ANALYSIS OF MOBILE MERCURY- -A NEW TECHNIQUE IN PROSPECTING for BLIND or BURIED ORE BODIES

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THE COVER OF THE REPORT ILLUSTRATES AN APPLICATION OF THE ANALYSIS OF MOBILE MERCURY FOR THE DETECTION OF BLIND GOLD MINERAL DEPOSITS (OVER 2000 SAMPLES WERE COLLECTED). THE DEPOSIT ON THE COVER IS A LOW TEMPERATURE CARLIN-TYPE DEPOSIT AT 500 FEET.

THE LARGE SURFACE HALO WAS DEVELOPED BY PRIMARY MINERALIZATION. THE NORTH-SOUTH ANOMALOUS MERCURY TRENDS REFLECT THE REMOBILIZATION PROCESS.

Mercury Forms In Mineralized Environments
Exploration Applications

by

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ABSTRACT

Mercury has been recognized to be an indicator element for many polymetallic hydrothermal ore deposits. Previous investigators have used mobile and total mercury analysis indiscriminately, resulting in mixed results. A close examination of the various forms of mercury containing compounds reveals distinct relationships between the occurrence of these compounds and the mineral zonation associated with the ore forming process, including the development of both primary and secondary halos.

A new extraction and analysis technique has been developed which employs differential thermal analysis (DTA) for the characterization of these various mercury forms. This DTA technique yields superior results as compared to the conventional analysis of making a total mercury measurement which combines all the mercury liberated from its different compounds. The superior performance of the DTA method also allows one to determine the most diagnostic low temperature forms of mercury which have the highest potential as a pathfinder for buried ore deposits.

The retention of mercury vapor by surface clays and organic matter has been clearly demonstrated to concentrate the mercury which best defines these blind ore bodies. A unique variation of this new DTA method has been developed for extraction and analysis of this mobile mercury which is rapid, highly reproducible, and very cost-effective.

Brief case studies of the application of this DTA exploration technology are presented.

INTRODUCTION

The use of mercury as a pathfinder for buried metallic ore bodies was first proposed by Saukov in 1946. His initial concept was based on mercury's high volatility, supported by studies which showed that the mercury content in metallic ore bodies is almost always higher than in their associated gangue rocks. During the formation of ore bodies, the highly volatile mercury (aided by temperature gradients) would develop primary aureoles, while in later stages the mercury liberated by supergene processes would generate secondary halos in the host rocks.

Saukov (1946) proposed the analysis of mercury vapor in soil-gas as an exploration method for buried or blind ore bodies. Since this pioneering work of Saukov, applications of mercury as a pathfinder for ore bodies has received numerous trials (see general reference list). However, it was found that the content of mercury vapor in the soil-gas is strongly affected by climatic and atmospheric factors which frequently produced unreliable data.

As an alternative, the analysis of total mercury content in soils and rocks was postulated as a way to generate stable and reliable results. This method of analysis, although stable and reproducible, results in very mixed reviews. The major problem with the analysis of total mercury content is the low anomaly/background ratio, which often results in very poor resolving power when exploring for buried ore bodies.

The difficulty in applying mercury as a pathfinder, lies in an oversimplification in the understanding of the various modes of occurrence of mercury containing minerals, and in the differentiation of these mercury forms in the natural environment. Volatile, temperature dependent, and more soluble mercury forms are capable of traveling the greatest distances from the ore zone and so form the best exploration pathfinders for buried deposits. Many higher temperature forms occur in and very near the ore zone which are very useful in predicting proximity to the ore forming processes. In fact, by examining the mercury over a wide temperature range, which includes high temperature forms, it is possible to vector the direction of an ore body from a set of borehole samples. Analysis of the different mercury forms also allows recognition of the ore zone, and differentiation between the primary and secondary halos.

Failure to recognize the importance of these various mercury forms is compounded by mercury analysis techniques, which use high temperature retorting (up to 600°C) to release the mercury from the solid phase. This type of total mercury analysis mixes these low and high temperature compounds during analysis and destroys the information conveyed by the presence of each of these individual mercury compounds. The purpose of this paper is to outline these various mercury forms and to explain their usefulness in solving exploration problems.

In order to use these concepts, new differential thermal analysis techniques have been developed which allow accurate and repeatable measurements of each of these mercury forms. These techniques are rapid, highly reproducible and cost-effective.

Extensive case studies have demonstrated the relationships of the individual mercury compounds to known mineralization, and will be the subject of future publications. Brief case study examples are included in this paper for the purpose of illustrating this newly developed technology.

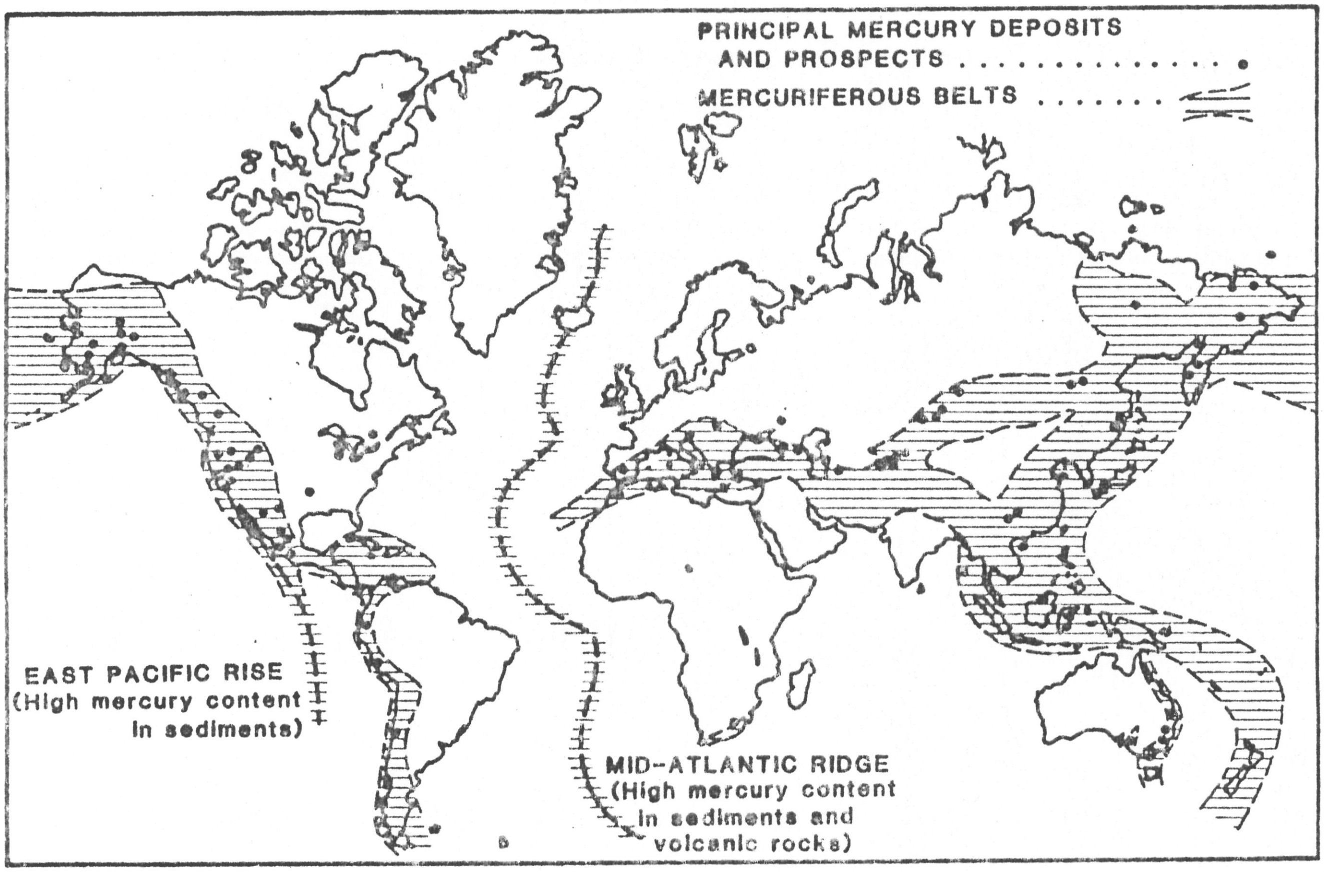
I. MERCURY IN THE NATURAL ENVIRONMENT

The use of mercury as an indicator for polymetallic hydrothermal deposits was first proposed by Saukov in 1946 and has since been the subject of numerous papers with a wide variety of conclusions (see general reference list). Some of the most important observations which bear directly on the proper understanding of the use of mercury as a pathfinder of buried deposits are summarized below, Jonasson and Boyle (1972), Moiseyev (1971), Gumenuk et al. (1973), Fursov (1977).

I.1 Regional Distribution of Mercury Deposits

The mercuriferous belts of the earth, in which most of the mercury deposits and prospects are located, are presented in a generalized map (Figure 1). These belts correspond to zones of instability or dislocation of the earth and are often marked by the presence of hot springs and other volcanic and thermal activity. A number of mercury occurrences are located outside the "belts", but all have one point in common, they are located in zones marked by deep faulting. This association suggests that the mercury source is the mantle where high temperatures cause expellation of mercury because of its appreciable vapor pressure (at 600°C, mercury vapor pressure is 22 atm). This aides the migration of mercury towards the lower temperature region at the surface. However zones containing mercury deposits are also always characterized by thick piles of sediments. In areas with oceanic volcanism, which lack these thick piles of sediments, the mercury deposits are absent suggesting that the mantle is not the main source of mercury. In contrast, mercury is generated and remobilized from sediments by deep heat sources.

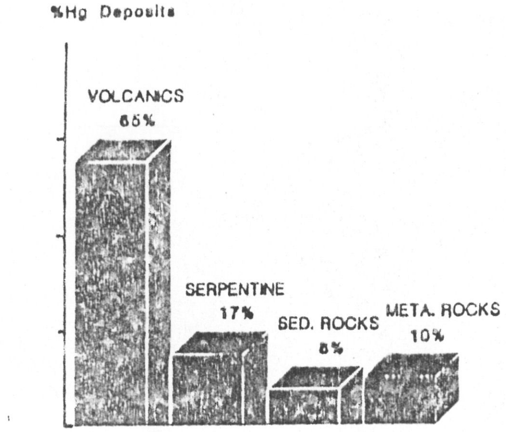
The distribution of mercury as a function of enclosing rocks is shown on Figure 2a. This figure illustrates the strong correlation between mercury deposits and volcanic rocks. From Figure 2b it is apparent that mercury shows no predilection for a particular volcanic rock type, a fact which suggests that mercury distribution is more dependent on heat sources, than on the chemical properties of individual magmas. Similar conclusions were obtained by Fursov (1977) who noted that "rocks having different origins, compositions, and ages differ very little with one another in mercury content (Figure 2D). Gumenuk (1973) observed that identical rocks in different areas have very different mercury contents (the means differing by factors of 6-20), whereas rocks differing in origin, age, and composition but spatially close together, are often similar in mercury content."



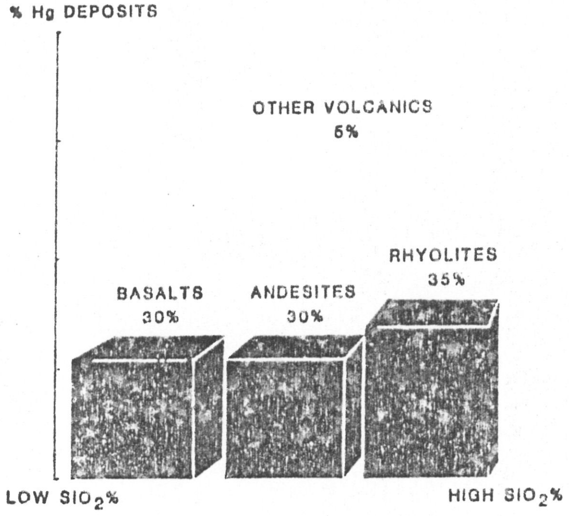
-GENERALIZED MAP SHOWING THE MERCURIFEROUS BELTS OF THE EARTH

(from Jonasson and Boyle, 1972)

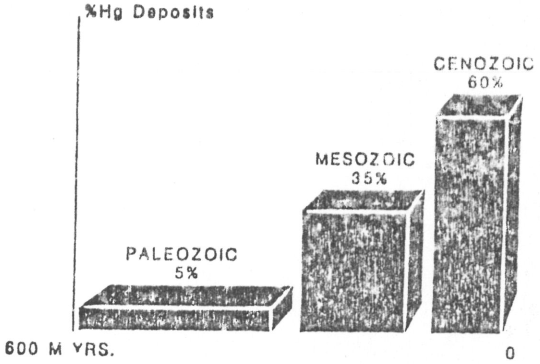
FIG.1



a Distribution according to wall rock types. No deep seated igneous rocks are found near mercury deposits. Deposits within sediments but near volcanic rocks are included with the volcanic group, and those without visible connection with volcanism are shown separately (Moiseyev, 1971).

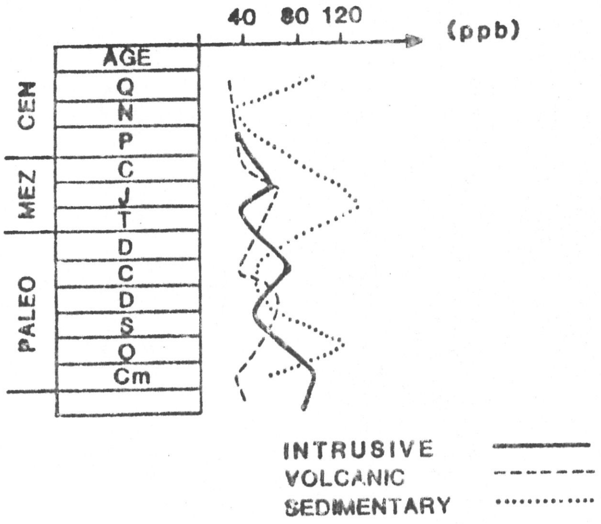


b Distribution according to the composition of igneous rocks found in the vicinity of mercury ore deposits. The rocks which represent the remaining 5% are alkaline rhyolites, trachytes, phonolites, etc. (Moiseyev, 1971).



c Distribution of mercury deposits according to age of formation (Moiseyev, 1971).

FIG.2



(Fursov - 77)

AVERAGE Hg CONTENT IN ROCKS

FIG.2D

The apparent age dependence of mercury deposits (Figure 2C) implies that because of its own high volatility, mercury was mobilized through geologic time by internal processes. Thus it can be concluded that heat and mercury's own high mobility are the two most important factors in mobilization and deposition of mercury. The various forms in which mercury in rocks exists are important for understanding and liberating this mercury from the enclosing rocks. Using different temperature ranges during analysis as shown below allows some distinction:

Temp. of Liberation	Mercury Forms
30°-300°	free, adsorbed, organically bonded
130°-600°	compounds
400°-900°	in crystal lattice of minerals

Assuming a normal geothermal gradient of 33°C/km, at 3 km depth, the subsurface temperature is about 100°C and only 10-20% of mercury can be liberated from rocks by this temperature. When a shallow magma reservoir is introduced, the thermal gradient can drive mercury towards the surface. Mercury is supplied from two possible sources, deep-magmatic and shallow-remobilized from sedimentary rocks by heat. If the magma was emplaced in homogeneous rocks, mobile mercury would be deposited as a shell in an outer zone where temperature changes are insignificant.

Erosion often removes the uppermost part of the system producing the well known "halo" or negative mercury anomaly. Obviously this erosional anomaly requires that the mercury surveyor be very concerned with the geology of the area. In addition, some regional control must be established by collecting samples over a large area in order to properly recognize such a halo-type anomaly. In shallow parts of the Earth's crust, where porosity is high, mercury is remobilized from rocks and carried with mineralized solutions to depositional sites.

Thus, the ideas presented above can be summarized as follows:

-- the distribution of mercury in the geologic environment shows a strong dependence on heat sources,

-- the distribution of mercury does not indicate any preferences for a particular rock type,

-- mercury may be introduced into the environment from deep sources through the emplacement of magmas, or be remobilized from sediments by heat introduced from magmas,

-- the total mercury content in nonmineralized soils and rocks is rather uniform and fairly high, typically the total mercury content averages from 40-200 ppb, and

- -- the mercury content in endogene ore bodies is almost always higher than the enclosing country rocks.

II. MERCURY IN MINERALIZED ENVIRONMENT

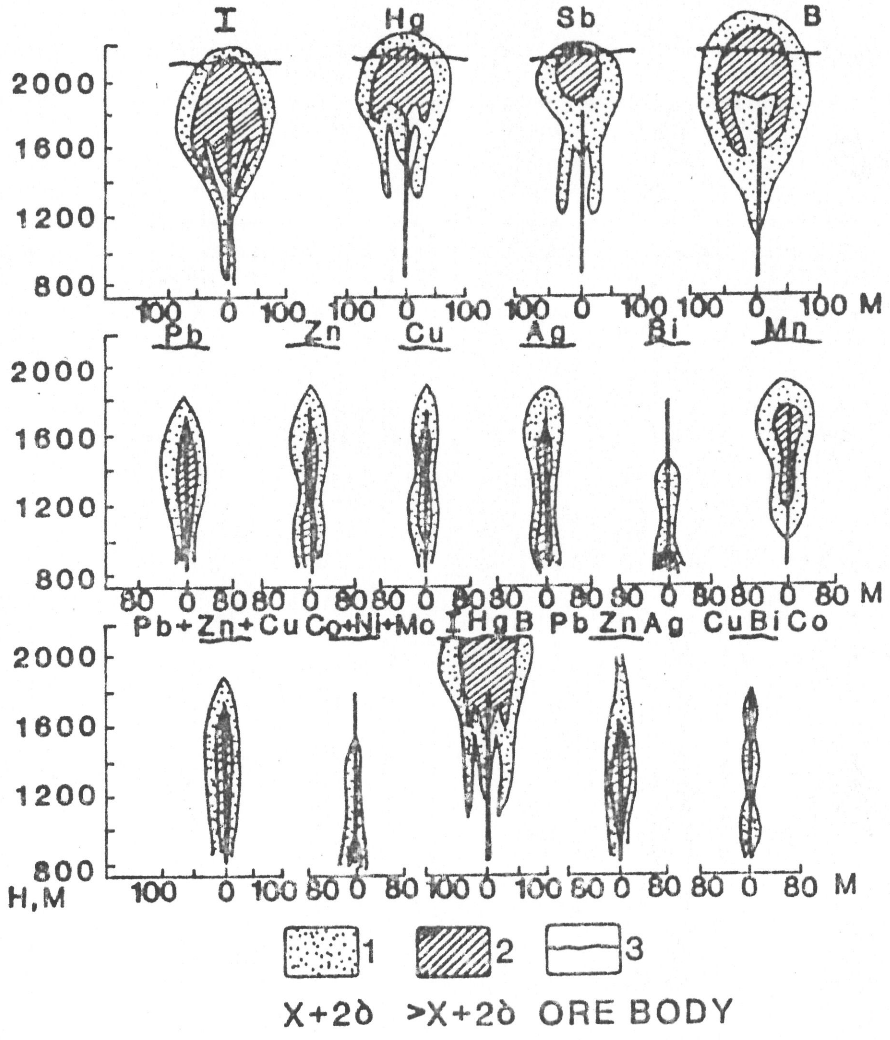
The processes which take place during the formation of an ore body frequently introduce mercury and other satellite elements into the host rock environment. Depending on mobilities, various elements travel different distances and develop aureole bands around an ore body, termed as a primary halo. In geologic time, secondary processes such as oxidation, dissolution, bacterial attack, and erosion takes place. This leads to the remobilization of elements and the development of a secondary halo.

II.1. Primary and Secondary Halos

During the processes which lead to the formation of an ore body, a primary halo is often developed in the host rocks. The shape and the size of this primary halo depends on the mobility of halo forming elements and the availability of geologic factors such as faults, fractures, and the permeability of the enclosing rocks. The most volatile or soluble elements have the greatest potential to travel significant distances from an ore body. Trofimuk (1978) who studied the distribution of volatile elements in the primary halo over the Sadonskoye polymetallic ore body, detected three bands of halos.

- -- in close proximity to an ore body - Pb, Zn, Cu, Ag, Mn,
- -- in the central and lower part of the ore body - Co, Ni, Mo, Bi, and
- -- in the upper part of an ore body, with continuity to large distances in both the vertical and horizontal plane: I-400 m, Hg-450 m, Sb-400 m, B-600 m.

The results of his findings are presented in Figure 3 and suggest that during the initial stages of exploration for blind or buried ore bodies, the analysis of volatile (Hg) or soluble (I) elements appears to have the greatest exploration potential. Boldy (1968) investigated primary halos above blind massive sulphide deposits. His analysis was conducted on samples from both surface and drill cores (Figure 4). He concluded that mercury from the primary halo developed above blind deposits and the detection of this mercury could provide a successful exploration technique in areas where the deposit was covered by nonmineralized rocks. Boldy sampled the mercury in minute fracture faces. As illustrated on Figure 4 the anomalous mercury content was detected at the surface as well as in drill holes. Boldy stressed the importance of sampling drill cores so that holes will not be stopped "prematurely". Fursov (1977), who studied the distribution of mercury in primary halos above numerous metallic deposits in detail, stated that the mercury



Idealized model of elements distribution and their ratios from Sadonskoye ore body (vertical and horizontal scale in meters).

FIG.3

halo could be developed above the ore body to a distance of as much as 1000 meters. The primary mercury halo is developed by native mercury or its compounds migrating in solution or as a vapor.

While the movement of soluble compounds is apparently an important part of the processes responsible for the development of the primary mercury halo, the migration of mercury vapor is the process which makes mercury so unique among pathfinder elements. The high ionization potential and fugacity of mercury vapor under the influence of temperature are the most important factors governing the behavior of mercury. Because of the high ionization potential, mercury converts easily to atomic form, reduces itself to metal from many associations and is a chemically stable element. The volatility of mercury and mercury vapor pressure under the effect of temperature is without parallel among the metals. One cubic meter (1.3 kg) of air at 20°C contains 14 mg, and at 100°C, 2.4 g of mercury. Mercury vapor is monoatomic and is the only element other than the inert gases which can give a measurable concentration of monatomic vapor at moderate temperatures. The resemblance to the inert gases does not stop here. The solubility of mercury in water has been found to be about 0.02 mg per liter at 20°C, and 0.6 at 100°C, this is the approximate value calculated for a heavy inert gas. (Sidgwick, 1950).

Since the behavior of mercury is so temperature dependent, it is logical to expect that the temperature gradients around an ore body will have a strong influence on the development of mercury in the primary halo. Inside and in proximity to the ore body, higher temperature mobile mercury forms should dominate, while more remote areas will contain the most volatile, and to some extent soluble mercury forms. Fursov, 1977 confirmed such zonations in the primary mercury aureoles, in which the more temperature resistant mercury forms are developed in proximity to an ore body, and less temperature resistant forms characterize the more remote parts of the halo. Permeability and fracturing has the most pronounced effects on zone II (soluble forms) and must be taken into consideration in order to produce a more realistic picture. The pressure and temperature gradient drives volatile mercury upwards. Thus zone III would be depleted in the lower levels as volatile mercury shifts upwards towards the cooler parts of the mineralized zone.

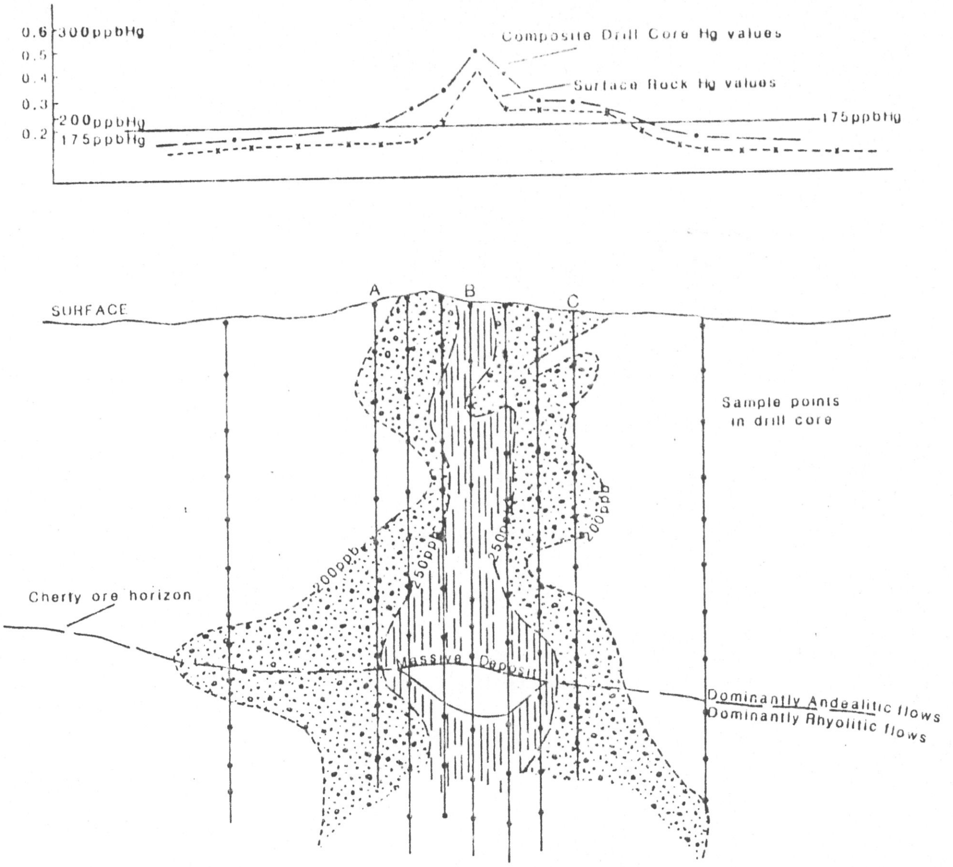
While the development of primary halos are stimulated by hypogene forces, the generation of secondary halos are governed by supergene processes. At significant distances, only the volatile or soluble forms of mercury are responsible for secondary halo development. Mercury gas dispersion is achieved through gas diffusion or effusion along fault and fracture openings. Migrating gas saturates pores and become sorbed by soils and rocks and forms organic complexes. Mercury migrating in solutions can be decomposed to metallic mercury, forming gas and occluded mercury halos. Mercury in compounds can be transported in the form of soluble anionic complexes ($HgCl_3$, $HgCl_4^{2-}$). Organic complexes may also provide some mobility. The soluble forms will be transported in solution along zones of higher permeability until sudden changes in conditions, such as Eh/Ph are encountered.

Fursov (1977) presented his research results on the distribution of mercury in secondary halos above both mercury and non-mercury mineralization. These results can be summarized as follows:

-- the ratio of anomaly/background was found to be about eight for mercury deposits, and about two-three for non-mercury deposits,
-- the ratio of the mercury halo diameter to the diameters of typical ore bodies was found to be about five for both mercury and non-mercury deposits,
-- the mercury halo was developed in the vertical direction to a distance of several hundred feet.

These observations strongly suggest that the movement of mercury in the gas phase is the most dominant form of migration and suggest the following concepts:

-- temperature is the most dominant factor stimulating mercury distribution in mineralized environments,
-- the temperature gradients around an ore body may be related directly to the distribution of mercury forms in the primary halo,
-- migration as a vapor and in solution are the two major mechanisms responsible for the buildup of mercury in halos,
-- the movement of mercury in the vapor phase appears to be dominant over solution,
-- therefore in the entire spectrum of existing mercury forms in the environment, only native mercury and soluble mercury compounds are indicative of the presence of primary or secondary halos.



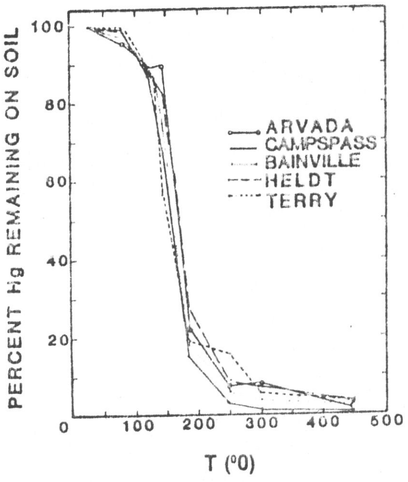
CASE III

CROSS SECTION-RELATIONSHIP OF ANOMALOUS MERCURY VALUES TO BLIND MASSIVE SULPHIDE DEPOSIT

NORANDA, QUEBEC

Boldy, 1968

FIG.4



VOLATILE LOSS OF SORBED MERCURY FROM SOILS AS A FUNCTION OF TEMPERATURE

Landa, 1979

FIG.5

II.2. Mercury Forms in Environment

Mercury exists in the environment in a number of states. It commonly occurs in the vapor state as sorbed mercury, as organo complexes, as compounds of mercury, and within the structure of minerals. The most convenient way to analyze different species of mercury is by thermal extraction. Table 1 is a compilation available from the literature illustrating thermal extraction of mercury.

1. Free mercury gas can be vaporized from the sample at a temperature of about 60°C; also lowering the pressure from 1-0.5 atm will serve this purpose.

2-3. Free sorbed and organo-complex mercury in soils can be liberated by temperature from 80°-220°C as demonstrated by Landa (1979) Figure 5. According to Fursov (1977) mercury in gangue rocks exists only in one form and can be released at temperatures from 240-360°C. This relatively low temperature of extraction indicates that mercury in gangue rocks does not exist within the crystal lattice. Based on this initial information, Fursov (1977) suggested that mercury exists in the lithosphere as free atoms in a disseminated form.

4. Compounds of mercury - The temperature ranges of mercury voltalization from synthetic standards are presented after Watling et al. (1972) Figure 6. From these compounds, only $HgCl_2$ (or rather its anions) are highly soluble. The others are insoluble and quite stable in the natural environment.

5. Mercury in Crystal Lattices of Minerals
According to Fursov (1977) in mineralized zones, the majority of mercury exists within crystal lattices of various minerals. The average content of mercury in minerals from sulphide deposits is 10-100 times higher than from the wall rock. A higher content of mercury is also common in the oxidation zone. The thermal ranges of mercury volatilization from common sulphide minerals are presented on Figures 7 and 8 (after Ryall, 1978).

The main points to consider are:

-- the total mercury content in nonmineralized environments is relatively high, averaging from 40-200 ppb,

-- in nonmineralized environments, mercury exists in relatively few forms, with an average temperature of extraction of about 320°C,

-- mercury content in mineralized environments is always higher than in host rocks,

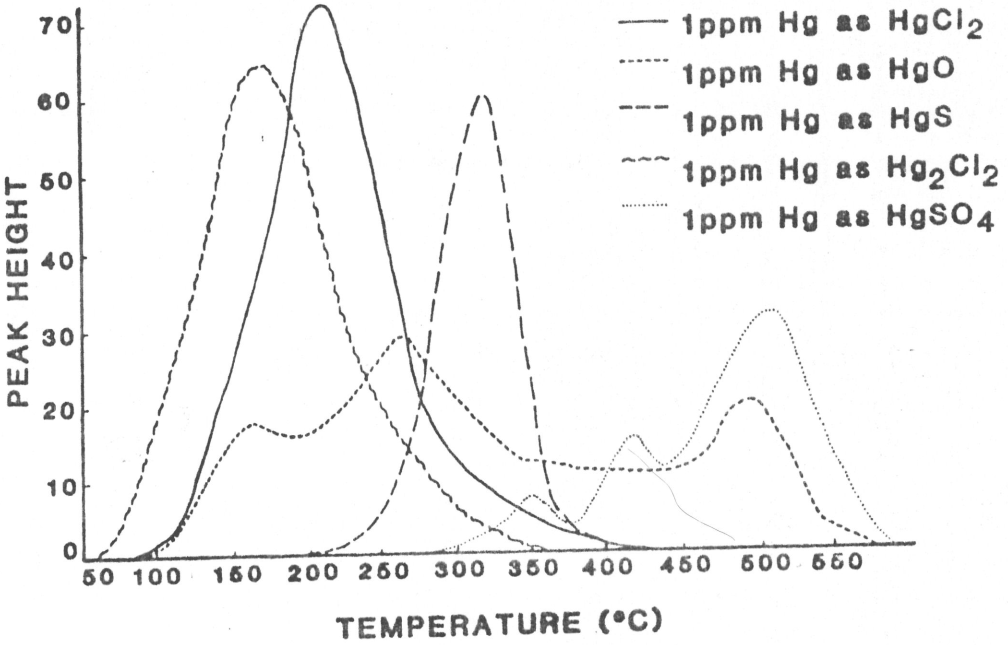
-- mercury exists in mineralized environments in numerous forms, with wide ranges of volatilization temperatures averaging from 150-800°C,

TABLE 1

Thermal Extraction of Mercury Forms

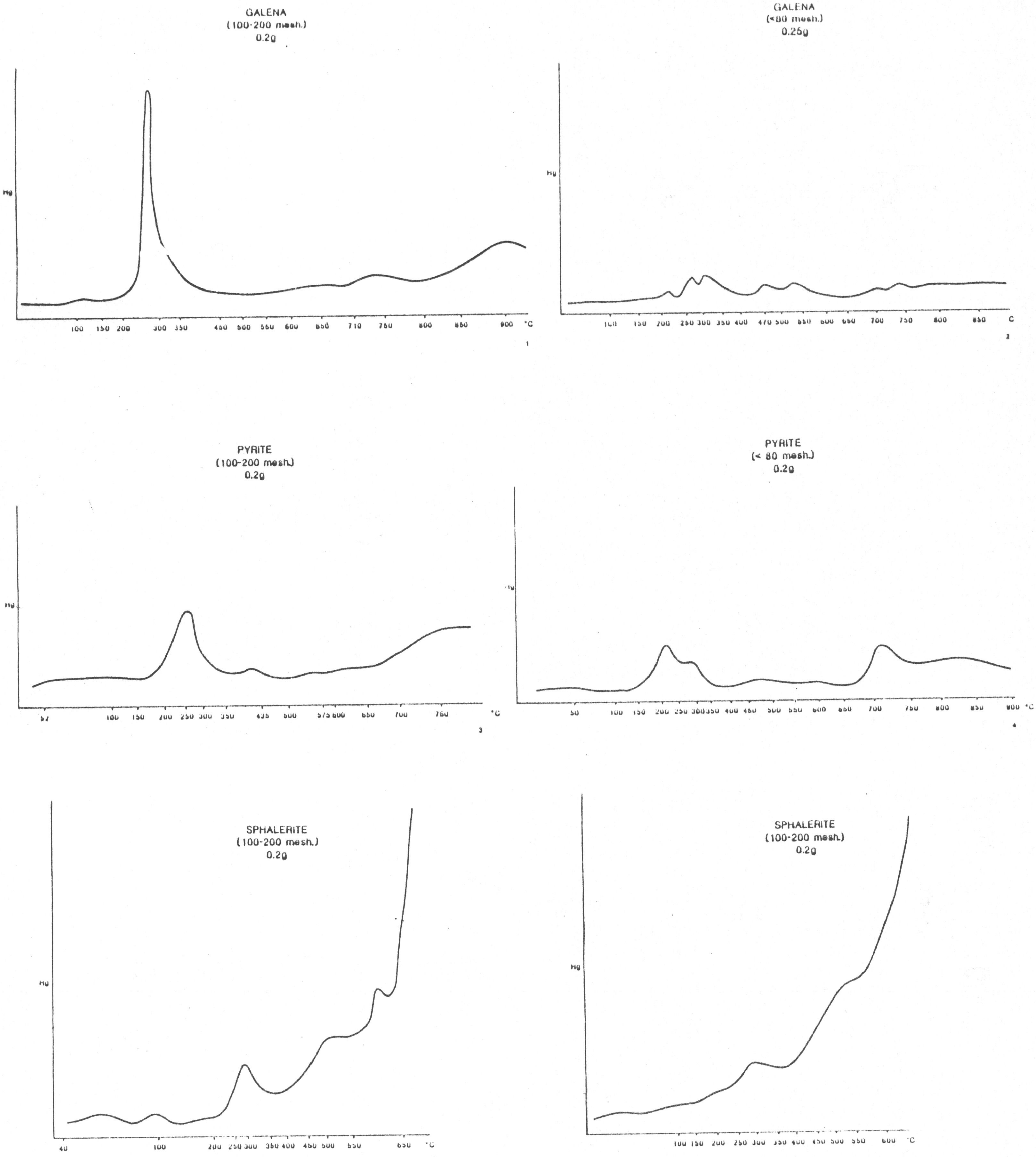
Mercury Form	Type of Existence	Temperature of Extraction °C	Author
free	in macropores	▨ <80°	Watling-72
		lowering pressure ~0.5 at	Fursov-77
	physically sorbed	▨ ~200°	Fursov-77
	chemically sorbed	≈400°	
	in micropores	260°-340°	
	organo-complexes	▨ <220°	Landa-79
compounds	Hg_2Cl_2	▨ 100°-220°	Watling-72
	$HgCl_2$	▨ 140°-270°	
	HgO	▨ 150°-530°	
	HgS	270°-360°	
	$HgSO_4$	400°-550°	
within structure of other minerals	tetrahedrite	400°-520°	Ryall-78
	sphalerite	670°-780°	
	galena	200°-500°	
	proustite	600°-680°	
	pyrargyrite	480°-600°	
	argentinite	230°-380°	
	dyscrasite	650°-1000°	

▨ ***FORMS OF Hg ANALYZED BY ETI APPARATUS***



Thermal release curves of mercury vapor from various mercury compounds (From Watling et al., 1973).

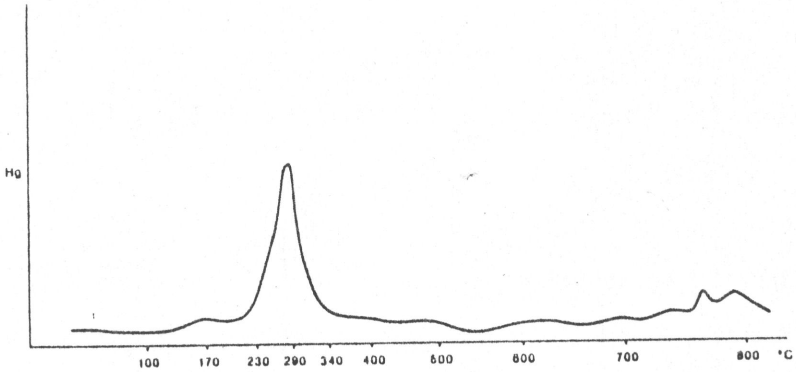
FIG.6



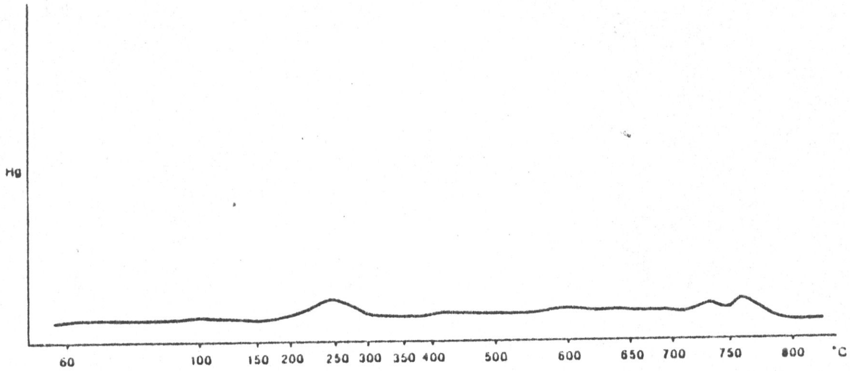
Hg THERMAL RELEASE CURVES.

FIG.7B

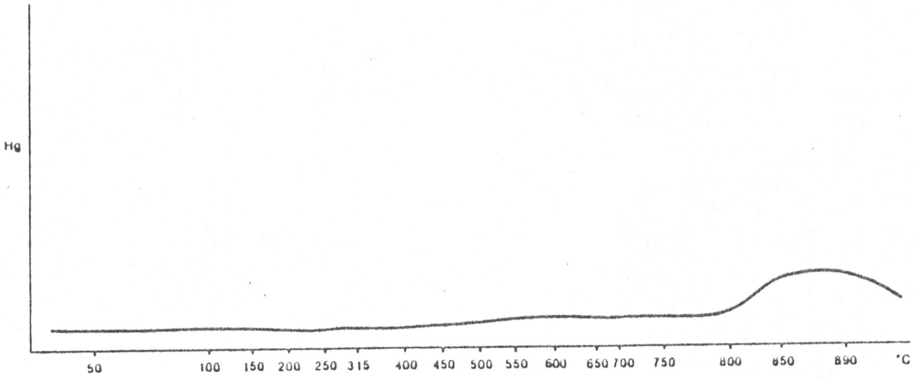
AZURITE - MALACHITE
(100-200 mesh.)
0.2g



SMITHSONITE
(100-200 mesh.)
0.2g

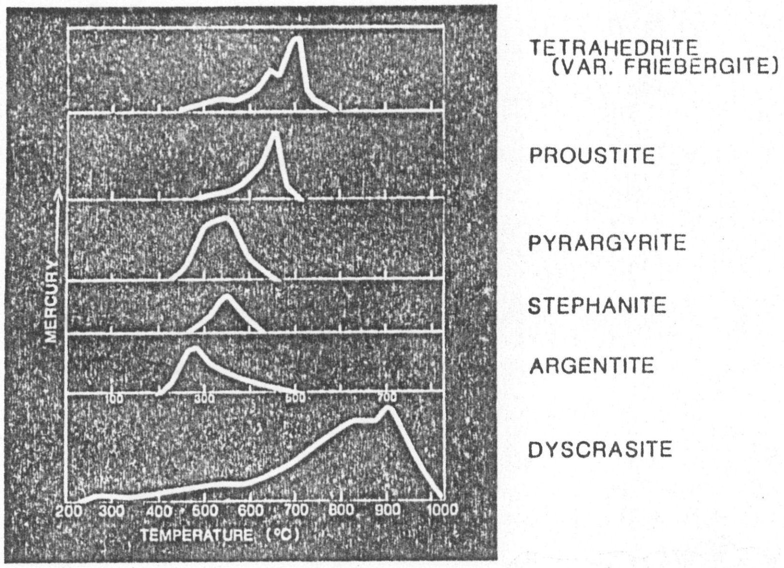


QUARTZ - IRISH ROSE
(< 100 mesh.)
0.25g

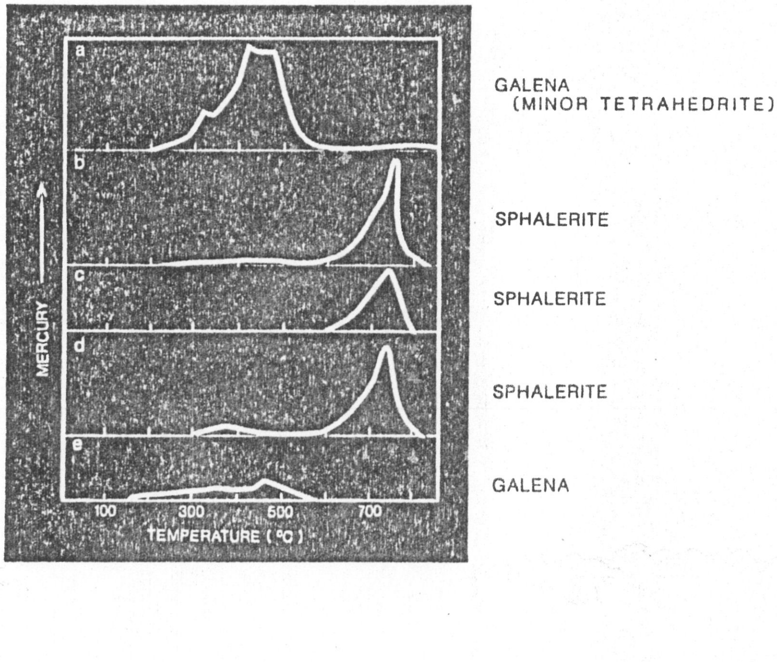


Hg THERMAL RELEASE CURVES.

FIG.7A



Thermal release curves of Hg from minerals of the Consols lode: (a) tetrahedrite (var. friebergite); (b) proustite; (c) pyrargyrite; (d) stephanite; (e) argentite; (f) dyscrasite.



Illustrates that the thermal curves for Hg extraction differ in temperature ranges for various minerals. Ryall indicated that in nearly all galenas which have mercury contents greater than 100 ppb, the mercury is contained in tetrahedrite, with lesser amounts in dyscrosite and pyrargyrite.

FIG.8

-- the zonation of mercury forms in the primary halo appears to be strongly temperature dependent,
-- the higher temperature forms are contained within or in proximity to the ore body, while lower temperature (more volatile) forms are characteristic of more remote environments distant from the ore body,
-- both primary and secondary halos from buried or blind ore bodies are developed by mobile mercury forms (i.e. vapor and soluble compounds), and
-- the movement of mercury in the vapor phase appears to be the dominant mode of migration.

III. APPLICATION OF MERCURY FORMS IN EXPLORATION

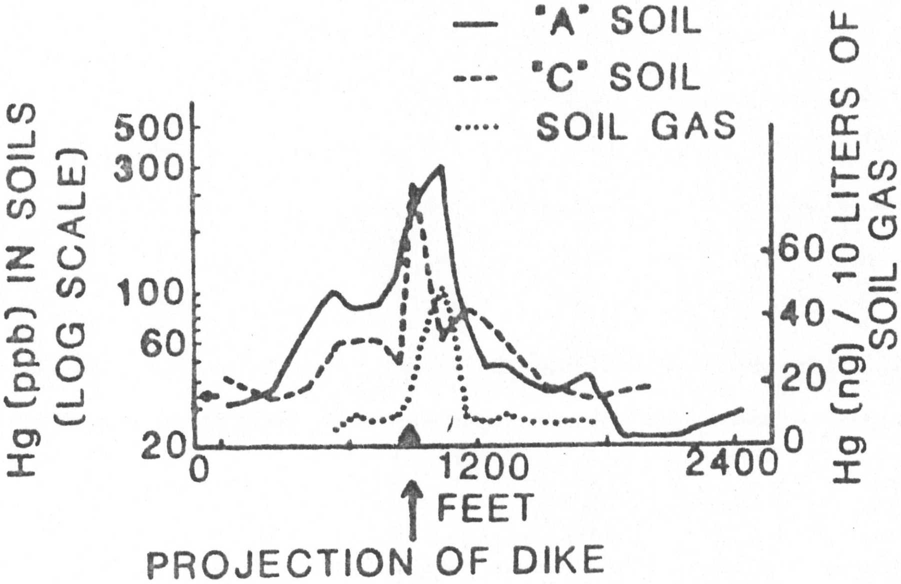
III.1 Soil Gas Mercury Measurements

Measurements of mercury vapor in soil gas were initially the most common method in the use of mercury as a pathfinder. Faults and fracture systems, particularly those which are mineralized or cutting through mineralization, provide the most favorable conditions for development of mercury vapor anomalies. McNerney and Buseck (1973) conducted measurements of mercury in soil gas and soil above the Vekol mine in Arizona which contains polymetallic mineralization. They concluded that there is a close correlation between mercury in soil from horizons A and C versus mercury in soil gas (Figure 9).

In a study of the Tashkent earthquake zone (Figure 10), Fursov et al. (1968) found that air aspirated from boreholes over faults contained as much as 15 times more mercury than air not located over fault zones. This work points out that faults can be the channelways through which mercury vapor migrates, but also indicates that tectonic activity can release mercury not necessarily related to economic mineral deposits.

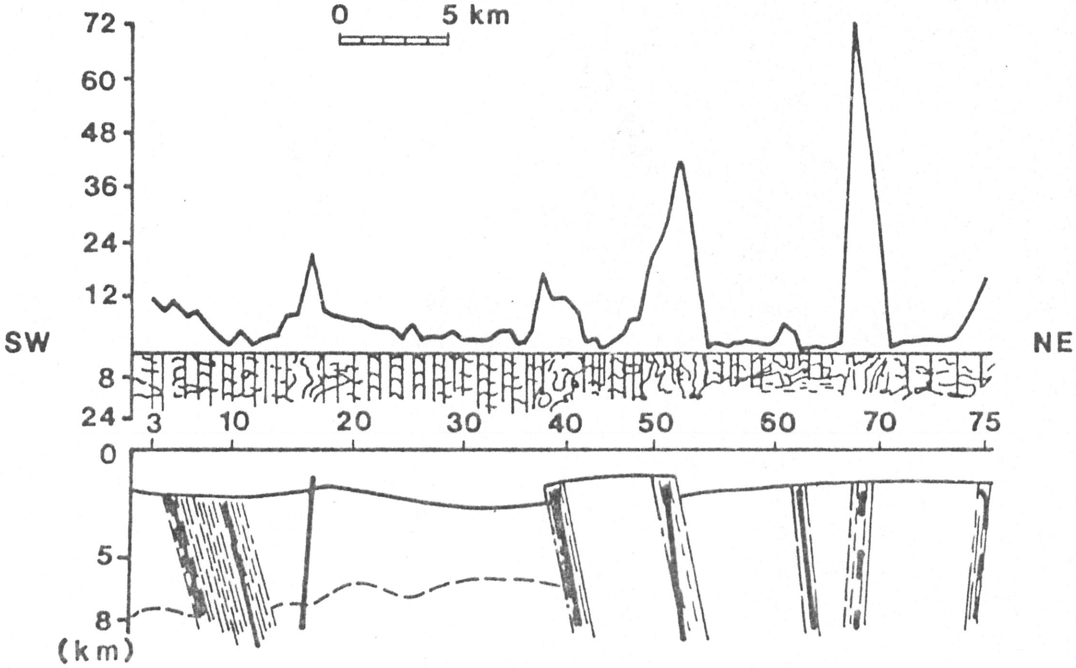
Fursov (1970) measured mercury in soil, soil gas, and air over several mercury deposits in the U.S.S.R.. At the Plamennoye deposit (Figure 11), disseminated cinnabar occurs in shattered zones of hydrothermally altered rhyolite. Gaseous dispersion aureoles of mercury were found in soil, soil gas, and in atmospheric air, all of which reflected the ore deposit. The mercury concentration in soil gas over the deposit varied from 100,000 to 500,000 ng/m^3 compared with a background of 100 ng/m^3. Additional surface traverses using a portable mercury spectrometer mounted in a truck, found the corresponding mercury concentration in air 1 m above the ground to be as high as 500 ng/m^3. A mercury halo was detected over the same deposit from a helicopter.

While vaporous mercury is expected to yield the most contrast between anomalous and background locations , the low levels of mercury content in soil gas, coupled with the strong and erratic influence of climatic and atmospheric factors, generally results in poor reproducibility and discourages this type of application. Figure 12 summarizes the influence of atmospheric factors on the mercury content of soil gas. Figure 12A illustrates that the influence of seasonal temperature variations have a pronounced effect on mercury soil gas content. Moisture of soils tend to clog the pores, thus limiting the flux of vapor as illustrated by Figure 12B. The mercury content in soil-gas is also significantly affected by changes of barometric pressure, as illustrated on Figure 12C. Wind tends to purify the soils, probably acting in a manner similar in principle to a Bernoulli pump (Figure 12D). Note that the scale for mercury content measured in calm weather is logarithmic, whereas for windy weather it is linear. There is also an apparent correlation between "lows" and "highs", particularly points 15/S and



Comparison of soil sampling versus vapor sampling for Hg over the Vekol dike. Note that the scale for the soil samples is logarithmic (McNerney, Buseck, 1973).

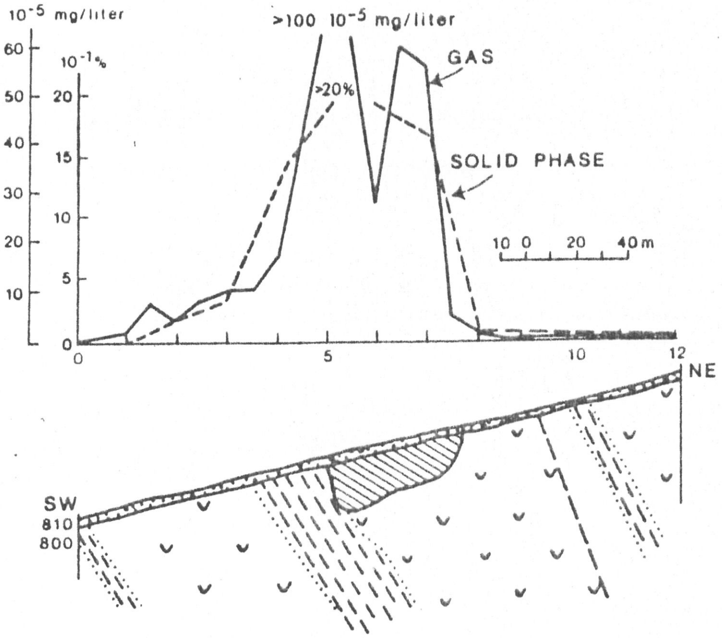
FIG.9



Mercury in the earthquake zone.

(Fursov - 68)

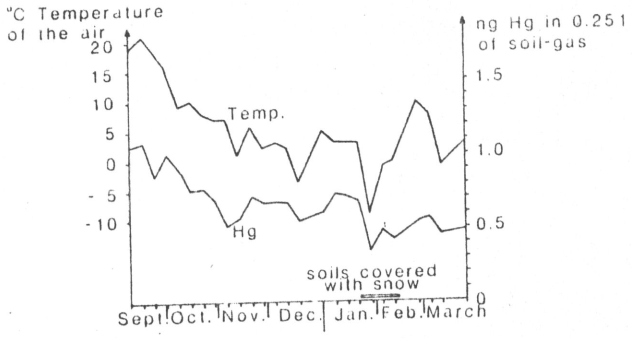
FIG.10



PLOT OF THE MERCURY CONCENTRATION IN GAS AND SOLID PHASES AT THE PLAMENNOYE DEPOSIT

(From Fursov, 1970)

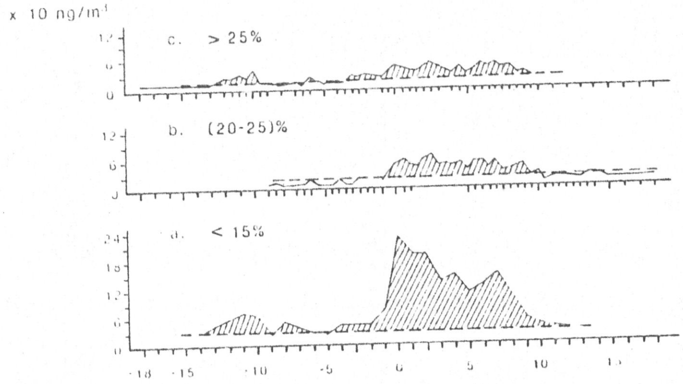
FIG.11



TEMPERATURE OF AIR AND MERCURY CONTENT IN SOIL GAS DURING A 7 MONTHS LONG-TERM IN-SITU EXPERIMENT.

Kramer, 1981

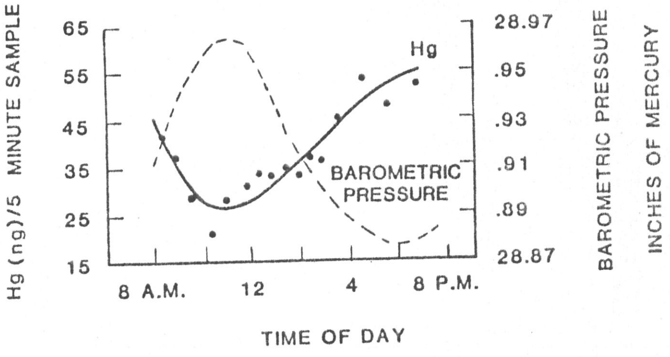
A



MERCURY CONTENT IN SOIL GAS AS A FUNCTION OF MOISTURE
(a,b,c - SOIL MOISTURE IN %)

Fursov, 1980

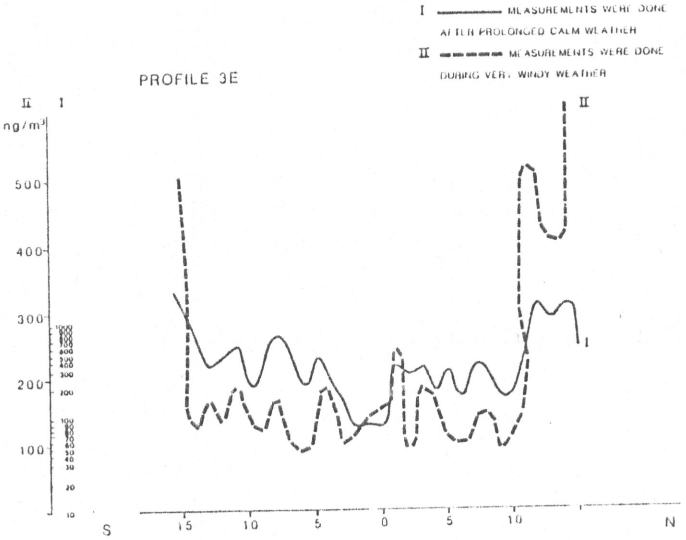
B



VARIATIONS IN Hg EMISSION FROM A DESERT SOIL EXPERIMENT AS A FUNCTION OF ATMOSPHERIC PRESSURE. THE DASHED LINE INDICATES THE BAROMETRIC PRESSURE AND THE SOLID LINE INDICATES Hg EMISSION. MERCURY WAS COLLECTED USING STATIC SAMPLER.

From McNerney and Buseck, 1973

C



RELATION BETWEEN SOIL GAS MERCURY VALUES DURING CALM AND WINDY WEATHER.

D

INFLUENCE OF ATMOSPHERIC FACTORS, ON MERCURY SOIL GAS CONTENT.

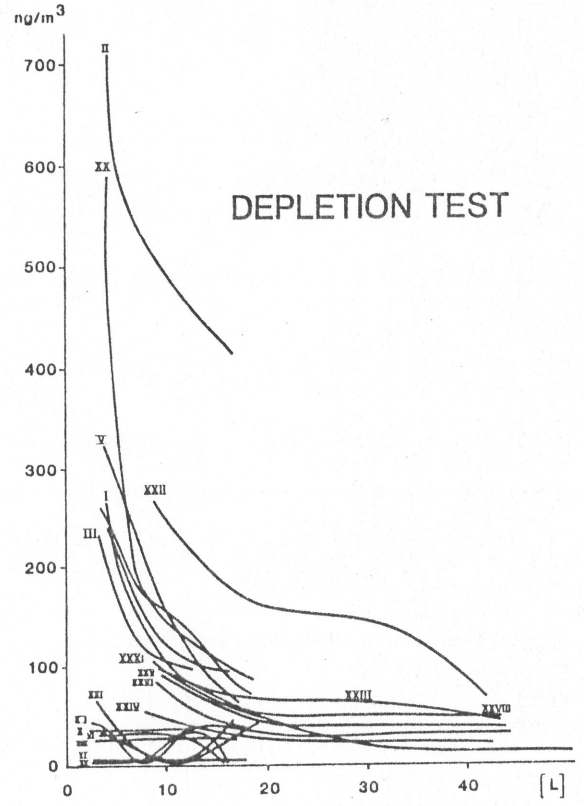
FIG. 12

(10-15)N, above fractured zones. This suggests rather rapid movement of mercury vapor along fractures.

In order to overcome the problems with low mercury content in soil gas and to limit the influence of atmospheric factors, mercury has been preconcentrated on gold coated quartz bead collectors. However, it was found that mercury in soil gas depletes rapidly as successive volumes of soil gas are removed. The tests presented in Figure 13 demonstrates that withdrawing 2 to 4 liters of soil gas causes the mercury content to fall to background values. These tests are independent of depth (tests were conducted in holes 3, 6, and 9 feet deep), and suggests a nonuniform distribution of mercury vapor in soil-gas.

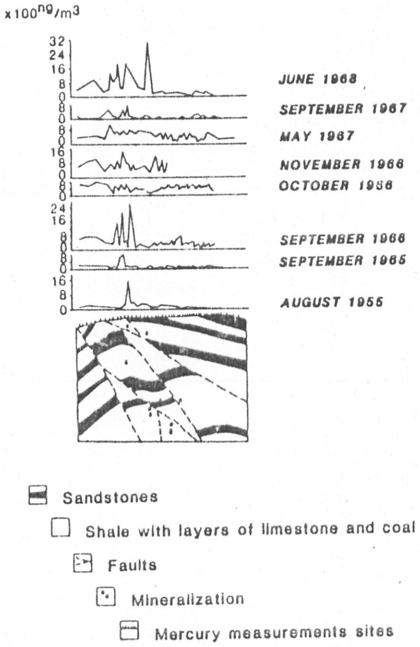
Edelman (1974) repeatedly determined the content of mercury in soil gas over a mercury deposit over a period of several years (Figure 14). These experiments indicated that the highest values were observed during the summer, and the lowest during the colder months. Edelman's experiments also indicate, that during unfavorable climatic conditions, the mercury content in soil gas does not differ by much from background values, even over mercury deposits.

There are two ways to limit the effect of climatic and atmospheric factors; one is to perform a survey in the shortest possible period of time under similar meteorologic conditions. This requirement is, however, very frequently difficult or even impossible to satisfy. The other way is to integrate the mercury over longer periods of time on some type of buried artificial collector, or by using soil itself as a mercury collector. The advantage of using soil is that the integration is obtained over the longest possible period of time.



MERCURY CONTENT IN SOIL GAS, AS SUCCESSIVE VOLUMES ARE WITHDRAWN.

FIG.13



THE STABILITY OF MERCURY VAPOR CONTENT IN SOIL GAS ABOVE MERCURY DEPOSIT.

FIG.14

III.2. Solid Phase Mercury Analysis

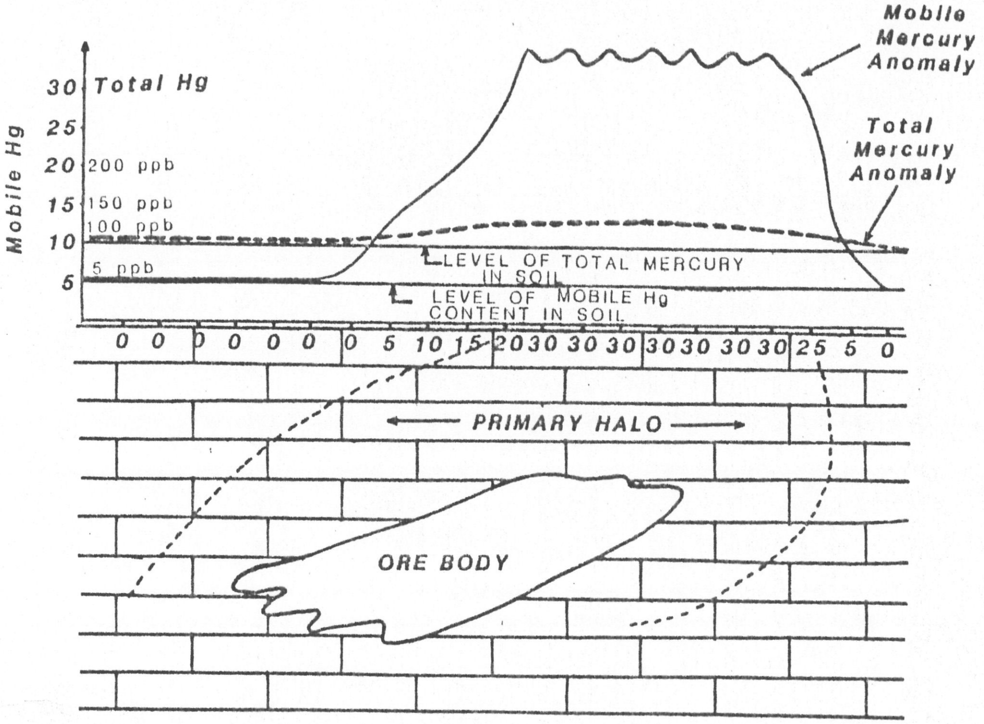
The analysis of mercury in the solid phase has been traditionally conducted by releasing the mercury by combustion of the soil at a temperature of about 600°C. At such temperatures, the majority of the mercury in the soil is released. The use of total mercury was reportedly successful in a number of surveys and tests as illustrated in Figures 9 and 11. These examples illustrate a successful application of soil gas and solid phase total mercury measurements, although in both cases mineralization existed at shallow depths. However, in general, total mercury measurements have obtained a mixed success ratio. This is attributed to the following considerations:

1. the low anomaly/background ratio for total mercury over buried or blind ore bodies,
2. the zonation of mercury forms in halos which are mixed together when only total mercury is analyzed.

Mercury may exist in soils, at a fairly high level of concentration, in average from 40-200 ppb. However, the signature from blind or buried ore bodies is developed in overlying soils by "mobile" mercury - vapor or soluble species. Therefore, in the total spectrum of mercury forms available in soils, only those species which originated either from vapor or solution are indicative of the presence of an ore body. This point is illustrated schematically in Figure 15, where the level of average total mercury background in the host rocks is of about 100 ppb and the level of mobile mercury background is of about 5 ppb. Mineralization processes in this example increased the mercury content in the primary halo by about 30 ppb. Since the primary halo is developed by mobile mercury forms, the analysis of mobile mercury forms would yield an anomaly/background ratio of about 7 (35 ppb/5 ppb), while the analysis of total mercury content would produce a ratio of about 1.3 (130 ppb/100 ppb). Thus, analysis of mobile mercury has a much greater likelihood of identifying a mineralized zone with greater confidence than total mercury techniques.

As discussed previously and confirmed by Fursov (1977), the temperature effect plays a dominant role in the distribution of mercury phases and their magnitudes in the primary halo. The more temperature resistant mercury forms are developed within and in proximity to an ore body. On the other hand, the halo at some distances from an ore body should be characterized by the lower temperature soluble and volatile mercury forms. More remote areas will contain the most volatile, and to some extent soluble mercury forms. Along these lines an idealized general distribution of mercury forms in the primary halo is postulated in Figure 16.

Above such a model, total mercury analysis would yield a broad halo with no significant anomaly/background ratio. Detailed differential analysis of particular mercury forms should show zonations within the halo, or even vector the direction of the

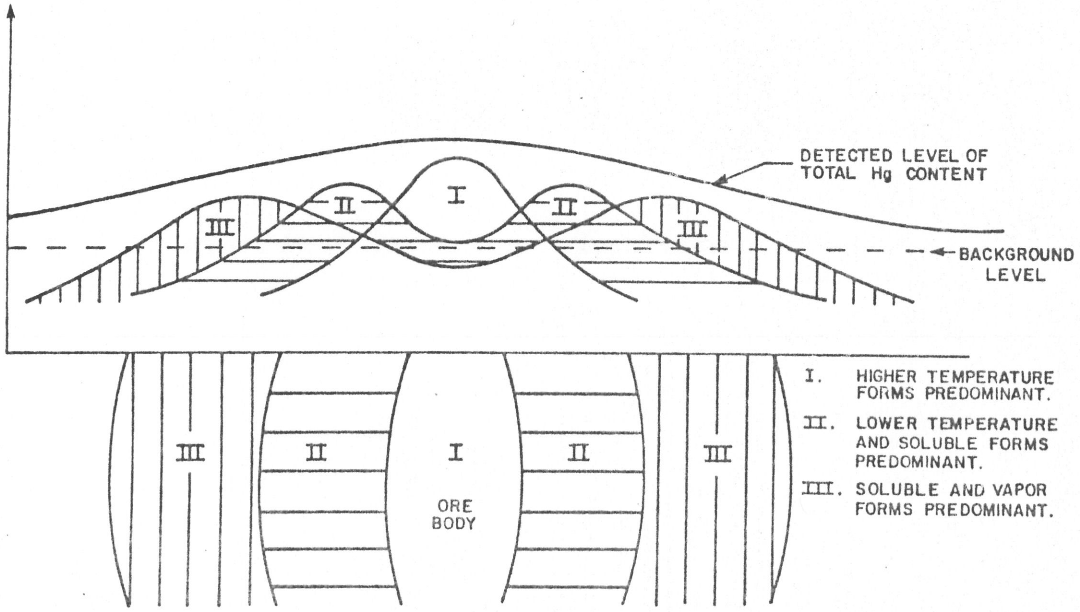


THE MAGNITUDE OF MOBLE MERCURY FORMS MIGRATING FROM ORE BODY IN RELATION TO THE BACKGROUND LEVELS OF:

—TOTAL MERCURY CONTENT

—MOBILE MERCURY FORMS

FIG.15



IDEALIZED HYPOTHETICAL DISTRIBUTION OF MERCURY FORMS IN ORE BODY AND PRIMARY HALO

FIG.16

ore body. However, localized geologic conditions could confuse the matter. If fracturing exists in the halo zone, one might expect false or displaced anomalies. Obviously, mercury will be liberated along these zones and will form strong anomalies near the surface. This may explain many of the reported examples where mercury anomalies are associated with faults, but not with ore bodies.

Thus, the analysis of total mercury content in such an area would mainly indicate anomalies associated with fault zones, since an anomaly from the fault zone should be large enough to overcome the high background of total mercury content. Measurements of mercury vapor would also pinpoint the fault zone, with somewhat higher but spotty readings over mineralized zones. It is intuitively obvious that the integration of mercury emanations over a long period of time would be the most advantageous, i.e., both fault zones and mineralized areas should be detected. These considerations can be summarized as follows:

- -- Free soil-gas measurements probably offer the best anomaly/background ratio, but can be unreliable since there are too many short term or seasonal factors involved,
- -- Measurements of the total mercury content in a soil offer good stability, but are characterized by poor anomaly/background ratios,
- -- Analysis of mobile mercury forms in soils, which originate from either vapor or solution, appears to offer the highest potential in mineral exploration.

III.3. Application of Mobile Mercury Forms

"Mobile mercury" refers to those forms of mercury which can be transported either in solution or the vapor state. This group of soluble compounds, from an exploration standpoint, may be limited to mercury chlorides and mercury contained in organic complexes. Elemental mercury can be released from these forms by sampling temperatures of 100-250°C (Table 1).

Mercury entering soils in the vapor state will be partially retained by soils, with the remaining mercury escaping to the atmosphere. That portion of the mobile mercury which is retained by the soils in clays, sorbed and/or organic complexes is of great practical exploration importance, since mercury is known to form many stable organo-metallic compounds (Sidgwicke, 1952).

Fursov (1977) conducted an experiment proving the volatility of mercury from the solid phase and its migration into soils. In his experiment he mixed clay with HgS in four different concentrations; 1.0%, 0.1%, 0.01%, and 0.001%. He placed those mixtures into four separate containers and covered each with a 0.5 meter thick layer of allochthonous clay. Analysis of mercury over a 1.5 year period indicated that the mercury gas vapor which was released by the HgS was distributed as follows:

--	0.05 - 0.1%	existed as a free mercury vapor in the layer with HgS
--	0.01%	free vapor in upper layer
--	2.0 - 10.0%	escaped to atmosphere
--	90.0 - 98.0%	was retained by clay in the upper layer.

This experiment indicates that when prospecting for buried or blind ore bodies, measurements of mercury retained by clays or soils may offer the highest diagnostic potential.

Fang (1978) and Landa (1979) performed other experiments in which five types of Montana soils were exposed to air containing elemental mercury vapor. These data indicated rapid uptake of mercury vapor by all soils. The sorption capacity of the soil for mercury vapor did not reach saturation after being continually exposed for 17 days, even when the mercury vapor concentration was increased to 209 ng/m^3. There was no mercury loss in these soils after being placed in a vacuum designator for 24 hours, heated in an oven at 110°C for two hours, exposed to a bubbling stream of air designed to remove mercury vapor, or to dry air for 16 days of the monitored period. A maximum of 5% of the total sorbed mercury was lost at the 1/3 bar moisture tension.

The adsorbed mercury was resistant to extraction by water, neutral salts, methanol, or DTPA. Cysteine, acetylacetone, and cupferron showed limited extraction of sorbed mercury. Benzene, and to a greater extent, hydrochloride acid and sodium hydroxide demonstrated high removals of sorbed mercury from the soil. The majority of the sorbed mercury was volatilized at 100-200°C (Figure 5), suggesting that sorbed elemental mercury was retained as an organo-complex.

These studies imply:

- mercury vapor is readily adsorbed by clay and soils,
- most of the mercury vapor which entered the soils is converted to the solid phase,
- retained mercury appears to be resistant to climatic and atmospheric conditions,
- retained mercury is rapidly and nearly totally released at temperature of 150-200°C.

Most of these mobile forms of mercury are released by heating to temperatures below 250°C. Furthermore, the low temperature offers another very important advantage. At temperatures less than 200°C, there are practically no combustion products, therefore, interference problems (from gases produced during combustion) are largely avoided. This characteristic also allows one to build simple and accurate analytical systems using high sensitivity atomic adsorption detection techniques.

III.4. Application of Differential Mercury Analysis

The forms of mercury occurrences can be divided into five groups:

- free mercury vapor
- sorbed mercury
- organic compounds of mercury
- mercury compounds
- mercury in crystal lattices of minerals.

These mercury forms are characterized by different physicochemical behavior, and are formed during different stages of mineralization development. Therefore, analysis of mercury with separation by species type (differential or partial extraction) yields valuable information about mineralogy, as well as about geometrical parameters of the ore body.

In addition, the temperature of mercury extraction from mineral compounds and crystal lattices of various minerals is different, and typical for the particular species (Koksoy, 1969; Watling, 1972; Fursov, 1977 and Ryall, 1978). This is aided by the fact, that in general, mercury in gangue rocks exists in only one form (Fursov, 1977). Therefore, the thermal spectrum of mercury forms yields specific information about the ore body, which are:

- type of mineralization
- temperature of formation
- proximity to the ore body
- level of erosion of the ore body.

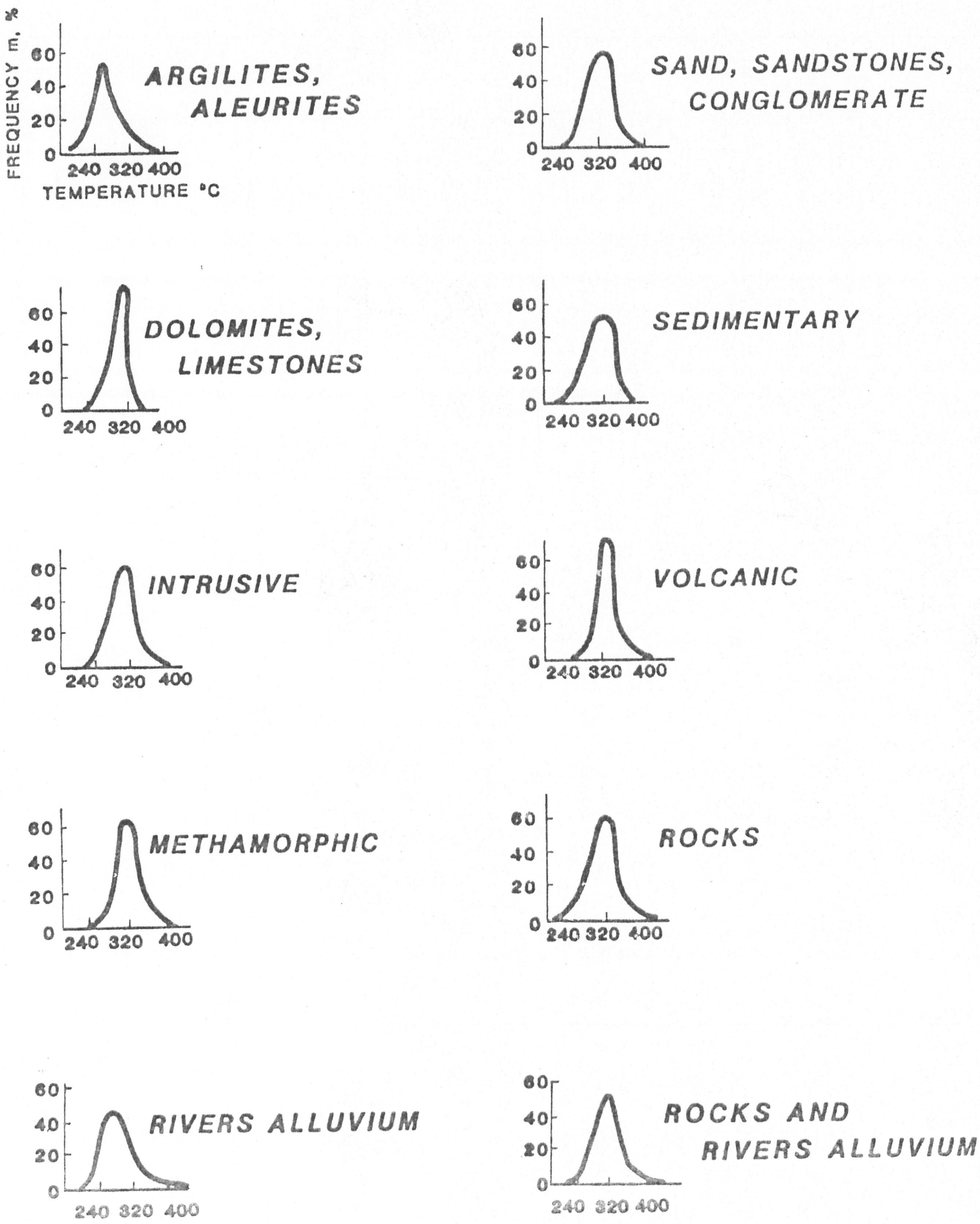
Fursov (1977) analyzed mercury species from a large number of samples from both gangue rocks and ore bodies. The summary of his findings are presented below.

1. Gangue Rocks

Fursov concluded that the gangue rocks from different ages and genesis--intrusive, volcanic, methamorphic and sedimentary--have only one form of mercury present which evolves over a temperature range of 260-380°C. Very frequently the temperature range is limited to 280-320°C. This information led Fursov to conclude that gangue rocks could be separated from mineralized rocks using differential heating. Figure 17 illustrates temperature plots of mercury sublimation from various gangue rocks.

2. Ores

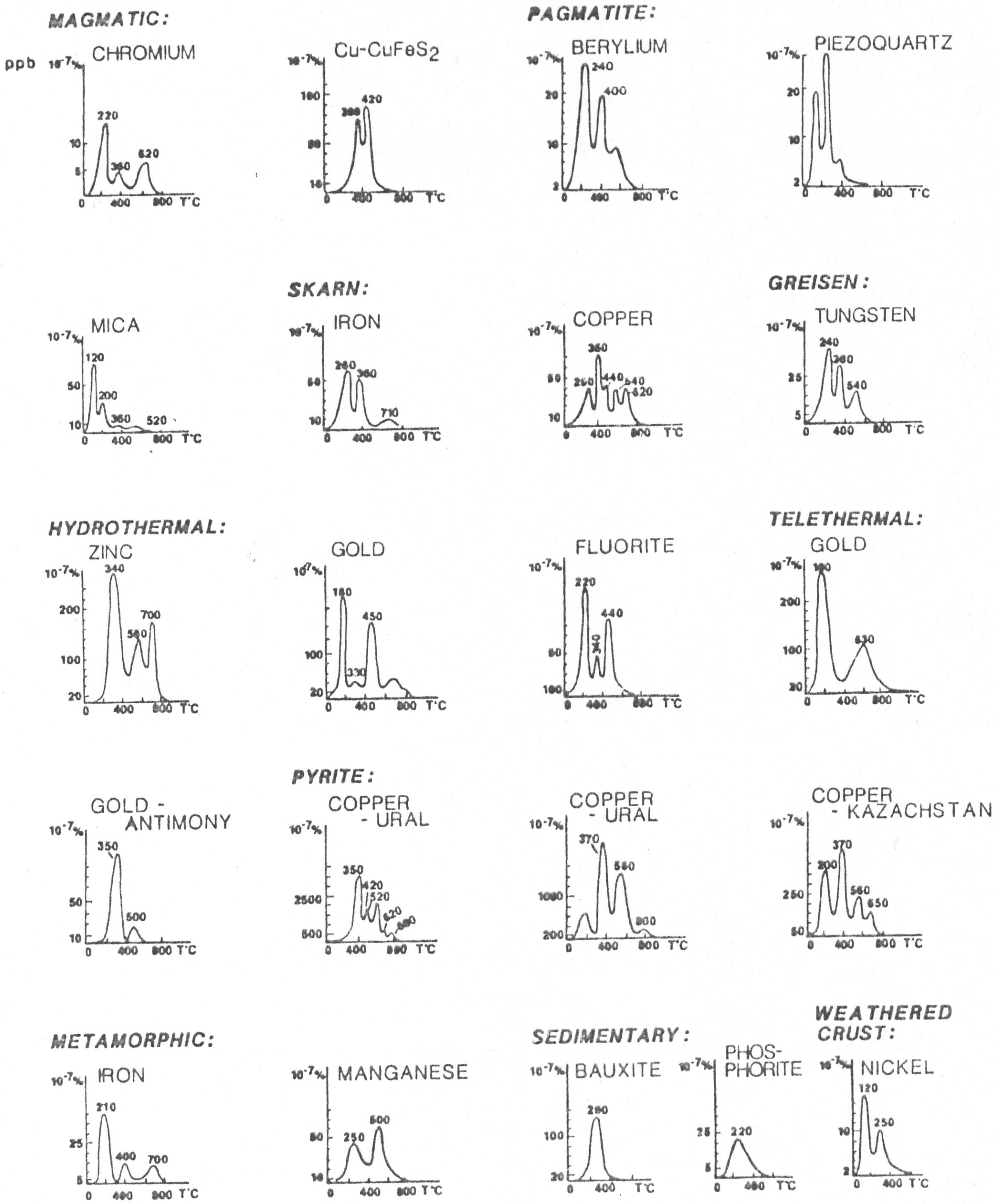
In contrast, mercury in ore deposits occurs in a larger variety of forms which extend over a much wider temperature range than that in gangue rocks and meteorites. Examples are summarized in Table 2 and in Figure 18. Therefore, thermal differential



Plots of the rate of Hg sublimation from rock (Fursov, 1977).

FIG.17

PLOTS OF RATE OF Hg SUBLIMATION FROM ORE BODIES



(Fursov - 77)

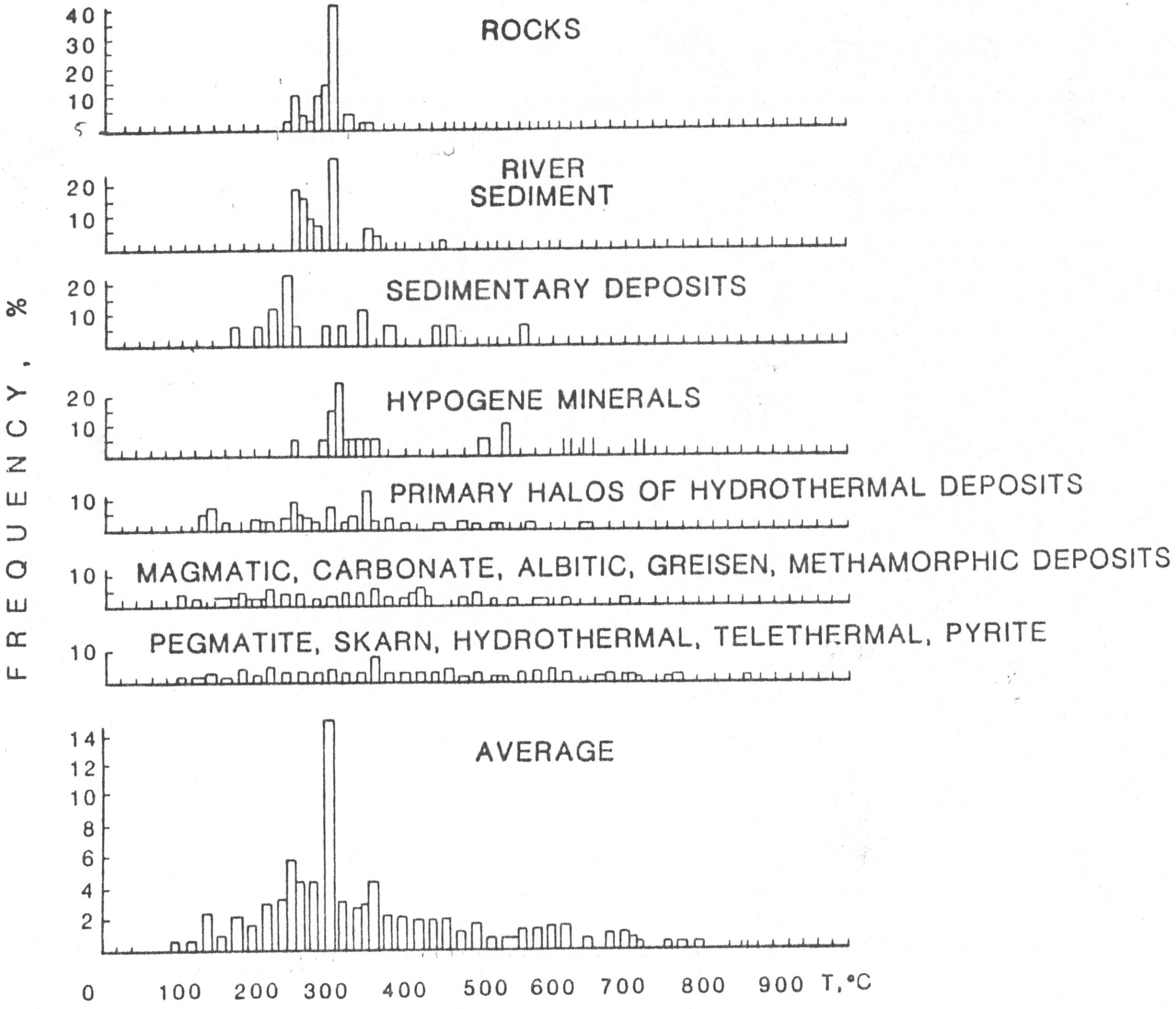
FIG.18

TABLE 2

		Number of Components of Hg		Max. Temp. of Release of Hg		
Rocks and Ore Deposits	Content of Hg 100 ppb	Max.	Average	Range	The Most Frequent Range	Number of Samples
Rocks						
Intrusive	0.7	1	1	260-380	280-320	31
Volcanic	0.5	1	1	280-400	280-320	23
Sedimentary	0.7	2	1.08	240-340	280-320	53
Metamorphic	0.4	1	1	280-370	280-320	19
Endogene deposits						
Magmatic	6	4	2.5	100-620	300-400	10
Carbonate	5	4	2.4	100-520	100-200	5
Albitic	4	1	1	140-160	110-160	2
Greisen	6	3	2.6	180-660	200-300	7
Pegmatite	10	4	2.7	100-700	200-300 500-600	9
Skarn	10	5	2.8	110-820	200-300 400-500	20
Hydrothermal						
Plutonic	10	5	3	130-860	300-400	34
Telethermal	23	3	2.5	140-650	100-200 300-400	8
Pyrite	45	5	3.5	140-860	300-400 500-600	10
Metamorphic deposits	5	4	2.6	210-700	200-300 600-700	6
Sedimentary	8	3	1.4	170-560	200-300	12
Biochemical	3.5	2	1.3	120-400	100-200 200-300	11
Crusts Destruction	2.0	3	2	120-560	100-200 500-600	6
Hypogenic	28	2	1.4	250-740	300-400 500-600	14
Primary Halo Endogene (skarn) Hydro telethermal	2	3	1.7	120-650	120-200 200-300 300-900	130

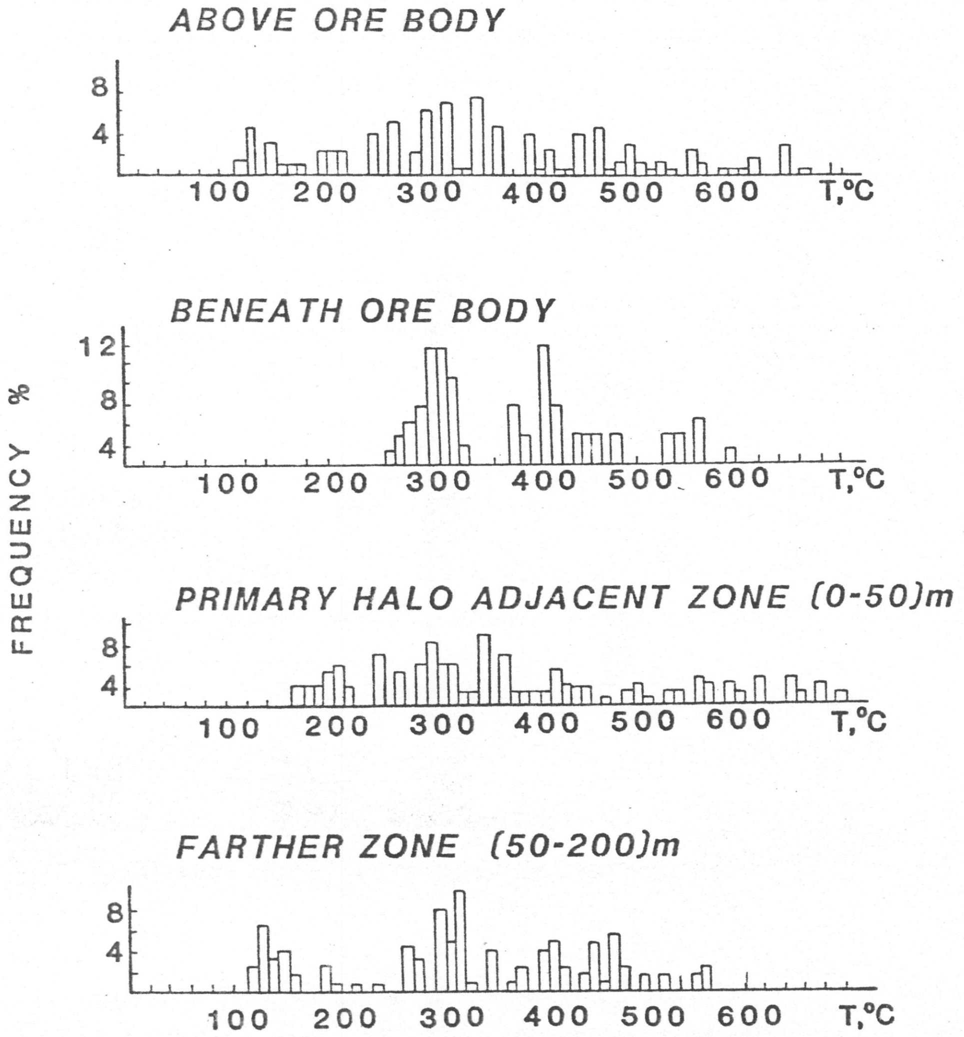
mercury analysis gives information not only about the possibility of mineralization, but also proximity to ore, and perhaps even more specific information about the type of mineralization. This appears to be true even when the mercury content is low compared to background.

Plots containing frequency of occurrence of mercury compounds as a function of temperature from various geological settings are illustrated in Figure 19. The application of differential analysis is a proximity indicator to the ore body. The separation of data into adjacent and remote zones will define the erosion level of the ore body. These zones, above and beneath the ore body, are illustrated in Figure 20.



(Fursov - 77)

FIG. 19



NUMBER OF COMPOUNDS	THE RANGE OF TEMPERATURE
$\frac{n1}{n2}=\frac{173}{74}=2.3$	120° - 700° C
$\frac{n1}{n2}=\frac{71}{42}=1.7$	260° - 600° C
$\frac{n1}{n2}=\frac{147}{65}=2.3$	170° - 700° C
$\frac{n1}{n2}=\frac{123}{64}=1.9$	120° - 560° C

THE LOWER TEMPERATURE FORMS OF Hg ARE CHARACTERISTIC FOR THE FARTHER ZONE.

n1 = NUMBER OF SAMPLES

n2 = NUMBER OF COMPOUNDS

DISTRIBUTION OF MERCURY FORMS IN PRIMARY HALO
(Fursov - 77)

FIG.20

IV. TESTS OF LOW TEMPERATURE MOBILE MERCURY

Analysis of thousands of soil samples from many locations in the U.S.A., using a newly devised partial extraction method, show that low temperature extraction yields background values in the range of 5-10 ppb, with anomalies in the range of 15-100 ppb. To illustrate the behavior of mobile mercury distributions in nonmineralized environments, over 270 samples were collected over nonmineralized bedrock and gravel valley fill areas in Railroad Valley, Nye County, Nevada. The histogram of mercury concentrations (Figure 21) illustrates the distribution of mercury content obtained in a nonmineralized environment. The median and mean values are below 4 ppb, with only a small percentage of the sites even in the range of 6-7 ppb. Low temperature anomalies are typically several times higher than background and can easily be differentiated from background by this new method.

1. The Reliability of Low Temperature Mercury Data

A number of tests have been undertaken in order to define the reliability of the new method and the natural variation of the low temperature mercury data. These include:

1. reproducibility from the same sample
2. reproducibility of samples from the same site
3. the variation of mercury in soils having background and anomalous values.

1) Reproducibility From the Same Sample

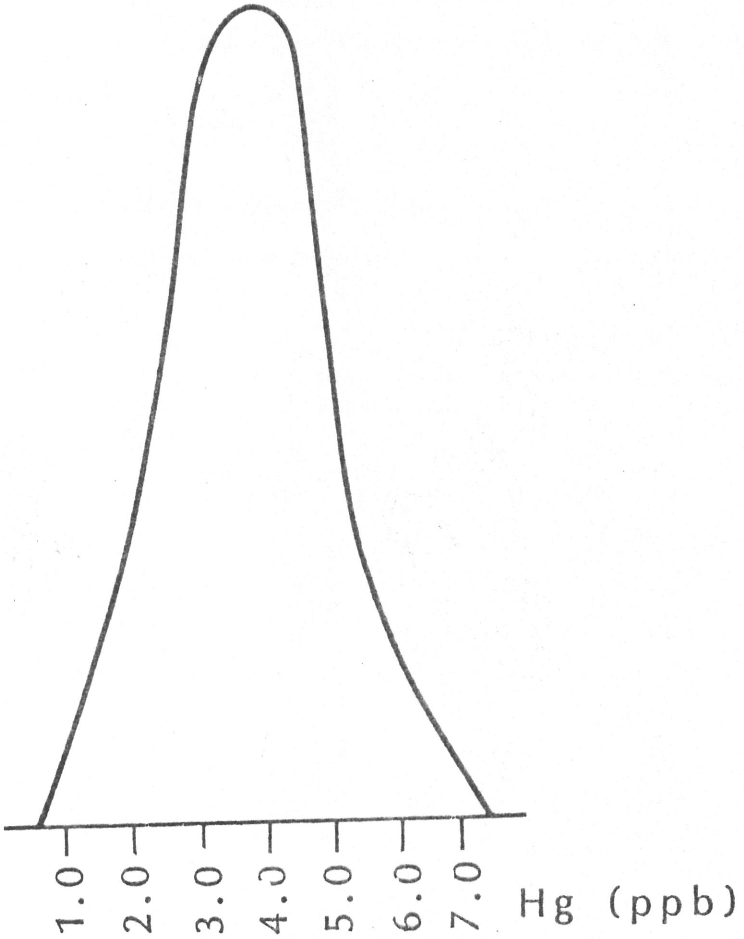
As has been established during hundreds of repetitions on samples, the analytical reproducibility from the same sample is on the average, better than 10% (see Figure 22). The reproducibility of the same sample analyzed on different days, is illustrated in Table 3A. As indicated by the results from this table, the average reproducibility is better than 7%, with no detectable trend suggesting losses or gains of mercury by samples stored in a plastic container in an air conditioned hotel room.

2) Reproducibility From the Same Site

The reproducibility of mercury content from samples collected from the same site, but on different days, is shown in Table 3B, as a "time test". The results obtained indicate very good stability of low temperature mercury content in soils over a period of two weeks. The experience which has been gained during three years of surveying indicates that the reproducibility from the same site is excellent, with the mean deviation seldom exceeding 15-20%.

In order to test the variation of mercury content in soils from a background area, samples were collected over a 5 foot gridded pattern. As illustrated in Table 3C, the "square test"

HISTOGRAM OF MOBILE MERCURY



Total sites 278
Mean 3.9 ppb
Median 3.6 ppb

Background concentrations
of mobil mercury in
non mineralized areas

FIG.21

variations did not exceed an average deviation of 15%, although areas with higher mercury values (site B) did have slightly greater variations.

3) Variation of Low Temperature Mercury in Soils

The impact of solar radiation on mobile mercury in soils was tested and quantified. Temperature measurements on desert soils indicated that the surface temperature may reach as much as 150°F. Below 20 cm, however, the temperature effects are much less pronounced. For comparison, samples were collected from both the surface and from a depth of 20 cm, as illustrated in Figure 23. There is a good correlation between the data obtained from the two depths, although the samples collected at a depth of 20 cm and analyzed for mercury at a temperature of 175°C provides the best anomaly to background contrast.

Mercury variations in soils over mineralized faults are illustrated in Figure 24. Initial samples were collected every 200 feet, along line 1 in order to detect a fault. The fault was noted to have an anomaly to background ratio of about 6:1. Then in order to further test for mercury variations in soils in an anomalous area, three lines were set 50 feet apart, and samples were collected every 20 feet along each traverse. The data obtained indicated that all samples contained anomalous mercury (see Figure 24C). Suggesting that mobile mercury migrates as a vapor or in solution toward the ground surface along joint or fracture channels. Clearly the closer-spaced sampling stations greatly improves the recognition of the fault. Whenever economic conditions permit, gridded surveys are recommended.

TABLE 3A

CONTROL SAMPLE
(VII/20 - VIII/30)81

	No. of Counts	NG
1.	230	4.6
2.	215	4.3
3.	220	4.4
4.	205	4.1
5.	210	4.2
6.	210	4.2
7.	205	4.1
8.	220	4.4
9.	215	4.3
10.	205	4.1
11.	210	4.2
12.	200	4.0
13.	215	4.3
14.	190	3.8
15.	200	4.0
16.	185	3.7
17.	200	4.0
18.	210	4.2
19.	210	4.2
20.	205	4.1
21.	210	4.2

$\overline{x}$ = 4.16 NG

σ_n = 0.196

σ_n = 4.7%

TABLE 3B

TIME TEST

Date	Counts	NG
8/81		
12	160	3.1
13	160	3.1
14	180	3.5
15	155	3.0
16	170	3.3
17	155	3.0
18	170	3.3
19	165	3.1
20	180	3.5
21	155	3.0

$\overline{x}$ = 3.19 NG

σ_n = 0.19 NG

σ_n = 6%

TABLE 3C

SQUARE TEST

Site A	No. of Counts	NG
1	165	3.2
2	165	3.2
3	180	3.5
4	165	3.2
5	150	2.9
6	165	3.2
7	155	3.0
8	175	3.4
9	165	3.2
10	190	3.7
11	140	2.7
12	145	2.8
13	140	2.7
14	135	2.6
15	135	2.6
16	155	3.0
17	145	2.8
18	145	2.8
19	195	3.8
20	185	3.6
21		

$\overline{x}$ = 3.1 NG

σ_n = 0.36 NG

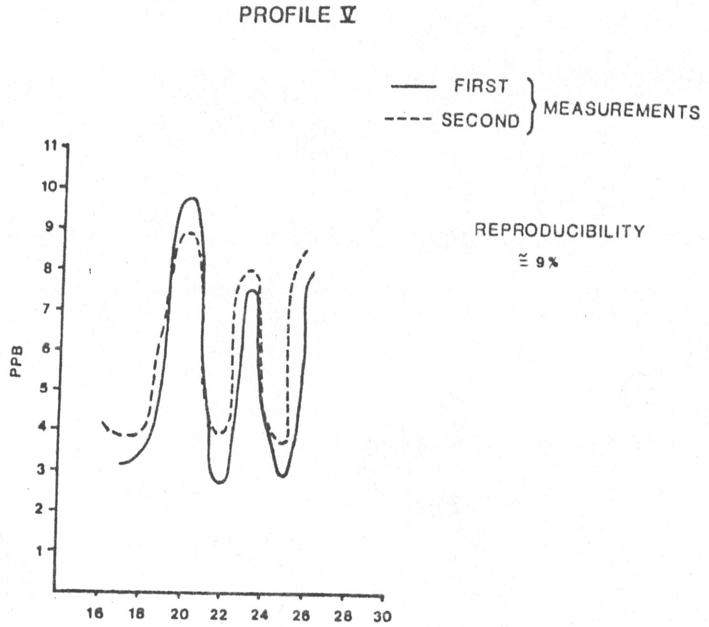
σ_n = 12%

Site B	No. of Counts	NG
1	265	5.2
2	240	4.7
3	285	5.6
4	205	4.1
5	185	3.6
6	195	3.8
7	230	4.5
8	225	4.4
9	295	5.8
10	255	5.0
11	175	3.4
12	225	4.4
13	215	4.2
14	205	4.0
15	210	4.1
16	200	3.9
17	290	5.7
18	190	3.7
19	235	4.6
21	240	4.9
21	240	4.7

$\overline{x}$ = 4.5 NG

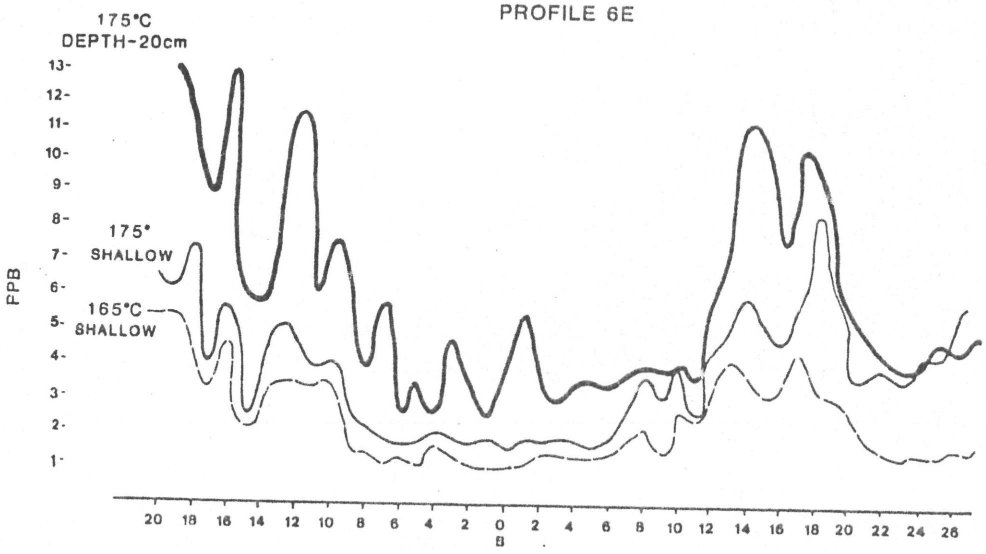
σ_n = 0.67 NG

σ_n = 15%



FIELD DATA REPRODUCIBILITY

FIG.22



PORTION OF PROFILE 6E, SAMPLES TAKEN AT DIFFERENT DEPTHS AND ANALYZE WITH DIFFERENT AMALGAMATION TEMPERATURES

FIG.23

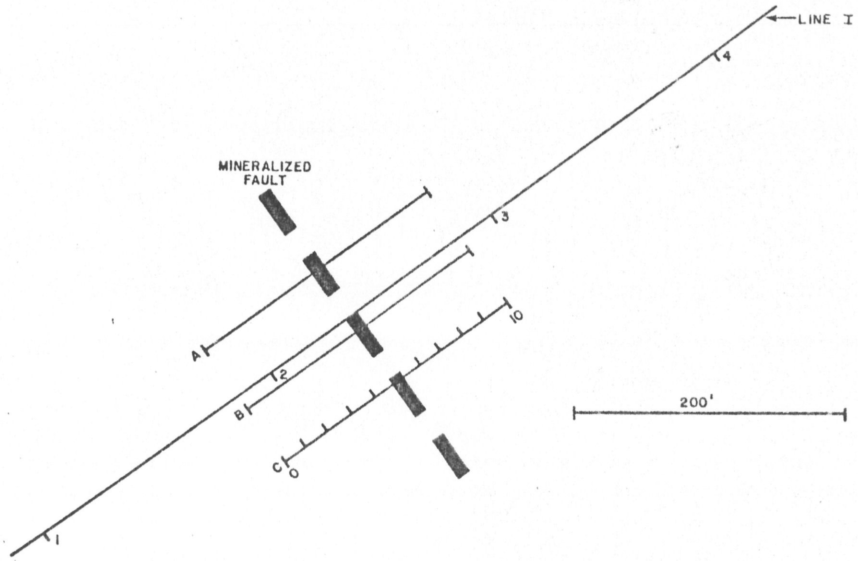


FIGURE A. SURVEY LINES OVER MINERALIZED FAULT

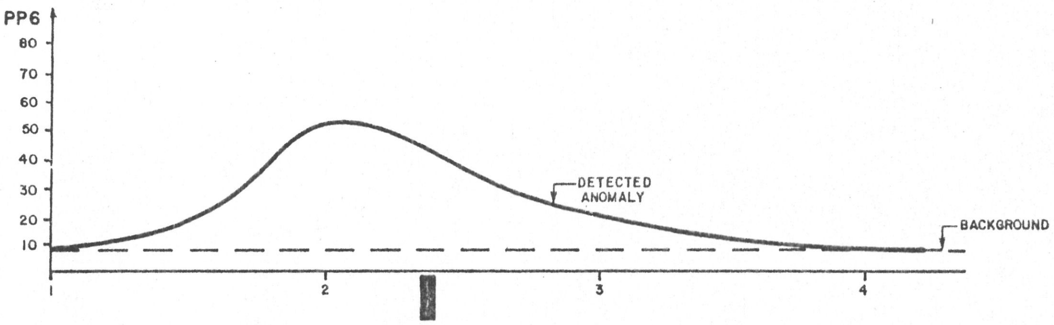


FIGURE B. LINE I. MERCURY ANOMALY DETECTED WITH 200' SPACING

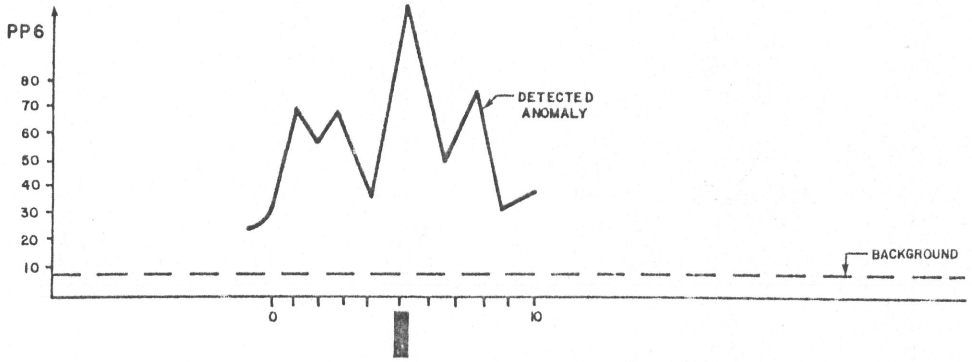


FIGURE C. LINE B. MERCURY ANOMALY DETECTED WITH 20' SPACING

FIG.24

V. MOBILE, DIFFERENTIAL, AND TOTAL MERCURY ANALYSIS IN FIELD APPLICATIONS

V.1 Mobile and Total Mercury Analysis - Comparison

During the development of the mobile mercury method, a large number of analyses were conducted over a wide extraction temperature range. This study provided a much better understanding on the behavior of mercury forms in the environment, and allowed a comparison of the resolving power of mobile and total mercury methods. In order to illustrate the diagnostic capabilities, both methods are presented for two case studies.

The first example, Area 1, illustrates a large scale mobile mercury survey over a deeply seated (approximately 1500 feet) molybdenum ore body in the New Mexico area. The second example, Area 2, shows the results of a survey conducted over gold mineralization in the Arizona area which is buried by 100 feet of gravel.

Area 1

During the course of a field survey in New Mexico, it was apparent that more important information could be obtained from low temperature mercury data besides the location of faults and fracture zones. Within the survey area, a small scale mining operation has been sporadically conducted since the turn of the century for Pb, Zn, Ag, and Au. A generalized geological cross-section for the area is presented in Figure 25, which shows this shallow mineralization. More recent geological studies, coupled with modern exploration concept and preliminary core drilling, suggested that this area has potential for a large molybdenum-tungsten ore body. The large Mo-W ore body detected by this mercury survey is also shown in the central part of the cross-section, on Figure 25. As shown, the total mercury content yielded the highest reading of approximately twice the background levels over the mineralized outcrop. However, the remaining traverses yielded only background values of approximately 40 ppb. Measurements of mercury in soil-gas provided more contrast, with significant anomalies being detected above major fault zones as well as over the mineralized outcrop.

Mobile mercury analysis was found to generate the most definitive and complete data set. While mobile mercury was observed to be sensitive not only to the presence of faults, known shallow mineralizations, breccia pipes, and near-surface alterations, it also indicated the presence of the deep concealed Mo-W mineralization at a depth of 1500 feet. Collection of over 3000 samples on closely-spaced 100 foot grid pattern (Figure 26), clearly demonstrated that the vertical projection of this ore body corresponds directly to a negative (below background) mercury halo.

GENERALIZED DISTRIBUTION OF TOTAL MERCURY, MOBILE MERCURY AND MERCURY IN SOIL GAS OVER GEOLOGICAL CROSS-SECTION - NEW MEXICO AREA -

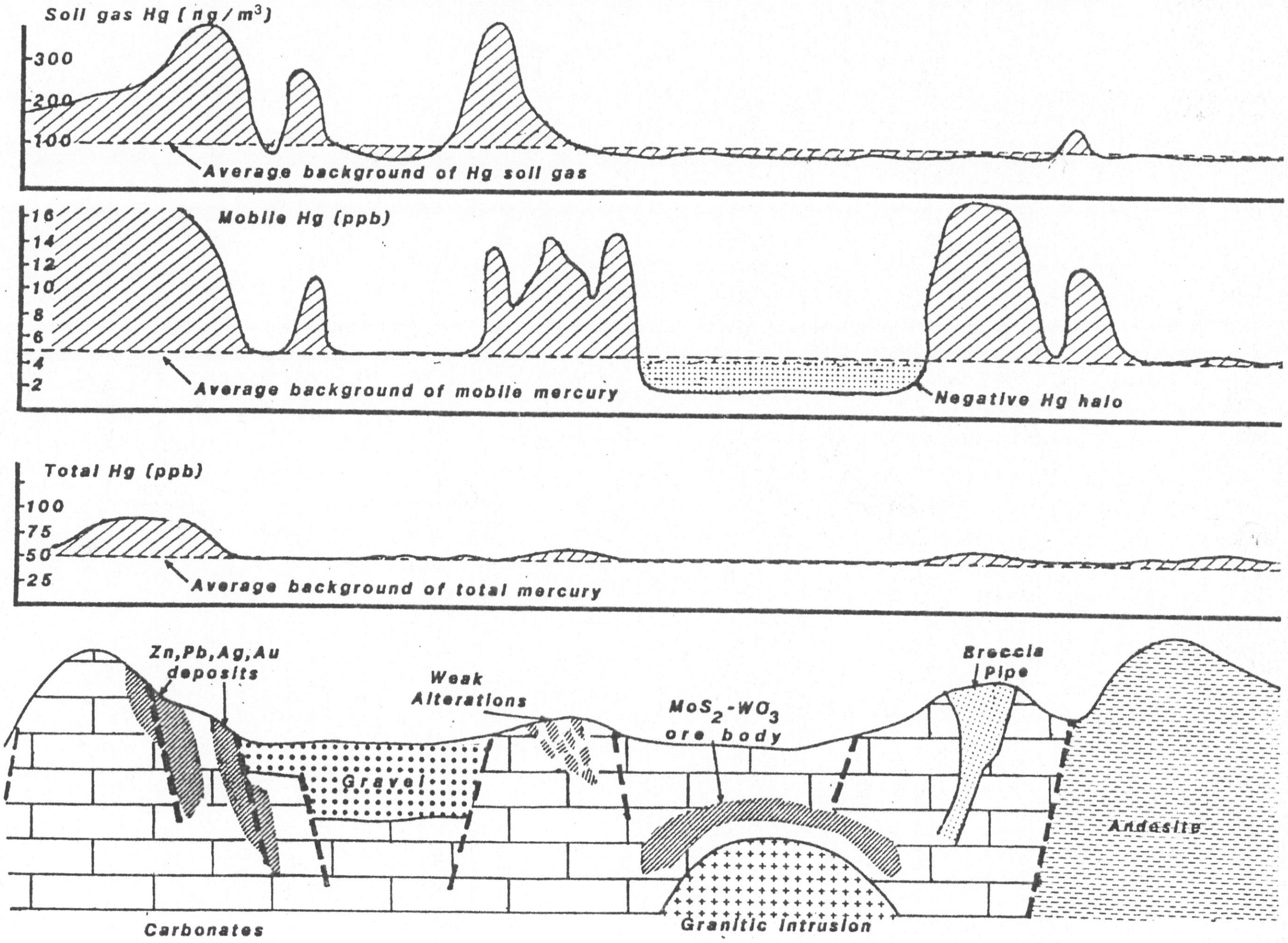
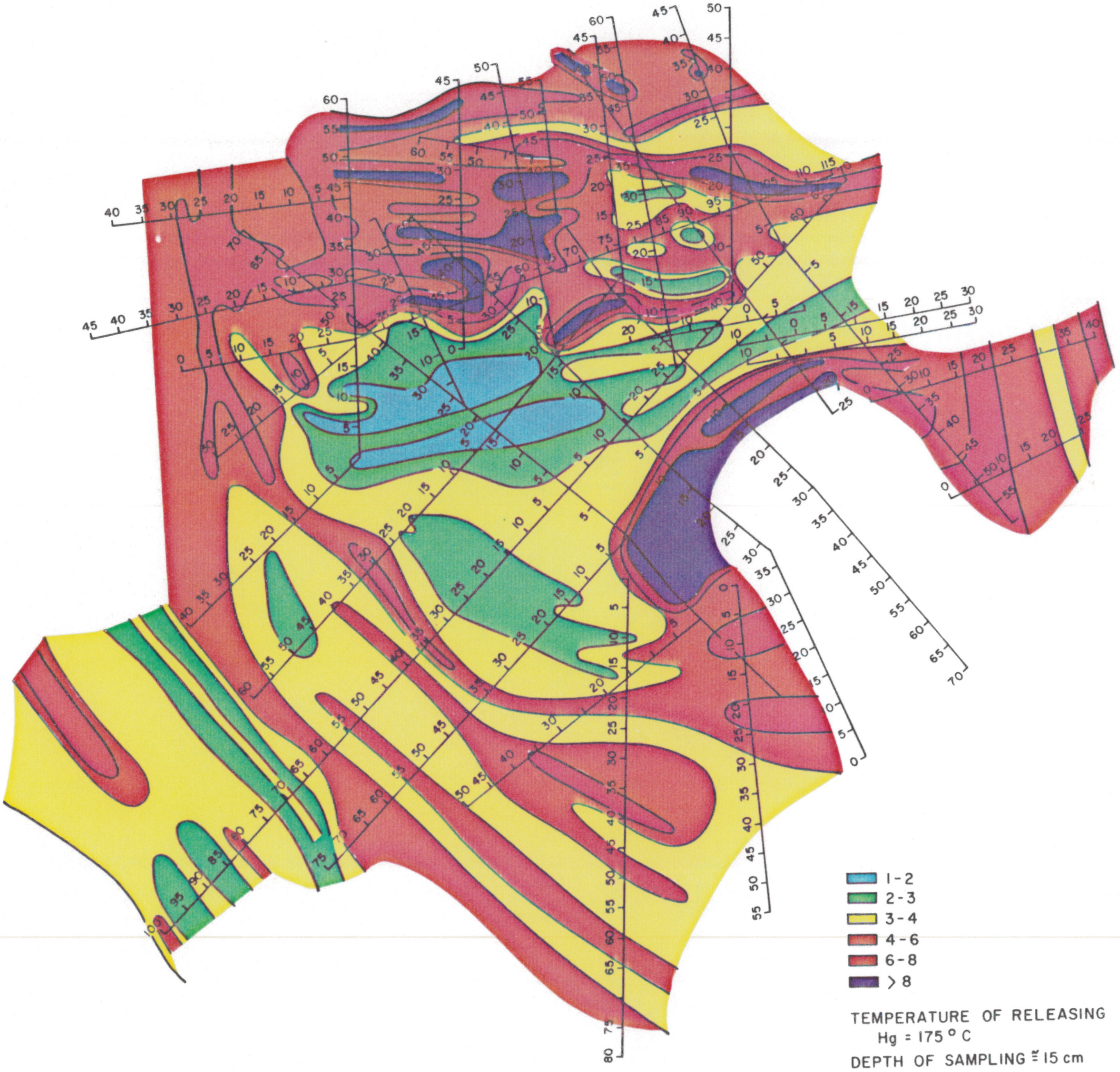


FIG.25



TEMPERATURE OF RELEASING
Hg = 175 °C
DEPTH OF SAMPLING ≅ 15 cm

MAP (2) OCCLUDED MERCURY MAP

FIG. 26

Area 2

In this area gold mineralization was discovered in subcropping rocks in the center of the valley. With the exception of this outcrop the rest of the bedrock is covered by a 100 foot thick cover of gravel. Detailed geologic and geochemical studies established that gold mineralization was formed though the leaching of gold by fluids from the volcanics and subsequent gold deposition on the volcanic/sedimentary fault contact. In order to trace this buried contact, samples were collected on 100 foot centers and analyzed for both total and mobile mercury content. The total mercury analysis yielded elevated values only above the subcropping mineralized rocks, while the remainder of the survey area showed only background values (Figure 27). Analysis of mobile mercury produced the best data set, with the highest mercury values found above the shaft and along the surface projection of the mineralized contact zones (Figure 28). In addition, two smaller anomalous zones were discovered which are associated with previously mapped valley boundary faults. The presence of gold mineralization in the subsurface was confirmed by two drill sites in the northern and southern portions of the survey.

V.2 Applications of Mobile and Differential Mercury Techniques

Three case studies conducted in different geological settings are presented in the following section to illustrate the resolving power and the efficiency of the mobile mercury method. In addition, the results of differential mercury analysis on drill cores illustrate the advantages of the DTA method for detailed studies. To illustrate the efficiency of the mobile mercury method a small scale reconnaissance survey was conducted over a gold prospect in the North Carolina area.

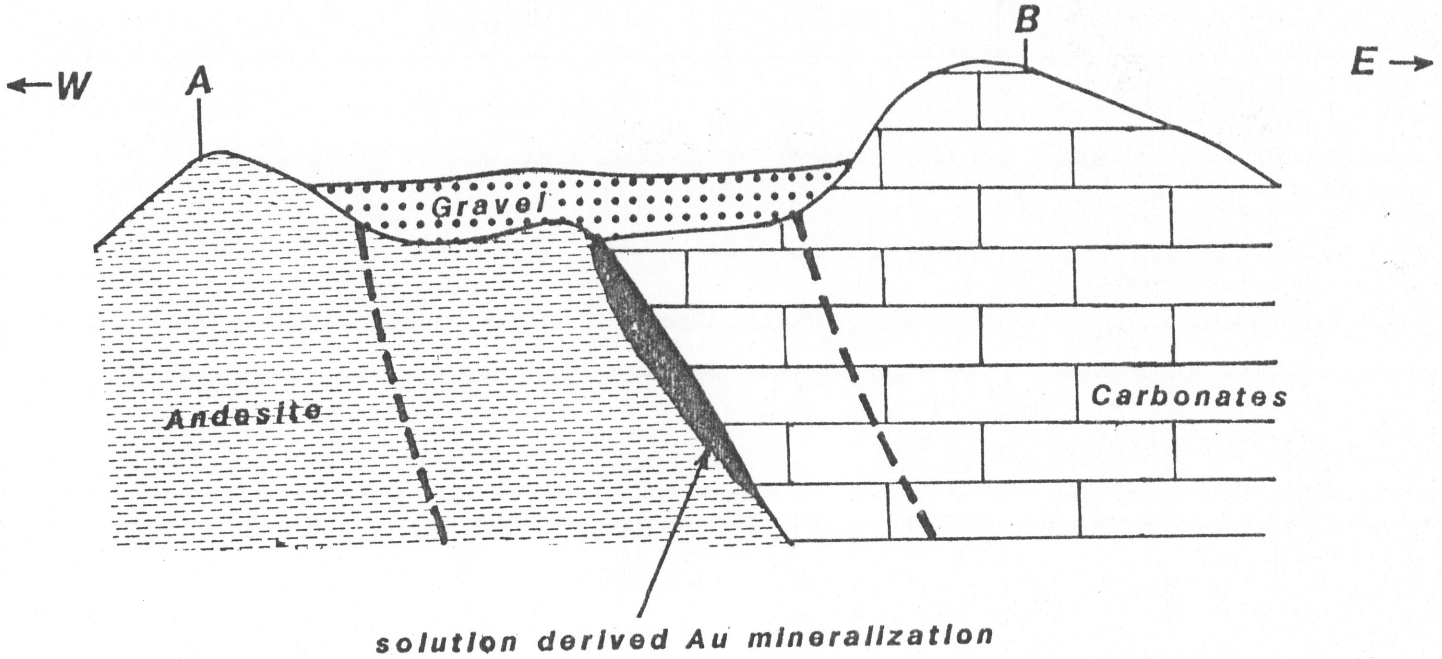
Case 1

The collection and analysis of about 60 samples was performed by a two man crew in a period of about 3 hours. The results of this survey are shown on Figure 29. As illustrated, the mercury values indicate sharp distinctive boundaries between background and anomalous areas. The high mercury values map the extent of gold mineralization. This survey demonstrated that the mobile mercury method has the diagnostic potential to map the presence of gold mineralization in the Appalachian area. In addition, this application also illustrates the speed and economy of such surveys.

Case 2

Another case study presented on Figure 30, illustrates a large scale survey (over 2000 samples were collected on a 100 foot centers) conducted in the Mohave Desert area. The gold

GEOLOGICAL CROSS-SECTION



RESULTS OF TOTAL Hg SURVEY

RESULTS OF MOBILE Hg SURVEY

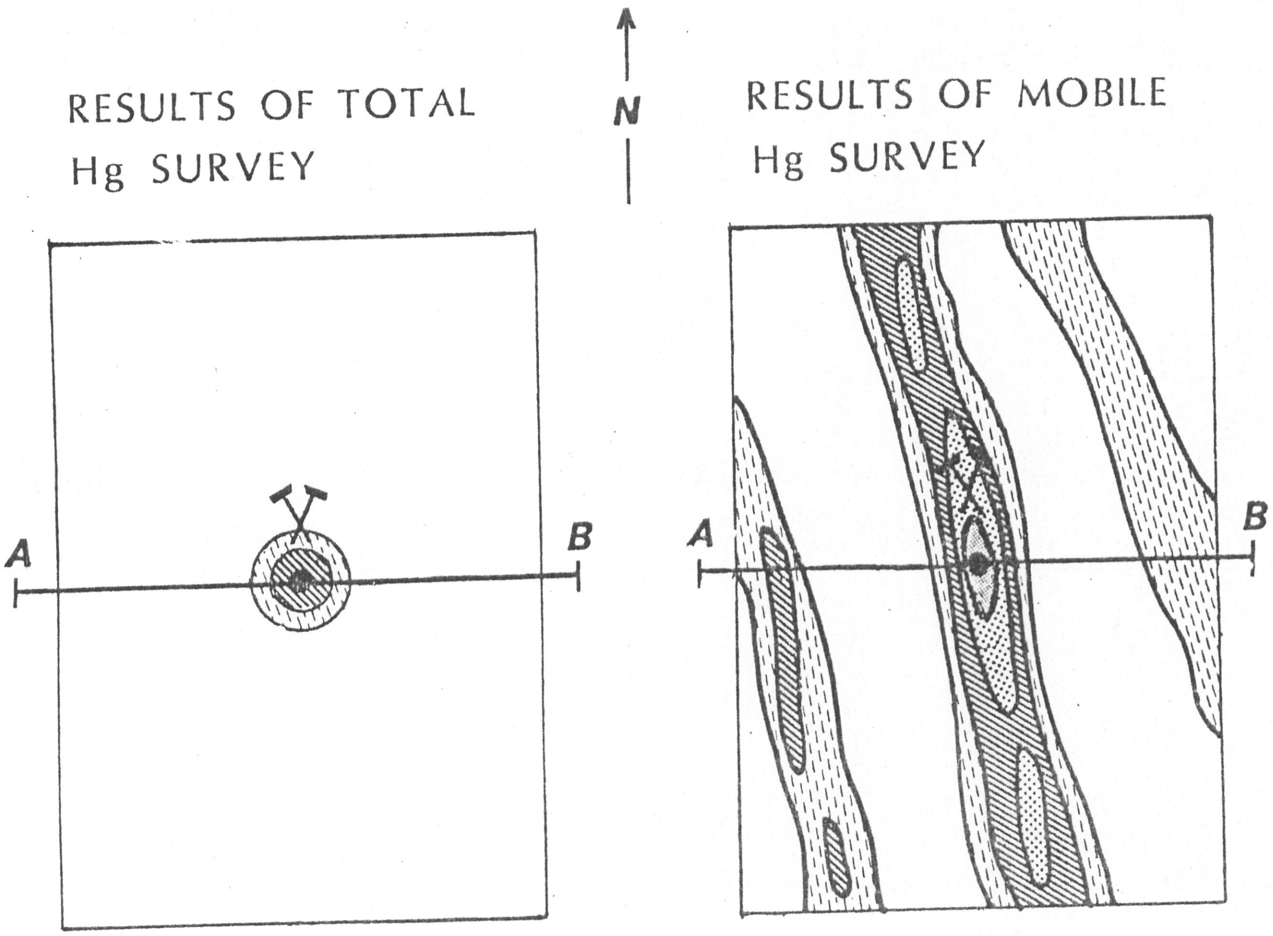


FIG. 27

OCCLUD MERCURY MAP

"GOLD BUG"

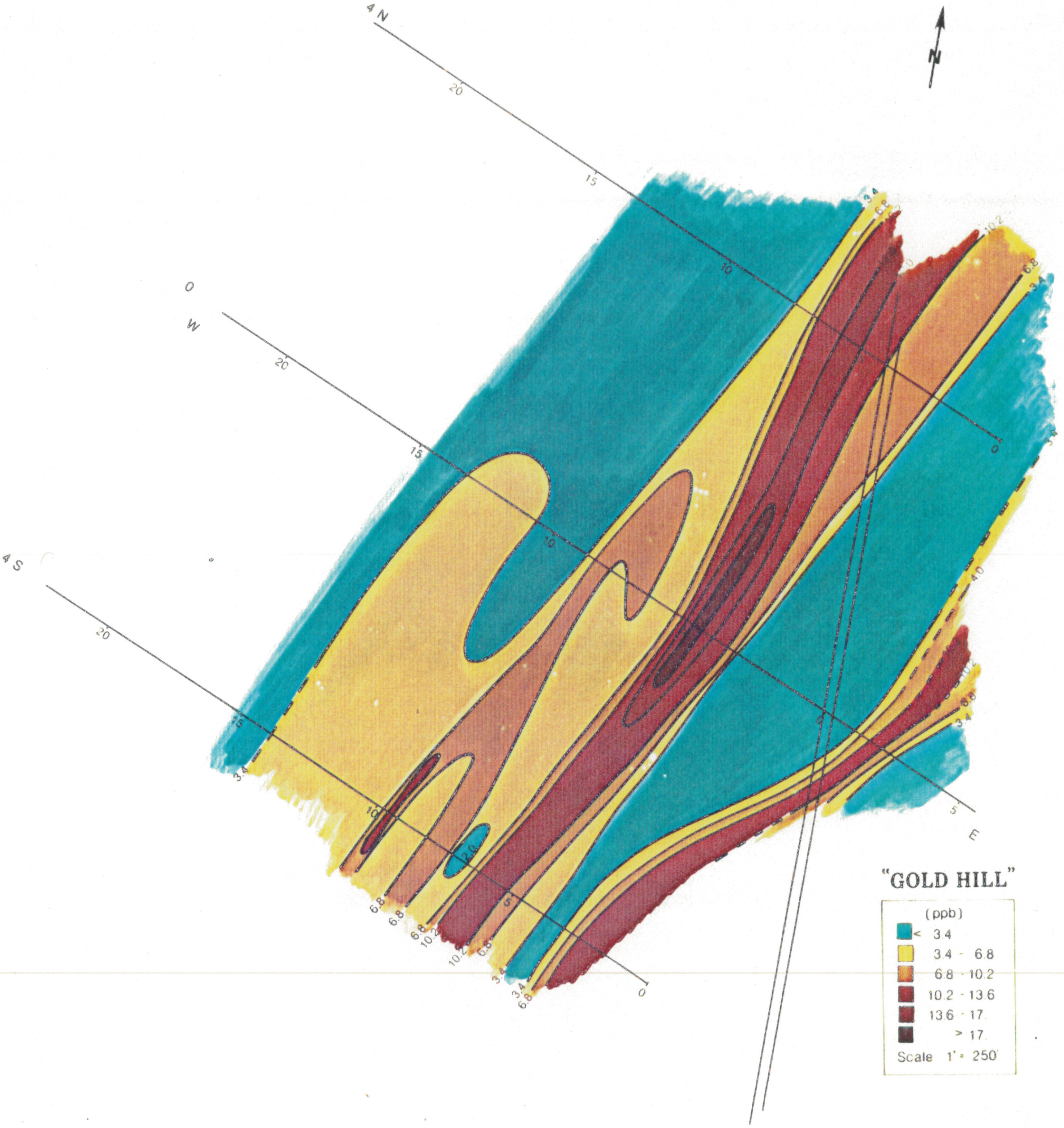
ppb

🟨	0 - 7.3
🟩	7.3 - 9
🟦	9 - 13.2
🟥	13.2-17.6
🟪	> 17.6

● DRILL SITES

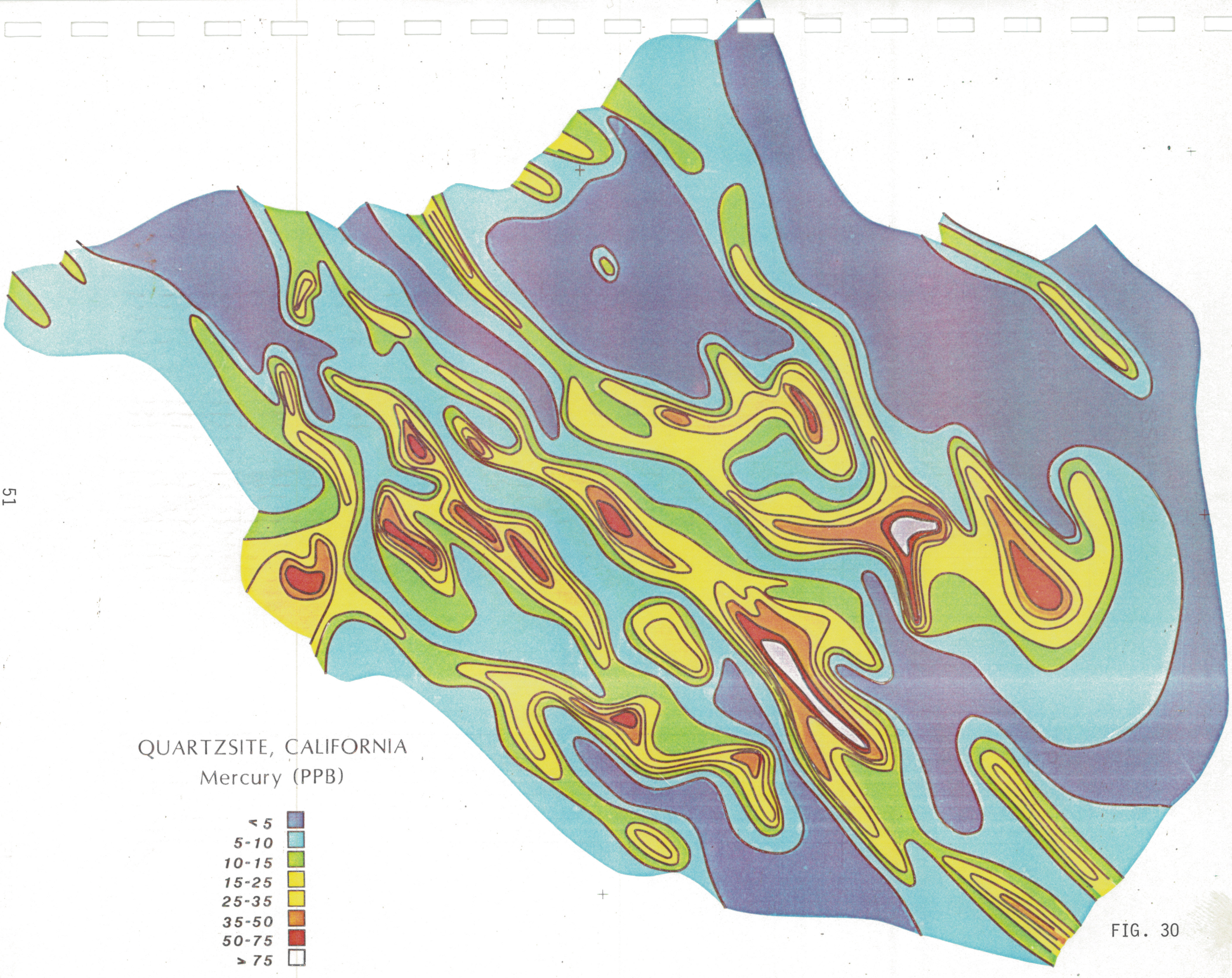
SCALE 1" = 1,000'

FIG. 28



4 N
20
15
10
0
W
20
15
10
4 S
20
15
10
5
0
5
E
N
3.4
6.8
10.2
13.6
17
20
40
"GOLD HILL"
(ppb)
🟦 < 3.4
🟨 3.4 - 6.8
🟧 6.8 - 10.2
🟥 10.2 - 13.6
🟥 13.6 - 17.
■ > 17.
Scale 1" = 250'

FIG. 29



QUARTZSITE, CALIFORNIA
Mercury (PPB)

FIG. 30

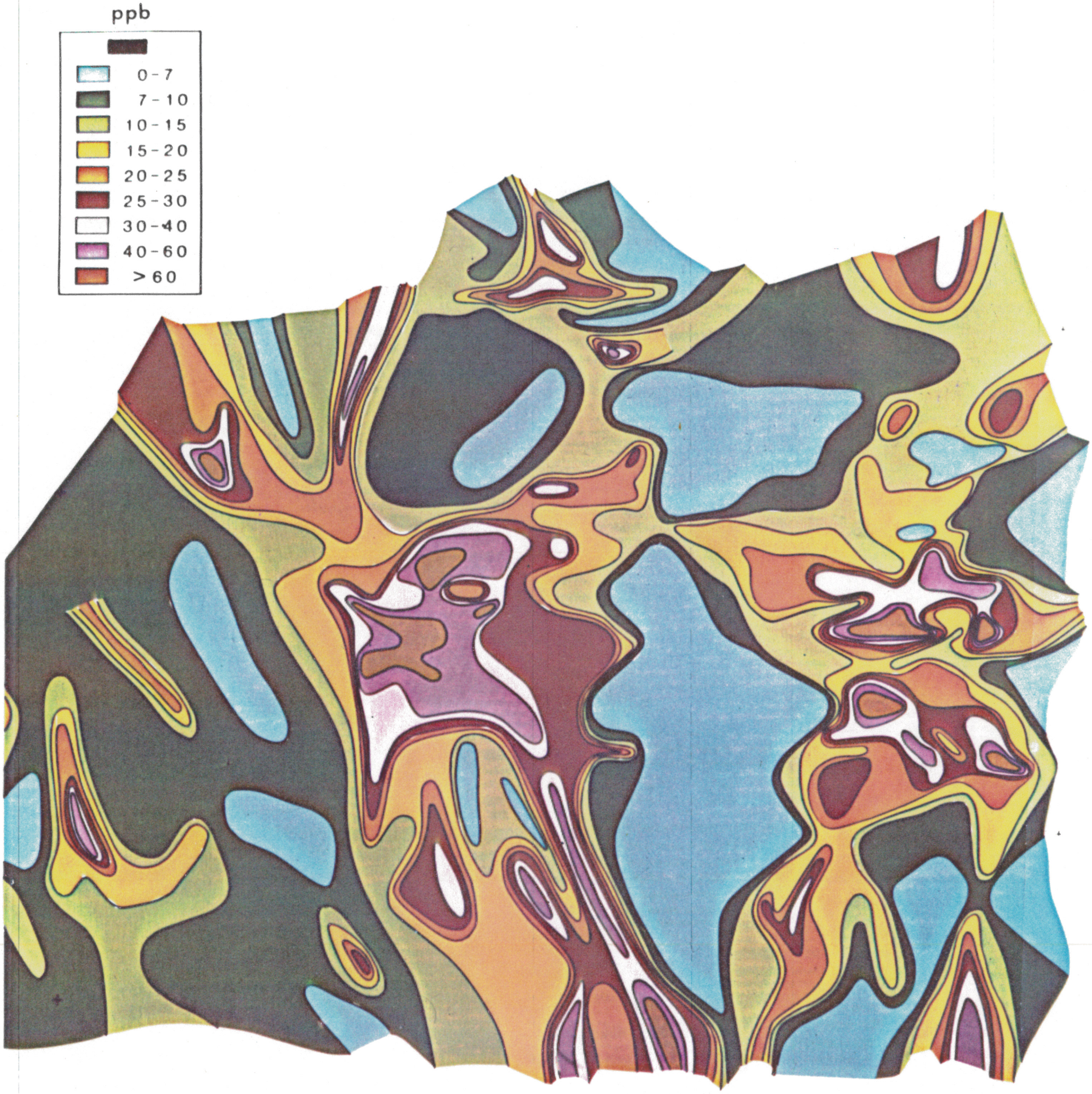


FIG. 31

mineralization in this area is associated with large scale (N-W trending) regional faulting. The majority of the survey area was covered by gravel with a thickness ranging from several to tens of feet. The mercury data (Figure 31) reflects this trend very well, allowing detection of gold mineralization through gravel cover. Analysis of mercury over several placer deposits in this area produced high reading of mobile mercury over each placer, demonstrating that this method could be indicative of gold in alluvial placer deposits.

Case 3

This final example illustrates a large scale detailed survey (of over 3000 samples collected) over an area where deeply seated Carlin type disseminated gold deposits were expected. The samples were collected on 100 and 50 foot centers. The results of this survey, presented in Figure 30) show two large N-S trending anomalies. Both anomalies were detected above the ridges of adjacent mountains, while the valleys indicated mostly background values. The eastern anomaly can be divided into two portions, southern and northern. The southern anomaly is related to shallow gold mineralization exploited since the turn of the century.

The northern anomaly outlined the aerial extensions of the gold ore body at 600 feet as established from over 20 drill holes. The western anomaly, although very promising, has not been tested by the drill bit. To further investigate the distribution of mercury forms with depth, differential mercury analyses were conducted on samples of soils and rocks from drill holes. The results of these analyses are described in the following section.

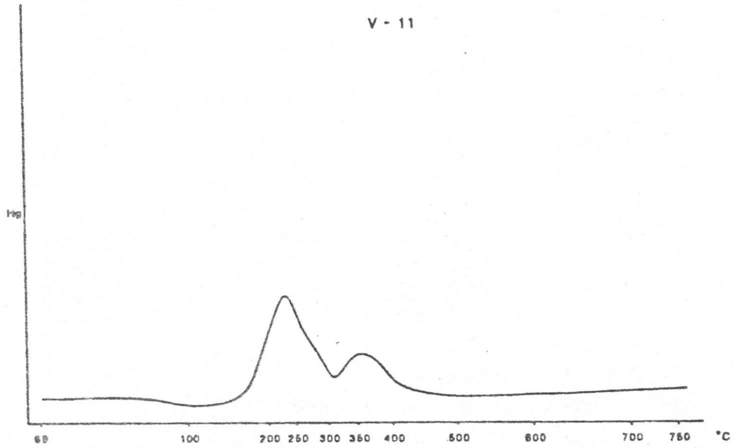
Application of Differential Mercury Technique

The study presented below exemplifies the use of differential mercury analysis in the exploration for precious metals. The differential mercury studies were conducted on samples of soils and rocks from both surface sediments and deep boreholes associated with a "Carlin type" gold deposit in Nevada. The following section summarizes the results of our findings regarding the behavior of mercury species in the soils and rocks over and within this gold ore deposit.

Soils

Differential mercury curves obtained on soil samples from this deposit have been divided into three general groups (Figures 32 A-C). These can be listed as follows:

MERCURY IN SOILS OVER MINERALIZED AREAS.



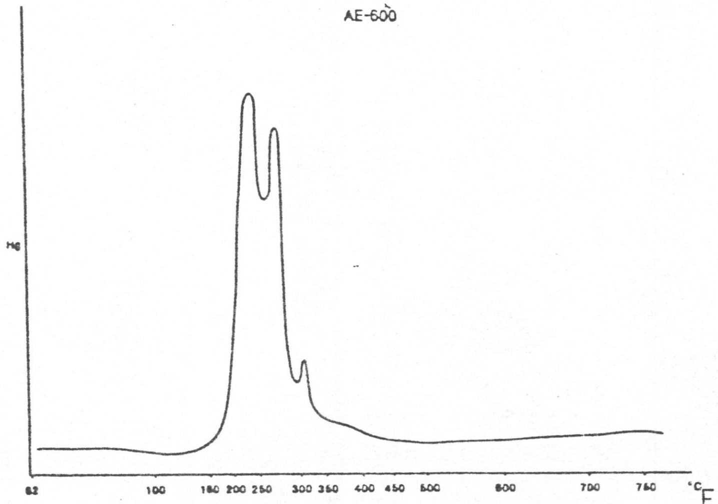


FIG. 32C

MERCURY IN SOILS OVER NON-MINERALIZED AREAS.

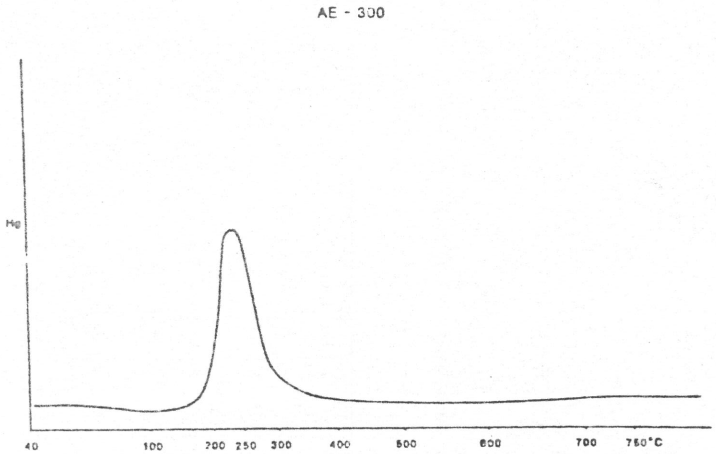


FIG. 32A

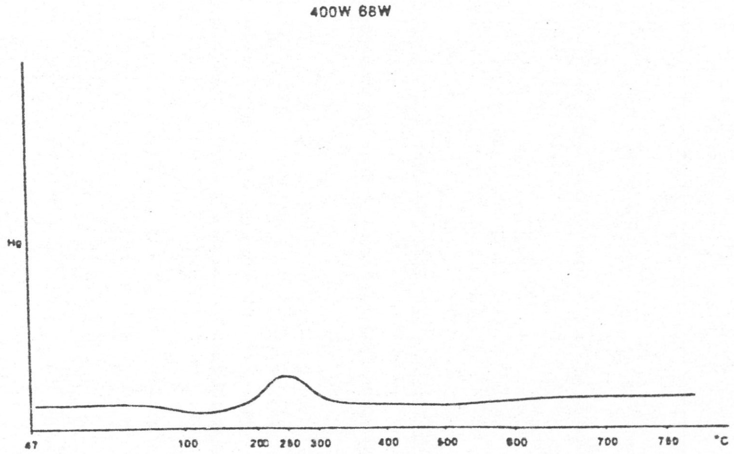


FIG. 32B

1. Soils collected over areas containing only gangue rocks

These soil samples yielded only one small peak of mercury with an extraction temperature in the range from 200°-300°C (Figure 32A). These results are in good agreement with Fursov's (1977) findings on the existence of mercury forms in nonmineralized rocks.

2. Soils collected above significant faults or concealed mineralization.

These soils yielded one large peak of mercury with a temperature of extraction in the range of 160-350°C (Figure 32B) which is somewhat wider in range than the gangue rock soils. This change in the magnitude of the peak can be interpreted as a result of mercury vapor influx, while the change in width indicates either the effect of soluble mercury compounds or near surface conversion of mercury forms.

3. Soils Collected from Mineralized Areas

Soils collected directly above mineralized areas showed two to three peaks of mercury with a temperature of extraction from 160-450°C (Figure 32C). This suggests the presence of mercury vapor, mercury compounds, and mercury within the mineral structure. These findings suggest that during initial exploration studies, the analysis of low temperature mobile mercury on soil samples is the most advantageous method of exploration.

Rocks

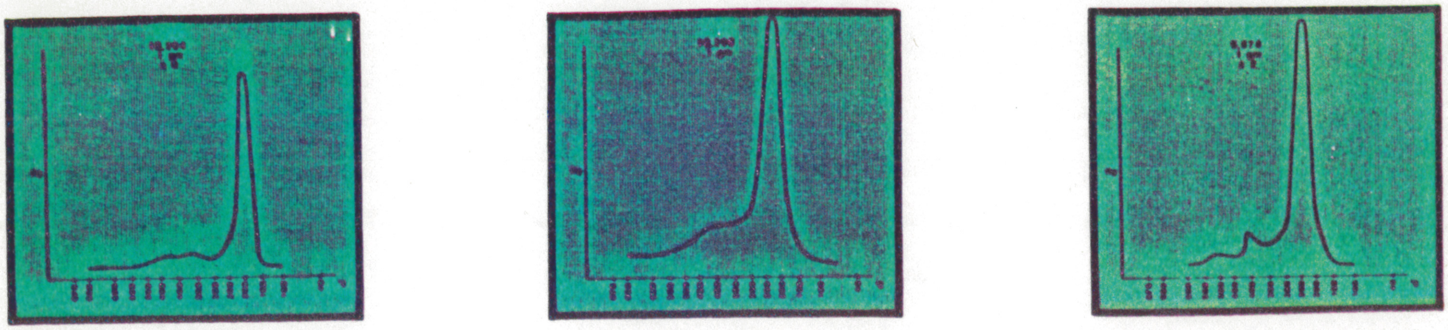
Differential mercury analysis conducted on surface and borehole samples of rocks yielded numerous mercury peaks in the temperature range from 150-700°C. The spatial location of these samples can be separated into four general groups. The zones are illustrated in Figure 33 and are listed as follows:

1. Far-zone: above the ore body

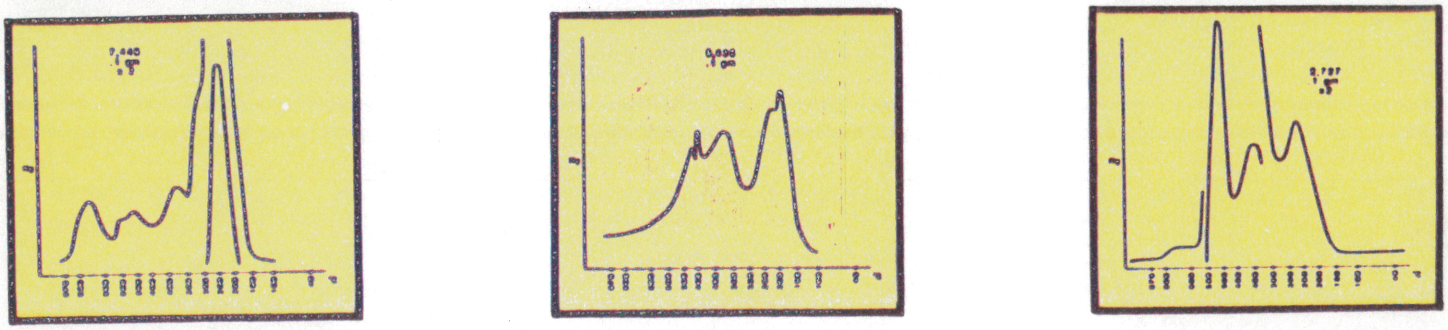
Samples that are collected at distances of several hundred feet, but not closer than 100 feet from any mineralization, have been classified as the far-zone. Results from the analysis of these samples yielded a single large mercury peak in the temperature range from 150-300°C with much smaller unresolved higher temperature forms. This pattern illustrates that at significant distances form an ore body, mercury vapor is mainly responsible for the development of the mercury halo. This mercury may be bound loosely to rocks, or it may exist in organo-complexed forms.

2. Near-zone: slightly above and containing the upper part of
an ore body.

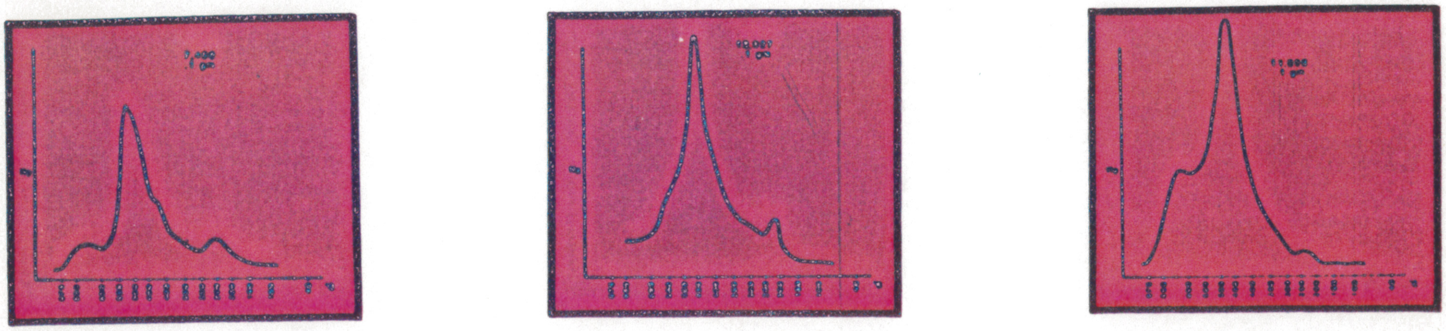
FAR ZONE—ABOVE ORE BODY



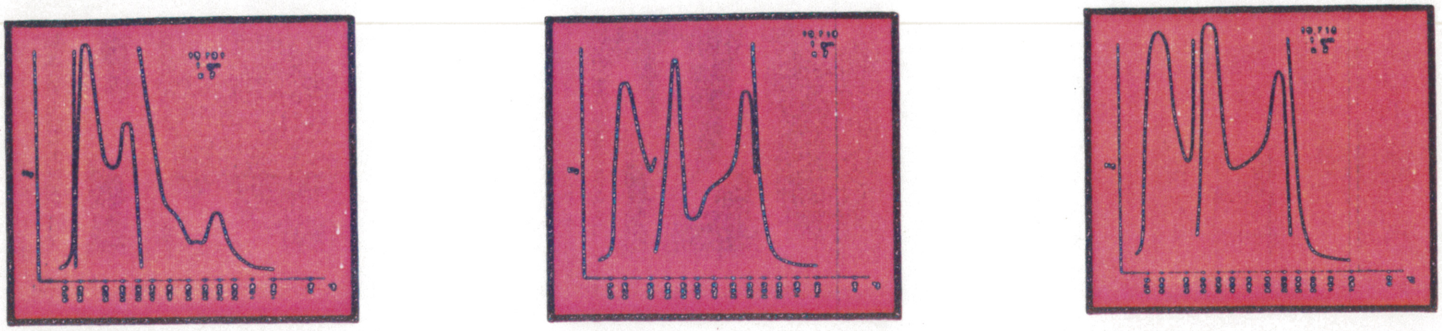
ABOVE AND UPPER PART OF ORE BODY



INDICATIVE OF GOLD



BELOW AND LOWER PART OF ORE BODY



CROSS SECTION OF MERCURY FORMS.

FIG. 33

The near-zone includes samples that were collected adjacent to and in the upper part of the ore body. Differential extraction of these samples yields more numerous peaks in a temperature range from 130-650°C. The low temperature mecury peak attains the largest values in this zone (depending on the proximity to the ore body, and intensity of secondary processes), although higher temperature forms are gaining importance. These higher temperature peaks may be indicative of less mobile more temperature resistant mercury forms, or mercury existing in crystal lattices of some minerals.

3. Ore-Zone: Samples from the ore zone.

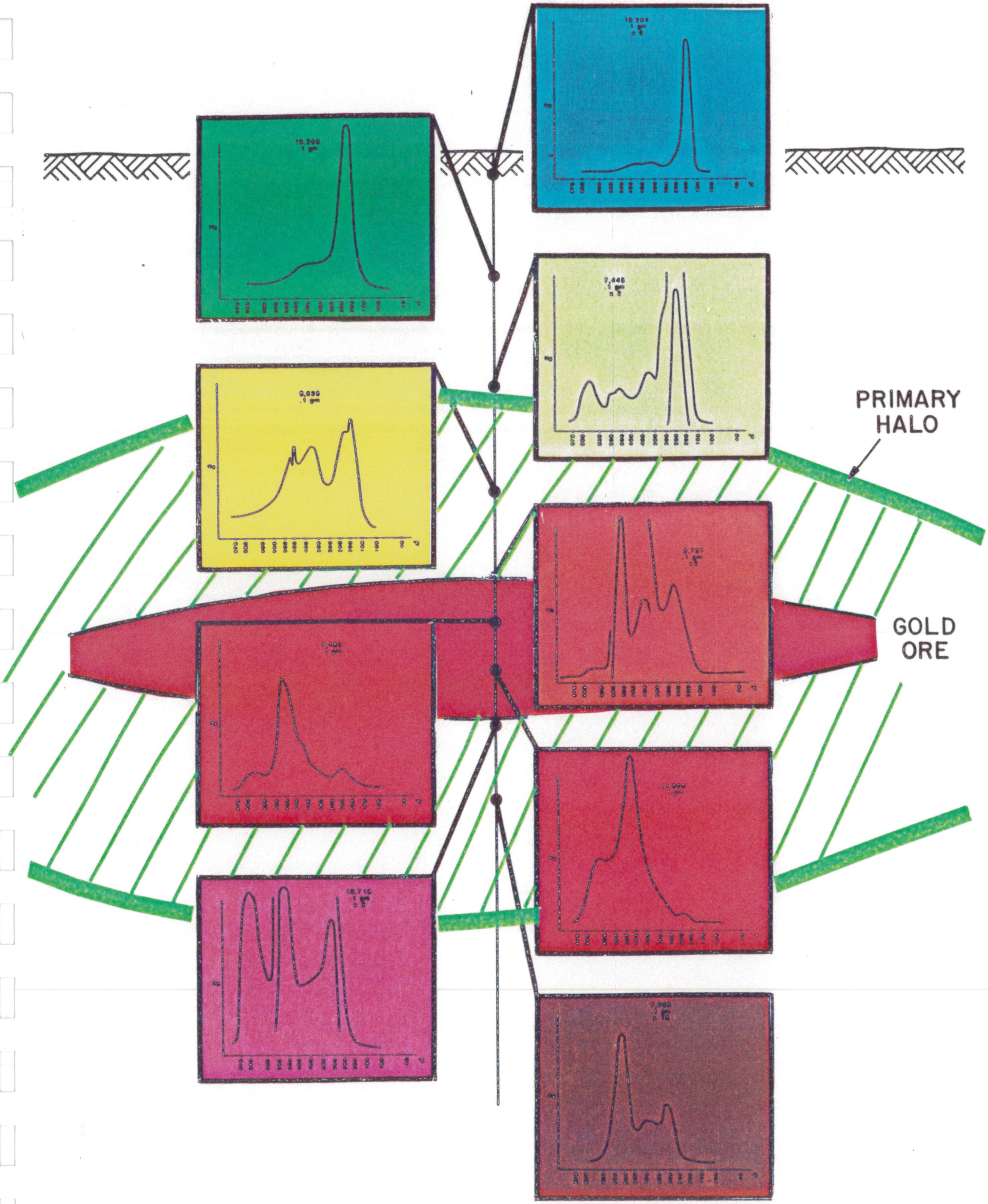
The samples collected directly from the mineralized ore zone, showed a dominant characteristic peak in the temperature range from 450-550°C, with smaller accompanying peaks in the temperature range from 200-700°C. This direct relation between temperature of extraction at 400-550°C and gold mineralization is interpreted as being an extraction of mercury from gold (mercury can be released from gold amalgam by temperature from 380-500°C) or possibly the release of mercury from the crystal lattice of arseno-pyrite, which is associated with the Au mineralization in this ore body.

4. Low-Zone: Zone below an ore body and containing lower part of an ore body.

Samples which are collected from the lower part of the ore body, and below the ore body is classified as the low-zone. These samples yielded a mercury extraction pattern having a wide range of peaks in the temperature range from 200-700°C. In this zone a characteristic high temperature peak (570-650°C) appears to be dominant. This peak was very seldom detected in the upper parts of this ore body, and in this case, is interpreted as an extraction of mercury from silica.

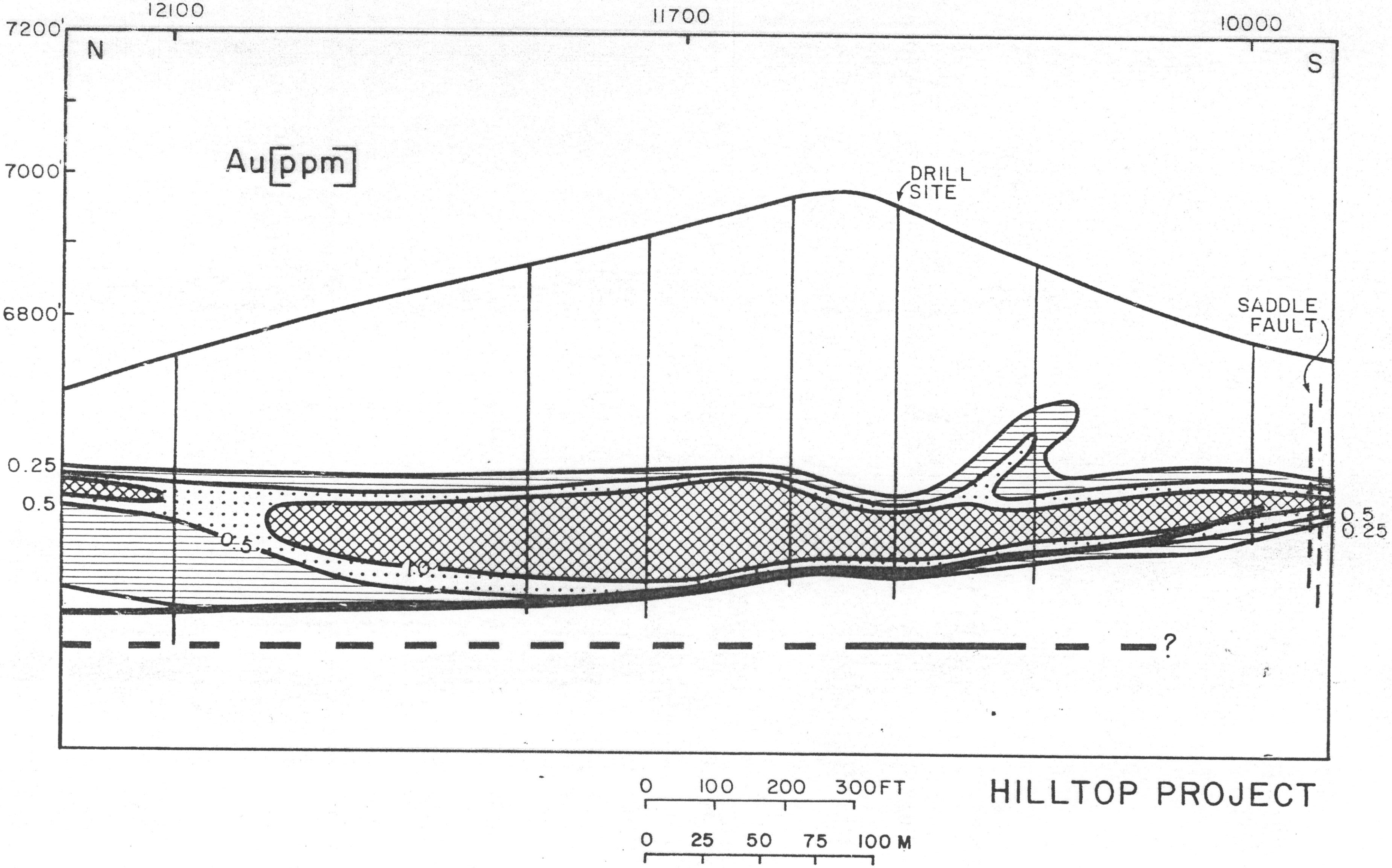
Detailed analysis of differential mercury curves allows one to establish a general relationship between the characteristics of these curves and the geometry of the ore body (Figure 34). As illustrated in this figure, there is a clear transition of mercury forms with depth. The lower temperature forms are characteristic of more distant zones, the far-zone and the near-zone. The higher temperature forms of mercury are distributed in the ore-zone and in the low-zone. This indicates that differential analysis of mercury can be helpful, not only to vector the direction to an ore body, but also to define the level of erosion once the pattern of differential curves for this type of mineralization has been established.

A vertical cross-section of low temperature mercury distributions in and around an ore body, with gold mineralization is shown as an overlay in Figure 35. As shown, the lowest mercury content was detected inside the ore body. Larger values were noted at a distance of about 100 feet from the ore body, with elevated concentrations continuing practically to the surface. A surface map of low temperature mercury is shown on Figure 31. The analysis of high temperature mercury in the range from 450-550°C through the entire deposit is presented in Figure 36. As shown in this figure, these high temperature mercury forms precisely outline the zone of gold ore.



SCHEMATIC REPRESENTATION OF VERTICAL DISTRIBUTION OF Hg FORMS.

FIG. 34



HILLTOP PROJECT

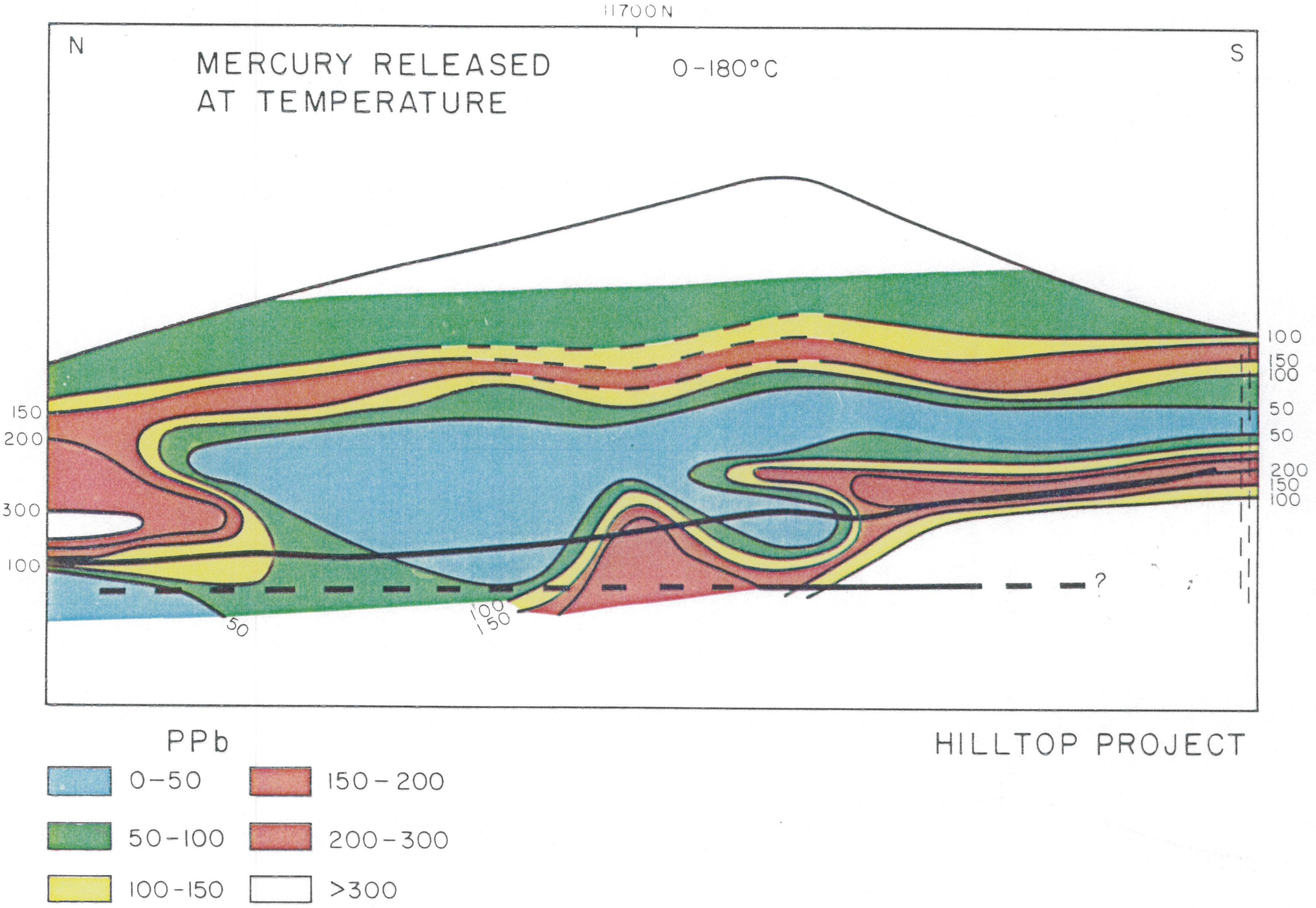

11700N
N
S
MERCURY RELEASED
AT TEMPERATURE
0-180°C
150
200
300
100
100
150
100
50
50
200
150
100
50
100
150
?
PPb
🟦 0-50
🟩 50-100
🟨 100-150
🟥 150-200
🟥 200-300
☐ >300
HILLTOP PROJECT

FIG. 35

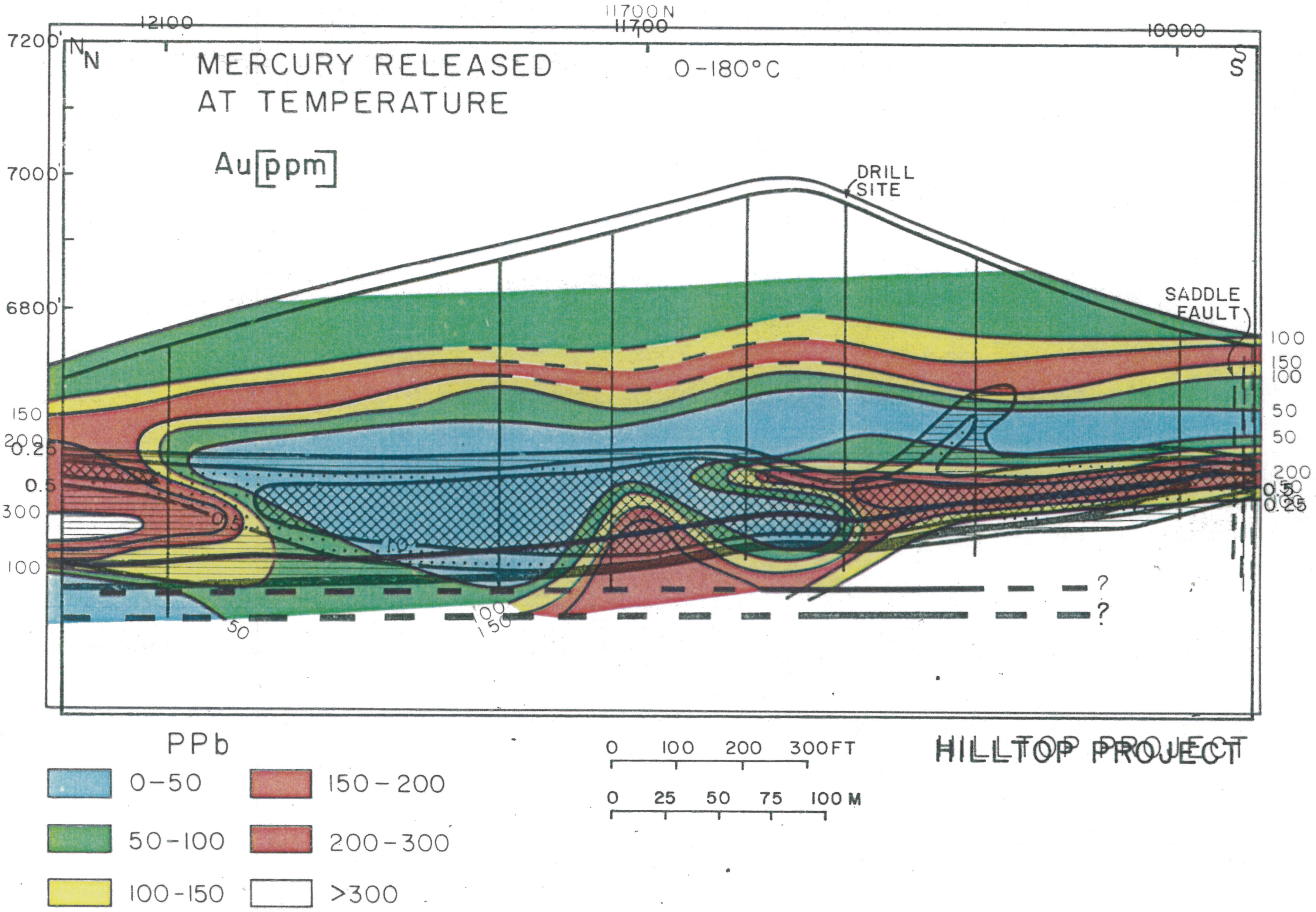
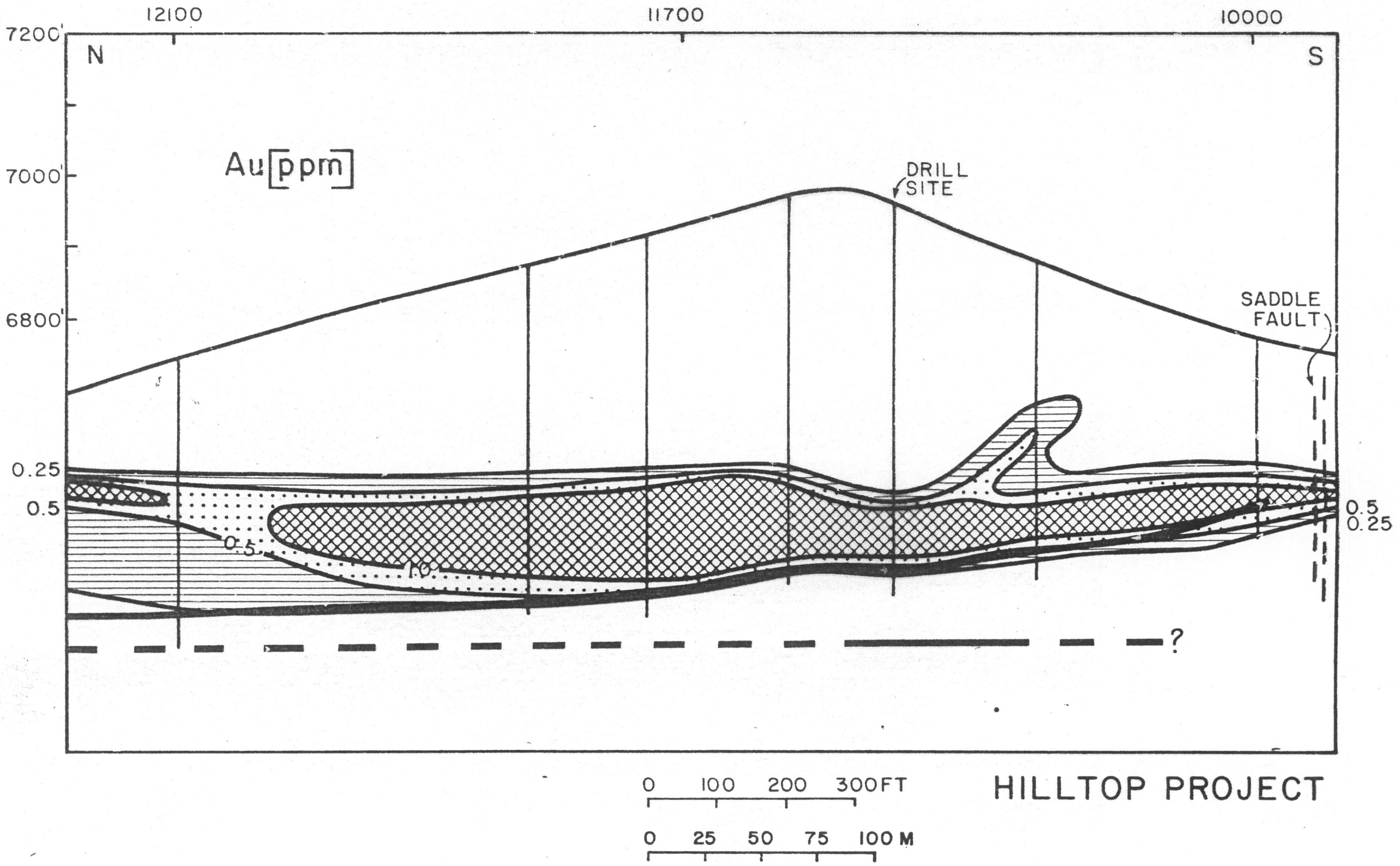

MERCURY RELEASED
AT TEMPERATURE
0-180°C
Au[ppm]
11700 N
12100
11700
10000
N
S
7200'
7000'
6800'
DRILL SITE
SADDLE FAULT
150
200
0.25
0.5
300
100
100
150
100
50
50
200
0.5
0.50
0.25
50
100
150
?
?
PPb
0-50
50-100
100-150
150-200
200-300
>300
0 100 200 300FT
0 25 50 75 100 M
HILLTOP PROJECT

FIG. 35



HILLTOP PROJECT

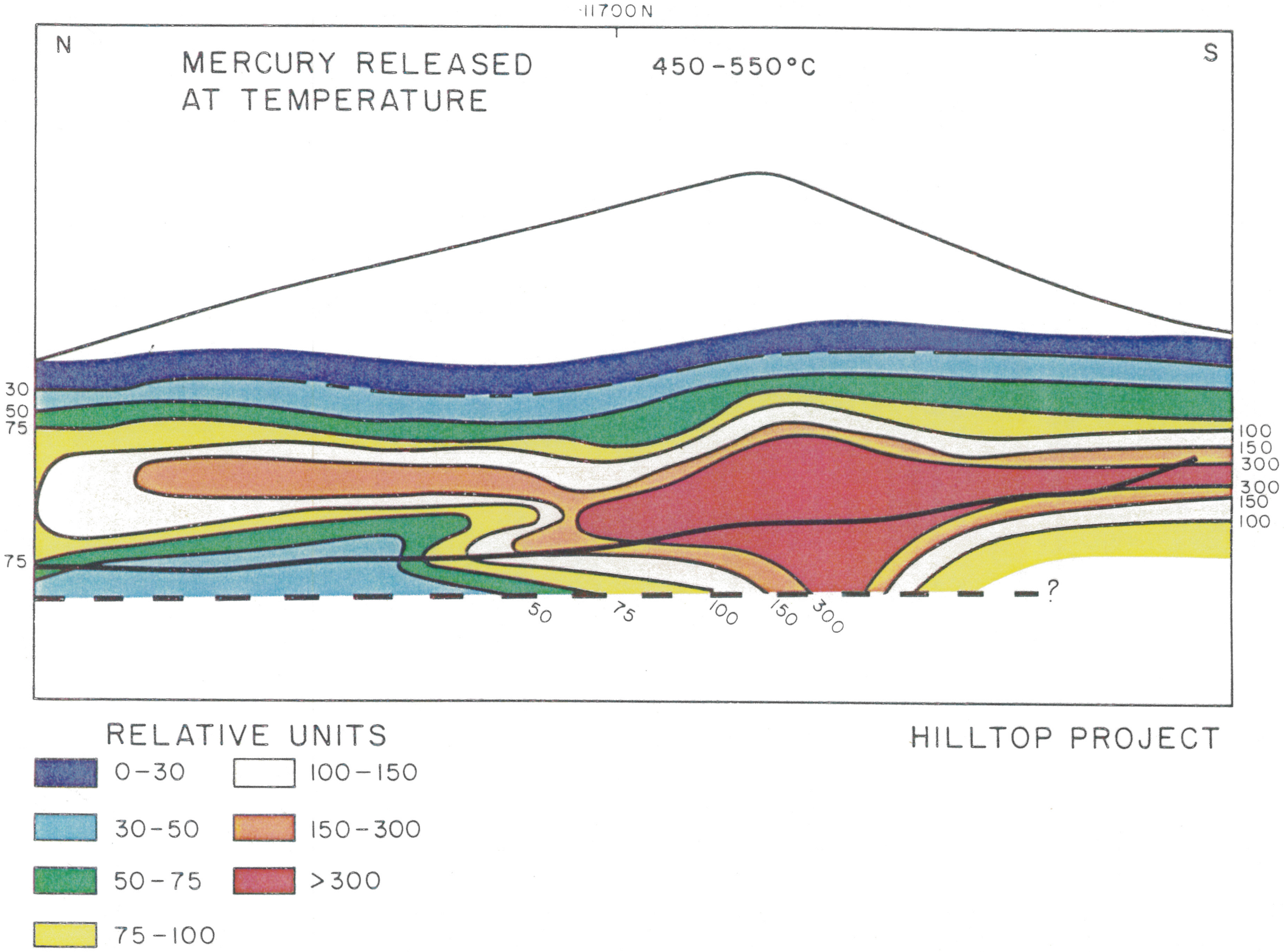

11700N
N
S
MERCURY RELEASED
AT TEMPERATURE
450-550°C
30
50
75
75
100
150
300
300
150
100
50
75
100
150
300
?
RELATIVE UNITS
0-30
30-50
50-75
75-100
100-150
150-300
>300
HILLTOP PROJECT

FIG. 36

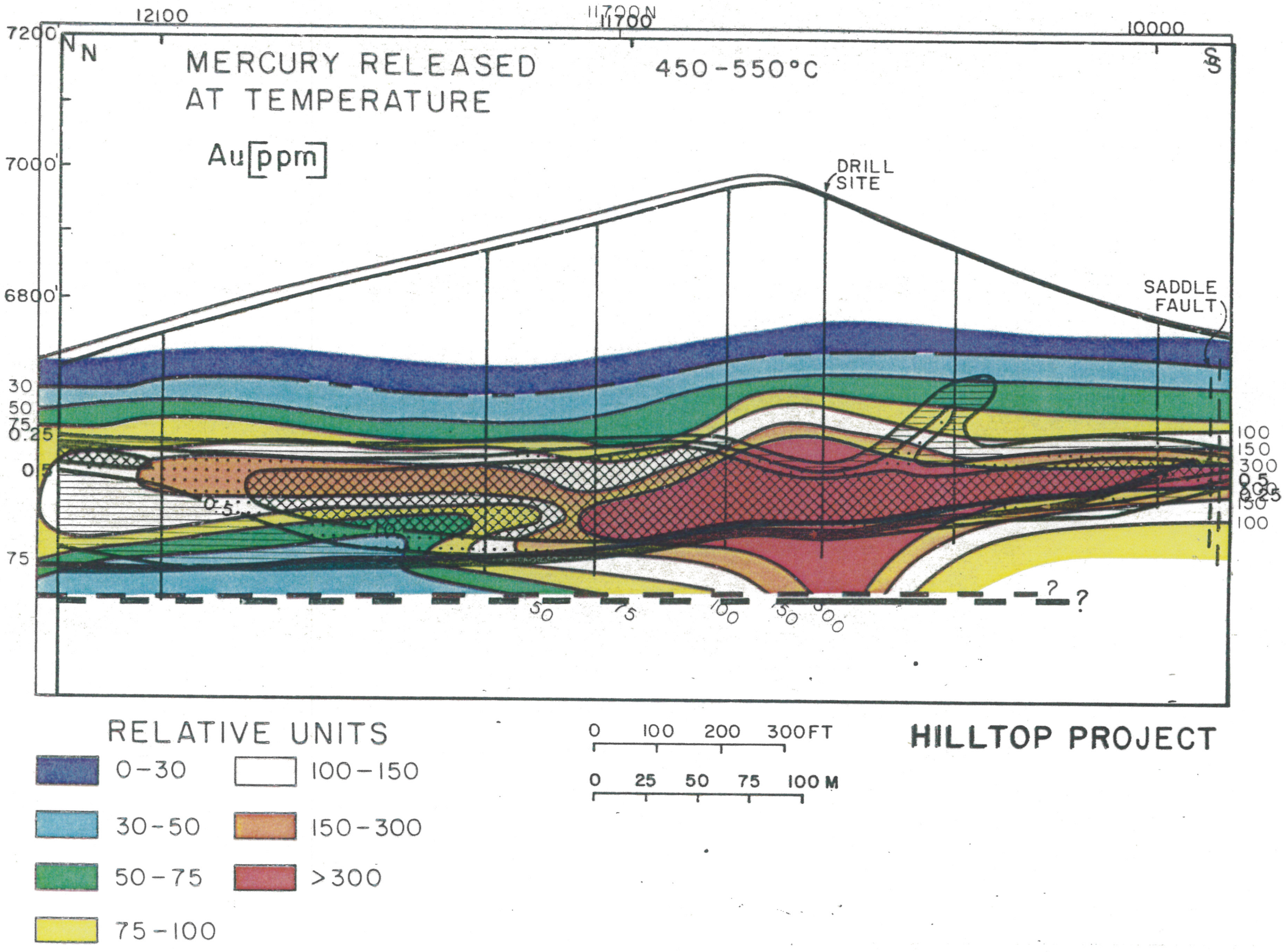

MERCURY RELEASED
AT TEMPERATURE
450-550°C
Au [ppm]
12100
11700N
11700
10000
7200
7000'
6800'
N
S
DRILL SITE
SADDLE FAULT
30
50
75
0.25
0
0.5
75
100
150
300
0.5
0.25
150
100
50
75
100
150
300
?
?
RELATIVE UNITS
0-30
30-50
50-75
75-100
100-150
150-300
>300
0 100 200 300FT
0 25 50 75 100 M
HILLTOP PROJECT

FIG. 36

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