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COMMISSION OF THE EUROPEAN COMMUNITIES

THE ESTIMATION OF MINERAL RESOURCES BY THE COMPUTER PROGRAM "IRIS"

by

H. I. DE WOLDE and J. W. BRINCK

1971

Joint Nuclear Research Centre
Ispra Establishment - Italy
Scientific Information Processing Centre - CETIS
and
Directorate-General Energy

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ABSTRACT

This paper describes the mathematical formulation of a theory as developed by one of the authors, on the long term availability of minerals. By means of this method one may calculate the probable distribution of ore deposits of any size and grade starting from the known reserves. The method is based on a limited binomial expansion. A computer program "IRIS" performs the actual calculations.

KEYWORDS

COMPUTERS
PROGRAMMING
MINERALS
DEPOSITS
MATHEMATICS
DISTRIBUTION
EXPANSION
FORTRAN
ECONOMICS
MINING

Contents

Introduction *)

Almost conventionally, ore reserves are considered as naturally defined, vanishing assets of mostly unknown, but certainly limited magnitude. This consideration, in view of the long term availability of sufficient raw materials has been of grave concern to mineral economists. So far all predictions on the exhaustion of the world's ore reserves have been answered by the mining industry with increased production. It therefore appears that such predictions were based on insufficient quantitative data on the mineral resources from which ore reserves of mineral commodities are developed continuously.One of the authors has developed a theory of which the kernel has been published previously, to increase the prognostic value of these estimations. The method applies a limited binomial expansion to the distribution of a metal in a defined region. The formulation is such that a single constant, the separation factor **q**, defines the dispersion of the metal in the considered region. The actual value of q can be calculated out of the known reserves. Sequentially the distribution of ore deposits of any size and grade can be calculated. To facilitate the computations a computer program named 'IRIS' has been developed. 'IRIS' may calculate also the distributions of minerals according to the log-normal theory for comparison with the present results.

*) Manuscript received on 29 October 1970

A limited binomial expansion

Consider an environment, two- or three-dimensional, of undefined shape, existing out of:

1. A matrix material being the dominant part : $(1-\bar{x}).R$
2. An addition representing a small part : $\bar{x}.R$

   in which R is the size of the environment, expressed in surface units, weight units or volume units and $\bar{x}$ is the average grade of the addition.

If the environment is divided in two parts, equal in respect to the units in which R is expressed, the grades of the two parts may be described as:

$$[1+q_{01}] \cdot \bar{x} \qquad \text{and} \qquad [1-q_{01}] \cdot \bar{x} \qquad [1]$$

in which q_{01} is the separation factor $0 \leq q \leq 1$

If the two parts are in turn divided in two other parts the grades of the four boxes will be:

$$[1+q_{11}] \cdot [1+q_{01}] \cdot \bar{x}\,, \qquad [1-q_{01}] \cdot [1+q_{21}] \cdot \bar{x}$$

$$[1+q_{01}] \cdot [1-q_{11}] \cdot \bar{x}\,, \qquad [1-q_{11}] \cdot [1-q_{21}] \cdot \bar{x} \qquad [2]$$

This is called the second order binomial expansion. Each of the four boxes has the size $\frac{R}{4}$

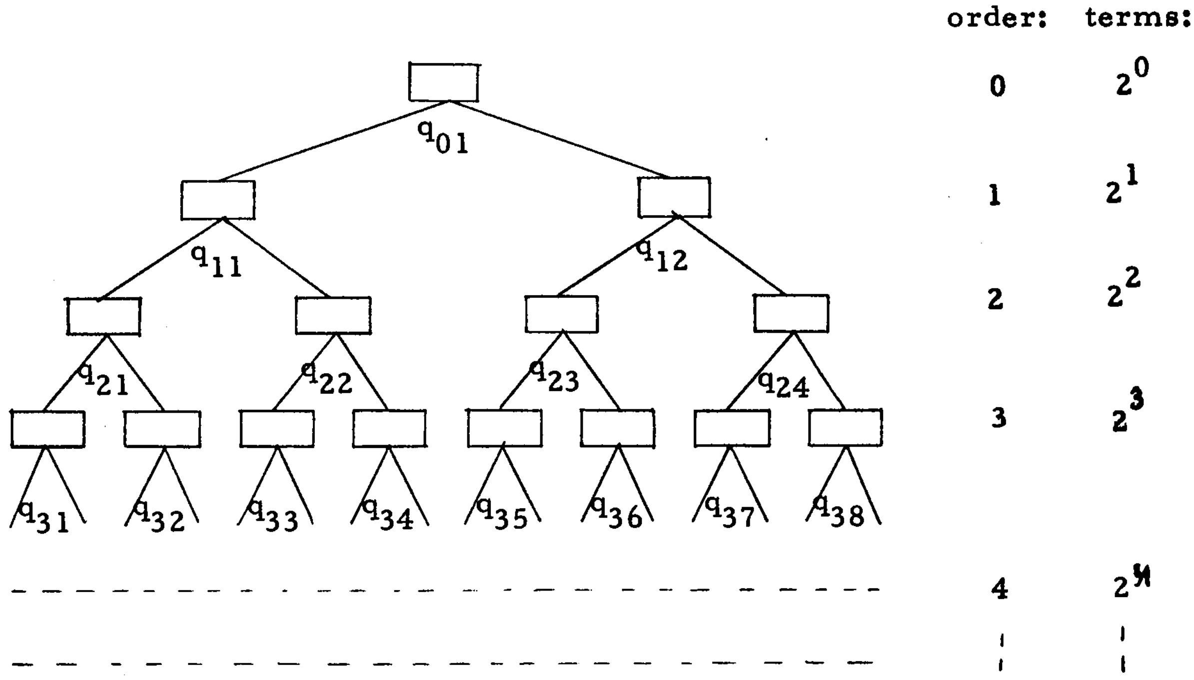
A third step gives 2^3 boxes of size $\frac{R}{2^3}$ with the grades:

1. $[1+q_{21}] \cdot [1+q_{11}] \cdot [1+q_{01}] \cdot \bar{x}$
2. $[1-q_{21}] \cdot [1+q_{11}] \cdot [1+q_{01}] \cdot \bar{x}$
3. $[1+q_{22}] \cdot [1-q_{11}] \cdot [1+q_{01}] \cdot \bar{x}$

----

8. $[1-q_{24}] \cdot [1-q_{12}] \cdot [1-q_{01}] \cdot \bar{x}$ [3]

This division may be continued as illustrated by the diagram:



[Fig. 1]

The K-th term in the N-order expansion is of the type:

$$\underbrace{[1 \pm q_{NK}] \cdot [1 \pm q_{ij}] \text{ ----- } \cdot [1 \pm q_{01}]}_{N \text{ Factors}} \cdot \bar{x} \qquad [4]$$

A reasonable approximation for the Nth order expansion may be obtained in case the many different q_{ij} 's are replaced by one average separation factor q, if N is not too small. This has been proved by testcalculations at which arbitrary distributions were generated and approximated with an average separation factor q, which can be calculated out of the highest occuring grade x_{MAX}:

$$[1+q]^N \cdot \bar{x} = x_{MAX}$$

Thus:

$$q = \sqrt[N]{\frac{x_{MAX}}{\bar{x}}} - 1 \qquad [5]$$

Consequently the grades of all the 2^n boxes at an Nth order expansion are given by:

$$x = \left[1+q\right]^{N-K} \cdot \left[1-q\right]^{K} \cdot \bar{x} \qquad C_K^N \text{ times, } K = 0, N \qquad [6]$$

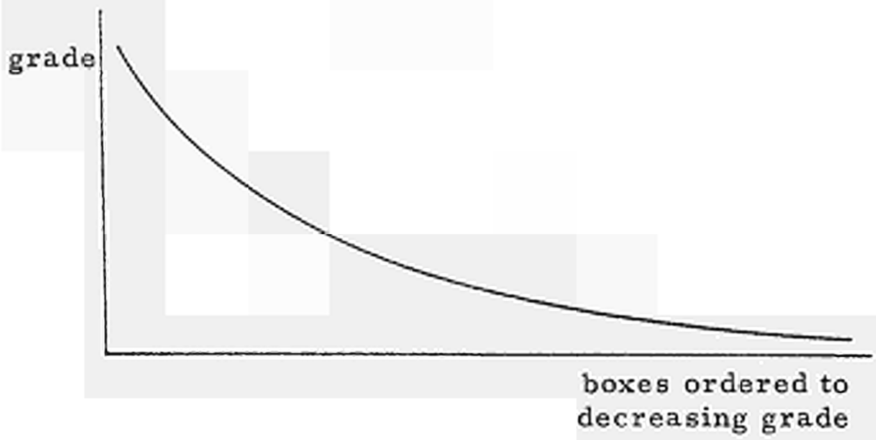
in which N is the order and:

$$C_K^N = \frac{N!}{K! \; (N-K)!} \qquad [7]$$

For our goals this binomial expansion will be extended to orders of rational numbers and the average separation factor q will be calculated out of the known exploitable reserves but the general idea is represented by the foregoing description.

The BDW-Function

Consider an environment R divided in many equal parts [boxes], of size s. After estimating the grade of each box a graphical presentation of grade distribution may be given:



[Fig. 2]

The BDW-function as developed hereafter, gives an approximation of this curve based on the binomial expansion.

The order α of an expansion for the environment R and the box size s, is given by:

$$2^{\alpha} = \frac{R}{s} \qquad [8]$$

or

$$\alpha = \frac{\text{Log}R - \text{Log}\, s}{\text{Log}\, 2} \qquad [9]$$

In general α will be a rational number and not an integer.

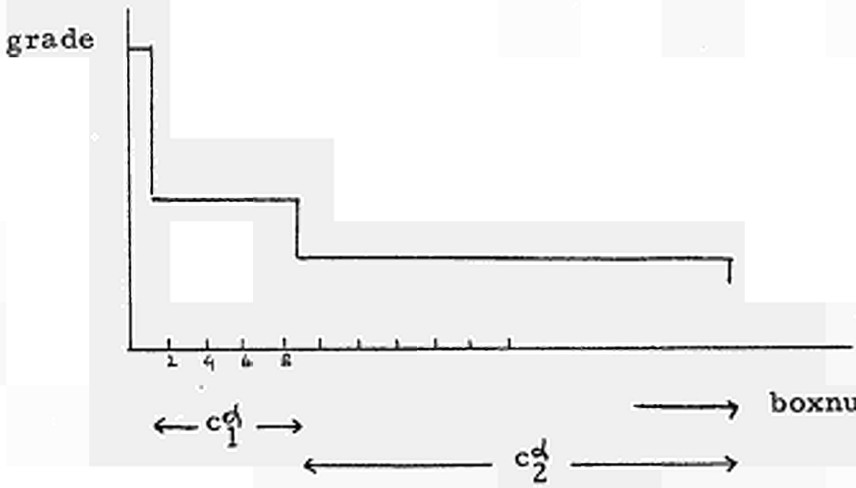
If the separation factor q is known, a first approximation to the distribution, analogous to expression [6] is given by:

$$x = [1+q]^{\alpha - k} \cdot [1-q]^{k} \cdot \bar{x} \qquad c_k^{\alpha} \text{ times} \qquad k = 0, 1, \ldots \qquad [10]$$

in which $\bar{x}$ is the average grade of the environment.
However c_k^{α} is not an integer anymore:

$$c_k^{\alpha} = \frac{\alpha \cdot (\alpha - 1) \cdot (\alpha - 2) \cdots\cdots (\alpha - k + 1)}{k\,!} \qquad [11]$$

If this approximation is ordered according to decreasing grades versus boxnumbers, the graphical presentation becomes :



[Fig. 3]

As such a step function is not very likely to occur in nature, a continous function may be shaped by connecting the centres of the intervals.
So we obtain a series points :

$$z_0 = 0.5 \; c_0^{\alpha} \quad ; \quad x_0 = [1+q]^{\alpha} \cdot \bar{x}$$

$$z_i = z_{i-1} + 0.5 \times [c_{i-1}^{\alpha} + c_i^{\alpha}] \quad ; \quad x_i = [1+q]^{\alpha - i} \cdot [1-q]^{i} \cdot \bar{x} \qquad [12]$$

The actual calculation may be simplified by:

$$c_i^{\alpha} = \frac{\alpha - i + 1}{i} \times c_{i-1}^{\alpha} \qquad [13]$$

The BDW-Function may be defined everywhere in the range $[z=0,\ z=2^{\alpha}]$ by considering the boxnumbers as size units and extrapolating the first branch to z=0.

The function is then given as a series of points i in parameter representation:

$$\text{BDW Function} \begin{cases} z_0 = 0 & ; \quad x_0 = \left[\dfrac{1+3q+\alpha+\alpha q}{1+\alpha}\right] \cdot [1+q]^{\alpha-1} \cdot \bar{x} \\ z_i = z_{i-1} + 0.5\left[c_{i-1}^{\alpha} + c_i^{\alpha}\right] & ; \quad x_i = [1+q]^{\alpha-i} \cdot [1-q]^{i} \cdot \bar{x} \qquad i = 1, 2, \ldots, \leq 2^{\alpha} \end{cases} \qquad [14]$$

Between these points the pairs of values $[z, x]$ may be obtained by linear interpolation.

Under the foregoing definition the BDW-Function is:

1. A monotonic decreasing continuous function
2. Defined over the interval $[z=0\ ,\ z=2^{\alpha}]$
3. Integrable
4. Reversible : the inverse function $[\text{BDWF}]^{-1}$ exists on the same interval.

It must be noted that the separation factor q is invariant for the environment R but the BDW-Function is depending on the number of blocks 2^{α} thus also on the size of the blocks, s.

<u>The calculation of the separation factor q</u>

Considering again an environment of R tons in which total exploitable reserves have been found of r tons metal in deposits of an average t tons metal with an average grade of x_r PPM, one may calculate the separation factor q for the environment R.

The individual deposits contain an average of t tons metal and the grade of these deposits is x PPM. Thus the individual size is:

$$s = \frac{t \cdot 10^6}{x_r} \text{ tons ore} \qquad [15]$$

If the whole environment is divided in boxes of size s tons then the order of the division is:

$$\alpha = \frac{\text{Log } R - \text{Log } s}{\text{Log } 2} \qquad [16]$$

and the reserves are:

$$10^{-6} \cdot s \cdot \int_0^{z_r} \text{BDWF}(z)\, dz = r \qquad [17]$$

in which: $z_r = \frac{r \cdot 10^6}{x_r \cdot s}$ ≙ number of boxes representing the reserves [18]

In this stage of the calculations the BDW-Function is not yet known, only the points z_i may be calculated according to the expressions [14]. By evaluating the relation [17] we can calculate the value of the separtion factor q and sequentially compute the values x_i.

If z_m is the largest z of the BDW-Function arguments for which $z_m < z_r$ then expression [17] may be written as:

$$0.5\,[x_m+x_r] \cdot [z_r-z_m] + \sum_{i=1}^{m} 0.5\,[x_i+x_{i-1}] \cdot [z_i-z_{i-1}] - \frac{r \cdot 10^6}{s} = 0 \qquad [19]$$

in which:

$$x_r = x_{m+1} + \frac{[x_m - x_{m+1}] \cdot [z_{m+1} - z_r]}{[z_{m+1} - z_m]} \qquad [20]$$

and the expressions for x_i are given by:

$$x_i = [1+q]^{\alpha-i} \cdot [1-q]^i \cdot \bar{x} \qquad i = 1, 2, \ldots \qquad [21]$$

$$x_o = \frac{1+3q+\alpha+\alpha q}{1} \cdot [1+q]^{\alpha-1} \cdot \bar{x} \qquad [22]$$

Out of these equations the separation factor q may be calculated by trial and error, as q has been defined : $0 < q < 1$.

Once q has been calculated one may construct the BDW-Function according to the definition [14], for each order α that means for each boxsize s.

The calculation of the reserves

Considering again the environment R with now a known separation factor q, one may calculate the total reserves r_t of a certain quality. Suppose the target deposit is defined as s_t tons ore with an average grade of $\bar{x}_t$ PPM of metal.
If the whole environment is divided in boxes of s_t tons then the order of the binomial expansion is

$$\alpha = \frac{\text{Log } R - \text{Log } s_t}{\text{Log } 2} \qquad [23]$$

As the order α and the separation factor q are known, the tabulated BDW-Function can be calculated according to [14], for a boxsize of s_t tons.

The total reserves r_t in deposits of size s_t tons and an average grade of $\bar{x}_t$ PPM are given by:

$$r_t = 10^{-6} \cdot s_t \cdot \int_0^{z_t} \text{BDWF}(z)\, dz \qquad [24]$$

in which the upper boundary z_t has to be calculated from:

$$\bar{x}_t = \frac{1}{z_t} \int_0^{z_t} \text{BDWF}(z)\, dz \qquad [25]$$

The first step in solving this equation is the identification of the interval $[z_j, z_{j+1}]$ of the tabulated BDW-Function in which z_t occurs.

The averages of the BDW-Function over each interval $[0, z_i]$ are given by:

$$\bar{x}_i = \frac{1}{z_i} \int_0^{z_i} \text{BDWF}(z)\, dz \qquad i = 1, 2, 3, \ldots \qquad [26]$$

or numerically written:

$$\bar{x}_i = \frac{1}{z_i} \sum_{k=1}^{i} 0.5\, [x_k + x_{k-1}] \cdot [z_k - z_{k-1}] \qquad [27]$$

or with a recurrent relation:

$$\bar{x}_i \cdot z_i = \bar{x}_{i-1} \cdot z_{i-1} + 0.5\, [x_i + x_{i-1}] \cdot [z_i - z_{i-1}] \qquad [28]$$

When all the averages x_i are calculated one can find an integer j for which:

$$\bar{x}_j < \bar{x}_t \leq \bar{x}_{j+1} \qquad [29]$$

By interpolation the next relations are derived:

$$\frac{0.5\,[x_j + x_t]\,[z_t - z_j] + \bar{x}_j \cdot z_j}{z_t} = \bar{x}_t \qquad [30]$$

$$x_t = x_{j+1} + \frac{[z_{j+1} - z_t] \cdot [x_j - x_{j+1}]}{[z_{j+1} - z_j]} \qquad [31]$$

out of which z_t can be solved.

We obtain a second degree equation in z_t by eliminating x_t and rearranging the terms:

$$-Az_t^2 + \left[B + A\,(z_{j+1} + z_j) - 2\bar{x}_t\right] \cdot z_t + \left[2\bar{x}_j \cdot z_j - Az_j z_{j+1} - Bz_j\right] = 0 \qquad [32]$$

in which

$$A = \frac{x_j - x_{j+1}}{z_{j+1} - z_j}$$

$$B = x_j + x_{j+1}$$

The upper boundary z_t of the integral [25] can now be calculated directly out of expression [32] .

The total reserves in depositsof size s_t and an average grade of x_t PPM are z_t boxes of the same size. Thus:

$$r_t = z_t \cdot s_t \cdot \bar{x}_t \cdot 10^{-6} \text{ tons of metal} \qquad [33]$$

By this result the calculation is completed.

The Log-Normal Concept

One of the authors of this paper has previously published another approximation to the inventarisation of mineral resources. As the computer program 'IRIS' provides also an option for this method, a short outline of the log-normal theory will be given here.

The log-normal distribution of the element concentrations is the basic concept of the method and the applied calculations:

> The weighted frequencies of the logarithms of the element concentrations, estimated from a series of regionally related samples, can be fitted into a normal probability distribution.

It is useful to express the weight of a geochemical sample as a linear equivalent which represents not only the actual quantity of material but also roughly the shape of the sample. The linear equivalent of a volume with the dimensions $a \geq b \gg c$ is approximately equal to:

$$d = a + b + c$$

Generally a description of a deposit is given by its content V and the dimension ratios b/a and c/b :

$$a = \sqrt[3]{\frac{V}{[b/a]^2 \cdot c/b}} \qquad [34]$$

$$d = a \cdot [1 + b/a + b/a \cdot c/b] \qquad [35]$$

The linear equivalent of a surface is given by:

$$a = \sqrt{\frac{S}{b/a}} \qquad [36]$$

$$d = a \cdot [1 + b/a] \qquad [37]$$

Considering now a random collection of geochemical samples with an average weight $\bar{d}$, the relation between the average grade $\bar{x}$ and the median γ is given by:

$$\bar{x} = \gamma \cdot e^{0.5\sigma^2}$$

in which σ is the standard deviation.

The probability of occurence P_K of a concentration $\geq x_K$ with size $\bar{d}$ in the same environment is given by:

$$P_K = 0.5 - 0.5 \text{ ERF} \left[\frac{\text{Log}x_K - \text{Log}\,\gamma}{\sqrt{2} \cdot \sigma} \right] \qquad [38]$$

Thus the probable available total quantity r_K of all concentrations $\geq x_K$ with average weight $\bar{d}$ is:

$$r_K = P_K \cdot R$$

in which R is the total quantity of the environment. The absolute dispersion coefficient α has been defined to express the relation between the standard deviation and the average size of the samples:

$$\alpha = \frac{\sigma^2}{3 \text{ Log } \frac{D}{d}} \qquad [39]$$

in which D is the linear equivalent of the environment. The dispersion coefficient α is a fractional value directly related to the occurence of the considered metal in the environment R. It is invariant in relation to the collection of samples taken to evaluate the environment R.

The previous expressions can be written as:

$$\alpha = \frac{100 \cdot \text{Log}^2 \left[\frac{x_K}{\gamma}\right]}{6 \text{ Log } \frac{D}{d} \cdot E^2} \qquad [40]$$

$$\frac{\bar{x}}{\gamma} = \text{EXP} \left[0.015 \cdot \alpha \cdot \text{Log } \frac{D}{d}\right] \qquad [41]$$

$$\gamma = \text{EXP} \left[- 2E^2 + \text{Log } x_K + 2E \sqrt{E^2 - \text{Log} x_K + \text{Log } \bar{x}}\right] \qquad [42]$$

in which $E = \text{ERF}^{-1} \left[1 - \frac{2r_K}{R}\right]$ [43]

If now for a certain element, the average grade $\bar{x}$ in the environment R is known and the present reserves r_K occur in deposits of size d with an average grade of x_K, then γ and respectively α may be calculated. Reversible: for each given x_K and d_K, the relations give the total occuring reserves of this quality.

Curves of equal metal content

Once the separation factor is known for a metal in a certain environment, one may calculate the total reserves of a given quality $[x, z]$, which means deposits with at least z tons of metal and an average grade of x PPM. The curves of equal metal content give the distribution of deposits with a fixed quantity of metal, t tons, at varying grades.

Considering all deposits with t tons of metal, there is one with the highest grade: x_{MAX}. According to expression [14] :

$$[1+q]^{\alpha} \cdot \bar{x} = x_{MAX} \qquad [44]$$

and $s \cdot x_{MAX} \cdot 10^{-6} = t$ [45]

in which s is the yet unkown box size in tons of ore. The order of the expansion for size s is:

$$\alpha = \frac{\text{Log } R - \text{Log } s}{\text{Log } 2} \qquad [46]$$

Out of these expressions x_{MAX} and α can be solved:

$$\frac{\text{Log } x_{MAX} - \text{Log } \bar{x}}{\text{Log } [1+q]} = \frac{\text{Log } R - \text{Log } t - \text{Log } 10^{-6} \cdot x_{MAX}}{\text{Log } 2}$$

$$\text{or: } x_{MAX} = \text{EXP} \left[\frac{\text{Log } \bar{x} \cdot \text{Log } 2 + \text{Log } [1+q] \cdot \text{Log} \left[\frac{R}{t \cdot 10^{6}} \right]}{\text{Log } 2 - \text{Log } [1+q]} \right] \qquad [47]$$

The total reserve of the quality $[x_{MAX}, t]$ is of course exactly t tons of metal because there is only one such a deposit. Then by choosing a series or $x_i < x_{MAX}$ and keeping the quantity of metal as t tons, one may calculate the corresponding series of total reserves. The lattice points for the curves of equal metal content are choosen as:

$$x_i = [1+q]^{\alpha - k} \cdot [1-q]^{k} \cdot \bar{x} \quad \text{with } k = 1, 2, 3, 4, 5 \qquad [48]$$

But, as the metal content of t tons stays constant, α is dependent of x_i.

The lattice points can be solved by the two additional relations:

$$\alpha = \frac{\text{Log } R - \text{Log } s}{\text{Log } 2} \qquad [49]$$

$$s = \frac{t \cdot 10^{6}}{x_i} \qquad [50]$$

Out of these three equations x_i , α and s can be solved:

$$\alpha = \frac{k \text{ Log } \frac{1-q}{1+q} + \text{ Log } \frac{\bar{x}.R}{t.10^6}}{\text{Log } \frac{2}{1+q}} \qquad [51]$$

The program 'IRIS'

The program 'IRIS' calculates the probable reserves for a series of target deposits which are specified by size and grade. The basic input data are the presently known reserves. The grade and size of the targets can be given directly or by specifying a development goal which has to be reached in a number of years. In this case the input requests a size increase factor and a grade decrease factor. For example it may be stated that for uranium a deposit of 2/3 times the present deposit grade must contain at least 2.5 times the amount of metal and such a deposit will become exploitable in 20 years. 'IRIS' provides the intermediate targets by logarithmic interpolation. Furthermore curves of equal metal content can be computed i.c. an inventarisation of all deposits with a fixed quantity of metal and varying grades. These curves may also be obtained as graphical output. The probable reserves can be calculated also according to the long-normal theory for comparison with the binomial expansion results.

The next list gives a description of the input.

Symbol	Fortran Names	Rel. Expr.	
Title			A description of the case of up to 71 characters. A '*' in the first column indicates the last case of the run.
I_1	IND(1)		= 0 no action = 1 [only if the specified environment R concerns the whole earth's crust] The probable reserves will also be calculated according to the Log normal concept.
I_2	IND(2)		= 0 each target deposit is given by size and grade = 1 the target deposits have to be calculated by a size increase factor F_z and a grade decrease factor F_x.
I_3	IND(3)		Calculate also equal metal content curves.
I_4	IND(4)		Graphical output required
r	RSMALL	19 - 22	Present total reserves in tons of metal of quality $[z, x_r]$
z	ZA	19 - 22	Average size of the deposits in tons of metal
x_r	XRSM	19 - 22	Average grade of the reserves in PPM
$\bar{x}$	XENV	19 - 22	Average grade of the environment R
R	R		Size of the environment in tons. The next card has to be present only if $I_1 > 0$ and the environment R is the whole earth's curst : $R = 10^{18}$ tons.
ρ	RHO	34 - 37	Specific gravity of the ore
b/a	BDA	34 - 37	dimension ratios for the average
c/b	CDB	34 - 37	deposit $a \geq b \gg c$.

Symbol	Fortran Names	Rel. Expr.	
			The next card has to be present only if $I_2 > 0$. The N target deposits will be calculated by: $$z_i = z . F_z^{\frac{i}{N_y}}$$ $$x_i = x_r . F_x^{\frac{i}{N_y}} \quad i = 1, \ldots, N$$
N_y			After N_y steps the target is $F_z . z$ tons metal and of grade $F_x . x_r$
F_z	FACA		Size increase factor
F_x	FACB		Grade decrease factor
N			Total number of targets
RTAR(i)	RTAR(i)		Size of the target in tons of metal
XTAR(i)	XTAR(i)		Grade of the target in PPM
NT			Number of equal metal content curves to be calculated
T(i)		44 - 47	Tons of Metal. For each T(i) 'IRIS' calculates the curve of the grades versus total reserves.

PROBLEM INPUT FOR THE PROGRAM 'IRIS' DATE PAGE OF

```
1   TITLE
2   I1 I2 I3 I4
3   u | Z | x_u | x̄ | R
4   ρ | b/a | c/b                 <-- ONLY IF I1>0
5   Ny | F2 | Fx                  <-- ONLY IF I2>0
6   N
7   RTAR(I)   | XTAR(I)    }
8   ------------------------  }  <-- ONLY IF I2=0
9   RTAR(N)   | XTAR(N)    }
10  NT                           } ONLY IF I3>0
11  T(1) | T(2) | | | T(NT)      }
```

```
* URANIUM RESOURCES
1111
0.72 E+6   4.0 E+3   1.65 E+3   3.0   1.0 E+18
2.7        0.5       0.1
4   2.5   0.666667
24
14
1.E+1 5.E+1 1.E+2 5.E+2 1.E+3 5.E+3 1.E+4 5.E+4 1.E+5 5.E+5 1.E+6 5.E+6
1.E+7 5.E+7
```

URANIUM RESOURCES

WORLD RESERVES	720000. TONS METAL
INDIVIDUAL SIZE	4000. TONS METAL
AVERAGE GRADE	1650. PPM
SIZE ENVIRONMENT	0 1000E 19 TONS
AVERAGE GRADE ENVIRONMENT	3. PPM
AVERAGE CONTENT IN CRUST	0.3000E 01 PPM
SPECIFIC GRAVITY	0.2700E 01 GR/CM3
DIMENSION RATIO B/A	0.5000E 00
DIMENSION RATIO C/B	0 1000E 00
GAMMA (CALCULATED)	0.1577E 01 PPM
ALFA (CALCULATED)	0.3981E 01 PERCENT
CALC. ENRICHMENT FACTOR Q	0 19050

PROBABLE RESERVES
****

TARGET DEPOSIT			RESERVES				
GRADE PPM	SIZE T. METAL	SIZE T. ORE	T. METAL	T. ORE	NUMBER OF DEP.	ORDER	LOG NORMAL
1650.	4000.	2424242.	0.7200E 06	0.4363E 09	179.99	38.586	189.82
1491.	5030.	3373523.	0.1046E 07	0.7017E 09	208.00	38.109	195.79
1347.	6325.	4694523.	0.1492E 07	0.1107E 10	235.85	37.632	212.20
1217.	7953.	6532801.	0.2091E 07	0.1718E 10	262.92	37.155	230.18
1100.	10000.	9090912.	0.2838E 07	0.2625E 10	288.80	36.679	249.94
994.	12574.	12650724.	0.3939E 07	0.3963E 10	313.23	36.202	271.69
898.	15811.	17604480.	0.5314E 07	0.5916E 10	336.07	35.725	295.66
812.	19882.	24498032.	0.7122E 07	0.8776E 10	358.22	35.249	322.13
733.	25000.	34090960.	0.9587E 07	0.1307E 11	383.46	34.772	351.38
663.	31436.	47440288.	0.1298E 08	0.1958E 11	412.78	34.295	383.81
599.	39529.	66016928.	0.1767E 08	0.2951E 11	447.07	33.818	389.81
541.	49705.	91367824.	0.2422E 08	0.4477E 11	487.37	33.342	374.26
489.	62500.	127841424.	0.3343E 08	0.6838E 11	534.92	32.865	402.90
442.	78590.	177901392.	0.4645E 08	0.1051E 12	590.99	32.388	425.14
399.	98821.	247563920.	0.6491E 08	0.1626E 12	656.83	31.911	444.96
361.	124261.	344504832.	0.9112E 08	0.2526E 12	733.29	31.435	469.82
326.	156250.	479406080.	0.1282E 09	0.3933E 12	820.37	30.958	496.42
295.	196474.	667131904.	0.1802E 09	0.6117E 12	916.98	30.481	521.56
266.	247054.	928367616.	0.2522E 09	0.9476E 12	1020.73	30.005	544.97
240.	310654.	1291896832.	0.3505E 09	0.1457E 13	1128.11	29.528	572.69
217.	390626.	1797777152.	0.4826E 09	0.2221E 13	1235.33	29.051	598.95
196.	491187.	2501749248.	0.6576E 09	0.3349E 13	1338.79	28.574	625.67
177.	617635.	3481383168.	0.8866E 09	0.4997E 13	1435.42	28.098	653.22
160.	776635.	4844617728.	0.1183E 10	0.7378E 13	1523.03	27.621	680.59

TABLES OF EQUAL METAL CONTENT
****

TARGET DEPOSIT 10. TONS OF METAL HIGHESTGRADE DEPOSIT 21622. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
21622.	1.	0.4625E 03	0.9999E 01	50.94
12915.	185.	0.7743E 03	0.1847E 04	50.20
7714.	3902.	0.1296E 04	0.3902E 05	49.45
4607.	54633.	0.2170E 04	0.5463E 06	48.71
2752.	560953.	0.3634E 04	0.5610E 07	47.97
1644.	4450018.	0.6084E 04	0.4450E 08	47.22

TARGET DEPOSIT 50. TONS OF METAL HIGHESTGRADE DEPOSIT 12588. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
12588.	1.	0 3972E 04	0.5000E 02	47.84
7519.	169.	0.6650E 04	0.8450E 04	47.10
4491.	3353.	0.1113E 05	0.1676E 06	46.35
2682.	43904.	0 1864E 05	0.2195E 07	45.61
1602.	420081.	0.3121E 05	0.2100E 08	44.86
957.	3093855.	0.5225E 05	0.1547E 09	44.12

TARGET DEPOSIT 100. TONS OF METAL HIGHESTGRADE DEPOSIT 9972. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
9972.	1.	0.1003E 05	0.9999E 02	46.50

5956.	162.	0.1679E 05	0.1624E 05	45.76
3557.	3131.	0.2811E 05	0.3131E 06	45.02
2125.	39780.	0.4706E 05	0.3978E 07	44.27
1269.	368652.	0.7380E 05	0.3687E 08	43.53
758.	2624942.	0.1319E 06	0.2625E 09	42.79

TARGET DEPOSIT   500. TONS OF METAL   HIGHESTGRADE DEPOSIT   5805. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
5805.	1.	0.8613E 05	0.5000E 03	43.40
3467.	147.	0.1442E 06	0.7369E 05	42.66
2071.	2651.	0.2414E 06	0.1325E 07	41.91
1237.	31276.	0.4042E 06	0.1564E 08	41.17
739.	267980.	0.6767E 06	0.1340E 09	40.43
441.	1756119.	0.1133E 07	0.8781E 09	39.68

TARGET DEPOSIT   1000. TONS OF METAL   HIGHESTGRADE DEPOSIT   4599. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
4599.	1.	0.2174E 06	0.9999E 03	42.06
2747.	141.	0.3641E 06	0.1411E 06	41.32
1641.	2459.	0.6095E 06	0.2459E 07	40.58
980.	28046.	0.1020E 07	0.2805E 08	39.83
585.	231865.	0.1709E 07	0.2319E 09	39.09
350.	1462862.	0.2861E 07	0.1463E 10	38.35

TARGET DEPOSIT   5000. TONS OF METAL   HIGHESTGRADE DEPOSIT   2677. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
2677.	1.	0.1868E 07	0.5000E 04	38.96
1599.	127.	0.3127E 07	0.6336E 06	38.22
955.	2044.	0.5235E 07	0.1022E 08	37.47
570.	21467.	0.8765E 07	0.1073E 09	36.73
341.	162488.	0.1467E 08	0.8124E 09	35.99
204.	933182.	0.2457E 08	0.4666E 10	35.24

TARGET DEPOSIT 10000. TONS OF METAL HIGHESTGRADE DEPOSIT 2121. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
2121.	1.	0.4715E 07	0.1000E 05	37.63
1267.	121.	0.7894E 07	0.1207E 07	36.88
757.	1880.	0.1322E 08	0.1880E 08	36.14
452.	19005.	0.2213E 08	0.1900E 09	35.40
270.	138135.	0.3705E 08	0.1381E 10	34.65

TARGET DEPOSIT 50000. TONS OF METAL HIGHESTGRADE DEPOSIT 1235 PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
1235.	1.	0.4049E 08	0.5000E 05	34.52
737.	107.	0.6780E 08	0.5353E 07	33.78
440.	1529.	0.1135E 09	0.7643E 08	33.04
263.	14067.	0.1900E 09	0.7034E 09	32.29

TARGET DEPOSIT 100000. TONS OF METAL HIGHESTGRADE DEPOSIT 978. PPM

GRADE	NUMBER	SIZE	TONS	ORDER

	DEPOSITS	DEPOSIT	METAL	
978.	1.	0.1022E 09	0.9999E 05	33.19
584.	101.	0.1712E 09	0.1013E 08	32.44
349.	1390.	0.2366E 09	0.1390E 09	31.70
208.	12252.	0.4798E 09	0.1225E 10	30.96

TARGET DEPOSIT 500000. TONS OF METAL HIGHESTGRADE DEPOSIT 569. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
569	1.	0.8781E 09	0.5000E 06	30.08
340.	88.	0.1470E 10	0.4423E 08	29.34
203.	1099.	0.2461E 10	0.5493E 09	28.60

TARGET DEPOSIT 1000000. TONS OF METAL HIGHESTGRADE DEPOSIT 451. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
451.	1.	0.2217E 10	0.1000E 07	28.75
269.	83.	0.3712E 10	0.8308E 08	28.01

TARGET DEPOSIT 5000000. TONS OF METAL HIGHESTGRADE DEPOSIT 263. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER
263.	1.	0.1904E 11	0.5000E 07	25.65

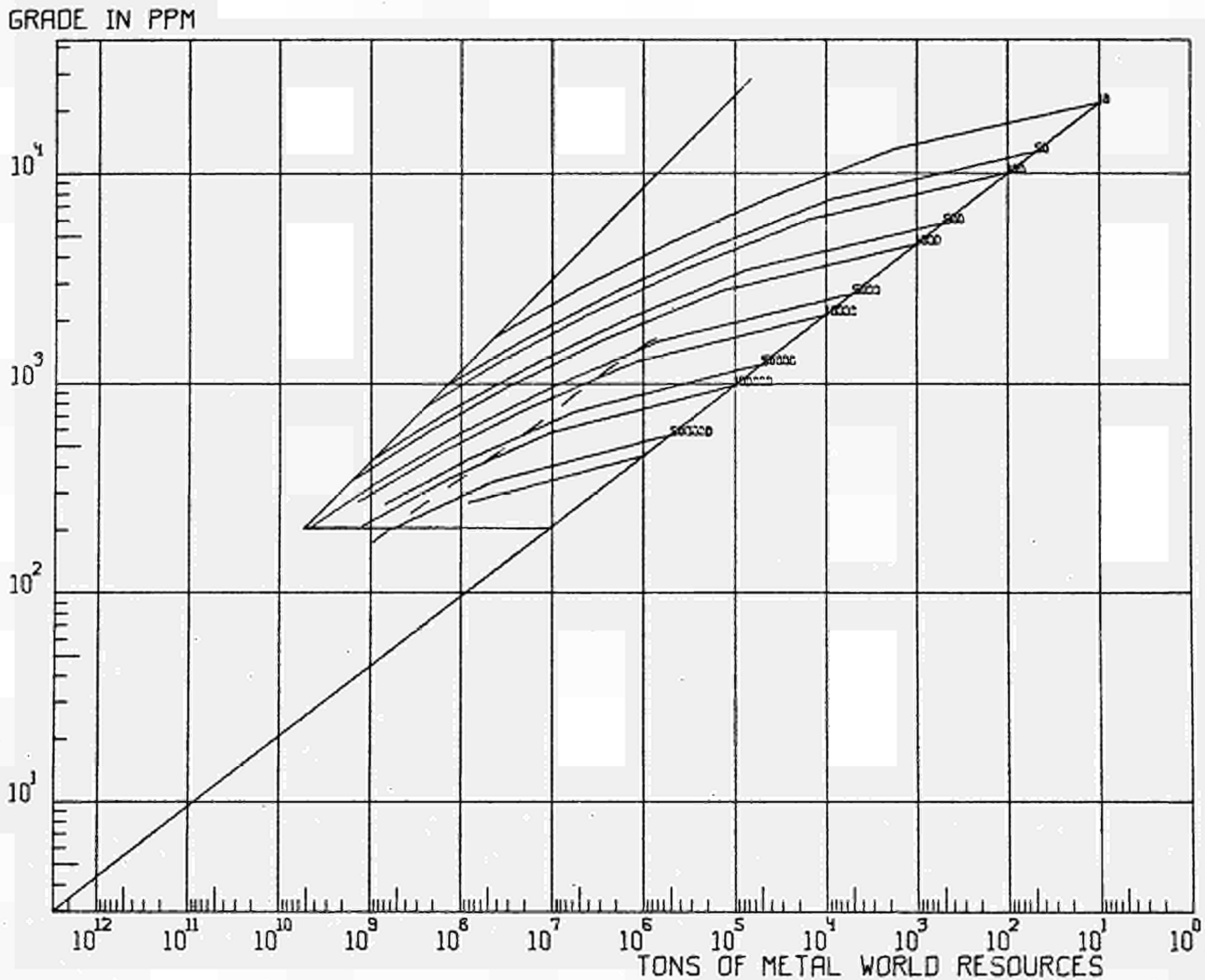
TARGET DEPOSIT 10000000. TONS OF METAL HIGHESTGRADE DEPOSIT 208. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER

208.	1.	0.4807E 11	0.9999E 07	24.31

TARGET DEPOSIT 50000000. TONS OF METAL HIGHESTGRADE DEPOSIT 121. PPM

GRADE	NUMBER DEPOSITS	SIZE DEPOSIT	TONS METAL	ORDER


GRADE IN PPM
10^4
10^3
10^2
10^1
10
50
100
500
1000
5000
10000
50000
100000
500000
10^12
10^11
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
TONS OF METAL WORLD RESOURCES

```
C-----PROGRAM IRIS-B BY HERMAN I. DE WOLDE-----JANUARY 1970------------
C
C     IRIS CALCULATES MINERAL RESERVES OF SPECIFIED GRADES AND SIZES
C     ACCORDING TO A BINOMINAL DISTRIBUTION
C
C     THE BASIC DATA FOR THE BINOMINAL DISTRIBUTION ARE DERIVED
C     FROM PRESENTLY KNOWN RESERVES
C
C
      DIMENSION ALF(18),RTAR(30),XTAR(30),ZXS(3,100)
      DIMENSION XX(100),OUT(10,100),BEX(100),AVZT(2),IND(6),T(100)
      DIMENSION XC(100),YC(100),SC(100),ALFC(100),TMC(100)
      DIMENSION GRAD(2,100),PATT(2,100)
      COMMON FX,FZ,XRSM,ZA,PATT,NTAR
      DATA STAR/'*'/
C
C-----READ THE INPUT----------------------------------------------------
C
  100 READ (5,102) STARA,(ALF(I),I=1,18)
  102 FORMAT (A1,18A4)
  104 FORMAT (6E12.4)
      READ (5,97) (IND(I),I=1,6)
   97 FORMAT (6I1)
      READ (5,104) RSMALL,ZA,XRSM,XENV,R
      IF(IND(1).EQ.0) GO TO 98
      READ (5,104) RHO,BDA,CDB
   98 IF(IND(2).EQ.0) GO TO 101
      READ (5,99) NY,FACA,FACB
      FX=FACB
      FZ=FACA
   99 FORMAT (I6,2E12.4)
  101 READ (5,99) NCAS
      IF(IND(2).GT.0) GO TO 107
      DO 103 I=1,NCAS
      READ (5,104) RTAR(I),XTAR(I)
  103 CONTINUE
  107 IF(IND(3).EQ.0) GO TO 111
      READ (5,99) NQ
      READ (5,109) (T(I),I=1,NQ)
  109 FORMAT (12E6.2)
  111 CONTINUE
  106 FORMAT (3I6)
      IF (IND(2).EQ.0) GO TO 1000
      RTAR(1)=ZA
      XTAR(1)=XRSM
      AF=FACA**(1./FLOAT(NY))
      BF=FACB**(1./FLOAT(NY))
      DO 105 I=2,NCAS
      RTAR(I)=AF*RTAR(I-1)
      XTAR(I)=BF*XTAR(I-1)
      IF (XTAR(I).GT.XENV) GO TO 105
      NCAS=I-1
      GO TO 1000
  105 CONTINUE
 1000 CONTINUE
C
C
C-----WRITE INPUT DATA--------------------------------------------------
C
```

```
  110 WRITE (6,112) (ALF(I),I=1,18)
  112 FORMAT (1H1/' ',18A4///)
      WRITE (6,116) RSMALL
  116 FORMAT (' WORLD RESERVES',15X,F10.0,' TONS METAL'/)
      WRITE (6,118) ZA
  118 FORMAT (' INDIVIDUAL SIZE',14X,F10.0,' TONS METAL'/)
      WRITE (6,120) XRSM
  120 FORMAT (' AVERAGE GRADE',16X,F10.0,' PPM'/)
  122 FORMAT (' AVERAGE GRADE ENVIRONMENT',4X,F10.0,' PPM'/)
      WRITE (6,124) R
  124 FORMAT (' SIZE ENVIRONMENT',13X,E10.4,' TONS'/)
      WRITE (6,122) XENV
C
C-----CALCULATE ALFA AND GAMMA-----------------------------------------
C
      IF(IND(1).EQ.0) GO TO 117
      Z=ZA*1.E+6/XRSM
      F=(Z*1.E-9)/RHO
      A=(F/(BDA**2*CDB))**0.333333
      DSMALL=A*(1.+BDA*(1+CDB))
      JA=1
      P=(RSMALL*1.E-12)/XRSM
      CALL PNP (P,ENP,JA)
C
      ENP=ENP/SQRT(2.)
      GAMENV=    (-4.*ENP**2+2.*ALOG(XRSM)+4.*ENP*
     1SQRT(ENP**2-ALOG(XRSM)+ALOG(XENV)))
      GAMENV=EXP(GAMENV/2.)
      ALFB=100.*(ALOG(XRSM/GAMENV))**2/(6.*ALOG(24400./DSMALL)*ENP**2)
      WRITE (6,119) XENV,RHO,BDA,CDB,GAMENV,ALFB
  119 FORMAT (' AVERAGE CONTENT IN CRUST',5X,E12.4,' PPM'//
     1' SPECIFIC GRAVITY',13X,E12.4,' GR/CM3'//
     2' DIMENSION RATIO B/A',10X,E12.4//
     3' DIMENSION RATIO C/B',10X,E12.4//
     4' GAMMA (CALCULATED)',11X,E12.4,' PPM'//
     5' ALFA (CALCULATED)',12X,E12.4,' PERCENT'/)
C
  117 CONTINUE
      S=1.E+6*ZA/XRSM
      ALFA=(ALOG(R)-ALOG(S))/ALOG(2.)
      NORDER=ALFA
      ADJ=R/(S*2.**NORDER)
      ZR=RSMALL*1.E+6/(XRSM*S)
C
C-----CALCULATE Z-VALUES OF THE BDW-FUNCTION---------------------------
C
      ZXS(1,1)=0.5
      CAI=1.
      DO 130 I=1,NORDER
      IPL=I+1
      ZXS(1,IPL)=ZXS(1,IPL-1)+0.5*CAI*(ALFA+1.)/FLOAT(I)
      CAI=CAI*(ALFA+1.-FLOAT(I))/FLOAT(I)
  130 CONTINUE
      ZXS(1,1)=0.0
      MAXZ=NORDER+1
C
C-----SELECT INTERVAL IN WHIGH ZR OCCURS-------------------------------
C
      DO 140 I=1,MAXZ
      IF(ZXS(1,I).GE.ZR) GO TO 146
  140 CONTINUE
```

```
      WRITE (6,142)
  142 FORMAT (' ERROR EXIT 1')
      STOP
  146 IPLM=I-1
      M=I-2
      IA=I
C
      IWAY=1
      Q=0.00001
      CFAC=RSMALL*1.E+6/S
C
  150 CONTINUE
      CALL XFQ(XX,XENV,Q,ALFA,IA)
      XR=XX(IA)+(ZXS(1,IA)-ZR)*(XX(IPLM)-XX(IA))/(ZXS(1,IA)-ZXS(1,IPLM))
      AFAC=(XX(IPLM)+XR)*0.5*(ZR-ZXS(1,IPLM))
      IF(M.EQ.0) GO TO 158
      DO 154 I=1,M
      AFAC=AFAC+(XX(I+1)+XX(I))*0.5*(ZXS(1,I+1)-ZXS(1,I))
  154 CONTINUE
  158 AFAC=AFAC-CFAC
      GO TO (162,166),IWAY
C
  162 CONTINUE
      DEL=1.0
      DO 174 KI=1,6
      DEL=DEL*0.1
      DO 168 J=1,9
      QA=Q
      BFAC=AFAC
      Q=Q+DEL
      IWAY=2
      GO TO 150
C
  166 IF ((BFAC*AFAC).LE.0.0) GO TO 170
  168 CONTINUE
      GO TO 174
  170 Q=QA
      AFAC=BFAC
  174 CONTINUE
      WRITE (6,176) Q
  176 FORMAT (' CALC. ENRICHMENT FACTOR Q',4X,F10.5/)
C
C-----AND NOW THE TARGET DEPOSITS------------------------------------
C
  250 NTAR=NCAS
      DO 300 ITAR=1,NTAR
      RT=RTAR(ITAR)
      XT=XTAR(ITAR)
      ST=1.E+6*RT/XT
      AL=(ALOG(R)-ALOG(ST))/ALOG(2.)
      NT=AL
      ADJA=R/(ST*2.**NT)
      MAXZ=NT+1
C
C-----CONSTRUCT THE BDW-FUNCTION FOR ORDER NT-------------------------
C
      ZXS(1,1)=0.5
      QAI=1.
      ZXS(2,1)=(1.+Q)**AL*XENV
      QPLUS=1.+Q
      QMIN=1.-Q
```

```
      DO 254 I=1,NT
      IPL=I+1
      ZXS(1,IPL)=ZXS(1,IPL-1)+0.5*CAI*((AL+1.)/FLOAT(I))
      CAI=(AL-FLOAT(I)+1.)*CAI/FLOAT(I)
      ZXS(2,IPL)=QPLUS**(AL-FLOAT(I))*QMIN**I*XENV
  254 CONTINUE
      ZXS(1,1)=0.0
      ZXS(2,1)=ZXS(2,2)+ZXS(1,2)*(ZXS(2,1)-ZXS(2,2))/(ZXS(1,2)-0.5)
C
C-----CALCULATE THE AVERAGES FROM Z(I) TO 2**N-------------------------
C
      ZXS(3,1)=0.
      DO 264 I=1,NT
      IPL=I+1
      ZXS(3,IPL)=ZXS(3,IPL-1)+(ZXS(2,IPL)+ZXS(2,IPL-1))*(ZXS(1,IPL)-ZXS(
     11,IPL-1))*0.5
  264 CONTINUE
      DO 268 I=1,NT
      IPL=I+1
      ZXS(3,IPL)=ZXS(3,IPL)/ZXS(1,IPL)
  268 CONTINUE
C
C
C-----SELECT THE (J,J+1) INTERVAL IN WHICH XT OCCURS-------------------
C
      DO 276 I=2,MAXZ
      IF (ZXS(3,I).LE.XT) GO TO 280
  276 CONTINUE
      WRITE (6,278)
  278 FORMAT (' ERROR EXIT 2')
      STOP
  280 J=I-2
      JPL=I-1
C
C-----CALCULATE THE RIGHT BOUNDARY OF THE INTEGRAL---------------------
C
      XJ=ZXS(2,JPL)
      XJ1=ZXS(2,JPL+1)
      ZJ=ZXS(1,JPL)
      ZJ1=ZXS(1,JPL+1)
      AFAC=(XJ-XJ1)/(ZJ1-ZJ)
      BFAC=XJ+XJ1
      AA=-AFAC
      BB=BFAC+AFAC*(ZJ1+ZJ)-2.*XT
      CC=2.*ZXS(3,JPL)*ZJ-AFAC*ZJ*ZJ1-BFAC*ZJ
      ZT=(-BB-SQRT(BB**2-4.*AA*CC))/(2.*AA)
C
      OUT(1,ITAR)=XT
      OUT(2,ITAR)=RT
      OUT(3,ITAR)=ST
      OUT(6,ITAR)=ZT
      OUT(7,ITAR)=AL
      OUT(5,ITAR)=OUT(6,ITAR)*ST
      OUT(4,ITAR)=OUT(5,ITAR)*XT*1.E-6
      OUT(8,ITAR)=0.
      PATT(2,ITAR)=XT
      PATT(1,ITAR)=OUT(4,ITAR)
      IF(IND(1).EQ.0) GO TO 300
      ZZZ=RTAR(ITAR)
      GRA=XTAR(ITAR)
      DDP=(ZZZ/GRA)*1.E+6
```

```
      VD=(DDP/RHO)*1.E-9
      AD=(VD/(BDA**2*CDB))**0.3333333
      DD=AD*(1.+BDA+BDA*CDB)
      GAMD=XENV/EXP(0.015*ALFB*ALOG(24400./DD))
      SIGD=SQRT(2.*ALOG(XENV/GAMD))
      ENP=ALOG(GRA/GAMD)/SIGD
      IPP=2
      CALL PNP(P,ENP,IPP)
      ENDEP=P*1.E+18/DDP
      OUT(8,ITAR)=ENDEP
  300 CONTINUE
      WRITE (6,308) (STAR,I=1,17)
  308 FORMAT (1H1/' PROBABLE RESERVES'/' ',17A1///)
      WRITE (6,310)
  310 FORMAT (7X,'T A R G E T   D E P O S I T',9X,'R   E   S   E   R   V   E   S
     1'/)
      WRITE (6,314)
  314 FORMAT (7X,'GRADE',8X,'SIZE',8X,'SIZE',4X,'T. METAL',6X,'T. ORE',6
     1X,'NUMBER',7X,'ORDER',12X,'LOG')
      WRITE (6,318)
  318 FORMAT (9X,'PPM',4X,'T. METAL',6X,'T. ORE',29X,'OF DEP.',21X,'NORM
     1AL'/)
      DO 322 I=1,NTAR
      WRITE (6,326) (OUT(J,I),J=1,8)
  322 CONTINUE
  326 FORMAT (3F12.0,2E12.4,F12.2,F12.3,F15.2/)
C
C-----CALCULATE THE LINES OF EQUAL METAL CONTENT-----------------------
C
      IF(IND(3).NE.0) GO TO 404
      IF(STARA.NE.STAR) GO TO 100
      STOP
  404 WRITE (6,410)
  410 FORMAT (1H1/' TABLES OF EQUAL METAL CONTENT'/
     1           ' ****************************'//)
C
      DO 480 INT=1,NQ
      TT=T(INT)
C
C-----SOLVE XMAX-------------------------------------------------------
C
      ELTWO=ALOG(2.)
      AF=ALOG(XENV)
      BF=ALOG(1.+Q)
      CF=ALOG(R/(TT*1.E+6))
      XMAX=EXP((ELTWO*AF+BF*CF)/(ELTWO-BF))
      NPOIN=0
      WRITE (6,420) TT,XMAX
  420 FORMAT (////' TARGET DEPOSIT',F15.0,' TONS OF METAL',10X,' HIGHEST
     1GRADE DEPOSIT',F8.0,' PPM'//)
      WRITE (6,422)
  422 FORMAT (5X,'GRADE   NUMBER',11X,'SIZE',11X,'TONS     ORDER'/
     112X,'DEPOSITS',7X,'DEPOSIT',10X,'METAL'/)
      NPOIN=6
      DO 460 IP=1,6
      IIP=IP-1
      ALFC(IP)=FLOAT(IIP)*ALOG((1.-Q)/(1.+Q))+AF+CF
      ALFC(IP)=ALFC(IP)/(ELTWO-BF)
      XC(IP)=(1.+Q)**(ALFC(IP)-FLOAT(IIP))*(1.-Q)**IIP*XENV
      SC(IP)=TT*1.E+6/XC(IP)
      IF (XC(IP).GE.200.) GO TO 423
```

```
      NPOIN=IP-1
      GO TO 464
  423 CONTINUE
      RT=TT
      XT=XC(IP)
      ST=SC(IP)
      AL=ALFC(IP)
      NT=AL
      MAXZ=NT+1
C
C-----CONSTRUCT THE BDW-FUNCTION FOR ORDER NT-------------------------
C
      ZXS(1,1)=0.5
      CAI=1.
      ZXS(2,1)=(1.+Q)**AL*XENV
      QPLUS=1.+Q
      QMIN=1.-Q
      DO 554 I=1,NT
      IPL=I+1
      ZXS(1,IPL)=ZXS(1,IPL-1)+0.5*CAI*((AL+1.)/FLOAT(I))
      CAI=(AL-FLOAT(I)+1.)*CAI/FLOAT(I)
      ZXS(2,IPL)=QPLUS**(AL-FLOAT(I))*QMIN**I*XENV
  554 CONTINUE
      ZXS(1,1)=0.0
      ZXS(2,1)=ZXS(2,2)+ZXS(1,2)*(ZXS(2,1)-ZXS(2,2))/(ZXS(1,2)-0.5)
C
C-----CALCULATE THE AVERAGES FROM Z(I) TO 2**N------------------------
C
      ZXS(3,1)=0.
      DO 564 I=1,NT
      IPL=I+1
      ZXS(3,IPL)=ZXS(3,IPL-1)+(ZXS(2,IPL)+ZXS(2,IPL-1))*(ZXS(1,IPL)-ZXS(
     11,IPL-1))*0.5
  564 CONTINUE
      DO 568 I=1,NT
      IPL=I+1
      ZXS(3,IPL)=ZXS(3,IPL)/ZXS(1,IPL)
  568 CONTINUE
C
C
C-----SELECT THE (J,J+1) INTERVAL IN WHICH XT OCCURS------------------
C
      DO 576 I=2,MAXZ
      IF (ZXS(3,I).LE.XT) GO TO 580
  576 CONTINUE
      WRITE (6,578)
  578 FORMAT (' ERROR EXIT 5')
      STOP
  580 J=I-2
      JPL=I-1
C
C-----CALCULATE THE RIGHT BOUNDARY OF THE INTEGRAL--------------------
C
      XJ=ZXS(2,JPL)
      XJ1=ZXS(2,JPL+1)
      ZJ=ZXS(1,JPL)
      ZJ1=ZXS(1,JPL+1)
      AFAC=(XJ-XJ1)/(ZJ1-ZJ)
      BFAC=XJ+XJ1
      AA=-AFAC
      BB=BFAC+AFAC*(ZJ1+ZJ)-2.*XT
```

```
      CC=2.*ZXS(3,JPL)*ZJ-AFAC*ZJ*ZJ1-BFAC*ZJ
      ZT=(-BB-SQRT(BB**2-4.*AA*CC))/(2.*AA)
C
      YC(IP)=ZT
      TMC(IP)=ZT*SC(IP)*XC(IP)*1.E-6
      GRAD(1,IP)=TMC(IP)
      GRAD(2,IP)=XC(IP)
      WRITE (6,440) XC(IP),YC(IP),SC(IP),TMC(IP),ALFC(IP)
  440 FORMAT (2F10.0,2E15.4,F10.2/)
  460 CONTINUE
  464 CONTINUE
      IF(IND(4).EQ.0) GO TO 438
      CALL GRAPH (GRAD,R,XENV,TT,NPOIN,INT)
  438 CONTINUE
  480 CONTINUE
      IF (STARA.NE.STAR) GO TO 100
      CALL FINTRA
      STOP
      END
```

```
      SUBROUTINE XFQ(X,XAV,Q,A,M)
C
C-----XFQ CALCULATES THE X TERMS OF THE BDW-FUNCTION------------------
C     FOR GIVEN Q AND ORDER
C     ONLY M TERMS WILL BE CALCULATED
C
      DIMENSION X(100)
C
      X(1)=(1.+Q)**(A-1.)*(1.+A+3.*Q+A*Q)*XAV/(1.+A)
      IF (M.EQ.1) RETURN
C
      MM=M-1
      QPLUS=1.+Q
      QMIN=1.-Q
      DO 100 I=1,MM
  100 X(I+1)=QPLUS**(A-FLOAT(I))*QMIN**FLOAT(I)*XAV
      RETURN
      END
```

```
      SUBROUTINE GRAPH (GRA,R,XENV,TT,N,INT)
C
      DIMENSION GRA(2,100),X(100),Y(100),AL(9),EN(9)
      DIMENSION PATT(2,100)
      COMMON FX,FZ,XRSM,ZA,PATT,NTAR
      DATA EN/0.6,0.2,0.2,0.2,0.4,0.2,0.2,0.2,0.2/
      IF(N.LT.2) RETURN
      IF(INT.GT.1) GO TO 148
C
C-----DRAW THE AXIS-----------------------------------------------------
C
      EN1=EN(1)
      SIZEX=15.
      SIZEX =25.
      SIZEY=25.
      SIZEY=15.
      SIZEX=18.
      SIZEY=14.
      EN(1)=SIZEY
      B=ALOG10(XENV*R*1.E-6)
      A=AINT(B)
      FACX=SIZEX/B
      CALL FINIM(0.0,2.0)
      START=(B-A)*FACX
      FLO=A
  108 CALL NUMBER (START,-0.3,0.2,0.0,FLO,-1)
      FLO=FLO-1
      START=START+FACX
      IF(FLO.GE.0.0) GO TO 108
      X(1)=SIZEX
      Y(1)=0.0
      X(2)=0.0
      Y(2)=0.0
      CALL LINE (X,Y,2,1,1)
      Y(1)=0.0
      IA=IFIX(A)
      IIA=IA+1
      DO 112 I=1,9
  112 AL(I)=ALOG10(FLOAT(I))
      START=(B-FLOAT(IIA))*FACX
      DO 120 I=1,IIA
      DO 116 J=1,9
      JJ=10-J
      X(1)=START+FLOAT(I-1)*FACX+FACX-AL(JJ)*FACX
      IF(X(1).LT.0.0) GO TO 116
      Y(2)=EN(JJ)
      X(2)=X(1)
      CALL LINE (X,Y,2,1,1)
  116 CONTINUE
  120 CONTINUE
      H=0.3
      YY=-0.6
      FLO=10.
      IAA=IA+1
      DO 124 I=1,IAA
      XX=(B-FLOAT(I-1))*FACX-8.*H/7.
      CALL NUMBER (XX,YY,H,0.0,FLO,-1)
  124 CONTINUE
      XX=0.5*SIZEX
```

```
      YY=-1.0
      CALL SYMBL4(XX,YY,H,0.0,' TONS OF METAL WORLD RESOURCES',30)
C
C-----AND NOW THE Y-AXIS--------------------------------------------------
C
      H=0.3
      EN(1)=SIZEX
      YMIN=ALOG10(XENV)
      YMAN=YMIN
      YMAX=ALOG10(GRA(2,1))
      YMAX2=YMAX+ALOG10(2.)
      C=YMAX2-YMIN
      FACY=SIZEY/C
      FACYY=FACY
      FLO=AINT(YMIN)
  128 FLO=FLO+1.
      IF(FLO.GT.YMAX2) GO TO 132
      YY=(FLO-YMIN)*FACY+H
      XX=-8.*H/7.
      CALL NUMBER (XX,YY,0.2,0.0,FLO,-1)
      GO TO 128
C
  132 X(1)=0.0
      Y(1)=SIZEY
      X(2)=0.0
      Y(2)=0.0
      CALL LINE (X,Y,2,1,1)
      X(2)=SIZEX
      Y(1)=SIZEY
      Y(2)=SIZEY
      CALL LINE(X,Y,2,1,1)
C
      START=-YMIN*FACY
  134 X(1)=0.0
      DO 136 I=1,9
      YY=START+AL(I)*FACY
      IF(YY.LT.0.0) GO TO 136
      IF(YY.GT.SIZEY) GO TO 140
      Y(1)=YY
      Y(2)=YY
      X(2)=EN(I)
      CALL LINE (X,Y,2,1,1)
  136 CONTINUE
      START=START+FACY
      GO TO 134
C
  140 FLO=10.
      XX=-1.0
      YY=SIZEY+0.2
      CALL SYMBL4 (XX,YY,H,0.0,' GRADE IN PPM',13)
      START=YMAX2
  144 YY=(AINT(START)-YMIN)*FACY
      IF(YY.LT.0.0) GO TO 150
      XX=-16.*H/7.
      CALL NUMBER (XX,YY,H,0.0,FLO,-1)
      START=START-1.
      GO TO 144
C
C-----DRAW THE CURVES-----------------------------------------------------
C
  150 CONTINUE
```

```
      DO 160 I=1,NTAR
      X(I)=(B-ALOG10(PATT(1,I)))*FACX
      Y(I)=(ALOG10(PATT(2,I))-YMAN)*FACYY
  160 CONTINUE
      CALL DASH (X,Y,NTAR,1,1)
  148 DO 152 I=1,N
      X(I)=(B-ALOG10(GRA(1,I)))*FACX
      Y(I)=(ALOG10(GRA(2,I))-YMAN)*FACYY
  152 CONTINUE
      XX=X(1)
      YY=Y(1)
      IF (TT.GT.999999.0) GO TO 153
      CALL NUMBER (XX,YY,0.15,0.0,TT,-1)
  153 CONTINUE
      CALL LINE (X,Y,N,1,1)
      IF (INT.GT.1) GO TO 151
      X(2)=0.0
      Y(2)=0.0
      CALL LINE (X,Y,2,1,1)
  151 CONTINUE
      CALL FINIM (0.0,0.0)
      RETURN
      END
```

```
      SUBROUTINE PNP(P,ENP,JA)
      DIMENSION XLPG(60),YNP(60)
      DATA
     1XLPG( 1),XLPG( 2),XLPG( 3),XLPG( 4),XLPG( 5),XLPG( 6),XLPG( 7),
     2XLPG( 8),XLPG( 9),XLPG(10),XLPG(11),XLPG(12),XLPG(13),XLPG(14),
     3XLPG(15),XLPG(16),XLPG(17),XLPG(18),XLPG(19),XLPG(20),XLPG(21),
     4XLPG(22),XLPG(23),XLPG(24),XLPG(25),XLPG(26),XLPG(27),XLPG(28),
     5XLPG(29),XLPG(30),XLPG(31),XLPG(32),XLPG(33),XLPG(34),XLPG(35),
     6XLPG(36),XLPG(37),XLPG(38),XLPG(39),XLPG(40),XLPG(41),XLPG(42),
     7XLPG(43),XLPG(44),XLPG(45),XLPG(46),XLPG(47),XLPG(48),XLPG(49),
     8XLPG(50),XLPG(51),XLPG(52),XLPG(53),XLPG(54),XLPG(55),XLPG(56)/
     10.301030,0.337030,0.375936,0.417836,0.462712,0.510692,0.561848,
     20.616250,0.673960,0.735040,0.799545,0.867528,0.939039,1.014122,
     31.092821,1.175176,1.261225,1.351001,1.444539,1.541868,1.643017,
     41.748012,1.856878,1.969639,2.086316,2.206930,2.331499,2.460042,
     52.592575,2.729114,2.869674,3.014269,3.162912,3.315615,3.472388,
     63.633245,3.798199,3.967251,4.140412,4.317712,4.499115,4.684625,
     74.874351,5.068057,5.265977,5.468369,5.674492,5.884772,6.098426,
     86.318250,6.536745,6.766082,6.997476,7.224720,7.474597,7.650689/
      DATA
     1YNP( 1),YNP( 2),YNP( 3),YNP( 4),YNP( 5),YNP( 6),YNP( 7),YNP( 8),
     2YNP( 9),YNP(10),YNP(11),YNP(12),YNP(13),YNP(14),YNP(15),YNP(16),
     3YNP(17),YNP(18),YNP(19),YNP(20),YNP(21),YNP(22),YNP(23),YNP(24),
     4YNP(25),YNP(26),YNP(27),YNP(28),YNP(29),YNP(30),YNP(31),YNP(32),
     5YNP(33),YNP(34),YNP(35),YNP(36),YNP(37),YNP(38),YNP(39),YNP(40),
     6YNP(41),YNP(42),YNP(43),YNP(44),YNP(45),YNP(46),YNP(47),YNP(48),
     7YNP(49),YNP(50),YNP(51),YNP(52),YNP(53),YNP(54),YNP(55),YNP(56)/
     10.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.1,1.2,1.3,1.4,1.5,
     21.6,1.7,1.8,1.9,2.0,2.1,2.2,2.3,2.4,2.5,2.6,2.7,2.8,2.9,3.0,3.1,
     33.2,3.3,3.4,3.5,3.6,3.7,3.8,3.9,4.0,4.1,4.2,4.3,4.4,4.5,4.6,4.7,
     44.8,4.9,5.0,5.1,5.2,5.3,5.4,5.5/
      IF(JA-1)102,102,200
C
C-----THE CALCULATION OF NP AS FUNCTION OF P--------------------------
C
  102 PP=-ALOG10(P)
      IF(PP-15.0)108,108,104
  104 JA=3
  105 WRITE (6,106) P
  106 FORMAT (29H ERROR ARGUMENT TOO SMALL  P=,E12.5)
      RETURN
  107 FORMAT (29H ERROR ARGUMENT TOO LARGE  P=,E12.5)
  108 IF(PP-7.650689)120,110,110
  110 ENP=2.27316+0.465285*PP-0.005688*PP**2
      IF(ENP-7.5)114,114,112
  112 JA=2
      RETURN
  114 IF(ENP-7.0)118,118,116
  116 JA=1
      RETURN
  118 JA=0
      RETURN
  120 IF(PP.GT.XLPG(1)) GO TO 121
      JA=4
      WRITE (6,107) P
      RETURN
  121 DO 122 I=1,56
      IF(PP-XLPG(I))124,124,122
  122 CONTINUE
```

```
      GO TO 104
  124 IN=I-1
      ENP=((PP-XLPG(IN))/(XLPG(IN+1)-XLPG(IN)))*(YNP(IN+1)-YNP(IN))+YNP(
     1IN)
      JA=0
      RETURN
C
C-----THE CALCULATION OF P AS A FUNCTION OF NP-------------------------
C
  200 IF(ENP-5.5)202,202,208
  202 JA=0
      DO 204 I=1,56
      IF(ENP-YNP(I))206,206,204
  204 CONTINUE
      GO TO 208
  206 IN=I-1
      PP=((ENP-YNP(IN))/(YNP(IN+1)-YNP(IN)))*(XLPG(IN+1)-XLPG(IN))+XLPG(
     1IN)
      P=10.**(-PP)
      RETURN
  208 IF(ENP-7.9)214,214,210
  210 WRITE (6,212) ENP
  212 FORMAT (30H ERROR ARGUMENT TOO LARGE  NP=,E12.5)
      JA=3
      RETURN
  214 ROOT=2072.51-175.79*ENP
  216 PP=40.9006-SQRT(ROOT)
      P=10.**(-PP)
      JA=0
      IF(ENP-7.0)218,218,220
  218 RETURN
  220 IF(ENP-7.5)222,222,224
  222 JA=1
      RETURN
  224 JA=2
      RETURN
      END
```

References

J. W. BRINCK: The calculation of uranium resources in the earth's crust EURATOM Bulletin December 1967

J. W. BRINCK: Note on the distribution and predictability of mineral resources. EUR 3461.e

H.I. DE WOLDE and J. W. BRINCK: The optimization of mineral exploiration investments by the computer program 'EXILE' EUR 4403.e

A. CARLIER: Contribution aux méthodes déstimation des gisements d'uranium. Rapport C.E.A. R 2332 (1964)

J. GREEN: Geochemical table of the elements for 1959 Bull. Geol. Soc. Am. 70 (1959)

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