STATISTICAL ANALYSIS OF STREAM SEDIMENT, PAN CONCENTRATE AND ROCK GEOCHEMICAL SAMPLES FROM THE TOLOVANA MINING DISTRICT, ALASKA

By
P.A. Metz

MIRL OPEN FILE REPORT 84-8

STATISTICAL ANALYSIS OF STREAM SEDIMENT, PAN CONCENTRATE AND ROCK GEOCHEMICAL SAMPLES FROM THE TOLOVANA MINING DISTRICT, ALASKA

By

P.A. Metz

OPEN FILE REPORT 84-8

Mineral Industry Research Laboratory
School of Mineral Engineering
University of Alaska, Fairbanks
Fairbanks, Alaska 99701

August 1984

TABLE OF CONTENTS

Page

Introduction..... 1

Bedrock Geology..... 1

Economic Geology..... 10

Geochemical Data Reduction..... 14

Discussion..... 53

Genetic Ore Deposit Models 55

Summary and Conclusions..... 56

References Cited..... 64

List of Figures

Figure 1 - Location map of the Tolovana mining district, Alaska..... 2

Figure 2 - Generalized geological map of the Yukon-Tanana Uplands Schist Terrane, Alaska..... 3

Figure 3 - Generalized geological map of the Tolovana mining district and adjacent areas..... 5

Figure 4 - Histogram of arsenic concentrations in stream sediments from the Tolovana mining district, Alaska..... 16

Figure 5 - Log Concentration - probability plot of arsenic concentrations in stream sediments from the Tolovana mining district, Alaska..... 17

Figure 6 - Histogram of copper concentrations in stream sediments from the Tolovana mining district, Alaska..... 18

Figure 7 - Log Concentration - probability plot of copper concentrations in stream sediments from the Tolovana mining district, Alaska..... 19

Figure 8 - Histogram of lead concentrations in stream sediments from the Tolovana mining district, Alaska..... 20

TABLE OF CONTENTS (cont'd)

Page

Figure 9 - Log Concentration - probability plot of lead concentrations in stream sediments from the Tolovana mining district, Alaska..... 21

Figure 10- Histogram of silver concentrations in stream sediments from the Tolovana mining district, Alaska..... 22

Figure 11- Log Concentration - probability plot of silver concentrations in stream sediments from the Tolovana mining district, Alaska..... 23

Figure 12- Histogram of zinc concentrations in stream sediments from the Tolovana mining district, Alaska..... 24

Figure 13- Log Concentration - probability plot of zinc concentrations in stream sediments from the Tolovana mining district, Alaska..... 25

Figure 14- Histogram of copper concentrations in pan concentrates from the Tolovana mining district, Alaska..... 26

Figure 15 - Log Concentration - probability plot of copper concentrations in pan concentrates from the Tolovana mining district, Alaska..... 27

Figure 16- Histogram of gold concentrations in pan concentrates from the Tolovana mining district, Alaska..... 28

Figure 17- Log Concentration - probability plot of gold concentrations in pan concentrates from the Tolovana mining district, Alaska..... 29

Figure 18- Histogram of mercury concentrations in pan concentrates from the Tolovana mining district, Alaska..... 30

Figure 19- Log Concentration - probability plot of mercury concentrations in pan concentrates from the Tolovana mining district, Alaska..... 31

Figure 20- Histogram of tin concentrations in pan concentrates from the Tolovana mining district, Alaska..... 32

TABLE OF CONTENTS (cont'd)

Page

Figure 21- Log Concentration - probability plot of tin concentrations in pan concentrates from the Tolovana mining district, Alaska..... 33

Figure 22- Histogram of tungsten concentrations in pan concentrates from the Tolovana mining district, Alaska..... 34

Figure 23- Log Concentration - probability plot of tungsten concentrations in pan concentrates from the Tolovana mining district, Alaska..... 35

Figure 24- Histogram of zinc concentrations in pan concentrates from the Tolovana mining district, Alaska..... 36

Figure 25- Log Concentrations - probability plot of zinc concentrations in pan concentrates from the Tolovana mining district, Alaska..... 37

Figure 26- Histogram of copper concentrations in rocks from the Tolovana mining district, Alaska..... 38

Figure 27- Log Concentration - probability plot of copper concentrations in rocks from the Tolovana mining district, Alaska..... 39

Figure 28- Histogram of gold concentrations in rocks from the Tolovana mining district, Alaska..... 40

Figure 29- Log Concentration - probability plot of gold concentrations in rocks from the Tolovana mining district, Alaska..... 41

Figure 30- Histogram of lead concentrations in rocks from the Tolovana mining district, Alaska..... 42

Figure 31- Log Concentration - probability plot of lead concentrations in rocks from the Tolovana mining district, Alaska..... 43

Figure 32- Histogram of molybdenum concentrations in rocks from the Tolovana mining district, Alaska..... 44

Figure 33- Log Concentration - probability plot of molybdenum concentrations in rocks from the Tolovana mining district, Alaska..... 45

TABLE OF CONTENTS (cont'd)

Page

Figure 34- Histogram of silver concentrations in rocks from the Tolovana mining district, Alaska..... 46

Figure 35- Log Concentration - probability plot of silver concentrations in rocks from the Tolovana mining district, Alaska..... 47

Figure 36- Histogram of tungsten concentrations in rocks from the Tolovana mining district, Alaska..... 48

Figure 37- Log Concentration - probability plot of tungsten concentrations in rocks from the Tolovana mining district, Alaska..... 49

Figure 38- Histogram of zinc concentrations in rocks from the Tolovana mining district, Alaska..... 50

Figure 39- Log Concentration - probability plot of zinc concentrations in rocks from the Tolovana mining district, Alaska..... 51

Tables

Table 1 - Threshold values in ppm for stream sediment, pan concentrate, and rock geochemical samples from the Fairbanks, Richardson and Tolovana mining districts, Alaska..... 52

Table 2 - Genetic ore models for the Tolovana mining district, Alaska 57

Plates

I. - Stream sediment, pan concentrate and rock geochemical sample locations - Tolovana mining district, Alaska..... In pocket

II. - Anomalous stream sedimet, pan concentrate, and rock geochemical samples from the Tolovana mining district, Alaska..... In pocket

INTRODUCTION

The Tolovana mining district is located at common corner of the Livengood B-3, B-4, C-3 and C-4 quadrangle in east central Alaska (see Figure 1). The district is in the northwestern portion of the Yukon-Tanana Upland Schist Terrane (see Figure 2). The Livengood B-3, B-4, C-3 and C-4 quadrangles were geologically mapped (Bundtzen, 1982; Albanese, 1982a; Smith, 1982; and Robinson, 1982) and geochemical samples were collected from the mapped areas (Albanese, 1982b) as part of a joint Mineral Industry Research Laboratory - Alaska Division of Geological and Geophysical Surveys project entitled "Mineral Resource Appraisal of Interior Alaska Mining Districts". The following report contains: a statistical analysis of the geochemical samples; a definition of anomolous elemental concentrations; and a determination of the spatial relationships between the anomalous samples and the bedrock and economic geology.

BEDROCK GEOLOGY

As noted previously, the Tolovana mining district is located on the northwestern margin of the Yukon-Tanana Uplands Schist Terrane. Figure 2 is generalized geological map of the terrane which is bounded on the south by Denali Fault and on the north by the Tintina Fault (Foster, et al., 1973). The terrane is composed of Precambrian and Paleozoic metamorphosed sedimentary and volcanic rocks that contain lower greenschist to amphibolite facies, eclogite facies and granulite facies mineral assemblages. The metamorphic rocks were considered Precambrian and were formerly designated Birch Creek Schist by Mertie (1937). The

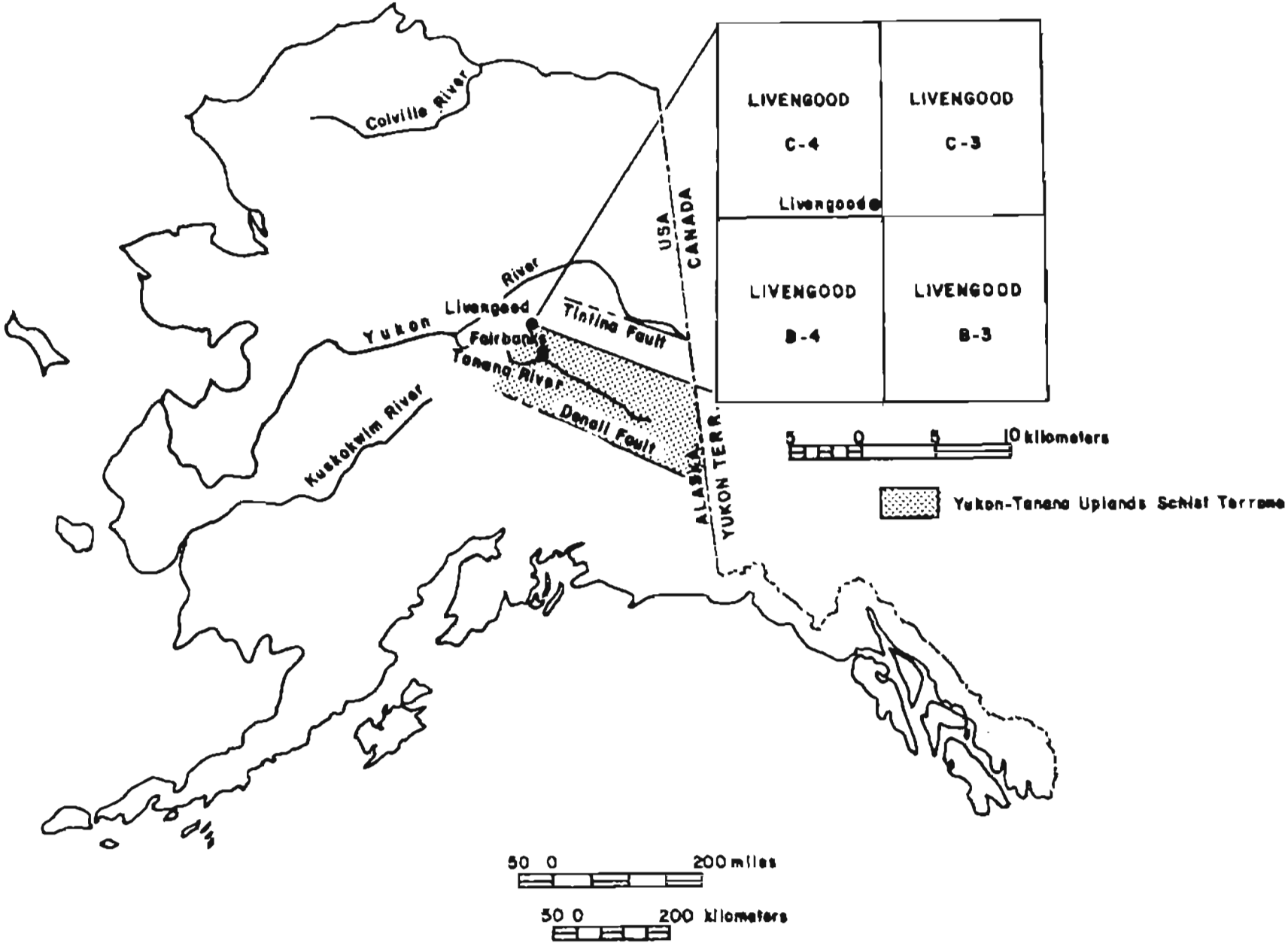


Figure 1. Location map of the Tolovana mining district, Alaska.

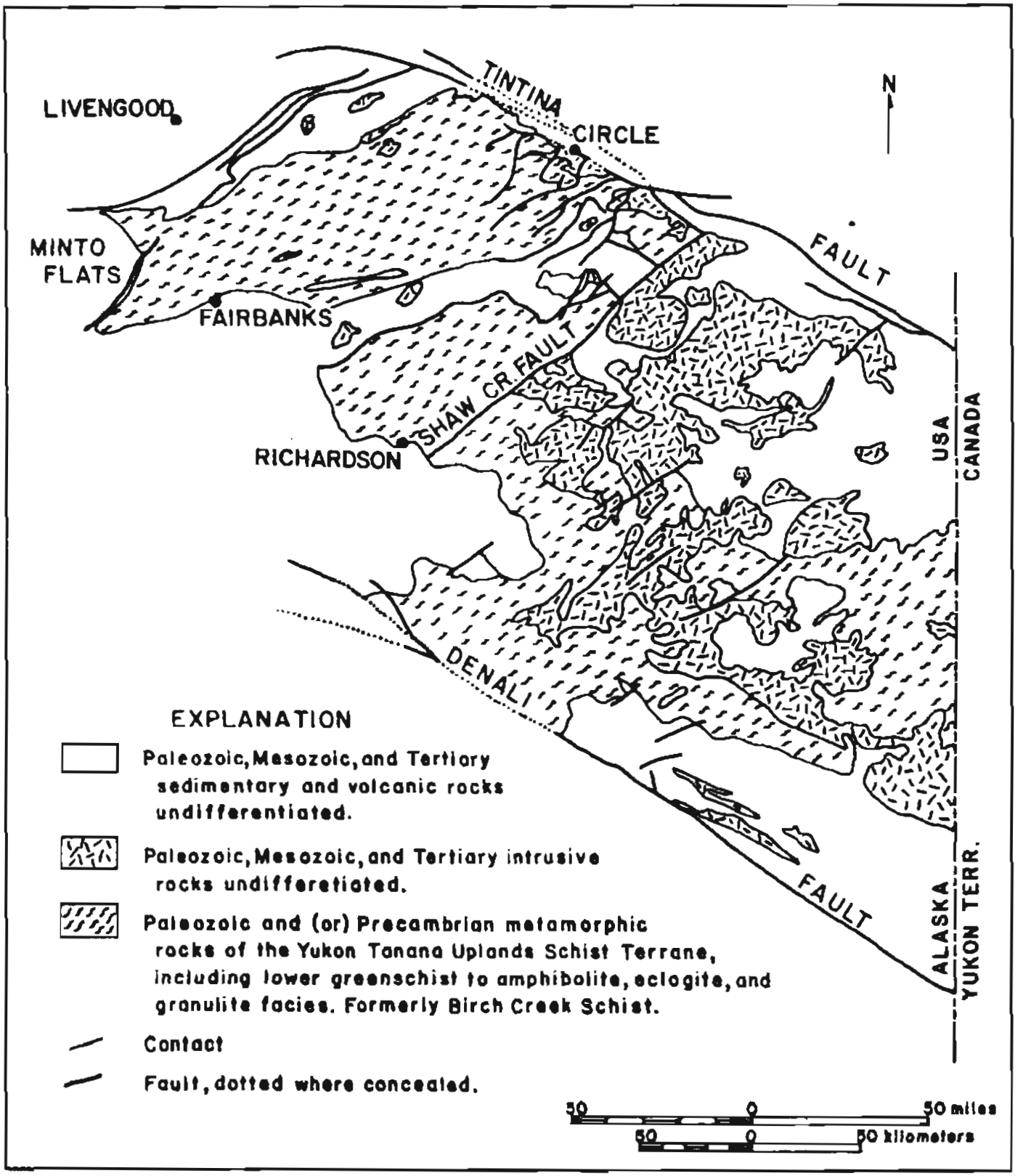


Figure 2. Generalized geological map of the Yukon-Tanana Uplands Schist Terrane, Alaska.

metamorphic rocks are unconformably overlain by Paleozoic, Mesozoic and Tertiary sedimentary and volcanic rocks. The metamorphic and sedimentary sequences are intruded by Paleozoic, Mesozoic and Tertiary rocks ranging in composition from peridotite to granite. Regional 1:250,000 scale geological mapping of the Tolovana district and the Livengood quadrangle has been completed by Chapman et al. (1971).

The bedrock geology of the Tolovana district has been mapped by Chapman et al (1971), Albanese (1983), Bundtzen (1983), Robinson (1983) and Smith (1983). Smith (1983) and Bundtzen (1983) define eight tectono-stratigraphic sequences separated by major thrust faults (see Figure 3). From north to south these sequences include:

A. Rampart Group (Permian or Triassic)

B. Paleozoic Clastics and Chert Unit (Silurian or Devonian)

C. Grit Unit (Late Proterozoic or Cambrian)

D. Chert Terrane (Middle Ordovician to Silurian)

E. Devonian Clastics and Mafic Complex (Middle Devonian)

F. Mesozoic Flysch (Jurassic or Cretaceous)

G. Paleozoic sedimentary, igneous and low grade metamorphic rocks (Cambrian or Ordovician)

H. Tolovana Limestone (Silurian and Devonian)

The Grit Unit includes conglomerate coarse-grained arenaceous sandstone, quartzite, siltstone, maroon and greenish slate, phylite, and coarse crytalline limestone or dolomitic limestone. Chapman and others (1971) refer to this sequence of rocks as the 'Grit Unit' of the Yukon Tanana Uplands and have made a tentative correlation with the late

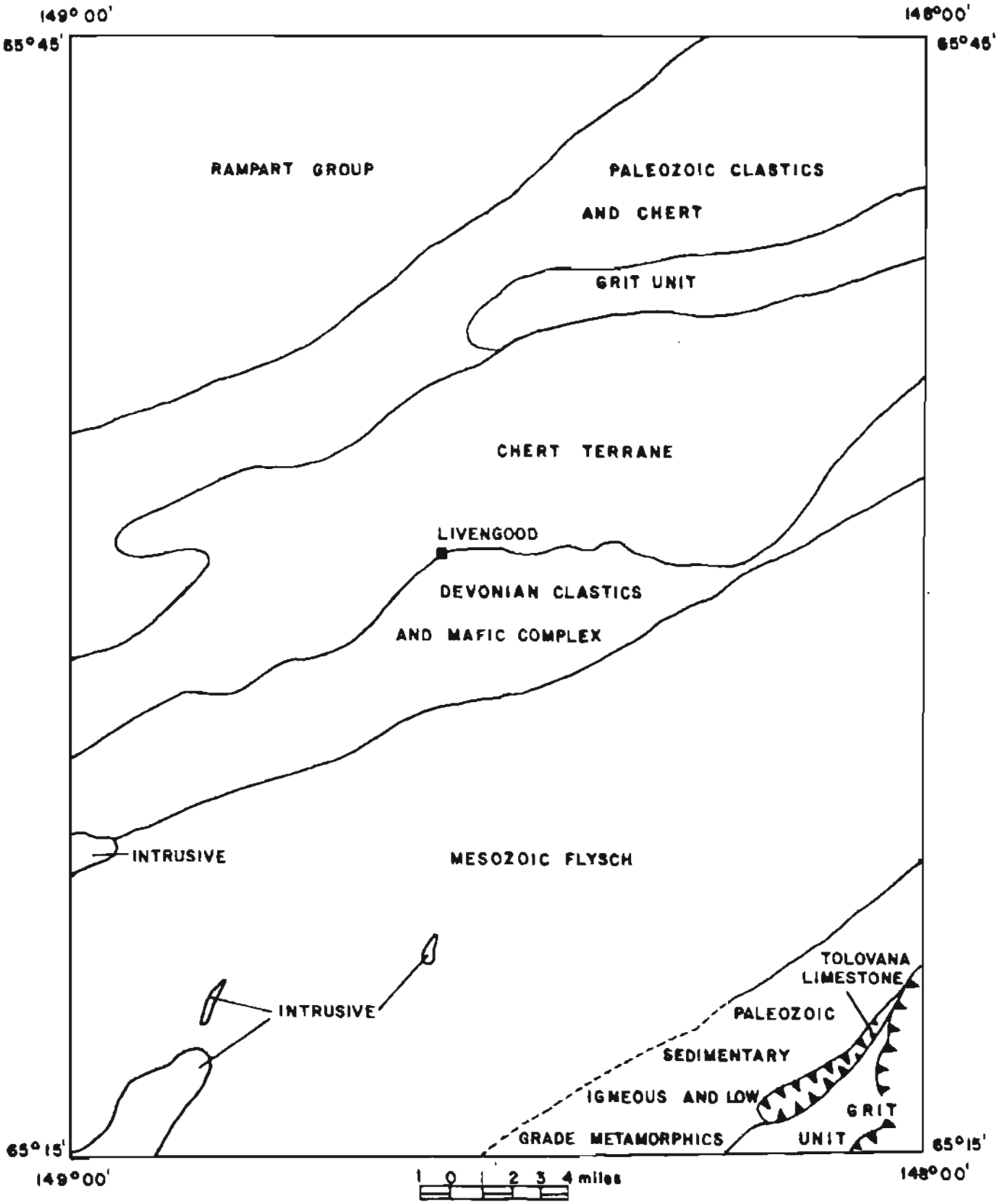


Figure 3. Generalized geological map of the Tolovana mining district and adjacent areas (after Albanese, 1983; Bundtzen, 1983; Robinson, 1983; and Smith, 1983). See text for rock unit descriptions.

Precambrian to Cambrian quartz rich shelf deposits of the Windemere Group of southern Canada and the northwestern United States. The rocks are regionally metamorphosed to lower greenschist facies with progressive increase from the northwest to southeast.

The Paleozoic sedimentary, igneous and low-grade metamorphic map unit includes fine to medium grained quartzite, dark gray to black phylite, gray slate, gray to green banded chert, light gray coarse crystalline limestone and amygdaloidal greenstone, gabbro, and diorite. The amygdaloidal greenstone is aphanitic to coarse-grained with vesicle fillings of calcite and prehnite. The gabbros and diorites are medium to coarse-grained rocks composed of diopside, orthophyroxene, hornblende, biotite and plagioclase feldspar (An 40-60).

The Paleozoic sedimentary rocks were correlated with the Oldhamia-bearing grits of Noodor Dome by Chapman and others (1971). The igneous rocks within the map unit are similar to the Fossil Creek volcanics of Church and Durfee (1961) which occur on strike to the northeast. The Fossil Creek Volcanics are of Middle Ordovician age and thus the Paleozoic sedimentary, igneous and low grade metamorphics may be of Cambrian or Ordivician age. The above map unit is regionally metamorphosed and metamorphic grade progressively increases from the northwest to southeast.

The Chert Terrane defined by Robinson (1983) includes the Livengood Dome chert of Chapman and others (1979). The lower portion of the map unit is composed of light gray to tan fine-grained and thinly layered chert; variegated black, red, green, blue, and white massive bedded radiolarian chert; chert congomerate; and grayish black siliceous shale

and siltstone. The lower portion of the map unit contains dark gray to green massive and highly altered mafic volcanic rock and fine-grained recrystallized dolomitic limestone. Fauna evidence suggests a range in age from Middle Ordovician to Silurian (Robinson, 1983).

Paleozoic Clastics and Chert Terrane defined by Robinson (1983) is composed of chert and shale pebble congolmerate; gray to brown, fine to medium grained lithic sandstones; maroon and green siliceous shale; and medium gray to buff recrystallized dolomitic limestone. The unit appears to overlie rocks of the Chert Terrane. With the exception of the absence of mafic volcanics, the map unit is similar to the Paleozoic sedimentary, igneous and low grade metamorphic rocks to the southeast described by Bundtzen (1983). Robinson (1983) does not indicate how the age of the Paleozoic Clastic and Chert Terrane was determined.

The Tolovana Limestone as defined by Mertie (1937) includes a belt of carbonate rocks that extends from Willow Creek, north of Cache Mountain to Globe Creek. In the Globe Creek, area Bundtzen (1983) divided the formation into three members. The Limestone Breccia member is a medium gray recrystallized limestone breccia with angular fragments up to 25 cm in diameter. The angular clasts contain amphipora and coral fragments. The Laminated Limestone member is a medium grey, thinly layered silty limestone that is locally brecciated. The Massive Limestone member is medium to dark-blue-gray massive oolitic and dolomitized micritic limestone. Faunal assemblages include Amphipora and Dendrostrella sp; D. Rhenana of Middle Devonian age.

The Devonian Clastics and Mafic Complex contains conglomerate, sandstone, shale, chert, and black dolomitic marble; andesitic flows and

agglomerate; mafic aphinitic to coarse grained igneous rocks; and serpentinite. The sandstones and conglomerates are gray to brown thin bedded to massive sublithic rocks. The coarse clastics are interbedded with gray to olive shale that locally grades to siltstone. The andesitic to dacitic flow rocks are interlayered with gray banded chert, black dolomitic marble, and clastic rocks. The flow rocks contain phenocrysts of plagioclase, hornblende and quartz and have vesicle fillings of calcite and epidote. The mafic igneous rock include fine to coarse-grained olive to tan weathering hypersthene gabbro, hornblende gabbro, augite bearing diorite, and massive greenstone. The serpentinite is a green to black altered peridotite occurring in and adjacent to the mafic igneious rocks (Bundtzen, 1983).

The Rampart Group in the Livengood C-3 and C-4 quadrangles is composed of mafic to intermediate intrusive and volcanic rocks intercalacted with clastic sediments including sandstone, siltstone, shale and chert. The instrusive rocks range in composition from gabbro to diorite and occur as irregular stocks and sills. The extrusive rocks range in composition from altered baslat to rhyodacte with the more mafic rocks predominating (Robinson, 1983; Smith, 1983).

Brosge and others (1969) provide faunal evidence for a Permian age of the Rampart Group rocks while potassium-argon determinations on hornblende from an intrusive grabbro indicate a Triassic radiometric age.

The Mesozoic Flysch has been divided into two sub-units that contain varying proportions of conglomerate and finer clastics. The conglomerate, minor sandstone and siltstone unit is composed of medium

to dark-olive-gray polymictic conglomerate with cobbles of greenstone, diorite, serpentinite, quartzite, siltstone, slate, phyllite, limestone and chert. The siltstone, sandstone and minor conglomerate unit is composed of medium-gray to greenish-gray siltstone, shale, and fine to medium-grained sandstone. The rocks exhibit graded bedding as well as flute casts, ripple marks, flame structures, cut and fill structures and channelling. The rocks are very immature and contain clasts and lithic fragments similar to those in the conglomerate unit. These lithic fragments are of probable local origin.

Invertebrate fauna includes Inoceramus and Buchia thus suggesting a Late Jurassic or Early Cretaceous age of the sediments.

The composition and sedimentary structures of the Mesozoic sediments indicate a proximal turbidite fan environment of deposition. Similar rocks occur on a northeast-southwest strike for over 150 kilometers and occur over a 60 kilometer wide area. The original size of the Mesozoic basin is indeterminant since the sediments have been structurally thickened.

These sequences have been intruded by Cretaceous and Tertiary age granitic rocks that range in composition from quartz monzonite to quartz syenite, and rhyolite quartz porphyry. The felsic intrusives of the Livengood quadrangle yield potassium-argon ages ranging from 58.0 to 88.8 my (Turner and others, 1975).

The above described tectono-stratigraphic sequences are deformed into isoclinal overturned and recumbent north vergent folds with axes generally striking northeast-southwest. The major terranes and rock

units within the terranes are separated by thrust faults of probable Mesozoic age. The thrust faults are cut by high angle generally north trending normal faults. The high angle structures may be controls for the localization of the Cretaceous and Tertiary felsic intrusives in the Livengood quadrangle. A major normal fault (Barnes, 1961) forms the eastern boundary of Minto Falts (see Figure 2) and can be traced in a north-south direction for 100 kilometers as a linear feature on Landsat imagery and aerial photography. The Tolovana Hot Springs Dome Pluton as well as other unnamed felsic intrusives are located along the fault in the Eagle and Wilbur Creek area and in the Shorty and Steel Creek area. The linear feature terminates near Livengood at Money Knob and several quartz monzonite stocks also outcrop in this area.

ECONOMIC GEOLOGY

Prior to this investigation there were: six known lode gold prospects; a lode antimony prospect, a lode chrome-nickel prospect and a copper-molybdenum porphyry prospect in the area. Previous descriptions of the economic geology of the Tolovana mining district includes: Mertie (1918); Overbeck (1920); Joesting (1942, 1943); Foster and Chapman (1967); Foster (1968); Robinson and Metz (1979); and Metz and Robinson (1980).

Foster (1968) describes the six known lode gold deposits as follows:

1. Gertrude Creek Prospect (Location 2, Plate II)

   - Massive, ironstained silica-carbonate rocks which is green on fresh surfaces, contains minor amounts of gold."

2. Ruth Creek Prospect (Location 3, Plate II)

   - "Pyritized, brecciated, iron-stained igneous rock shows replacement by silica and carbonate and contains traces of gold."

3. Lillian Creek Prospect (Location 3, Plate II)

   - "Narrow auriferous arsenopyrite-quartz-scorodite veins occur in and near a limonite-stained dike in altered and contorted graywacke-argillite country rock. Samples from the prospect contain from 0.5 to 48 ppm gold."

4. Griffin Prospect (Location 4, Plate II)

   - "Massive sulfide-bearing, green-stained silica-carbonate-talc rocks veined by quartz contains as much as 3.9 ppm gold."

5. Old Smoky Prospect (Location 4, Plate II)

   - "Narrow, northwestward-trending auriferous arsenopyrite-quartz veins occur in a ferruginous quartzite footwall near the intersection of an altered porphyritic biotite monzonite dike and a potassium feldspar-rich porphyritic dike. Samples from the prospect contain from 3 to 13 ppm gold."

6. Sunshine No. 2 Prospect (Location 4, Plate II)

   - "A northwestward-trending, crumbly, auriferous dike with internal limonite veinlets is in contact with altered argillite."

Foster (1968) concluded that the known lode gold vein type deposits of the Livengood area are either below economic grade or have low potential for large tonnage mineralization, however, the known occurrences may be an indication of concealed deposits at depth. The

host rock lithologies, trace elemental associations, and structural features of the area are similar to the Carlin-type deposits of north-central Nevada which are relatively low grade but large tonnage deposits thus future exploration should encompass the Carlin type genetic model as well as the gold quartz vein hydrothermal model (Foster, 1968).

Overbeck (1920) and Joesting (1942) report the occurrence of stibnite in bedrock at an alluvial bench placer deposit on the north side of Livengood Creek near the mouth of Amy Creek (location 1, plate II). Prior to the current investigation this was the only evidence of a potential lode mineral source north of Livengood Creek.

Foster and Chapman (1967) report chromite, magnetite, and iron-nickel alloys in a serpentinite located on the southeast side of Amy Dome (location 5, Plate II). Although there is considerable strike length to the serpentinite bearing sequence only one lode sample contained anomalous elemental concentrations, and Foster (1968) found only minor chrome and nickel concentrations in stream sediment samples collected below the serpentinite outcrops.

Robinson and Metz (1979) briefly describe an occurrence of disseminated copper mineralization in a quartz feldspar porphyry near the head of Shorty Creek (location 6, Plate II). The host rock is a light gray to green quartz feldspar porphyry with relict potassium feldspar altered to sericite and plagioclase feldspar altered to albite-quartz-calcite. The quartz and feldspar phenocrysts are up to a centimeter in diameter. The groundmass is light gray to green and weathers to light tan. The rock contains disseminated pyrite, chalcopyrite, arsenopyrite and rutile.

The Shorty Creek porphyry is located along the previously described major north-south linear feature that is probably an extension of the Minto Flats Fault. The porphyry is hosted in the siltstone, sandstone and minor conglomerate unit of the Mesozoic Flysch Terrane. The mineral occurrence was originally located for antimony and 80 state mining claims were staked in 1972 by the Earth Resources Company. The property was subsequently drilled by British Petroleum Minerals, however that drill data is not currently available.

Placer gold was discovered in the district in 1914 and the first definitive descriptions of the placer deposits was by Mertie (1918). He notes that the major placer deposits occur on Livengood Creek both as major paystreaks on bedrock or other impermeable layers and as fine-grained disseminations throughout the gravels. He also provided considerable physiographic evidence for stream capture and the resulting changes in the flow direction of Livengood Creek. Metz (1984) has shown that stream capture, and the resulting change in flow direction and stream gradient is an important process in the formation of alluvial placer paystreaks. Fine-grained disseminated placer deposits generally occur in distal areas such as beach deposits or as residual or eluvial deposits. The later process is probably responsible for the fine-grained disseminated deposits above the bedrock paystreaks of Livengood Creek.

Mertie (1918) suggests that the lode sources for the gold placers of Livengood Creek and its tributaries were quartz feldspar porphyry dikes and stocks and associated quartz veins. The intrusives and quartz veins are located on or near Money Knob and Amy Dome. Foster (1968)

provides additional geochemical evidence to support that hypothesis but also suggests a potential for Carlin-type and massive sulfide related mineralization in the area. The high gold fineness values of 907 to 934 (Metz and Hawkins, 1980) for Amy, Gertrude, Lillian, Livengood, Lucky Myrth, and Olive Creek would be compatible for the Carlin type genetic model. The moderately low value of 866 for Ruth Creek would support a massive sulfide source as proposed by Foster (1968). The occurrence of placer gold on Wilbur Creek (818 fine) indicates an additional source area southeast of Amy Dome. The low fineness value could be attributed to either a massive sulfide or a subvolcanic porphyry source.

From 1914 to date the Tolovana mining district has produced approximately 375,000 troy ounces of placer gold (Robinson and Bundtzen, 1979) most of which has come from Livengood Creek. Hargraves (1975) and Albanese (1981) have discussed the history, mining methods and estimated placer gold reserves of Livengood Creek. The deposit is estimated to contain 600,000 troy ounces of proven, probable, and possible reserves.

GEOCHEMICAL DATA REDUCTION

Albanese (1983) reported analyses for 1597 stream sediment, 297 pan concentrate and 305 rock samples from the Livengood B-3, B-4, C-3 and C-4 quadrangles. Antimony, arsenic, gold, lead, molybdenum, and silver contents were determined at the ADGGS laboratory by atomic-absorption spectrophotometry on aqua-regia digests. Cadmium, chromium, cobalt, copper, iron, manganese, nickel and zinc were analyzed at the ADGGS laboratory by inductively coupled plasma emission spectrophotometry on aqua-regia digests. Detection limits were 1ppm for antimony, cadmium,

copper, lead, molybdenum and zinc; 10ppm for arsenic, chromium, cobalt, iron, manganese and nickel; and 0.1ppm for gold and silver. Tin, tungsten and mercury were analyzed by Bondar-Clegg and Company Ltd., Vancouver, B.C. Canada. Tungsten was analyzed by colorimetry with a lower limit of detection of 2ppm. Mercury was analyzed by cold-vapor atomic-absorption spectrophotometry with a lower detection limit of 5ppb. Tin content was determined by x-ray flourescence with a lower detection limit of 5ppm (Albanese, 1983).

Since all the samples were not analyzed for all the elements, data reduction could not be completed for all elements for all three groups of geochemical samples. Data reduction including histograms and log-concentration-probability plots (see Figures 4 - 39) were completed for the following elements:

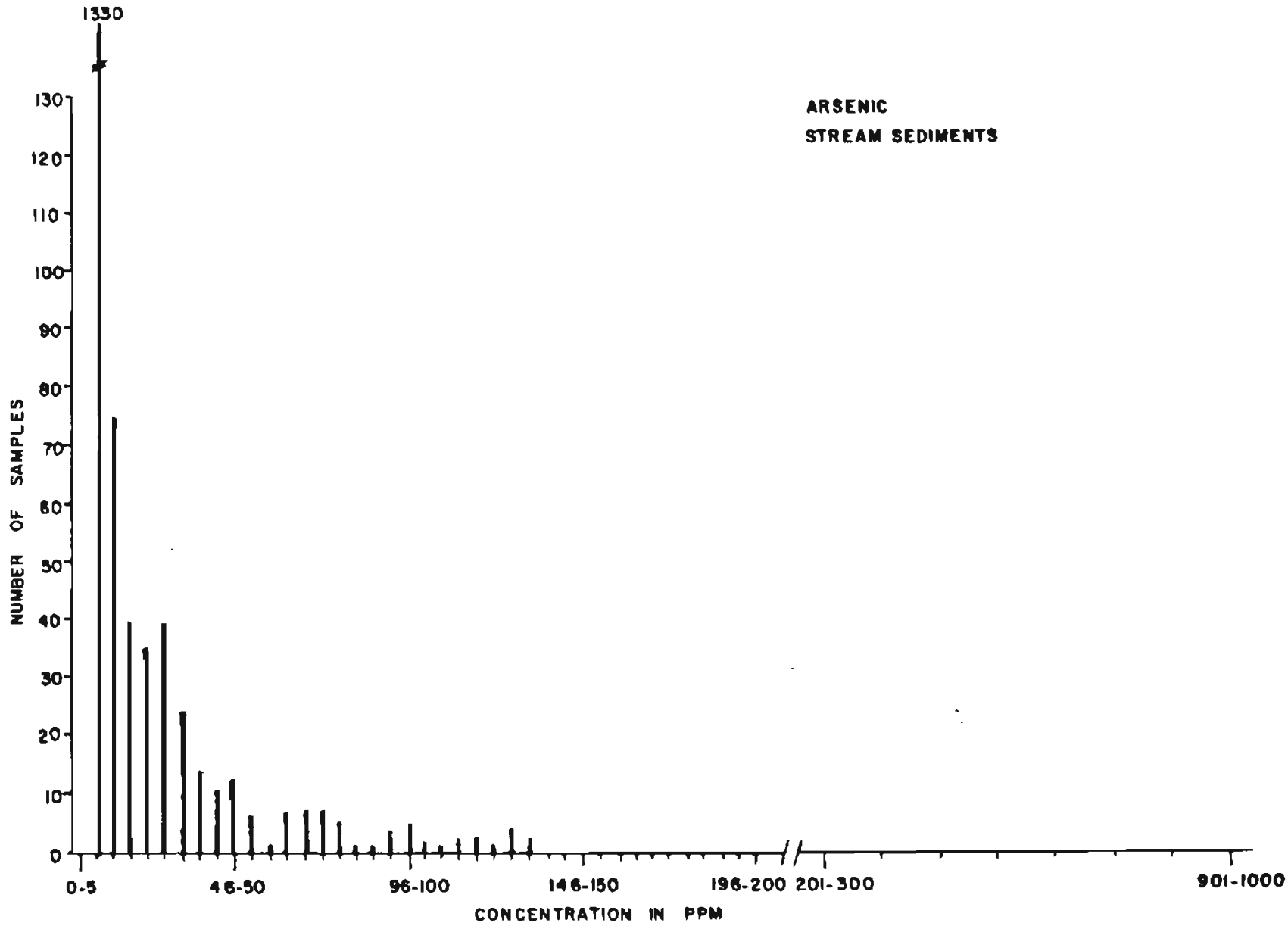
A. Stream sediment samples - As, Cu, Pb, Ag, Zn.

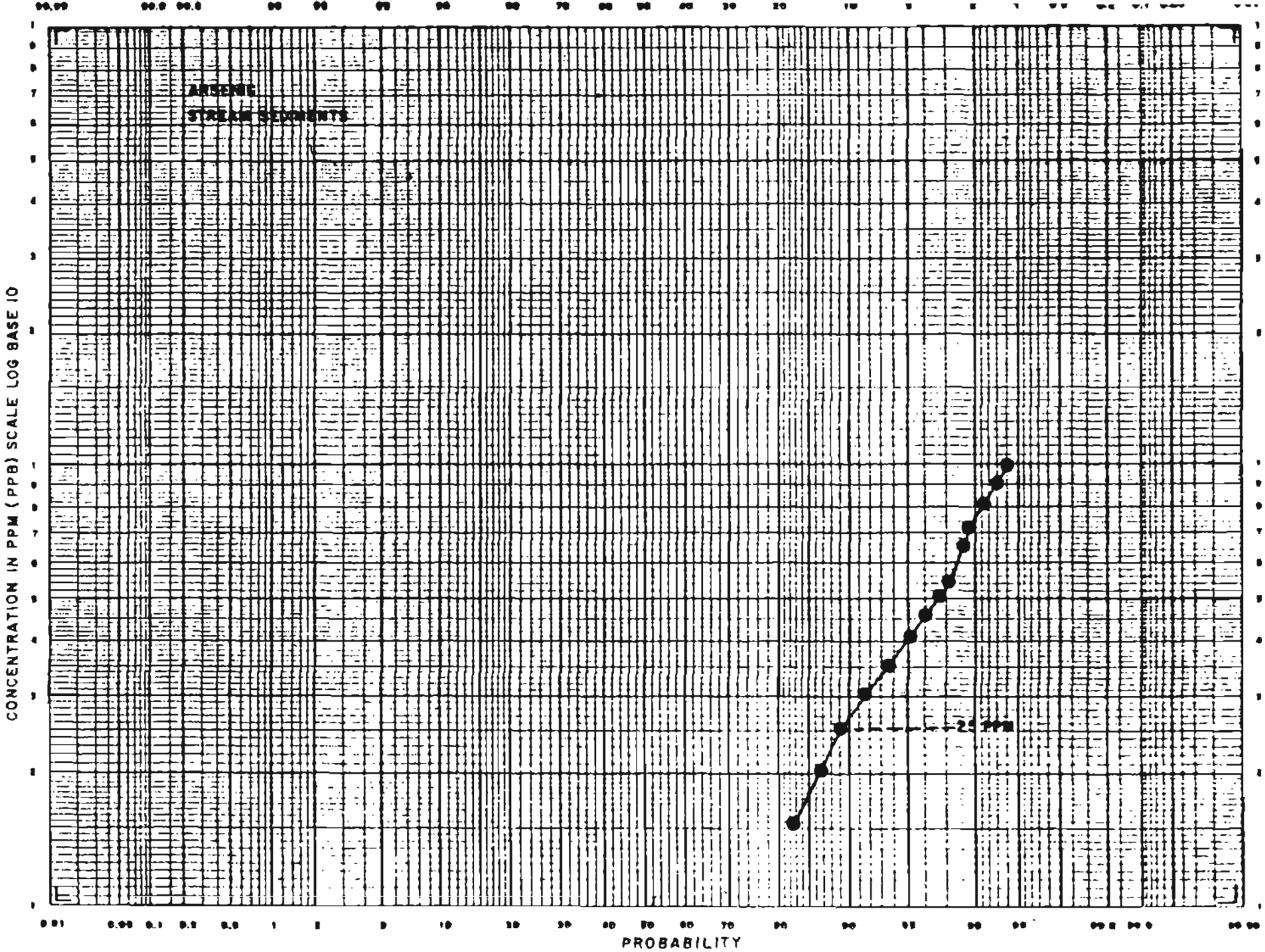
B. Pan concentrate samples - Cu, Au, Hg, Sn, W, Zn.

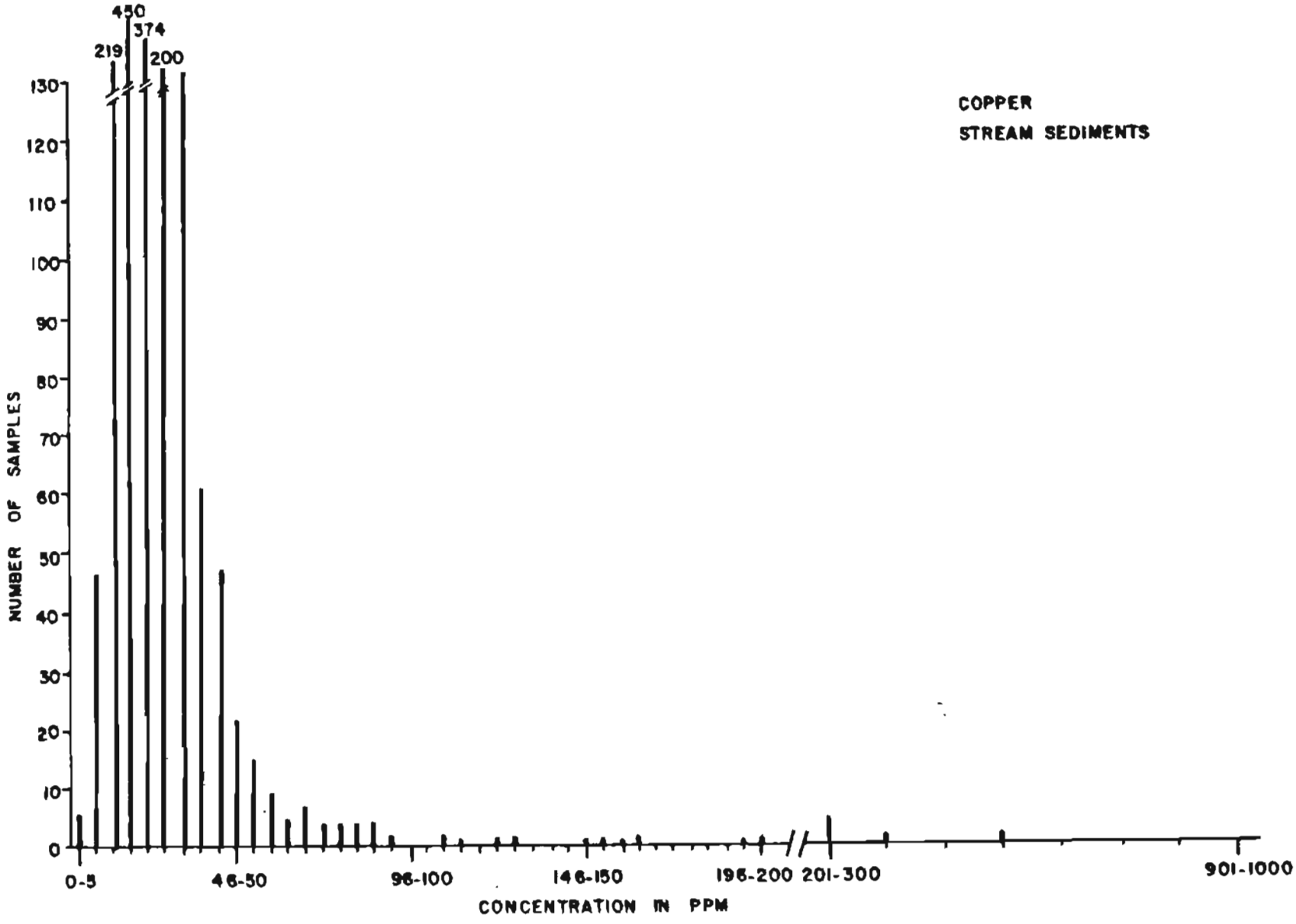
C. Rock samples - Cu, Au, Pb, Mo, Ag, W, Zn.

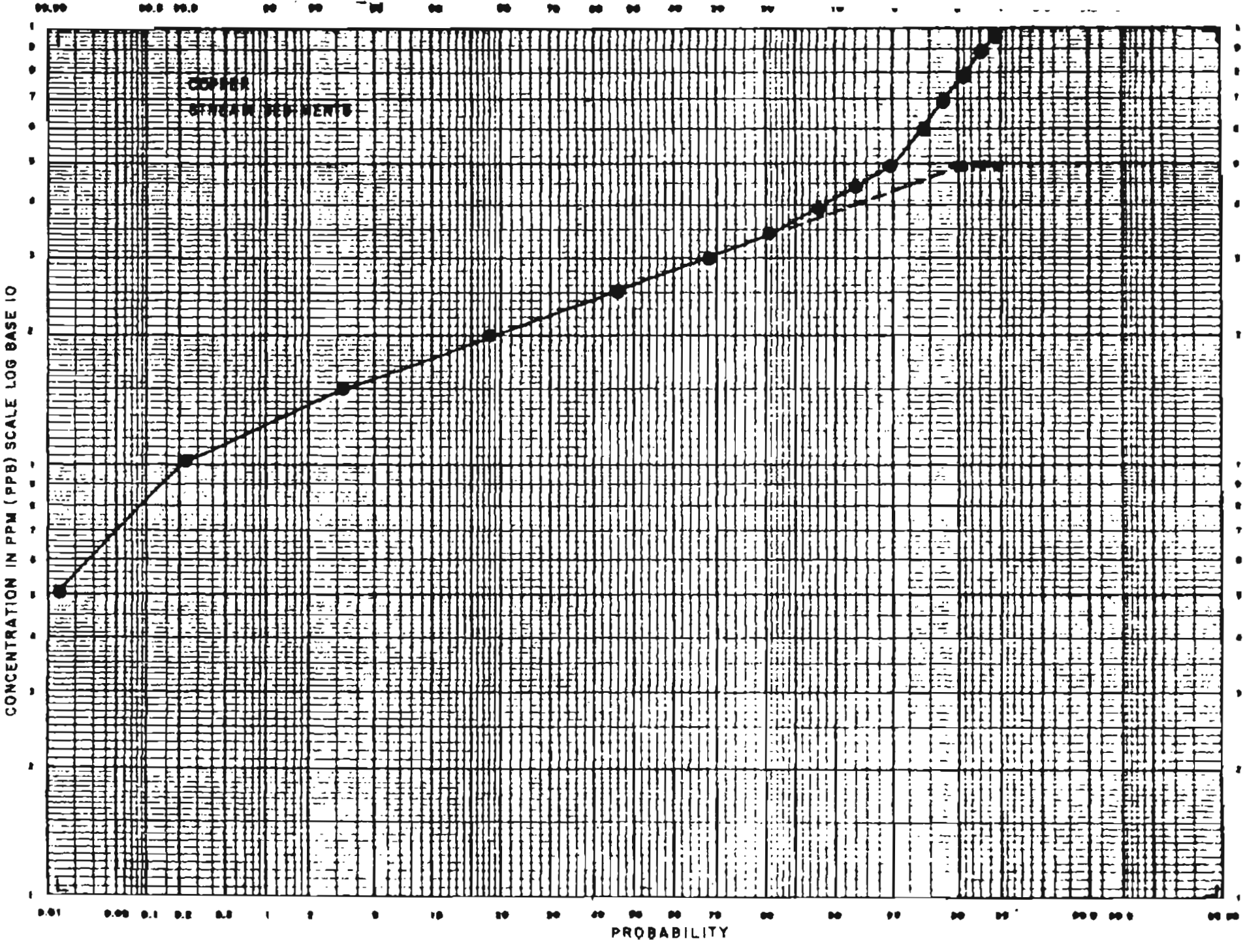
Anomalous sample concentrations were estimated by the technique described by Lepeltier (1969) and are defined as concentrations above the 97.5 probability level. Table 1 is a tabulation of threshold values of elements from geochemical samples from the Fairbanks, Richardson and Tolovana mining districts.

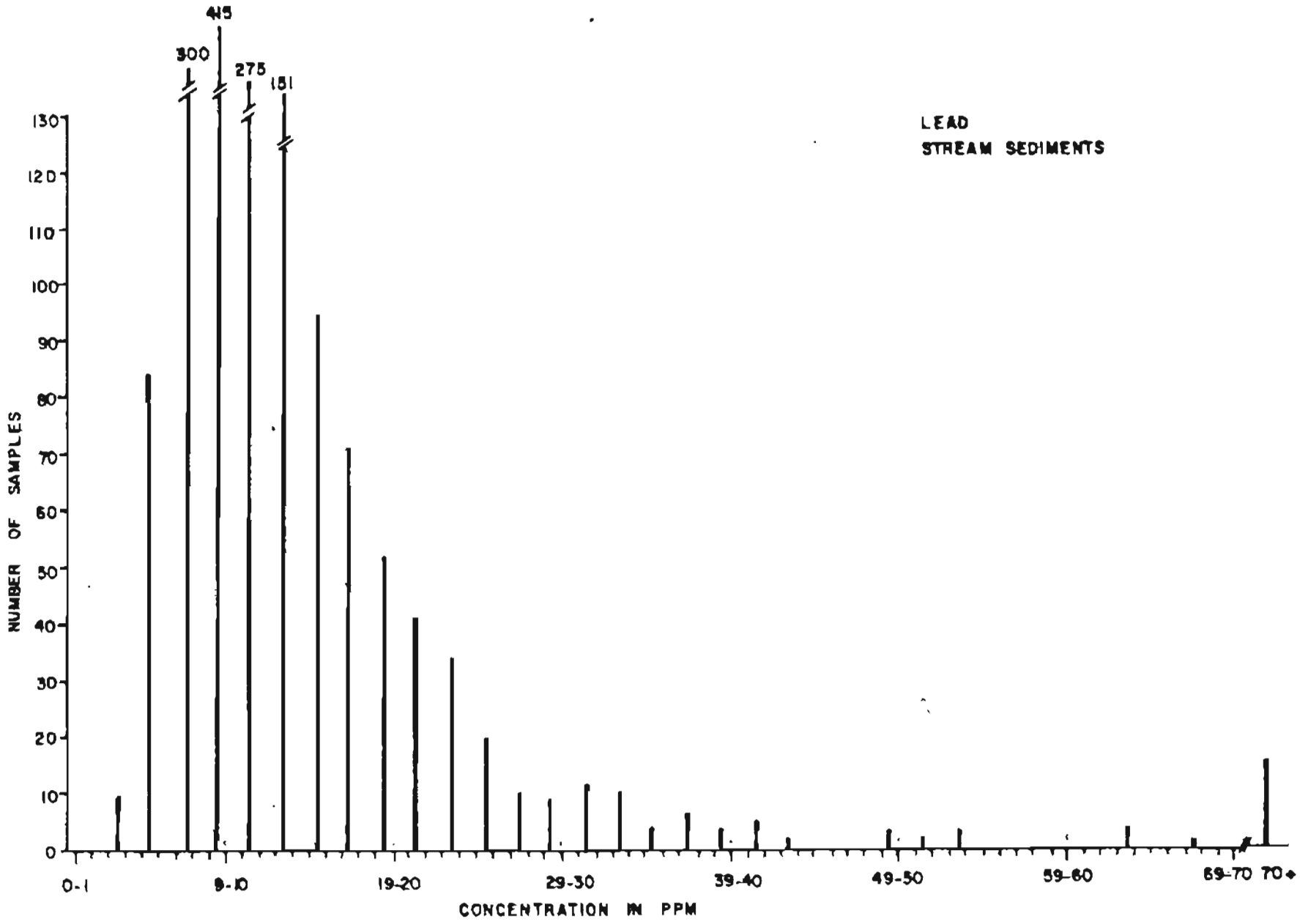
Plate I indicates sample locations of all geochemical samples from the Tolovana mining district while Plate II displays the anomalous sample locations for the region. Anomalous samples are defined as those with one or more elements above the threshold value.

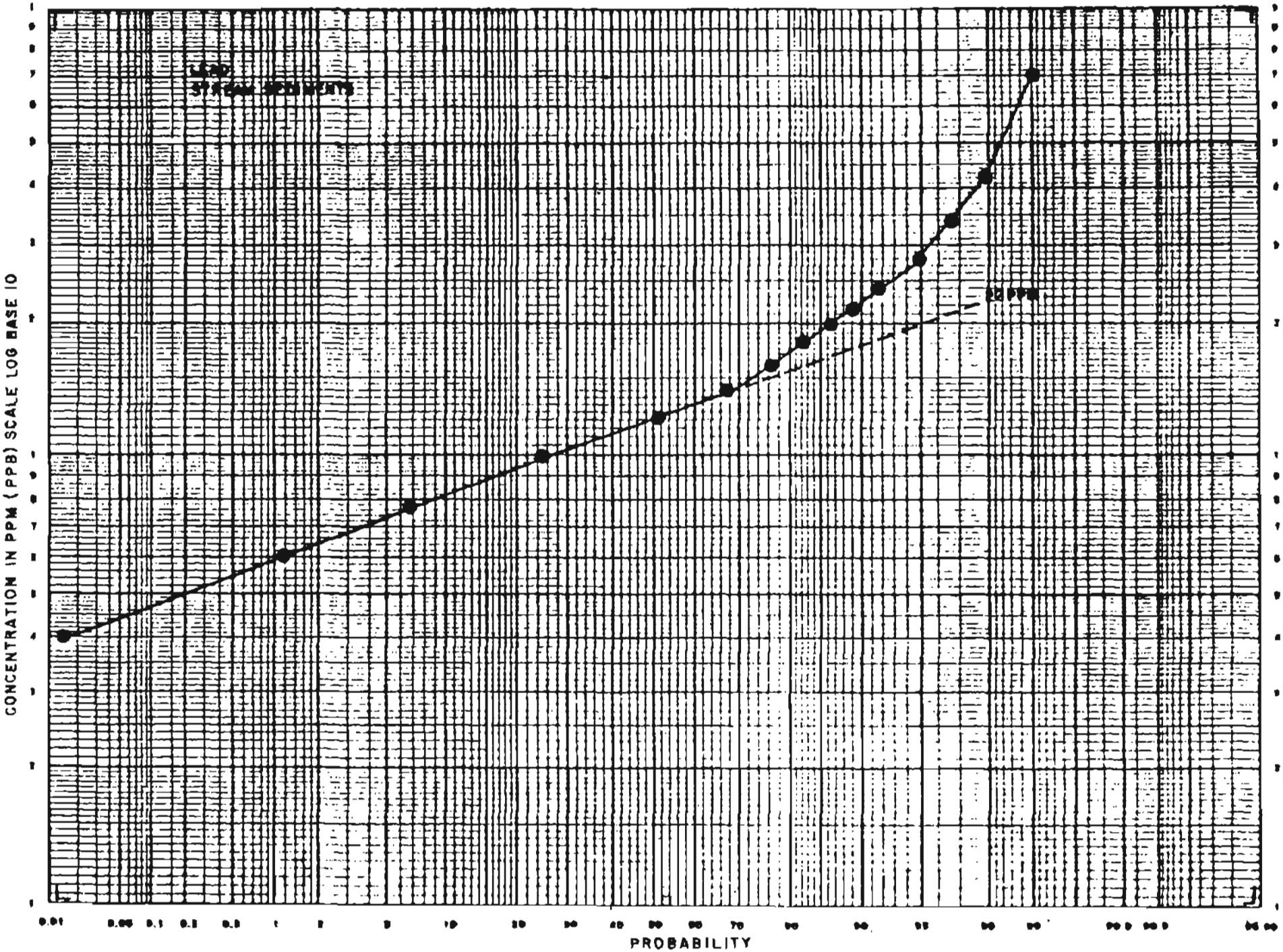

1330
ARSENIC
STREAM SEDIMENTS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

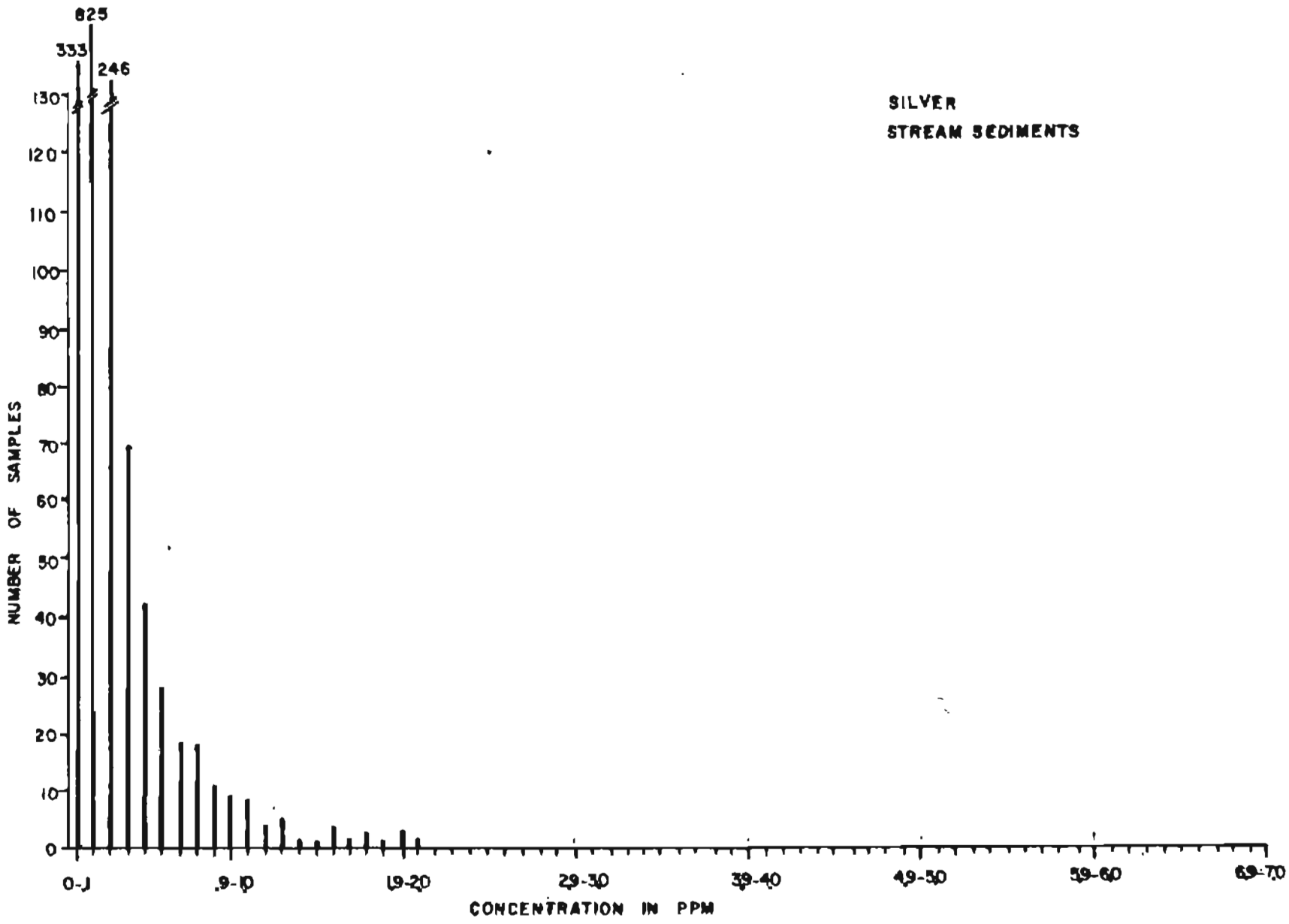

ARSENIC
STREAM SEDIMENTS
25 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

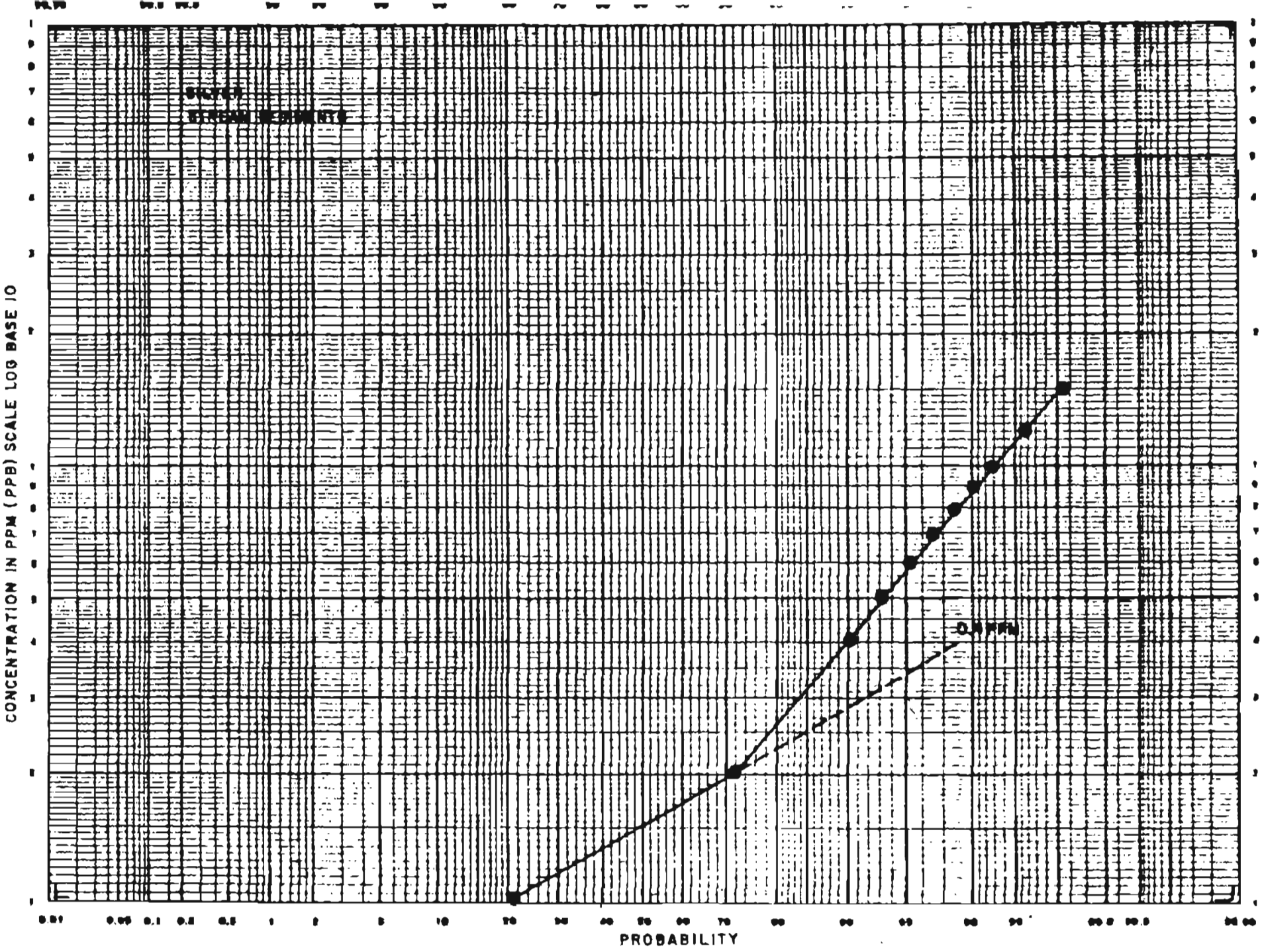

COPPER
STREAM SEDIMENTS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
450
374
219
200
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

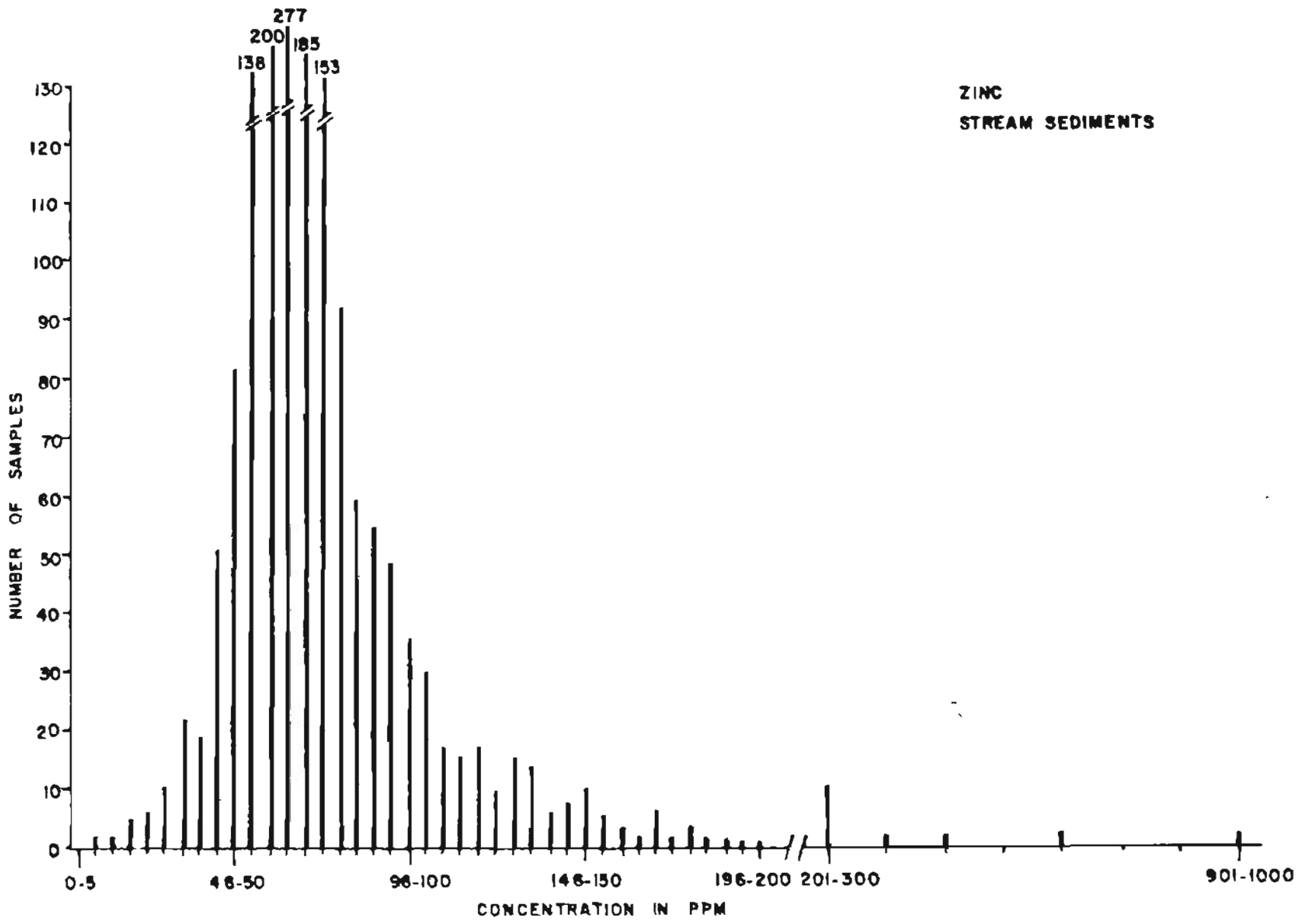

COPPER
STREAM SEDIMENTS
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

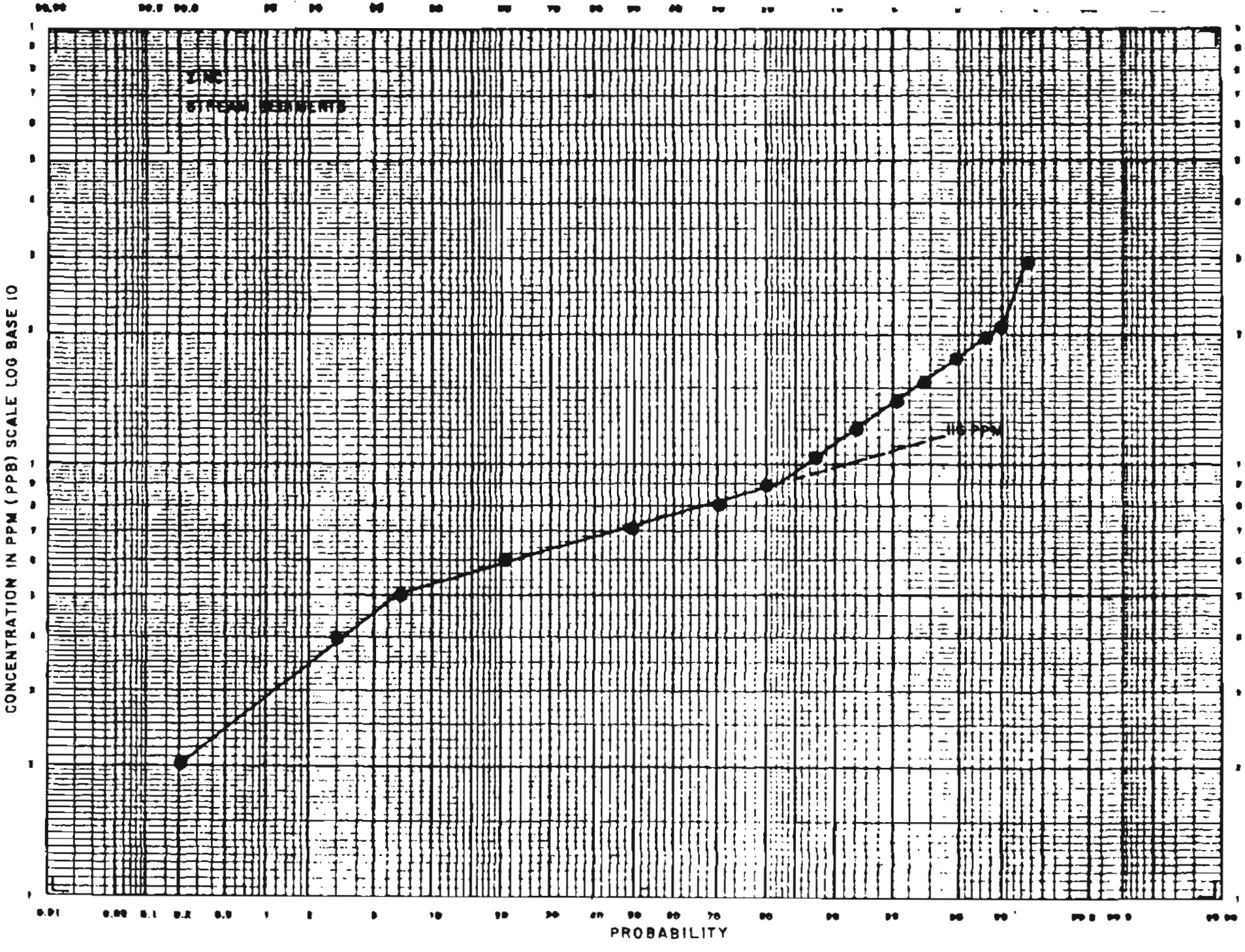

LEAD
STREAM SEDIMENTS
NUMBER OF SAMPLES
CONCENTRATION IN PPM
0-1
9-10
19-20
29-30
39-40
49-50
59-60
69-70
70+
300
415
275
151
0
10
20
30
40
50
60
70
80
90
100
110
120
130

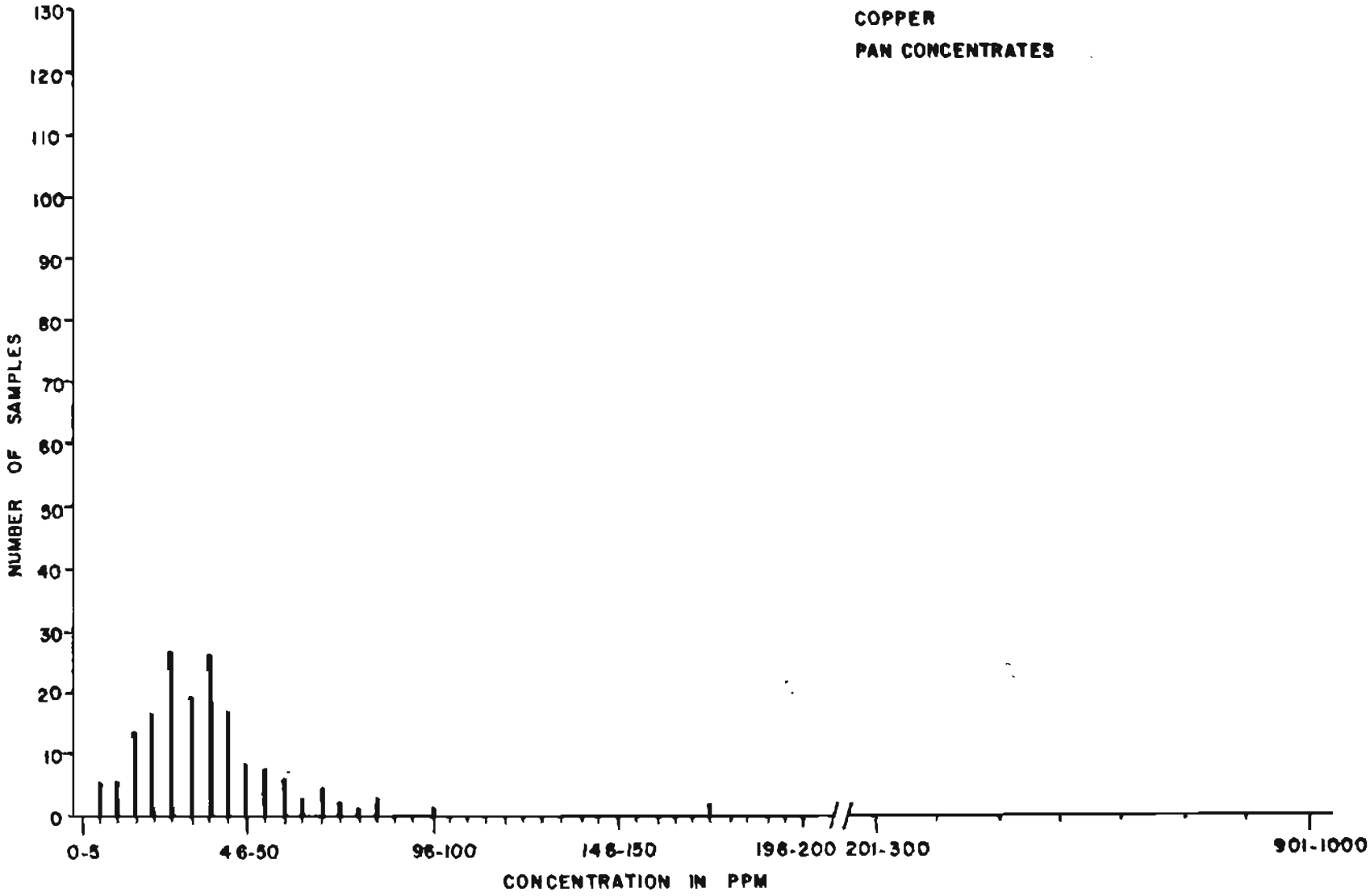

LEAD
STREAM SEDIMENTS
22 PPB
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

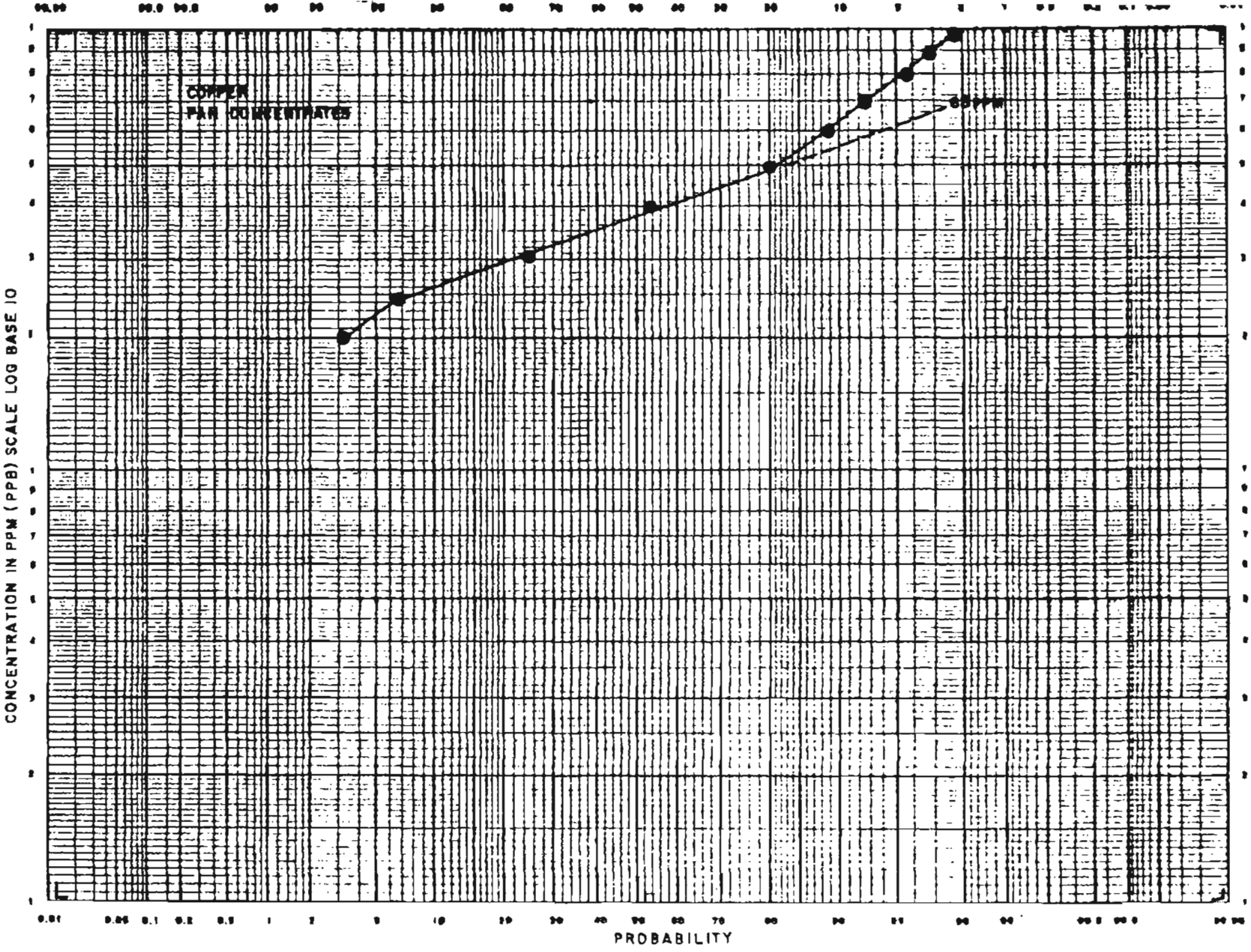

SILVER
STREAM SEDIMENTS
825
333
246
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-.1
.9-1.0
19-20
29-30
39-40
49-50
59-60
69-70
CONCENTRATION IN PPM

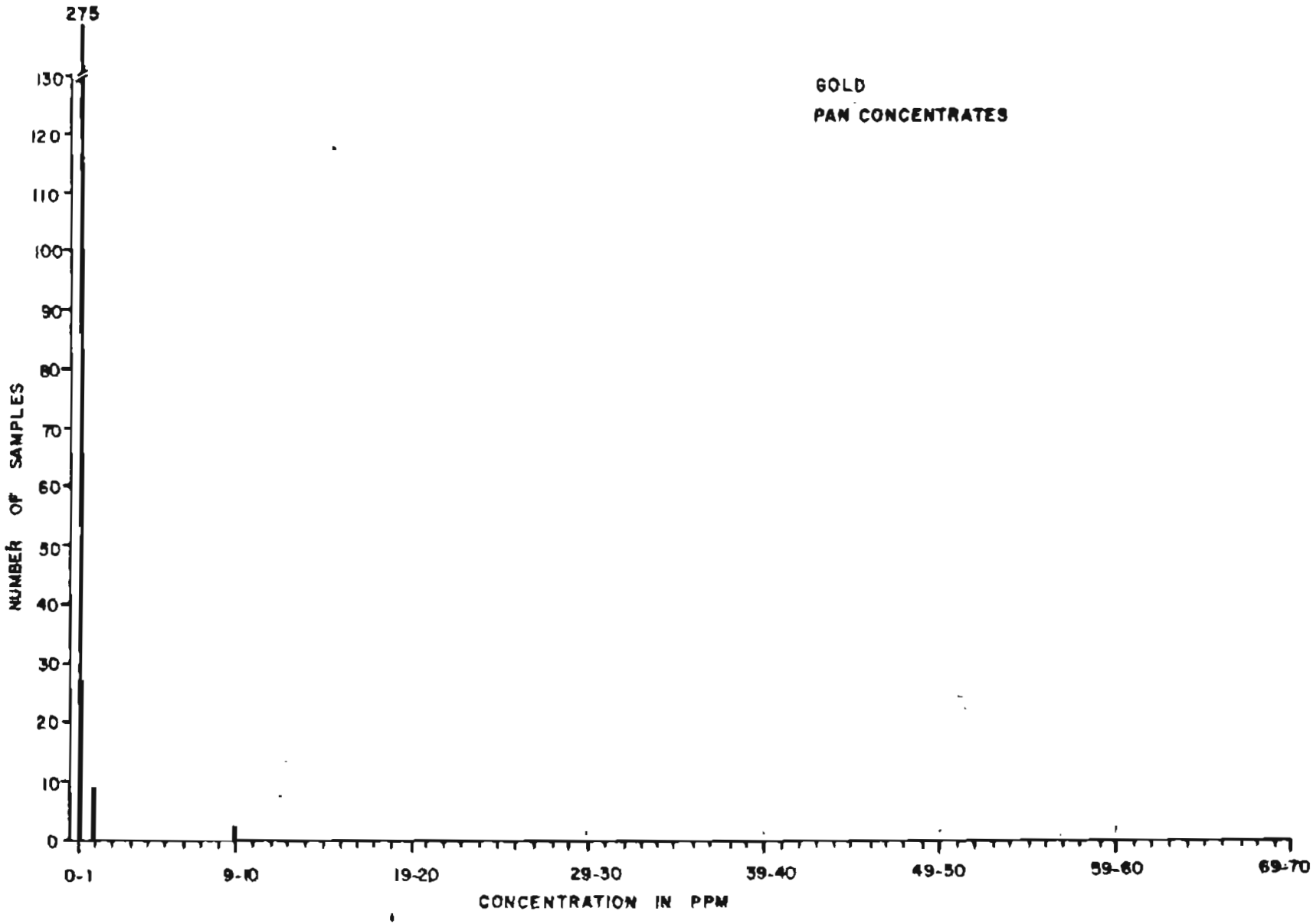

CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

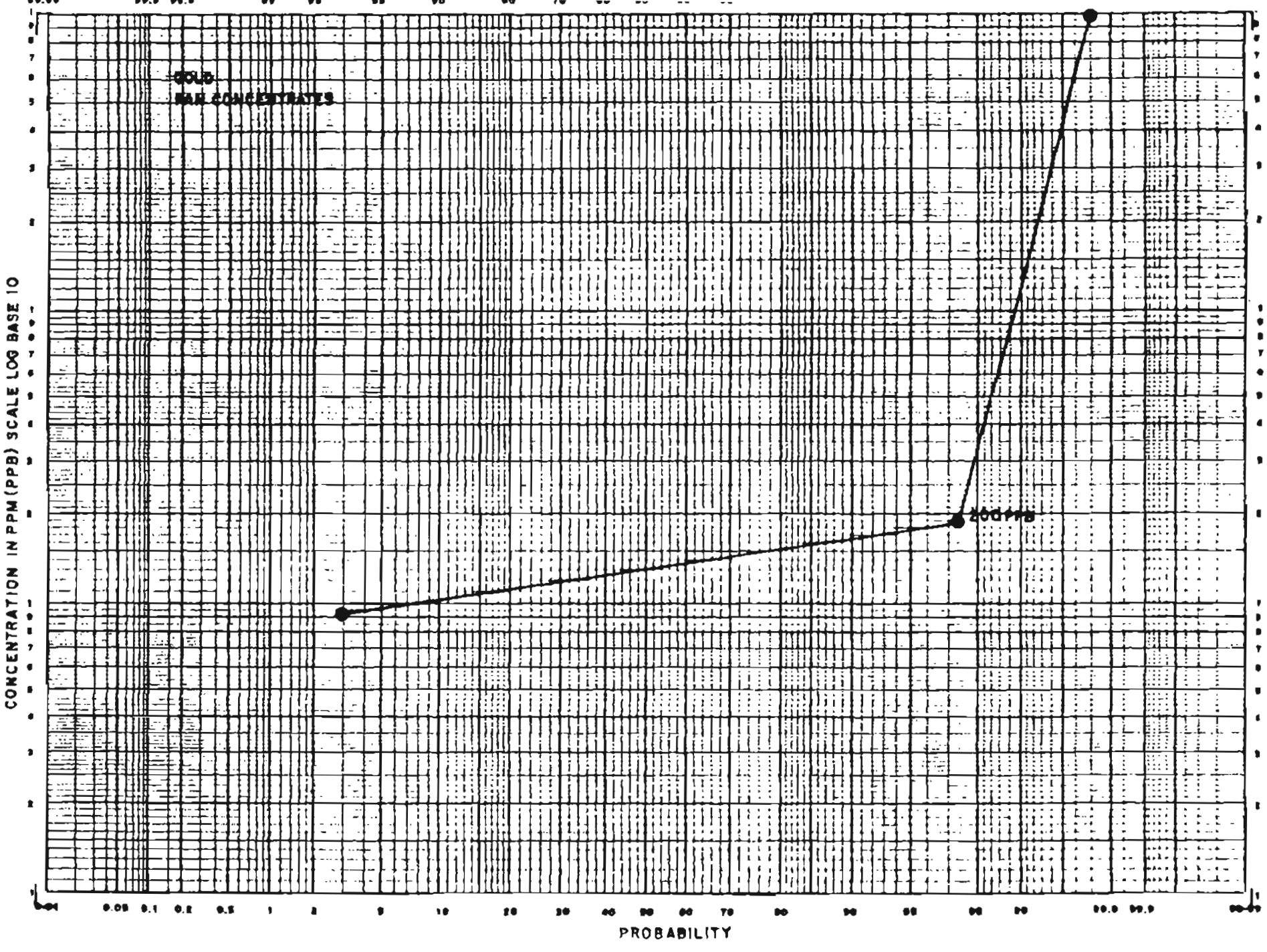

ZINC
STREAM SEDIMENTS
277
200
185
138
153
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

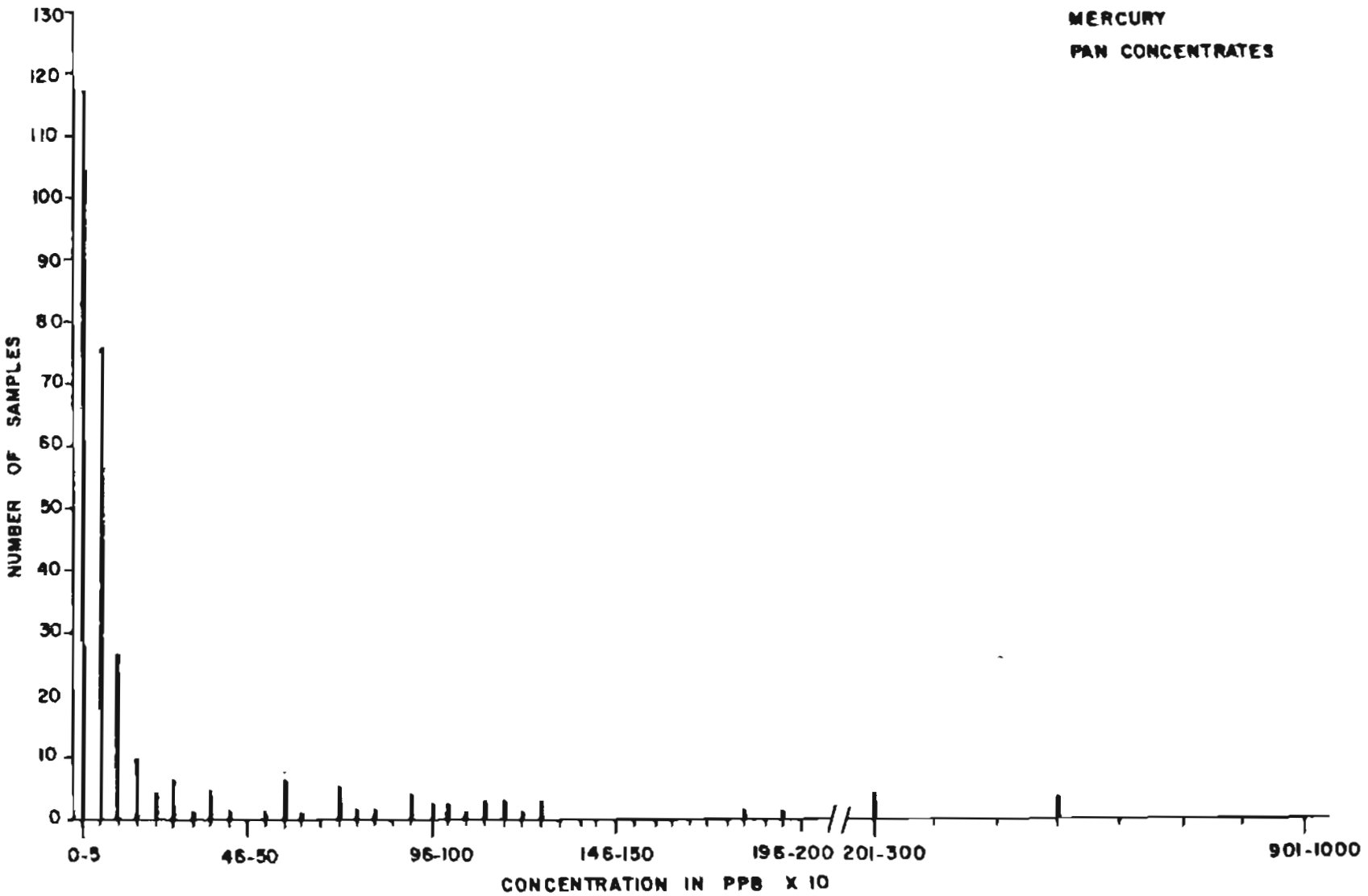

ZINC
SEDIMENTS
116 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

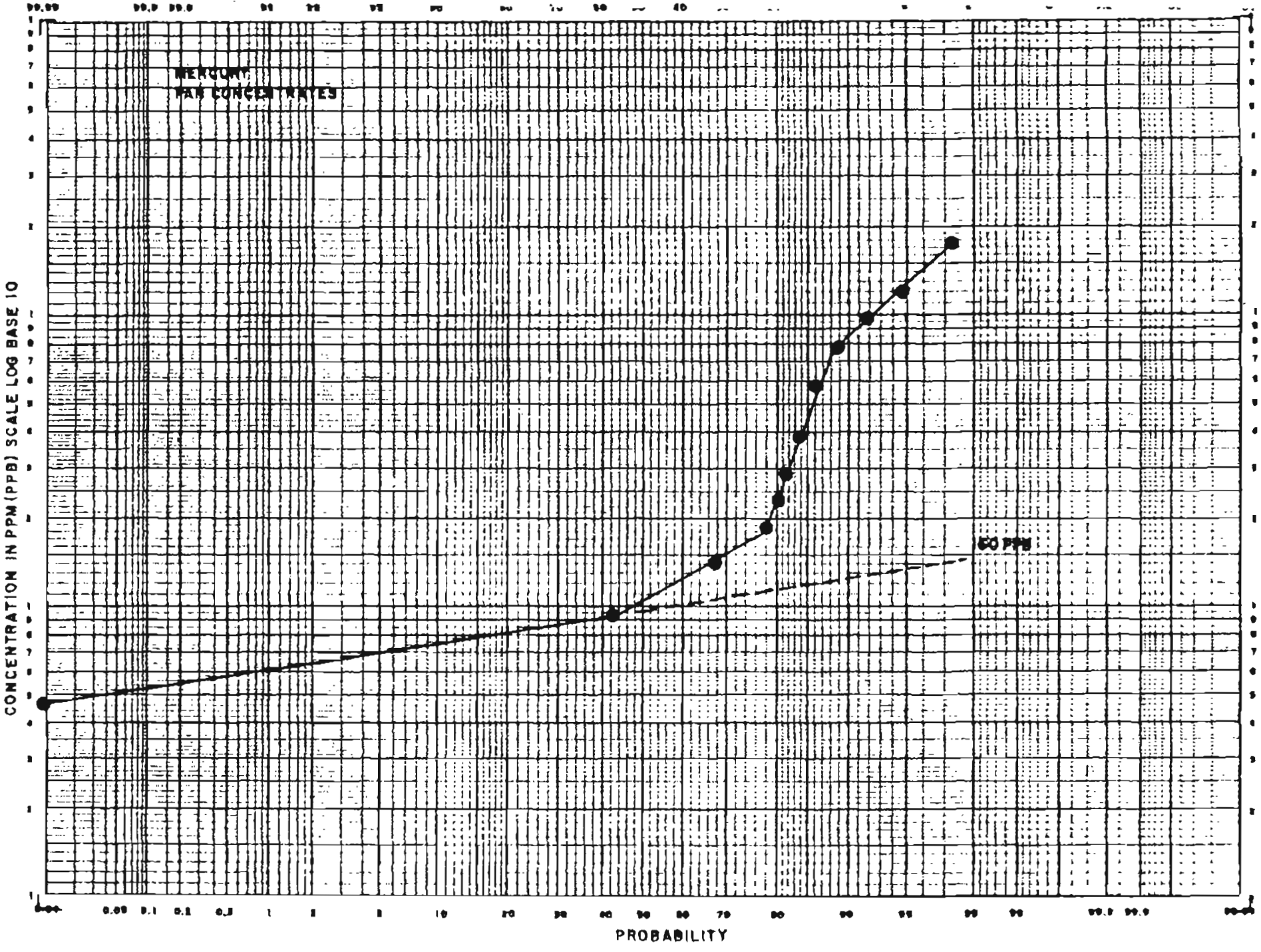

COPPER
PAN CONCENTRATES
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

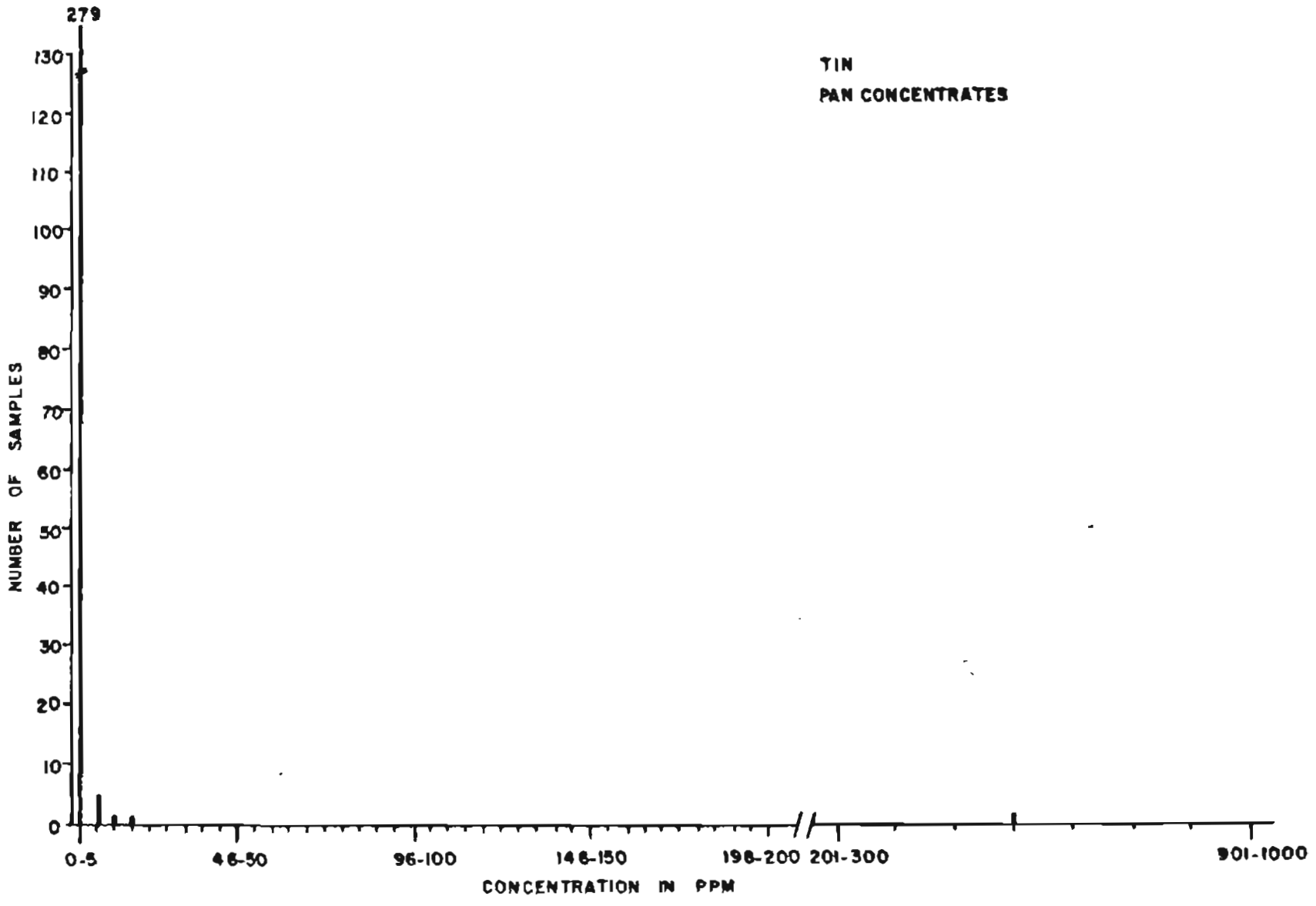

COPPER
FAR CONCENTRATES
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

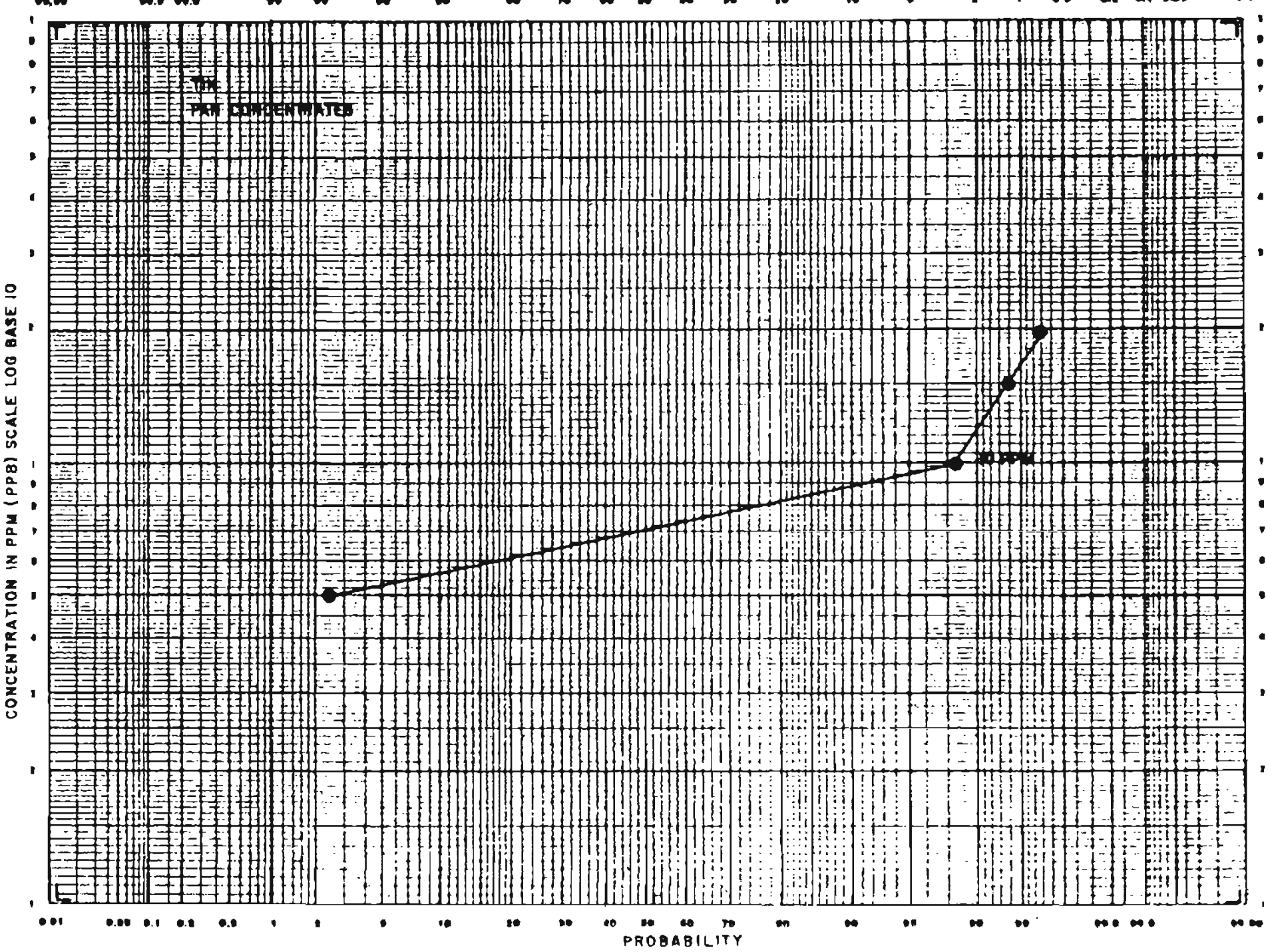

GOLD
PAN CONCENTRATES
275
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-1
9-10
19-20
29-30
39-40
49-50
59-60
69-70
CONCENTRATION IN PPM

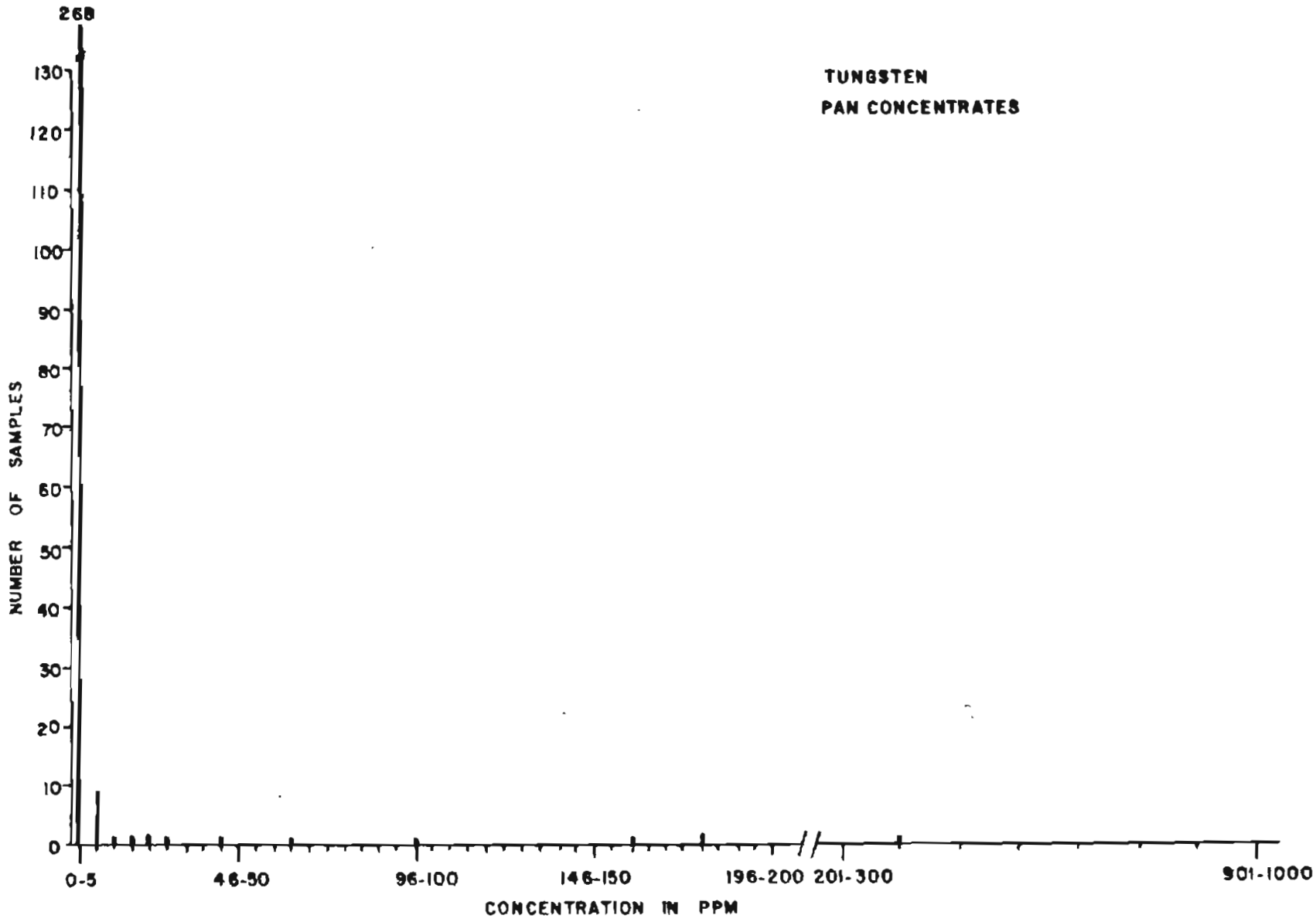

GOLD
BAR CONCENTRATES
200PPB
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

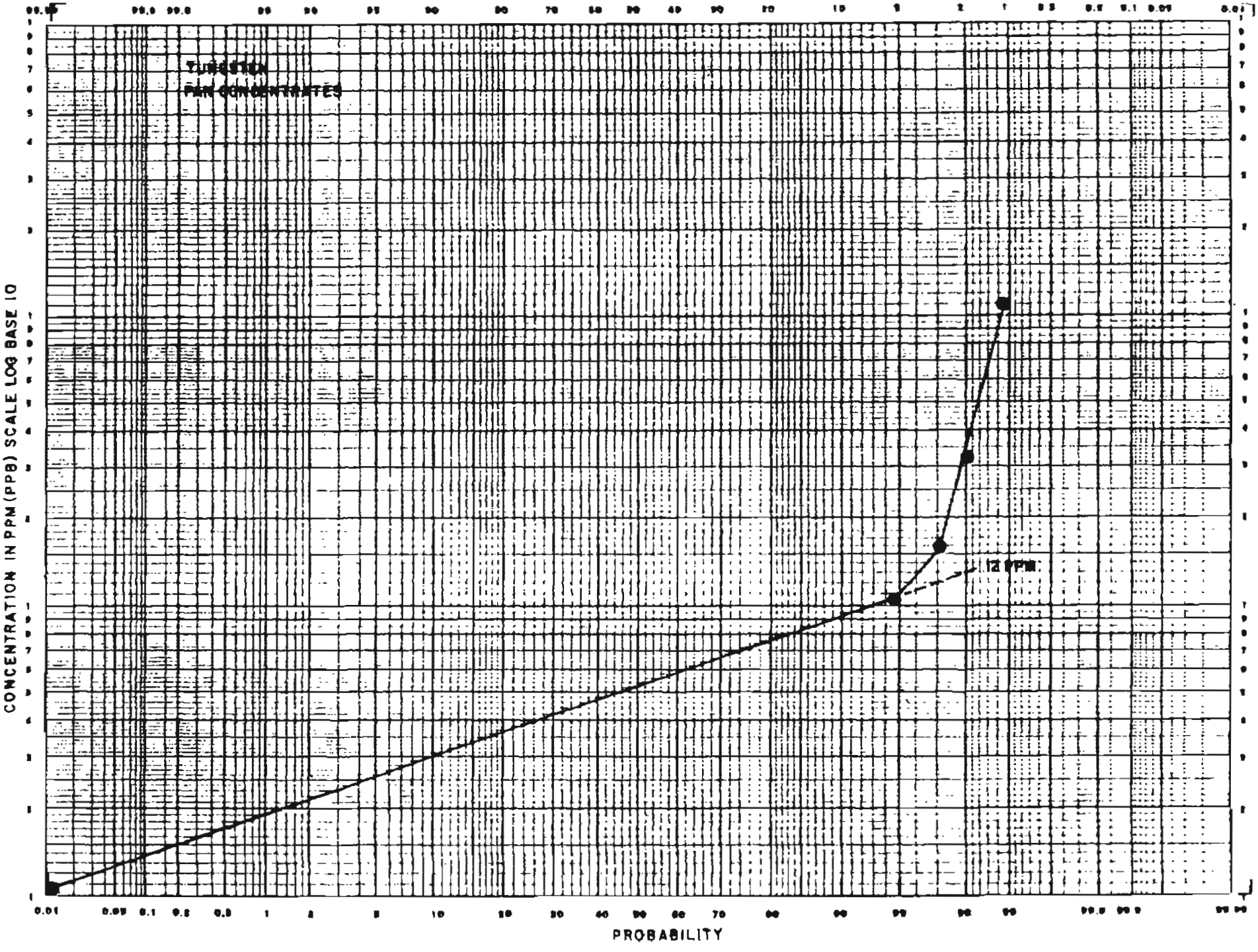

MERCURY
PAN CONCENTRATES
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPB X 10

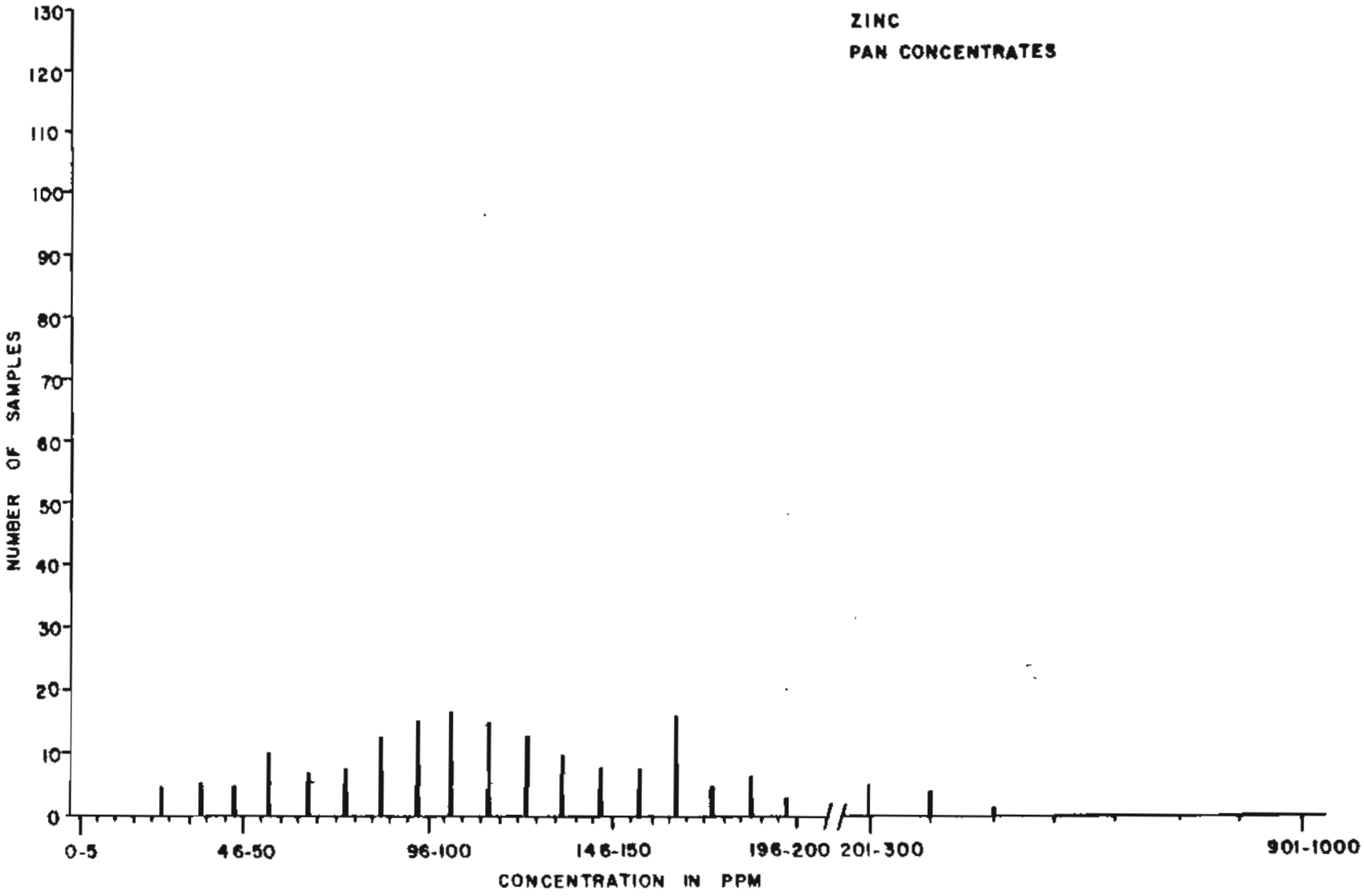

MERCURY
PAN CONCENTRATES
60 PPB
CONCENTRATION IN PPM(PPB) SCALE LOG BASE 10
PROBABILITY

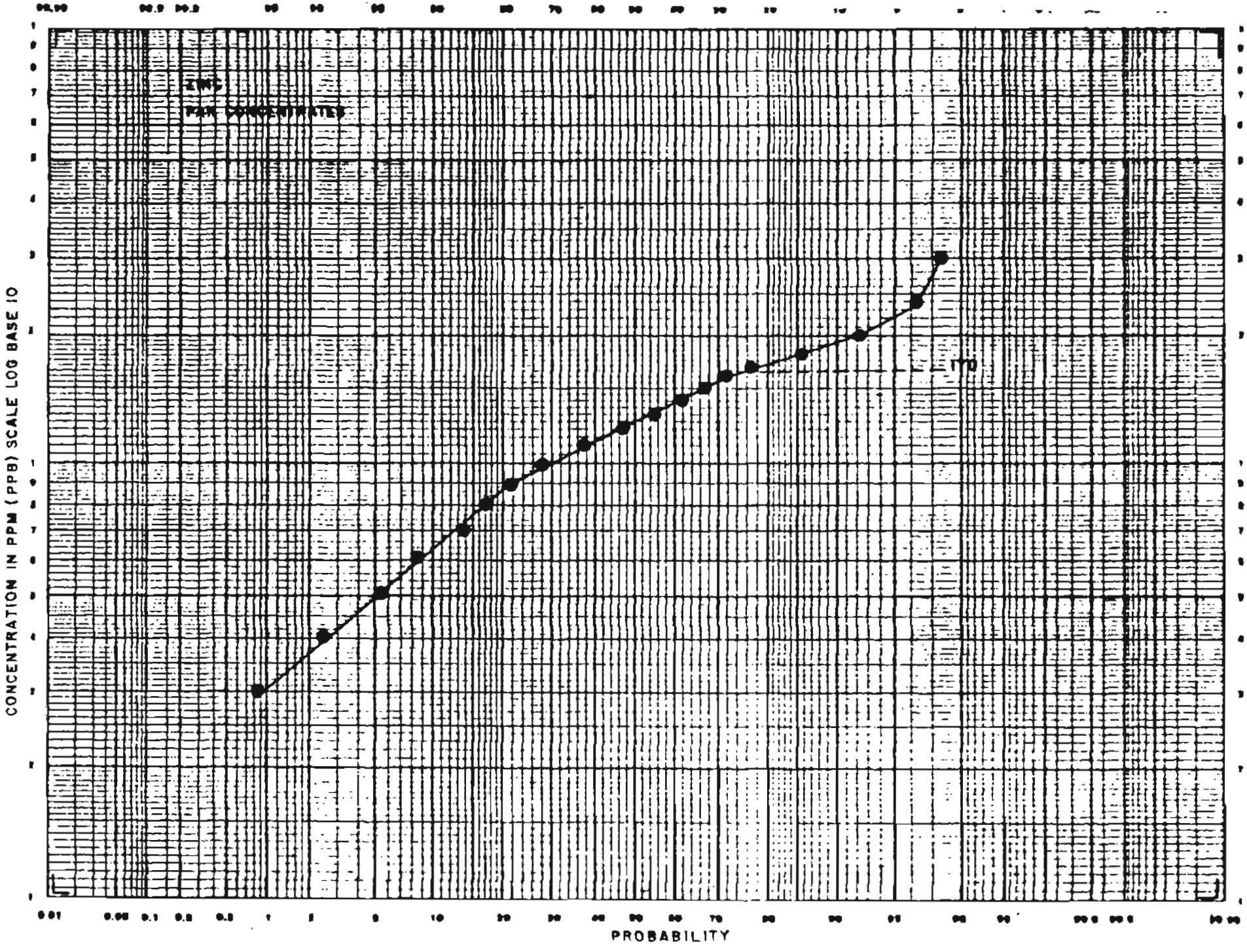

TIN
PAN CONCENTRATES
279
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

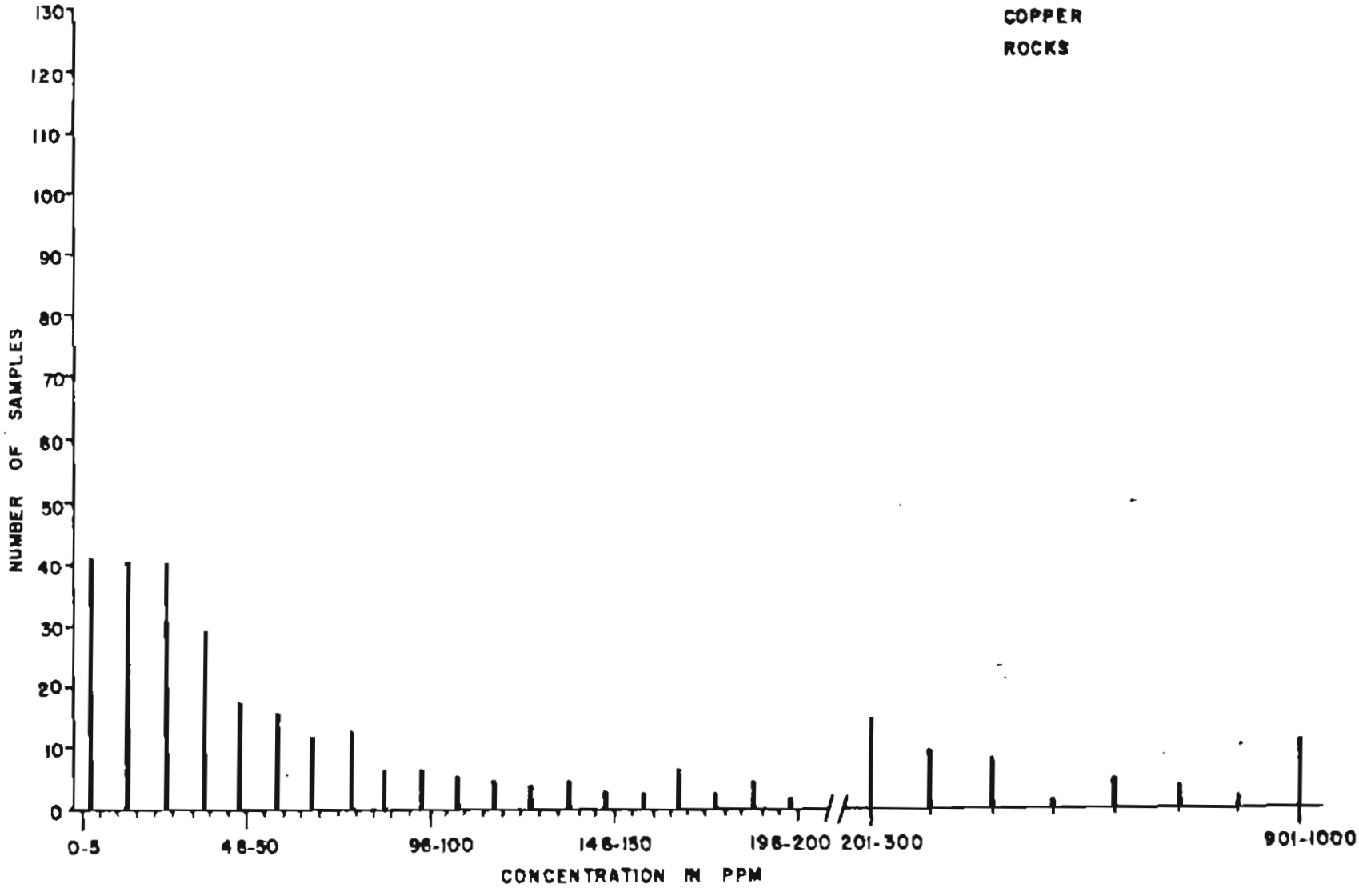

PAH CONCENTRATED
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

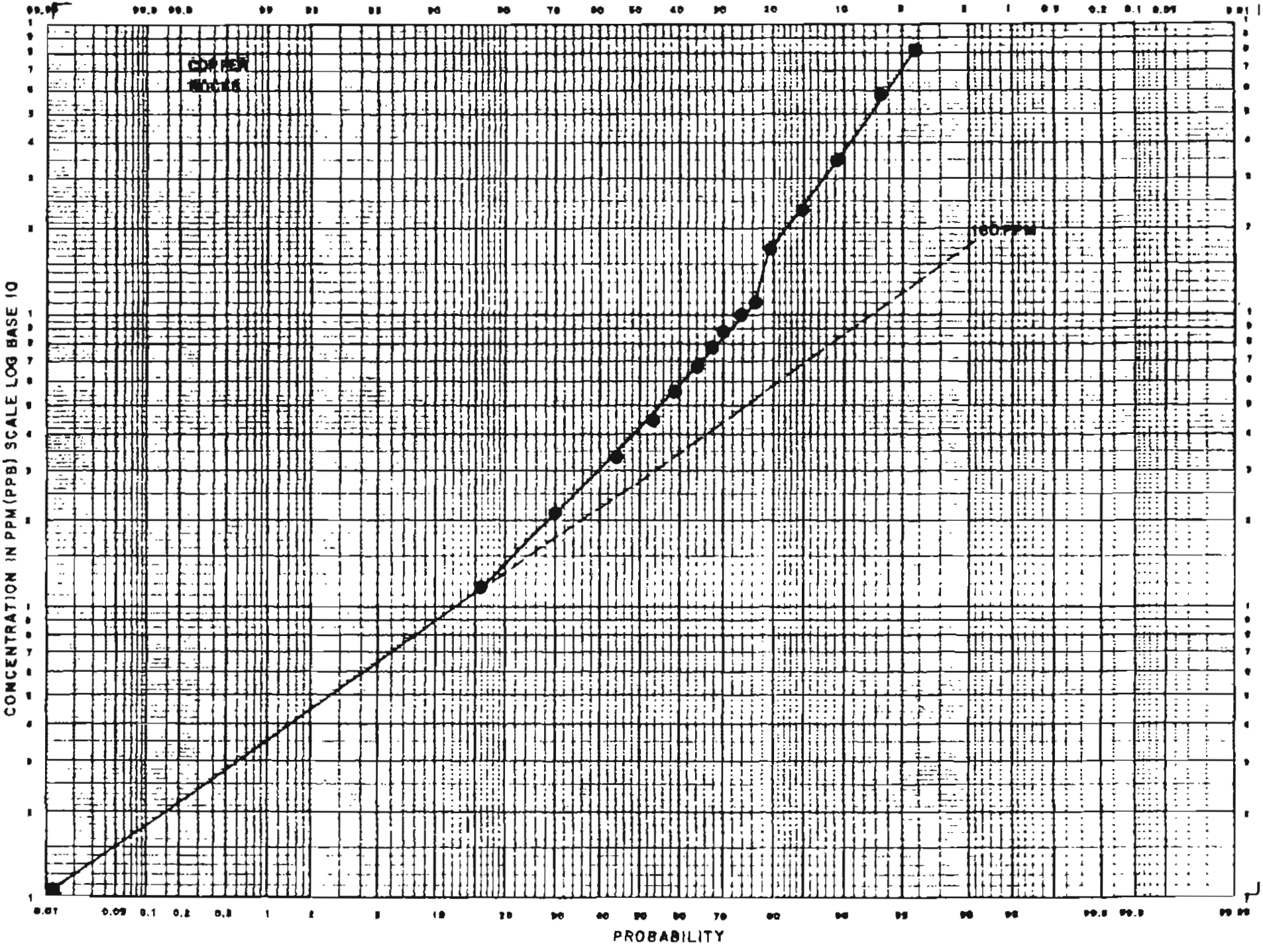

TUNGSTEN
PAN CONCENTRATES
268
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

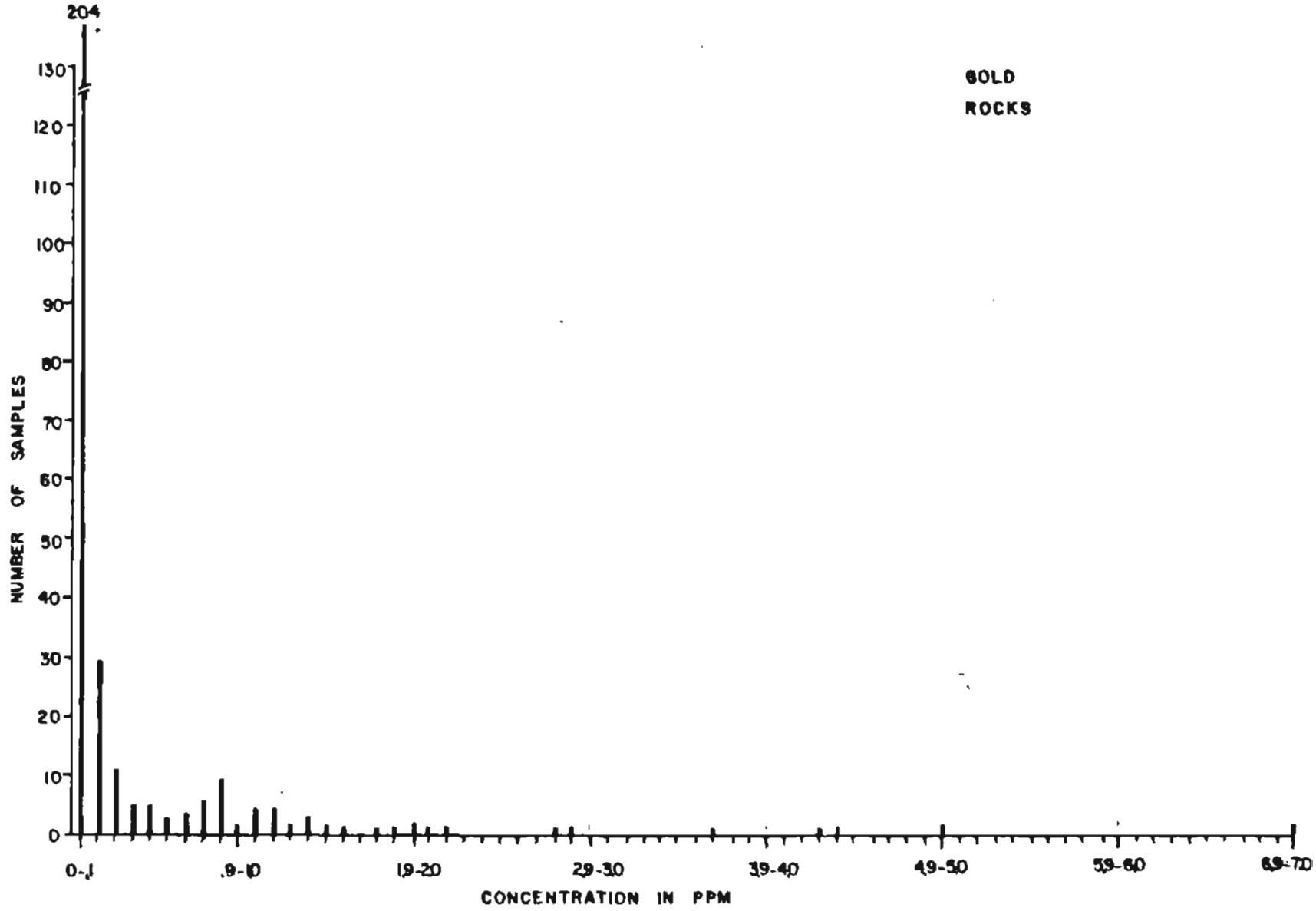

TUNGSTEN
PAN CONCENTRATES
12 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

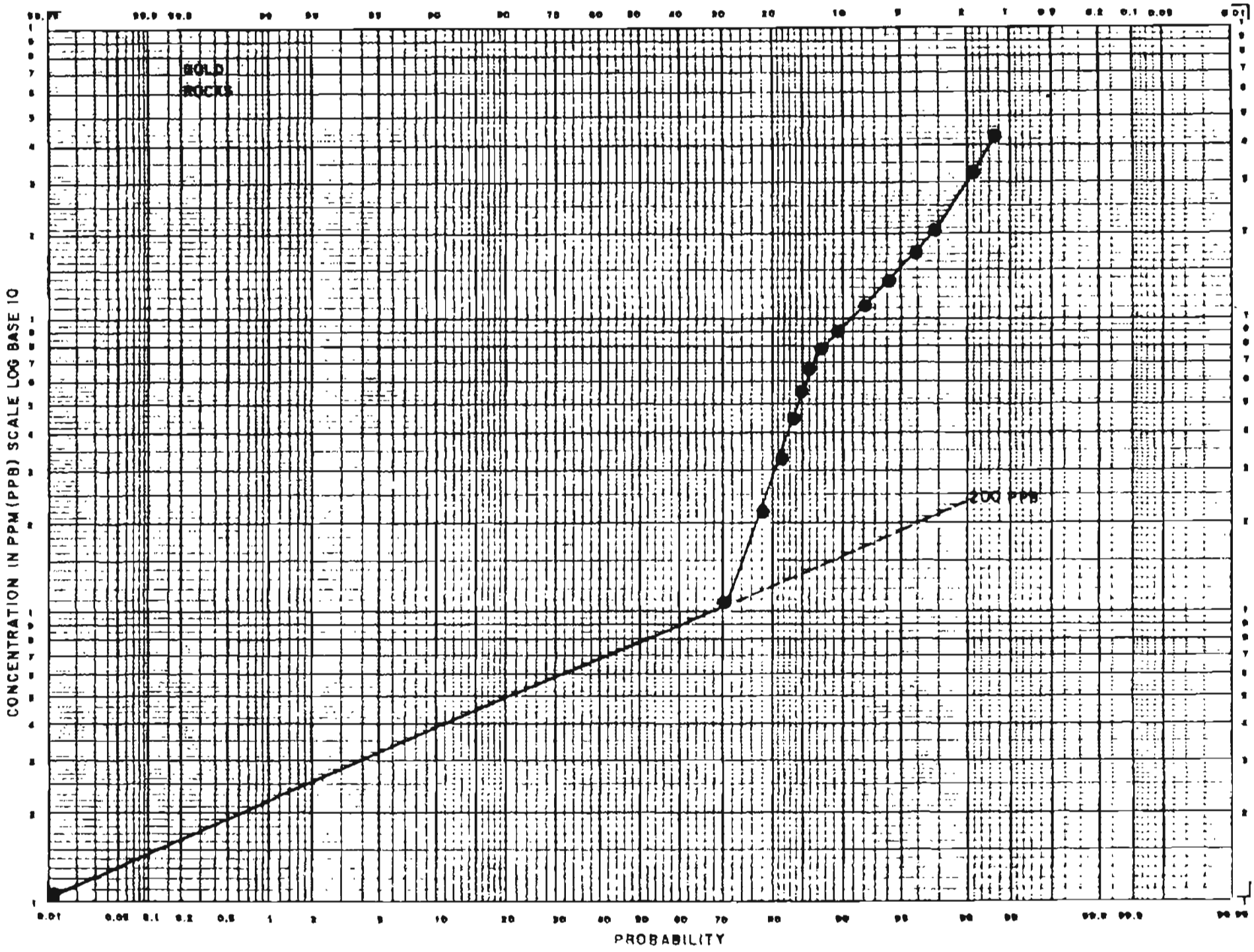

ZINC
PAN CONCENTRATES
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

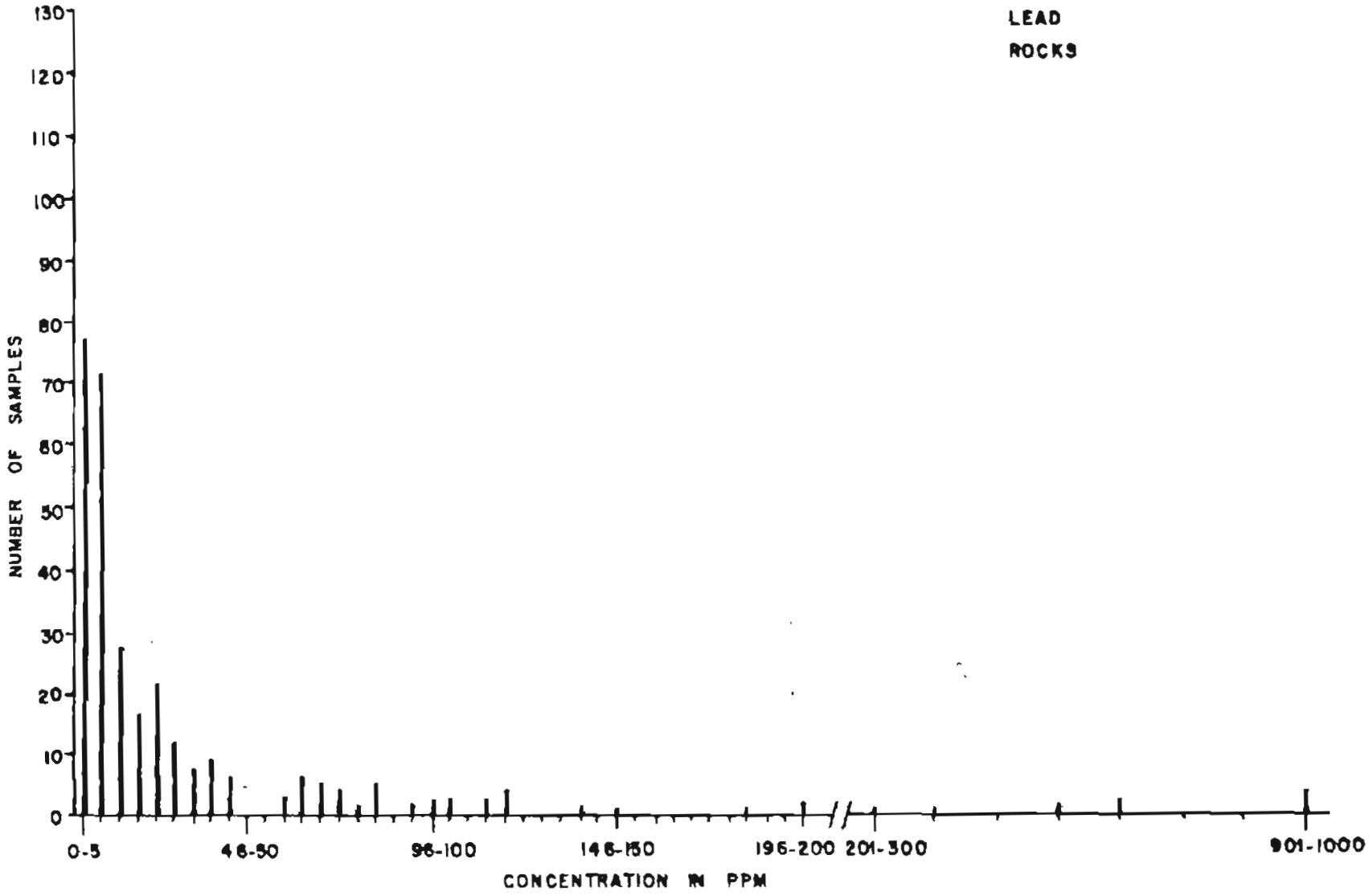

ZINC
PER CONCENTRATES
170
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

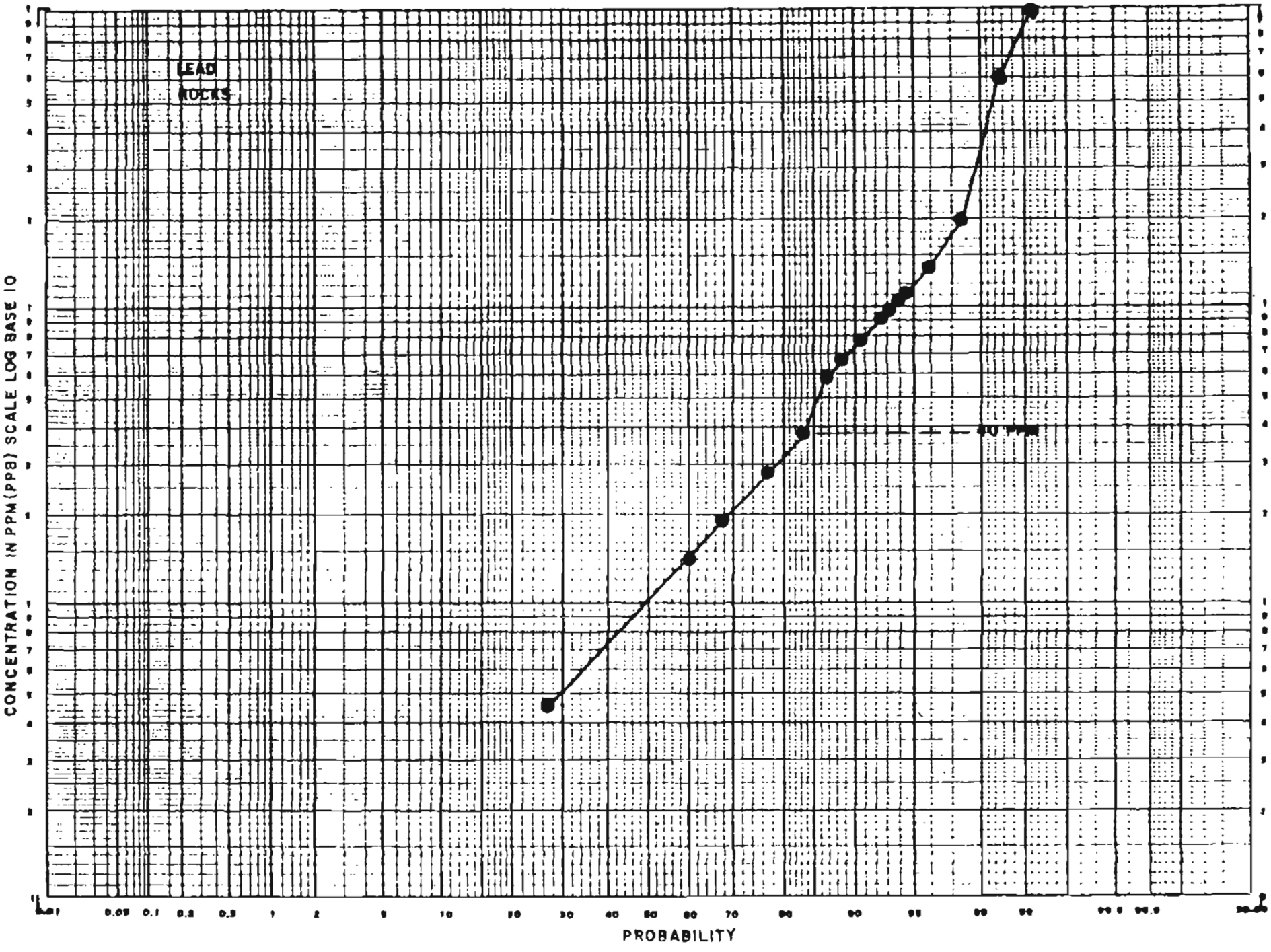

COPPER
ROCKS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

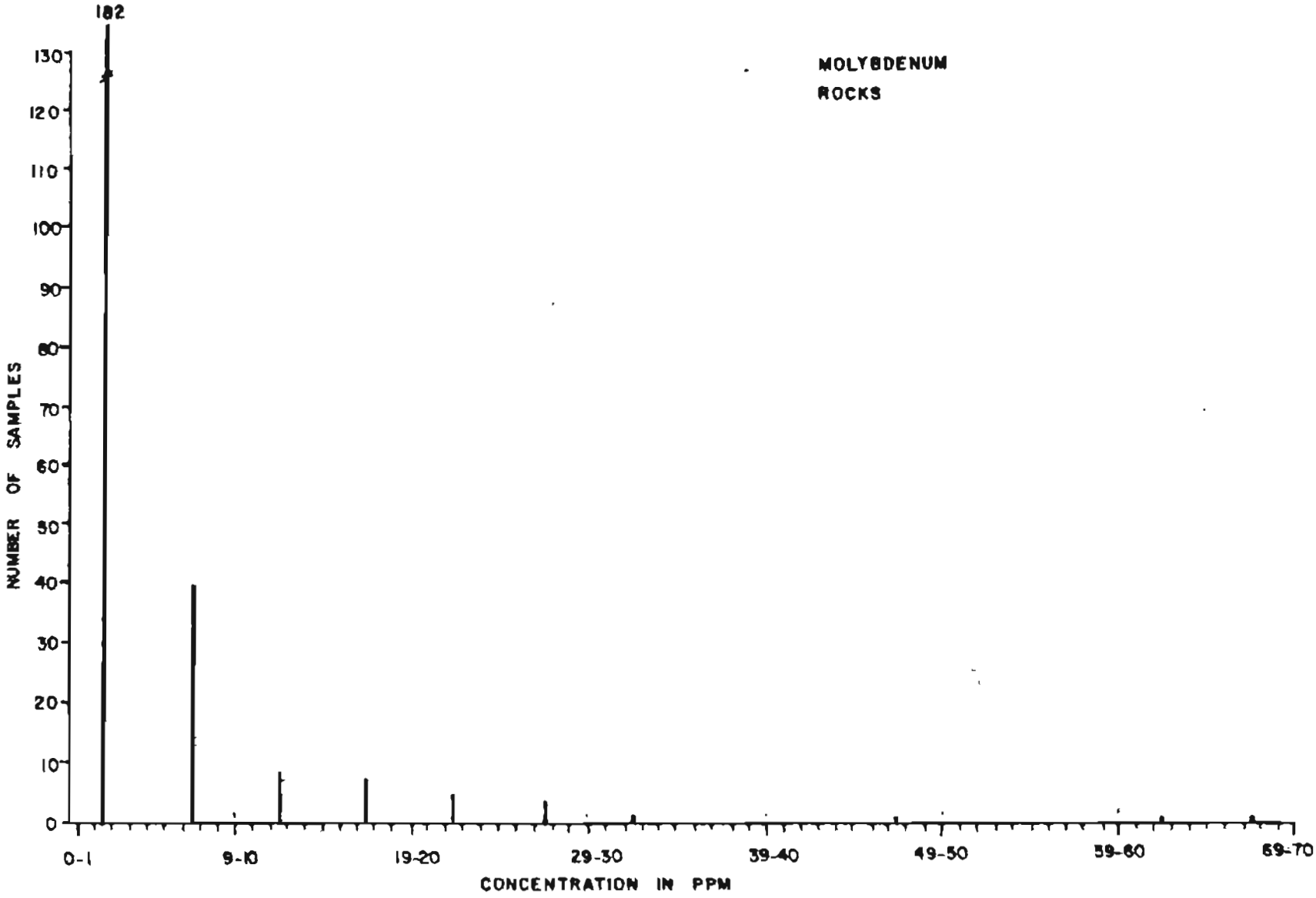

COPPER
160.77
COMCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

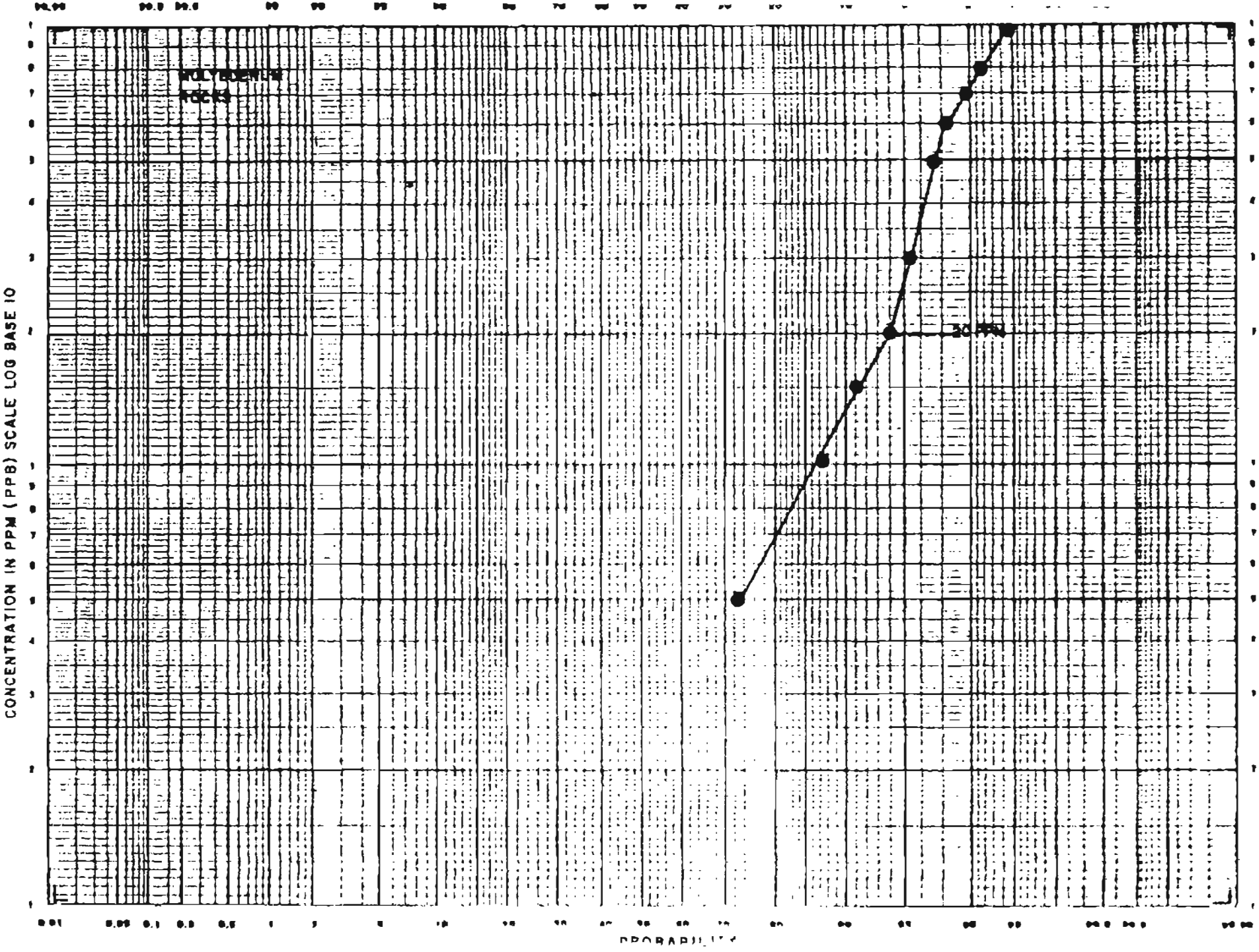

GOLD
ROCKS
NUMBER OF SAMPLES
204
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-.1
.9-1.0
1.9-2.0
2.9-3.0
3.9-4.0
4.9-5.0
5.9-6.0
6.9-7.0
CONCENTRATION IN PPM

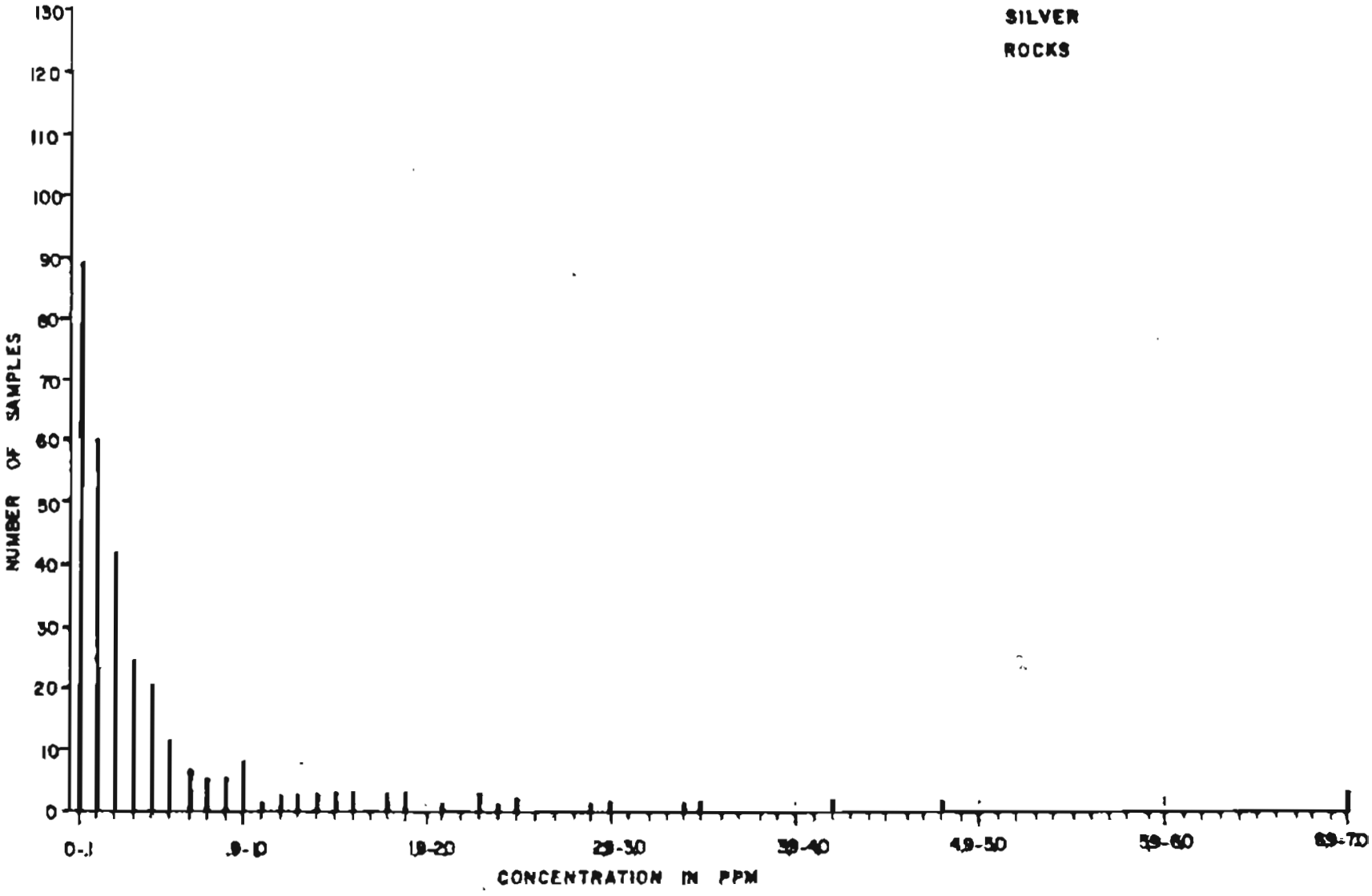

GOLD
ROCKS
200 PPB
CONCENTRATION IN PPM(PPB) SCALE LOG BASE 10
PROBABILITY

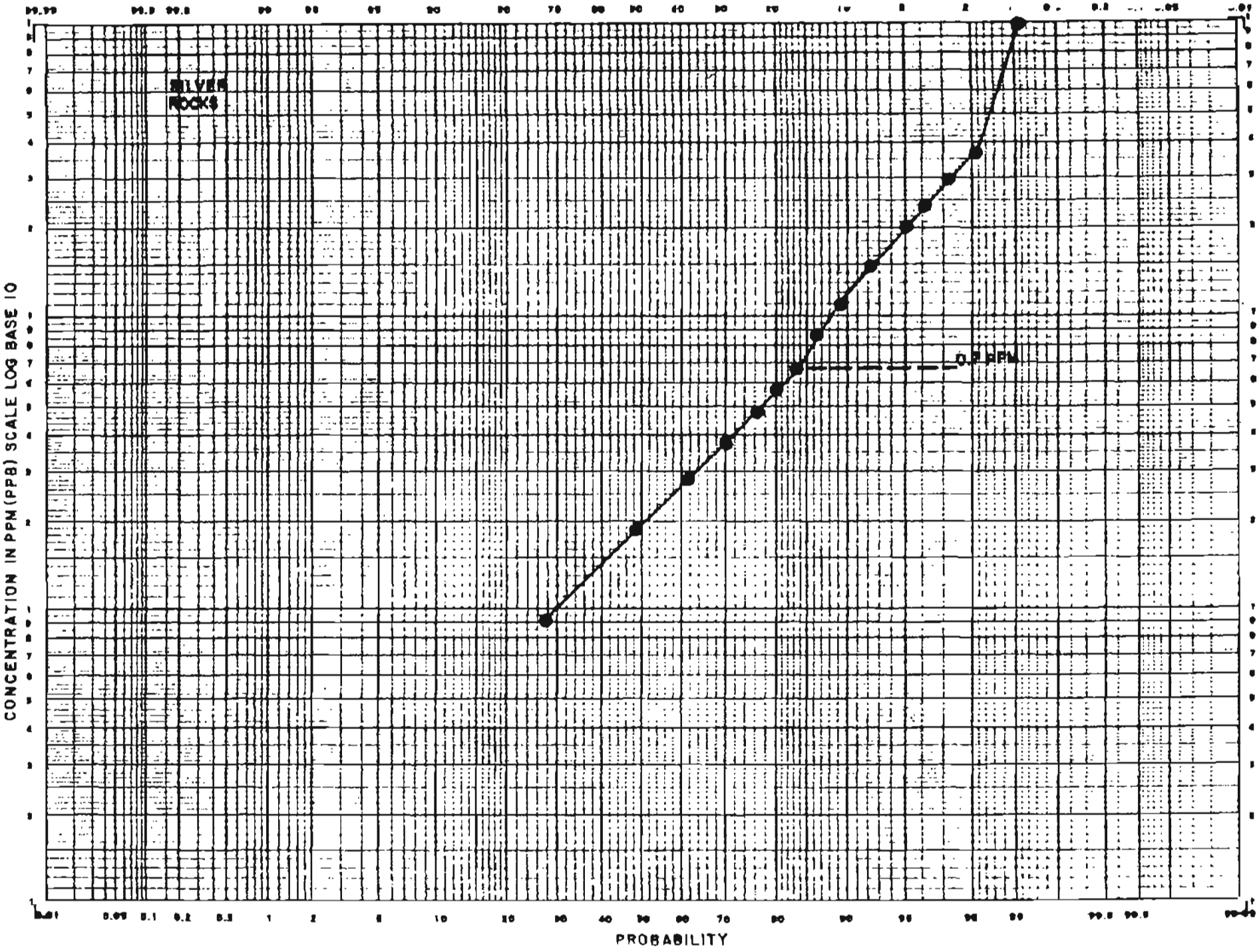

LEAD
ROCKS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

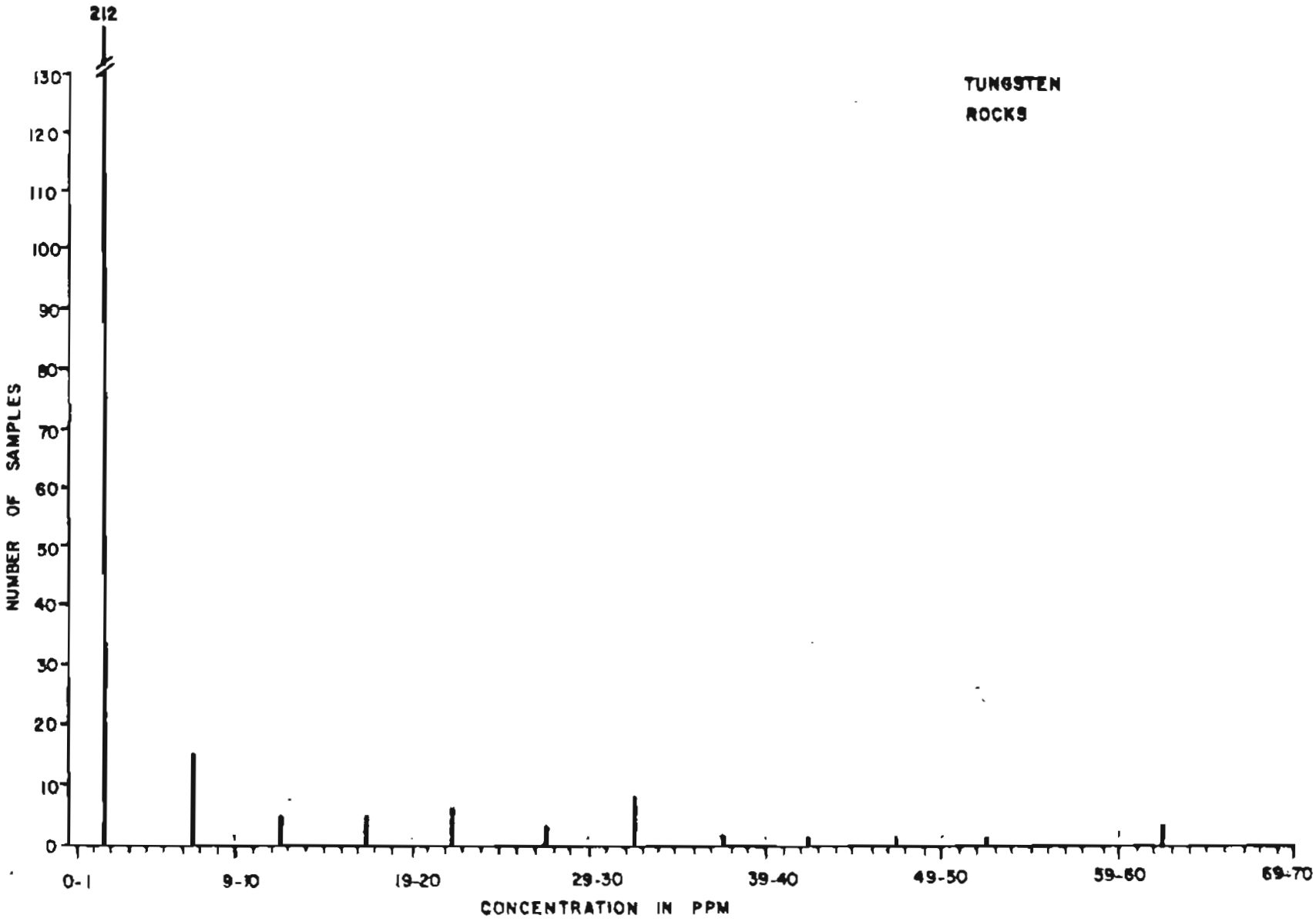

LEAD
ROCKS
40 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY

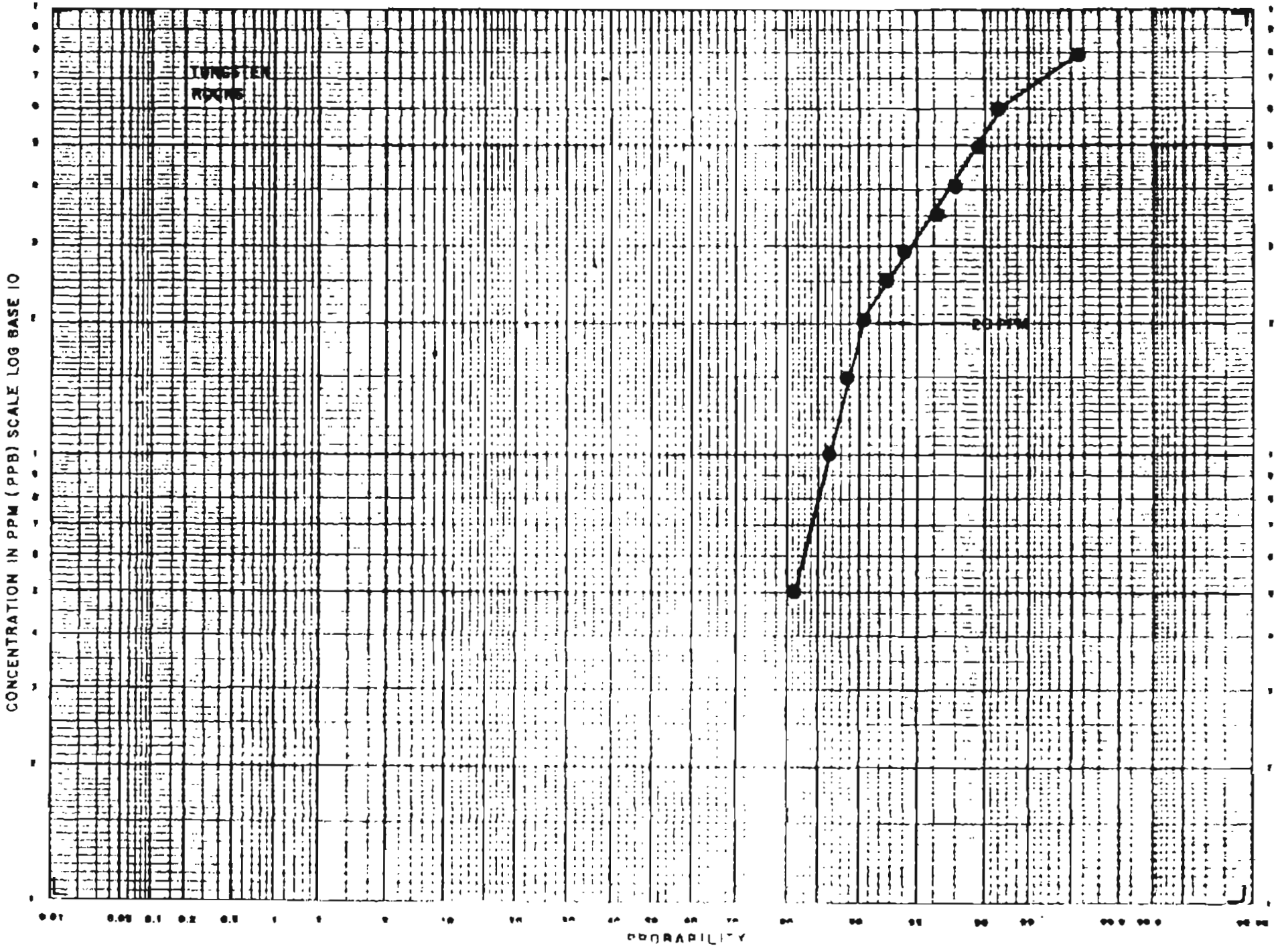

182
MOLYBDENUM
ROCKS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-1
9-10
19-20
29-30
39-40
49-50
59-60
69-70
CONCENTRATION IN PPM

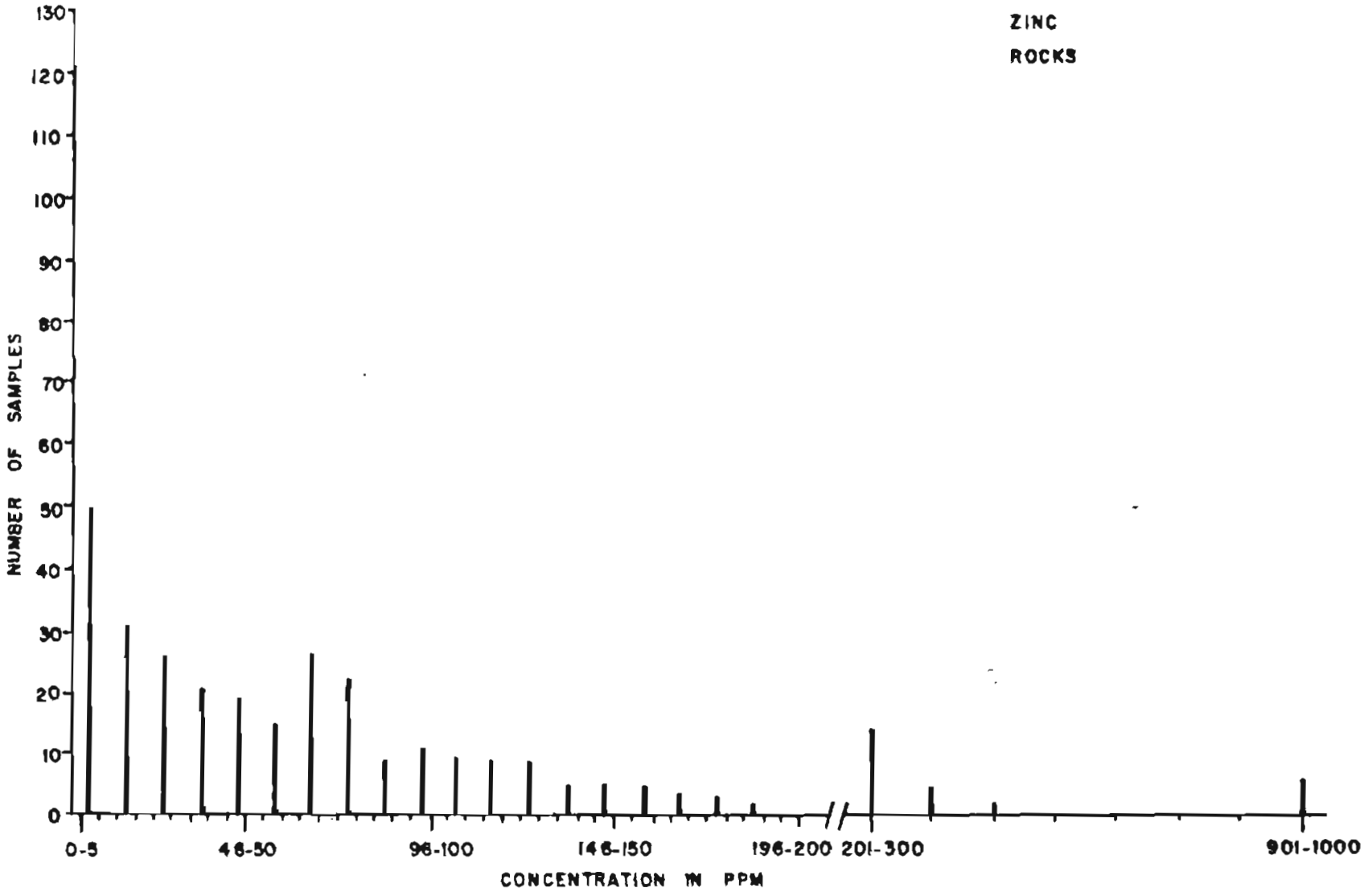

MOLYBDENUM
ROCKS
30 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY


SILVER
ROCKS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-.1
.9-1.0
1.9-2.0
2.9-3.0
3.9-4.0
4.9-5.0
5.9-6.0
6.9-7.0
CONCENTRATION IN PPM


SILVER ROCKS
0.2 PPM
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY


TUNGSTEN
ROCKS
212
130
120
110
100
90
80
70
60
50
40
30
20
10
0
NUMBER OF SAMPLES
0-1
9-10
19-20
29-30
39-40
49-50
59-60
69-70
CONCENTRATION IN PPM


TUNGSTEN
ROCKS
CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY


ZINC
ROCKS
NUMBER OF SAMPLES
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0-5
46-50
96-100
146-150
196-200
201-300
901-1000
CONCENTRATION IN PPM

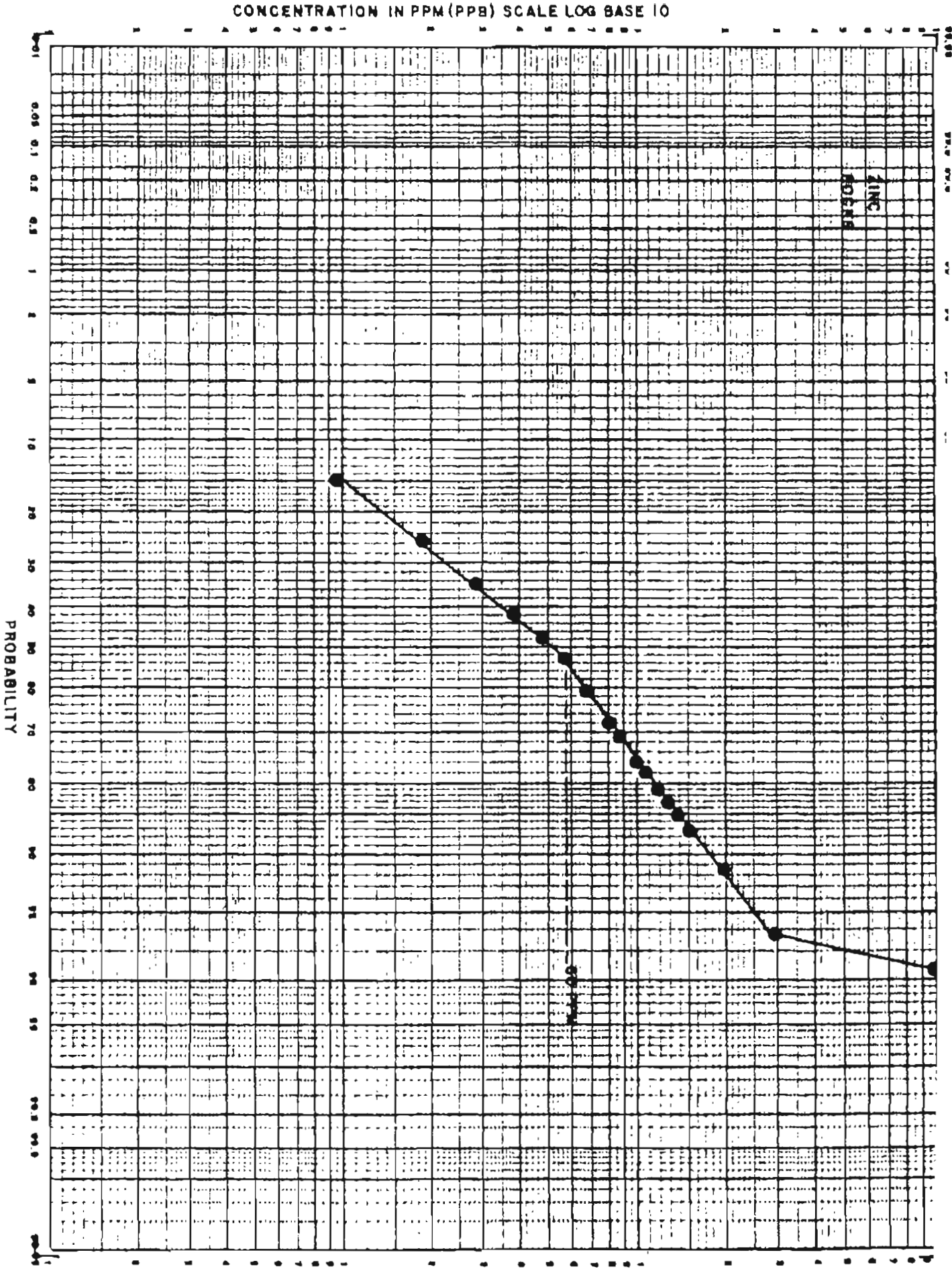

CONCENTRATION IN PPM (PPB) SCALE LOG BASE 10
PROBABILITY
ZINC
BORE

TABLE 1. Threshold values in PPM for stream sediment, pan concentrate, and rock geochemical samples from the Fairbanks, Richardson and Tolovana mining districts, Alaska

	FAIRBANKS			RICHARDSON		TOLOVANA		
Element	Rocks	Stream Sediment	Pan Concentrate	Stream Sediment	Pan Concentrate	Rocks	Stream Sediment	Pan Concentrate
Sb	42	--	10	--	42	--	--	--
As	22	52	--	--	30	--	25	--
Cu	180	28	--	36	--	160	48	68
Au	0.50	--	0.45	--	0.45	0.20	--	0.20
Pb	48	17	--	18	--	40	22	--
Hg	6	--	--	--	0.12	--	--	0.16
Mo	--	--	--	--	--	20	--	--
Ag	1.00	0.50	--	--	0.70	0.70	0.40	--
Sn	15	--	10	--	22	--	--	10
W	27	--	19	--	27	20	--	12
Zn	110	74	--	70	--	60	116	170
Ni	--	--	--	40	--	--	--	--
Fe	--	--	--	4000	--	--	--	--
Mn	--	--	--	1100	--	--	--	--
Cr	--	--	--	45	--	--	--	--
	n=812	n=1013	n=159	n=378	n=111	n=305	n=1597	n=297

DISCUSSION:

The anomalous localities shown on Plate II suggest that there are at least eight areas of potential lode mineralization in the district in addition to those previously defined by Foster (1968) and Robinson and Metz (1979). Anomalous areas are defined by more than one sample with one or more anomalous elements. Samples with a single anomalous element are generally less significant than those samples with multiple anomalous elemental concentrations. Roman numerals on Plate II depict these anomalous areas.

Area I is located in T10N, R6W, F.M. The major elemental associations include As-Cu-Pb-W-Zn. Bedrock in the area is Rampart Group including greenstone, gray chert and variegated chert (Robinson, 1983). Arsenic concentrations are restricted to areas with chert exposure. High zinc concentrations in stream sediment and pan concentrate samples can be attributed in part to the relatively high zinc content of the Rampart Group greenstones with a mean of approximately 70 ppm (see Fig. 38).

Area II is located in T9N, R4W, F.M. The major elemental associations include As-Cu-Au-Pb. Bedrock in the area is Chert Terrane including gray and tan chert and chert conglomerate (Robinson, 1983; Smith, 1983).

Area III is located in T9N, R3W, F.M. The major elemental associations are As-Cu-Pb-Hg-Ag-Zn. Bedrock is Chert Terrane including gray and tan chert, chert conglomerate and chert breccia (Smith, 1983).

Area IV is located in T8N, R6W, F.M. The major elemental associations are As-Cu-Au-Pb-Hg-Mo-Ag-Zn. Bedrock is Chert Terrane

including gray and tan chert, chert conglomerate and chert breccia (Robinson, 1983).

Area V is located in T7N, R5W, F.M. The major elemental associations are As-Cu-Pb-Hg-Mo-Ag-Zn. Bedrock is Mesozoic Flysch including shale, siltstone, and sandstone. In the north and south extremities of the area the sedimentary rocks are intruded by quartz porphyry (Albanese, 1983). The quartz porphyry dikes and plutons may be structurally controlled since they occur along a major north-south linear feature.

Area VI is located in T7N, R4W, F.M. The major elemental associations include As-Cu-Pb-Mo-Ag-Zn. Bedrock in the area is Mesozoic Flysch including conglomerate, minor sandstone and siltstone. The sedimetary rocks are intruded by quartz porphyry dikes and plutons. The plutonic rocks are sericitically and propylitically altered and sulfides were reported in the plutons and in a shear zone in the western extreme of the Livengood B-3 quadrangle (Bundtzen, 1983).

Area VII is located in T6N, R3W, F.M. The major elemental associations are Pb-Hg-Ag-Zn. Bedrock in the area is gabbro and diorite of the Paleozoic Sedimentary, Igneous, and Low Grade Metamorphic Terrane (Bundtzen, 1983).

Area VIII is located in T5N, R6W, F.M. The major elemental associations are As-Cu-Pb-Ag $\pm$ Sn-W. Bedrock is the quartz monzonite of the Tolovana Hot Springs Dome and the shale and siltstone unit of the Mesozoic Flysch Terrane (Albanese, 1983). Chapman and others (1971) report a biotite K^{40}/Ar^{40} age date of 63.3 $\pm$ 2.5 m.y. for the pluton.

The intrusive contains up to 8 percent biotite, 7 percent blue-green hornblende and traces of tourmaline and pyrite.

GENETIC ORE DEPOSIT MODELS

Epithermal gold-quartz veins associated with quartz monzonite stocks and quartz feldspar porphyries have generally been accepted as the lode source of the major gold placer deposits of the Tolovana mining district. The veins and intrusive rocks are centered around the Money Knob/Amy Dome area and are hosted in the Devonian Clastics and Mafic Complex.

As note above, Foster (1968) suggested that the Devonian carbonaceous siltstones, argillites, cherts, and marbles exhibit petrologic, structural and trace elemental associations similar to the Carlin-type gold deposits. From a review of recent geological mapping and a statistical analysis of concurrent geochemical sampling of the district the following generalizations can be made:

1. Precious metal mineralization occurs in the Chert Terrane, in the Mesozoic Flysch Terrane in association with porphyritic intrusives and in the Paleozoic Sedimentary, Igneious, and Low grade Metamorphic Terrane as well as in the Devonian Clastics and Mafic Complex.
2. In addition to the epithermal vein and Carlin-type genetic ore deposit models, a Precambrian greenstone/exhalite type gold model should be considered to account for the mineralization in the Chert Terrane.

3. The copper-molybdenum porphyry at Shorty Creek and the anomalous areas V and VI should be examined to determine if these systems are of the gold porphyry type of Harris (1979) and Sillitoe (1979).

4. A precious metal enriched massive sulfide model should be considered in the evaluation of both the Ruth Creek area and anomalous area VII since both areas contain mafic volcanic sequences.

The above genetic ore models are summarized in Table 2 along with tonnage and grade ranges for each genetic type.

SUMMARY AND CONCLUSIONS

Stream sediment, pan concentrate, and rock geochemical sampling in the Tolovana mining district indicate eight additional areas of potential lode mineralization. These areas of mineralization are in tectono-stratigraphic terranes not previously considered as lode gold source areas. The elemental associations in the anomalous areas of the Chert Terrane and host rock lithology suggest a Precambrian greenstone / exhalite type ore deposit mode of origin. The arsenic, antimony, copper, molybdenum ± gold and silver anomalies associated with quartz feldspar porphyries in the Mesozoic Flysch terrane are suggestive of gold porphyry type mineralization. The base and precious metal anomalies associated with mafic volcanic rocks in both the Devonian Clastic and Mafic Complex and the Paleozoic Sedimentary, Igneous, and Low Grade Metamorphic Terrane may be indicative of precious metal enriched massive sulfide type mineralization. These genetic ore deposit

Table 2. Genetic ore models for the Tolovana mining district, Alaska

Genetic Model	Examples	Elemental Associations	Host Rock Associations	Ore Mineralogy	Gangue Mineralogy	Age of Host	Age of Mineralization	Sulfur Isotope Ratios	Hydrogen/ Oxygen Isotope Ratios
1. Precambrian Greenstone Terrane Hosted Gold	Yellowknife, N.W.T. Canada; Hemlo Ontario, Canada; Red Lake Ontario, Canada; Little Long Lac, Ontario, Canada; Larder Lake Area, Ontario, Canada; Homestake/Rockford, Black Hills, South Dakota, USA; Minas Gerais, Brazil; Ramagiri Goldfield, India; Kolar Goldfield, India; Western Australia; Kilo-Moto Area, Zaire; Barberton Goldfield, South African Republic	Au, Ag, As	Metamorphosed Basalt, andesite, felsic volcanics & pyroclastic rocks, silicic carbonate, exhalite chert, talc/fuchsite schist, black schist, cummingtonite schist, cherty iron formation, phyllite.	Native gold, arsenopyrite pyrite, magnetite, pyrrhotite, hematite sphalerite, tetrahedrite, scheelite, galena	quartz, ankerite siderite, albite sericite, tourmaline, cummingtonite, chloritoid fuchsite	Archian or Proterozoic	Archian or Proterozic remobilized from host.	(?)	$\delta^{18}O$ 8-11 per mil.
2. Precious metal enriched massive sulfides	Flin Flon, Manitoba, Canada; Manitouwadge, Ontario, Canada; Kidd Creek, Ontario, Canada; Noranda, Quebec, Canada; Mattagami, Quebec, Canada; Vermillion, Ontario, Canada; Crandon, Wisconsin, USA; Buchans, Newfoundland, Canada; Granby Bay, British Columbia, Canada; Shasta, California, USA; Pueblo Viejo, Dominican Republic; Bergslagen, Sweden; Outokumpu, Finland; Rio Tinto, Spain; Innsbruch, Austria; Montenegro, Yugoslavia; Hitachi, Honsku, Japan; Mt. Lyell, West Tasmania	Zn, Cu, Pb, Au, Ag	m-basalt, m-andesite, m-hyaloclastites, m-rhyolite, tuff, m-keratophere, muscovite quartz schist, m-chert, talc-actinolite schist, m-chert carbonate, chert breccia, black schist, slate, fuchsite schist, and jaspilite.	pyrite, sphalerite, chalcopyrite pyrrhotite, galena, tetrahedrite, barite magnetite, bornite, and molybdenite	See Host Rock Type	Archian to Miocene	--	$\delta^{34}\delta$ -5 to +10	$\delta^{18}O$ to 10 per mil.

Table 2. (cont'd)

	Lead/Lead Isotope Ratios	Fluid Inclusions Type	Salinity	Temp. Hom.	Temp. Trap.	Regional Structural Setting	Local Structural Control	Tonnage Range	Grade Range	Comments	References
1.	(?)	H_2O+ CO_2+ NaCl	1-10 wt% Na Cl Equiv.	300-360°C	400-500°C	Mobile belts adjacent to stable cratons. Early tensional and subsequent compressional tectonics accompanied by regional greenschist facies metamorphism.	Remobilized mineralization in stratabound quartz carbonate veins and in major shear zones with both normal and strike slip components. Remobilized mineralization also localized at fold hinges.	80-900 tonnes Au	9-20 grams/ tonnes	Ore bodies include sulfide/gold disseminations and lenses in metavolcaniclastics, exhalites, and iron formations and major shear zone related mineralization exhibiting both open space filling and replacement structures and textures.	Brown et. al, 1959; Riley, 1972; Borwood and Pye, 1955; Bragg, 1967; Ridler, 1970; Rye and Rye, 1974; Bayley, 1972; Gair, 1962; Tolbert, 1964; Fleischer and Routhier, 1973; Putzer, 1976; Ghosh, et al., 1970; Krishnaswamy, 1972; Woodall, 1975, Woodth, 1961; Gribnitz, 1964; Viljoen, et al., 1969; Pye and Roberts, 1981, Anhaeusser, 1976; Patterson, 1981.
2.	206/204, 13.2-15.7; 207/204, 14.4-15.5; 208/204, 33.1-35.3.	H_2O + NaCl (liq. vapor)	1.0-5.0 wt% NaCl equiv.	200-350°C	300°-500°C	Back arc, inter-arc, and intracratonic basins formed in tensional tectonic environment. Formed by submarine volcanic and exhalative activity.	Mineralization occurring generally in volcaniclastic sequence in transition zone from mafic to felsic volcanism and in sediments occurring in local structural depressions in the volcanic pile.	3-11Mt, Zn; 0.5-2Mt, Cu; 25-480Tt, Pb; 3-200t, Au; 0.5-15Tt, Ag.	1-5%, Zn; 0.5-4% Cu; 0.5-1 %, Pb; 0.14-3.7 gm., Au; 7-70gm Ag.	Ore bodies include sulfide and gold disseminations in volcaniclastics rocks and sediments. Massive sulfide lenses may be up to tens of meters in thickness and continuous for several thousand meters on strike.	Koo and Mossman, 1975; Suffel et al., 1971; Matulick et al., 1974; Spence & de Rosenspence, 1975; Roberts, 1975; Martin, 1957; Staff, Engineering Mining Jour., 1977; Thurlow, 1975; Thompson & Panteleyev, 1976; Albers, 1966, Staff, Engineering Mining Jour., 1977; Skillings, 1976; Magnuson, 1970; Peltola, 1978; Strauss, et al., 1977; Schulz, 1972; Cissarz, 1957; Imai, 1978; Reid, 1975.

Table 2. (cont'd)

Genetic Model	Examples	Elemental Associations	Host Rock Associations	Ore Mineralogy	Gangue Mineralogy	Age of Host	Age of Mineralization	Sulfur Isotope Ratios	Hydrogen/ Oxygen Isotope Ratios
3. Carlin type gold.	Carlin, Cortez, Gold Acres, Getchell, Pinson-Preble, Northumberland Manhattan, Marlboro Canyon, and Windfall, Nevada; Mercur, Utah USA.	Au-Ag-As-Sb-Hg-W-Tl	Dolomite siltstone, silty limestone.	Gold, pyrite, arsenopyrite, orpiment, realgar, stibnite, cinnabar, barite, sphalerite (tr), galena (tr).	Quartz, sericite, kaolin, carbonate, illite, montmorillonite, & organic carbon.	Cambrian to Devonian.	Younger than host.	-	-
4. Precious metal enriched porphyry deposits.	Bajo de la Alumbrera, Argentina; Saindak, Pakistan; Cariboo-Bell, Afton, Galora Creek, and Fish Lake, British Columbia, Canada; Santo Tomas, Dizon, Marian, Mountain Mines, Boneng, and Amacan, Philippines; Mamut, Sabak; Panguna, Bougaiville Is.; Cabang Kiri, Sulawesi; OK Tedi, Papua-New Guinea; Salave, Spain.	Cu-Mo-Au-Ag.	Associated with either high-K shoshonitic rocks ranging from diorite to syenite or with low-K calc-alkaline quartz diorite to granodiorite. Host rocks for the intrusives may be of any age or composition.	Gold, chalcopyrite, molybdenite, bornite, pyrite, magnetite, arsenopyrite, stibnite, and sphalerite.	Biotite, alkali feldspar actinolite, tremolite, garnet, albite, carbonate, sericite.	Hercynian to Cenozoic	Slightly younger than host intrusive.	-	-

Table 2. (cont'd)

	Lead/Lead Isotope Ratios	Fluid Inclusions Type	Salinity	Temp. Hom.	Temp. Trap.	Regional Structural Setting	Local Structural Control	Tonnage Range	Grade Range	Comments	References
3.	-	H_2O-CO_2-NaCl (liq-liq. vapor) + hydrocarbon.	2-5 wt% NaCl equiv.	150-300°C	200-300°C	Paleozoic stable platform carbonate subjected to Paleozoic and Mezoic compressional tectonic and thrust faulting. Subsequent tensional tectonics and formation of the Basin & range province by high angle faults.	High angle faults generally provided conduits for the low to moderate temperature ore forming fluids and most ore replacements are associated with the hanging walls of these structures.	10-160 tonnes Au.	3-7 grams/tonne.	Ore bodies include tabular or irregular replacement with attitudes similar to the host rocks or as pipe-like and vein type ore bodies spatially related to high angle faults. Alteration envolope include silicification, sericitization, kaolinization and carbonation.	Dickson, et al., 1979; Harris and Radtke, 1976; Bayba, 1983; Nash, 1972; Noble and Radtke, 1978; Radtke, et al., 1972; Radtke, et al., 1980; Roberts, et al., 1971; Roedder, 1984, Wargo, 1979.
4.	-	H_2O-CO_2-NaCl (liq-vapor)	5-15 wt% NaCl equiv.	250-350°C	300-400°C	Intrusive hosts often near major thrust and high angle faults.	Gold occurs in stockwork veinlets associated with chalcopyrite, bornite, or arsenopyrite or as inclusions in disseminations of the above minerals.	50×10^6 to 1000×10^6 tonnes ore.	0.4-1.0% Cu; 0.02-0.2% Mo; 0.5-3.1 ppm Au.	Gold mineralization is centrally located in cores of potassium silicate alteration. The gold mineralization may in turn be surrounded by a molybdenum rich zone and or a zone of sericitic or propylitic alteration.	Harris, 1979; Sillitoe, 1979; 1980; 1982.

Table 2. (cont'd)

Genetic Model	Examples	Elemental Associations	Host Rock Associations	Ore Mineralogy	Gangue Mineralogy	Age of Host	Age of Mineralization	Sulfur Isotope Ratios	Hydrogen/ Oxygen Isotope Ratios
5. Epithermal precious metal veins in volcanic and hypabyssal intrusive rocks.	Oatman, Arizona; Monitor, Bodie, California; Eureka, Creede, Lake City, Red Mountain, Summitville, Colorado; Delamar, Idaho; Guanajuato, Packuca, Mexico; Comstock, Tonopak, Goldfield, Silver Peak, Round Mountain, Aurora, Nevada; Colqui, Julcani, Peru.	Au, Ag ± Pb ± Zn ± Cu ± Sb ± As.	Andesitic to rhyolitic volcanics and hypabyssal plutons.	Altaite, silver, aguilarite, argentite, arsenopyrite, gold, bornite, bromurite, chalcocite, chalcopyrite, covellite, cerargyrite, electrum, enargite, famatinite, goldfieldite, galena, rematite, kessite jamesonite, marcasite, miargyrite, molybdenite, naumannite, pyrargyrite, polybasite, pyrrhotite pyrolusite, proustite, powellite, pyrite, realgar, semseyite, stephanite, sphalerite, stromeyerite, stibnite, tetrahedrite, tennanite.	Adularia, alunite, ankerite, barite, calcite, cerussite, chlorite, dolomite fluorite, kaolinite, laumontite, quartz (chalcedony) rhdochrosite, rhodonite, sericite, tourmaline.	Early to late Tertiary, minor Cretaceous	Usually 2-3 million years younger than host.	$\delta^{34}S$-5 to +10 per mill.	δD, -50 to -120 per mill; δO^{18} 0 to -16

Table 2. (cont'd)

Lead/Lead Isotope Ratios	Fluid Inclusions Type	Salinity	Temp. Hom.	Temp. Trap.	Regional Structural Setting	Local Structural Control	Tonnage Range	Grade Range	Comments	References
5. $^{206}Pb/^{204}Pb$, 18.75 to 19.50; $^{207}Pb/^{204}Pb$, 15.55 to 15.65; $^{208}Pb/^{204}Pb$, 38.20 to 39.10.	H_2O-CO_2-NaCl (liq-vapor)	1 to 10 wt% NaCl (usually 1 to 3 wt%)	200-320°C	220-350°C	Volcanic sequences formed above subduction zone. Regional structures often related to radial and concentric fracture zone of caldera and resurgent caldera complexes.	High angle complex fault systems provide conduits for fluids. Ore shoots are usually much smaller than the vein structure and include dilatant zones in bends in the fault zones in vein intersections, and in area of dip decrease.	4-300t Au; 11-50,000t, Ag, 0-3 Mt combined Pb-Zn-Cu.	2-34gm, Au; 6-1000gm Ag; 0-4% Combined Pb-Zn-Cu.	Ore bodies include fracture fillings and replacement in either volcanic flow rocks or a hypabyssal intrusive. Alteration suites include propylitic, potassic, argillic, phyllic, alunitic, and silicic with ore shoots generally associated with silicic and alunitic alteration. Ore shoots associated with boiling or effervescing CO2 fluids and are generally limited to a 200 meter vertical interval with horizontal to vertical ratios of 16:1 to 1:1. Vein width average less than 10 meters.	Armbrustmacker and Wrucke, 1979; Ashley, 1974, 1975, 1979; Ashley and Keith, 1978, Ashley & Silberman, 1976; Bethke & Rye, 1979; Buchanan, 1981; Casedevall, and Ohmote, 1977; Poley et al., 1982; Hayba, 1983. Beald-Wetlaufer, et al., 1983; Ramilli and Ohmote, 1977; Kesler, 1978; Lipman, et al., 1976; Lipman and Steven, 1976; McKee, 1979; O'Neil et al., 1973; Rye et al., 1970; Rytuba, 1981; Silberman, 1982; Silberman and Chesterman, 1972; Silberman and McKee, 1974; Sellitoe, 1977, Slack, 1980; Steven and Eaton, 1975; Taylor, 1973.

models as well as the Carlin-type model proposed for the Money Knob/Amy Dome area by Foster (1968) are large tonnage low grade models relative to the epithermal gold-quartz vein model of Mertie (1918). Based on analogy with major precious metal producing districts worldwide, the possibility of exhalite, porphyry, massive sulfide, and Carlin-type precious metal mineralization in the Tolovana district indicates a greater potential for the area than could be predicted from the previous gold quartz vein epigenetic model.

REFERENCES

Albanese, M. D., 1983a, Bedrock geologic map of the Livengood B-4 Quadrangle, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 83-3, 1 pl., scale 1:40,000.

Albanese, M. D., 1983b, Geochemical reconnaissance of the Livengood B-3, B-4, C-3, and C-4 Quadrangles, Alaska: Summary of data on stream-sediment, pan-concentrate, and rock samples: Alaska Division of Geological and Geophysical Surveys Report of Investigations 83-1, 55 p., 4 pl., scale 1:63,360.

Albanese, Thomas, 1981, The valuation of mining feasibility of a deep gold placer near Livengood, Alaska: University of Alaska unpub. M.S. Thesis, 211 p.

Albers, J. P., 1966, Economic Deposits of the Klamath Mountains. In: E. H. Bailey (Editor), Geology of Northern California, Calif. Div. Mines Bull., 190: 51-62.

Anhaeusser, C. R., 1976, The nature and distribution of Archean gold mineralization of South Africa: Minerals Sci. Eng., v. 8, no. 1, p. 46-84.

Armbrustmacher, T. J. and Wrucke, C. T., 1979, The disseminated gold deposit at Gold Acres, Lander County, Nevada, in Lovering, T. G., and McCarthy, J. H., Jr. (eds.), Conceptual models in exploration geochemistry: Jour. Geochem. Explor., v. 9, no. 2/3, p. 195-203.

Ashley, R. P., 1974, Goldfield mining district, in Guidebook to the geology of four Tertiary volcanic centers in central Nevada: Nevada Bureau of Mines and Geology Report 19, p. 49-66.

_____ 1975, Preliminary geologic map of the Goldfield mining district, Nevada: U.S. Geological Survey Miscellaneous Studies Map MF-681.

_____ 1979, Relation between volcanism and ore deposition at Goldfield, Nevada, in International Association for the Genesis of Ore Deposits (IAGOD), 5th Quadrennial Symposium Proceedings, Vol. II: Nevada Bureau of Mines and Geology Report 33, p. 77-86.

Ashley, R. P. and Keith, W. J., 1978, Goldfield mining district, Esmeralda County, Nevada, in Lovering, T. G., and McCarthy, J. H., Jr., eds., Conceptual models in exploration geochemistry--The Basin and Range province of the western United States and northern Mexico: Journal of Geochemical Exploration, v. 9, p. 204-208.

Ashley, R. P. and Silberman, M. L., 1976, Direct dating of mineralization at Goldfield, Nevada, by potassium-argon and fission-track methods: Economic Geology, v. 71, p. 904-924.

Barnes, D. F., 1961, Gravity low at Minto Flats, Alaska, in Geophysical Survey research 1961: U.S. Geol. Survey Prof. Paper 424-D, p. D254-D257.

Bayley, R. W., 1972, A preliminary report on the geology and gold deposits of the Rochford district, Black Hills, South Dakota, U.S. Geol. Surv. Bull, 1332-A.

Bethke, P. M. and Rye, R. O., 1979, Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part IV. Source of fluids from oxygen, hydrogen, and carbon isotope studies: Econ. Geol., v. 74, p. 1832-1851.

Bragg, J. G., 1967, Upper Canada Mine. In: Guidebook to C.I.M. Centen. Field Excursion, N.W. Quebec-N. Ontario, pp. 89-92.

Brosge, W. P., Lanphere, M. A., Reiser, H. N., and Chapman, R. M., 1969, Probable Permian age of the Rampart Group, central Alaska: U.S. Geological Survey Bull. 1294-B, p. B1-B18.

Brown, C. E. G., Dadson, A. S. and Wrigglesworth, L. A., 1959, On the ore-bearing structures of the Giant Yellowknife Gold Mine. Trans. Can. Inst. Min. Metall., 62:107-116.

Buchanan, L. J., 1981, Precious metal deposits associated with volcanic environments in the southwest, in Dickinson, W. R., and Payne, W. D., editors, Relations of Tectonics to Ore Deposits in the Southern Cordillera: Ariz. Geol. Soc. Digest, v. XIV, p. 237-262.

Casedevall, T. and Ohmoto, 1977, Sunnyside mine, Eureka mining district, San Juan County: Geochemistry of gold and base-metal ore deposition in a volcanic environment: Econ. Geol., v. 72, p. 1285-1320.

Chapman, R. M., Weber, F. R., and Taber, Bond, 1971, Preliminary geologic map of the Livengood Quadrangle, Alaska: U.S. Geological Survey Open-file Report 71-66 (483), 2 sheets, scale 1:250,000.

Chapman, R. M., Weber, F. R., Churkin, Michael Jr. and Carter, Claire, 1979, The Livengood Dome Chert, a new Ordovician formation in central Alaska, and its relevance to displacement on the Tintina fault in Shorter contributions to stratigraphy and structural geology, 1979: U.S. Geological Survey Professional Paper 1126, p. F1-F13.

Church, R. E., and Durfee, M. C., 1961, Geology of the Fossil Creek area, White Mountains Alaska: Fairbanks, University of Alaska, unpub., M.S. thesis, 96 p.

Churkin, M., Jr., Foster, H. L., Chapman, R. M., and Weber, F. R., 1982, Terranes and suture zones in east-central Alaska: Journal of Geophysical Research, v. 87, no. B5, p. 3718-3730.

Cissarz, A., 1957, Lagerstatten des Geosynklinalvulkanismus in den Dinariden und ihre Bedeutung fur die Geosynklinale Lagerstattenbildung. Neues Jahrb. Mineral. Abh., 91: 485-540.

Dickson, F. W., Radtke, A. S. and Rye, R. O., 1975, Implications of the occurrence of barium minerals and sulfur isotopic compositions of barite on late stage processes in Carlin-type gold deposits (abs.): Geol. Soc. America Abs. with Programs, v. 7, no. 5, p. 604-605.

Dickson, F. W., Rye, R. O. and A. S. Radtke, 1979, The Carlin gold deposit as a product of rock-water interactions. Nevada Bureau of Mines and Geology Rept. 33: Proceedings, Fifth Quadrennial Symposium. The International Symposium on the Genesis of Ore Deposits, Volume 11.

Fleischer, R. and Routhier, P., 1973, The "consanguinous" origin of a tourmaline-bearing gold deposit: Passagem de Mariana (Brazil). Econ. Geol., 68:11-22.

Foley, N. K., Bethke, P. M. and Rye, R. O., 1982, A reinterpretation of D_{H2O} values of inclusion fluids in quartz from shallow ore bodies [abs.]: Geol. Soc. America, Abstracts with Programs, v. 14, no. 7, p. 489.

Foster, R. L., 1968, Descriptions of the Ruth Creek, Lillian Creek, Griffin, Old Smoky, Sunshine No. 2, and Olive Creek lode prospects, Livengood district, Alaska: U.S. Geol. Survey Open-file Report, 21 p.

Foster, R. L., 1968, Potential for lode deposits in the Livengood gold placer district, east-central Alaska: U.S. Geol. Survey Circular 590, 18 p.

Foster, H. L., Weber, F. R., Forbes, R. B., et al., 1973, Regional geology of Yukon-Tanana Upland, Alaska, in Arctic Geology: Am. Assoc. Petroleum Geologists Mem. 19, p. 388-395.

Foster, R. L., 1966, The petrology and structure of Amy Dome area, Tolovana mining district, Alaska: Columbia, University of Missouri, Ph.D. thesis, 219 p.

Gair, J. E., 1962, Geology and ore deposits of the Nova Lima and Rio Acimo Quadrangles, Minas Gerais, Brazil. U.S. Geol. Surv. Prof. Pap., 341-A:67 pp.

Ghosh, D. B., et al., 1970. Ore environment and ore genesis in Ramagiri Gold Field, Andhra Pradesh, India, Econ. Geol., 65:801-814.

Gribnitz, K. H., 1964, Notes on the Barberton Goldfield. In: S. H. Haughton (Editor), The Geology of Some Ore Deposits in Southern Africa, 2. Johannesburg, pp. 77-90.

Hargraves, David, 1975, The Livengood placer deposit - a developing Alaskan gold mine: Mining Mag., v. _____, p. 363-368.

Harris, Michael and A. S. Radtke, 1976, Statistical study of selected trace elements with reference to geology and genesis of the Carlin gold deposit, Nevada. U.S. Geol. Surv. Prof. Paper 960. 21 p.

Harris, Michael, 1979, Alteration and mineralization at the Salave gold prospect, N.W. Spain: unpublished Ph.D. thesis, Imperial College of Science and Technology, London, 328 p.

Hayba, D. O., 1983, A compilation of fluid inclusion and stable isotope data on selected precious and base metal epithermal deposits: U.S. Geol. Survey Open File Report 83-450, 24 p.

Heald-Wetlaufer, P., Hayba, D. O., Foley, N. K., and Goss, J. A., 1983, Comparative anatomy of epithermal precious and base metal districts hosted by volcanic rocks: U.S. Geol. Survey Open File Report 83-710, 8 p.

Horwood, H. C. and Pye, E. G., 1955, Geology of Ashmore Township. Ont. Dep. Min., 60 (part 5): 1-105.

Imai, H., 1978, Geological studies of the mineral deposits in Japan and East Asia: University of Tokyo Press, Tokyo, p. 261-264.

Joesting, H. R., 1942, Strategic mineral occurrences in interior Alaska: Alaska Dept. Mines Pamph. 1, 46 p.

_____, 1943, Supplement to Pamphlet No. 1 - Strategic mineral occurrences in interior Alaska: Alaska Dept. Mines Pamph. 2, 28 p.

Kamilli, R. J. and Ohmoto, H., 1977, Paragenesis, zoning, fluid inclusion and isotopic study of the Finlandia vein, Colqui district, Central Peru: Econ. Geol., v. 72, p. 950-982.

Kesler, S. E., 1978, Metallogenesis of the Caribbean region: J. Geol. Soc. London, v. 135, p. 429-441.

Koo, J. and Mossman, D. J., 1975, Origin and metamorphism of the Flin Flon stratabound Cu-Zn sulfide deposit, Saskatchewan and Manitoba. Econ. Geol., 70: 48-62.

Krishnaswamy, S., 1972, India's Mineral Resources. Oxford Press, Delhi, 503 pp.

Lipman, P. W., Fisher, F. S., Mehnert, H. H., Naeser, C. W., Luedke, R. G., and Steven, T. A., 1976, Multiple ages of mid-Tertiary mineralization and alteration in the western San Juan Mountains, Colorado: Econ. Geol., v. 71, no. 3, p. 571-588.

Lipman, T. A. and Steven, P. W., 1976, Calderas of the San Juan volcanic field, southwestern Colorado: U.S. Geol. Survey Prof. Paper 958, 35 p.

Magnusson, N. H., 1970, The origin of the iron ores in central Sweden and the history of their alterations. Sver. Geol. Unders. Ser. C, 643: 364 pp.

Martin, W. C., 1957, Errington and Vermillion Lake Mines. In: Structural Geology of Canadian Ore Deposits, 2, Montreal, pp. 363-376.

Matulich, A., Amos, A. C., Walker, R. R. and Watkins, J. J., 1974, The geology department. Can. Min. Metall. Bull., 67: 56-63.

McKee, E. H., 1979, Ash-flow sheets and calderas: Their genetic relationship to ore deposits in Nevada: Geol. Soc. of America Special Paper 180, p. 205-211.

Mertie, J. B., Jr., 1918, The gold placers of the Tolovana district: U.S. Geol. Survey Bull. 662, p. 221-277.

Mertie, J. B., Jr., 1937, The Yukon-Tanana region, Alaska: U.S. Geological Survey Bulletin 872, 276 p.

Metz, P. A., 1984, Geological factors governing the formation of the gold placer deposits of the Fairbanks mining district, Alaska (abstr.): in University of Alaska, Mineral Industry Research Laboratory Report No. 69, 85 p.

Metz, P. A. and Hawkins, D. B., 1981, A summary of gold fineness values from Alaska placer deposits: University of Alaska, Mineral Industry Research Laboratory Report No. 45, 63 p.

Metz, P. A. and Robinson, M. S., 1980, Investigation of mercury-antimony-tungsten metal provinces of Alaska: University of Alaska, Mineral Industry Research Laboratory Open-file Report 80-8, 37 p.

Nash, J. T., 1972, Fluid inclusion studies of some gold deposits in Nevada: U.S. Geol. Survey Prof. Paper 800-C, p. C15-C19.

Noble, L. L. and A. S. Radtke, 1978, Geology of the Carlin disseminated replacement gold deposit, Nevada. Nevada Bureau of Mines and Geol. Rept. 32. Guidebook to mineral deposits of the central great basin, prepared for I.A.G.O.D. Symposium, Mackay School of Mines, Reno, Nevada, 1978.

Oliver, W. A., Jr., Merriam, C. W., and Churkin, M., Jr., 1975, Ordovician, Silurian, and Devonian corals of Alaska: U.S. Geological Survey Professional Paper 823-B, p. 13-42.

O'Neil, J. R., Silberman, M. L., Fabbi, B. P. and Chesterman, C. W., 1973, Stable isotope and chemical relations during mineralization in the Bodie mining district, Mono County, California: Economic Geology, v. 68, p. 765-784.

Overbeck, R. M., 1920, Placer mining in the Tolovana district: U.S. Geol. Survey Bull. 712, p. 177-184.

Patterson, G. C., 1984, Field trip guidebook to the Hemlo area: Ontario Geol. Survey Misc. Paper 118, 33 p.

Peltola, E., 1978, Origin of Precambrian copper sulfides of the Outokumpu district, Finland, Econ. Geol., 73: 461-477.

Putzer, H., 1976, Metallogenetische Provinzen in Sudamerika, Schweizerbart, Stuttgart, 299 pp.

Pye, E. G. and Roberts, R. G., 1981, Genesis of Archean volcanic hosted gold deposits: Ontario Geol. Survey Misc. Paper 97.

Radtke, A. S., 1976a, Features of Carlin-type gold deposits: U.S. Geol. Survey Prof. Paper 975, p. 4-5.

Radtke, A. S., 1976b, Genesis of Carlin-type gold deposits in the framework of tectonic evolution of the Basin and Range province (abs): Econ. Geology, v. 71, no. 3, p. 702.

Radtke, S. S., Heropuolos, C., Fabbi, B. P., Scheiner, B. J. and Essington, M., 1972, Data on major and minor elements in host rocks and ores, Carlin Gold Deposit, Nevada. Economic Geology, v. 67, no. 7, p. 975-978.

Radtke, A. S., Rye, R. O. and Dickson, F. W., 1980, Geology and stable isotope studies of the Carlin gold deposit: Econ. Geol., v. 75, p. 641-672.

Radtke, A. S., Taylor, C. M. and C. L. Christ, 1972, Chemical distribution of gold and mercury at the Carlin deposit, Nevada; Econ. Geol., v. 67, p. 1009, (abst).

Reid, K. O., 1975, Mount Lyell copper deposits, In: C. L. Knight (Editor), Economic Geology of Australia and Papua New Guinea, Aust. Inst. Min. Metall. Monogr., 5:604-618.

Ridler, R. H., 1970, Relationship of mineralization to volcanic stratigraphy in the Kirkland-Larder Lakes area, Ontario. Geol. Assoc. Can., 21:33-42.

Riley, R., 1972, Campbell Red Lake Mines Ltd. gold mine, Red Lake Area, Ontario, 24th Int. Geol. Congr. Montreal, Guidebook, Excursion A33-C33, pp. 53-56.

Roberts, R. G., 1975, The geological setting of the Mattagami Lake Mine, Quebec, A volcanogenic massive sulfide deposit, Econ. Geol., 70:115-129.

Roberts, R. J., Radtke, A. S. and Coats, R. R., 1971, Gold bearing deposits in north-central Nevada and southwestern Idaho; Econ. Geol., v. 66, p. 14-33.

Robinson, M. S., 1983, Bedrock geologic map of the Livengood C-4 Quadrangle, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 83-4, 1 pl., scale 1:40,000.

Robinson, M. S. and Bundtzen, T. K., 1979, Historic gold production in Alaska: Alaska Division of Geological and Geophysical Surveys Mines and Geology Bull. v. 28, no. 3, p. 1-4.

Robinson, M. S. and Metz, P. A., 1979, Evaluation of the mineral resources of the pipeline corridor, Phases I and II, 264 p., maps, 84 sheets, scale 1:63,360.

Rye, D. M. and Rye, R. O., 1974, Homestake gold mine, South Dakota: I. Stable Isotope studies. Econ. Geol., 69: 293-317.

Rye, R. O., Doe, B. R. and Wells, J. D., 1970, Stable isotope study of the Cortez, Nevada, gold deposit and surrounding area: U.S. Geol. Survey Jour. Research, v. 2, no. 1, p. 13-23.

Rytuba, J. J., 1981, Relation of calderas to ore deposits in the western United States, in Relations of tectonics to ore deposits in the southern Cordellera, Dickinson, W. R. and Payne, W. D., eds., Ariz. Geol. Soc. Digest, v. XIV, p. 227-236.

Schulz, O., 1972b, Horizontgebundene altpalaozoische Kupferkiesvererzung in der Nordtiroler Grauwackenzone, Osterreich. Tschermaks Mineral. Petrogr. Mitt., 17: 1-18.

Silberman, M. L., 1982, Hot-spring type, large tonnage, low-grade gold deposits, in Erickson, R. L., ed., Characteristics of mineral deposit occurrences: U.S. Geological Survey Open-File Report 82-795, p. 131-143.

Silberman, M. L. and Chesterman, C. W., 1972, K-Ar age of volcanism and mineralization, Bodie mining district and Bodie Hills volcanic field, Mono County, California: Isochron/West, no. 3, p. 13-22.

Silberman, M. L. and McKee, E. H., 1974, Ages of tertiary volcanic rocks and hydrothermal precious-metal deposits in central and western Nevada: Nevada Bur. Mines Geol. Report No. 19, p. 67-72.

Sillitoe, R. H., 1977, Metal mineralization affiliated to sub-aerial volcanism - a review: Volcanic Processes in Ore Genesis, Geol. Soc. London Spec. Pub. 7, p. 99-116.

Sillitoe, R. H., 1979, Some thoughts on gold-rich porphyry copper deposits: Mineralium Deposita, v. 14, p. 161-174.

Sillitoe, R. H., 1980, Types of porphyry molybdenum deposits: Mining Magazine, v. 142, p. 550-553.

Sillitoe, R. H., 1982, Unconventional metals in porphyry deposits: Soc. of Mining Engineers pre-print 82-63, 13 p.

Skillings, D. N., 1976, Rosario Dominicana S. A. Pueblo Viejo operations: Skillings Mining Review, v. 65, no. 12, p. 10-15.

Slack, J. F., 1980, Multistage vein ores of the Lake City district, western San Juan Mountains, Colorado: Econ. Geol., v. 75, p. 963-991.

Smith, T. E., 1983, Bedrock geologic map of the Livengood C-3 Quadrangle, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 83-5, 1 pl., scale 1:40,000.

Spence, C. D. and de Rosen-Spence, A. F., 1975, The place of sulfide mineralization in the volcanic sequence at Noranda, Quebec. Econ. Geol., 70: 90-101.

Staff, Engineering Mining Journal, 1977a, Development of Wisconsin's mineral potential is stymied by the state: Eng. Mining Jour., v. 178, no. 2, p. 23-27.

Staff, Engineering Mining Journal, 1977b, Rosario Dominicana operates largest open-pit gold mine: Eng. Mining Jour., v. 178, no. 11, p. 145-149.

Steven, T. A. and Eaton, G. P., 1975, Environment of ore deposition in the Creede mining district, San Juan Mountains, Colorado: Part I. Geologic, hydrologic and geophysical setting: Econ. Geol., v. 70, p. 1023-1037.

Strauss, G. K., Madel, J. and Alonso, F. F., 1977, Sulphide deposits in the Spanish-Portuguese pyrite belt: geology, geophysics and geochemistry. In: D. D. Klemm and H. J. Schneider (Editors), Time and Strata-Bround ore Deposits. Springer, New York, N.Y., pp. 55-93.

Suffel, G. G., Hutchinson, R. W. and Ridler, R. H., 1971, Metamorphism of massive sulphides at Manitouwadge, Ontario, Canada. Soc. Min. Geol. Jpn Spec. Issue, 3: 235-240.

Taylor, H. P., 1973, $0^{18}/0^{16}$ evidence for meteoric-hydrothermal alteration and ore deposition in the Tonopah, Comstock Lode, and Goldfield mining districts, Nevada: Econ. Geol., v. 68, p. 747-764.

Templeman-Kluit, D. J., 1976, The Yukon Crystalline Terrane---Enigma in the Canadian Cordillera: Geological Society of America Bulletin, v. 87, p. 1343-1357.

Thompson, R. I. and Panteleyev, A., 1976, Stratabound mineral deposits of the Canadian Cordillera: in Wolf, K. H., (editor), Handbook of Stratabound and Stratiform Ore Deposits, v. 5, Regional Studies and Specific Deposits, Elsevier Scientific Publishing Company, N.Y., p. 37-108.

Thurlow, J. G., Swanson, E. A. and Strong, D. F., 1975, Geology and lithogeochemistry of the Buchans polymetallic sulfide deposit, Newfoundland. Econ. Geol., 70: 130-144.

Tolbert, G. E., 1964, Geology of the Raposos gold mine, Minas Gerais, Brazil. Econ. Geol., 59: 775-798.

Turner, D. L., Grybeck, Donald, and Wilson, F. H., 1975, Radiometric dates from Alaska---a 1975 compilation: Alaska Division of Geological and Geophysical Surveys Special Report 10, 64 p.

Viljoen, R. P., Saager, R. and Viljoen, M. J., 1969, Metallogenesis and ore control in the Steynsdorp Goldfield, Barberton Mountain Land, South Africa, Econ. Geol., 64: 778-797.

Wargo, Joseph G., 1979, The next exploration stage for Carlin-type gold deposits. Mining Engineering, Sept. 1979, v. 31, no. 9, p. 1321-1323.

Woodall, R., 1975, Gold in Precambrian shield of Western Australia, in C. L. Knight (editor), Economic Geology of Australia and Papua-New Guinea, 1. Metals, Australian Inst. of Mine. Metal., Melbourne, p. 175-185.

Woodtli, R., 1961a, Gold impregnations deposits in the Moto area (Central Africa). Econ. Geol, 56: 603-607.

Woodtli, R., 1961b, Relationships of general structure to gold mineralization in the Kilo area (Central Africa), Econ. Geol., 56: 584-591.