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SECTION 4

Mineral Deposits

Gîtes Minéraux

MONTREAL, 1972

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PREFACE

The seventy papers that make up Section IV, Mineral Deposits, were selected to reflect the current thinking, in various parts of the world, on ore genesis in terms of the geological, geophysical and geochemical knowledge of the environment. In reflection of this theme, the papers in this volume have been subdivided into the following groups:

A — Global Concepts
B — Regional Metallogeny
C — The Intrusive Environment
D — The Volcanic Environment
E — The Sedimentary Environment
F — The Metamorphic Environment
G — Silver-Arsenic Ore Deposits

J. L. Jambor, assisted by W. Petruk, has done the organizational work and the editing of papers related to subsection G. We are also pleased to acknowledge the assistance, in reviewing and editing manuscripts, of J. E. Klovan, C. H. Smith, V. G. Ethier, L. P. Tremblay, P. S. Simony, A. A. Levinson, E. D. Ghent, F. Henderson, J. W. Nicholls, P. E. Gretener, P. Laznicka and W. C. Brisbin.

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PRÉFACE

Les soixante-dix communications qui constituent la Section 4 intitulée "Gîtes minéraux" ont été choisis pour représenter les idées actuelles, venant d'un peu partout dans le monde, sur la genèse des minerais, sous l'aspect des connaissances géologiques, géophysiques et géochimiques du milieu. Pour être conformes à ce thème, les communications de ce volume ont été subdivisés en plusieurs groupes. Les voici:

A — Concepts globaux
B — Métallogénie régionale
C — Le milieu intrusif
D — Le milieu volcanique
E — Le milieu sédimentaire
F — Le milieu métamorphique
G — Les gîtes métallifères du groupe argent-arséniure

J. L. Jambor, assisté de W. Petruk, a fait le travail d'organisation et l'édition des communications reliées à la sous-section G. Nous désirons aussi remercier J. E. Klovan, C. H. Smith, V. G. Ethier, L. P. Tremblay, P. S. Simony, A. A. Levinson, E. D. Ghent, F. Henderson, J. W. Nicholls, P. E. Gretener, P. Laznicka et W. C. Brisbin pour l'aide apportée à la révision et à l'édition des communications.

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Global Concepts

Concepts Globaux

The Prediction of Mineral Resources and Long-Term Price Trends in the Non-Ferrous Metal Mining Industry

JOHAN W. BRINCK,
Belgium

ABSTRACT

The quality and size of the mineral resources of an element are defined by its average concentration in, and its specific mineralizability for, a given geological environment. Taking the earth's upper crust as the environment of ore deposits in general, for a free market economy the long-term average price differences between the non-ferrous metals are determined by the same factors. This is demonstrated for copper, zinc, lead and gold. On this basis a long-term target price has been determined for uranium.

Resources are inferred from "reasonably assured" reserves and previous production by a log-binomial, equal probability model (IRIS — diagram).

Exploitation cost is calculated by a DCF method as a function of the grade and size of the individual deposits making up the resources. Exploration cost is estimated as a function of the chance to discover such deposits.

It is indicated that the mineral potential of more restricted areas such as continents, countries, provinces or districts can be estimated by this method from the results of multi-element geochemical stream sediment surveys.

DEFINITIONS AND TERMINOLOGY

THE TERM "Reserves" is limited to estimated quantities of mineral substances considered "exploitable" under present conditions, whereas "Resources" represent: "Reserves" plus all mineral materials which might become exploitable under more favourable conditions in the widest sense.

The terminology used for estimating resources is based on our current incomplete knowledge of the occurrence of useful substances in mineral deposits (quantitative aspect) and of the cost of their extraction, concentration or refining, transport and marketing in respect to a given price of the mineral product (qualitative aspect).

The terminology used in this paper, as shown in Figure 1, follows closely the recommendations by F. Blondel and S. G. Lasky on behalf of, and approved by, an international Committee of the Society of Economic Geologists in 1956.

ESTIMATION OF RESOURCES

Quantitative Aspects

Resources are inferred from a log-binomial model of element distribution in the geological environment as proposed by the author (1967) and for which

Authors' addresses are given at the back of this book.

the calculation methods were developed by De Wolde of CETIS (De Wolde and Brinck, 1971), according to the general formula:

$$M = RX = \sum_{k=o}^{\alpha} \frac{\binom{\alpha}{k}}{2^{\alpha}} * R * X * (1+Q)^{\alpha - k} * (1-Q)^{k} \quad \ldots\ldots \quad (1)$$

where:

- M = total resources of the element in the geological environment in metric tons of metal;
- R = size of the geological environment in metric tons of rock. It should be remembered that the distribution is volumetric and that this procedure is valid only if the specific gravity of the calculated mineral deposits is similar to that of the environment;
- X = average concentration of the element in the environment;
- Q = specific mineralizability of the element for the environment;
- α = a rational number indicating the order of subdivision of the environment;
- k = an integer 0, 1, 2 . . . . N [$\alpha - 1 < N \leqslant \alpha$]

For each value of k the value $\binom{\alpha}{k}$ represents the largest possible number of mineral deposits of size $R/2^{\alpha}$ and average grade $X^* (1+Q)^{\alpha - k}_{*} (1-Q)^{k}$.

By defining:

$$X_k = \left(\sum_{k'=o}^{k} \binom{\alpha}{k'} * X (1+Q)^{\alpha - k'} * (1-Q)^{k'}\right) / \sum_{k'=o}^{k} \binom{\alpha}{k'} \quad \ldots\ldots \quad (2)$$

and $$Z_k = \left(\sum_{k'=o}^{k} \binom{\alpha}{k'}\right) * R/2^{\alpha} \quad \ldots\ldots \quad (3)$$

a slightly modified version of the BDW-Function for each value of α is then given as a series of points k in parameter representation, for which the right boundary is determined by $Z_\alpha = R$; $X_\alpha = X$

Between these points the pairs of values [Z_i ; X_i] may be obtained by linear interpolation between log [Z_k ; X_k] and log [Z_{k+1} ; X_{k+1}] for $k \leqslant i < \alpha$

Under this definition the BDW-Function is:

(1) a monotonic decreasing continuous function;
(2) defined over the interval $R/2^{\alpha} \rightarrow R$;
(3) integrated over the interval $i = O \rightarrow i$;
(4) reversible: the inverse function $[BDWF]^{-1}$ exists on the same interval.

From the BDW-Function metal resources are found by:

$$M_i = Z_i * X_i \quad \ldots\ldots \quad (4)$$

By plotting the log (M_i) values for deposits with equal metal content against the log (X_i) grades of these deposits, an equal probability distribution [IRIS-diagram] is obtained on which resources of all possible size-grade specifications are inferred for the given geological environment. However, only those of possible economic interest (potential reserves) are shown on the diagrams.

The parameters required for their estimation are average concentration, size of the environment and specific mineralizability.

Average Concentration (X)

The average concentrations of the elements in the earth's crust are relatively well known. For the calculation of world resources we have used the values given by Green (1959).

The data given in this table show a systematic underestimation of the average concentration. This results from the sampling method and the particular distribution of the elements in the earth's crust. In fact, Green's values should be considered as median values for a rather high-order subdivision of the environment (α = large).

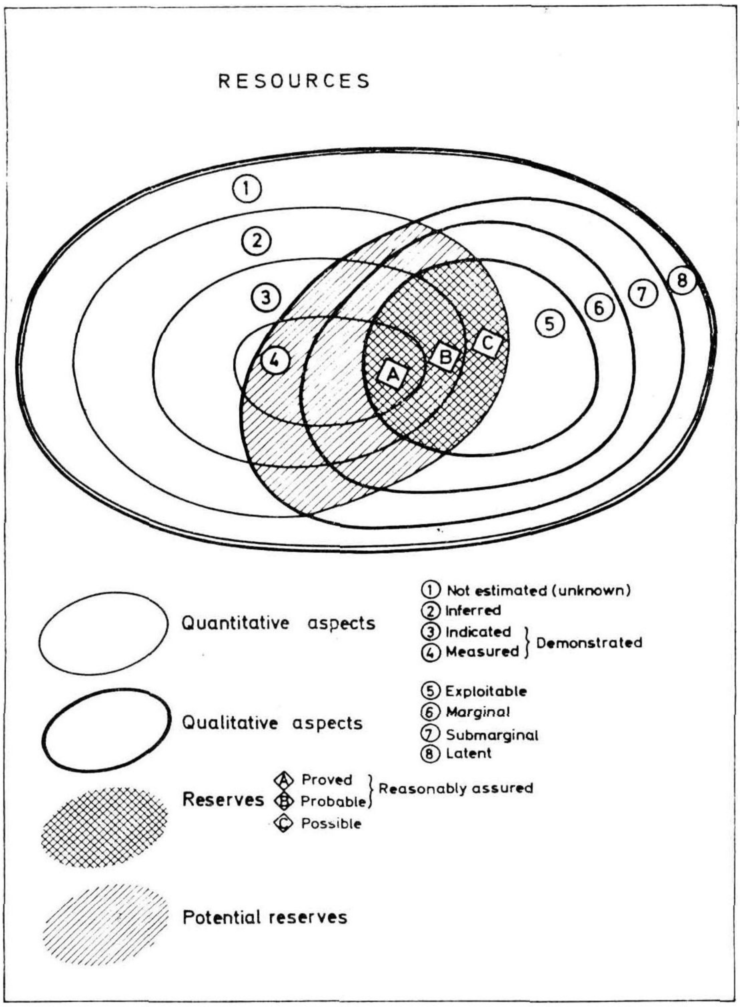

FIGURE 1.

For the interpretation of the results of a multi-element stream sediment survey in the Oslo Region, Norway, the average concentrations of copper, zinc and lead, after testing for possible composite distributions, have been determined from the median concentration (γ) and the logarithmic standard deviation (σ) as determined from 146 samples (Brinck, 1967) by:

$$X = \gamma * \mathrm{Exp}\ (0.5 * \sigma^2) \qquad (5)$$

Size of Environment (R)

For the world resources, the size of the environment is taken as the total dry land surface to a depth of 2.5 km. For an average specific gravity of 2.7 this environment contains

1.0×10^{18} metric tons of rock

For the Oslo Region the environment is taken as 10,000 km^2 to a depth of 2.5 km, representing

$$6.75 \times 10^{13} \text{ metric tons of rock}$$

which have been sampled on the surface by 146 samples representing an average surface area of 15 km^2 each, thus covering approximately 20% of the total area.

Specific Mineralizability (Q)

For the world resources the value of Q is calculated by a trial-and-error method from the measured frequency of ore deposits of given specifications (total size of reserves + previous production; average ore grade; average size of the ore deposits), the size of the environment and the average concentration of the element therein.

An auxiliary program, QFIND, has been developed to perform the calculations.

For the Oslo Region the Q values have been determined from

$$\alpha = \left[\log\left(\frac{S}{s}\right)\right]/\log(2) \qquad (6)$$

where:

S = surface of the Oslo Region

s = average sample surface

and $Q = \text{Exp}\left([\log(\gamma / X) + \sigma\sqrt{\alpha}]/\alpha\right) - 1 \qquad (7)$

LONG-TERM PRICE

It was found that the historical average price of some major non-ferrous metals such as copper, zinc, lead and gold is determined within 25% by X and Q:

$$\$/\text{kg metal} = \text{Exp}(8.96637 - 25.5688 * Q)/(X * 10^6) \qquad (8)$$

An index of determination of 0.99801, indicating this relation to be very significant in the statistical sense, has been determined by non-linear multiple regression analysis on the historical price (constant dollar value) and the values of X and Q. Figure 2 illustrates this relation as calculated with the values as in Table 1.

The Q values for copper, zinc and lead were determined from the estimated reserves plus previous production as at 1/1/1963 and confirm that the quality and size of the ore reserves of these metals is rather indicative for their natural availability at the marginal and higher grades of enrichment (EUR 3461e). For

TABLE 1 — Estimated "reasonably assured" reserves
(metric tons metal)

Metal	Year	Reserves total t.	Reserves Average t.	Grade %	α	X	Q
U.....	1967	5.00×10^5	4.00×10^3	0.15	38.44	3.0×10^{-6}	0.1915
U.....	1969	7.17×10^5	4.00×10^3	0.165	38.58	3.0×10^{-6}	0.1955
U.....	1971	4.30×10^5	1.00×10^4	0.185	37.43	3.0×10^{-6}	0.2003
Cu....	1963	2.19×10^8	1.11×10^6	1.7	33.84	7.0×10^{-5}	0.1981
Zn....	1963	1.74×10^8	0.43×10^6	4.3	36.54	8.0×10^{-5}	0.2126
Pb....	1963	1.55×10^8	0.50×10^6	5.0	34.96	1.6×10^{-5}	0.2793
Au....	1968	4.00×10^4	5.64×10^2	0.0015	34.66	1.0×10^{-9}	0.3547

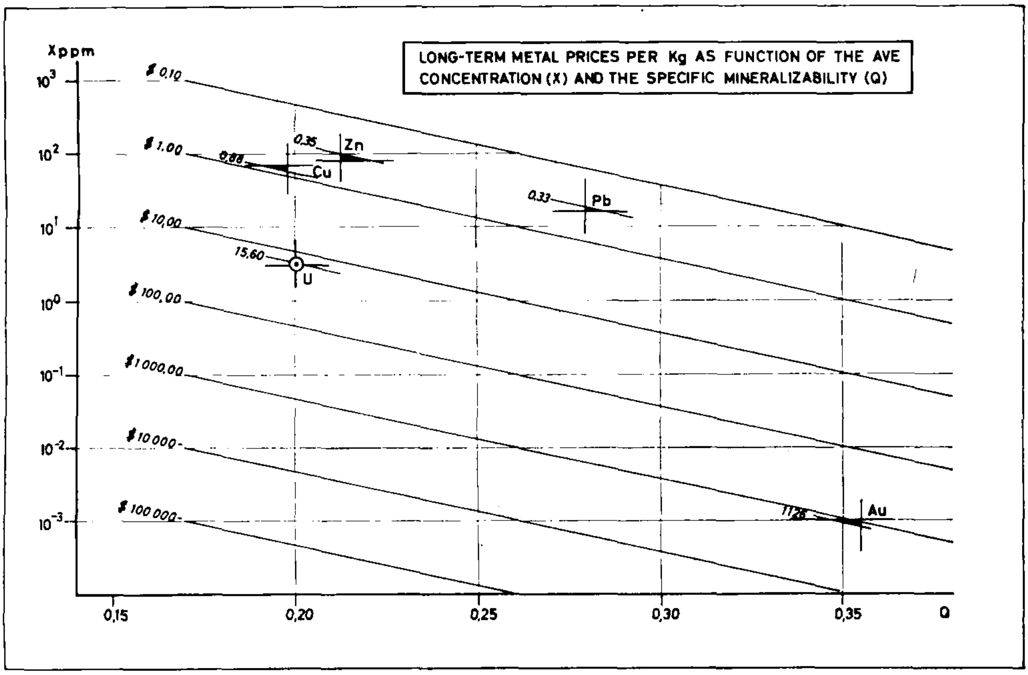

FIGURE 2.

gold, with a fixed market price, this relation appears to be quite coincidental. However, the reserves as estimated in 1968 appear to be equally well balanced with the natural availability of gold at this price.

The discrepancies between the predicted and the long-term prices actually observed, can be explained as follows.

(a) *estimating* errors

The slightly overestimated value of Q which results from the systematic underestimating of X largely corrects for an influence on the predicted long-term price. The major source of error can be expected to be found in the rather rough estimates on reserves, grade and average size of the ore deposits of the different metals.

(b) differences in production costs

It can be seen from Figure 2 that, contrary to common belief, differences in mining-, milling- and ore processing cost seem hardly to be reflected in the long-term price differences between the different products.

(c) differences in the development of the different mining industries

As indicated from the α values in Table 1, the price of metals with the largest average ore deposits appears to be underestimated (copper and gold), whereas the price of lead and zinc with somewhat smaller average ore deposits appears to be overestimated.

QUALITATIVE ASPECTS

Average unit production costs are determined from the size-grade specifications of the mineral deposits making up the inferred resources.