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SPECIFIC GRAVITY ESTIMATION FROM METAL GRADE VALUES

A. Boyer

DIVISIONAL REPORT MRL 89-52 (TR)

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ABSTRACT

The basic information used for this study comes from previous work associated with the estimation of uranium deposits specific gravity. The generation of estimated values was necessary to complete drilling data files because only 1/5 of the core samples have been measured for dry bulk specific gravity. This lack of specific gravity data is explained by the high cost of such laboratory measurements.

The main study goal is to establish the best methodology for this type of estimation. First, comparison must be done between experimental results and estimated specific gravity results obtained from deterministic equations for single or selected rock types, or without discriminating the rock types. The linear deterministic relationship between specific gravity and the metal grade values of certain minerals forming the rock mass is used to estimate the specific gravity of ore samples. Secondly, the statistical method is introduced. This method also implies a linear relationship between the specific gravity and the metal grade. As in the first case, the estimated values are compared with the associated experimental values.

The results obtained from both methods permit a good appreciation of each one. The fluctuations between estimated and associated experimental values are calculated in each case and serve as one of the main basic criteria for the appreciation of the two methods: deterministic and statistic.

The present study permits comparison between various results from three uranium deposits using two different estimation procedures. The analysis is supported, in each case, by charts showing both experimental and estimated curves, precision Figures, Tables, and results from statistical studies using several metal grade values and experimental dry bulk specific gravity values. Geological interpretations based on these results are also described further in the text.

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*** **Key words**: CANMET/MRL, R & D, reserves estimation, specific gravity, methodology

All these values (experimental and estimated) are used for further ore reserve estimation work of high grade uranium deposits where a variable specific gravity is deemed essential for ore tonnage estimates.

ESTIMATION DE LA DENSITÉ SPÉCIFIQUE À PARTIR DES TENEURS EN MÉTAL

par

A. Boyer**

RÉSUMÉ

L'information de base qui a servi à cette étude provient de différents travaux initiés dans le passé sur l'estimation de la densité spécifique. Ces dernières valeurs étaient requises pour compléter les fichiers de données de forages où environ 1/5 des échantillons carottés ont été mesurés pour la densité spécifique. Ce manque de données sur la densité spécifique s'explique par le coût élevé des mesures en laboratoire.

Le sujet principal de cette étude est d'établir la méthodologie la plus adéquate pour ce genre d'estimation. Premièrement, les résultats des valeurs estimées de densité spécifique par la méthode déterministique pour un type de roche en particulier ou pour plusieurs types sans discrémination pour le type de roche sont comparés avec les valeurs expérimentales associées. La relation linéraire déterministique entre la densité spécifique et les valeurs en teneur métal de certains minéraux qui composent la masse rocheuse est utilisée pour l'estimation de la densité spécifique d'échantillons de minerai Deuxièmement, la méthode statistique est introduite. Elle implique aussi une relation linéaire entre la densité spécifique et les teneurs en métal. Comme dans le premier cas, les valeurs estimées sont aussi comparées aux valeurs expérimentales associées.

Les résultats obtenus par les deux méthodes permettent une appréciation juste de celles-ci. Les fluctuations des valeurs estimées par rapport aux valeurs expérimetales associées sont calculées dans chacun des cas et servent de critères de base pour l'appréciation des deux méthodes: déterministique et statistique.

L'étude actuelle permet de comparer les résultats de trois gisements d'uranium en utilisant deux méthodes d'estimation. L'analyse de chaque méthode est supportée

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*** Mots clés: CANMET/LRM, R & D, détermination des réserves, densité spécifique, méthodologie

par des graphiques montrant les courbes des valeurs expérimentales versus les courbes de celles estimées, ainsi qu'à l'aide de tableaux montrant les calculs de précision et de certains résultats des études statistiques sur les teneurs en metal et la densité spécifique expérimentale. Une interprétation géologique des résutats obtenus est également décrite plus loin dans ce texte.

L'ensemble des valeurs estimées et expérimentales sont utilisées pour des travaux subséquants d'estimation de réserves, spécialement pour les dépôts d'uranium à hautes teneurs où la densité spécifique, comme variable, est nécessaire pour un meilleur estime du tonnage de minerai.

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INTRODUCTION

Normally, a constant value is used to estimate ore tonnage. Still, in the case of deposits which are characterized by high variations in metal grade and consequently high variations in dry or wet bulk specific gravity, it is necessary for each assayed core sample to have its corresponding specific gravity value. With such data file completed for specific gravity values, it is then possible to use a variable specific gravity (dry or wet bulk ...) for estimation of ore tonnage.

In the following pages, severals cases are analysed using two different methods. Both methods use the relationship between metal grade values and specific gravity.

The first method is a deterministic approach based on the basic relationship between specific weight/volume and specific gravity, which relationship was adapted to integrate the metal grade values of one or several minerals. These minerals are known to influence the variation in specific gravity of the rock mass. The porosity factor can be another important parameter that will be considered in the equation to estimate the dry or wet bulk specific gravity, when the porosity factor of a rock sample is greater than zero.

The second approach also uses a linear estimator in relation with the metal grade values which are proportional to the useful grade of minerals containing these metals. The statistical parameters used are determined from 'n' experimental metal grade values.

The description of both methods and results are followed by a discussion at the end of this report. This section summarizes the main conditions required to achieve the best results for both methods.

The report also includes charts (fig. 7 to 9) to demonstrate the practical use of the statistical method. These charts permit a quick estimation of SG (if only two metals are involved) by reading the SG values corresponding to the intersecting point of two metal values read from x and y axis (Ni and U_3O_8).

Appendix A consists of four charts showing dry bulk specific gravity ranges by rock type. These charts are derived from all the experimental values available for Northern Saskatchewan uranium deposits and can be used as a reference material for newly discovered uranium deposits. The main feature shown on the charts is the wide specific gravity range obtained for many rock type, thus the importance to use a variable specific gravity.

DETERMINISTIC APPROACH TO ESTIMATE ROCK SPECIFIC GRAVITY

Rock specific gravity is quite often taken as a constant value in ore tonnage calculations where it is regarded as a variable independent from metal grades. In practice, it is not always the case. The following chapters will show several case studies where metal grades (high grade ore) have a major influence on specific gravity variation in ore materials.

This study will define the relationship between the grain* and the bulk specific gravity of a rock sample in relation with the weight percentage of some heavy metallic constituents (grade values in %) contained in some minerals. These minerals are normally ore-bearing minerals in a deposit and are responsible for the high variations of specific gravity within the rock mass hosting them.

Rock grain specific gravity calculated from metals grade

First, the grain specific gravity of a rock sample is defined as the ratio between the mass of its constituents and its true volume unaffected by porosity. Mass is defined as the sum of individual mineral masses present in the rock material.

The grain specific gravity (D_g) of a rock sample can then be defined in terms of its minerals (heavy minerals) using the following formula:

$$D_g = V_1 D_1 + (1 - V_1) D_w \tag{1}$$

In equation (1) we arbitrarily equalized the total volume (unaffected by porosity) of the rock mass to unity, with V_1 being the proportion of total volume occupied by the heavy mineral grains and $(1 - V_1)$ being the volume occupied by other minerals forming the mass of the waste rock material. D_1 and D_w are respectively the specific gravity of mineral (1) and waste rock material.

The grade of a mineral is defined as the ratio: weight of the heavy metal mineral over rock sample total weight; grade is reported as a percentage of the rock sample total weight .

* grain specific gravity: specific gravity of a rock sample reduced to fine grained material with a porosity close to zero.

$$g_1 = V_1 D_1 / D_g \times V \quad (2)$$

with $V = 1$.

Replacing V_1 in (1) by $g_1 \times D_g / D_1$ yields:

$$D_g = g_1 D_g \quad (1 - g_1 D_g / D_1)\, D_w$$

or

$$D_g = D_w / (1 - g_1(1 - D_w / D_1)) \quad (3)$$

where g_1 is the grade of the mineral containing heavy metal 1.

To convert mineral grade into metal grade, the following relationship holds:

$$g_1 = G_1(\%) / (K_1 \times 100) \quad (4)$$

where

K_1 = mineral atomic weight/metal atomic weight

and G_1 is the metal grade.

Equation (3) can be transformed to provide the grain specific gravity of a rock in relationship to the grade of a metal,

$$D_g = \frac{D_w}{(1 - G_1(\%) \times (1 - D_w/D_1)/(K_1 \times 100))} \quad (5)$$

or

$$\frac{1}{D_g} = \frac{1}{D_w} \times (1 - G_1(\%)\ (1 - D_w/D_1)/(K_1 \times 100)) \quad (6)$$

with

D_g = grain specific gravity

D_w = waste rock specific gravity

D_1 = mineral specific gravity

G_1 (%) = metal grade in percent

by defining:

$D_0^1 = \frac{1}{D_w}$,

$A_1^1 = (1 - D_w/D_1)/(D_w \times K_1 \times 100)$,

and $Y = \frac{1}{D_g}$

Equation (6) becomes a linear expression of the form:

$$Y = D_0^1 - A_1^1 \times G_1(\%) \qquad (7)$$

and for (n) different metal grades, equation (7) becomes a multiple linear expression:

$$Y = D_0^1 - \sum_{i=1}^{n} A_i^1 \times G_i(\%) \qquad (8)$$

where

$A_i^1 = \left(1 - \frac{D_w}{D_i}\right) / (K_i \times 100 \times D_w)$

D_i = average mineral specific gravity (eg. PbS = 7.5)

NOTE:

Waste specific gravity must also be provided. It is normally obtained by calculating the arithmetic average of specific gravity measured from waste rock grab samples or core samples of barren rock.

Dry bulk specific gravity

In the preceeding section, we ignored the porosity factor. It must be considered in estimating the specific gravity of a dry rock sample (dry bulk specific gravity). The following relationship holds between grain specific gravity, dry bulk specific gravity and porosity:

$$D_g = D_b/(1 - P) \qquad (9)$$

where

D_g = grain specific gravity of the rock sample;
D_b = dry bulk specific gravity of the rock sample;
P = overall porosity of the rock sample (as a fraction of 1).

$$Y = \frac{1}{D_g} = \frac{(1-P)}{D_b} = D_0^1 - \sum_{i=1}^{n} A_i^1 \times G_i(\%) \tag{10}$$

and

$$Y_b = \frac{1}{D_b} = D_0^1/(1-P) - \sum_{i=1}^{n} A_i^1 \times G_i(\%)/(1-P) \tag{11}$$

or

$$Y_b = B_0^1 - \sum_{i=1}^{n} B_i^1 G_i(\%) \tag{12}$$

where

Y_b = inverse of the dry bulk specific gravity

$B_0^1 = D_0^1/(1-P)$

$B_i^1 = \left(1 - \frac{D_w}{D_i}\right) / (K_i \times 100 \times D_w \times (1-P))$

The porosity of rock samples, especially of core samples is rarely available because of time and money involved in laboratory measurements. Normally, only a few data are available on porosity determination of core samples. An estimator can be derived from the slope of the regression line using grain specific gravity and dry bulk specific gravity data. Regression lines do not serve the purpose of formulating a simple relationship between dry bulk specific gravity and grade values of metals. Therefore, it is more convenient to use a single porosity estimator value in equation (12).

A common case: several mineral grades for the same metal grade

In practice, a metal can be present in more than one mineral within the same rock sample. Therefore, we must consider the portion of each mineral containing the same assayed metal. In this case, the grade $G_i(\%)$ is the sum of the metal grade of each mineral contributing to this sample single metal grade value ($G_i(\%)$).

$$G_i(\%) = \sum_{j=1}^{m} g_i^j \times K_i^j \times 100 \tag{13}$$

with m being the number of different minerals for the same metal present in the rock sample.

For $m = 2$, Equation (3) becomes:

$$D_g = D_w/(1 - g_1^1(1 - D_w/D_1^1) - g_1^2(1 - D_w/D_1^2)) \tag{14}$$

Normally, contribution of each mineral to the grade of a single metal is not available and an estimated value must be used in each case. Let's define G_1^J as a given metal grade of mineral J.

When two minerals are present, metal content is:

$$G_1(\%) = G_1^1(\%) + G_1^2(\%)$$

where $G_1(\%)$ is the actual assay value for metal 1

Now we can simulate mineral grade values in relation to metal 1, actual grade, according to the following equation:

$$G_1^1(\%) = MG_1^1 \times G_1(\%) \tag{15}$$

where,

$MG_1^1 = \frac{G_1^1(\%)}{G_1(\%)}$

and $G_1^1(\%)$ = metal 1 grade of mineral 1.

Using the relationship between mineral and metal grades in (14), when several mineral grades contribute to a single metal grade, the following equation can be found:

$$D_g = D_w/(1 - G_1(\%)(\sum_{j=1}^{n} MG_1^j(1 - D_w/D_1^j)/K_1^j)/100) \tag{16}$$

This equation establishes a multiple linear relationship between grain or bulk specific gravity of a rock sample and the grade(s) of metal(s) influencing specific gravity of the host rock in a mineralized rock mass.

Dry bulk specific gravity

As demonstrated earlier in the section, the relationship in (9) can be used to estimate the dry bulk specific gravity of a rock sample from the grain specific gravity.

Replacing D_g by $D_b/(1 - P)$ in (16) yields:

$$D_g = D_b/(1-P) = D_w \times (1 - P)/(1 - G_1(\%)(\sum_{j=1}^{n} MG_1^j(1 - D_w/D_1^j)/K_1^j)/100) \quad (17)$$

where D_b is the dry bulk specific gravity of the rock sample.

It should be noted that in practice, only an overall porosity value is used for the estimation of the dry bulk specific gravity of a sample from the grain specific gravity.

ANALYSIS OF EXPERIMENTAL [1] VS ESTIMATED VALUES

Specific gravity vs rock type

a) Dry bulk S.G.* estimation using all rock types —

The following set of figures (1 to 6) are used to compare S.G. values measured in a laboratory with the ones derived from the deterministic equations using grade values of metals contained in a sample.

First, it is important to mention that what is called here measured S.G. (figures 1 to 4) is in fact the dry bulk S.G. of drill core samples. Estimated values are the estimated dry bulk S.G. (if porosity is negligeable) of the same drill core samples.

The following case concerns the estimation of dry bulk S.G. for three uranium deposits without discriminating for rock type. Figures 1 to 3 show various degrees of curve fitting with the best fit for deposit B (fig. 2). The rock mass of deposit B is very

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[1] experimental dry bulk specific gravity values measured in laboratories

* S.G.: for specific gravity

Fig. 1 — Comparison Between Measured and Estimated Specific Gravity Values

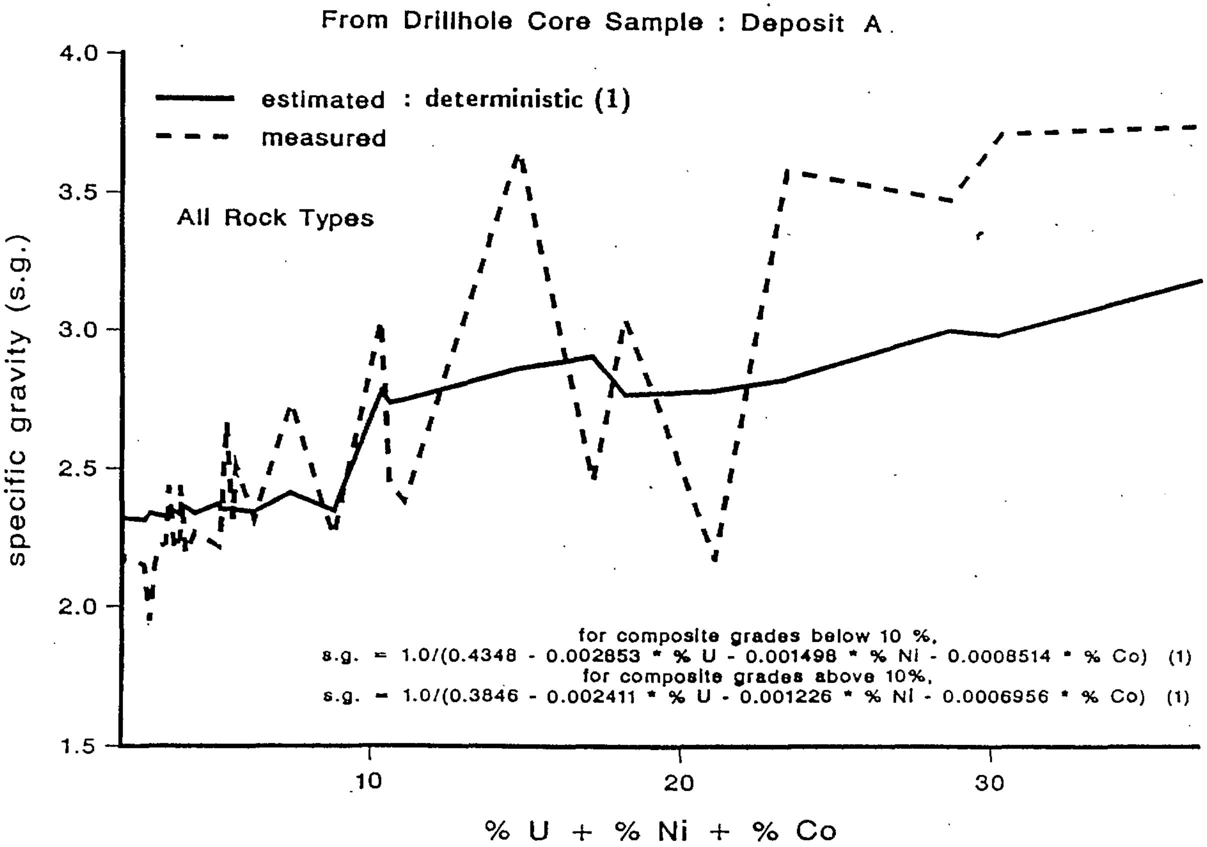


Fig. 2 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit B

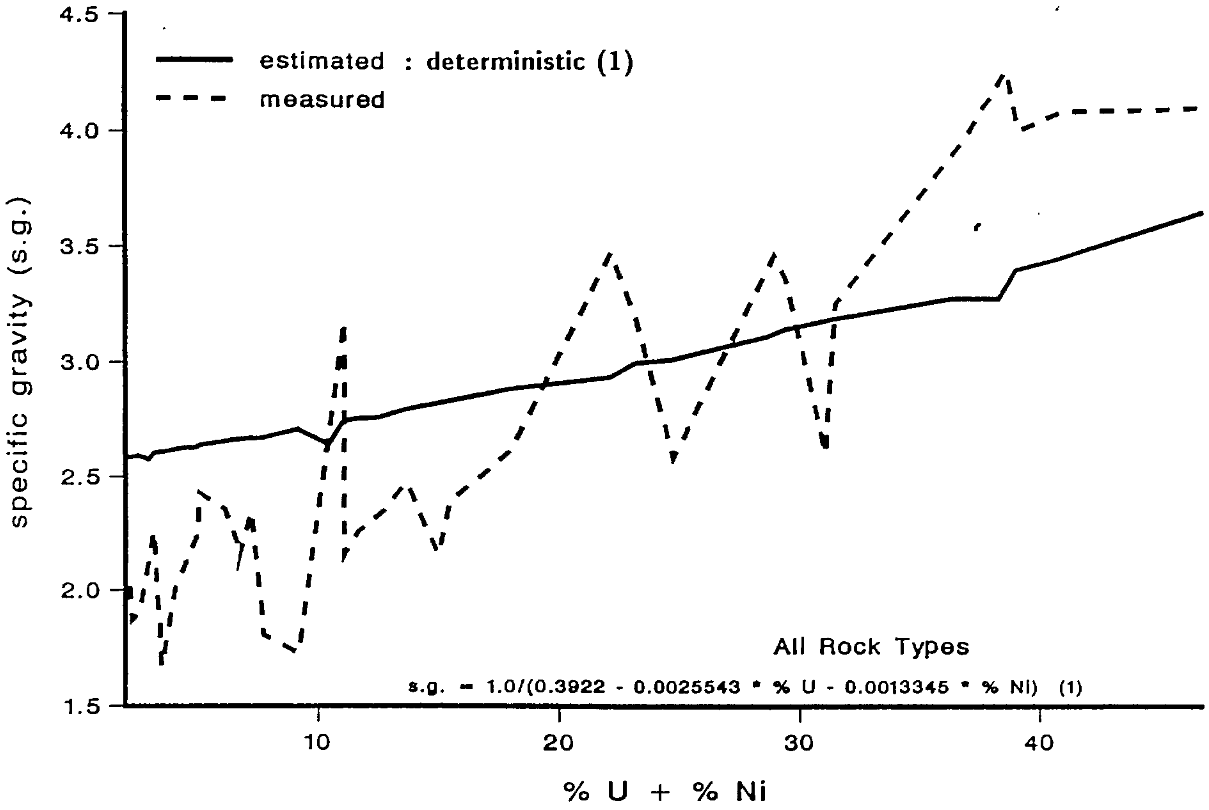


Fig. 3 — Comparison Between Measured and Estimated Specific Gravity Values

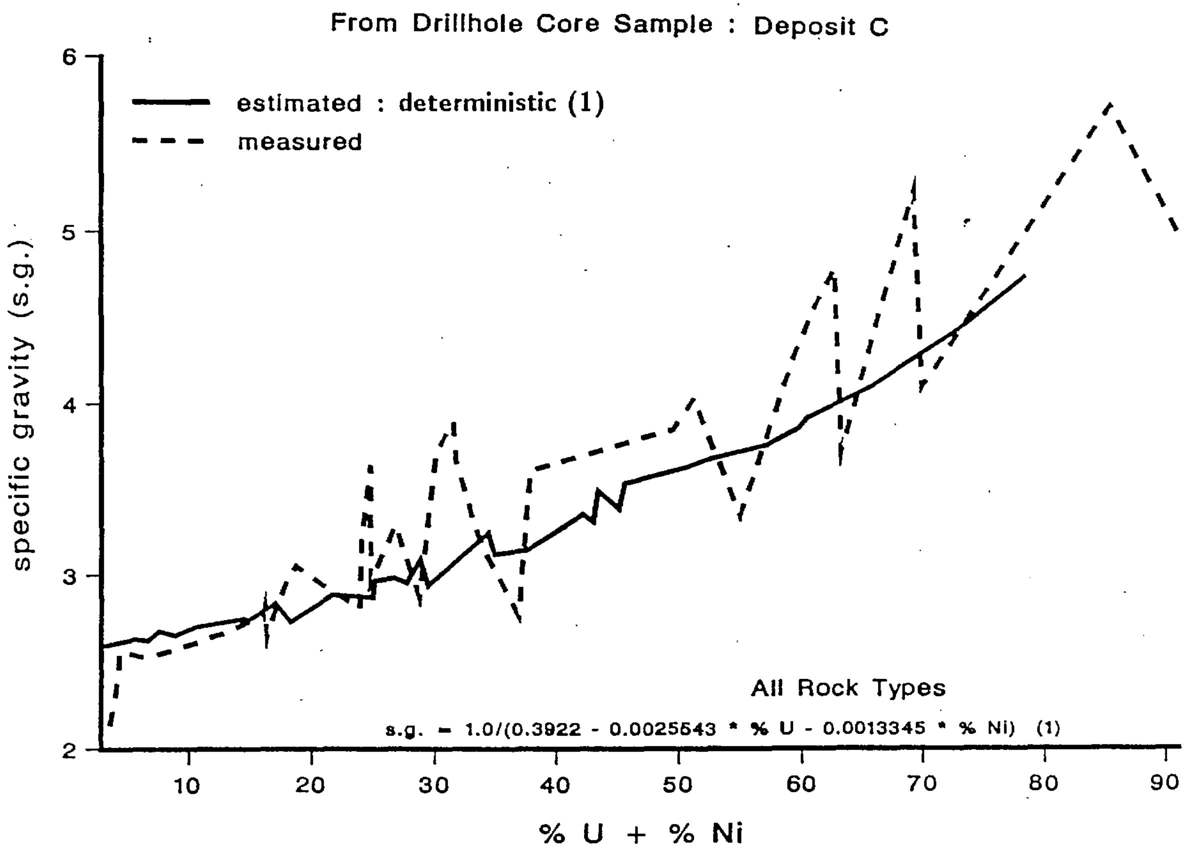
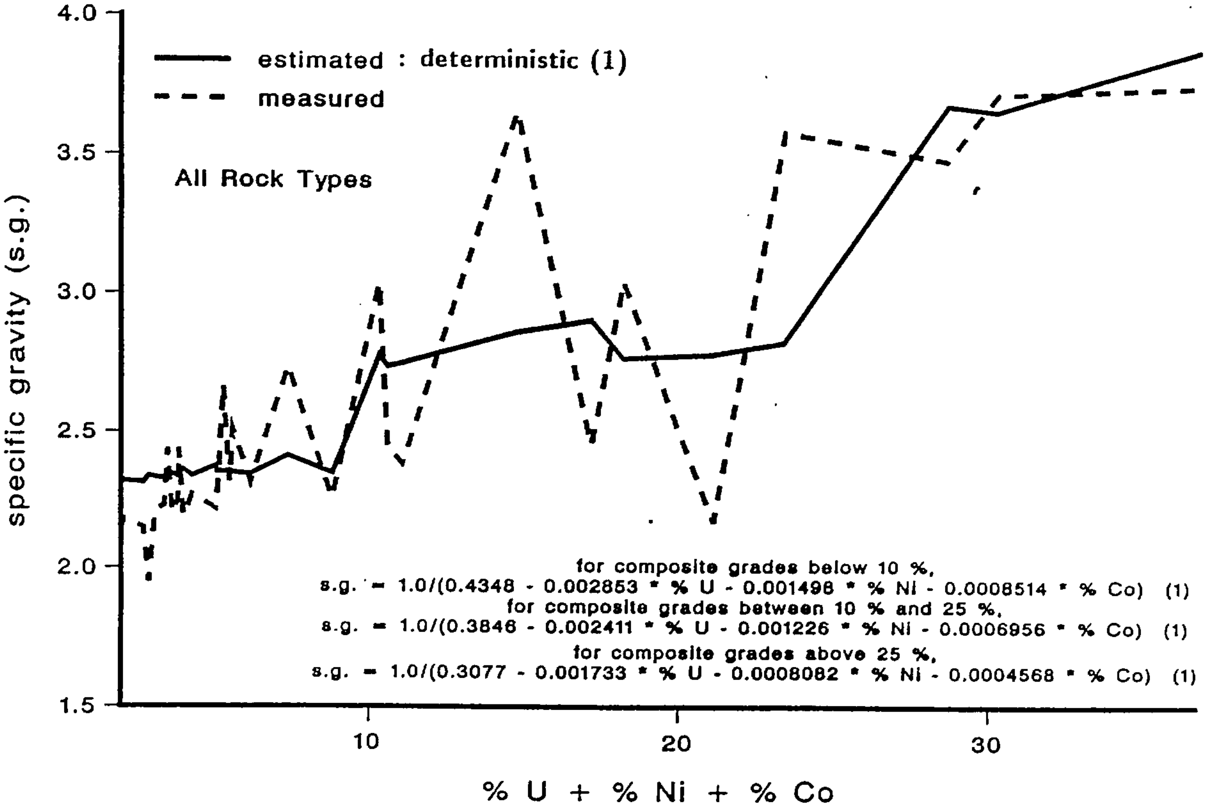


Fig. 4 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A



altered and therefore represents a more homogeneous host rock mass for mineralization than deposits A and C. The rock masses of deposits A and C comprise various rock types affected by poor to high degrees of alteration. It should be noted here that the rock mass mentioned above is the one hosting the uranium mineralization associated with other metals.

As it was described in the preceeding chapter, average dry bulk S.G. of waste rock material must be provided to estimate the dry bulk S.G. of a sample. It is obvious from figures 1, 2 and 3 that best results are obtained for a more homogeneous rock mass or samples from the same type of rock. It should also be noted that the experimental data curves of deposits A and C (fig. 1 and 3) compared with their respective curves of estimated values, show an underestimation of the dry bulk S.G. for composite metal grades above 20 % (fig. 1) and 30 % (fig. 2). We also observe an overestimation for composite grade values below 10 % in both cases.

Some readjustments can be done to get a better fit between the measured and estimated specific gravity values. One of them consists of re-estimating the average dry bulk S.G. (D_w, waste rock specific gravity) for specific metal grade ranges as shown in figure 4 for composite grades values above 20 % (compare with fig. 1). Other factors influencing the results are porosity and additional metal grades. Simulation studies combining these variables in proper manner will yield a better curve fitting.

It should be mentioned at this point that Saskatchewan deposits are characterized by alteration associated with the ore zones. The degree of alteration varies from weak to very strong and can influence the dry bulk specific gravity of the rock due to a variable porosity. This last factor is not directly considered in the estimation of the dry bulk specific gravity. The percentage of these alteration minerals will be necessary and used in equations (6) or (11).

b) Dry bulk S.G. estimated by rock type —
Two examples of the same deposit are shown (figures 5 and 6) where experimental values are grouped, in both cases, for three ranges of composite grades (U (%) + Ni (%) + Co (%)) and for specific rock types. The curve fits between the measured and the estimated values are slightly improved. In both cases, the average differences (see table 1) between measured and estimated values is lower than the ones calculated for figures (1) and (4) data.

This latest approach is more consequent with geological environment where more than one rock type is involved and where alteration processes have affected rock masses at various degrees.

Fig. 5 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A

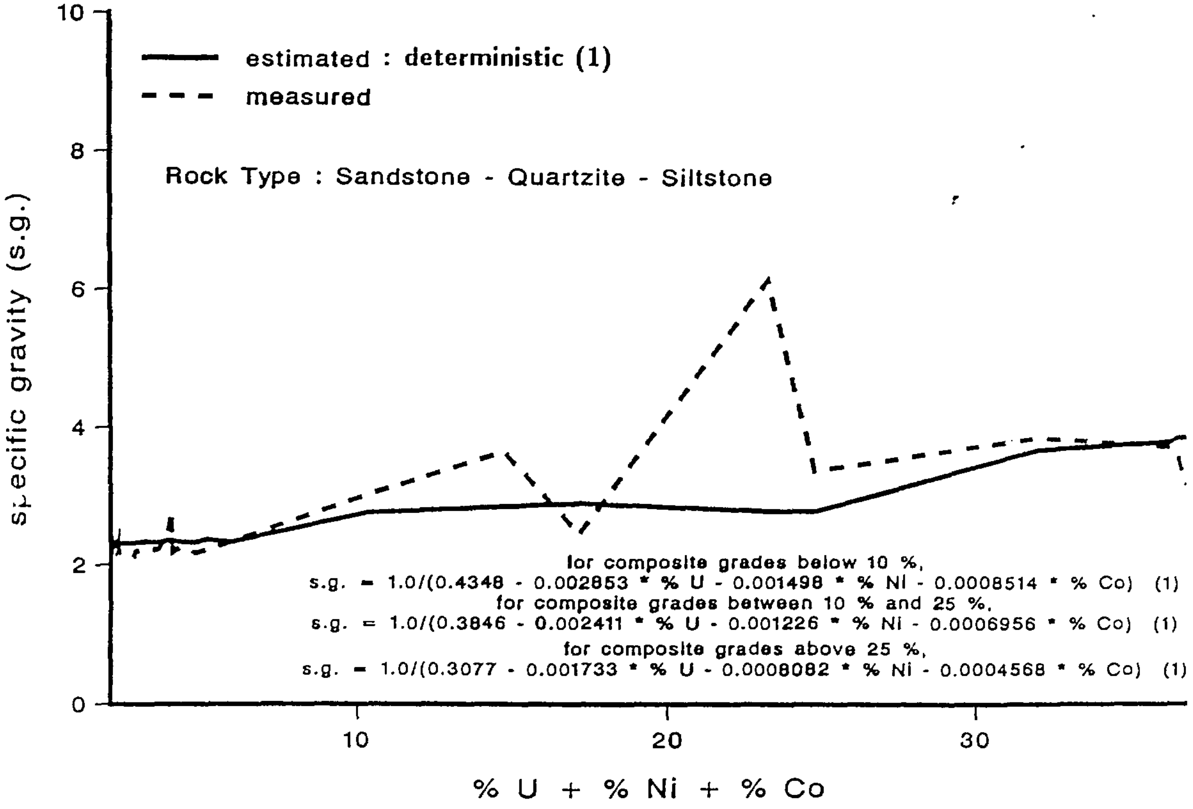


Fig. 6 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A

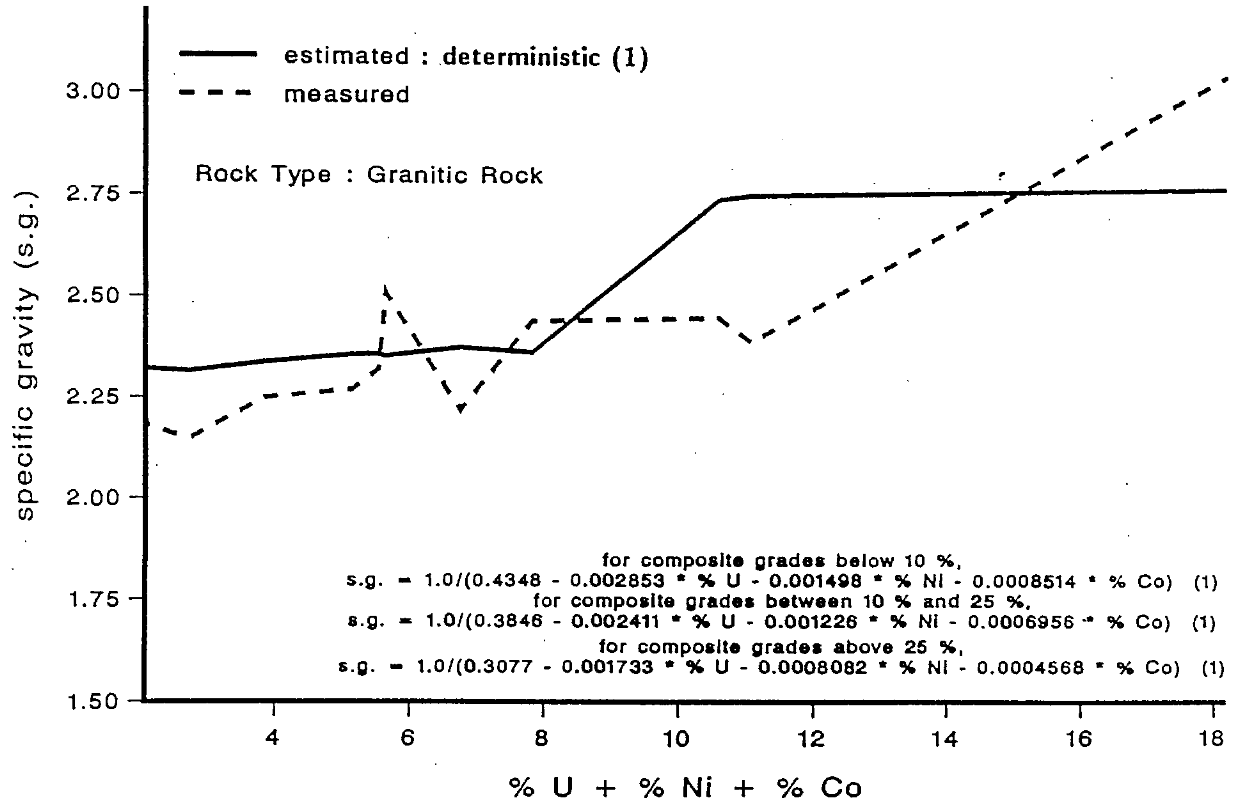


Table 1 — Average of differences: measured - estimated values

(Dry bulk specific gravity derived from deterministic equations)

Deposit name	Corresponding fig. number	Rock type	Average of differences
Deposit A	figure 1	all types	0.3147
Deposit B	figure 2	all types	0.5016
Deposit A	figure 4	all types	0.2773
Deposit A	figure 5	sandstone - quartz.- silt.	0.2550
Deposit A	figure 6	granitic	0.1645

Table 2 — Average of differences: measured - estimated values

(Dry bulk specific gravity derived from statistical parameters)

Deposit name	Corresponding fig. number	Rock type	Average of differences
Deposit A	figure 10	all types	0.3057
Deposit A	figure 11	clay rock	0.5059
Deposit A	figure 12	granitic rock	0.2724
Deposit A	figure 13	unspecified	0.3261
Deposit A	figure 14	sandstone - quartz.-silt.	0.2000
Deposit B	figure 15	all types	0.5077
Deposit B	figure 17	all types	0.2356
Deposit B	figure 18	all types	0.3094

CLASSICAL STATISTICS AND SPECIFIC GRAVITY

The influence of S.G. in relation to the grade of two metals a and b, contained in minerals A and B was well described by Matheron (1962).

The specific volume $(1/\rho)$ of an ore sample appears as a regionalized variable like the metal grade. Because of the strong correlation between that variable and grades a and b, equation (18) is interpreted as an expression of the best possible estimator of the specific volume of a and b, i.e., as the estimator of the minimal variance.

In practice we take, *at priori*, a linear estimator in relation to the grade of metals x and y which are proportional to the useful grade of minerals A and B. The equation is:

$$\frac{1}{\rho} = \mu = \lambda x + \beta y + \mu_0 \qquad (18)$$

The parameters λ, β and μ_0 are determined from n experimental grade values assayed for minerals A and B from samples for which the specific gravity has been determined. Variance of the estimator is minimal if these parameters have the following classical values:

$$\lambda = \frac{R_{\mu x} - R_{\mu y} R_{xy}}{1 - R_{xy}^2} \frac{S_\mu}{S_x}$$

$$\mu = \frac{R_{\mu y} - R_{\mu x} R_{xy}}{1 - R_{xy}^2} \frac{S_\mu}{S_y}$$

$$\mu_0 = \bar{\mu} - \lambda \bar{x} - \beta \bar{y}$$

with:

— $\bar{\mu}$ = arithmetic average: inverse of the specific gravity (experimental values),

— $\bar{x}$ = assayed sample, grade of metal x,

— $\bar{y}$ = assayed sample, grade of metal y,

— S_μ, S_x and S_y : standard deviation of the above variables,

— $R_{\mu x} = \frac{1}{n} \frac{\sum (\mu_i - \bar{\mu})(x_i - \bar{x})}{S_\mu S_x}$; coefficient of correlation between variables μ and x,

— $R_{xy} = \frac{1}{n} \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{S_x S_y}$; coefficient of correlation between variables x and y,

— $R_{y\mu} = \frac{1}{n} \frac{\sum (y_i - \bar{y})(\mu_i - \bar{\mu})}{S_y S_\mu}$; coefficient of correlation between variables μ and y.

Finally, the estimator variance for these parameter optimal values, i.e. the residual variance of the specific volume when considering grade values x and y, becomes:

$$\sigma_\mu^2 = \frac{1 + 2R_{\mu x}R_{xy}R_{y\mu} - R_{\mu x}^2 - R_{xy}^2 - R_{y\mu}^2}{1 - R_{xy}^2} S_\mu^2 \qquad (19)$$

This variance will be zero if the specific volume can be derived strictly with grade values x and y. In general, it will be different from zero and will represent the degree of residual variability of the regionalized variable, i.e. the specific volume when grade values x and y are known. It is simply the calculation of the degree of precision where equation (18) permits the estimation of the specific volume and its inverse, i.e. the specific gravity.

Equation (19) permits the construction of simple linear charts to determine the specific gravity of a deposit from actual metal grades. Figures 7 to 9 are examples of linear specific gravity charts derived from actual U_3O_8 (%) and Ni (%) grade values in three deposits.

ANALYSIS OF EXPERIMENTAL [1] VS ESTIMATED VALUES

General comments

The discrepancy between estimated and experimental values is (on average) less than 10 % with the average difference between experimental - estimated values ranging from 0.17 to 0.32 (see table 2) when $U_3O_8\% + Ni\%$ composite grades or $U_3O_8\% + Ni\% + Co\%$ composite grades are used to estimate the dry bulk specific gravity. Minimal discrepancies are obtained when the proper metal grades are used to estimate SG.

The discrimination by rock type does not seem to be necessary when using this statistical method. Because results are derived from a data set of measured specific gravity values, the representativity of the selected samples is a basic condition to accurately estimate the specific gravity within certain metal grade ranges.

Deposit A

First, let us consider the case where no discrimination for rock type is applied (fig. 10). This case shows one of the best fits according to the results listed in table 2.

[1] experimental dry bulk specific gravity values measured in laboratories

Figure 10 shows an example of a slight underestimation of the dry bulk specific gravity for composite grade values ($U_3O_8\% + Ni\%$) above 20 %.

The second part concerns the cases where a linear relationship is applied to several SG estimations for each rock type (figures 11 to 14). The application of the method using for single or grouped rock types the same metal grade values does not indicate better results then the ones obtained in the first case, except for results related to figure 14. Again, as mentioned in the first case above, the figures (11 to 14) indicate a slight underestimation of the dry bulk specific gravity for composite metal grade values above 20 %. The worse case is shown by figure 11 for clay material. These samples are related to altered rock where the alteration intensity varies from weak to strong. This last geological feature may explain local variations in porosity and dry bulk waste SG. Also, locally, other anomalous heavy metal minerals may occur and influence the SG of a rock mass. These factors will explain anomalous results observed in the above mentioned figures.

Deposit B

This section is concerned with cases where the rock type is ignored, i.e. samples of all rock types are taken for the calculations. In the following cases, the results derived from different combinations of metal grade composites is the only subject of the study.

The first case involves a single metal grade (U %) where estimated results show major discrepancies with experimental values (see fig. 15 and table 2).

In the second case, Pb (%) is added to U (%). The estimated results compared to experimental values show a systematic underestimation of the dry bulk SG. In this case, such results were anticipated based on the statistical results obtained previously in the study. The correlation coefficient indicates a weak dependance between the two variables (see appendix B).

The last two cases refer to metal grade composites where metal grade values are combined according to the best results obtained from the regression slope analysis of several metal assays (U, Ni, Pb and Co), including regression analysis studies of various combinations of these metal grade values with experimental dry bulk SG values. In these last two cases, the comparison between experimental and estimated values for dry bulk SG shows satisfactory results and demonstrates the importance of selecting the proper metal grade composite specific to deposit B.

Fig. 7 — **CHART for the Computation of the Specific Gravity**

(using actual Uranium and Nickel grades)

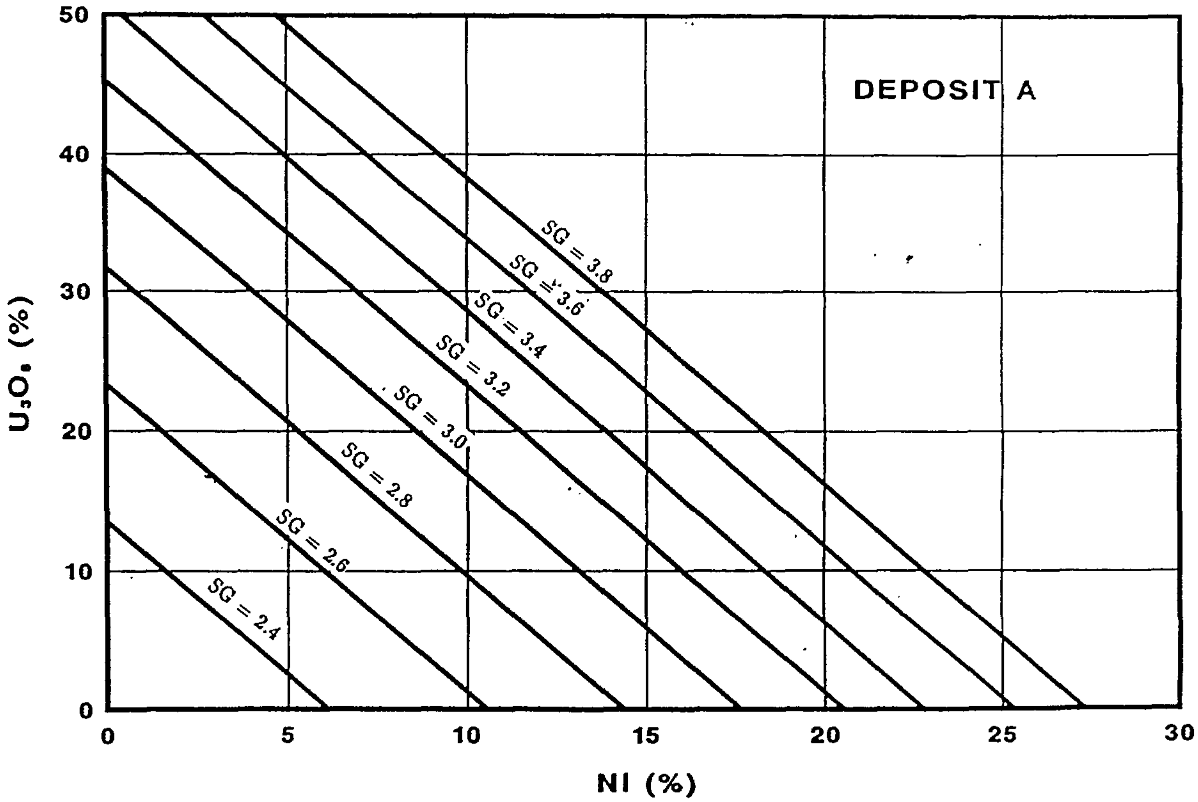


Fig. 8 — **CHART for the Computation of the Specific Gravity**

(using actual Uranium and Nickel grades)

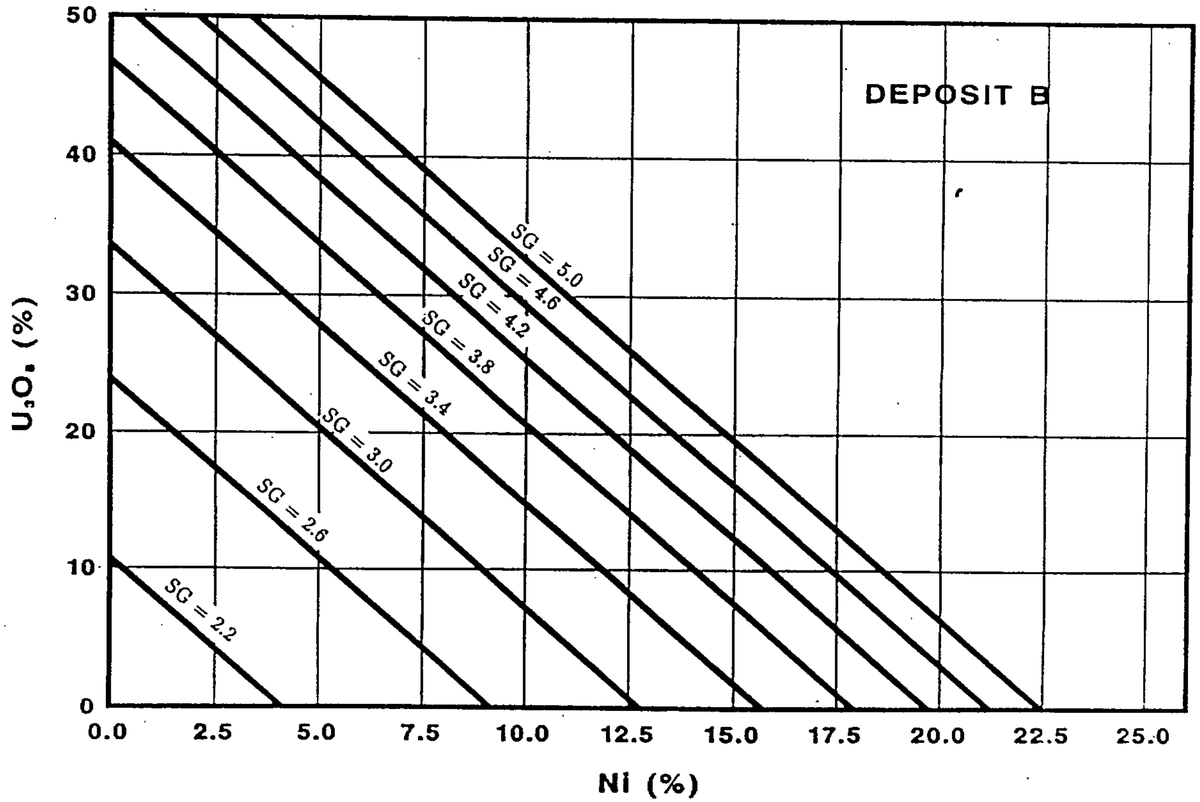


Fig. 9 — **CHART for the Computation of the Specific Gravity**

(using actual Uranium and Nickel grades)

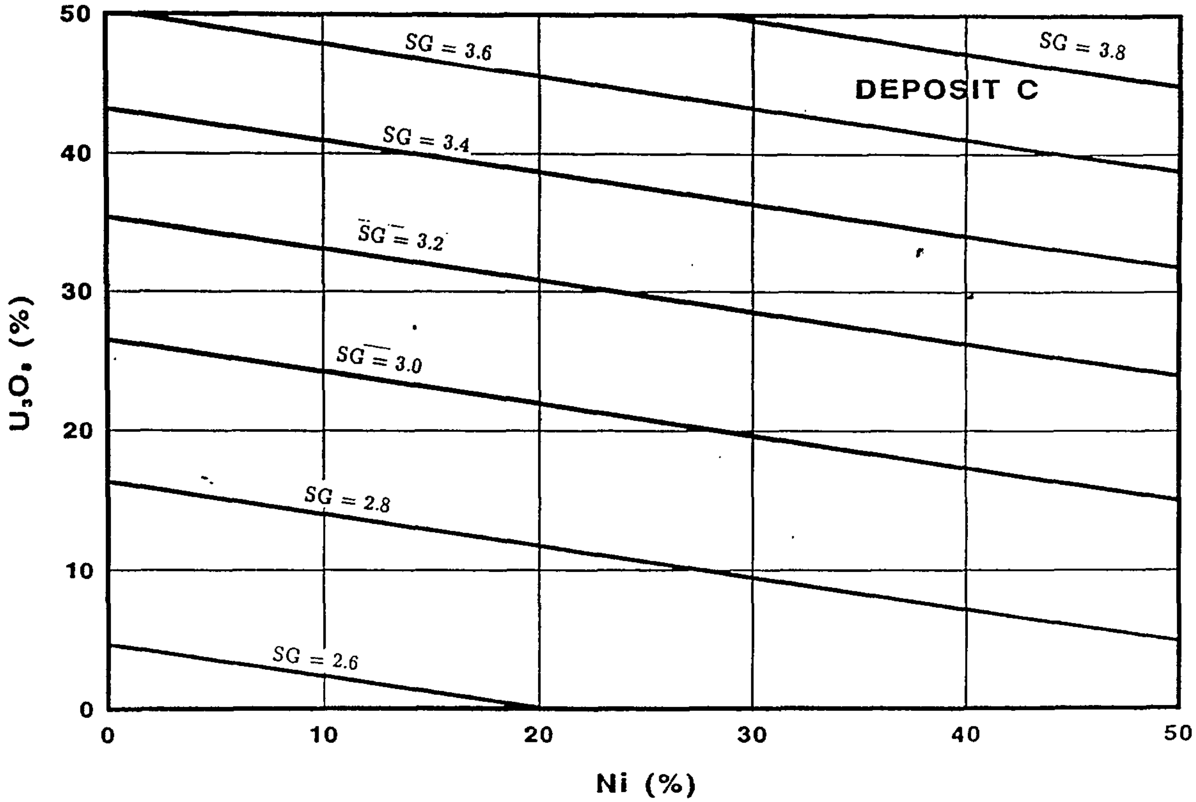


Fig. 10 — Comparison Between Measured and Estimated Specific Gravity Values

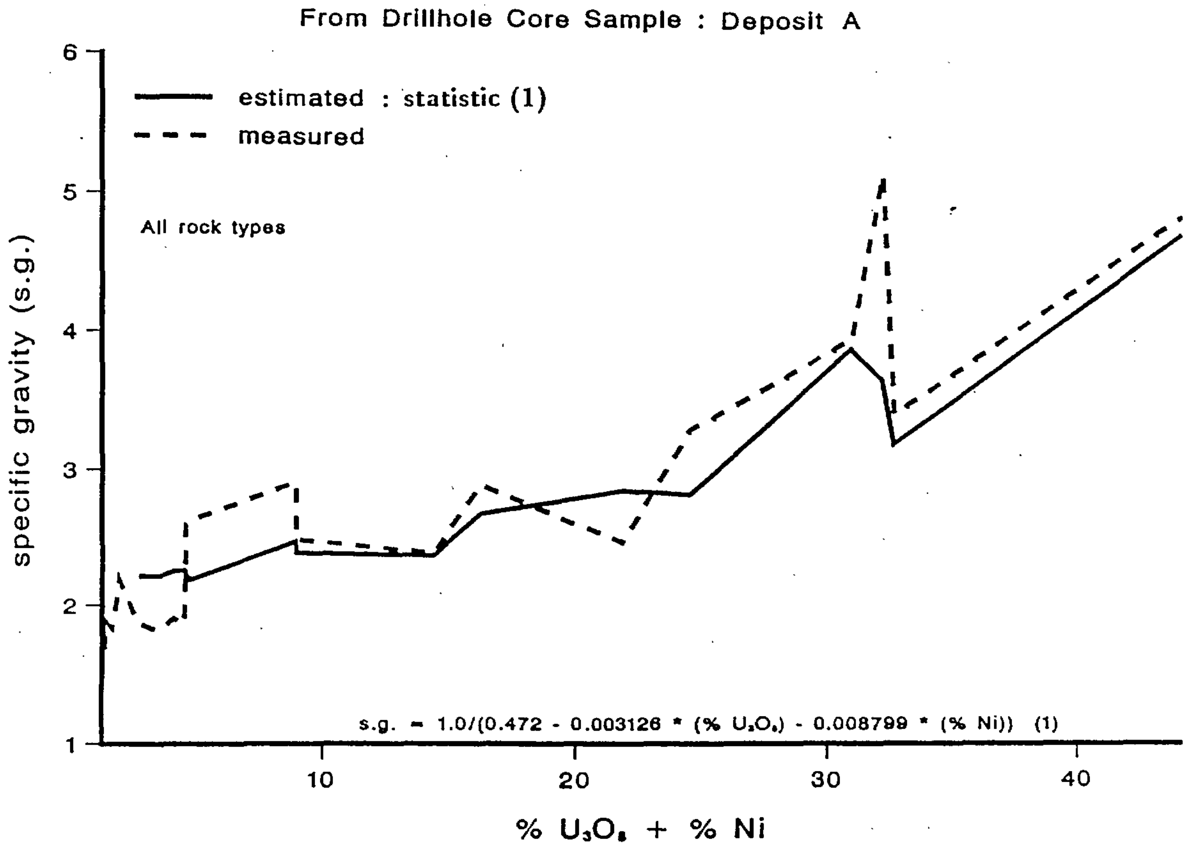


Fig. 11 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit: A

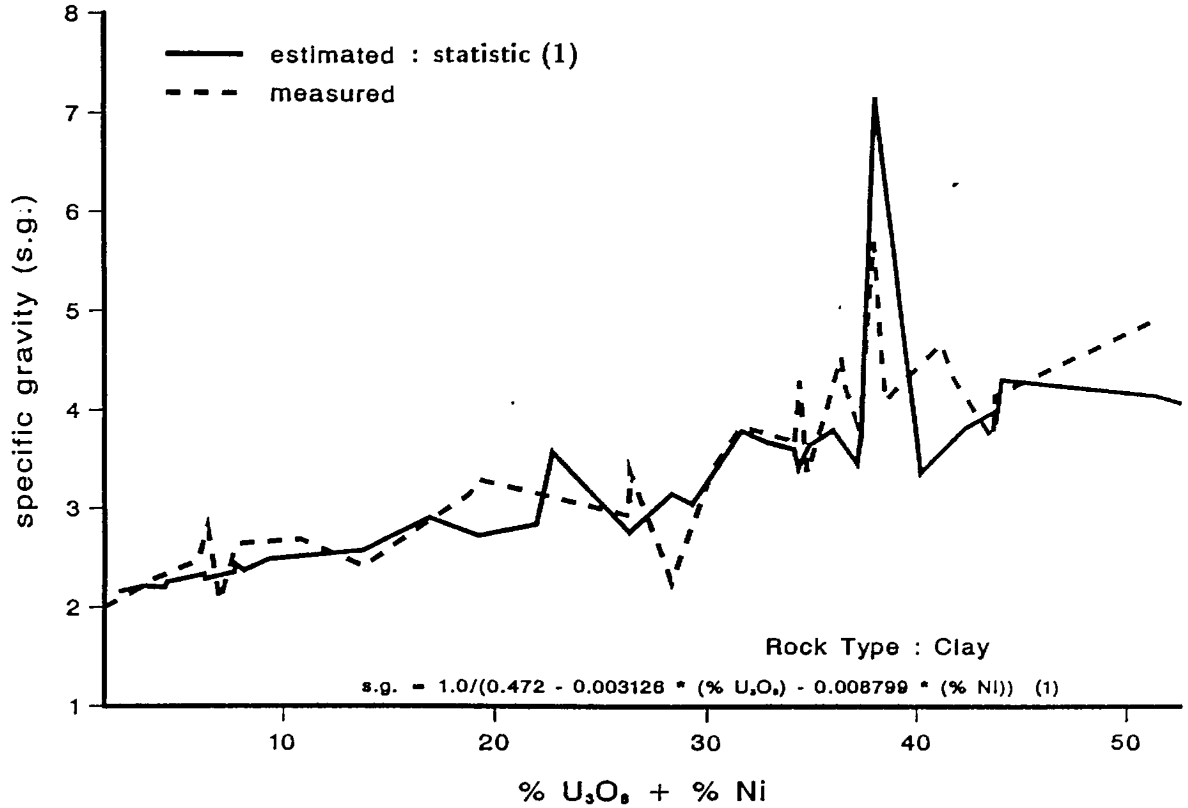


Fig. 12 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A

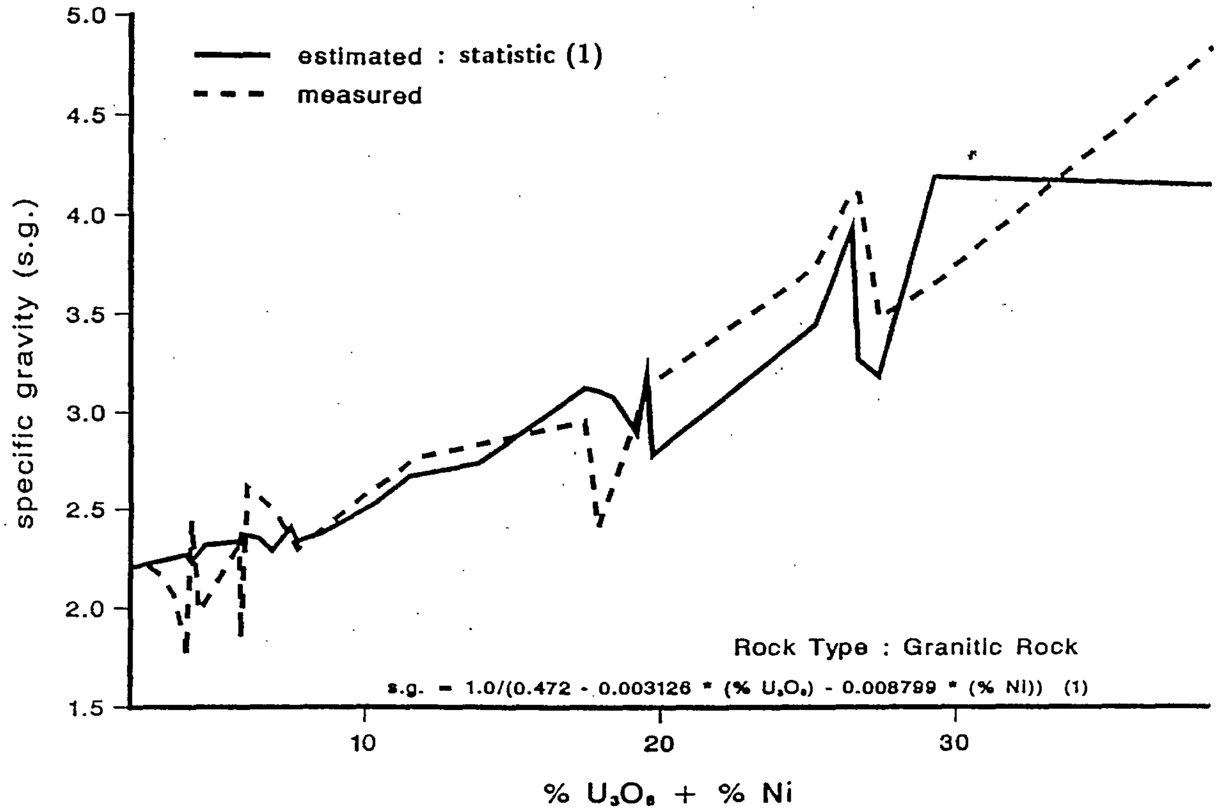


Fig. 13 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A

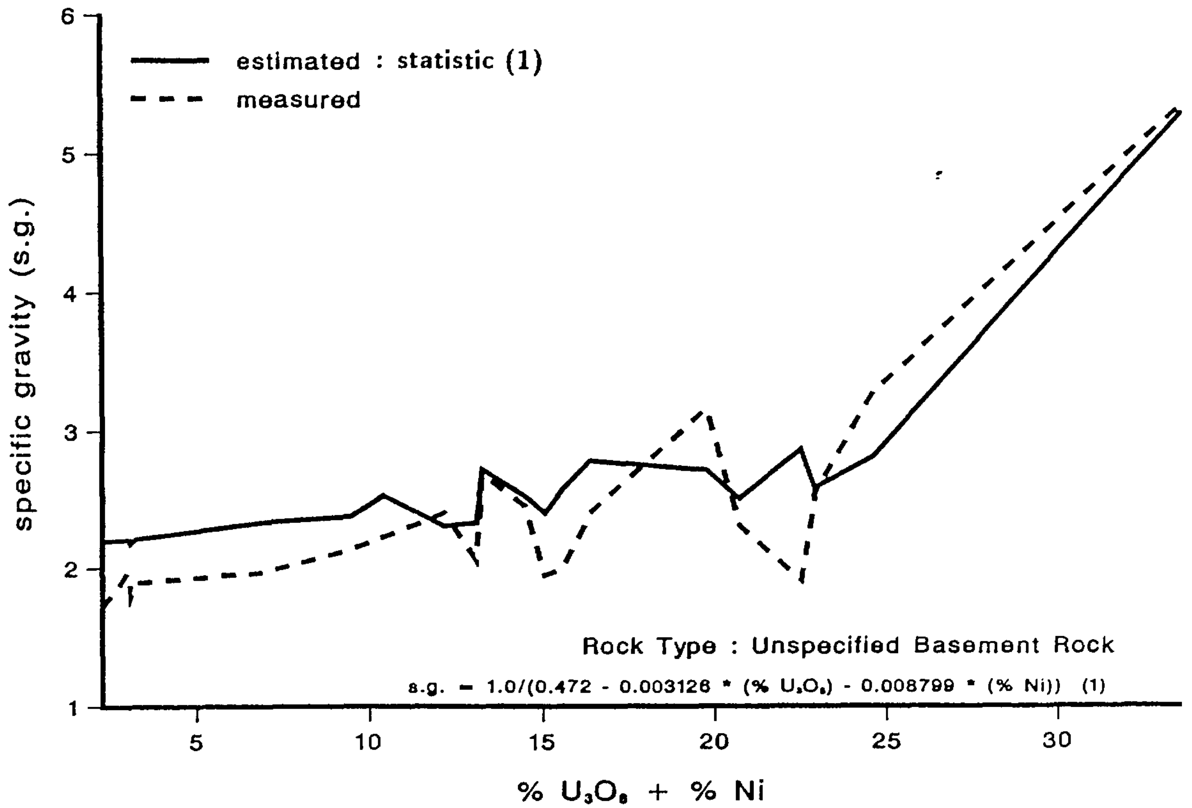


Fig. 14 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit A

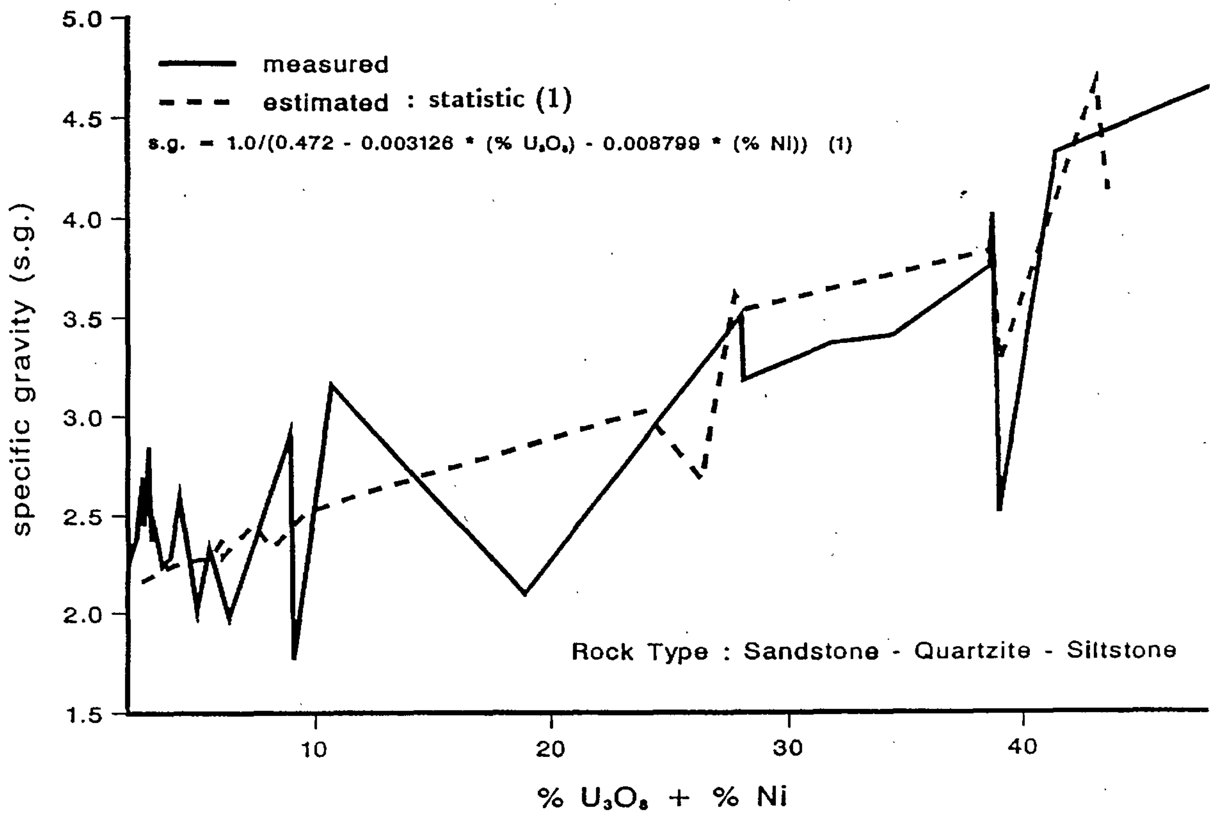


Fig. 15 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit B

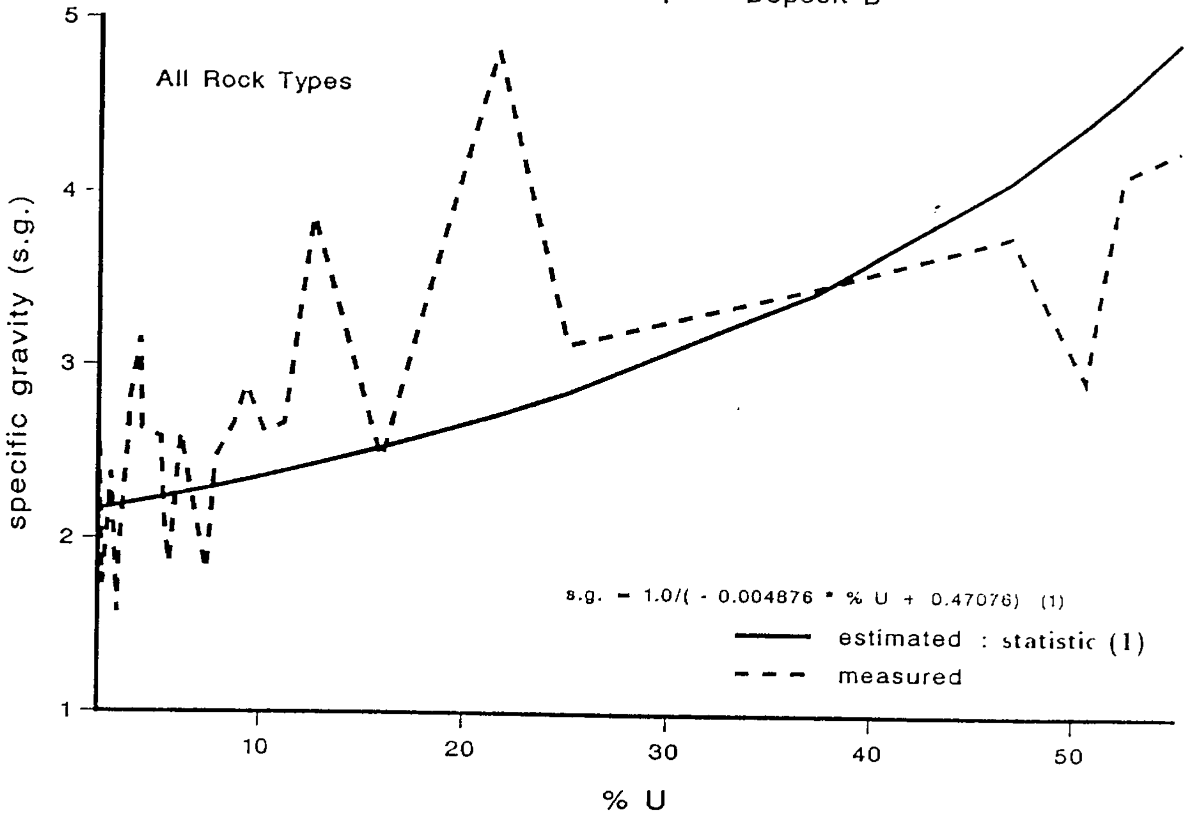


Fig. 16 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit B

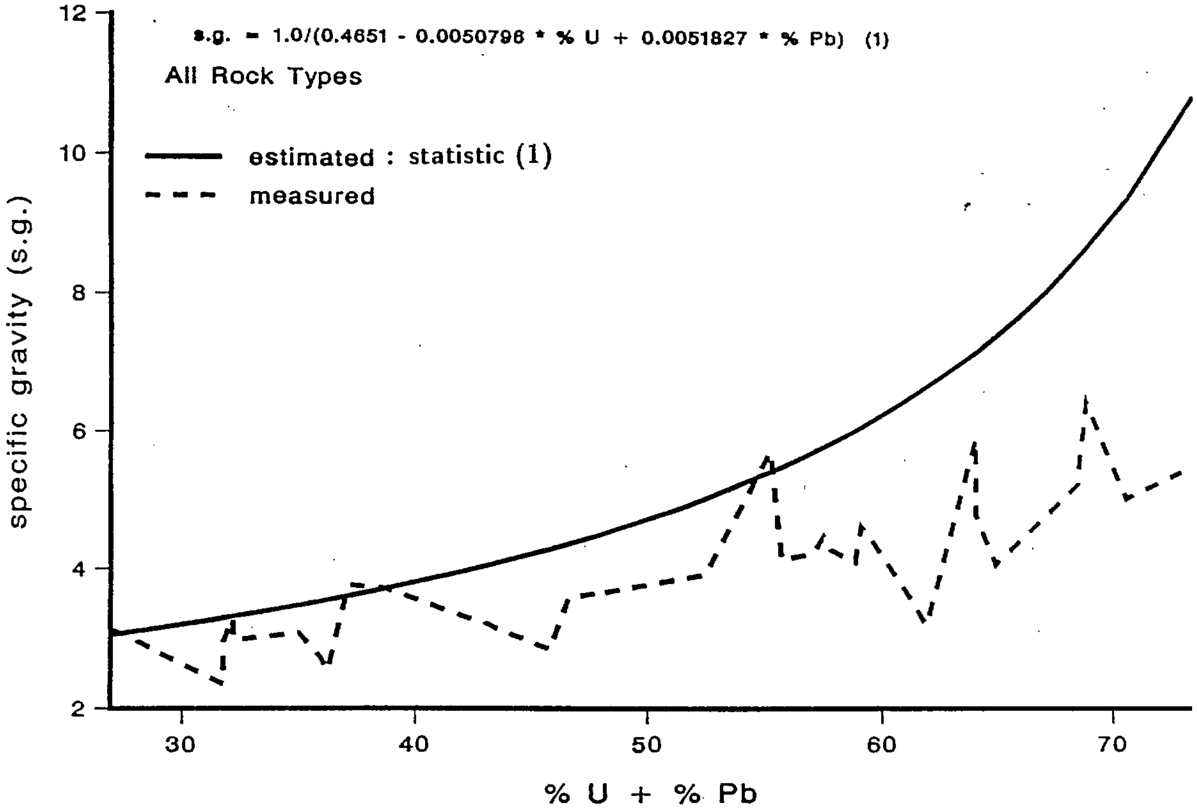


Fig. 17 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit B

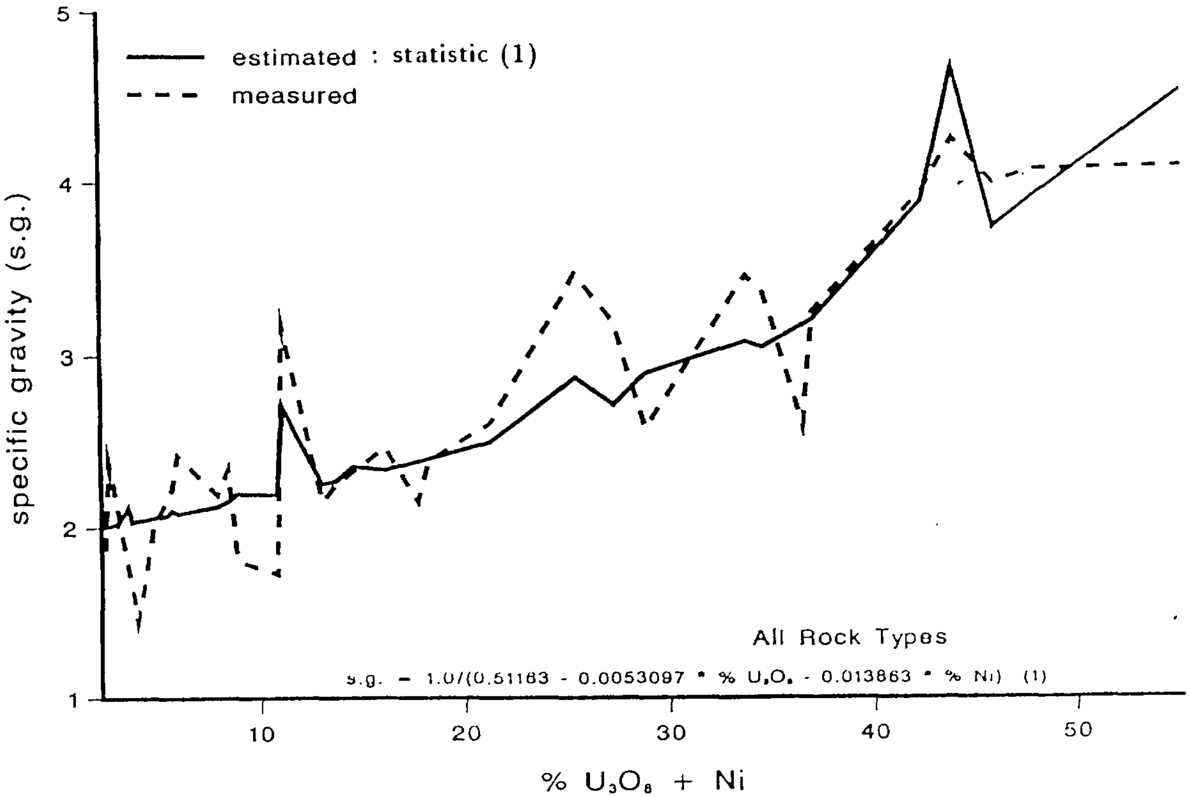
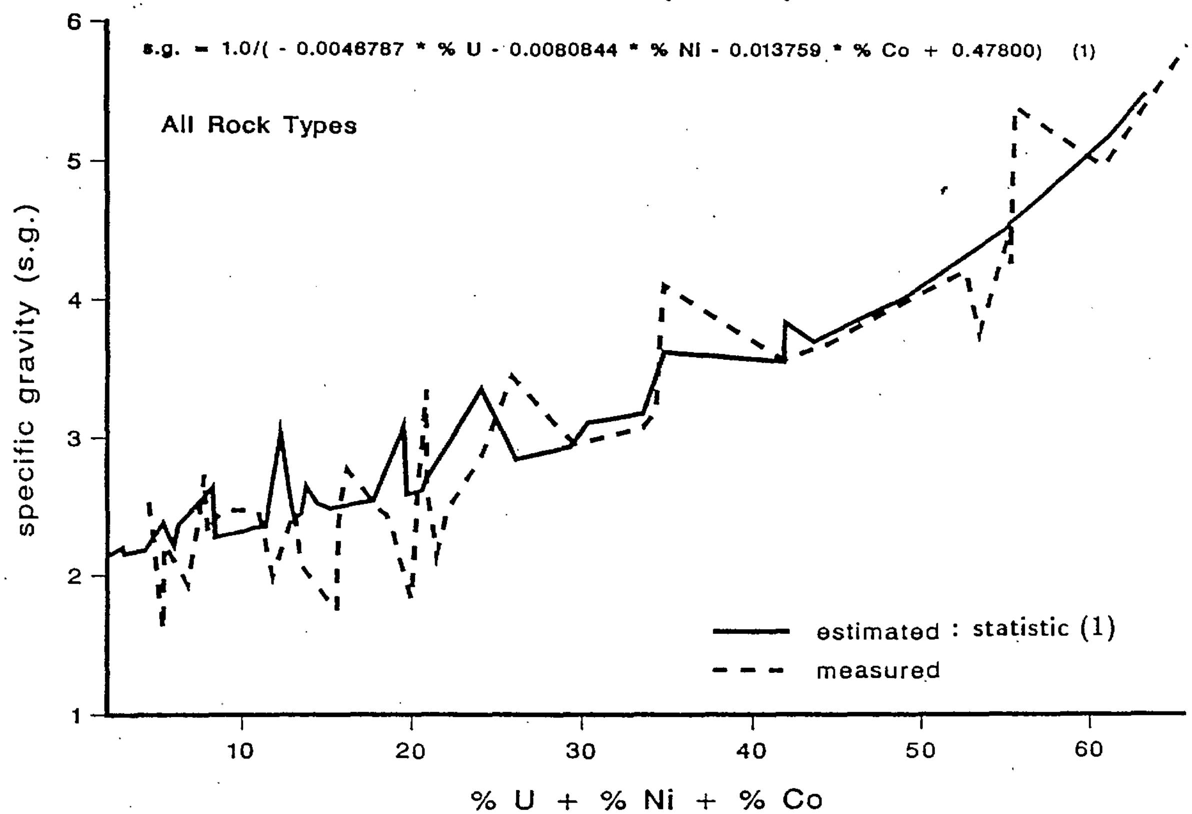


Fig. 18 — Comparison Between Measured and Estimated Specific Gravity Values

From Drillhole Core Sample : Deposit B



DISCUSSION

1) Theoretically, the **deterministic** approach should be the most accurate method to estimate the SG of a rock sample. The method is independent from experimental data set of metal grade values or bias that may be associated with such data set. In many cases, more parameters are necessary (eg.: porosity, waste specific gravity) to obtain a proper SG estimate. In practice, it is almost impossible to get all the necessary parameters and metal grade (non-common) values that will cover up all the local variations of the SG in a rock mass. If the rock mass (i.e., the host rock) under study has a uniform porosity and if no major geological processes affect the rock mass, limited local variations of SG will occur. Then the accuracy of the SG estimation depends only on the metal grade values of a rock sample. Again, the mineralogy of the rock mass should be relatively simple to positively identify the minerals associated with the metal grade values.

The following parameters are the main source of discrepancy between the experimental and their associated estimated values:

1a) The variation of waste specific gravity (D_w) of the rock mass due to a variable lithology where rock units have a distinct SG. Several geological factors like porosity and alteration of the rock mass contribute also to the variation of waste SG.

1b) The lack of quantitative data on the percentage of each mineral ($G_1^j\%$) contributing to the metal grade value of a sample. The percentage of each mineral must be assumed according to the geological information available for the deposit. As mentioned above, the lack of uniformity in the mineralogy of the rock mass under study will cause, at least locally, discrepancies between experimental and their associated estimated values.

If more than one rock type is involved, a slight improvement of results is observed when using metal grade values of a specific rock type to estimate SG and by dividing metal grades in various ranges with a different deterministic equation used in each case. As shown in table 1, there is less discrepancy in cases where this method is applied.

All the experimental specific gravity values used for this study were grouped by rock type to illustrate specific gravity variations (figures 19 to 22, appendix A) characterizing the uranium deposits of Northern Saskatchewan. These figures show complete ranges of SG values by rock type, i.e. from the lowest value to the highest one. Most of the SG ranges show a wide interval of values with the low end side below 2.0 showing an high degree of alteration for most of these rock units. All the SG ranges having the low end side below 2.0 show an high end side above 5.0 which corresponds to an high concentration of uranium minerals with or without sulphides and arsenides minerals. Again, these wide SG ranges show the necessity of having complete set of SG value for the ore tonnage estimation.

2) With the **statistical** approach, results depend on the metal grade values and their associated SG values derived from samples measurements in laboratories. Therefore, the representativity of the selected samples is crucial if we estimate local SG anywhere within the rock mass. For instance, in all cases involved in the present study, a large number of values are used for regression analysis and it is assumed that the representativity of samples is a minor issue. The use of this method is simply dictated by the statistical results obtained from regression analysis between SG values and metal grade values. The parameters derived from the best regression slope are used to establish the equation, which is a linear relationship between SG and metal grade values.

   If more than one type of metal grade is involved, it is important to verify if a correlation exist between these metal grade values. If not, then it is possible to combine them and proceed further with the exercise.

CONCLUSION

According to the results obtained from both the deterministic and the statistical methods for estimating three uranium deposits specific gravity, the following conclusions can be stated:

a) Theoretically, the deterministic approach permits the best estimate of specific gravity if all necessary parameters are available for their quantification. In practice, in most cases, not all the necessary parameters (eg. porosity, non-common metal grades) are available. To overcome this problem, simulation studies are necessary to improve the accuracy of the results. Otherwise, according to the experimental results, the method seems to be more adequate for homogeneous rock masses.

b) The statistical approach permits reasonably accurate estimates (see table 2) using metal grades to derive, from the regression slope, the parameters used to estimate the specific gravity. This method is very practical because no other parameters but the last ones mentioned are needed to produce an estimate. Moreover, all the other variables that may influence the specific gravity of a rock mass are indirectly integrated in the parameters used. Because these parameters are derived from experimental specific gravity values and their associated metal grade values, all the variables that affect the normal specific gravity of a rock mass are reflected in the specific gravity values of core samples.

c) Finally, the deterministic method is theoretically more accurate but involves data on more parameters than what is needed for the statistical method. The statistical method needs however, a representative data set of metal grade values and associated SG values of a rock mass. The estimation of SG is thus dependant on the data set used for regression analysis. This last method provides more consistent results when the rock mass is heterogeneous and the estimation by similar rock type is disregarded.

This study has been a thorough exercise showing how to establish links between geological information and experimental values and how to quantify some parameters of the rock mass, i.e. the lithosphere, to derive accurate specific gravity values.

ACKNOWLEDGEMENT

M. Boutin assisted with the computer programming work and processed all of the graphics using the SUN graphics terminal.

Dr. N.R. Billette revised the report and provided good advice on the subject.

REFERENCES

Boyer, A. and Boyle, R. (1987) *A User-Manual of the CDDE/1.0 Computer Program — Optimization of Drill Log Data Entry into a Computer Data Bank*, CANMET, MRL Div. Report 87-8(TR), 108pp.

Matheron, G. (1962) *Traité de Géostatistique Appliquée (Tome 1)*, Mémoire No. 14 pp. 247-250.

APPENDIX - A

DRY BULK SPECIFIC GRAVITY RANGES BY ROCK TYPE

for Northern Saskatchewan Uranium Deposits

Fig. 19 — Specific Gravity Distribution by Rock Type

Northern Saskatchewan Uranium Deposits

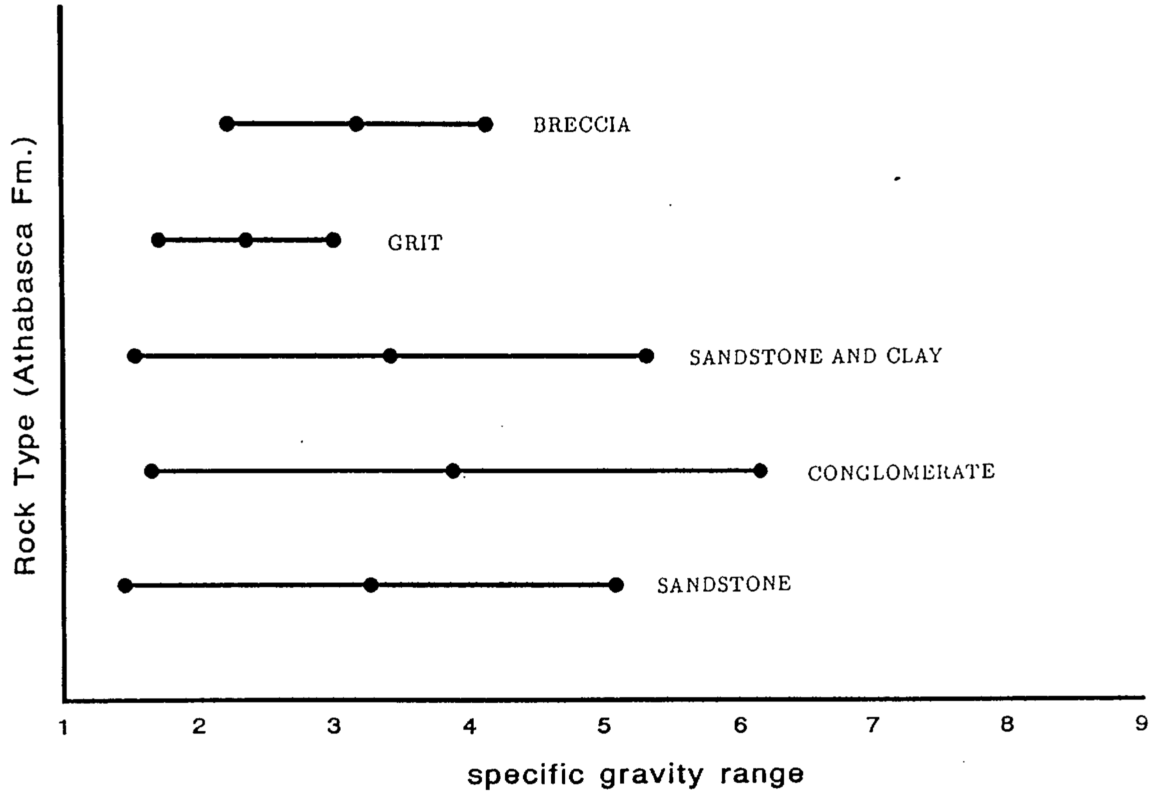


Fig. 20 — Specific Gravity Distribution by Rock Type

Northern Saskatchewan Uranium Deposits

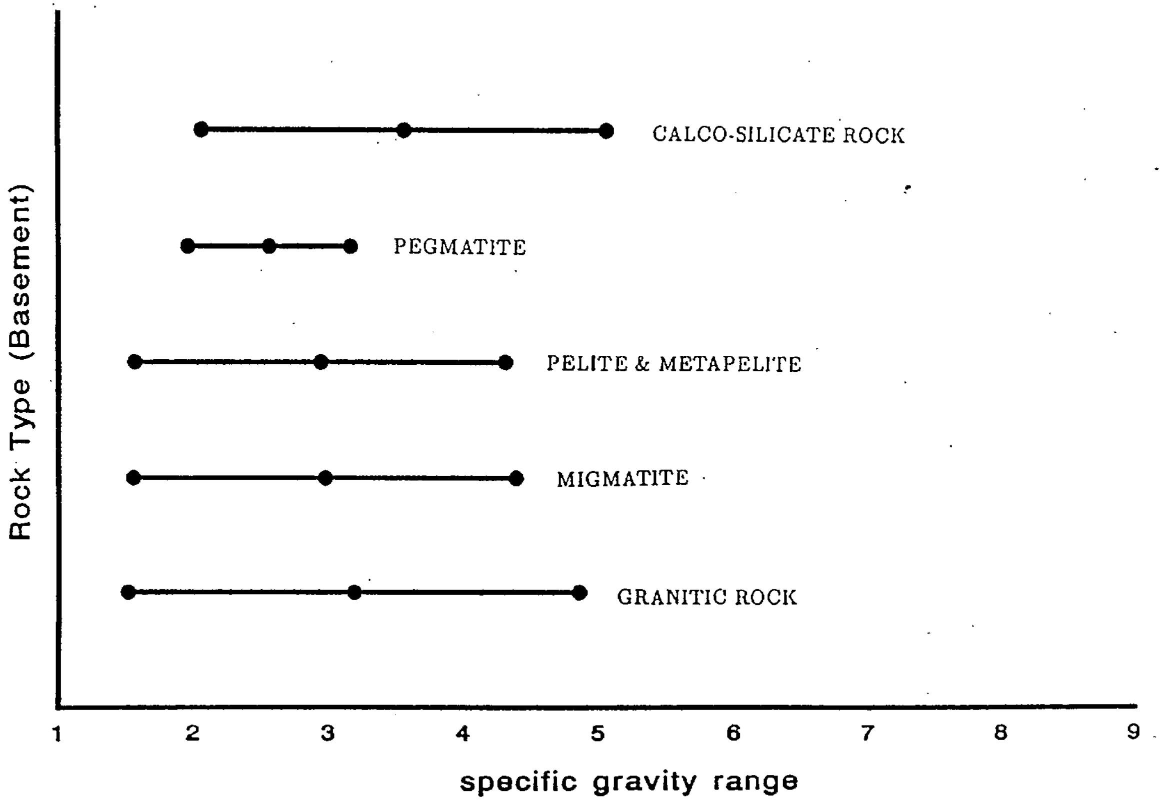


Fig. 21 — Specific Gravity Distribution by Rock Type

Northern Saskatchewan Uranium Deposits

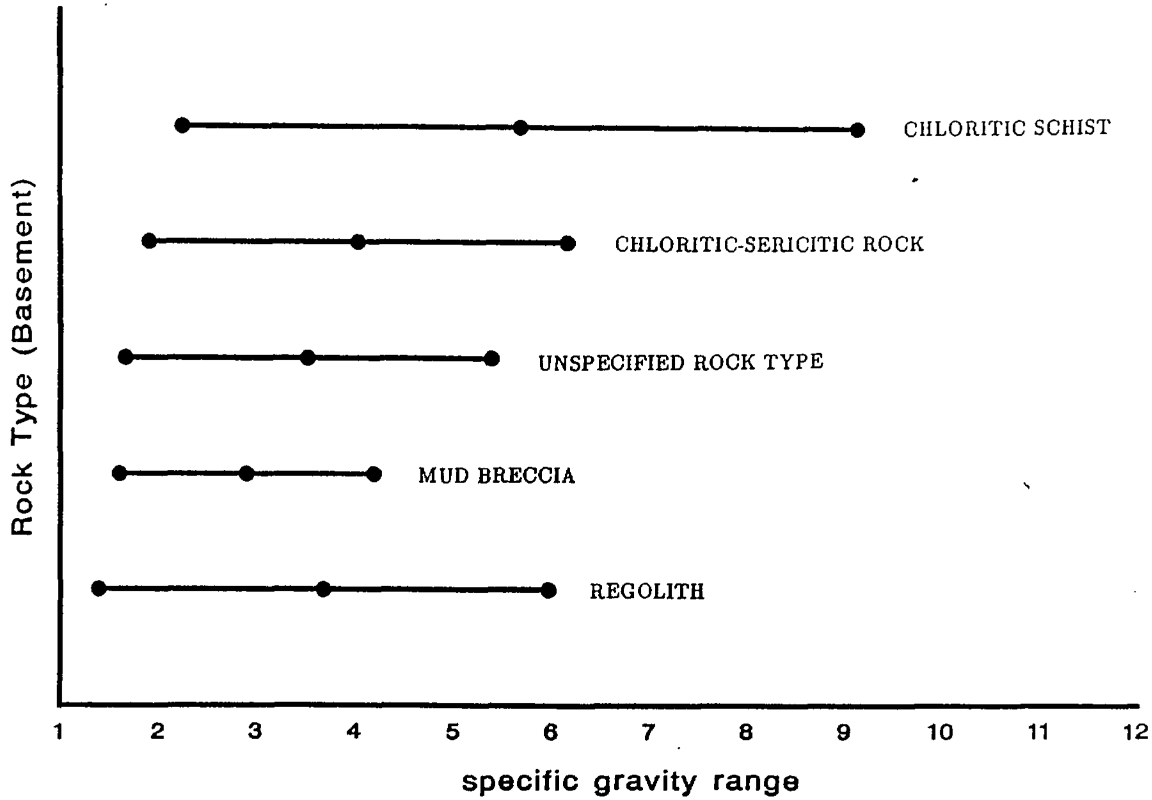
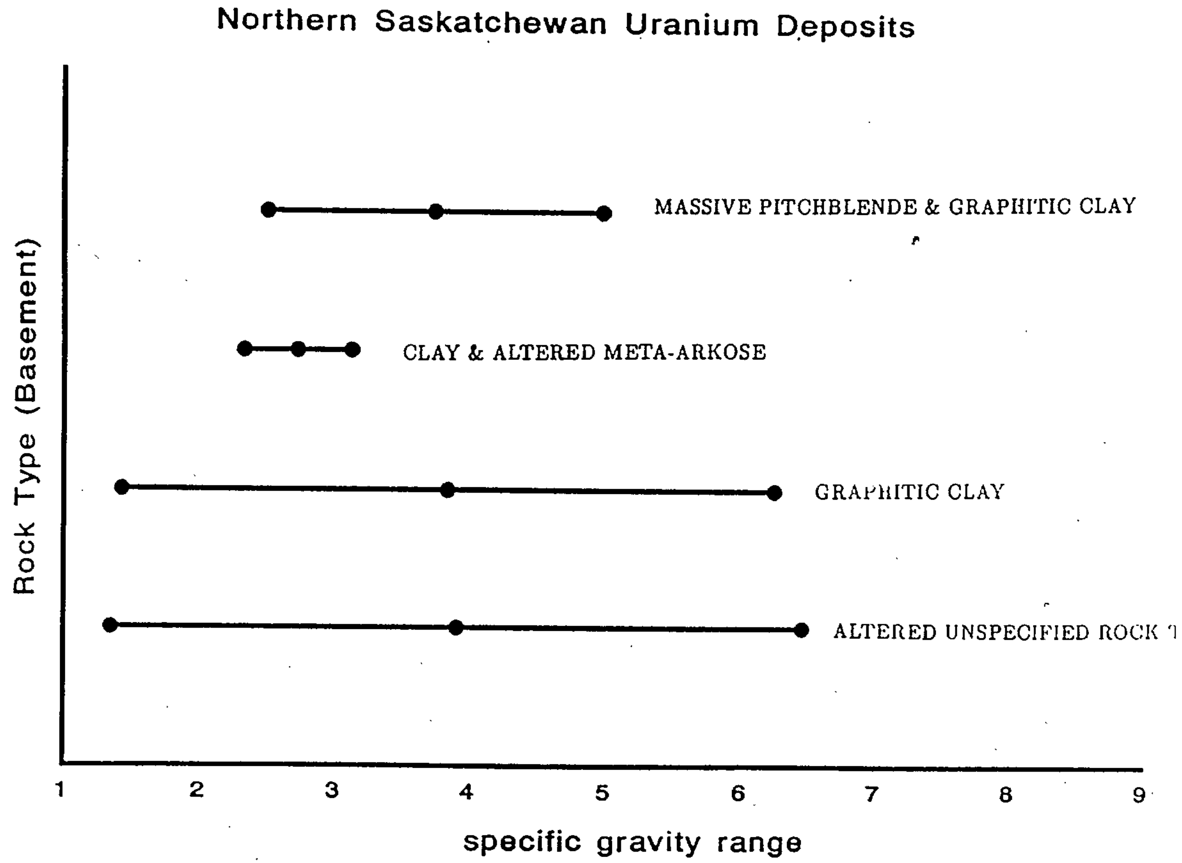


Fig. 22 — Specific Gravity Distribution by Rock Type



APPENDIX - B

STANDARD STATISTICAL RESULTS INCLUDING REGRESSION ANALYSIS

Deposit B

SECTION 4 - STATISTICS OF VARIABLE 5 (IREJ=0)

SPECIFIC GRAVITY

326 ACCEPTED OBSERVATIONS USED TO PRODUCE THE FOLLOWING STATISTICS

326	NOBS	0.462963	MEDIAN	0.509619	RANGE
0.466658	ARITHMETIC MEAN	0.458869	GEOMETRIC MEAN	0.450052	HARMONIC MEAN
0.006684	VARIANCE	0.081759	STANDARD DEVIATION	0.175200	COEFFICIENT OF VARIATION
0.000000	SICHEL MEAN	0.000000	SICHEL STAN. DEV.	0.000000	SICHEL COEF. OF VAR.
0.460871	QUENOUILLE MEAN	0.085349	QUENOUILLE STAN. DEV.	0.185191	QUENOUILLE COEF. VAR.
0.015785	DAVIES COEF. OF SYM.	0.021819	WIJS COEF. VAR.		

FIRST FOUR MOMENTS ABOUT ZERO	0.46665847E+00	0.22443448E+00	0.11085346E+00	0.56127805E-01
FIRST FOUR MOMENTS ABOUT THE MEAN	0.25012011E-06	0.66639865E-02	-0.10047232E-03	0.18412291E-03
FIRST FOUR K-STATISTICS	0.25012011E-06	0.66844909E-02	-0.10140357E-03	0.52837226E-04

-0.184691	SKEWNESS (ESTIMATED FROM MOMENTS)	-0.185546	SKEWNESS (ESTIMATED FROM K-STATISTICS)
1.146099	KURTOSIS (ESTIMATED FROM MOMENTS)	1.182506	KURTOSIS (ESTIMATED FROM K-STATISTICS)

SECTION 5 - HISTOGRAM AND CUMULATIVE FREQUENCY DIAGRAM

SPECIFIC GRAVITY

NO. OF OBSERVATIONS = 326

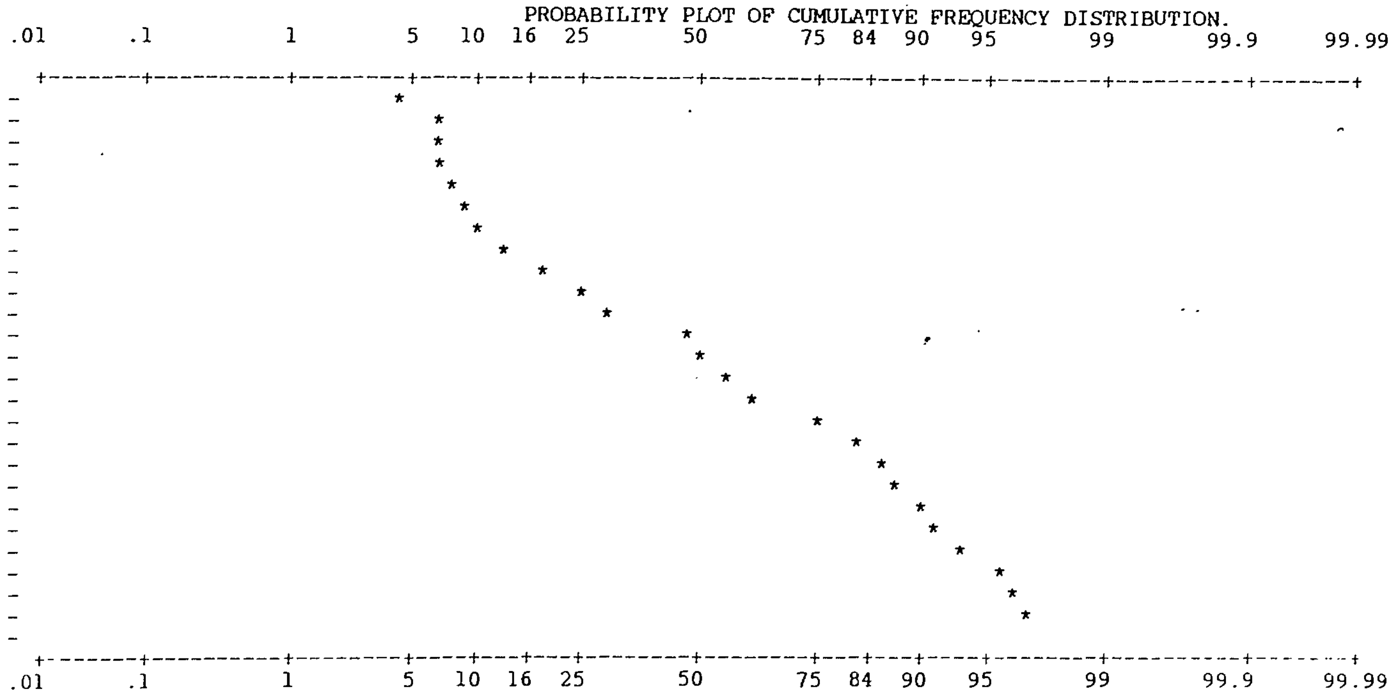
MINIMUM = 0.199601   MAXIMUM = 0.709220   MEAN = 0.466658

```
  UPPER  FREQ   REL    CUM  1              RELATIVE FREQUENCY DIAGRAM                  1              CUMULATIVE FREQUENCY DIAGRAM
  LIMIT         FREQ   FREQ 1                                                          1
   0.303   15   4.60   4.60 1*******                                                   1**
   0.317    7   2.15   6.75 1***                                                       1***
   0.330    0   0.00   6.75 1                                                          1***
   0.344    0   0.00   6.75 1                                                          1***
   0.358    2   0.61   7.36 1*                                                         1****
   0.371    5   1.53   8.90 1**                                                        1****
   0.385    5   1.53  10.43 1**                                                        1*****
   0.399    9   2.76  13.19 1****                                                      1*******
   0.412   19   5.83  19.02 1*********                                                 1**********
   0.426   20   6.13  25.15 1*********                                                 1*************
   0.439   15   4.60  29.75 1*******                                                   1***************
   0.453   53  16.26  46.01 1*************************                                 1***********************
   0.467   16   4.91  50.92 1********                                                  1*************************
   0.480   18   5.52  56.44 1********                                                  1****************************
   0.494   15   4.60  61.04 1*******                                                   1*******************************
   0.508   47  14.42  75.46 1**********************                                    1**************************************
   0.521   16   4.91  80.37 1********                                                  1****************************************
   0.535   14   4.29  84.66 1*******                                                   1******************************************
   0.548    5   1.53  86.20 1**                                                        1*******************************************
   0.562   11   3.37  89.57 1*****                                                     1*********************************************
   0.576    3   0.92  90.49 1*                                                         1*********************************************
   0.589   10   3.07  93.56 1*****                                                     1***********************************************
   0.603    6   1.84  95.40 1***                                                       1************************************************
   0.617    2   0.61  96.01 1*                                                         1************************************************
   0.630    3   0.92  96.93 1*                                                         1************************************************
>  0.630   10   3.07 100.00 1*****                                                     1**************************************************
```

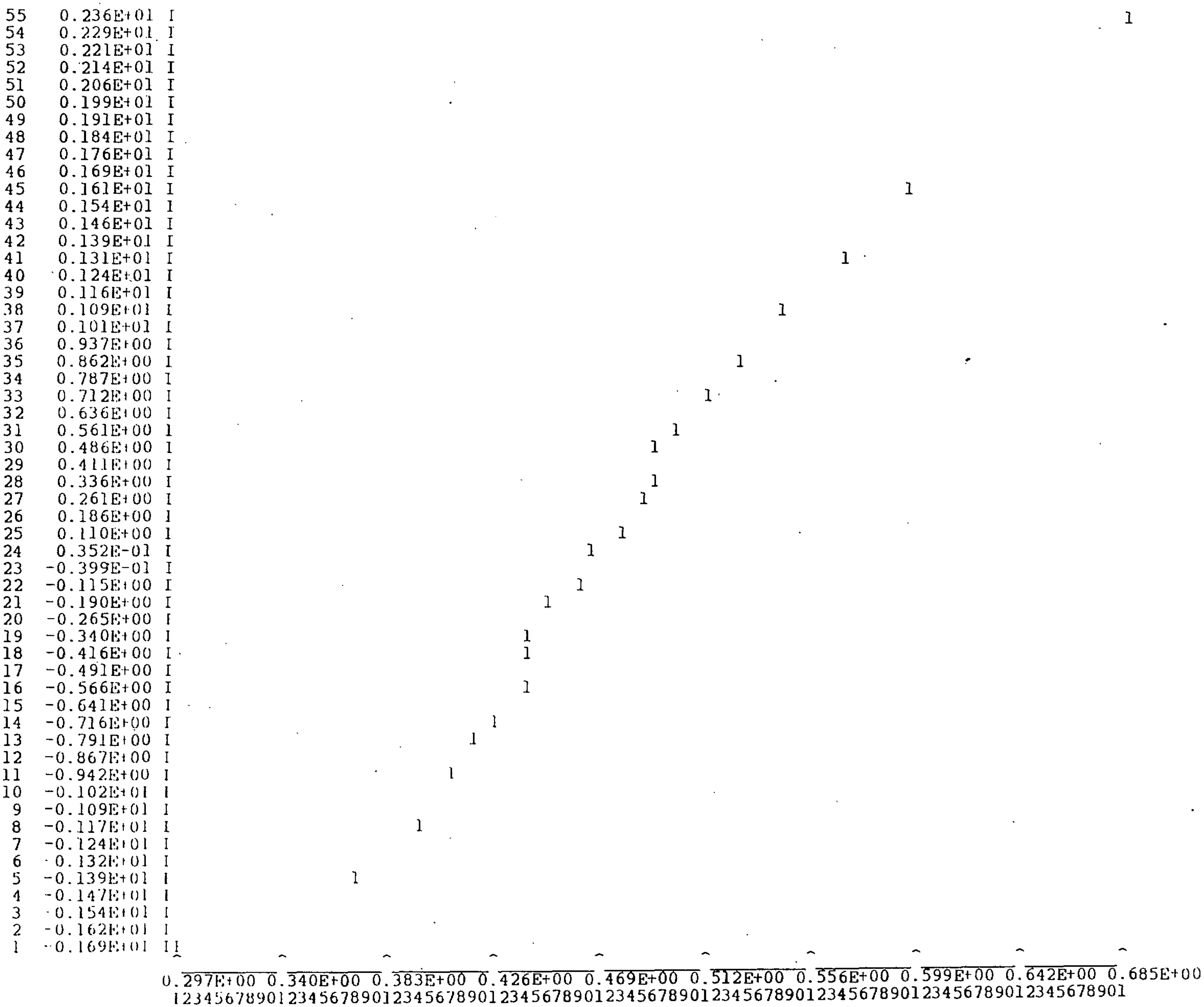
SECTION 5A - PROBABILITY PLOT OF CUMULATIVE FREQUENCY DISTRIBUTION

SPECIFIC GRAVITY

UPPER LIMIT	CUM. PCT.
0.303	4.601
0.317	6.748
0.330	6.748
0.344	6.748
0.358	7.362
0.371	8.896
0.385	10.429
0.399	13.190
0.412	19.018
0.426	25.153
0.439	29.755
0.453	46.012
0.467	50.920
0.480	56.442
0.494	61.043
0.508	75.460
0.521	80.368
0.535	84.663
0.548	86.196
0.562	89.571
0.576	90.491
0.589	93.558
0.603	95.399
0.617	96.012
0.630	96.933
> 0.630	100.000



CUMULATIVE FREQUENCY GRAPH



SECTION 9 - REGRESSION STATISTICS CASE (1)

D E P E N D E N T   V A R I A B L E   N O .   1

TITLE = REGRESSION : % U3O8 VS % Pb

DESCRIPTION OF THE VARIABLES

DFR - DEGREES OF FREEDOM FOR THE REGRESSION;
SSR - SUM OF SQUARES DUE TO REGRESSION;
MSR - REGRESSION MEAN SQUARE;
F - F-RATIO, USED TO TEST MSR FOR SIGNIFICANCE;
DFE - DEGREES OF FREEDOM FOR ERROR;
SSE - ERROR SUM OF SQUARES;
MSE - ERROR MEAN SQUARE;
DFT - TOTAL DEGREES OF FREEDOM;
SST - TOTAL SUM OF SQUARES OF DEPENDENT VARIABLE;
TOT - TOTAL PER-CENT VARIATION;
SED - STANDARD ERROR;

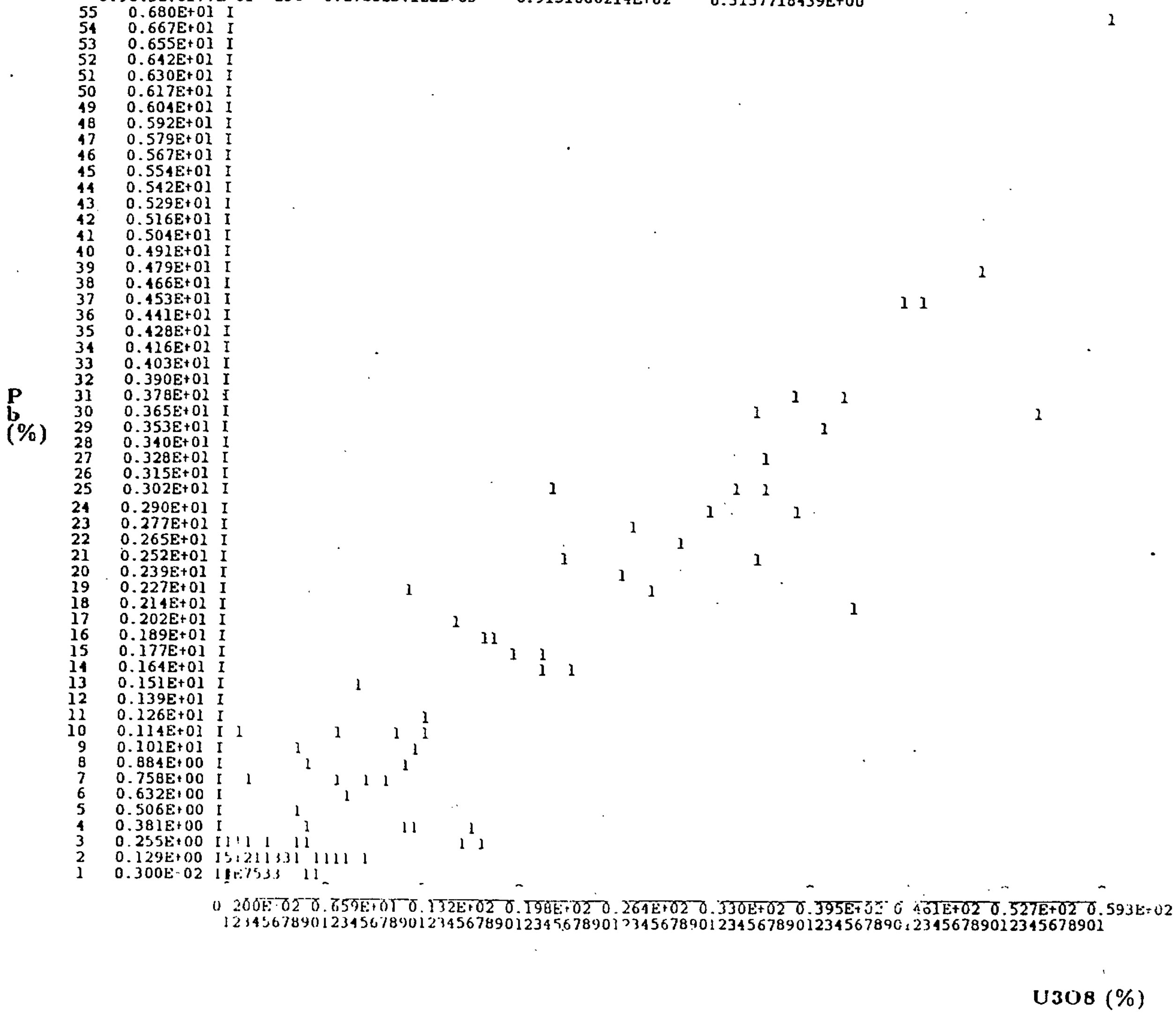
CORRELATION COEFFICIENT BETWEEN VARIABLES 1 AND
0.9566102624E+00 --------- 2

REGRESSION STAGE 1 CONSTANT TERM = -0.7496058941E-02

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	0.8892128617E-01	0.1766780159E-02	0.5032957077E+02	0.9151531982E+02

DFR	SSR	MSR	F	DFE	SSE
1	0.2493873138E+03	0.2493873138E+03	0.2533065674E+04	235	0.2313639832E+02

MSE	DFT	SST	TOT	SED
0.9845276177E-01	236	0.2725237122E+03	0.9151000214E+02	0.3137718439E+00



SECTION 9 - REGRESSION STATISTICS CASE (2)

DEPENDENT VARIABLE NO. 1

TITLE = REGRESSION : % U3O8 + % Pb VS SPECIFIC GRAVITY

DESCRIPTION OF THE VARIABLES

DFR - DEGREES OF FREEDOM FOR THE REGRESSION;
SSR - SUM OF SQUARES DUE TO REGRESSION;
MSR - REGRESSION MEAN SQUARE;
F - F-RATIO, USED TO TEST MSR FOR SIGNIFICANCE;
DFE - DEGREES OF FREEDOM FOR ERROR;
SSE - ERROR SUM OF SQUARES;
MSE - ERROR MEAN SQUARE;
DFT - TOTAL DEGREES OF FREEDOM;
SST - TOTAL SUM OF SQUARES OF DEPENDENT VARIABLE;
TOT - TOTAL PER-CENT VARIATION;
SED - STANDARD ERROR;

VARIABLE	AVERAGE VALUE AND STANDARD DEVIATION	
1	0.5700997353E+01	0.1154333591E+02
2	0.6691226959E+00	0.2548799515E+01
3	0.4706337154E+00	0.8934345841E-01

CORRELATION COEFFICIENT BETWEEN VARIABLES 1 AND
0.9137344360E-01 --------- 2
-0.6712027192E+00 --------- 3

CORRELATION COEFFICIENT BETWEEN VARIABLES 2 AND
-0.3037439883E+00 --------- 3

REGRESSION STAGE 1 CONSTANT TERM = 0.5002503991E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.5194995087E-02	0.3742623958E-03	-0.1388062286E+02	0.4505630875E+02

DFR	SSR	MSR	F	DFE	SSE
1	0.8486819267E+00	0.8486819267E+00	0.1926717072E+03	235	0.1035130024E+01

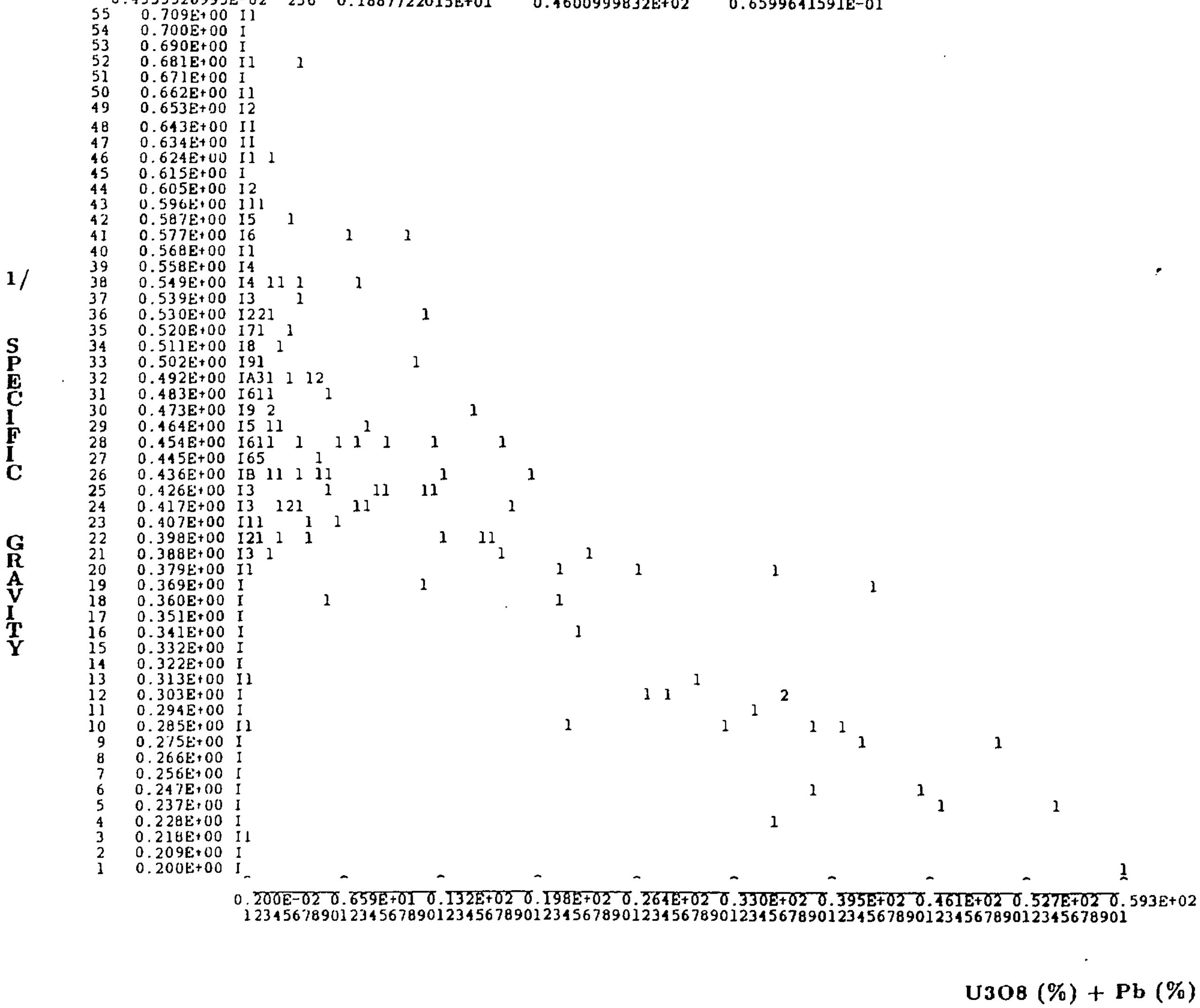
MSE	DFT	SST	TOT	SED
0.4404808395E-02	236	0.1883811951E+01	0.4504999924E+02	0.6636872888E-01

REGRESSION STAGE 2 CONSTANT TERM = 0.5000611544E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.2861442743E-02	0.1275390736E-02	-0.2243581295E+01	0.4516732407E+02
2	2	-0.2628884651E-01	0.1372058224E-01	-0.1916015387E+01	0.8520302176E+00

DFR	SSR	MSR	F	DFE	SSE
2	0.8685287237E+00	0.4342643619E+00	0.9970420837E+02	234	0.1019193292E+01

MSE	DFT	SST	TOT	SED
0.4355526995E-02	236	0.1887722015E+01	0.4600999832E+02	0.6599641591E-01



SECTION 9 - REGRESSION STATISTICS CASE (3)

D E P E N D E N T   V A R I A B L E   N O .   1

TITLE = REGRESSION : % U3O8 + % Ni VS SPECIFIC GRAVITY

DESCRIPTION OF THE VARIABLES

DFR - DEGREES OF FREEDOM FOR THE REGRESSION;
SSR - SUM OF SQUARES DUE TO REGRESSION;
MSR - REGRESSION MEAN SQUARE;
F - F-RATIO, USED TO TEST MSR FOR SIGNIFICANCE;
DFE - DEGREES OF FREEDOM FOR ERROR;
SSE - ERROR SUM OF SQUARES;
MSE - ERROR MEAN SQUARE;
DFT - TOTAL DEGREES OF FREEDOM;
SST - TOTAL SUM OF SQUARES OF DEPENDENT VARIABLE;
TOT - TOTAL PER-CENT VARIATION;
SED - STANDARD ERROR;

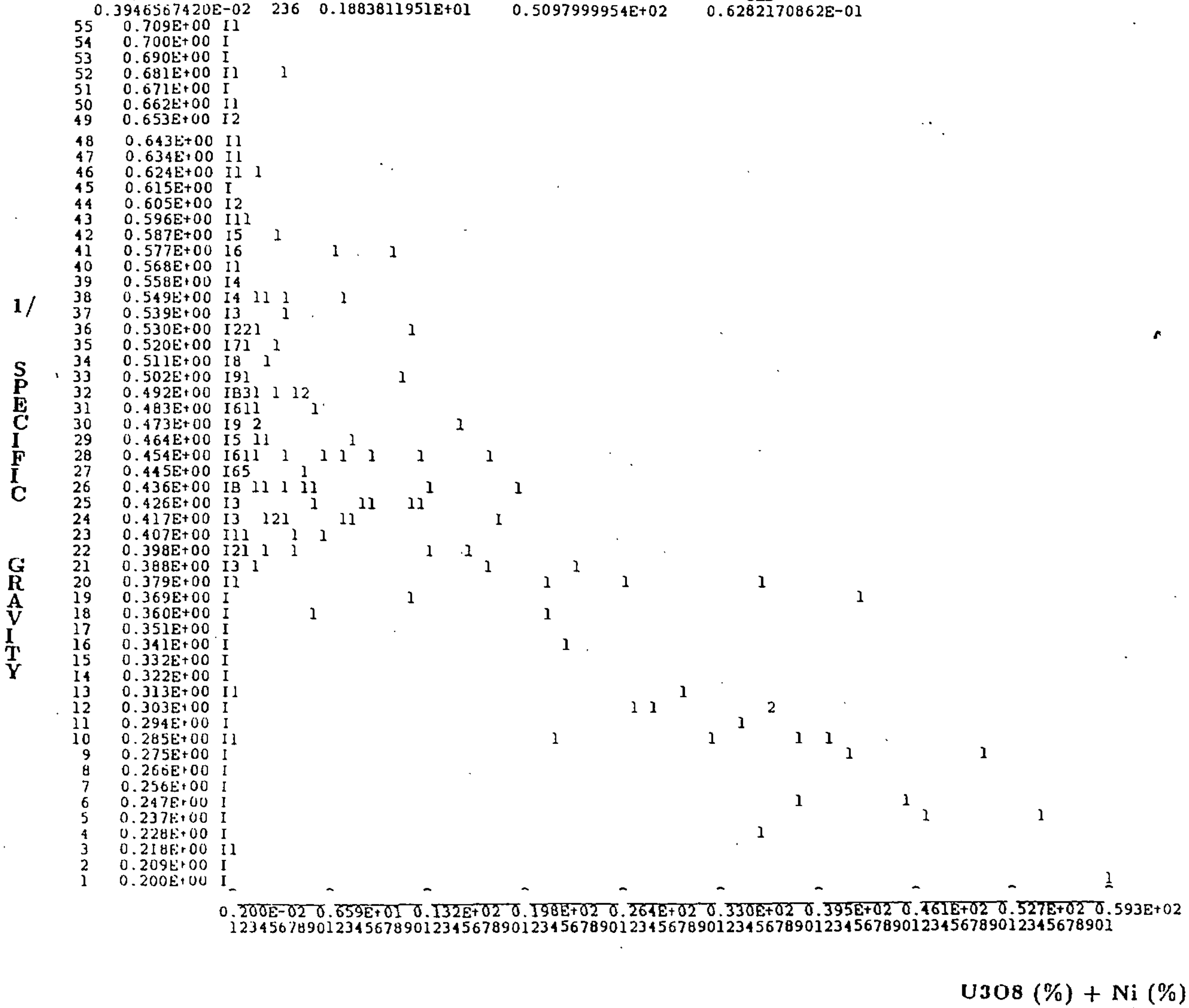
```
VARIABLE  AVERAGE VALUE AND STANDARD DEVIATION

    1       0.5700997353E+01  0.1154333591E+02
    2       0.6691226959E+00  0.2548799515E+01
    3       0.4706337154E+00  0.8934345841E-01



CORRELATION COEFFICIENT BETWEEN VARIABLES  1 AND
 0.9137344360E-01 ---------   2
-0.6712027192E+00 ---------   3

CORRELATION COEFFICIENT BETWEEN VARIABLES  2 AND
-0.3037439883E+00 ---------   3



REGRESSION STAGE  1          CONSTANT TERM =  0.5002503991E+00

VARIABLE  ORDER  REGRESSION COEFT   STANDARD ERROR OF COEFT  T-VALUE FOR COEFT=0  PROPORTION OF VARIATION

    1        1   -0.5194995087E-02   0.3742623958E-03        -0.1388062286E+02     0.4505630875E+02

DFR        SSR               MSR                F            DFE       SSE
  1    0.8486819267E+00  0.8486819267E+00   0.1926717072E+03  235   0.1035130024E+01

      MSE          DFT       SST                TOT                SED
   0.4404808395E-02  236  0.1883811951E+01   0.4504999924E+02   0.6636872888E-01
```

REGRESSION STAGE 2 CONSTANT TERM = 0.5049984455E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.5022113211E-02	0.3557484597E-03	-0.1411703396E+02	0.4505630875E+02
2	2	-0.8568913676E-02	0.1611160114E-02	-0.5318474293E+01	0.5930925846E+01

DFR	SSR	MSR	F	DFE	SSE
2	0.9603152275E+00	0.4801576138E+00	0.1216646194E+03	234	0.9234967232E+00

MSE	DFT	SST	TOT	SED
0.3946567420E-02	236	0.1883811951E+01	0.5097999954E+02	0.6282170862E-01



SECTION 9 - REGRESSION STATISTICS CASE (4)

D E P E N D E N T   V A R I A B L E   N O .   1

TITLE = REGRESSION : % U3O8 + % Ni + % Co VS SPECIFIC GRAVITY

DESCRIPTION OF THE VARIABLES

DFR	-	DEGREES OF FREEDOM FOR THE REGRESSION;
SSR	-	SUM OF SQUARES DUE TO REGRESSION;
MSR	-	REGRESSION MEAN SQUARE;
F	-	F-RATIO, USED TO TEST MSR FOR SIGNIFICANCE;
DFE	-	DEGREES OF FREEDOM FOR ERROR;
SSE	-	ERROR SUM OF SQUARES;
MSE	-	ERROR MEAN SQUARE;
DFT	-	TOTAL DEGREES OF FREEDOM;
SST	-	TOTAL SUM OF SQUARES OF DEPENDENT VARIABLE;
TOT	-	TOTAL PER-CENT VARIATION;
SED	-	STANDARD ERROR;

VARIABLE	AVERAGE VALUE AND STANDARD DEVIATION	
1	0.5525226593E+01	0.1114112282E+02
2	0.6809828877E+00	0.2584978819E+01
3	0.1403042972E+00	0.4788203835E+00
4	0.4708685279E+00	0.8816123754E-01

CORRELATION COEFFICIENT BETWEEN VARIABLES 1 AND

0.1009771228E+00	---------	2
-0.3930914099E-03	---------	3
-0.6611182094E+00	---------	4

CORRELATION COEFFICIENT BETWEEN VARIABLES 2 AND

0.5066793561E+00	---------	3
-0.3179711699E+00	---------	4

CORRELATION COEFFICIENT BETWEEN VARIABLES 3 AND

-0.1551289260E+00	---------	4

REGRESSION STAGE 1 CONSTANT TERM = 0.4997738600E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.5231519230E-02	0.3931933607E-03	-0.1330520725E+02	0.4371273041E+02

DFR	SSR	MSR	F	DFE	SSE
1	0.7779470086E+00	0.7779470086E+00	0.1770289459E+03	228	0.1001937389E+01

MSE	DFT	SST	TOT	SED
0.4394462332E-02	229	0.1779884338E+01	0.4370999908E+02	0.6629074365E-01

REGRESSION STAGE 2 CONSTANT TERM = 0.5045478940E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.5028720479E-02	0.3729782766E-03	-0.1348260975E+02	0.4371273041E+02
2	2	-0.8655943908E-02	0.1607516780E-02	-0.5384667873E+01	0.6380826473E+01

DFR	SSR	MSR	F	DFE	SSE
2	0.8914293647E+00	0.4457146823E+00	0.1138799820E+03	227	0.8884549737E+00

MSE	DFT	SST	TOT	SED
0.3913898487E-02	229	0.1779884338E+01	0.5009000015E+02	0.6256115437E-01

REGRESSION STAGE 3 CONSTANT TERM = 0.5051345229E+00

VARIABLE	ORDER	REGRESSION COEFT	STANDARD ERROR OF COEFT	T-VALUE FOR COEFT=0	PROPORTION OF VARIATION
1	1	-0.5043626763E-02	0.3741161781E-03	-0.1348144531E+02	0.4371273041E+02
2	2	-0.8024523966E-02	0.1870265813E-02	-0.4290579319E+01	0.6380826473E+01
3	3	-0.6658620201E-02	0.1004528534E-01	-0.6628602147E+00	0.1018582284E+00

DFR	SSR	MSR	F	DFE	SSE
3	0.8931533098E+00	0.2977177799E+00	0.7587895203E+02	226	0.8867310286E+00

MSE	DFT	SST	TOT	SED
0.3923588432E-02	229	0.1779884338E+01	0.5018999863E+02	0.6263855100E-01