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THE SUITABILITY OF THE MERCURY HALO PROSPECTING TECHNIQUE IN SOUTH AUSTRALIA.

by

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SUMMARY

Background

This project was proposed in 1971 as a consequence of the large number of determinations carried out at Amdel on soils. It seemed that insufficient background data were available on the mercury content of ores and rocks and the proposal was for a systematic study of the mercury content of South Australian ores.

Objective

The purpose of the project was to determine for what ore types and in what conditions the mercury halo technique is suitable for prospecting for base and other metals in South Australia.

Summary of Work Done

After a search of the literature on prospecting using this technique had been carried out, the South Australian Department of Mines submitted samples (mainly core material) from six copper-bearing areas in South Australia.

Determinations of copper, lead, zinc and mercury were made on samples from Kapunda, Parabarana and Kanmantoo. Copper and mercury were determined on samples from Burra, and mercury alone on samples from Mutooroo and Moonta.

Analysis for mercury proved difficult and several analytical methods were used to ensure adequate accuracy and reproducibility.

Conclusions

The results of the experimental work show a low, but positive, correlation of mercury with low levels of copper, and also show some tendency for there to be some concentration of mercury in the near-surface zone above copper ore-bodies. Significant amounts of mercury are associated with the ores of Kapunda and Burra.

The results of this work have demonstrated that, before embarking on a project of this nature, rigid controls must be applied at all stages from sampling through transport, sample preparation and storage to the determination of the mercury. Possibilities for contamination after collection and before analysis are high.

However, the premises on which the project was formulated, namely that mercury is a common associate of base metal ore deposits or of gold or uranium ore deposits and should be a useful guide, are still valid. It may confidently be expected that, in the future, mercury haloes can be used to

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determine the position of blind orebodies.

Recommendations

It is recommended that the project be held in abeyance until a completely satisfactory sampling, storage and analytical scheme has been developed.

1. INTRODUCTION

The element mercury is chalcophile and is commonly associated with other (base) metals in hydrothermal and epithermal deposits. Illustrative of these types of occurrence are a number of short articles published in World Mining recently (Argall, 1971), which discussed the recovery of mercury as a by-product during the extraction of:

(i) copper from copper ores at Rudnany (Czechoslovakia) and Gortdrum (Eire);

(ii) zinc from zinc ores at Rosebery (Tasmania), at Outokumpu Oy (Finland), and at Balmat and Edwards Mines (New York State);

(iii) gold from gold ores (Nevada).

Interest in mercury lies in its value as an indicator or pathfinder element for buried ore deposits. Elemental mercury has a very high vapour pressure and its compounds decompose at low (geologically speaking) temperatures. This means that mercury has the potential to disperse over a wide area away from ore and elevated values may be found at the surface above a buried sulphide deposit. If the orebody is sufficiently deeply buried, mercury may reach the surface when none of the other metals present in the orebody has been sufficiently mobile to do so. Ideally, the surface expression of anomalous mercury can be mapped and contoured with the highest values overlying the ore.

However, ideal conditions rarely apply, since both primary and secondary dispersion of mercury may have taken place. The surface expression of mercury may be controlled by jointing or faulting as much as by the position of the ore. Alternatively, the orebody, itself deficient in mercury, may mobilise mercury from the country rock and drive it down the temperature and pressure gradient in front of the ore, eventually causing anomalous readings which are difficult to interpret.

At the surface, mercury adsorbed on soil is believed to maintain some sort of equilibrium with mercury in soil air and this in turn is thought to maintain a relationship with mercury in the atmosphere immediately above the earth's surface. Soil mercury, soil air mercury and atmospheric mercury may all be measured, and used to indicate anomalous mercury concentrations.

The present investigation arose out of service work which has been carried out at Amdel over some years. As a consequence of this work, it was suggested to the Mines Department that a systematic attempt should be made to investigate the mercury content of South Australian ores and to determine for what ore types and in what conditions the mercury halo technique is a suitable prospecting tool.

The Report is divided into two parts. The first part is intended to summarise the main literature which discusses the use of mercury as an exploration tool. The second part reports the results of assays carried out at Amdel and provides some discussion of the data.

PART 1

LITERATURE REVIEW

1. INTRODUCTION

The references collected for, and cited in, this Report have been obtained from Chemical Abstracts, Mineralogical Abstracts and the Index and Bibliography of Geology published by the Amercian Geological Institute.

Where possible, papers cited have been read, but in some circumstances (either because the paper is unobtainable in Australia, or is written in a foreign language), the abstract has been used. In addition, a number of references are cited in the bibliography which are not discussed in the main body of the Report. These papers appear to be relevant to the topic, but neither paper nor abstract have been sighted.

2. THE HISTORICAL DEVELOPMENT OF THE METHOD

The possibility of using a 'mercury halo' technique for detecting hidden sulphide orebodies was postulated by Saukov (1946) in his book 'The Geochemistry of Mercury' (not available in English), but it was not until papers by Fursov (1958) and Ozerova (1959 and 1962) were translated into English that the technique was seriously considered by non-Soviet geologists.

Little interest had been shown in mercury in the past because of its low total concentration in the earth's crust, estimated at only 80 ppb* (Krauskopf, 1967) and the consequent difficulties of determining mercury at this low level. The papers of Fursov (1958) and Ozerova (1959) cited above quoted detection limits of 150 ppb and 300 ppb respectively. Recent developments in analytical chemistry using flameless atomic absorption spectroscopy have brought the detection limits down to 1 to 5 ppb and better views of the patterns of mercury distribution have been obtained.

The method has become of even greater interest because of its alleged universality. Ozerova (1962) discussed primary mercury dispersion patterns around deposits of:

mercury,
mercury-antimony,

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* 1 ppb = 1 part per billion = 10^{-7}% = 0.001 parts per million

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a number of authors as X00 (100 - 999) ppb; however, Ozerova and Aidin'yan (1966a) found that over a wide area of the Russian platform the average of 58 samples of clay was 35 ppb. Other sedimentary rocks on the Russian platform appeared to have values lower than the world average.

It is only in recent years that mercury assays have become at all reliable at the low levels of concentration of the element in rocks. 'Early' assays are therfore inherently suspect.

In any investigation in the field it is clear that a local background value for each rock type must be established before consideration can be given to possibly anomalous results.

Table 2 gives selected data on mercury values in rocks and soils of unmineralised regions, while Table 3 gives comparable data for rocks in soils in mineralised regions.

4. MERCURY IN INDIVIDUAL MINERALS

It is pertinent to consider which minerals may be expected to be rich in mercury. This may provide a clue for the choice of suitable ores for testing for their mercury content and indicate potential limits for the use of the mercury halo method.

Mercury tends to be concentrated in minerals where it can diadochically replace divalent cations such as iron, zinc or lead in compounds of these elements. Their respective ionic radii (6-fold co-ordination) are (Mason, 1966, p297-9):

Ion	Ionic Radius (Å)
Hg^{2+}	1.10
Fe^{2+}	0.74
Zn^{2+}	0.74
Pb^{2+}	1.20
Ba^{2+}	1.34
Ca^{2+}	0.99
Cu^{2+}	0.72
Cu^{+}	0.96
Sr^{2+}	1.12

Since the mercuric ion is of different size to those of the most common ore metals there will be strain in the crystal when mercury (II) replaces the host element, and only limited replacement is expected.

The main minerals which contain mercury in diadochic replacement are discussed by Warren and Thompson (1944), Fleischer (1955), Sergeyev (1961) Ozerova (1962), Hawkes and Williston (1962), James (1964), Chan (1969) and Friedrich and Pluger (1971).

In order of possible preferential replacement the main ore minerals given by James (1964) are as follows:

stibnite,
sphalerite,
cerussite,
galena,
chalcopyrite,
pyrite.

In addition, mercury can form an amalgam with native gold, silver or copper.

The typical range of mercury in the above minerals (and including native gold) is of the order of 0.5 to 25 ppm. Atypically, the concentration of mercury may reach several thousand ppm, particularly in sphalerite and stibnite (Ozerova, 1962).

The mercury content of these minerals may depend on the temperature of formation of the minerals but no comments have been published about temperatures of origin.

The following 'gangue' minerals have been examined and shown to be able to contain varying proportions of mercury:

barite,
calcite,
fluorite,
siderite,
aragonite,
sericite,

These minerals, when occurring as vein 'gangue' in mineralised areas, have a typical mercury content from about 0.01 to 20 ppm, averaging 2 to 5 ppm (Ozerova, 1962; James, 1964). Atypically, the mercury concentration may reach several hundred ppm.

Chan (1969), in an area of lead-silver mineralisation (Shoshone Co., Idaho) measured the mercury contents of various minerals in and near the ore veins of the Galena Mine. His Table 3 (p156 in the original) is reproduced below:

Mineral	Mercury Range, ppm	No. of Measurements
Tetrahedrite	5.1 - 62.6	22
Chalcopyrite	3.5 - 38.0	10
Galena	3.8 - 10.4	10
Pyrite	1.0 - 2.5	10
Arsenopyrite	0.9 - 2.3	8
Siderite	0.2 - 2.5	10
Quartz (vein)	0.04 - 1.8	10
Quartz (wall rock)	0.08 - 0.5	10

Friedrich and Pluger (1971) found that samples of barite from various deposits in Germany contained between 1.2 ppm and 250 ppm mercury.

In general, it may be said that mercury is a universal component of rocks and minerals but that the concentrations are normally very low. For the purposes of prospecting it is possible, but not normally economic, to separate-out suitable minerals which may show an elevated content of mercury in the hope of accentuating unusual mercury values.

Table 4 shows the mercury content of common ore and gangue minerals and is taken from Jonasson and Boyle (1972, p34). This represents the latest information available. The high capacity for tetrahedrite to contain mercury as shown in the table is confirmed by other writers.

5. MERCURY DISPERSION HALOES IN ROCKS

The classic papers whose English translations stimulated the work of Western geochemists were those of Fursov (1958) and Ozerova (1959).

Fursov investigated mercury haloes at the Achisai lead-zinc deposit of Kazakhstan. The ores (a mixture of fresh and weathered sulphides of zinc and lead) averaged 79 ppm - approximately 1000 times the estimated crustal average. The oxidised ore averaged 130 ppm against an average of 6.3 ppm in fresh ore. The highest mercury value was found in cerussite sands (1000 ppm). The ores are found in faults and veins in carbonate host rocks. Mercury is concentrated in cerussite, and to a lesser extent, in galena and sphalerite. The primary dispersion halo is marked, 23 ppm being found in limestone 73 m from the contact. At distances of 140 to 195 m from ore the mercury concentrations were 0.4 to 0.5 ppm. Anomalies occurred over all known mineralisation and over known fracture zones adjacent to ore. In two cases anomalies were present at the surface, 230 m above blind orebodies. As Fursov's analytical technique had a lower limit of detection of 0.3 ppm (300 ppb) the haloes shown were not very wide.

Ozerova (1959) discussed dispersion away from lead-zinc orebodies of the Fergana region of Turkestan. The deposits were found in middle Palaeozoic limestones, dolomites, sandstones and conglomerates. Orebodies crop out, or are buried up to 100 m deep. Traverse lines over the orebodies showed the presence of mercury haloes 1.2 km to 1.8 km wide with values of mercury rising gradually from ≤50 ppb (the normal detection limit) to 500 ppb, and with a sharp peak of 1000 ppb directly over the deposit. Only in 15 out of 69 sand and limestone samples assayed was mercury detected, the values being 70 ppb or lower.

Ozerova's (1962) book 'Primary Dispersion Haloes of Mercury' has recently become available (English edition, 1971). She reviews all known Russian orebodies and quotes mercury contents of ores and individual minerals, and background values for different rock types. This is too large a volume to summarise in this Report, but Ozerova's conclusions are that mercury can form extensive, continuous and easily detected haloes around deposits of other chalcophile elements, 'even though there may be no minerals of mercury in the deposits'. In particular, she cites Sb, Cu-Pb-Zn and Ag-Au ores as being rich in mercury. She notes that in the 'Great Basin' mercury is known to penetrate basin-fill more than 300 m above ore deposits; she reports haloes to be commonly more than 1 km wide around hydrothermal deposits. Mercury can penetrate up to 200 m of unfractured rock vertically and at least 600 m along faults.

More general work on haloes, in which mercury is treated as one element among many, has been carried out in the USSR by Dvornikov and co-workers (1961, 1963), Bulkin (1962), Bulkin and Lepilin (1964), Terziev (1966), Lazutin (1966), Kovrigo (1966), Polikarpochkin and Kitaev (1971) and other writers whose work is not available in English.

In general their work supports that of Ozerova; however, there is some disagreement as to whether the haloes obtained are wider (or more meaningful) than those of the base metals or, for example, antimony. Various papers (e.g.

Dvornikov, 1962) written about the Nagol'nyi Range 'polymetallic' (lead-zinc) deposit, of the S.E. Donets Basin, show a wide mercury halo (up to 1600 m from ore). In this area the mercury halo is twice as wide as that of lead and zinc, three times that of copper and 2.5 times that of antimony.

Research outside Russia has developed more slowly, but a number of recent papers describe case histories where mercury haloes in rocks have been used in the search for mercury or other metals.

Bercé (1960, 1965), Bradshaw and Koksoy (1968), and Koksoy and Bradshaw (1969) have investigated mercury dispersion away from mercury deposits. The last two papers discuss, respectively, primary and secondary dispersion of mercury away from, not only cinnabar, but also stibnite, deposits in Turkey.

Authors who have investigated mercury in rocks in relation to other types of ore include the following:

Authors	Date	Ore Type
Friedrich and Hawkes	1966a, 1966b	Cu, Pb, Zn, Ag
Gott and McCarthy	1966	Au, Ag, Te
Erickson *et al.*	1966	Zn, Pb, Ba, As, etc
Gott *et al.*	1967, 1969	Au, Ag, Te, Cu, Pb, Zn
Cornwall *et al.*	1967	Ag, Au
Jolly and Heyl	1968	Pb, Zn
Akright *et al.*	1969	Au
Chan	1969	Ag-Pb-Zn
Crosby	1969	Pb-Zn-Ag
Sears	1971	Base metals, Au
Friedrich and Pluger	1971	Ba, CaF_2

These authors show that mercury behaves more erratically than is indicated by the Russians. Friedrich and Hawkes (1966a), for instance, found that although hydrothermal ore veins contained values of mercury up to 26 ppm, the host rock, andesite, a few centimetres away from the ore, rarely contained more than background concentrations ($\leqslant$20 ppb). Despite their observations about the rather erratic behaviour of mercury and the patchy distribution patterns it displays, all the above authors are agreed that mercury haloes exist and they believe that, in the correct circumstances, the halo technique can be useful.

It is clear that some mineralised areas have high backgrounds of mercury; thus Akright *et al.* (1969) found the background mercury in unaltered sedimentary rocks (shales, quartzites, limestones) to be 20 ppm while the mineralised rock (Au-bearing) itself contained an average of 31 ppm.

Crosby (1969), working in the Coeur d'Alene district, Idaho, sampled underground 'cross-cuts' across various Pb-Zn mineralised veins. He found that mercury behaved in one of two ways; there was either a peak of mercury values directly above the ore or else there was a double peak, one on either side, with a 'low' directly over the ore. The variation in absolute concentrations of mercury was wide, ranging from 10 to 40 ppb in one traverse (which cut ore) to 200-X000 ppb in other traverses. Though the lower values gave the same profile pattern, it is clear that unless the veins had been known previously the low anomalies would have been missed during prospecting.

The double peak with a central low may be interpreted in either of two ways:

(a) The mercury has dispersed as an envelope in front of the ore, with less mercury inherent in the ore than in the envelope, or

(b) The fissuring or jointing associated with the mineralised veins has allowed secondary dispersion of mercury with a consequent loss of mercury from the ore zone itself.

Sears (1971) has approached the problem of mercury in ores from a rather different standpoint. He collected approximately 600 samples from 19 producing base-metal mines, three producing gold mines and five previously-producing base-metal mines in Quebec, and assayed the samples *in toto* for mercury and other ore metals (mainly copper, lead and zinc) as appropriate. He showed (p386) a wide variation of mercury content of the ores even from the same mine. Thus the mercury concentration in ore from the Normetal base metal mine ranged from 10 ppb to 18 000 ppb in 23 samples. Sears plotted mercury contents against copper, lead and zinc concentrations and was unable to find any relationship between mercury and the other elements, except that there was a weak positive correlation between zinc and mercury values. Sears did not assay individual minerals; his conclusions, however, were, firstly, that of copper, lead, zinc and iron sulphides, the zinc sulphides have the highest concentration of mercury and, secondly, that lead sulphides generally have higher mercury contents than iron-copper sulphides.

6. MERCURY IN SOILS

Though the practical work of this project has been carried out on ores and adjacent rocks, it is relevant to provide a brief summary of the state of knowledge of the distribution of mercury in soils, since most of the papers which discuss the mercury halo prospecting technique are case histories in which soil or stream-sediment samples have been collected.

6.1 Mercury Content of Soils in Unmineralised Regions

Data on the mercury contents of soils in unmineralised areas are sparse. Figures obtained from the main papers are given in Table 3: these are generalisations and represent background levels. Only two papers have been located which discuss, in detail, mercury in unmineralised soils. These are Stock and Cucuel (1934), summarised by Vinogradov (1959), and Aidin'yan *et al.* (1964).

Aidin'yan *et al.* (1964) found, for soils from the USSR (Europe) and from Vietnam, that the upper 10 cm of the soils were lacking in mercury. There was usually a sharp rise to the 'B' horizon or equivalent. This level then held steady or the values gradually decreased through the 'C' horizon. Average soil values were approximately 10 times the values of mercury in the country rocks. Iron-manganese nodules in Vietnam have higher mercury contents than the soils, and mercury is believed to be readily absorbed by sesqui-oxides. The lack of mercury near the surface was attributed to evaporation of mercury from the surface (?followed by redistribution).

Goldschmidt (1954) hypothesises that mercury probably concentrates in forest litter and in the uppermost layers of forest humus. This assertion is repeated by Boyle and Dass (1967).

Some writers, particularly those from the USSR, do not make it clear whether the assays they have reported refer to soil or to the parent rock.

6.2 Mercury Content of Soils in Mineralised Regions

Most of the authors cited as discussing mercury in rocks also discuss mercury in soils. Additional papers concern case history studies related to mercury as an exploration tool. Such papers include those of Fedorchuk (1961), Dvornikov and Petrov (1961), Dvornikov *et al.* (1963), Bol'shakov (1964), Brown (1966 and 1967), Friedrich and Hawkes (1966a and 1966b), Bradshaw and Koksoy (1968), Koksoy and Bradshaw (1969), and Friedrich and Pluger (1971). Much of the data offered by these and other authors summarised in Table 4.

Dvornikov and co-workers, (1961, 1962, 1964) investigated soils at the Nagol'nyi Range. The soils at 5 to 10 cm and at 10 to 20 cm gave similar values (Dvornikov and Petrov, 1961) with background at 80 to 100 ppb, a plateau of 200 to 300 ppb adjacent to ore, and up to 9500 ppb over ore. No data are given in these papers on the mercury content of the ore, which either crops out or is at shallow depth. The maximum halo width is 1700 m.

Bol'shakov (1964) found that lead-zinc orebodies in the S.E. Donets Basin buried to depths of 200 to 300 m had mercury dispersion aureoles which reached the surface, though there were faults which provided possible access paths for the mercury.

Friedrich and Hawkes (1966a) examined residual soils over volcanic rocks mineralised with Ag, Pb and Cu at Pachuca-Real del Monte, Mexico and found that the soil assay values, though erratic in distribution, were rather more consistent than values obtained for rocks. Where the rock is suitably fractured, mercury anomalies were discovered at the surface above ore buried to a depth of 300 m. In a second paper (1966b), Friedrich and Hawkes found anomalies in residual soils on unmineralised volcanic rocks with ores buried at 16 to 60 m (50 to 200 ft) depth (Shasta District, California). Mercury values peaked at 340 ppb over ore against background values of 20 to 60 ppb.

Brown (1966, 1967) assayed line traverse samples across high temperature molybdenite orebodies in British Columbia and found subdued but definite haloes. Background was in the range 15 to 40 ppb with peaks up to 175 ppb. Over copper ore comparable figures were 25 to 60 ppb and 170 ppb, and over a silver-lead-zinc orebody the comparable figures were 25 to 100 ppb and 500 ppb. Brown believed this area of British Columbia to be similar to much of the Crimean Highlands (quoted by Bulkin, 1962). It has such a high general background level of mercury that shallow peaks associated with molybdenum, or other high temperature mineralisation, may be lost in background fluctuations.

Most authors have sampled the upper, humic layers of the soil; however, Friedrich and Hawkes (1966b) found that mercurcy values increased with depth from the surface. Few authors have written about areas with an aridity comparable with South Australia. In the author's experience the 'B' or hardpan horizon has acted as a collector of mercury and the highest values are to be found there. As in so many areas of geochemistry, it appears that thorough orientation is needed before full-scale exploration programmes are carried out.

7. MERCURY IN STREAM SEDIMENTS AND WATERS

Prospecting using mercury in stream sediments has been relatively little used; however, the papers by Missaghi (1966) and Koksoy and Bradshaw (1969) do discuss secondary dispersion of mercury away from mineralisation in the stream sediments. Both the above papers report favourably on the detection of mercury in such sediments. Missaghi's data are summarised in Table 3.

There is little merit in seriously discussing mercury in stream waters with a view to using this method in South Australia. However, papers on prospecting using mercury in streams have been written by Dall'aglio (several, in particular 1971), Dvornikov (1964) and Bayev (1968). Various estimates/measurements of mercury in water are given in Table 6.

It is clear from the literature that mercury can disperse in streams but the mechanism of this dispersion is not clear. Missaghi (1966) and Koksoy and Bradshaw (1969) evidently believe that sulphide minerals with attendant mercury may migrate mechanically downstream. Dall'aglio (1971) believes that mercury moves either in solution, perhaps as $HgCl_2$ or as a chloride complex, or adsorbed on clay or in some colloidal form.

8. MERCURY IN AIR AND SOIL AIR

A study of mercury in either soil air or the atmosphere may prove to be a worthwhile prospecting technique in South Australia where large areas of ground are covered by moderate thicknesses of relatively loose sand. It has been shown experimentally that sand does not easily retain mercury (by absorption, adsorption or any other process) but allows mercury to pass freely through it. It may therefore be better to explore sandy surface materials by sampling either soil air at a depth of a few metres or by sampling the atmosphere at no great distance from the ground surface.

Discussions of mercury in soil air have been given by Hawkes and Williston (1962), Karasik and Bol'shakov (1965), Fursov *et al.* (1968), McCarthy *et al.* (1969a) and Fursov (1970). Discussion of mercury in the atmosphere has been given by Williston (1968), Barringer (1964, 1969), McCarthy *et al.* (1969a) and Seigel Associates (1971).

All these authors maintain that assay of mercury in air or soil air is possible at the very low levels expected and Karasik and Bol'shakov (1965), Fursov *et al.* (1968), McCarthy *et al.* (1969), Seigel Associates (1971) and Fursov (1970) have demonstrated to their satisfaction gaseous dispersion haloes of mercury associated with ores. Fursov (1970), dealing with gaseous mercury over blind mercury ores, obtained anomalous values up to 1100 times background. (Background values were 10 ng of mercury/litre of soil air.) No depth to ore was given.

9. DISCUSSION

It is clear from the literature that the problems of the potential of the mercury halo prospecting method have never been fully resolved. The early work was hindered by a lack of adequate analytical techniques and only in the last 4 to 5 years has the flameless atomic absorption technique, potentially one of the most sensitive techniques available, become sufficiently reliable to handle all types of sample and to be able to separate true mercury values from false values attributable to contamination or non-atomic absorption.

The use of mercury for prospecting purposes rests on an understanding of the geochemistry of mercury in its relation to ore deposits. Most studies to date have used mercury assays of surface samples of soils, unmineralised rocks or oxidised ores. Comparatively few studies have been made of mercury concentrations in ores and in minerals within or associated with ores, and no paper sighted to date has attempted to relate, other than by inference, the mercury content of ores to their temperatures of formation. Most papers, e.g. Williston (1962), glibly assume that as mercury is commonly associated with mineralised thermal springs as at Ngawha, New Zealand or Sulphur Bank, California, mercury will only be found in, or associated with ores of low temperature. This is probably true, but the literature reveals that little confirmatory work has been reported on the mercury contents of ores of various types. Cinnabar and mercury ores in general may be truly low temperature in origin, but mercury may be taken into, e.g. a galena lattice, at much higher temperatures.

Establishment of the levels of mercury in various ore types seems, therefore, to be a pre-requisite for intelligent use of the halo method. In this regard Sears' (1971) paper is most instructive for he has attempted this type of work on the ores of Quebec. Points that stand out from his paper are:

(a) The wide variation of mercury content within the ores, indicating that, in order to characterise a deposit, the assay of a suitably large number of samples is needed.

(b) The lack of relationship between mercury concentrations and those of the other ore metals (except for a broad correlation of mercury with zinc).

Sears gave no comparable figures for individual minerals within the ore, nor did he try to relate the mercury content to the temperatures of formation of the various ores. Accumulation of the fundamental data such as Sears has started to collect is vital.

An alternative hypothesis has been raised by Moiseyev (1971). He believes that a non-magmatic source is possible both for the formation of mercury ore deposits and for the formation of mercury haloes. He believes that mercury may be derived from intruded sediments, rather than magmas, and that it can be mobilised by volcanic heat. By his hypothesis, intrusive ore or magma may contain very little mercury but, if the surrounding host rocks contain a sufficient quantity, mercury may be mobilised in front of the ores and be reprecipitated where temperature and pressure conditions are suitable. Moiseyev's paper refers mainly to mercury deposits but he does say (p598) '....if the magma was emplaced in homogeneous rocks the mobilised mercury would deposit in an outer zone where the temperature change was insignificant. This deposition would nearly double or treble the geochemical Clarke (value) and form .... a 'geochemical anomaly'.'

Thus a complicating factor has been introduced. Moiseyev does not consider in his paper the intrusion of sulphide ores but clearly, if mercury haloes can be related to both orebodies and to magmatic intrusions, then some geochemical haloes (from the prospecting point of view) will be spurious, since a large number of surface halo discoveries will be related to magma intrusion rather than ore.

Additional work is needed to test this hypothesis. Some suggestion of its truth has been obtained in one area by the writer, but much better documented analytical work on samples which represent a passage outwards from a magma to cool country rock is needed.

Various papers have been written on the transport of mercury in hydrothermal solutions/fluids, and the origins of mercury deposits and haloes. The more important papers have been written by Thompson (1954), White (1955, 1967), White and Robertson (1962), Dickson (1968), Barnes *et al.* (1967), Krauskopf (1951) and Moiseyev (1968). Mechanisms postulated are transported as vapour, in solution as chloride (or chloride complex), carbonate and borate, or as a sulphide complex. Many of the studies have been based on limited observations of hot springs followed by appropriate thermodynamic calculations. Mercury may then be concentrated in the rocks by condensation as the temperature falls (Moiseyev, 1971, gives a figure of 120°C below which mercury driven off in front of intruding magma is essentially fixed) by adsorption or absorption onto or into clays, limonite, etc., by fixation by diadochic substitution into the lattice of crystallising minerals or by precipitation as mercuric sulphide.

The above discussion centres on what may be termed the primary dispersion characteristics of mercury. Before the halo prospecting method can be used with success it is necessary to consider the behaviour and disperion of mercury in the supergene environment, for this will have a marked influence on the values of mercury obtained by soil or air determinations at or near the ground surface.

If sulphide ore is introduced and the mercury is an integral part of the sulphide component, either as cinnabar or in the lattice of some other sulphide, one or more of the following patterns of mercury dispersion may apply after deposition of the ore.

(a) The mercury may remain fixed in sulphide either as cinnabar or in other sulphides. Presumably no further dispersion will take place until the sulphides crop out.

(b) The mercury may remain fixed in the sulphide until the sulphide is oxidised. The mercury may then be released:

(i) as vapour, or
(ii) in solution

After some dispersion (of unspecified distance) it may then be trapped by one of the processes instanced earlier.

(c) Mercury may be released at a uniform or slowly decreasing rate (?proportional to its concentration) from unoxidised sulphide and then behave as under (b) above.

(d) Mercury released under (b) may migrate to the surface soil and then may be:

(i) held in the soil
(ii) released to the atmosphere as vapour, or
(iii) dispersed mechanically (trapped on clay), etc., by normal erosional processes.

(e) An equilibrium of uncertain nature may be set up between mercury in the atmosphere and mercury in the soil which, though possibly owing its origins to mercury released from ore, creates a pattern of mercury apparently unrelated to the position of ore.

If the mercury has been driven out as an envelope in front of the invading ore its behaviour will not only depend on the temperature of the ore but also on the capacity of mercury to volatilise (or remain volatile) or to be taken into solution, or on the presence of clays or other suitable substances to fix it.

It has been shown (by Rinse (1928), Krauskopf (1951) and Dickson (1968)) that there is a significant vapour pressure associated with HgS even when buried under water. If fluids (solutions, etc.) remove mercuric ions/atoms as they form, dissociation may go to completion over a period of time. However, it is not yet clear whether mercury can be released from sulphides which are not being oxidised; nor is it clear whether haloes can be detected when all the sulphide has been completely oxidised.

The interpretation of the behaviour may be rendered more difficult because of contamination. Kurbanyev and Is'kov (1964) discuss mercury values of samples collected in mines and conclude that they have been contaminated with mercury from mercuric fulminate used in detonators. Bradshaw and Koksoy (1968) discuss the same problem though with a different emphasis. Aidin'yan and Ozerova (1969) and Koksoy *et al.* (1967) point out the fact that mercury from mercury-rich samples may contaminate adjacent mercury-low samples when the two types of samples are stored together.

In recent years considerable prominence has been given to pollution by organic mercury, in particular the methyl-mercury compounds (e.g. Jonasson, 1970). It is more than conceivable that some of the methyl mercury travelling in ground water may be fixed by clays or by sesqui-oxides. In agricultural areas direct contamination by the addition of weedicides and fungicides is possible though the amounts of materials used are quite low. In South Australia, for example, cereals may be treated with 'Ceresan' or 'Leytosan' (1 to 1.5% Hg), at the rate of 2 to 4 ounces of these products per acre. Potatoes may be treated with either methyl-mercuric guanidine (0.61% Hg) or mercuric chloride (approx. 18% Hg). The latter is used at the rate of 3 to 4 ounces per 1000 sq.ft. Pine plantations are commonly treated with 'Lanetan', a spray which contains 3% mercury.

PART 2

EXPERIMENTAL WORK

1. INTRODUCTION

Experimental work to date has involved the assay of a number of cores taken at copper mines or prospects in South Australia. These cores are listed as follows:

Locality	Drill Hole Number
Parabarana	PDD2 PDD3 NFP22
Kapunda	K6 K10 A4
Kanmantoo	KS31 KS86
Mutooroo	DDMM6 DDMM15D1 DDMM21A DDMM26
Burra	BS4
Moonta	DDM14

The Kapunda and Burra ores appear to contain secondary copper minerals (both carbonates and sulphides). Kanmantoo, Mutooroo and Moonta ores appear to contain primary copper (iron) sulphides, whereas the material from Parabarana was received in a crushed state and the copper mineralisation was understood to be primary.

The cores from Parabarana and Kanmantoo were submitted for assay for copper, lead and zinc as well as mercury. Copper values were already known for the Kapunda ores and these samples were submitted for lead and zinc in addition to mercury. The Burra samples were analysed for copper and mercury only.

Samples from the remaining cores were submitted for mercury assay after a binocular microscope examination of the cores to determine whether or not sulphide mineralisation was present.

2. ANALYTICAL METHODS

Copper, lead and zinc were determined by conventional atomic absorption analysis after digestion of finely ground portions of the samples in hot concentrated perchloric acid.

Several techniques were used for the determination of mercury in the samples. The original technique was to use the Lemaire mercury detector. The method here is to heat the powdered sample and drive off mercury. The mercury is diluted with air in constant volume and then driven through a flameless absorption cell. The mercury is determined by reference to known standards, using the absorption line at 2534 Å.

Other techniques now include those of Hatch and Ott (1968) with variations on the technique. The method involves a cold nitric acid digestion of the sample followed by reduction using stannous chloride in combination with another reducing agent such as hydroxylamine hydrochloride. Mercury in the sample is extracted into the acid solution by nitric acid and is reduced to mercury by the reducing agents. An inert gas is then blown through the solution, taking the volatile mercury out of the liquid through an atomic absorption chamber in the position usually occupied by a flame, and the absorption is measured at 2534 Å. Calibration is made by using samples of known mercury concentration and reagent blanks.

The Amdel procedure finally adopted includes digestion with a mixture of cold concentrated nitric and hydrochloric acids (aqua regia), containing free bromine. Aliquots of the solution are treated with stannous chloride as already described and the reduced mercury is determined by the standard flameless atomic absorption method.

Additional confirmatory testing was carried out by emission spectrography.

3. RESULTS

Assay results are presented in Tables 8 to 13.

4. DISCUSSION

4.1 Assay Data

There have been considerable problems in obtaining reliable analytical data. The technique using the Lemaire mercury analyser is satisfactory for the determination of mercury in soils which contain little chloride, sulphate and carbonaceous material. The actual extent of interference and loss of signal when determining mercury in rocks, and, in particular, sulphide-bearing rocks, had not been fully realised until values were obtained which were clearly well below accepted Clarke values.

A programme of experimentation followed in which the second technique cited in the section on methods (Section 2), was developed. It was then found that various other elements interfered with analysis for mercury. Of these, gold, selenium and tellurium, when present to the extent of a few parts per million in solution, lowered the apparent mercury content of solutions spiked with mercury very appreciably, because of either the precipitation of mercury selenide or telluride or the formation of a gold amalgam. By reducing aliquots of mercury (and increasing the dilution) satisfactory values were obtained for the spiked samples.

No major problems have been found in analysis of lead and zinc ores using acid digestion followed by reduction of the mercury but, as Band and Wilkinson (1972) discovered, low values were obtained for copper-bearing ores/solutions. Part of the answer to this lies in increasing the digestion time for acid attack on the sample, since copper in chalcopyrite seems more difficult to get into solution than copper in other forms. Copper is relatively easily reduced by stannous chloride solutions and it is believed that the reduced copper may trap some of the mercury. However, the mechanism of entrapment is not fully known.

The samples received in connection with the project have been analysed for mercury in a number of ways. However, the results presented in Tables 8 to 13 are all generated by the same technique of analysis.

It is now believed that the results genuinely represent the mercury content of the ores - with one reservation which will be discussed later. The samples have been assayed in duplicate and the average value is given. The precision of analysis is ±15% relative.

As with all samples in which mercury is sought, there are possibilities of loss of mercury to the air, or of contamination of the samples by mercury accreted from the air, analytical apparatus or chemicals. No adequate assessment can be made of the former, but contamination can be checked by the use of solution blanks.

Recent investigations on a number of containers have shown that glass is the ideal storage medium when mercury analysis is to be undertaken. Most plastic containers (in particular, Duranol containers) also appear to be free of mercury. However, paper sample-bags of the type commonly used for the collection of soil samples contain up to 5 ppm of mercury and will undoubtedly contaminate samples stored in them. It is believed that these bags are deliberately treated with a mercury compound which is a fungicide to enable the bags to store wet samples.

Fortunately the samples of which assays are listed in this Report have been kept mainly in plastic bags. However, in the periods between re-assaying, they have from time to time been in reasonable proximity to samples in paper sample-bags. The effects of possible contamination from this source cannot be assessed at this stage.

4.2 Discussion of Results

The mercury values now finally determined are similar to overall values published for rocks of their respective types around the world. In unmineralised rocks the mercury values range between about 30 and 150 ppb with the exception of DDH14 at Moonta where the overall values of mercury are appreciably higher, commonly well over 150 ppb. However, in all discussion of background values it is necessary to remember the volatility of mercury. The rocks at Moonta are mineralised over considerably greater lengths than most of the rocks from the other cores, and with the extra volatility of mercury the higher values may reflect the greater overall degree of mineralisation - or the possibility of unsuspected mineralisation.

Of interest are the values near the surface. In the upper 15 to 30 m (50 to 100 ft) of each core, a considerable degree of weathering may be expected with some formation of clay. As clay has long been known as a collector of mercury, enhanced values of mercury are to be expected in these parts of the cores if mercury has been able to diffuse upwards. It is therefore particularly interesting to note that at Kanmantoo (Table 10, Figs 10, 11), almost the highest values of each core occur at 1.5 to 7.5 m (5 to 25 ft) depth. Other samples in the possible weathered zones at Kanmantoo do not show particularly high values. Of the other cores, this near-surface enrichment is only shown at Mutooroo (Table 11, Figs 13, 14). In this case the surface mercury may possibly be unrelated to the sulphide mineralisation at depth since, for the most part, mineralisation occurs at depths greater than 300 m (1000 ft) below the surface. A series of surface soil or rock samples over the line of known mineralisation should be made, after assessing the position of possible channelways from the ore to the surface. A high value of mercury at 38 m (126 ft) in the Moonta core may also represent mercury trapped by clay.

Reference to the down-hole profiles, or the assays themselves, shows that both at Burra (Fig. 15) and at Kapunda (Figs 1, 2), mercury occurs in association with the copper mineralisation. At Burra, mercury has a maximum value of 300 ppb whereas at Kapunda the maximum value recorded in K10-12 is about 1 ppm.

Elsewhere there does not appear to be any significant increase in mercury with the copper mineralisation. However, it is not absolutely clear whether this is due to interference in the determination of the mercury by the high concentration of copper or to inherently low mercury values. Band and Wilkinson (1972) comment that on normal assay there is a negative correlation between mercury and copper in massive sulphides. This they ascribe to purely analytical problems. As far as the present determinations are concerned, the values of mercury found in rocks containing abundant sulphide are believed to be accurate.

The pattern of the relationships of copper and mercury at Kanmantoo KS31 is particularly interesting. Although the correlation coefficient is only +0.18, it will be seen from the down-hole profile (Fig. 8) that there is a decidedly sympathetic behaviour pattern between copper and mercury. In general, when copper increases so does mercury and vice versa. The scatter plot of copper versus mercury (Fig. 11) suggests two trends, both with a simple positive relationship. When the high copper values are removed from consideration and the correlation coefficient is recalculated, it increases to +0.53 and the scatter diagram (Fig. 12) emphasises the relationship.

Overall, at Kanmantoo (when both holes are considered) there is a reasonable correlation of zinc with mercury, and lesser but positive correlations of lead and copper with mercury (Table 15).

The same treatment has been carried out on the results of the determinations made on the Parabarana samples. Down-hole profile plots (Figs. 3, 4, 5) do not indicate any great correlation of copper with mercury or of zinc with mercury. Correlation coefficients derived from the analyses of all the samples indicate absolutely no correlation between mercury and any of the three other metals (Table 14 A). However, recalculation of the correlation coefficients for 'non-mineralised' samples - that is, those samples showing less than 500 ppm copper - does show a positive relationship (and a correlation coefficient of +0.32) between copper and mercury, the coefficients for lead and zinc with mercury remaining much as before (Table 14 B). The scatter diagrams (Figs. 6, 7) show this trend but indicate visually the widely dispersed spread of values.

No copper, lead or zinc determinations were made for the remaining two areas. It was not felt that this was justified until an analytical technique for mercury had been shown to be demonstrably sound. However, down-hole profile plots were drawn for mercury against the depth in the hole with the position of sulphides visible in the hand specimen marked on them.

The sample from Mutooroo (Figs 13, 14) showed some variations and, in many cases, there is an enhancement of mercury at the position of the sulphides at or in the upper portion of the sulphide zone. Moreover, although other mercury peaks occur elsewhere where there are no visible sulphide minerals, the highest values of mercury in DDM6 and DDM7 occur in the vicinity of sulphide mineralisation. The tendency to higher values of mercury at or near the surface at Mutooroo has already been noted, and it does appear that there is a limited but positive relationship between mercury and the presence of sulphides.

At Moonta (Fig. 16), although the mineralised zones are generally richer in mercury, the correspondence is by no means exact and several sulphide-bearing samples show low mercury values. Again, this may be due to interference by copper or other elements.

5. CONCLUSIONS AND RECOMMENDATIONS

With the continuing interest in the possibilities of using volatile elements in prospecting for base metal or gold orebodies, it is too soon to discount the value of the mercury halo prospecting technique without further research; however, it must be said that progress in this project has not been ideal, largely due to analytical difficulties and possible sample contamination. Work is continuing on the development of an adequate, economic method for making geochemical determinations of mercury in rocks, particularly those with sulphides. The method currently in use has been found to be viable for samples of all types but results reflect the sample as presented for analysis and do not take into account possible contamination or loss of mercury between collection and the time of analysis.

The results to date, however, show a low but positive correlation of mercury with low levels of copper, and also show a tendency for there to be some concentration of mercury in the oxidised, near-surface zone above copper ore-bodies. This is mildly encouraging but not as informative as was hoped when the project commenced.

It is considered that continuation of the project is/will be worthwhile once the problems of sampling, contamination and analysis have been overcome with certainty.

The results have demonstrated that, before embarking on a project of this nature, rigid controls must be applied at all stages from the collection of samples through to the determination of mercury values. However, the premises on which the project was formulated, namely that mercury is a common associate of base-metal ore deposits or of gold ore deposits and should be a useful guide to ore, are still valid; and it may confidently be expected that, in the future, mercury haloes can be used to determine the position of blind orebodies. Fewer problems occurred in the determination of mercury in soils which had been collected and preserved in Duranol containers. The greater part of the results obtained by assay of the soils by Amdel is considered to be valid.

It is recommended that the project be held in abeyance until a completely satisfactory sampling, storage and analytical scheme has been developed. It is anticipated that a further project proposal will be submitted when the analytical method has been upgraded.

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TABLES 1 to 15

FIGURES 1 to 16

TABLE 1: ESTIMATES OR MEASUREMENTS OF MERCURY IN ROCKS (Selected Figures Only)
Values in ppb mercury

Author	Basic	Inter-mediate	Acid	Lime-stone	Shale/Clay	Sand-stone	Other	Remarks
Preuss (1940)	100		10		300	10		Estimated average values
Hawkes and Webb (1962)	90		40	30	400	30-100		Estimated average values
Turekian and Wedepohl (1961)	90	XO	80	40	400	30	XO, ultrabasic rocks	Estimated average values
				XO	XOO			Deep sea sediments
Krauskopf (1967)	80		80		400			Estimated average values
Vinogradov (1962)	90	50	80		400		10, ultrabasic rocks	Estimated average values
Afanas'yev and Aidin'yan (1961)	30-250	65-500	60-200		40-60		60(1) schist	North Caucasus. These rocks unmineralised but near mineral-isation
Ozerova (1962)		60-200						Nepheline syenites, USSR
Bulkin (1962)	17600		70-500	4000	2000	5000		Average values, USSR Crimea mercury province.
Ozerova and Unanova (1965)	←	20-200	→					Lavas, unspecified, Kamchatka
Aidin'yan *et al.* (1966)		140-580						Alkali syenites, USSR
Ozerova and Aidin'yan (1966a)				31	35	39	80-200 limonite	Russian platform, average values
					85	97		Kamchatka, average values
					400		70 phosphorites	Combustible shales, Volga River
Golobnynya (quoted by Ozerova and Aidin'yan (1966a)							57(2) quartzite 51(5) paragneiss 47(7) granite gneiss 57(5) orthoamphibolite	Average values, Valdai Series, phyllites to granite
							7-28	Irtysh, USSR
Karasik & Morosov (1966)					100-900			Kerch Peninsula, average values
					400			average values
Dvornikov (1967d)							20-100 coal	Donets Basin, background values
Jovanovic & Reid (1968)							193(1) pelitic schist	Vermont, USA
							18(1) amphibolite	Vermont, USA
Aidin'yan *et al.* (1969)		10-75 →						Estimated average values

For a much more detailed list of measurements of mercury in rocks see USGS Prof. paper 713, Tables 2 to 12.

Figures in brackets in column 'Other' indicate numbers of samples analysed.

TABLE 2: MEASUREMENTS OF MERCURY IN UNMINERALISED SOILS

Author	Mercury Value in ppb Range	Mercury Value in ppb mean	Remarks
Stock & Cucuel (1934)		70	Average value, soils
	30- 34		Clay soil
	1- 29		Sand
	30- 81		Humic horizon, forest soil
	100- 290		Forest soil
Dvornikov & Petrov (1961)		30	Average, background clay soils, Nagol'nyi Range
Hawkes & Webb (1962)	30- 300		Average value, soils
Dvornikov *et al.* (1963)		20	Average background, Nagol'nyi Range
		400	Soil over dispersed mineralisation (Hg province)
Aidin'yan *et al.* (1964)		30	Average values
	15- 75		Forest podsol
	10- 40		Chernozem
	8- 36		Latosol
	10- 30		Clays with laterite
Warren, Delavault & Barakso (1966)	10- 50		Unmineralised soils, British Columbia
	50-2500		Near mineralisation, British Columbia
	250-2500		Above mineralisation, British Columbia
Karasik & Morozov (1966)		300	Clay soils of Kerch Peninsula (Hg province)
Williston (1968)	20- 40		Unmineralised, California
	100- 200		Franciscan Formation, California
Anderssen (1967)	- 60		Sweden
	- 23		Africa
Jonasson & Boyle (1971)	20- 150	70	Unmineralised soils (estimated)
	20- 100	50	Glacial tills
	60- 200	161	Soil, mineralised belt, A horizon
	30- 140	89	Soil, mineralised belt, B horizon
	25- 150	96	Soil, mineralised belt, C horizon
	50- 200	100	Iron enriched, weathered crusts

TABLE 3: SOME VALUES FOR MERCURY IN ROCKS, SOILS AND STREAM SEDIMENTS IN MINERALISED AREAS (Values in ppb unless otherwise stated)

Author	Sample Type	No.	Minimum	Maximum	Average	Type Mineralisation	Locality
Fursov (1958)	Sedimentary rocks		<300	>1000		Pb, Zn, pyrite	Achisai, Kazakhstan
	Bedrock above ore	13			1.7 ppm		
Ozerova (1959)	Sedimentary rocks		< 10	500		Pb, Zn	Turkestan
Sergeyev (1961)	Sediments		< 20	30ppm		Base metals	Khaidarkanskoe, USSR
Fedorchuck (1961)	Limestones		< 1ppm	480ppm	2 ppm	Hg	Middle Asia and Pacific provinces USSR
	Dolomites		< 1ppm	180ppm	2 ppm	rocks adjacent to orebody	
	Marls		< 1ppm	140ppm	4 ppm	background at distance	
	Shales		< 1ppm	120ppm	3 ppm	0.1 ppm	
Dvornikov & Petrov (1961)	Soil				830	Hg	Khpek, Dagestan
	Shale		80	300		Hg	Manuson, Georgia, USSR
	Shales				700	(Hg	Ak-Tash, Dagestan
	Limestone				300		
	Limestones				200	(Hg	Chagan-Uzun, Dagestan
	Sandstones				1.35ppm		
	Soil, 'A' horizon		80	9.5ppm		Polymetallic	Nagol'nyi Range, USSR
Dvornikov (1962)	Limestone		< 70	22ppm	4 ppm	Polymetallic	Nagol'nyi Range (one area)
	Shale		Trace	4.4ppm	1.9 ppm	Pb-Zn	
	Sandstone		100ppb	3ppm	700 ppb	Hg	Donets Basin, USSR
Dvornikov *et al.* (1963)	Soils		20	2.7ppm	400 ppb (Dispersed mineralisation)	Polymetallic and Au	Nagol'nyi Range
Dvornikov (1964)	Clay shales				20-40	Background values	S.E. Donets Basin
	Sandstones						
	Limestones		100	1000	570	Dispersed mineralisation ?uncertain type	S.E. Donets Basin
	Coal				20-40	Background	S.E. Donets Basin
					600		Nagol'nyi Range
Karasik & Bolshakov (1964)	Soil		5ppm	60ppm		Hg	Nikitovka, USSR
Bolshakov (1964)	Soil				1.7 ppm	Dispersed Hg	Nikitovsk, USSR
	Sandstone				700 ppb	Dispersed Hg	Nikitovsk, USSR
	Shale				500 ppb	Dispersed Hg	Nikitovsk, USSR
Berce (1965)	Shales, Dolomite		< 1ppm	>1000ppm		Hg	Idrija, Yugoslavia
Gott & McCarthy (1966)	Various rocks	500		70ppm	180	Au, Ag, Te	White Pine Co. Nevada
Erickson *et al.* (1966)	Limestones, Jasperoids		10	3.2ppm		Au, Sb, W	Cortez, Nevada

Continued

TABLE 3: CONTINUED

Author	Sample Type	No.	Minimum	Maximum	Average	Type Mineralisation	Locality
Missaghi (1966)	Stream sediment		<150	1270		Zn, Pb, Cu, Ag, Au	Magdalena District, New Mexico
	Acid volcanics, Limestone, Quartzite		< 50	196			
Friedrich & Hawkes (1966b)	Soil		< 20	340		Cu, Pb, Zn, As	West Shasta, California
	Volcanic rocks (acid)		< 30	1300			
Friedrich & Hawkes (1966a)	Andesites		< 10	2600		Pb, Zn, Cu, Ag, pyrite	Hidalgo, Mexico
	Soil		< 50	1900	300		
Brown (1966)	Soil		< 20	200ppm	1ppm	Hg	British Columbia
Brown (1967)	Soil		10	175	50	Mo and Au, Bi	British Columbia
Cornwall *et al.* (1967)	Altered andesites		100	> 300		Au, Ag	Comstock, Nevada
	Soil and altered andesites		20	> 200		Au, Ag	Tonopah, Nevada
	Soil, sandstones, shale		20	> 300 (to 2000 when soil also contained silver)		Ag	Silver Reef, Utah
Gott *et al.* (1967)	Altered phonolites				190	Au	Cripple Creek, Colorado
Bradshaw & Koksoy (1968)	Sericite Schist		33	45	Background	Hg, Sb	Halikoy, West Turkey
			100	350	dispersed mineralisation		
				> 500	over ore		
	Metasediments		20	35	Background		
	Biotite schist		180	700	Dispersed mineralisation		
	Marble		23	35			
	Granite		68	> 500			
	Unaltered andesite				∿200	Hg	Ivrindi, Turkey
	Altered andesite		<300	>10000			
Haas (1968)	Soil		1000	> 4000			Secret Canyon, Nevada
	Soil	5	<110	2230			Roberts Mt. Thrust, Nevada
Akright *et al.* (1969)	Sedimentary rocks		20	140		Au	Carlin Mine, Nevada
Crosby (1969)	Greenschist, Metasediments, Samples in adits, Cross cuts		20	> 1000		Pb, Zn	Coeur d'Alene, Idaho

Continued

TABLE 3: CONTINUED

Author	Sample Type	No.	Minimum	Maximum	Average	Type Mineralisation	Locality
Koksoy & Bradshaw (1969)	Weathered metamorphics	19	33	700		Hg	Halikoy, Turkey
	Soil (-80#)	22	45	375			
	Stream sediments	15	53	226			
	Soil	13					
	Stream sediments	5					
Dall'aglio (1971)	Stream sediments	1000	< 50	50ppm		Hg	Tuscany, Italy
Friedrich & Pluger (1971)	Soils		< 50	>2000		Ba	Dreislar, Germany
	Soils		< 20	> 600		CaF_2	Osor Mine, Spain

TABLE 4: MERCURY CONTENTS OF SOME COMMON ORE AND GANGUE MINERALS*

Mineral	Composition	'Normal' Range Limits ppm	Highest Reported Content %
Tetrahedrite	$Cu_{12}Sb_4S_{13}$	10 - 1000	17.6; 21
Grey copper ores	$(Cu,As,Sb)_xS_y$	5 - 500	14
Sphalerite	ZnS	0.1 - 200	1
Wurtzite	ZnS	0.1 - 200	0.03
Stibnite	Sb_2S_3	0.1 - 150	1.3
Realgar	AsS	0.2 - 150	2.2
Pyrite	FeS_2	0.1 - 100	2
Galena	PbS	0.04- 70	0.02
Chalcopyrite	CuFeS	0.1 - 40	
Bornite	Cu_5FeS_4	0.1 - 30	
Bournonite	$PbCuSbS_3$	0.1 - 25	
Chalcocite	Cu_2S	0.1 - 25	
Marcasite	FeS_2	0.1 - 20	0.07
Pyrrhotite	$Fe_{1-x}S$	0.1 - 5	
Molybdenite	MoS_2	0.1 - 5	
Arsenopyrite	FeAsS	0.1 - 3	
Orpiment	As_2S_3	0.1 - 3	
Native gold	Au	1 - 100	60
Native silver	Ag	1 - 100	30
Barite	$BaSO_4$	0.2 - 200	0.5
Cerussite	$PbCO_3$	0.1 - 200	0.1
Dolomite	$CaMg(CO_3)_2$	0.1 - 50	
Fluorite	CaF_2	0.01- 50	0.01
Calcite	$CaCO_3$	0.01- 20	0.03
Aragonite	$CaCO_3$	0.01- 20	3.7
Siderite	$FeCO_3$	0.01- 10	0.01
Silica (all forms)	SiO_2, $SiO_2.nH_2O$	0.01- 10	
Pyrolusite	MnO_2	1 - 1000	2
Limonite	$Fe_2O_3.nH_2O$	0.1 - 500	0.2
Graphite	C	0.5 - 10	0.01
Coal		0.05- 10	2
Gypsum	$CaSO_4.2H_2O$	0.01- 4	

*Table 1 of Jonasson and Boyle, 1972, p34

TABLE 5: DEPTH OF BURIAL OF DISCOVERED OREBODIES

Author	Region	Depth	Mineralisation
Friedrich & Hawkes (1966b)	California	15 - 65 m	Cu, Pb, Zn, Ag
Friedrich & Hawkes (1966a)	Mexico	120 m	Cu, Pb, Zn, Ag
Fursov (1958)	Kazakhstan	25 -300 m	Pb-Zn
Bol'shakov (1964)	Nitikovsk, USSR	200 -300 m	Hg, minor-Pb,Zn
Bercé (1965)	Yugoslavia	100 m	Hg
Friedrich (1968)	Idaho	30 m	Cu, Pb, Zn
Ozerova (1959)	Fergana, Turkistan	100 m	Pb, Zn

TABLE 6: SOME RECORDED MERCURY CONTENTS OF NATURAL WATERS
Values in ppb

Author	Samples	Minimum	Maximum	Average	Location
Stock & Cucuel (1934)				0.1	Rhine River
				0.03	Seawater
		0.05	0.48	0.2	Rainwater
		0.01	0.05		Springs, Germany
Hawkes & Webb (1962)		10	100		Average, fresh water
Aidin'yan & Belavskaya (1963)		1	2		Danube
	9	0.4	1.6	1.2	Atlantic Ocean
Karasik *et al.* (1965)	26	<1	6.5		Permian salt beds, USSR
Karasik & Morozov (1966)		<1	2.5		Mud volcanoes, Kerch
Kraynov *et al.* (1966)	37	<0.005	80	<1	Springs, Elbrus, Caucusus
Krauskopf (1967)				30	Average, marine
Dvornikov (1967c)				0.3	North Sea, average
White & Robertson (1962)			20		Sulphur Bank Springs (HgS depositing)
Dvornikov (1964)	for 21 values obtained out of 170 samples assayed	<1	10		Donets Basin

TABLE 7: MAXIMUM MERCURY CONCENTRATIONS IN AIR
(Table from Fleischer *et al.* (1970) with additions)

Location	Mineralisation	Maximum Hg Concentration, ng/m³		
		Soil Air	Ground Surface	120 m (400 ft)
Ord Mine, Arizona	Hg	–	20,000 (50 readings)	108 (4 readings)
Silver Cloud, Nevada	Hg	–	2,000 (50 readings)	24 (8 readings)
Dome Rock, Arizona	Hg	–	128 (6 readings)	57 (20 readings)
Cerro Colorado Mts. Arizona	Base metals/Au/Ag	–	1,500 (5 readings)	24 (2 readings)
Cortez (Au), Nevada	Au	–	180 (60 readings)	55 (4 readings)
Coeur d'Alene, Idaho	Base metals/Ag	–	68 (40 readings)	
San Xavier, Arizona	?	–	–	25 (3 readings)
Silver Bell, Arizona	Cu	–	–	52 (3 readings)
Esperanza, Arizona	Cu	–	–	32 (3 readings)
Vekol, Arizona	Cu	–	–	32 (4 readings)
Ajo, Arizona	Cu	–	–	30 (3 readings)
Mission, Arizona	Cu	–	–	24 (3 readings)
Twin Buttes, Arizona	Cu	–	20	22 (3 readings)
Puma, Arizona	Cu	–	–	13 (3 readings)
Safford, Arizona	Cu	–	–	7 (2 readings)
Blythe, California	None	–	–	9 (20 readings)
Cula Bend, California	None	–	–	4 (2 readings)
Salton Sea, California	None	–	–	3.5 (2 readings)
Los Altos, California (Williston, 1966)	None	–	1 to 20	Height unknown
Arivaca, Arizona	None	–	–	3 (2 readings)
Nikitovka (Kavasik & Bolshakov, 1964)	Base metal + Hg	⟵ Range 2000 to 16000 ⟶ 40000 underground air in mine		
Various, USSR (Fursov, 1970)	Hg	1000 to 10000 – background values soil air above ore; 11 to 30000 in adits of mine		

TABLE 8: ASSAY OF KAPUNDA DRILL CORES

Drill Hole and Footage	Cu %	Pb ppm	Zn ppm	Hg ppb
K6 - 6	0.04	5	45	130
16	0.55	5	120	315
26	0.09	10	5	130
35	0.02	5	<5	50
41	<0.01	5	20	100
K10 - 4	0.60	5	20	100
12	1.20	5	45	1000
21	0.03	10	<5	100
29	0.015	10	10	325
39	0.01	<5	20	350
55	0.015	<5	20	130
	ppm			
A4/6	<80	25	10	100
/12	<50	25	45	130
/17	50	25	10	30

TABLE 9: ASSAY OF PARABARANA DRILL MATERIAL

Drill Hole and Footage	Departmental Sample No.	Cu ppm	Pb ppm	Zn ppm	Hg ppb
PDD2 20	5441	5	15	20	60
50	5442	10	<5	20	110
100	5443	80	20	220	90
300	5444	20	15	25	30
500	5445	20	5	85	50
600	5446	110	15	130	50
650	5447	35	5	75	80
660	5448	35	5	90	50
670	5449	30	5	120	50
680	5450	740	5	70	30
685	5451	55	5	45	80
700	5452	2100	5	40	50
710	5453	310	15	70	110
720	5454	20	10	50	50
730	5455	20	15	50	30
756	5456	220	5	40	80
PDD3 500	5457	25	15	210	25
700	5458	110	120	150	40
800	5459	5	15	55	50
900	5460	15	5	20	50
1000	5461	5	5	55	50
1020	5462	50	5	40	110
1040	5463	30	5	70	40
1050	5464	5	20	90	30
1060	5465	50	20	55	170
1070	5466	2200	5	120	40
1110	5467	2.6%	40	60	30
1150	5468	310	10	110	70
1190	5469	90	15	30	120
1200	5470	10	10	40	140
1210	5471	140	10	25	120
1220	5472	5	10	20	70
1230	5473	10	35	45	120
1250	5474	100	40	85	170
1300	5475	10	20	80	110
1400	5476	60	45	250	40
NPP22 5	5478	35	390	1100	70
10	5479	120	2000	2600	80
20	5480	95	460	1300	100
50	5481	15	35	120	100
100	5482	95	45	120	140
150	5483	10	85	150	40
200	5484	5	120	120	50
220	5485	35	200	310	100
230	5486	15	350	310	70

Continued

TABLE 9: CONTINUED

Drill Hole and Footage	Departmental Sample No.	Cn ppm	Pb ppm	Zn ppm	Hg ppb
235	5487	95	530	270	70
240	5488	4400	60	140	50
245	5489	1750	20	100	90
300	5491	1600	20	45	90
325	5492	4100	20	55	60
375	5493	1.1%	20	85	70
425	5494	1.6%	35	55	70
445	5495	5300	10	40	80
465	5496	1650	10	30	100
475	5497	890	15	25	100
485	5498	2000	35	45	150

TABLE 10: ASSAY OF KANMANTOO DRILL CORES

Drill Hole and Footage	Departmental Sample No.	Rock Type	Cu ppm	Pb ppm	Zn ppm	Hg ppb
KS 31 - 5	G 5499/72	mica schist	170	30	300	170
25	5500		90	20	260	100
50	5501		35	20	190	50
100	5502		35	290	450	50
300	5503		45	710	2500	60
500	5504		70	75	180	80
700	5505		15	30	310	50
900	5506	andalusite mica schist	45	10	130	100
1000	5507		25	10	160	25
1050	5508	ferruginised zone	4.4%	40	90	55
1100	5509	andalusite quartz mica	100	10	65	30
1200	5510	garnet schist	890	15	70	35
1300	5511	altered mica schist	8700	15	50	55
1375	5512	andalusite mica schist	210	10	95	80
1400	5513		10	15	120	30
1415	5514		240	10	65	50
1425	5515		20	10	90	80
1435	5516		20	10	85	80
1455	5517		30	15	55	80
1475	5518	schist quartzite	470	10	55	130
1500	5519	andalusite mica schist	10	15	110	80
1550	5520		3700	10	85	60
1585	5521		100	15	40	80
1605	5522	chlorite schist	250	15	75	80
1615	5523	andalusite chlorite schist	10	5	60	30
1625	5524		1200	5	65	40
1635	5525		280	5	80	100
1655	5526	schist with kyanite	10	5	85	50
1675	5527	schist	150	10	95	130
1700	5528		110	5	95	160
1800	5529		50	5	80	40
2000	5530	quartz muscovite schist	240	20	140	100
2300	5531	quartz mica amphibole schist	110	15	100	20

Continued

TABLE 10: CONTINUED

Drill Hole and Footage	Departmental Sample No.	Rock Type	Cu ppm	Pb ppm	Zn ppm	Hg ppb
2600	5532	quartz chlorite schist	40	15	150	45
3000	5533	schist	550	10	200	180
KS 86 - 5	5534	mica schist	160	250	510	180
10	5535		80	45	330	100
25	5536	andalusite mica schist	180	15	140	55
80	5537		95	30	250	50
100	5538		55	20	140	50
200	5539		15	15	120	80
300	5540		5	15	150	20
400	5541	andalusite garnet schist	30	5	75	80
500	5542	(sulphides)	35	20	80	35
550	5543		<5	10	30	40
565	5544	(sulphides)	370	15	40	45
575	5545		970	10	35	80
585	5546	(sulphides)	430	5	25	30
600	5547	chalcopyrite rich rock	3.7%	20	220	80
615	5548	garnet mica schist	130	10	25	50
625	5549	quartz garnet mica schist	500	5	25	35
635	5550	schist	280	5	25	30
650	5551		260	5	15	50
670	5552		55	10	15	50
680	5553	schist with visible sulphides	1800	30	20	80
690	5554		9800	20	55	65
700	5555		370	15	45	50
705	5556	schist	110	10	40	80
710	5557		780	10	35	40
730	5558	andalusite mica schist	130	5	20	50
760	5559	quartz mica schist	95	10	25	50
800	5560	quartz mica schist	35	15	45	50
850	5561		25	10	35	200
879	5562		45	15	35	50

TABLE 11: ASSAY OF MUTOOROO CORES

Drill Hole and Footage	Departmental Sample No.	Rock Type	Hg ppb
DDMM6 - 12	G 5567/72	acid gneiss	120
18	5568		130
30	5569		100
50	5570		80
150	5571		100
300	5572		100
550	5573	amphibolite	140
800	5574		70
950	5575	feldspathic amphibolite	50
1050	5576	feldspar ? 'breccia'	30
1065	5577	amphibolite with pyrite	70
1070	5578		80
1075	5579	amphibolite	50
1150	5580	acid gneiss	50
1180	5581	schistose acid gneiss	50
DDMM7 - 30	5582	acid gneiss	50
35	5583		100
39	5584		80
80	5585		100
200	5586		180
400	5587	schistose acid gneiss	80
600	5588	amphibolite	80
850	5589	acid gneiss	50
1100	5590	amphibolite	100
1350	5591		50
1450	5592		90
1500	5593		80
1535	5594	amphibolite with pyrite	290
1540	5595	sulphide rich rocks	160
1550	5596		130
1555	5597		370
1560	5598		310
1580	5599	gneiss	100
1700	5600	amphibolite	180
DDMM 15DI -			
59	G 5601/72	weathered acid gneiss	130
65	5602	muscovite schist	100

Continued

TABLE 11: CONTINUED

Drill Hole and Footage	Departmental Sample No.	Rock Type	Hg ppb
70	5603	schistose micaceous quartzite	50
150	5604	acid gneiss	80
300	5605	tremolite gneiss	110
DDMM26 -			
345	G 5643/72	acid gneiss	70
480	5644	? intermediate gneiss	50
680	5645		20
880	5646		20
1200	5647	amphibolite	20
1500	5648		120
1600	5649		50
1700	5650		30
1750	5651		120
1770	5652	amphibolite, pyrite	50
1780	5653	"amphibolite"	50
1790	5654	amphibolite, mica jarosite	20
1795	5655		50
1800	5656	amphibolite	70
1805	5657	quartzite, chlorite partings	50
1810	5658	quartz, chalcopyrite	55
1812	5659		80
1815	5660	quartz, part oxidised sulphide	30
1830	5661	quartz, marcasite	30
1832	5662	pyrite, chalcopyrite	100
1840	5663	amphibolite	50
1850	5664		20
1900	5665		70
2000	5666	basic gneiss	40

TABLE 12: ASSAY OF BURRA DRILL CORE

Drill Hole and Footage		Departmental Sample No.	Cu ppm	Hg ppb
B54	33	G 5906/72	32	100
	200	5907	22	90
	300	5908	55	110
	400	5909	290	80
	500	5910	2400	310
	600	5911	150	80
	750	5912	100	140

TABLE 13: ASSAYS OF MOONTA CORE, DDH14

Footage	Departmental Sample No	Rock Type	Sulphides*	Hg ppb
21'5"	G6160/72	Weathered porphyry	-	205
74'	6161	Porphyry	-	245
126'	6162	Porphyry	-	355
178'	6163	Weathered acid porphyry	-	220
230'	6164	Sheared? acid porphyry	x	210
282'	6165	Sheared amphibole-feldspar rock	x	245
334'	6166	Acid porphyry with sulphides	x	210
386'	6167	Volcanic rock?	x	260
438'	6168	Actinolite (black) schist	x	200
490'	6169	Actinolite schist	-	150
542'	6170	Pyritic actinolite schist	x	220
594'	6171	Biotite-amphibole schist	-	230
646'	6172	Actinolite schist	x	290
698'	6173	Actinolite schist	x	215
750'	6174	Magnetite rock	x	310
802'	6175	Amphibolite (diorite) with pyrite	x	160
854'	6176	Amphibolite	x	225
906'	6177	Amphibolite with calcite	-	115
958'	6178	Mica-amphibolite	x	190
1010'	6179	Schistose amphibolite	x	150
1062'	6180	Quartz-amphibole-mica rock	x	200
1114'	6181	Sheared amphibolite	x	110
1166'	6182	Sheared amphibolite	x	110
1218'	6183	Amphibolite	-	105
1270'	6184	Schistose amphibolite	-	250
1322'	6185	Actinolite schist	-	150
1374'	6186	Sulphide-bearing porphyry	x	200
1426'	6187	Amphibolite	-	150
1478'	6188	Amphibolite	-	110
1530'	6189	Amphibolite	x	100
1582'	6190	Magnetite rock	x	90

* x indicates sulphides visible in hand specimen

continued

TABLE 13: CONTINUED

Footage	Departmental Sample No	Rock Type	Sulphides*	Hg ppb
1634'	6191/72	Schistose amphibolite	-	155
1686'	6192	Schistose amphibolite	-	110
1738'	6193	Schistose amphibolite	x	120
1790'	6194	Gneissic amphibolite	-	190
1894'	6195	Schistose biotite ?diorite	-	200
1946'	6196	'Diorite'	-	220
1998'	6197	Amphibolite	-	240
2050'	6198	Sheared amphibolite	-	150
2102'	6199	Amphibolite	x	200
2154'	6200	Sheared acid volcanic rock	-	300
2206'	6201	Amphibolite	-	165
2258'	6202	Diorite-amphibolite	-	215
2310'	6203	Schistose amphibolite	-	170
2362'	6204	Mica-diorite	-	380
2414'	6205	Foliated ?diorite/granodiorite	-	330

* x indicates sulphides visible in hand specimen

TABLE 14A: PARABARANA CORRELATION COEFFICIENTS (All Samples)

Correlation	Depth	Cu	Pb	Zn	Hg
Depth	1.000/57	0.060/57	-0.574/57	-0.549/57	-0.106/57
Cu	0.060/57	1.000/57	0.035/57	-0.008/57	0.039/57
Pb	-0.574/57	0.035/57	1.000/57	0.767/57	0.089/57
Zn	-0.549/57	-0.008/57	0.767/57	1.000/57	-0.094/57
Hg	-0.106/57	0.039/57	0.089/57	-0.094/57	1.000/57

TABLE 14B: PARABARANA CORRELATION COEFFICIENTS OF SAMPLES WITH LESS THAN 500 PPM COPPER

Correlation	Depth	Cu	Pb	Zn	Hg
Depth	1.000/42	0.006/42	-0.582/42	-0.569/42	-0.071/42
Cu	0.006/42	1.000/42	0.156/42	0.309/42	0.317/42
Pb	-0.582/42	0.156/42	1.000/42	0.804/42	0.082/42
Zn	-0.569/42	0.309/42	0.804/42	1.000/42	0.047/42
Hg	-0.071/42	0.317/42	0.082/42	-0.047/42	1.000/42

TABLE 15A: KANMANTOO CORES KS31, KS86 CORRELATION COEFFICIENTS, (All Samples)

Correlation	Depth	Cu	Pb	Zn	Hg
Depth	1.000/64	0.088/64	-0.505/64	-0.444/64	-0.211/64
Cu	0.088/64	1.000/64	0.003/64	-0.162/64	0.114/64
Pb	-0.505/64	0.003/64	1.000/64	0.705/64	0.189/64
Zn	-0.444/64	-0.162/64	0.705/64	1.000/64	0.259/64
Hg	-0.211/64	0.114/64	0.189/64	0.259/64	1.000/64

TABLE 15B: KANMANTOO CORES KS31, CORRELATION COEFFICIENTS (All Samples)

Correlation	Depth	Cu	Pb	Zn	Hg
Depth	1.000/35	0.099/35	-0.469/35	-0.545/35	-0.194/35
Cu	0.099/35	1.000/35	-0.026/35	-0.262/35	0.166/35
Pb	-0.469/35	-0.026/35	1.000/35	0.785/35	0.013/35
Zn	-0.545/35	-0.262/35	0.785/35	1.000/35	0.075/35
Hg	-0.194/35	0.166/35	0.013/35	0.075/35	1.000/35

TABLE 15C: KANMANTOO HOLE KS31 CORRELATION COEFFICIENTS FOR NON-MINERALISED SAMPLES (750 ppm Cu or less)

Correlation	Depth	Cu	Pb	Zn	Hg
Depth	1.000/30	0.017/30	-0.472/30	-0.538/30	-0.174/30
Cu	0.017/30	1.000/30	-0.080/30	-0.121/30	0.528/30
Pb	-0.472/30	-0.080/30	1.000/30	0.823/30	-0.028/30
Zn	-0.538/30	-0.121/30	0.823/30	1.000/30	0.025/30
Hg	-0.174/30	0.528/30	-0.028/30	0.025/30	1.000/30

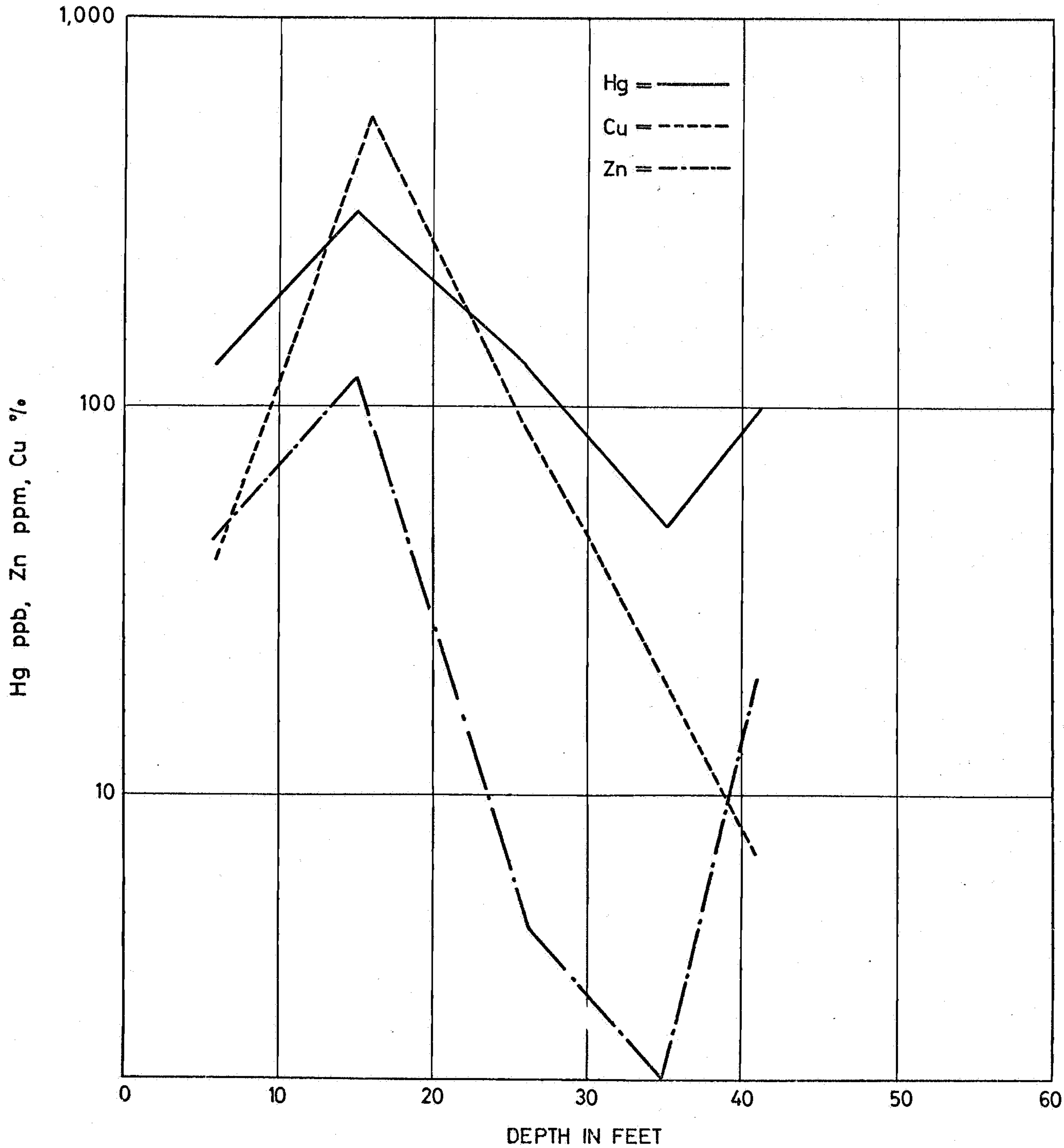


FIG. 1: DOWN-HOLE PROFILE K6 KAPUNDA

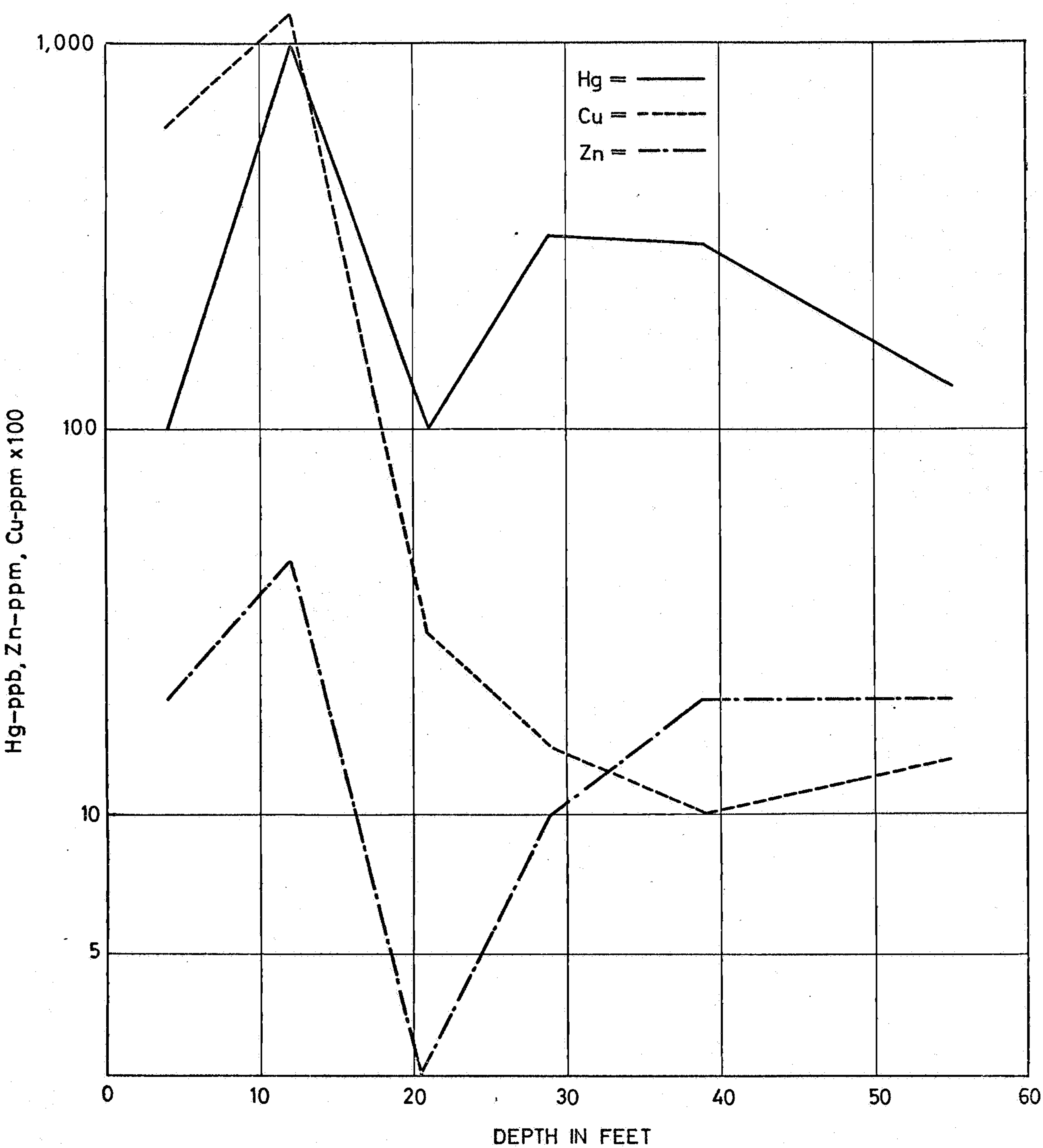


FIG. 2: DOWN-HOLE PROFILE K10 KAPUNDA

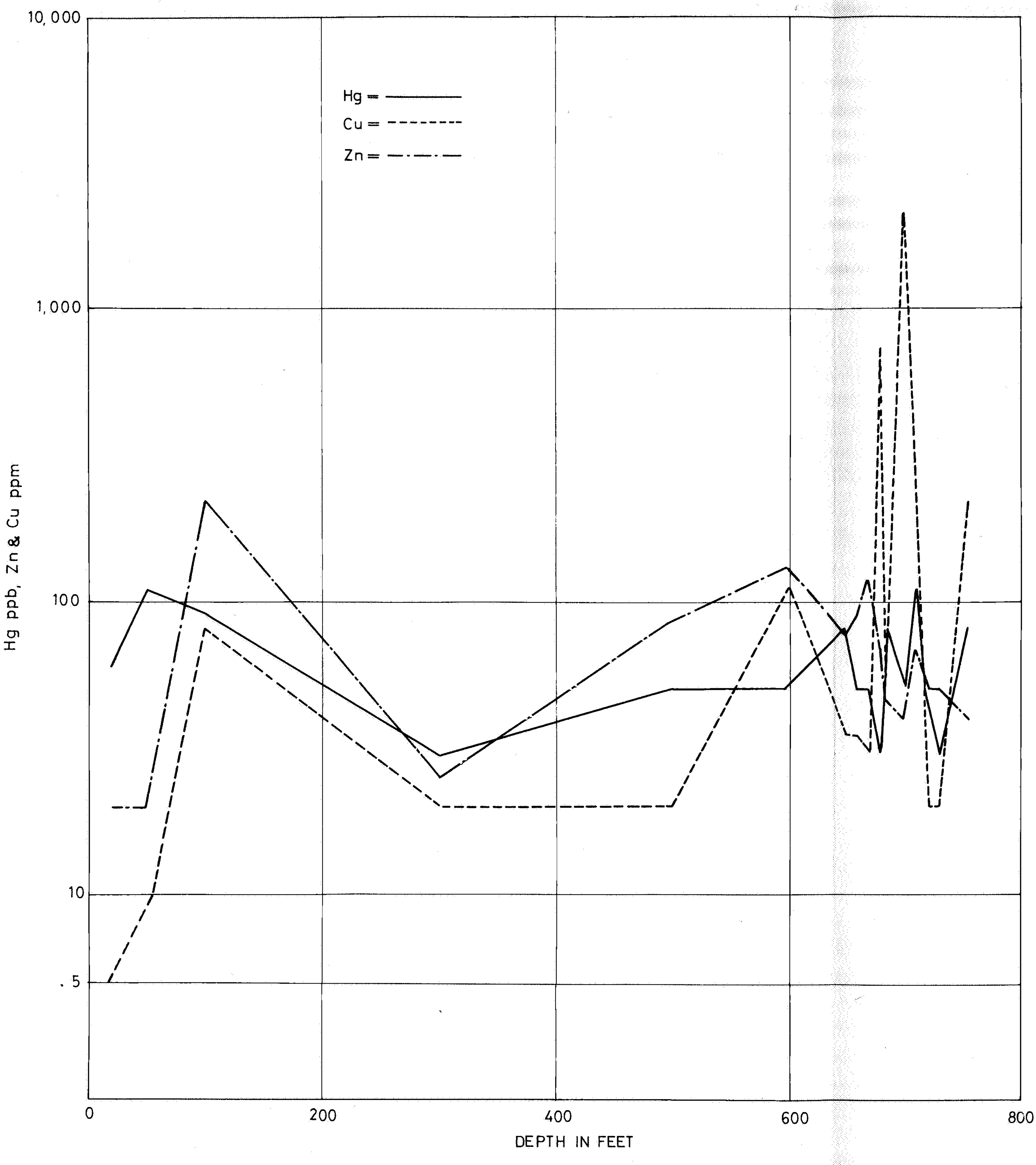


FIG. 3: DOWN-HOLE PROFILE OF PDD 2 PARABARANA

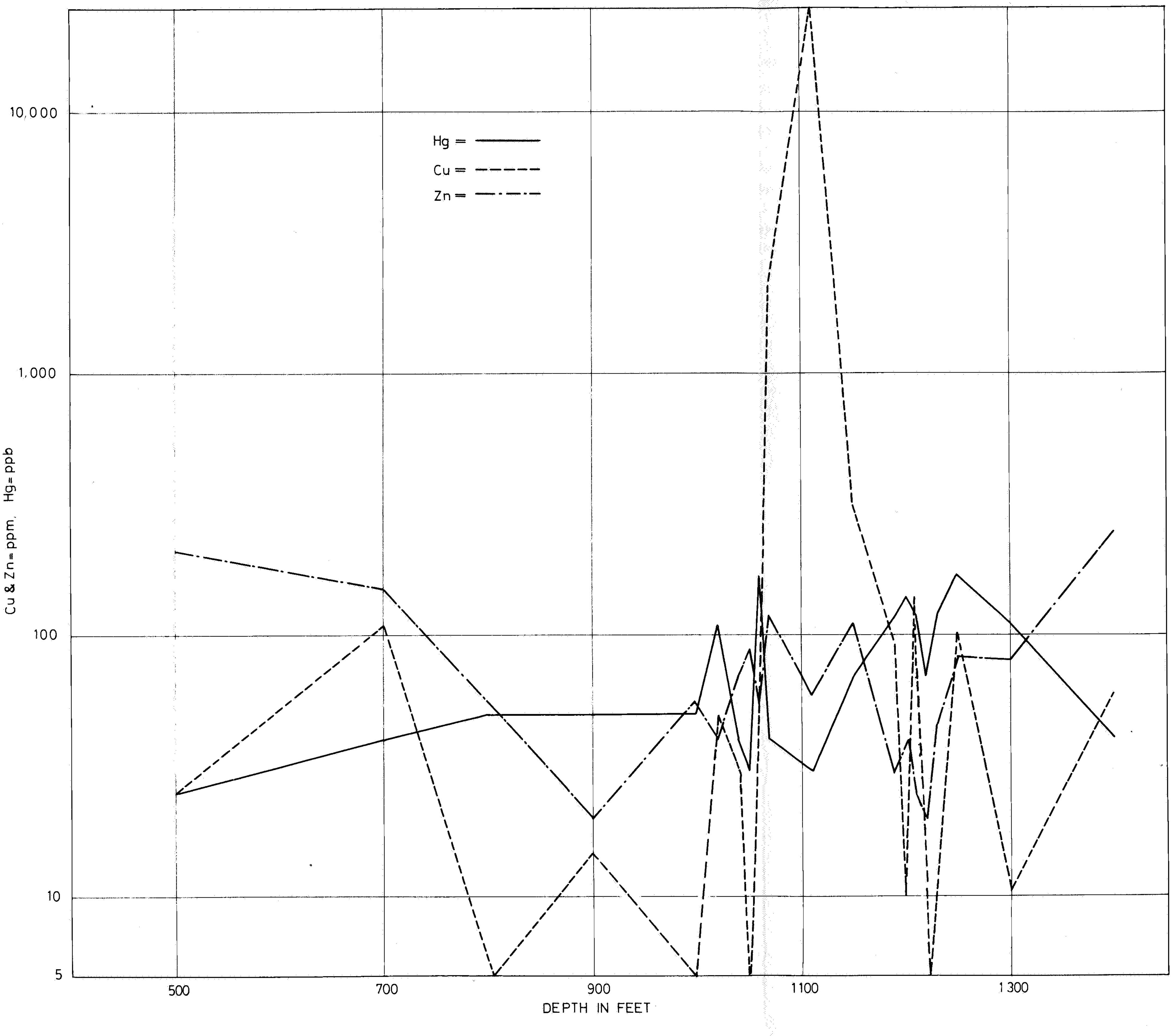


FIG. 4 : DOWN-HOLE PROFILE OF PDD3 PARABARANA

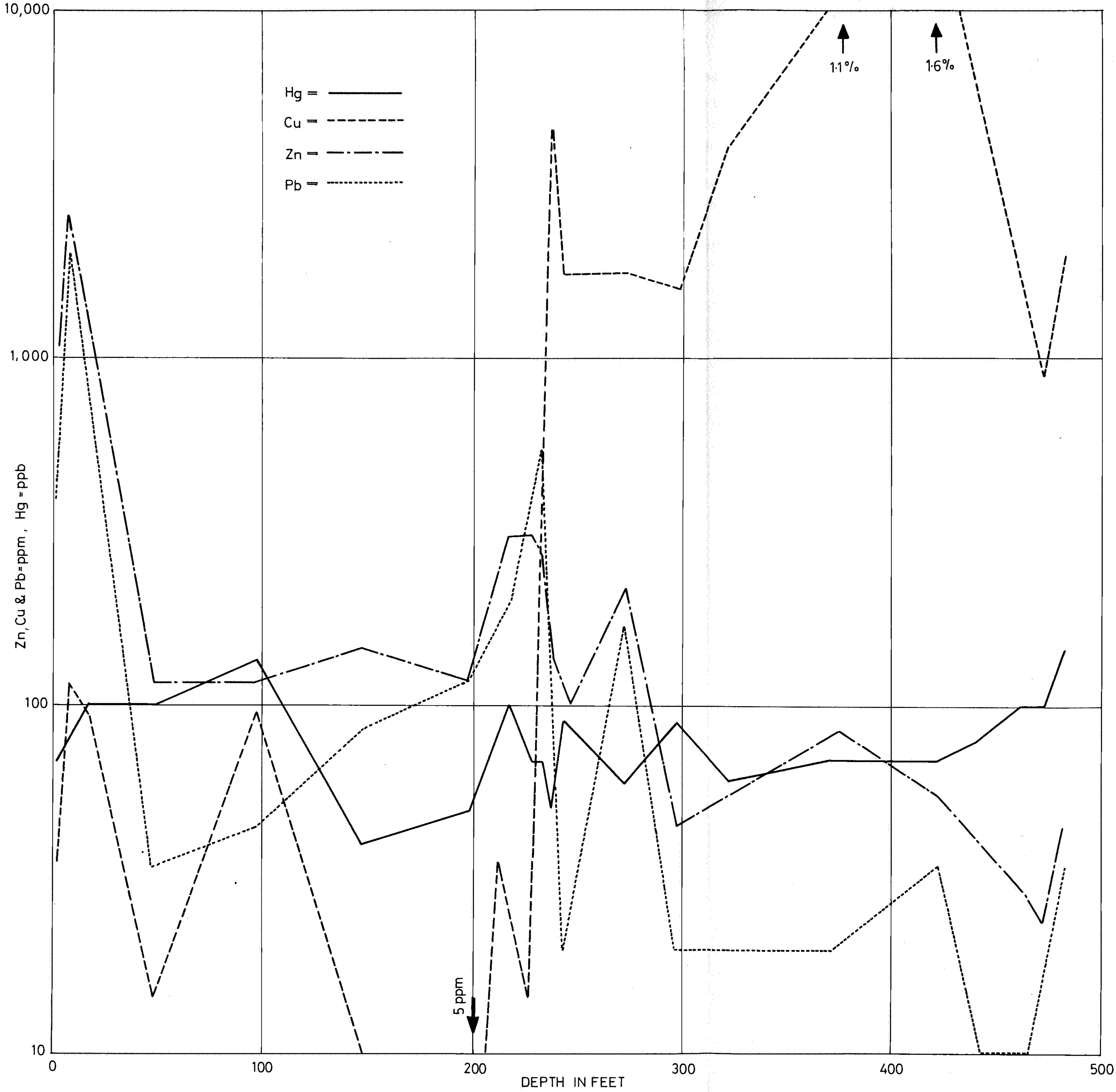
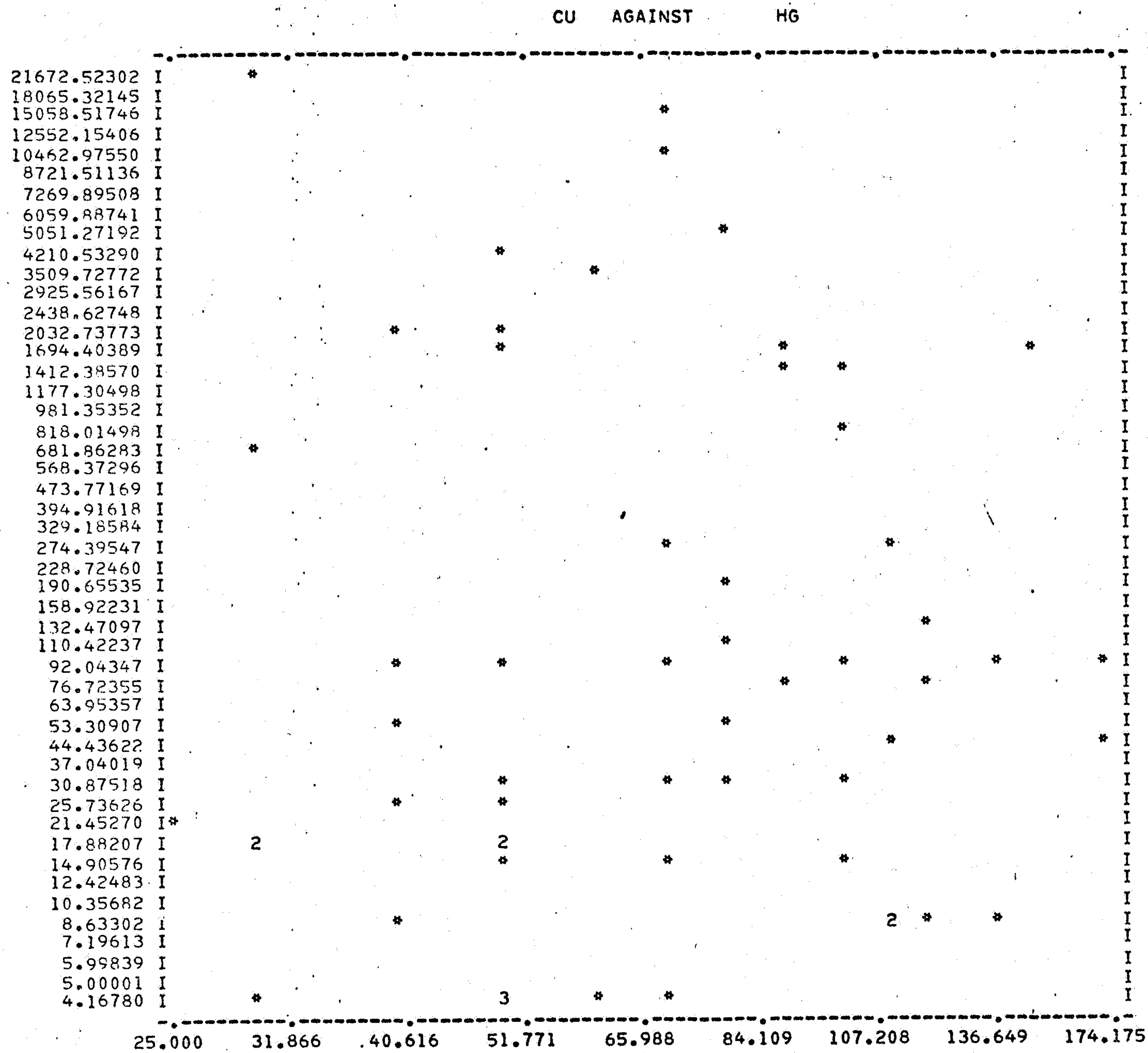


FIG. 5: DOWN HOLE-PROFILE OF NDP 22 PARABARANA



FSTATS FIG. 6: PARABARANA. SCATTER PLOT OF Cu VERSUS Hg (ALL SAMPLES)

P

RG.7274/D.

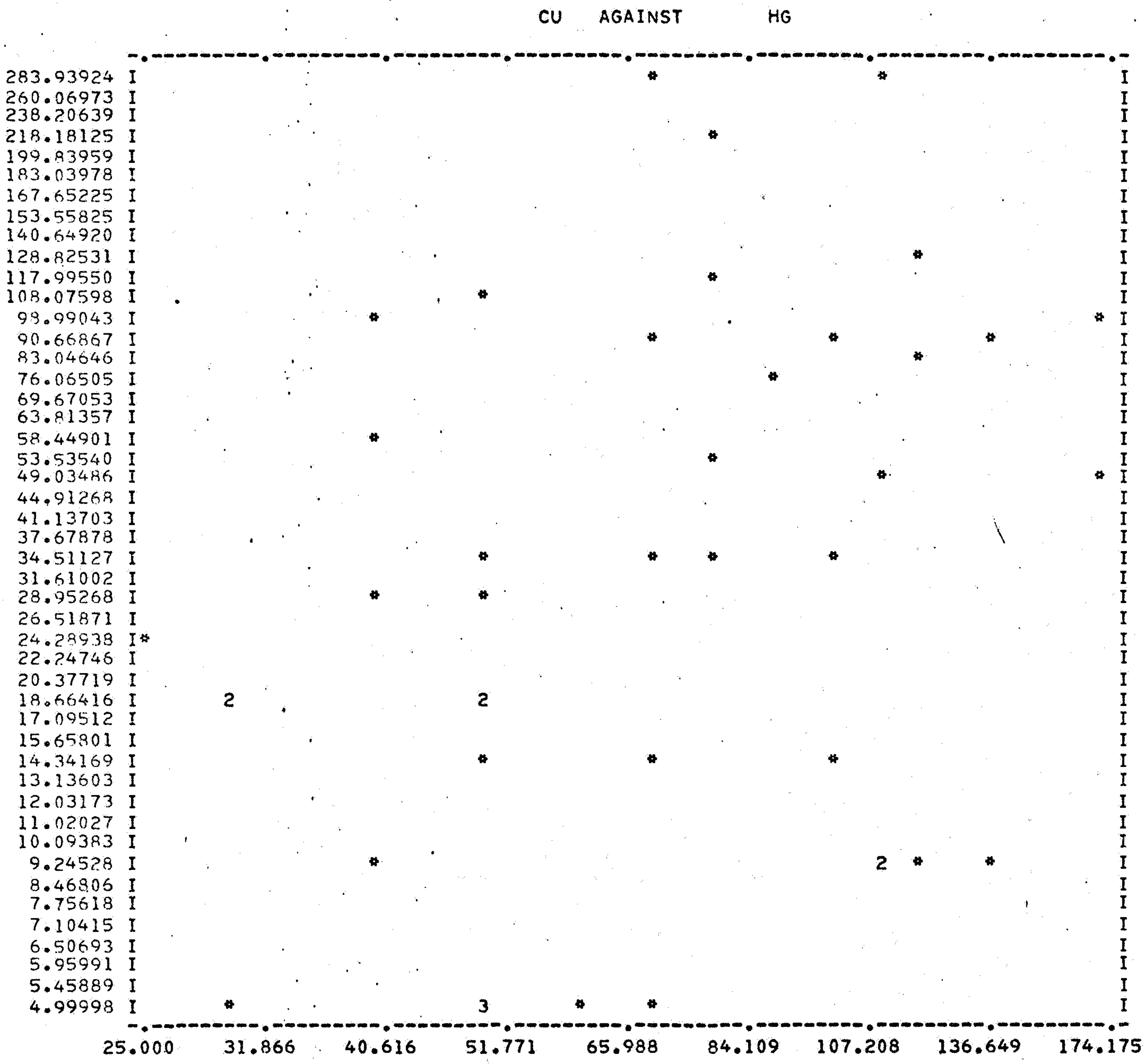


FIG. 7: PARABARANA. SCATTER PLOT OF Cu VERSUS Hg.
SAMPLES WITH COPPER VALUES BELOW 500 ppm

R6.7275/D

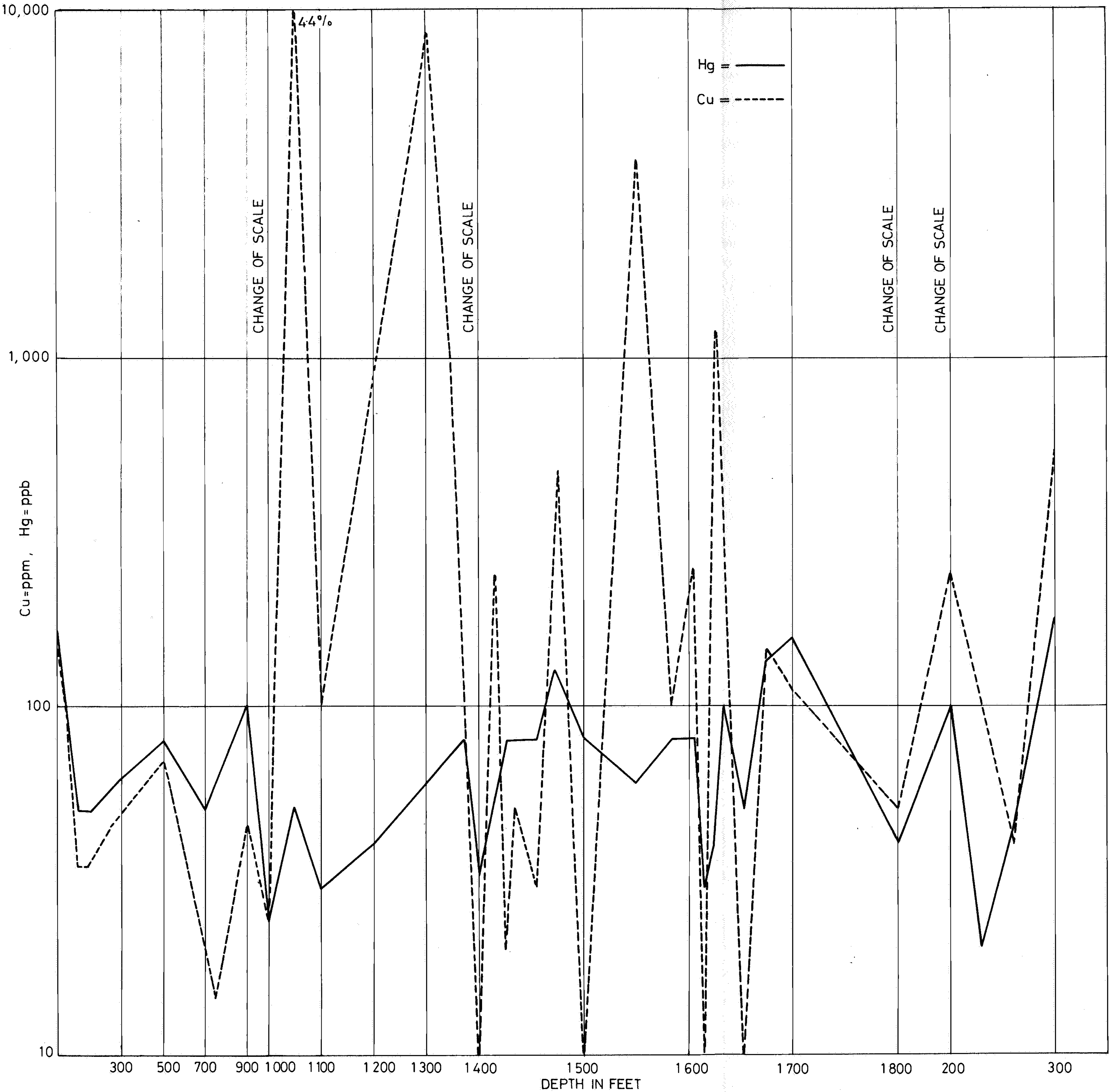


FIG. 8 : DOWN-HOLE PROFILE OF KS 31 KANMANTOO

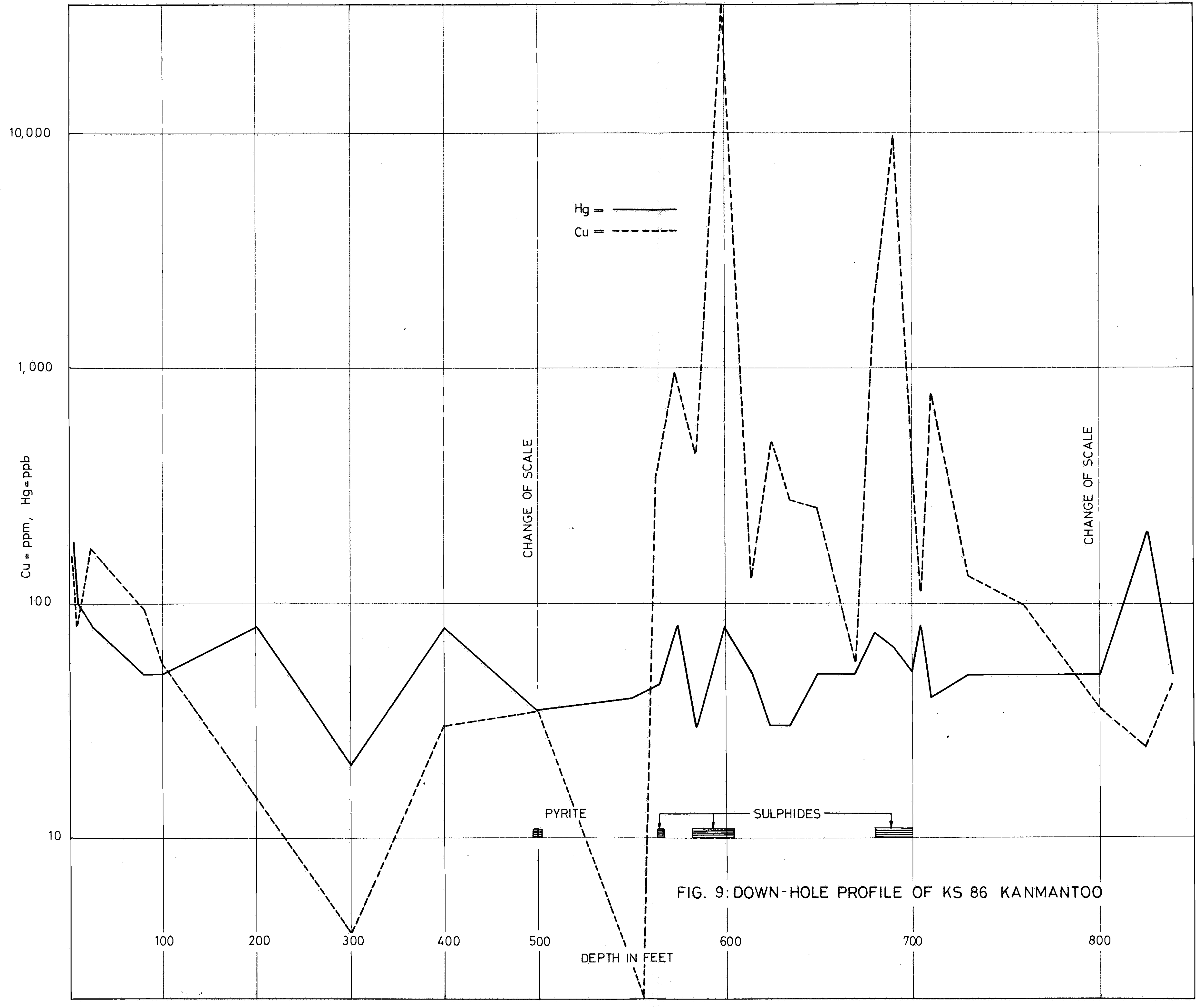


FIG. 9: DOWN-HOLE PROFILE OF KS 86 KANMANTOO

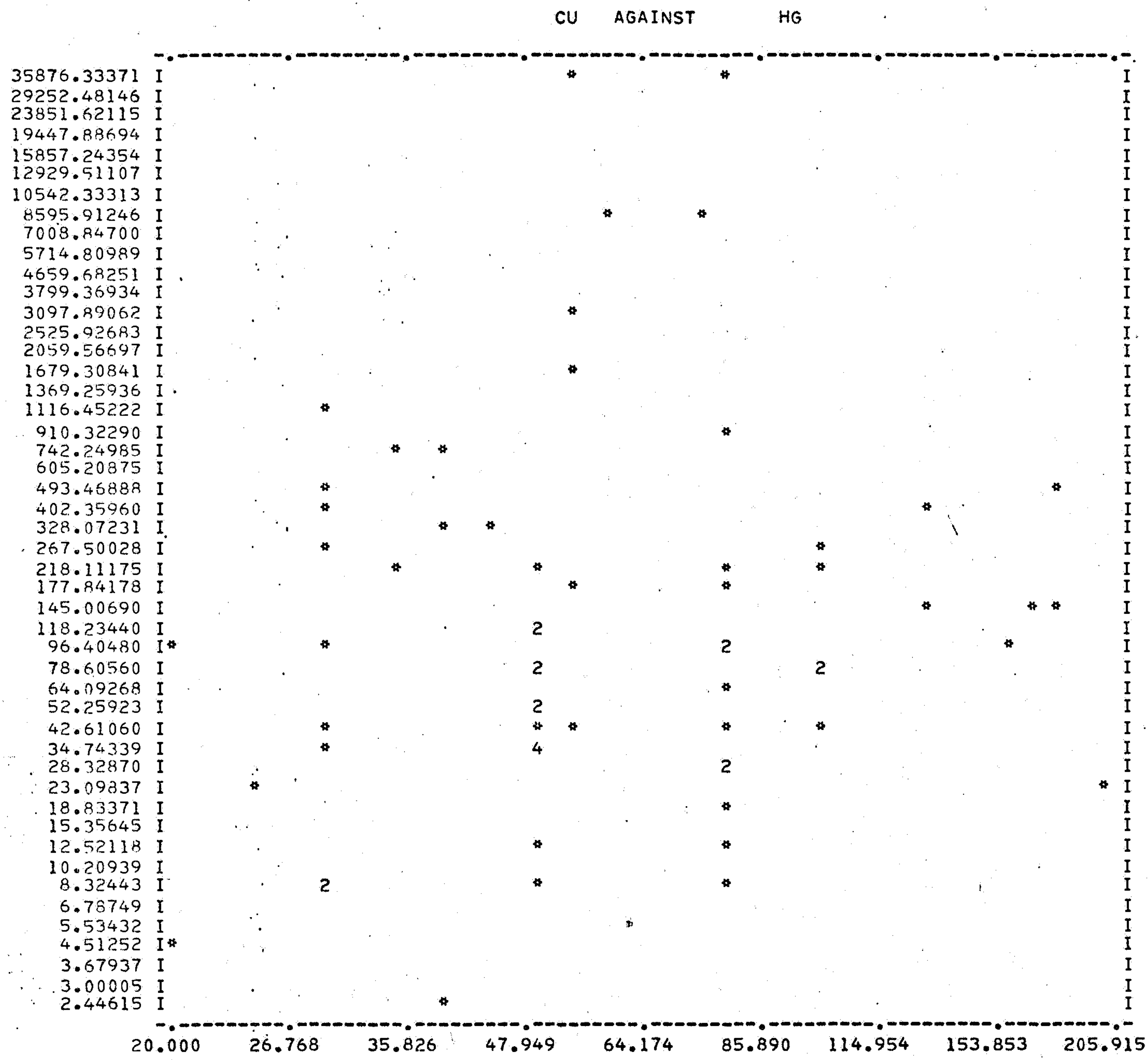


FIG.10: KANMANTOO CORES KS 31, 86 SCATTER PLOT (ALL SAMPLES)

RG 7278/D

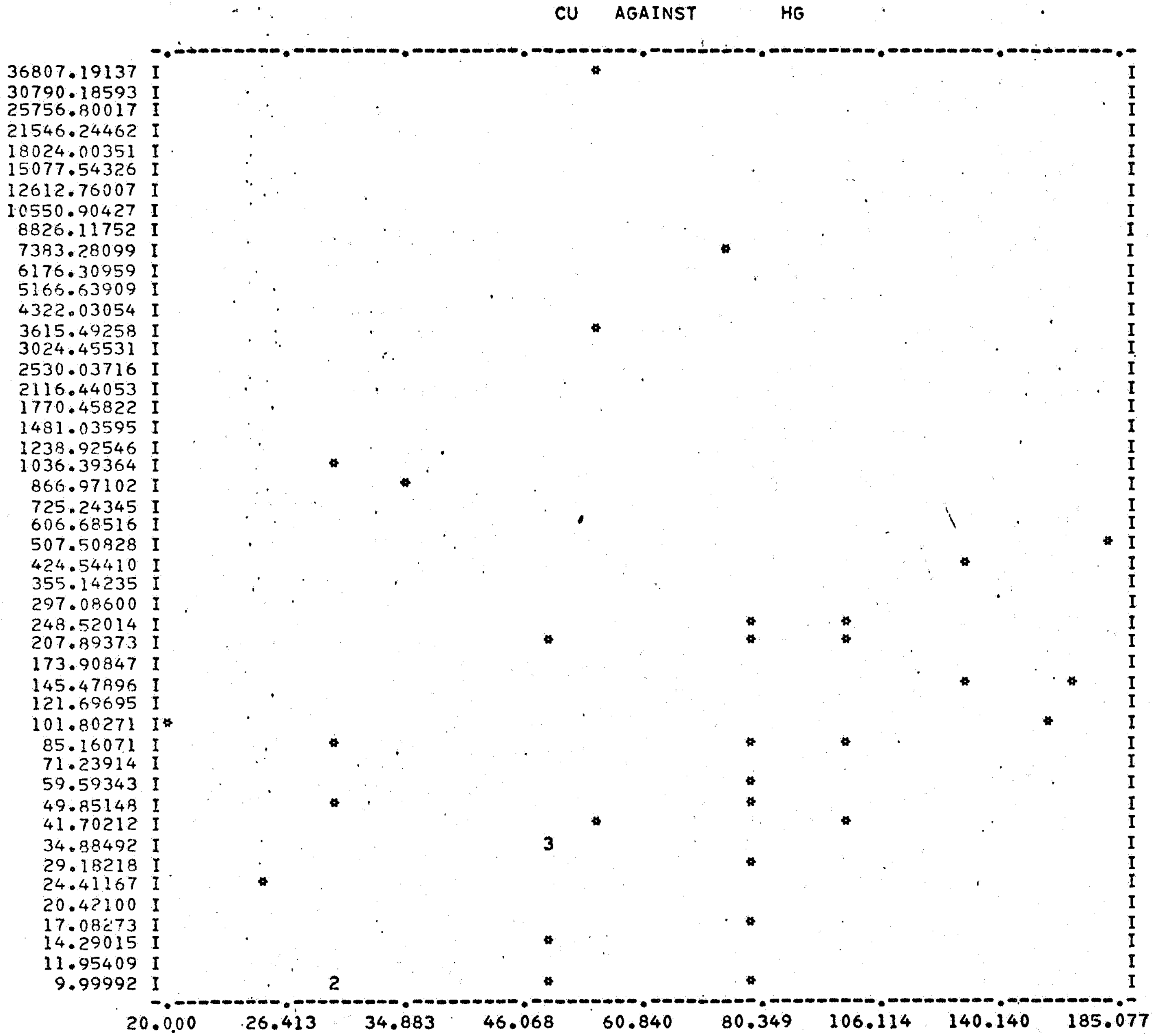


FIG.11: KANMANTOO, CORE: KS 31. SCATTER PLOT (ALL SAMPLES)

RG.72.79/D. P

FSTATS

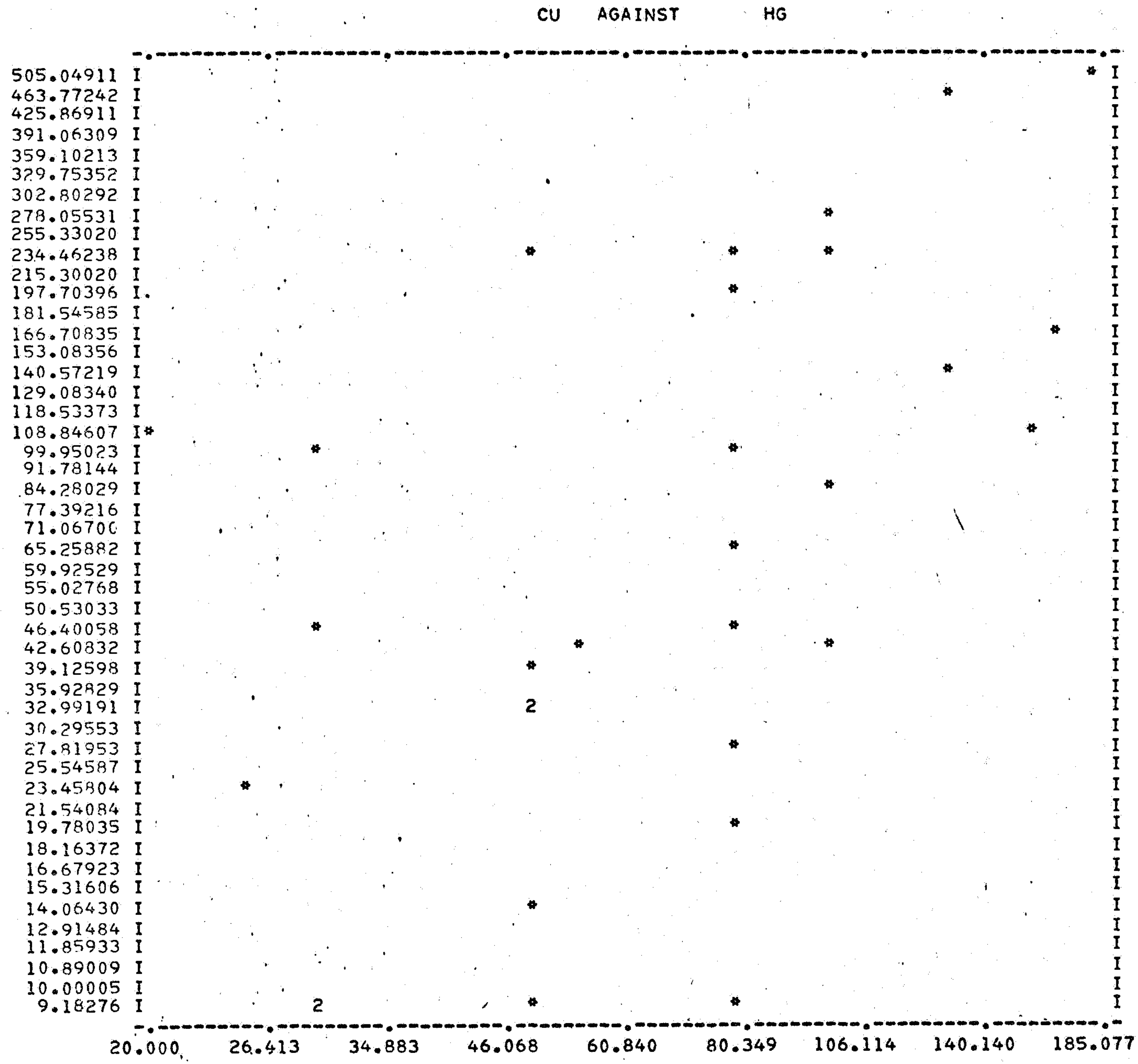


FIG. 12: KANMANTOO KS 31. SCATTER PLOT FOR NON-MINERALISED SAMPLES (750 ppm Cu or less)

RG.7280/D

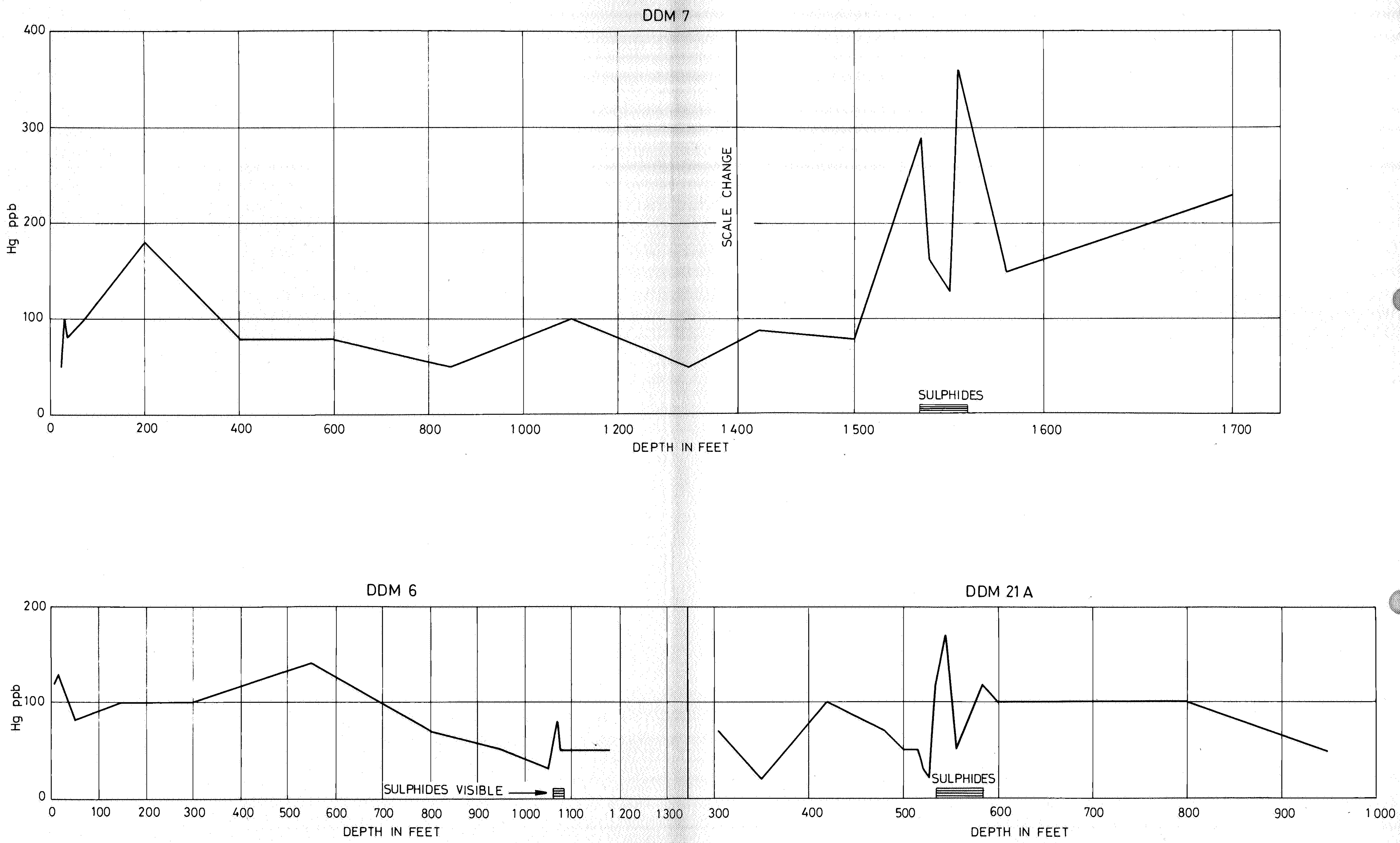


FIG. 13 : DOWN-HOLE PROFILES MUTOOROO

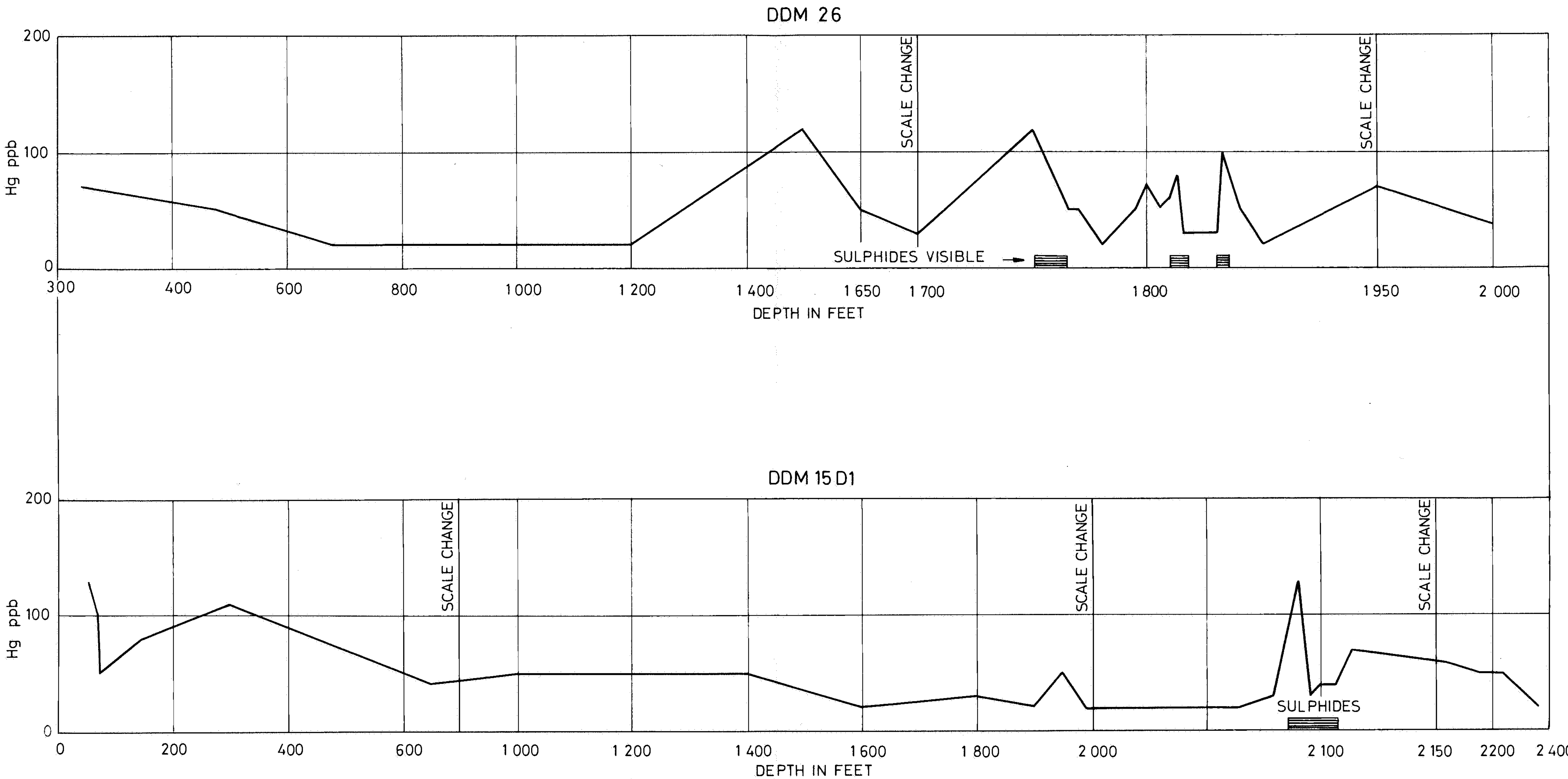


FIG. 14: DOWN-HOLE PROFILES MUTOOROO

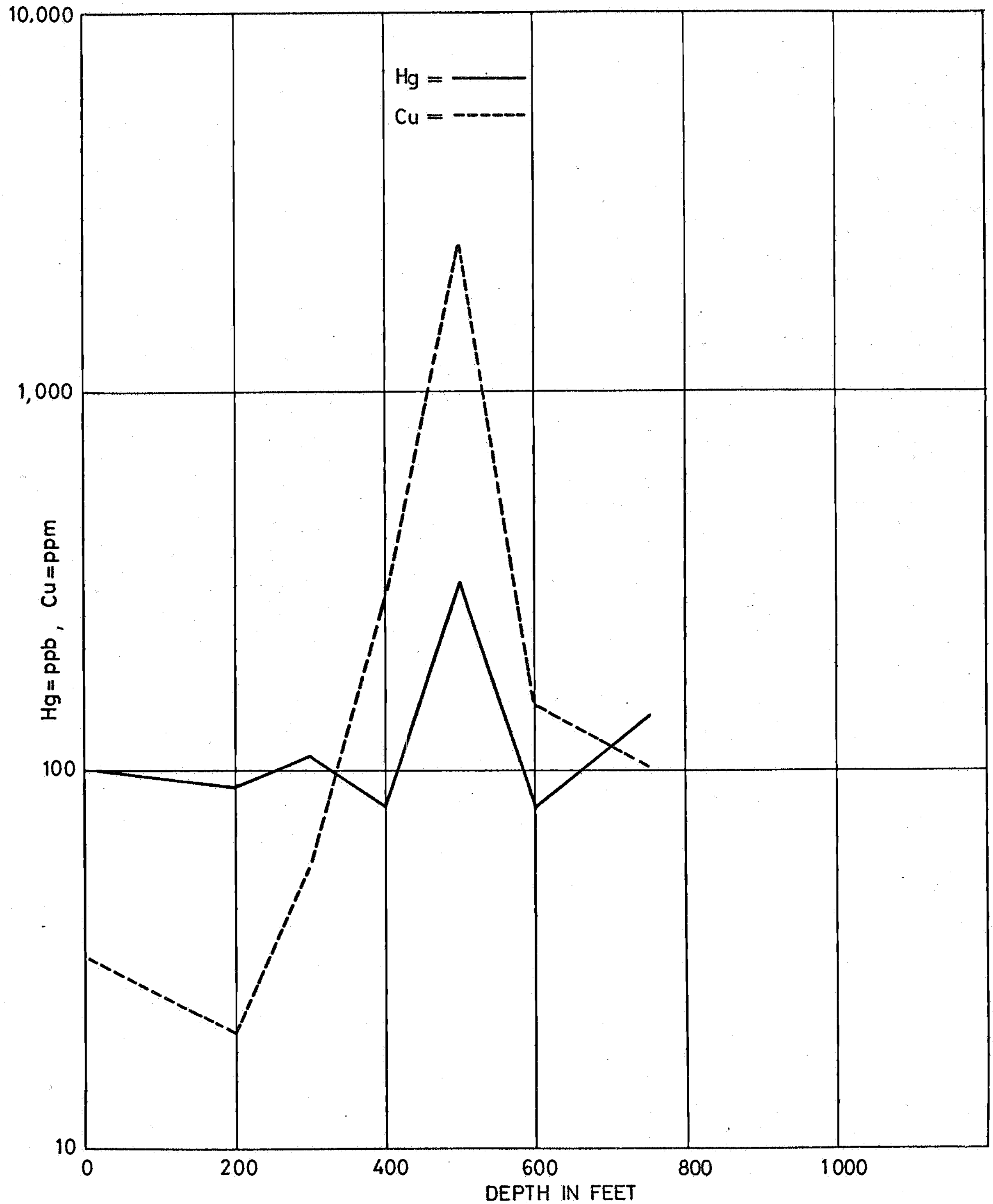


FIG. 15 : DOWN-HOLE PROFILE BURRA BS 4

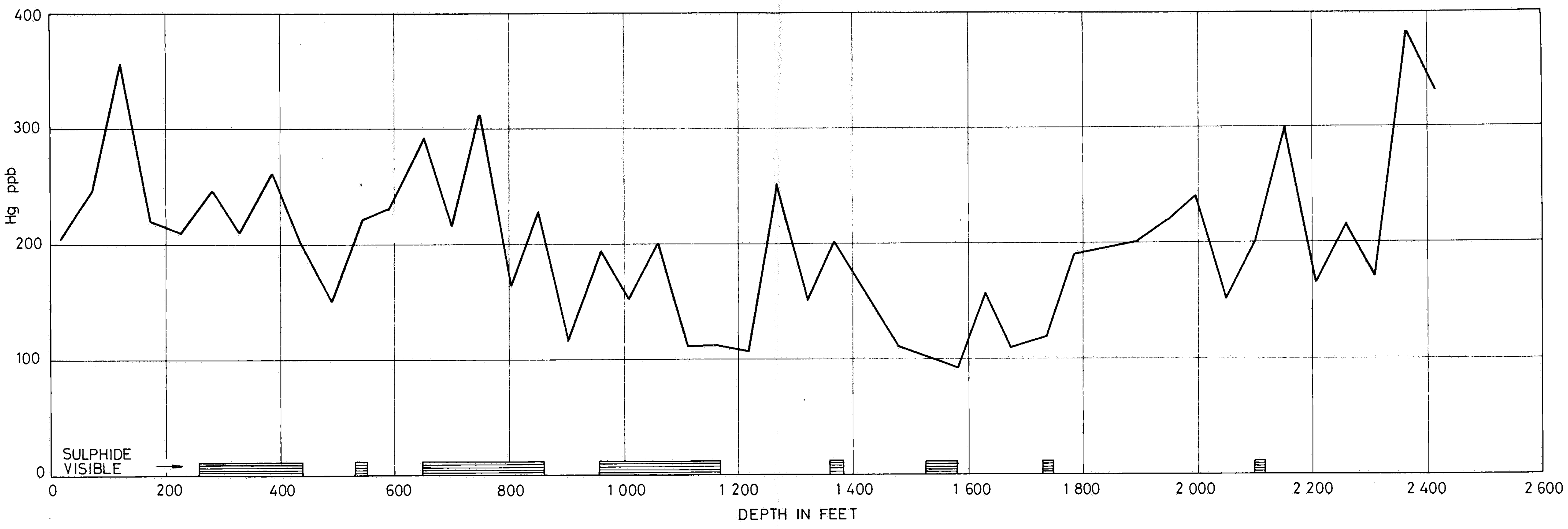


FIG. 16: DOWN - HOLE PROFILE DDH 14 MOONTA