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OREBODIES AND MINING ENVIRONMENT, LINKS BETWEEN GEOLOGY AND QUANTIFICATION

A. Boyer and N.R. Billette

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Canadian Mine Technology Laboratory

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by

A. Boyer* and N.R. Billette**

ABSTRACT

The application of quantitative techniques to solve geological and geoengineering problems is relatively recent. Often borrowed from other fields, models must be selected with care to ensure that they are appropriate. The introduction, increasing use and rapid development of these techniques follows the fast evolution of more powerful computer hardwares and softwares.

Studies have been carried out to establish the usefulness of several quantitative techniques in solving typical geological/geotechnical problems using available exploration and production drillhole data. Results derived from these studies show the techniques are suitable for use in orebody modelling and mine planning. Practical case studies are presented in the report. Following these studies, modelling of bulk material handling systems is used to control mineral or metal feed fluctuations.

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keywords: quantification techniques, 3-D modelling, orebodies, computer, mine-mill blending, environment and mine planning.

GISEMENTS ET ENVIRONNEMENT MINIER, PASSAGE DE LA GÉOLOGIE À LA QUANTIFICATION

par

A. Boyer* et N.R. Billette**

RÉSUMÉ

L'application de techniques de quantification pour résoudre des problèmes géologiques et de géoingénierie est relativement récente. Plusieurs de ces techniques sont des adaptations de modèles développés dans d'autres disciplines et, conséquemment, la sélection de techniques appropriées est de première importance. Le sujet est nouveau et son stage de développement rapide suit l'évoluton accélérée de quincailleries et languages d'ordinateurs.

Dans le but de définir les modèles les plus appropriés, plusieurs techniques de quantification ont été mises au point et/ou vérifiées, en utilisant des données expérimentales disponibles dans nos fichiers informatisés de forages d'exploration ou de production. Les résultats obtenus confirment la validité des modèles de modélisation géologique et de planification minière. Des études de cas sont présentés dans le rapport. La présentation sera finalisée avec l'estimation des mélanges potentiels mine-usine minéralurgique à l'aide de la modèlisation sur la manipulation de matériel en vrac.

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Mots clés: techniques de quantification, modélisation 3-D, gisements, ordinateur, planification minière, mélange mine-usine, environnement et planification minière.

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INTRODUCTION

The Mining Research Laboratories (MRL) are a research division of the Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada. Research, engineering studies and service activities are carried out in the following specialized areas: explosives technology; equipment safety certification; mine environment; explosive atmospheres; rock mechanics; mining methods and equipment; mine feasibility and mineral reserve estimation. The presentation relates to the areas of mineral reserve assessment and mining methods.

Table I indicates some of the possible ways geological data are treated in mining and the desired end applications. Results derived from recent studies in the field of reserve estimation in relationship with orebody modelling and ore blending will be presented. The significance of these latter studies in terms of enhanced resource recovery will be demonstrated.

GENERAL APPROACH

CANMET's Mining Research Laboratories have developed computer tools needed to investigate advanced mathematical models in the field of mining geology and planning. Modelling is being assessed to create the basis for future expert systems in these fields.

Primary data used in the presentation is extracted from confidential drilling data files. Mines are identified by letters to respect data confidentiality. Development of new models and adaptation of existing ones are being made on the basis of that information. Non-parametric, parametric, deterministic and engineering approach is currently used in the areas of drilling data analysis and operational exploitation procedures to model mineral reserves and mine planning activities.

MATHEMATICAL DATA ANALYSIS

Non-parametric functions

Mining geologists and engineers carrying out geostatistical reserve estimation are regularly faced with the problem of minimizing the effect of irregular drillhole patterns

Table I — 2-D and 3-D GRAPHICS MODELLING

	TREATMENT		END RESULT
2-D	DATA ANALYSIS	→	STATISTICAL MODEL
2-D	INTERPRETATION INTERPOLATION GEOSTATISTICS	→	GEOLOGICAL AND GEOSTATISTICAL MODELS
OR			
3-D	MINE LAYOUT	→	MINE DESIGN
	MINE PLANNING	→	PRODUCTION MODEL

on variogram calculations. Journel (1983) has developed the Cell-Declustering technique for the purpose of selecting optimal cell size with irregular drillhole patterns, Figure 1.

The authors have experimented with the technique using available uranium deposits data, Figure 2. There would not appear to be a clearly defined optimal cell size for this deposit on the basis of Journel's theory.

In most practical cases, in mining, clusters in drillhole patterns correspond to the subareas containing higher grade values. In the simplest case, a uniform drill pattern exists, with the exception of some small clusters. A basic grid cell of size t can then be selected which contains at least one datum in most cells. Declustering is applied in the following steps:

(a) overlay a regular grid with cell size t over area T
(b) count the number of data n_l within each cell t_l
(c) weight each value within t_l by $\frac{1}{n_l}$
(d) estimate the average parameter values according to the formula

$$\phi^*(A; z) = \frac{1}{L}\sum_{l=1}^{L}\sum_{\alpha_l=1}^{n_l}\frac{1}{n_l}i(x_{\alpha l}; z)$$

Figure 1 indicates the theoretical curve expected when the Cell-Declustering technique is applied to a simple case. In the more complex case, irregular drill patterns exist and clusters often correspond to high grade areas. The formula must be used repeatedly with various cell sizes. The lowest estimate $E^*(T; O)$ is retained for subsequent use. Figure 2 shows the curve realized in applying this procedure to a uranium mine data. The curve differs from Figure 1 with a peak at about 8,000 m^2 preceded and followed up by minima. The drillhole pattern of the area under study consisted of a subarea (single large cluster) with preferentially high grade values surrounded by a halo where drillhole pattern was half as dense. The 8,800 m^2 peak is related to a relative loss of influence of the cluster: i.e. the proportion of cells associated with the cluster is rapidly decreasing.

The declustering technique applied in this case involves repetitive calculations for various cell-sizes with clusters corresponding to subareas with high values which cause multiple minima plots. To ensure a declustering procedure independent of origin, the cell size may be held constant while cell grid origin is moved (Deutsch, 1989). Declustering weights may be changed, but that part of the study has not been carried out in the present study.

This example enlights the zoning problem of several mineral deposits. In such situations, geostatistical estimation requires in-depth non-standard analysis.

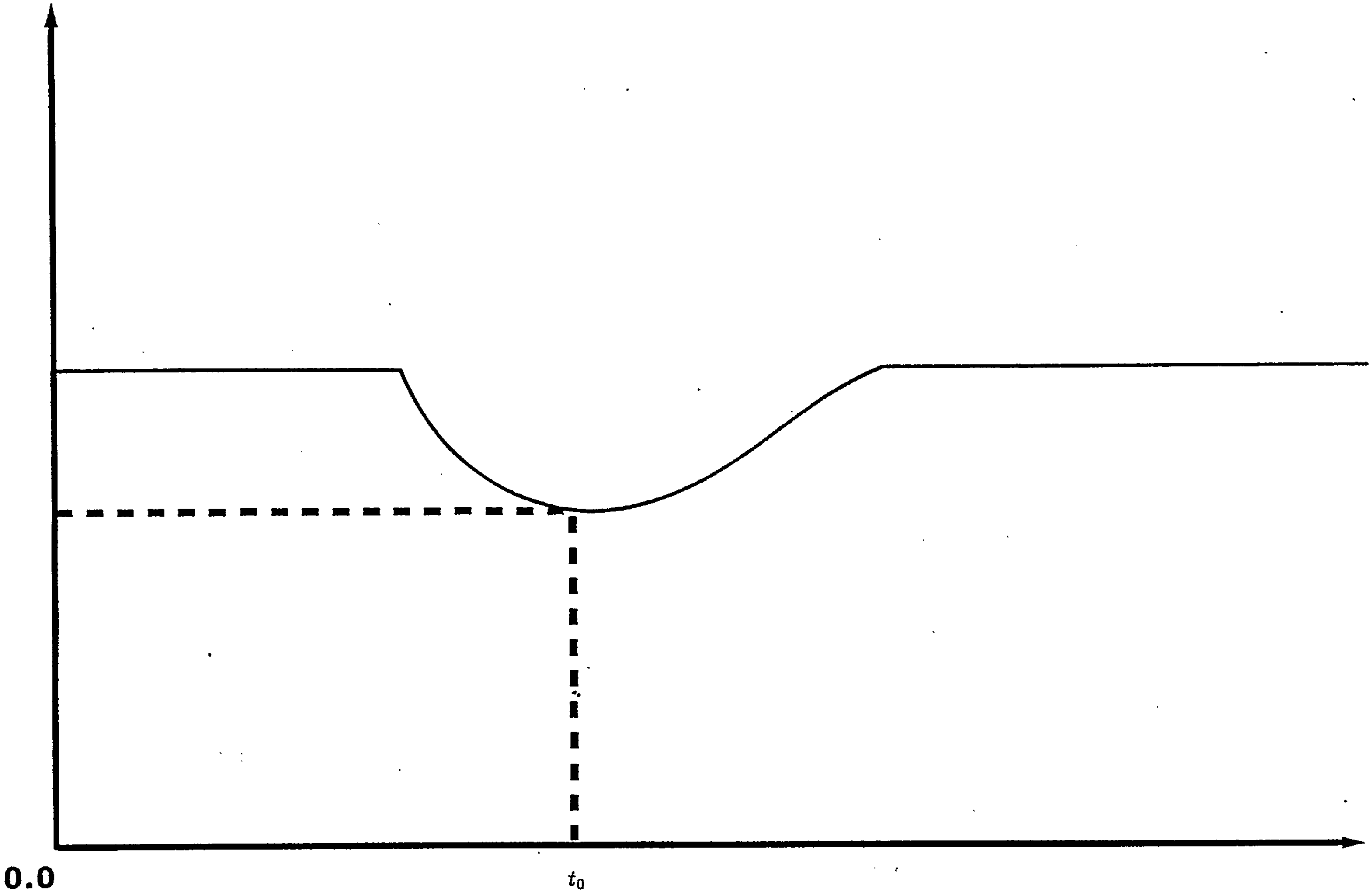

Fig. 1 — Weighted average grade vs unit cell size

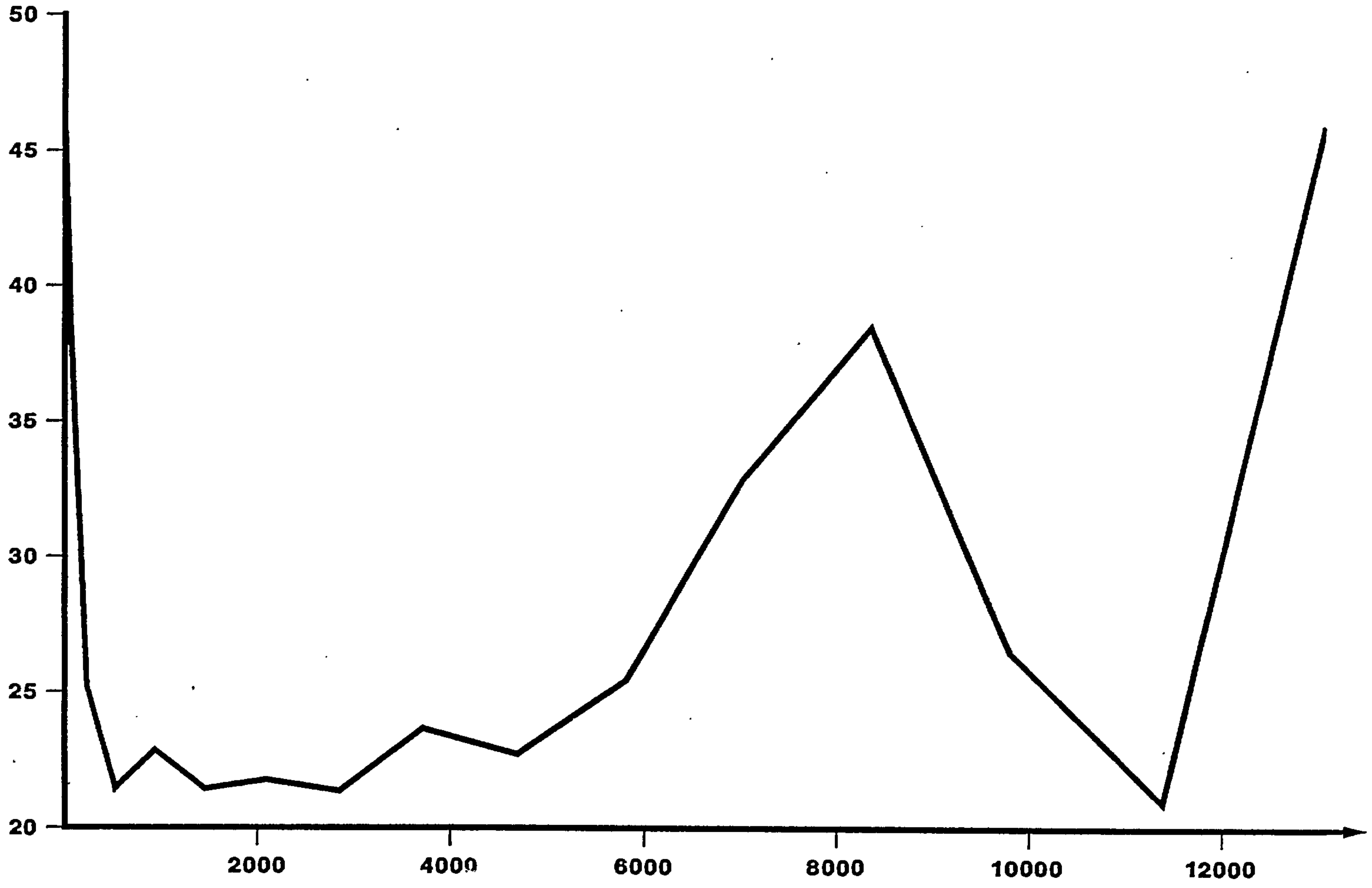

Fig. 2 — Weighted average grade ($U_3O_8\%$) vs cell surface (m^2)

Parametric analysis

Graphical representation of experimental values of the variogram and mathematical model fitting are routine steps in data processing with respect to geostatistical deposit modelling. Figure 3 is a 2-D configuration of directional variograms which has been developed to assess the isotropic or anisotropic nature of an orebody.

QUANTIFICATION TECHNIQUES

Specific gravity (**S.G.**) is one of several geological parameters correlated to metal grade, which has been used to demonstrate some of the quantitative mathematical techniques.

The purpose of the study was to establish the best methodology for estimating specific gravity. Values established using deterministic equations and statistical methods were compared with experimental values. Basic data from three uranium deposits were used in the study. The study results have been presented in the form of graphs and tables of measured, estimated and statistical values.

Rock (**S.G.**) is quite often taken as a constant value in ore tonnage calculations and independent of metal grade. In practice, this is not always the case, especially when metal grades vary widely in a deposit.

Deterministic: rock grain specific gravity calculated on the basis of metal grades

The study first defines the relationship between the grain specific gravity (**S.G.**), i.e. (**S.G.**) of rock samples reduced to fine grained dried materials, and the bulk (**S.G.**) of a rock sample in relation with the weight percentage of heavy metallic constituents (metal grade values) of some minerals. These metal minerals normally account for the high fluctuations of (**S.G.**) within the host rock mass. In practice, a metal can be present in more than one mineral form within a same rock mass. Therefore, one must consider the portion of different minerals hosting an assayed metal to establish the percentage contribution of each one to (**S.G.**).

Boyer, 1989 has developed formulae which can be used to establish the grain and bulk (**S.G.**) of a rock sample on the basis of metal grades.

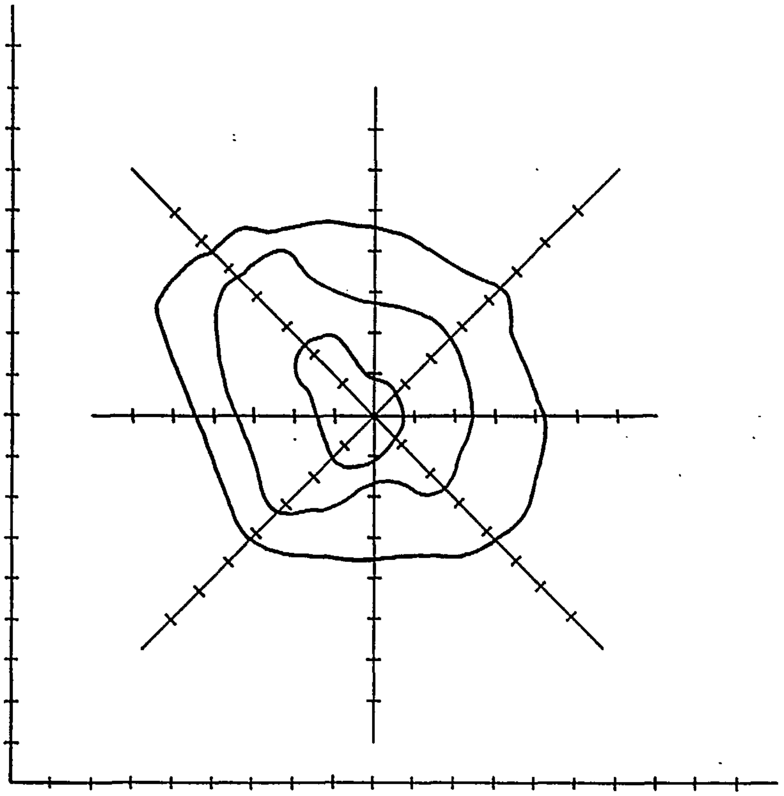

Fig. 3 — Isocurves: directional values (variogram)

Figure 4 is an example where measured and estimated (S.G.) values are plotted against three components composite grades (U (%) + Ni (%) + Co (%)). Some method readjusments could be made to achieve a better fit between the measured and estimated (S.G.) values. One of the adjustments, illustrated in Figure 5, consists of re-estimating average dry bulk (S.G.) values of waste rock for composite grade values above 20 % (compare with Fig. 4).

The following parameters are the main cause of discrepancies between experimental and estimated values:

1) The variation of dry bulk specific gravity of the rock mass because of geological factors (eg. porosity and alteration),

2) The lack of quantitative data on the percentage contribution of each mineral to the metal grade value of a sample.

To quantify the dry bulk (S.G.) with this method, it has been necessary to integrate porosity into the grain specific gravity formula.

Classical statistics and specific gravity

The relation between (S.G.) and the grade of two metals, a and b, contained in two minerals A and B has been described by Matheron (1962).

The specific volume of an ore sample can be used as a regionalized variable similar to metal grade. If a strong correlation exists between specific volume and grades a and b, then the best possible estimator of the specific volume of a and b can be derived as the estimator of the minimal variance.

This method permits the construction of simple linear charts relating the specific gravity of a deposit to actual metal grades (see Fig. 6).

Minimal discrepancies are obtained when suitable metal grades have been used to estimate (S.G.). This example concerns a case where rock type is ignored, i.e. the best metal grade composite was used to estimate (S.G.), Figure 7.

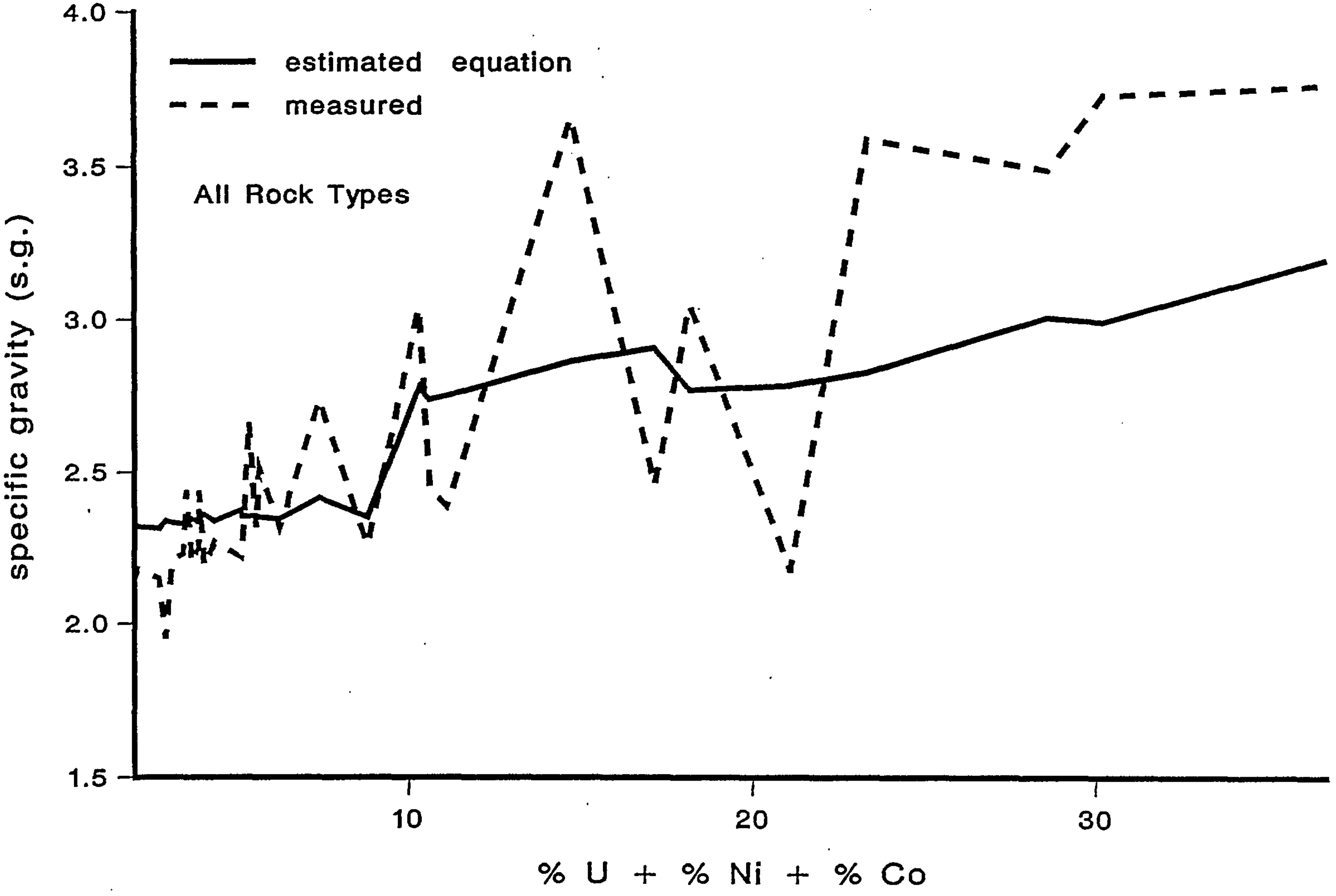

Fig. 4 — Measured/estimated grain specific values with grade

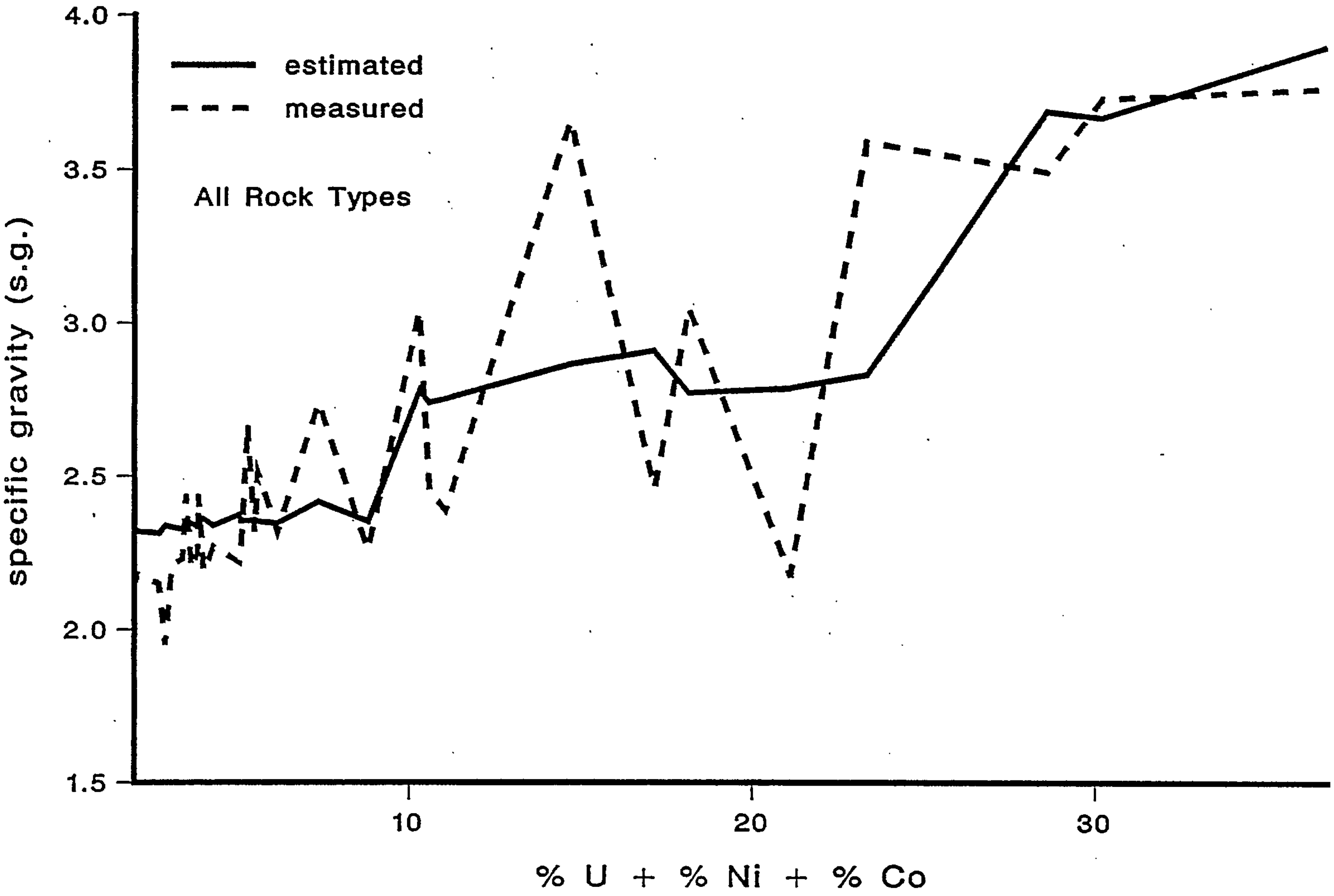

Fig. 5 — Measured/estimated grain specific values with grade

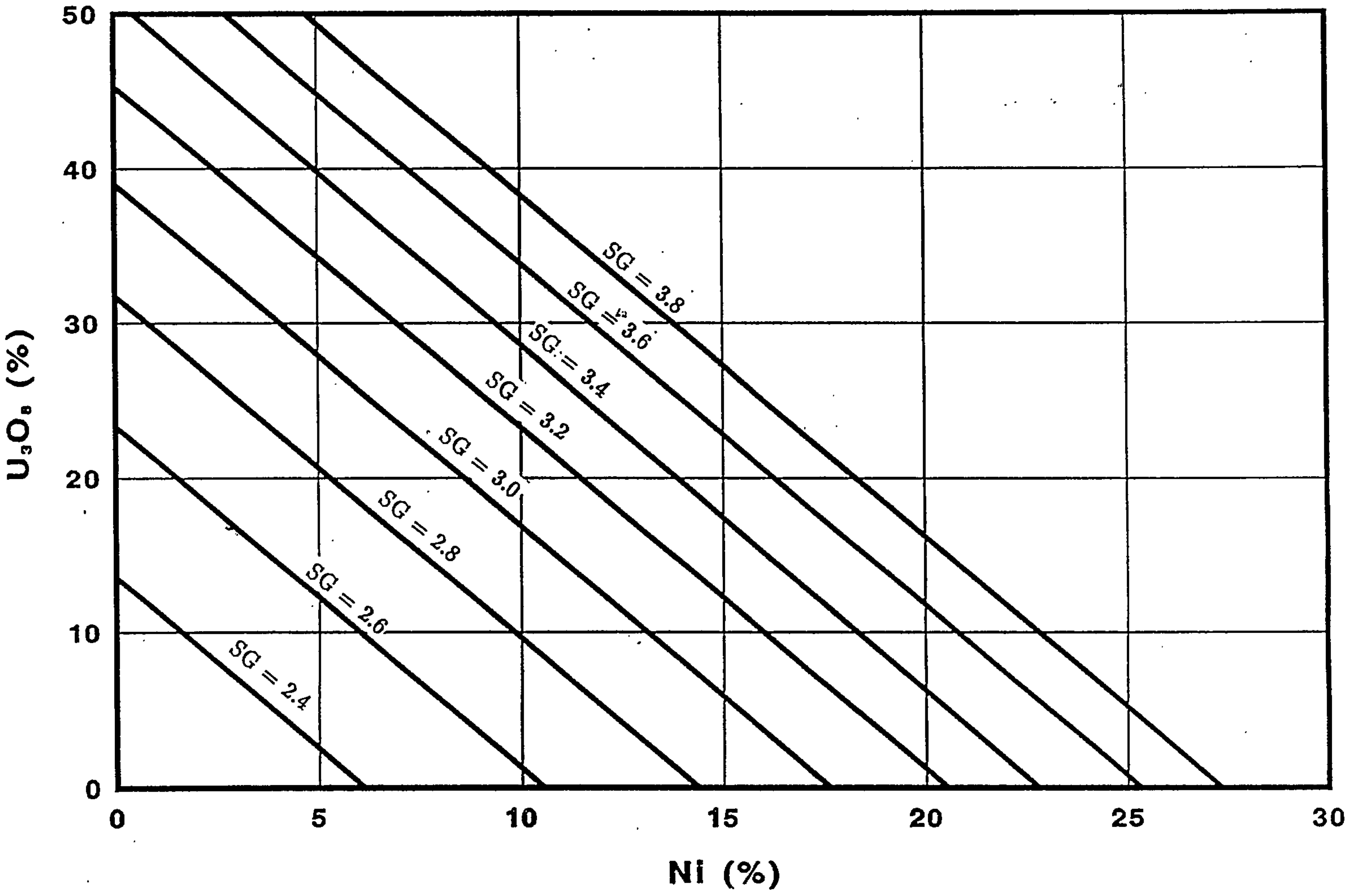

Fig. 6 — Specific gravity chart

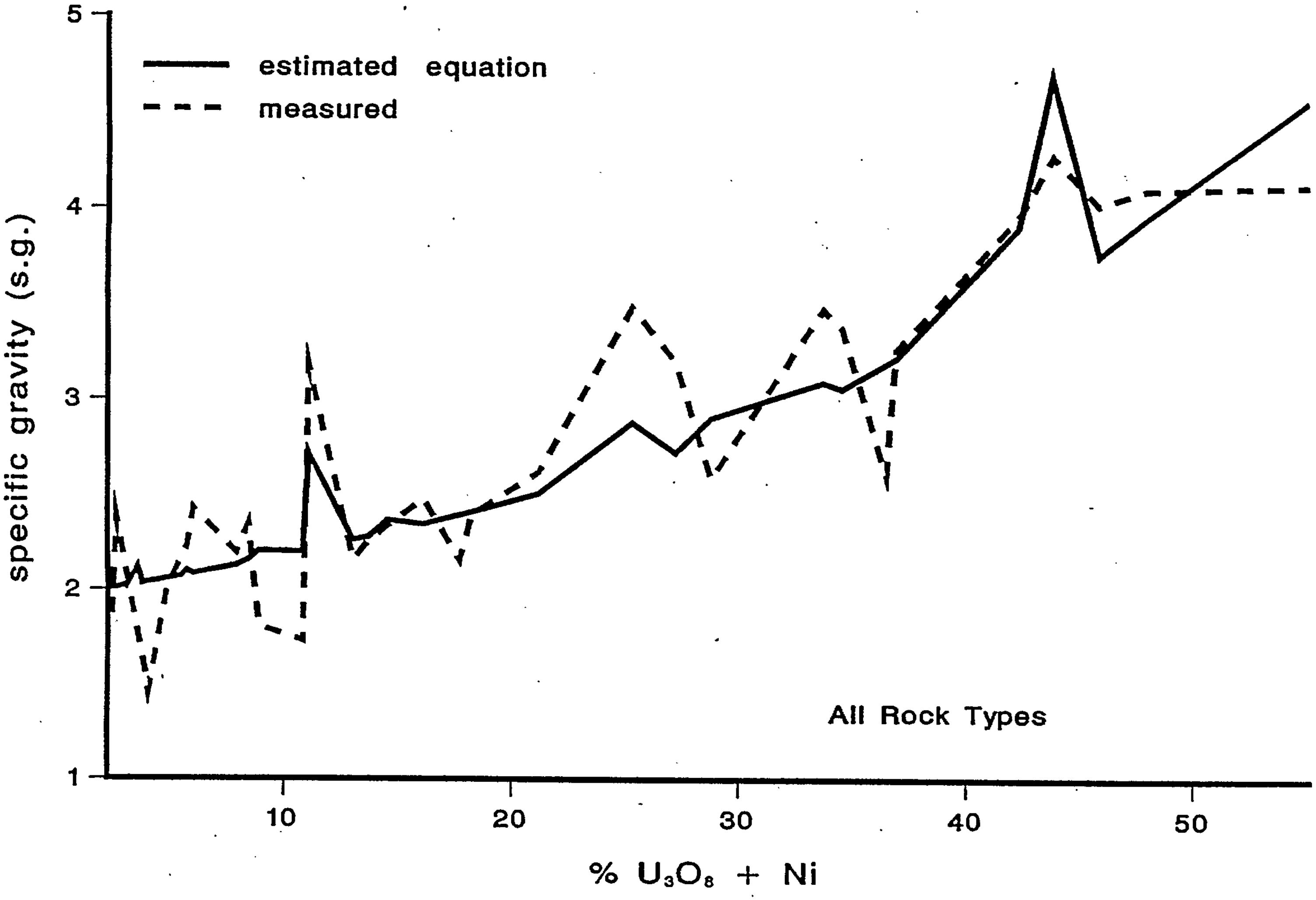

Fig. 7 — Measured/estimated dry bulk specific values with grade

GEOLOGICAL MODELLING

The statistical technique of cross-correlation must be used when a sequence of data from one drill log is to be compared with a sequence of observation points from a second drill log to evaluate the optimal degree of matching (Day and Tucker 1987).

Some recent attempts have been made in the field of 2-D modelling, and what should be called 2 1/2-D geological modelling, to interpolate borehole or core section geophysical properties.

The development of algorithms for 3-D solid modelling is in its infancy. The hidden-line algorithm using the picture subdivision technique (Lo 1988) is one of the few methods presently available. It was adapted to the authors computer system for the purpose of 3-D modelling of reserve blocks and stopes.

MINE PLANNING

Not all geological modelling at the Mining Research Laboratories, CANMET, is concerned with ore reserve assessment. Some modelling is developing tools for use in mine planning and design. Several 3-D graphical representations will be required relating geology and mining units with mine layout.

To improve mine design and planning, and to increase metal or mineral recovery, with reduced negative impact of mining on environment, it is necessary to establish an appropriate model of material flow out of the mine to become mill or washery feed (Billette, 1986).

Figure 8 indicates the steps involved in modelling open pit ore blending. Related operational activities and possible problems in model development are indicated. The steps in building a model are the following: quantify correlation on a bench or level basis; model ore flow out of the bench; blend ore streams from various benches; define blending or segregation in ore piles or silos.

Directional variograms can be generated for each bench of a pit to represent the selected variable correlation for material in the mineralized area. The quality of information output is dependent upon the quality of field sample information. At the production stage, field sample information comprises all blasting drillholes and thus

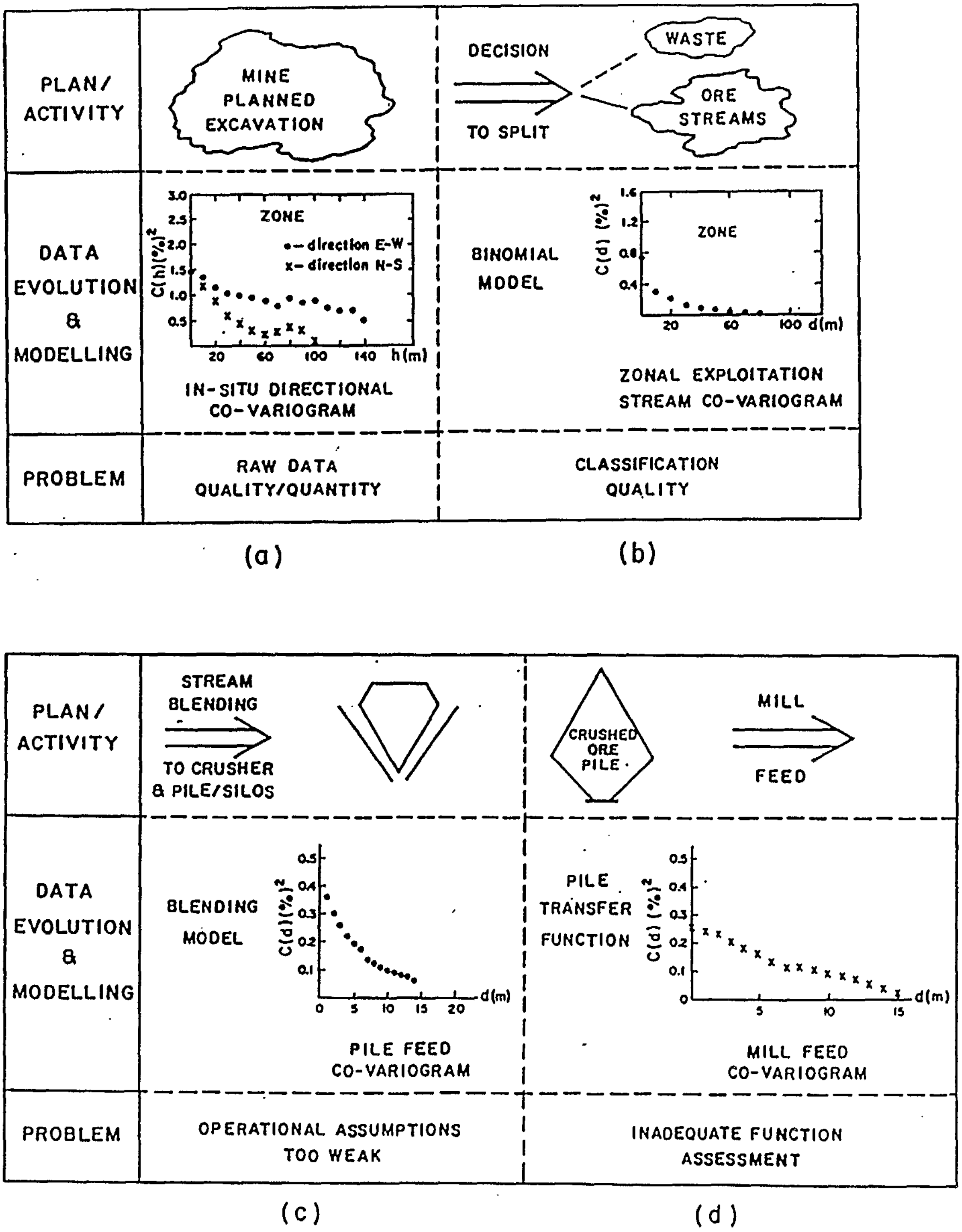

Fig. 8 — Integrating ore blending into mine planning (steps a to d)

correlation models are better than at exploration stage. Sampling errors can be introduced if no automatic device is used to gather drill cuttings for analysis. Quantity is no guaranty of quality for data used in deciding allocation as waste or ore zones.

After ore/waste cut-off decision, in-situ correlation of ore blocks differs from total material, because of a much lower variance or more uniform grade. A modified binomial model may be used to model correlation for ore streaming with respect to production block sequencing. Correlation is now unidimensional, considering the linear stream out of the zone. Success in arriving at a fair representation of reality is dependent on the following factors: satisfactory classification of ore and waste removal activities; length of ore and waste sequences; block selectivity.

Once each ore stream correlation has been properly defined, different combinations of the various streams can be analyzed to determine the most efficient operation taking into account ore fluctuations. A signal model is required to represent ore stream correlation from the mine to either the crusher or a blending/reserve pile, according to each mine setup. Average train length from each zone is used to calculate correlation at this point. Calculations need to be made to allow for inter-zone correlation when this condition exists (Billette, 1986). At this point, discrepancies between the real system and model normally result from deviation in day to day activities from the ideal smooth operation. Operational deviations from an established plan are unavoidable and the model should be sufficiently flexible to take them into consideration.

Mineral correlation is modified when depositing ore on a pile for future use. Granulometry segregation occurs which modifies feed quality. When centrally reclaimed underneath, segregation occurs only when the pile is being built. Ore properties are modified afterwards in a constant way. However, a transfer function needs to be established to estimate ore correlation in the outlet stream. The accuracy of this function is often questionable, but usually does not adversely affect establishment of the correlation for the ore exiting the pile or silo. Unless there is a repeat of one or more of the previous steps, ore enters the mill for processing with the properties given by the model at this point. Ore is normally sampled when reaching the mill and provides a means of checking model validity.

Once established, the model makes it possible to analyze the impact of modifications to existing operations. Thus modifications in operations can be assessed in terms of their impact on: mine economics; reduced cut-off grade; minerals recovery due to reduced fluctuations in feed grade; mine-mill communications.

CONCLUSION

The presentation has shown that theoretical and pragmatic or statistical techniques may be used to model various parameters in mineral reserve assessment and mine planning. Case studies have demonstrated the difficulty in linking mathematical models to the reality of the geological environment. Potential economic benefits derived from similar investigations are spectacular and justify such technological developments.

Further extensions will see the introduction of mine design and planning 2-D and 3-D capacities and standard mine planning tools, while mathematical algorithms and other operations research techniques (see table I) will be developed in-house.

Canadian environment is generally fragile and ecosystems are easily disrupted. Governments have become more concerned by any environmental disruption caused by industrial activities, including mining. Consequently, tailings and other mine wastes are being continuously monitored for solids or heavy metal discharge into the hydrological network. Recent regulation changes tend to become more stringent. It is thus imperative that enhanced recoveries of metallic minerals contained in the ore produced take place.

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