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ABSTRACT

The distribution of mercury deposits and of the assured reserves in the world are reviewed, and a description is given of the application of a model called MIMIC which uses geochemical as well as economic-geological parameters for an estimation of the global potential reserves of mercury.

The model indicates that about 3.10^6 tonnes of mercury could still be made available at the current average cost and that there are no indications of an imminent exhaustion of this metal.

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Abstract

The distribution of mercury deposits and of the assured reserves in the world are reviewed, and a description is given of the application of a model called MIMIC which uses geochemical as well as economico-geological parameters for an estimation of the global potential reserves of mercury.

The model indicates that about $3 \cdot 10^6$ tonnes of mercury could still be made available at the current average cost and that there are no indications of an imminent exhaustion of this metal.

Résumé

Après avoir passé en revue la distribution des gisements de mercure et des réserves mesurées dans le monde, un modèle appelé MIMIC, utilisant des paramètres géochimiques et économico-géologiques, a été appliqué pour une évaluation des réserves potentielles de mercure.

Le modèle indique qu'environ $3 \cdot 10^6$ tonnes de mercure pourraient être encore disponibles au prix de revient courant et qu'il n'existe pas de problème imminent de raréfaction pour ce métal.

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WORLD RESOURCES OF MERCURY

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I. GEOLOGICAL DISTRIBUTION OF MERCURY DEPOSITS

The most important commercial mercury mineral is cinnabar. It is frequently associated with small amounts of native mercury and sometimes with other low temperature minerals such as pyrite and marcasite (FeS_2), stibnite (Sb_2S_3) and realgar (As_2S_3). Metacinnabar may be also present.

Commercial mineralizations of mercury are mostly found in post Proterozoic formations. Generally speaking, mercury ore deposits are limited to two well defined geological regions:

- the circumpacific orogenic belt, in which most of the mineralizations are associated with Tertiary volcanism (from Chile to Alaska and from Kamchatka to the Philippines and New Zealand),
- the Alpine - Himalayan orogenic belt extending from Spain and North Africa to China and Indonesia. Here the ore deposits may be related to older volcanic activity. The important Almaden deposits in Spain which occur in folded and faulted Silurian quartzites and slates, belong to this belt.

To date, no important mercury ore deposits have been found in the old, Precambrian shield areas. The main reason is that mercury ore deposits are formed at relatively low temperatures, whereas erosion in the shield areas normally has progressed to, and exposed, the deeper, higher temperature zones. However, it cannot be excluded that mercury deposits could still be found in Precambrian volcano-sedimentary basins or in connection with later magmatic or hydrothermal activity. In any case, the low temperature of formation of mercury deposits seems to favour concentration of the metal in the cool, superficial layers of the earth's crust, especially in Tertiary orogenic belts.

The best chances for finding mercury deposits therefore appear to exist where the superficial strata of such regions have been protected against relatively deep erosion.

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In the Community, the Monte Amiata district in Tuscany, Italy, (provinces of Siena and Grosseto) is the major mercury producer. Small amounts of stibnite may occur with the mercury mineralization. A new producing district (1968) is County Tipperary in Ireland, where mercury and silver are recovered as by-products from the Gortdrum copper mine. Old mine works are found at Landsberg and Stahlberg in the Federal Republic of Germany, where cinnabar is associated with stibnite. Mercury indications, sometimes exploited in the past, occur in several places in Northern Italy, in Britain, France.

II. MERCURY RESERVES

In contrast with many other industrial metals such as copper, zinc, lead, nickel, and uranium, for which intensive exploration programme are in progress on a more or less permanent basis, very little prospecting for mercury deposits has been done. Not until 1965, when there was a substantial increase in the price of mercury on the world market, was some prospecting carried out with favourable results, especially in Algeria, Canada and Turkey. This effort has resulted in a near doubling of the reasonably assured reserves from 115.600 tonnes in 1968 to about 215.000 tonnes by the end of 1972 (1) (2). The published figures on the world mercury reserves (US Bureau of Mines (2) - US Geological Survey (3) - World Mining (4)) show variations according to their origin and these of the spanish reserves certainly are underestimated. From the available sources (2) (3) (4) an estimate of "reasonably assured" reserves at an upper price limit of about 250 UC +/per flask and the ore grade of the producing mines is shown in table 1.

In the beginning of 1973, a total of about 215,000 tonnes of mercury were available in the world. For the European Community the reasonably assured mercury reserves in 1974 may be evaluated as 20,500 tonnes Hg of which 500 tonnes are in Ireland and the rest in Italy. In Italy, a marked decrease in ore grade can be observed from 0.90 % Hg in 1953 to 0.50 Hg in 1972 (15). Several indications for mercury mineralization were discovered outside the Monte Amiata mining district as a result of geochemical reconnaissance surveys in Tuscany in 1966 and 1968 (6) (7) but so far exploration has given few promising results.

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+) UC - European monetary unit equivalent to $ (value 1970)

TABLE I

REASONABLY ASSURED WORLD RESERVES OF MERCURY
(price limit about 250 UC/flask)

Country	Reserves in metric tonnes of Hg	Average ore grade % Hg
United States	6,000	0.25
Canada	10,000	0.23
Italy x	21,000	0.5–0.3
Mexico	10,000	0.25
Spain xx	87,000	1 – 2
Yugoslavia	20,000	0.16–0.9
Turkey xxx	11,000	0.3–0.4
USSR xxxx	30,000	0.1–0.6
China	10,000	?
Others	10,000	0.15–0.7
TOTAL	215,000	

x) New data 1974 (15).
xx) Average ore grade 2 % in 1973 – reserves appear much larger.
xxx) Possible additional reserves are estimated at 15,750 tonnes (4).
xxxx) Includes the reserves recently discovered in N.E. Siberia (5). Average ore grade of the three mercury deposits exploited in 1970 was 0,07 % for Nikitovka, 0,55 % for Khaidarkan, 0,3 % for Gaga-Uzum.

The major mercury district of the world, Almaden in Spain, which has been producing since ancient times, still contains about half the total known reserves. These reserves are made up mostly of high grade ores ($\geq$1 % Hg). It is clear that this dominant market position of one producer does not encourage mercury prospecting on a world-wide scale. Consequently the reserve situation as a function of world prices is very sensitive to changes in demand and Spain's willingness to supply. Recent new important producers of mercury are Canada, Algeria, Turkey and USSR.

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The Meadows report on "The Limits to Growth" outlined an exhaustion of mercury reserves within 13 years if primary production continued to increase as before (8). This conclusion was based on the assured reserves amounting to 115,000 tonnes in relation to the recent consumption trend and to the sudden rise of the price of mercury between 1965 and 1968. However, since the publication of this report in 1971, the figures on future mercury consumption and reserve development have deviated appreciably from the predicted trend.

Anti-pollution measures have already promoted the recovery and recycling of this metal and thus a decreasing need for primary mercury in the non-Communist industrialized countries. The high prices on the world market between 1965 - 1968 stimulated a short mercury exploration boom which resulted in an appreciable increase in the reasonably assured reserves after 1971. These factors have combined to depress the market prices of mercury to their normal long-term average level.

The reserve level at any given time, therefore, does not reflect the ultimate economic potential of a mineral substance. The latter is determined by the concentration and distribution of the different mineral materials in the geological environment and their respective uses.

III. RESERVE POTENTIAL

In order to estimate the ultimate reserve potential of mineral resources an econometric model MIMIC (Mining Industry Model for Inventorization and Cost evaluation of mineral resources) has been developed by Brinck (9).

This model is based on the observation, both from mineral exploration and geochemical surveys, that the distribution of element concentrations in the geological environment can best be described by a log-binomial model, i.e. the weighted frequencies of the logarithms of different concentrations in the geological environment tend to fit a binomial distribution. Such distributions are characterized by a median concentration and a standard deviation which reflect the average concentration of an element and its specific mineralizability in a given geological environment.

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By using the size of the reasonably assured reserves of an element as the measured probability of occurrence of mineral deposits of given average grade and size in the upper part of the earth's crust, this specific mineralizability of an element can also be estimated. It was found that the specific mineralizabilities determined in this way are very similar to those found by geochemical surveys and mineral exploration. It also was found that for metals with similar mining cost structure such as lead, zinc, copper, uranium, gold, antimony, molybdenum and several others, their long-term average price differences are determined within 35 % by the specific mineralizability as found from the reasonably assured reserves and the average concentrations of the elements in the earth's crust.

In order to estimate the ultimate mercury reserve potential the following input data were used for the MIMIC calculations.

1. Average concentration of mercury in the earth's crust

   A concentration of 70 ppb has been taken as a best estimate from different geochemical publications. (10), (11), (12).

2. Average concentration in ore deposits

   Nearly half of the presently known reserves occur in the 3 Almaden vein deposits San Pedro, San Nicolas and San Francisco in Spain. These deposits have been worked well over 2000 years and an annual production of some 10,000 pounds of mercury was recorded even in Roman times (13).

   The ores produced averaged well over 1 % Hg (5-7 % in 1945; 1.1 % in 1967, 1.35 % in 1968, and 1.6 % in 1970).

   The remainder of the reserves is found in various countries with most of the reserves averaging about 0.5 % Hg or less. Thus it can be said that approximately 50 % of the reserves have a grade of 0.5 % Hg or less and the other 50 % a grade of 1 % or more.

   With Spain restricting its supply to about 20-25 % of annual world production, it is clear that the market price is determined completely by the lower grade marginal producers (0.5 % Hg). Therefore the value of 0.5 % Hg in ore deposits has been accepted as the average. ./.

Subsequent tests for average grades of 0.75 %, 1.00 % and 1.25 % mercury showed increasingly large discrepancies between the observed average long term price and the price predicted from the specific mineralizibility and average concentration.

3. Average size of the ore deposits

Here again the Almaden deposits with average known reserves of ± 40,000 tonnes Hg per vein represent approximately 50 % of total reserves. The average size of all other deposits is substantially less. Taking into account the former production in Almaden, the deposits there must have been much larger even than 40,000 tonnes. Other important deposits which have produced more than 40,000 tonnes of mercury are Idria, Yougoslavia and Huancavelica, Peru. For our calculations, we have accepted an average size of 40,000 tonnes per ore deposit.

4. The size of the environment

The dry land surface of the earth to a depth of 2.5 km was taken as the geological environment of ore deposits of mercury. The fact that the depths of most of the known ore deposits and former production are less than 500 m has little incidence on the ultimate size of the inferred reserves. Estimates for a shallower environment (say less than 500 m) would increase the specific mineralizability in such a way as to compensate for the loss of environmental space and would result ultimately in inferred reserves of similar magnitude. This bas been tested.

All reserve estimates made by MIMIC are based on the actually observed depths of demonstrated reserves and former production.

5. Demonstrated reserves and former production

Demonstrated reserves amount to 215,000 tonnes Hg and former production can be estimated at 800,000 tonnes Hg for a rounded total of 1,000,000 tonnes Hg. (14).

6. Price development

The average US price 1954 - 1973 has been approximately $ 250.- (250 UC) (1970 value) flask of 76 lbs Hg = 34.5 kg Hg of $ 7.24 per kg Hg. The price range during this period has been between $ 175 and $ 575 per flask mercury.

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7. Annual production

During the same period annual production has been between 7,000 and 10,000 tonnes Hg. Here a value of 10,000 tonnes Hg is accepted for current production capacity.

8. Specific mineralizability (Q.) x

With these input data and taking account of the uncertainty in respect of average ore grade a series of Q determinations and predicted target prices was made with the following results :

Ave. grade ore	Predicted target price $/Kg (1970 value)	Spec. min. Q	Ratio long-term price/ predicted target price
0.5 % Hg	7.41	.376	.98
0.75 % Hg	5.96	.385	1.21
1.00 % Hg	5.12	.397	1.41
1.25 % Hg	4.57	.395	1.59

These data confirm that the average grade of 0.5 % Hg best represents the market evaluation of the mercury mining industry. As this evaluation also gives the most conservative estimates of ultimate potential, the Q value .476 was used for the MIMIC calculations.

9. Inferred reserves

Figure I has been compiled from MIMIC output data and show the inferred mercury reserves of the world according to the classical definition of reserves (estimated quantities of mineral meterials which, with current technology, can be profitably extracted from the geological environment, i.e. at costs up to the market price).

According to this definition, inferred reserves can be estimated at 10.10^6 tonnes (± 30 %) of exploitable mercury at prices up to 7.42 UC

x) Q is a dispersion coefficient indicating whether an element is densely distributed (values greater than 0.25) or homogeneously (values less than 0.15) or somewhere between extremes.

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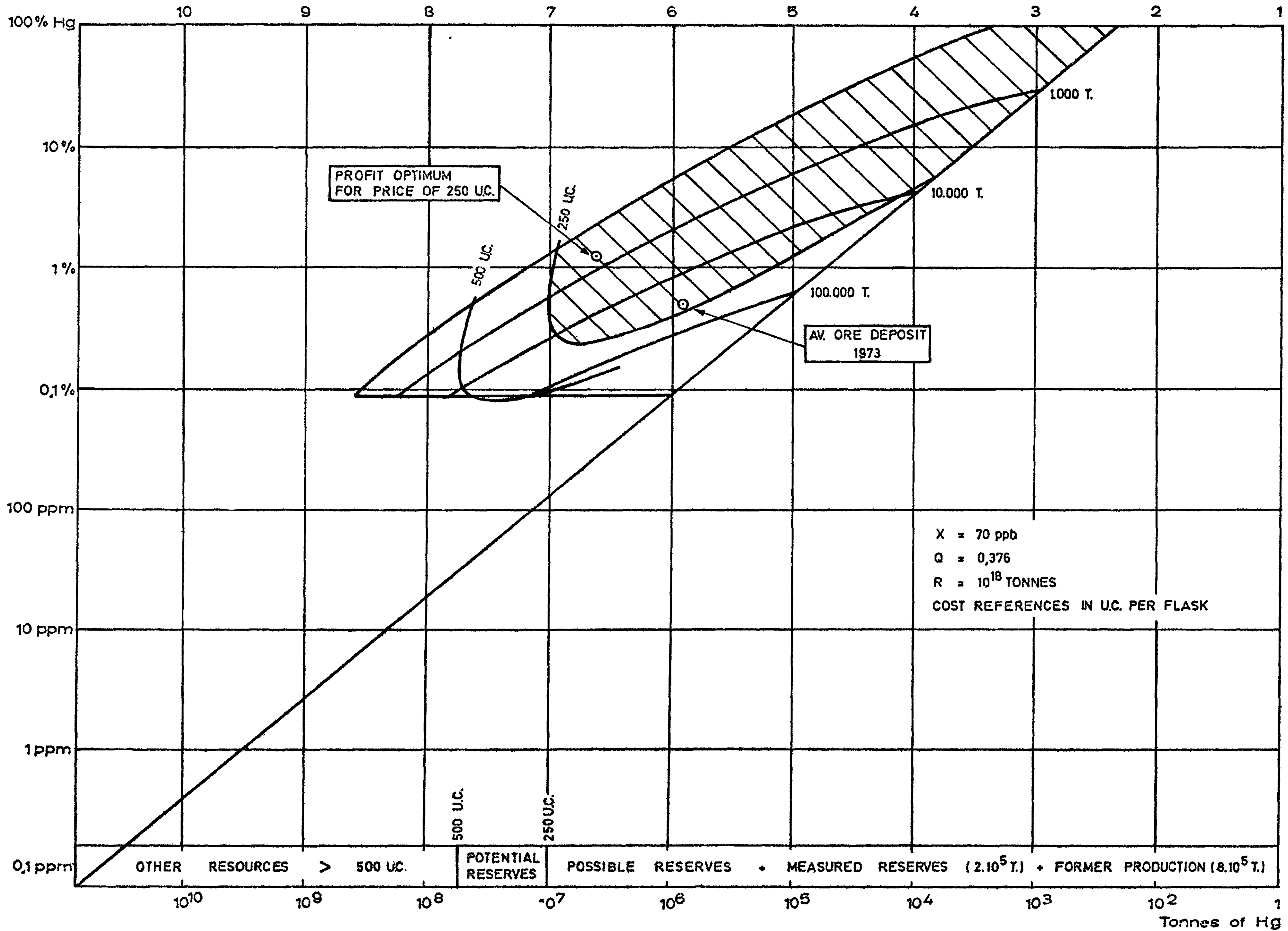
(± 30 %). The costs do not include royalties or rent.

- A profit optimum for the system is found for inferred resources of about 4.10^6 tonnes of mercury. Deducting 8.10^5 tonnes of former production, a total of $3.2.10^6$ tonnes of mercury could still be made available at the current average costs. The potential resources at two times the average long term price may be evaluated at 60.10^6 tonnes. Therefore, the inferred potential reserves as determined by the MIMIC model indicate ample supply possibilities for mercury and no danger of imminent exhaustion.

FIGURE 1 : ESTIMATED WORLD RESOURCES OF MERCURY



Explanations of Figure 1

- Inferred resources of mercury occurring in deposits containing between 1 and 7.10^{10} tonnes of mercury are indicated on the abscissa
- The mercury concentration between 70 parts per billion and 100 % is shown on the ordinate
- The main diagonal line corresponds to mercury deposits with highest possible grades for a given mercury content
- From this diagonal, lines of equal metal content corresponding to deposits of lower mercury concentration are drawn. Together these constitute the Iris or rainbow diagram. Superimposed on this diagram are the unit production costs expressed in U.C. per flask of mercury content (tonnes of mercury).

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