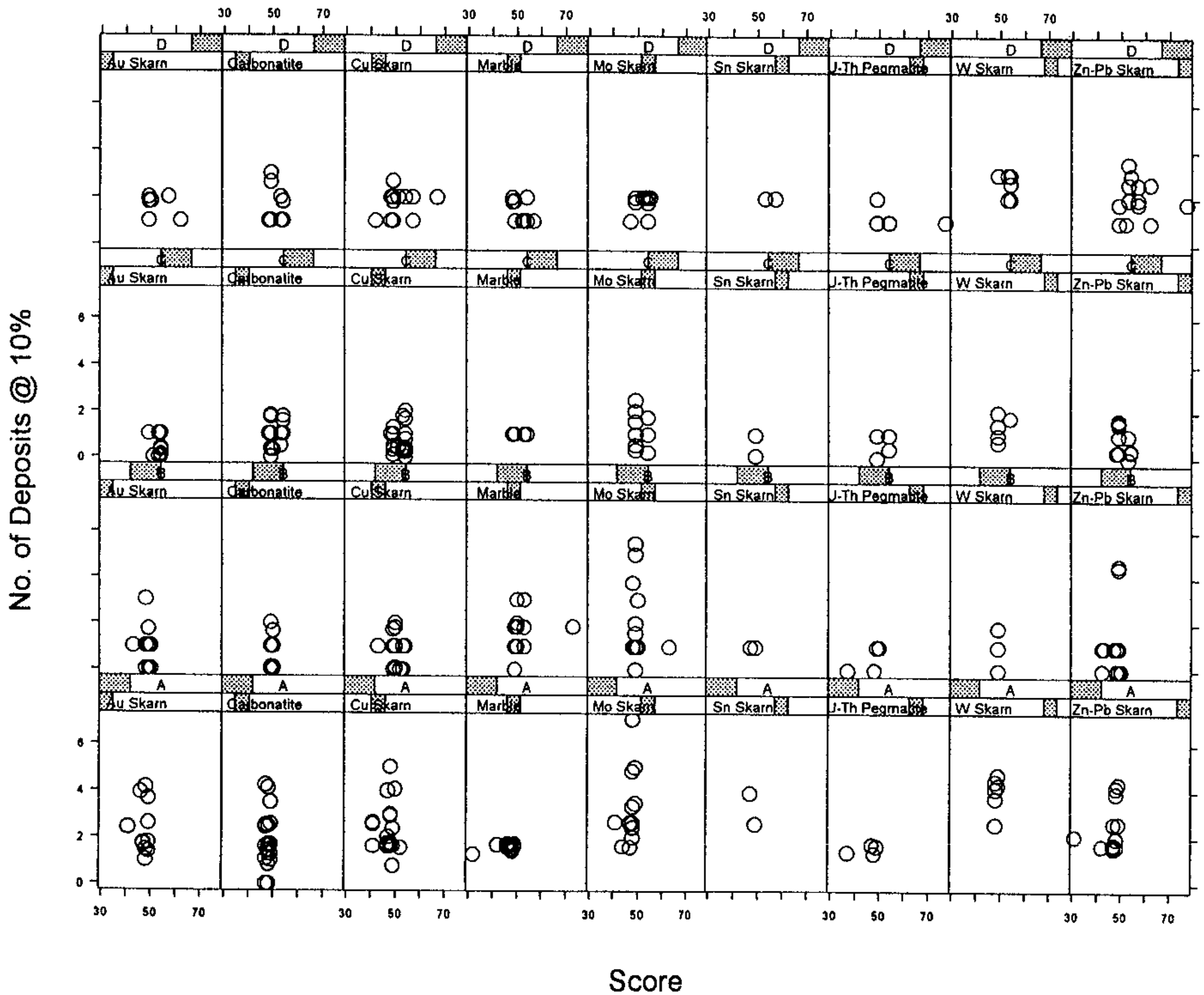

Figure 11. A plot of the number of predicted deposits at the 10% level of probability as a function of score for each mineral deposit profile and estimator.

(or score) that each estimator gives the others can be examined to see who in the group receives the most weight and who, the least weight. Figure 7 shows a compilation of weights that were assigned to each of the four estimators. For four estimators, the average weighting that could be assigned was 50/3 which means that two estimators would be given 17 points and one estimator would be given 16 points. A summary of the responses is as follows:

- Estimator B was given a low weighting for two estimates and very high weightings for three estimates,
- Estimator C shows little variation in the weighting assigned by others.
- Estimator D shows the greatest variation of weighting and received high weights for two estimates.
- Estimator A was given a low weighting for three particular estimates.

The variation in the weighting does not appear to be very dramatic and suggests that generally the estimators had consistent confidence in each other's ability. Alternatively, there may have been some reluctance to depart from a neutral weighting in expressing confidence in each other's estimates.

ESTIMATES AT DIFFERENT PROBABILITY LEVELS

Figure 8 is a plot of the number of estimates made by each estimator for each model at three confidence levels. The number of estimates represents the number of ticks that were placed along the estimate scale as shown in Figure 1. Comparison of Figures 8a, b, and c provides an estimate how certain the estimators were of finding at least one deposit at the 90, 50 and 10% confidence levels. Figure 8a shows that only estimator D has made predictions of at least one deposit at 90% or better confidence for any of the skarn mineral deposit models. At the 50% and 10% levels of confidence, estimators B and C are more conservative than A or D, as shown in Figures 8b and 8c. However, estimator D does not predict more deposits than the others at the 10% level of confidence. This estimator displayed high levels of confidence in his/her own estimates (Figure 5) and has predicted a greater likelihood of finding additional deposits relative to the other group members, particularly at the greater than 50% level of confidence. The results of this analysis indicate that estimator D will predict more tonnes of metal than the other estimators, due to the higher probability of finding a deposit.

EVALUATION OF THE ESTIMATES BASED ON ESTIMATOR SCORES

Although each estimator generated a range of estimates as illustrated in Figure 8, these results were modified based on the score that each estimator received as shown in equation 1. The scores can be summarized in terms of the mineral deposit models and the actual estimates made. Figure 9 shows a boxplot of scores given each estimator for each model. Examination of the figure indicates that the overall scores that each estimator received do not differ greatly. The mean scores for estimators A, B, C and D were 47, 49, 51 and 52, respectively. However, in Figure 8, it appears that estimator A received lower scores for several estimates and estimators C and D received higher. The scores can also be viewed in terms of the number of deposits predicted made by each of the estimators. Figure 10 is a scatterplot of score versus number of predicted deposits at the 10% probability level. This is analogous to the plot shown in Figure 8c. Examination of this figure shows that estimators A and B estimated a higher number of deposits than estimators C or D, but have a corresponding lower score. Figure 11 shows a further breakdown of the information illustrated by Figure 10. In this figure predictions at the 10% probability level are plotted with respect to each estimator and mineral deposit model. This permits a closer examination of score and prediction as a function of model and estimator.

CONCLUDING COMMENTS

In the example described in this paper, it appears that there is not a great degree of variation between the estimates and scores of the four estimators. Of the four estimators, D appears to have had the highest degree of confidence. The self confidence expressed by estimator D also influenced the scores given D by the other group members. Estimator D, on the average was assigned a higher weight than the other three estimators. Also, because D has predicted the presence of deposits at a higher degree of probability, D will have more influence on the resulting tonnage estimates that are generated in the Monte Carlo simulation program. The assessments of the group of estimators described here require further analysis to capture the range of thinking that was expressed in the estimates. Further analysis is being carried out on the five groups that took part in the resource estimate workshop for northeast British Columbia. These results will be reported in the near future.

REFERENCES

Church, B.N. (1995): Mineral Potential of the Okanagan-Similkameen-Boundary Area (82E, 82L/SE, SW, 92H/SE, NE); *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 424-434

Grunsky, E.C. (1995): Grade and Tonnage Data for British Columbia Mineral Deposit Models; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 417-423.

Grunsky, E.C., Massey, N.W.D. and Kilby, W.E. (1994): Mineral Resource Assessment in British Columbia, The Mineral Potential Project; *Nonrenewable Resources*, Volume 3, No. 4, pages 271-283.

Kilby, W.E. (1995): Mineral Potential Project - Overview; *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 411-416.

Lefebure, D.V., Alldrick, G.J., Simandl, G.J. and Ray, G. (1995): British Columbia Mineral Deposit Profiles, *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors. *B.C.*

Ministry of Energy, Mines and Petroleum Resources, Paper 1995-1, pages 469-490.

Massey, N.W.D. (1995): The Vancouver Island Mineral Potential Project (92B, C, E, F, G, K, L and 102I); *in* Geological Fieldwork 1994, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1995-1, pages 435-448.

Resource Science, Inc. (1994): Mineral Resource Evaluation Workshop, March 15-17, 1994, Victoria, British Columbia, *in* Mineral Resource Evaluation Workshop, *B.C. Ministry of Energy, Mines and Petroleum Resources*.

Root, D.H., Menzie, W.D. and Scott, W.A. (1992): Computer Monte Carlo Simulation in Quantitative Resource Assessment; *Nonrenewable Resources*, Volume 1, No. 2, pages 125-138.

Singer, D.A. (1993): Basic Concepts in Three-part Quantitative Assessments of Undiscovered Mineral Resources; *Nonrenewable Resources*, Volume 2, No. 2, pages 69-81.