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Health Effects of Lead in Secondary Smelter Workers

Results of an investigation of employees of a secondary lead smelter in Vernon, California, November, 1976

Initial Report of a Clinical Field Survey

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FOREWORD

Evidence has become available that significant clinical lead disease exists among secondary lead smelter workers in the United States; clinical studies by our Laboratory among workers employed in two such smelters in Indianapolis, Indiana demonstrated the frequent occurrence of both clinical abnormalities and laboratory findings indicative of lead induced metabolic changes. Of particular note were central nervous system symptoms, the inappropriate use of chelation therapy, the incomplete relevance of blood lead measurements under these circumstances and the pertinence of zinc protoporphyrin measurements in the evaluation of current findings.

These observations, important as they were, did not provide information on the health status of workers employed in similar smelting facilities, with higher or lower lead exposure nor were data available concerning effects of differences in the medical management of cases with high lead body burden. Therefore, it has been considered useful to investigate a much larger number of lead-exposed workers, under a variety of conditions, to collect data concerning the spectrum of lead-induced biological effects, including those at low levels of exposure. Such information would be useful in considering nervous system (central and peripheral), hematological, renal and other clinical aspects of lead toxicity in environmental as well as occupational settings, and would also provide guidance in evaluation of proposed regulatory and control measures designed to prevent adverse health effects in both these settings.

The United Steelworkers of America, concerned both with the findings of lead disease among its members employed in the Indianapolis smelters and with evidence of lead disease its staff had obtained among workers in other lead facilities elsewhere in the country, reviewed with us the desirability of investigating the health status of workers employed in a secondary lead smelter in Vernon, California. Here, clinical findings consistent with adverse lead effects had been noted by medical practitioners, despite the understanding of the Union that engineering improvements in the production process had been made and that medical supervision of the work force had been made available by the management. Data available to the Steelworkers Union were reviewed with officials and concerned members of the local Union, Messrs. Alvin Cass, John Cox, Jim Gruber, Lawrence Spears and Everett Wills (Local #2018, United Steelworkers of America, District #38) and with the broadly knowledgeable representative of the national office of the Union, Mr. George Becker, during a field visit by Dr. Ruth Lilis and Dr. Alf Fischbein of our Laboratory in June, 1976.

Analysis of available information and data by Dr. Lilis and Dr. Fischbein indicated that investigation of workers employed in this smelter would provide information of considerable scientific value, and would furnish data that would provide additional guidance concerning regulatory and control approaches. Thus, it was decided that a clinical field survey would both render a health service to the workers concerned and also provide information of broader scientific nature.

A field survey group of the Mount Sinai School of Medicine undertook a study of 111 secondary lead smelter workers November 18-20, 1976. The field group included:

Dr. H. Anderson	Dr. N. Holstein
Dr. J. Bellin	Dr. R. Lilis
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Mr. S. Freedman	Dr. K. Rosenman
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Dr. J. Valciukas

We gratefully acknowledge the participation of Dr. Laszlo Sarkozi and Dr. Steven Kon of the Department of Chemistry of the Mount Sinai Hospital who did the blood lead determinations and blood chemistry analyses. Dr. Michael Greenberg of the Department of Hematology was responsible for the serum iron studies.

Particular thanks are due to Dr. Josef Eisinger and to Dr. William Blumberg of Bell Laboratories. Their investigation of zinc protoporphyrin levels in the two groups enriched the survey and provided data which will be of unique worth in our evaluation of the results of the study. Their assistance in the statistical analysis of the data was essential.

Valuable assistance was also provided by The City of Hope Medical Center in Duarte under the direction of Dr. Hector Blejer and staff members Ruby Ellis, Joann Fairless, Dawn Fitzgerald, Chuck Gutzwiller, Alex Jaramillo, Pam Severson and Dr. Dale Stevens; a number of laboratory studies were undertaken including coproporphyrins and delta-aminolevulinic acid, and sputum cytology. Dr. Walter Rogan of the National Institute of Environmental Health Sciences gave valuable assistance, as well.

We are particularly grateful for the help given us in the preparation and conduct of the examinations by members of the staffs of both the national office of the Steelworkers Union and members and officials of

Local #2018, Mr. Frank Valenta of District 30, Claudia Miller, Industrial Hygienist, and Mr. Ulysses Townsend. Further, we have special appreciation for Mr. Wilfred Anderson, President, and members of Local #1845, Huntington Park, California, who allowed the use of their Union Hall for the clinical field studies and who also arranged for the participation of 55 of their members employed in local steel plants. The majority of these workers had no history of lead exposure. Their examination, concurrent with those of the lead smelter workers, served both to establish their own health status and allowed comparison of the findings with those made during the smelter workers' examinations.

The present report, prepared by Dr. Ruth Lilis, M.D. and Dr. Alf Fischbein, M.D., provides preliminary results of the study. A more complete presentation is being undertaken and will be available.

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January 31, 1977

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Contents

Introduction

The results of a clinical field examination of workers in two secondary lead smelters in Indianapolis in February 1976 had indicated a relatively high prevalence of adverse lead-induced health effects.

The findings were included in a report to NIEHS and were reviewed with representatives of NIOSH. It was thought that the health status of secondary lead smelter workers was a reason for concern, and therefore clinical studies of additional groups were considered.

Methods of investigation

A clinical field survey of 111 secondary lead smelter workers (Vernon, California) was conducted November 18-20, 1976. Four were retired, and 107 were currently employed.

Another group of 55 workers from two steel plants in the same area were concomitantly examined, as a control group. After thorough analysis of their occupational histories it was found that 37 were completely free of history of lead exposure, while 18 had had minimal exposure. It was decided to restrict the control group to those without any lead exposure.

Careful review of each individual's experience was undertaken, including detailed occupational history, past medical history, completion of the MRC respiratory questionnaire and symptoms potentially related to lead effects. In addition, history of elevated blood levels in the past, chelation therapy (intravenous and/or oral), changes in job assignments due to high blood lead levels and hospital admissions for lead poisoning were recorded. All workers were clinically examined with special attention to signs possibly related to lead effects (lead line, paleness, tremor, extensor weakness).

The laboratory tests included blood lead determinations by atomic absorbtion, urinalysis, complete blood counts, SMA-12, serum iron and total iron binding capacity, zinc protoporphyrin (hematoflurometer), delta-aminolevulinic acid and coproporphyrins in urine. Nerve conduction velocity measurements were done on the right radial and the left peroneal nerves, using the method previously described. A battery of behavioral tests was used in 90 of the lead-exposed workers and in 25 control workers.

There was long duration of lead exposure in many of the examined workers; for 40 it exceeded ten years and 29 had worked for more than 20 years (Table 1). This was a major difference between this population and that previously studied in Indianapolis.

The age distribution of the lead-exposed workers and control subjects (Table 2) is comparable, except for a higher proportion of younger (less than 30 years) individuals among the exposed workers. 67 (62%) of the lead-exposed workers were white, and 42 (38%) were black. The race distribution was somewhat different in the control group, with 16% black. All the lead-exposed workers were males except for one female; there were 4 females in the control group.

Results

1. Clinical symptoms -- Symptoms consistent with lead poisoning were considered.

   a. Central nervous system symptoms such as tiredness, fatigue, nervousness, headaches, anxiety, dizziness, sleeplessness, and combinations of these were found in a significant proportion of the lead-exposed workers (Table 3). The overall prevalence of central nervous system symptoms was threefold greater in the lead-exposed workers compared to the control group.

These symptoms were manifest even during the first year of employment; 10 of 23 workers in this subgroup gave a positive history in this respect.

The prevalence of CNS symptoms increased with blood lead levels (Table 4). A similar relationship was found with ZPP levels (Table 5).

b. As in other lead-exposed populations, muscle and joint pain and/or soreness was the second most prevalent group of symptoms (in 31% of smelter workers as compared to 11% of controls) (Tables 6 and 7).

c. Less prominent were gastrointestinal symptoms such as loss of appetite, weight loss, or the combination of these, reported by 22% of the lead-exposed workers as compared to 11% among the control workers (Table 8).

d. A positive history of lead colic was given by 21 (19%) workers; 9 had had repeated such episodes. This did not occur among the controls.

2. The medical surveillance program included periodic blood lead tests; the frequency of these tests varied between once every month and once every two or three months. 59 workers (56.2%) had been notified of high blood lead levels; 22 (more than one-third of these) had had high blood lead levels on several occasions.

The actual blood lead level thought to be excessive in the past was not known to most of the workers; only 26 were able to indicate the reported blood lead levels. These had exceeded 80µg/100ml in 9 cases, while in 17 they had been in the range of 60-80µg/100ml.

Chelation therapy had not been a prominent feature of medical management in cases with elevated blood lead levels in the past. Only 18

(16%) of those examined had undergone chelation therapy with EDTA (i.v.) in the past; and there were 4 workers with a history of repeated chelation therapy. The use of oral chelating agents (EDTA or penicillamine) was reported by 3 (3%) workers; 2 of these had had repeated courses of therapy. Overall, there were only 6 (5.5%) individuals who had been given repeated courses of chelation therapy. Chelation therapy had obviously not been used excessively in the management of workers with elevated lead levels. Rather, the practice had been to remove such individuals from working areas where excessive lead exposure had resulted in high blood lead levels. 32 (29%) of the 111 lead-exposed workers had been admitted to a hospital with a diagnosis of lead poisoning; only one had had more than one hospital admission.

3. Physical examination -- The physical examination revealed:

   a. The presence of a definite lead gum line in a very small number of cases (4). Many workers had obvious constitutional pigmentation of their oral mucosa. Paleness of the skin was also difficult to assess for the group as a whole since there was a high proportion of blacks.

   b. Hypertension, defined as systolic blood pressure above 150mm Hg and/or diastolic blood pressure above 95mm Hg was found in 11 lead-exposed workers (10.7%) and in 3 (8.6%) of the controls (Table 9). While the prevalence of systolic hypertension was similar in the lead-exposed and the control group, diastolic hypertension was more frequently found in the lead-exposed workers. The mean length of lead exposure of those with diastolic hypertension was 23.5 years and the mean age was 49.6 years. While there was a definite trend for more hypertension with increased length of lead exposure (Table 10), the increase of prevalence with age was rather unimpressive, suggesting that duration of lead exposure has a greater impact than age (Table 11). These observations are, however, based on small numbers and we are reluctant to draw any conclusions. However, it is noteworthy that ten of the lead-exposed workers with hypertension were black and only one was white.

c. Peripheral motor neuropathy, manifested by weakness of extensor muscles of wrists and/or fingers in the most active extremity was found in 23 workers (21.3%).

The prevalence of extensor weakness increased from 13.2% in workers with less than ten years of lead exposure, to 27% of those with duration of exposure of 10-20 years and 37% in those with more than 20 years exposure (Table 12).

The mean duration of lead exposure for the 23 workers with extensor weakness was ten years, while it was 4.5 years for the rest of the lead-exposed workers. There was no difference between mean blood lead levels, but mean ZPP levels were different in the group with extensor weakness (mean ZPP 251μg/100ml) when compared to other of the lead-exposed workers (160μg/100ml).

4. Laboratory findings

a. Blood lead levels were measured by atomic absorbtion spectrophotometry (Perkin Elmer model 303 combined with a Varian-Techtron carbon rod atomizer, model 63). Values exceeded 80μg/100ml in one case and were in the range of 60-79μg/100ml in 20 cases. Thus, 21% of the workers had blood lead levels of 60μg/100ml or higher at the time of the examination. None of the control workers had a blood lead level in excess of 50μg/100ml; 94% had less than 40μg/100ml (Table 13).

The proportion of lead-exposed workers with blood levels of 60μg/100ml or higher at the time of the examination (21%) is significantly lower than that of workers who had been notified in the past of elevated blood lead (56%). This is consistent with levels of lead exposure having been recently reduced.

When analyzing the relationship between blood lead levels and duration of lead exposure, a gradual increase in blood lead levels was noted ($r = 0.20$). Although this correlation is not a strong one, it is, nevertheless, more than threefold that found for a previously examined group of lead smelter workers, in whom chelation therapy had been extensively used (Fig. 1).

b. Zinc protoporphyrin was determined by a hematofluorometer. ZPP was found to be less than 100μg/100ml in 36 (32.7%) of the workers; 31% had ZPP levels in excess of 200μg/100ml; 36 of 37 control workers had a ZPP level of less than 100, and in 30 the level was less than 50μg/100ml (Table 14).

The ZPP levels did not show a sharp increase during the first years of employment. Mean ZPP did not exceed 100μg/100ml in workers employed for less than two years. This finding would support a proposal that lead exposure levels had been reduced during this period of time. In workers with more than five years of exposure the mean ZPP was 200μg/100ml level, and the mean rose to 300μg/100ml in those with more than 25 years of exposure. ZPP levels correlated well with blood lead levels (Fig. 2).

c. Hematological findings

Low hemoglobin levels (less than 14gm/100ml) were found in 20 lead smelter workers (18.3%); there was only one individual with a hemoglobin of less than 13gm/100ml. In the control group 4

(11.4%) workers had hemoglobin levels of less than 14gm/100ml; none had less than 13gm/100ml (Table 15).

Thus, the prevalence of anemia was relatively low in this lead-exposed group; this finding is consistent with the distributions of blood lead levels, the dynamics of ZPP and with the relatively lower (when compared to other exposed groups) prevalence of symptoms.

Although most of the hemoglobin levels were above 14gm/100ml, and relatively few blood lead levels exceeded 60μg/100ml, the correlation between hemoglobin ($r = 0.23$) and blood lead was higher (Fig. 3) than that found in a previously examined group of secondary lead smelter workers in which chelation therapy had been extensively used. Hemoglobin levels showed a stronger correlation (Fig. 4 and Table 16) with ZPP levels ($r = 0.42$).

d. Serum iron levels were measured and were found to be in the normal range for the great majority of the population examined. The mean serum iron was 90.4 ± 29μg for the lead-exposed workers. Since both serum iron and hemoglobin levels were mostly in the normal range, there was no significant correlation ($r = 0.084$).

Much consideration has been given to the fact that ZPP levels may be affected (increased) by iron deficiency. It was shown that women have a more marked increase in ZPP at similar blood lead levels, and this has been attributed to their lower hemoglobin levels. In the lead-exposed population studied no correlation was found (Fig. 5) between serum iron and zinc protoporphyrin ($r = 0.038$).

- The lack of correlation between serum iron and ZPP (r = 0.038).
- The good correlation between zinc protoporphyrin and hemoglobin (r = 0.42).

These results indicate that in a male lead-exposed population low hemoglobin levels are related to high ZPP levels (attesting to the metabolic effect of lead) and not to low serum iron levels. Also, that elevation of ZPP in a lead-exposed population is a result of the enzyme inhibiting effects of lead and not of iron deficiency.

e. Urinary delta-aminolevulinic-acid (ALA-U) was determined on spot urine samples (Table 17). There was good correlation (Fig. 6) between blood lead levels and ALA-U (r = 0.36). The correlation was even stronger (Fig. 7) between ALA and ZPP (r = 0.437).

While there was a correlation between hemoglobin levels and ALA-U, this was less (r = 0.25) than the one found for hemoglobin and ZPP (r = 0.42; Fig. 8).

f. The level of urinary coproporphyrins was also measured. The correlation between coproporphyrin levels and blood lead was weaker (r = 0.19) than that between ALA-U and blood lead (r = 0.36), as previously found by others. The same applied for the correlation between coproporphyrins and ZPP levels (r = 0.437).

There was, as expected, a high correlation between coproporphyrin levels and ALA-U (r = 0.62 Fig. 9).

g. Other tests, such as BUN, creatinine and creatinine clearance tests, and nerve conduction velocity measurements are still in the process of being analyzed.

5. Psychological Functions

a. Populations. Ninety secondary lead smelter workers and 25 non-exposed steel workers were examined by means of performance tests. These tests were aimed at assessing the status of higher central nervous system functions (ability to detect spatial relations, ability to manipulate abstract symbols, and detection of visual stimuli in masked conditions) and motor coordination (use of one or both hands). All subjects - except one - were males. Sixty subjects (52%) were white and 38 (33%) black. (Whenever necessary, tests were given in Spanish.)

The mean age of the secondary lead smelter workers and controls were 42.8 (S.D. = 12.1) and 44.8 (S.D. = 11.3) respectively. The difference was not statistically significant.

Educational level of each subject was rated according to a scale given in Table I8. Mean educational level of secondary lead smelter workers and controls were 2.5 (S.D. = 0.69) and 2.65 (S.D. = 0.67) respectively; the difference was not statistically significant. The educational background of both groups represents a few years of high school learning without reaching high school graduation.

b. Investigative Techniques. Five different performance tests were used: Block Design (B.D.), Digit-Symbol (D.S.), Embedded Figures (E.F.) and Santa Ana Dexterity Test for preferred hand (D.H.) and both hands (B.H.). Block Design, Digit-Symbol and Embedded Figures were chosen to examine the status of higher functions of the central nervous system. The Santa Ana Dexterity Test was aimed at assessing eye-hand coordination and the accuracy of fine manual movements.

Block Design is a part of the well-known Wechsler Adult Intelligence Scale and has been widely used in the behavioral evaluation of neurotoxic substances. The test provides a quick and objective measure of the subject's ability to see spatial relations. The examinee is presented with a set of colored cubes. Each cube has two sides which are red, two white and two half red and half white. The task involves arranging the cubes in such a way that the top surface reproduces a design displayed for the examinee. In the first six trials, only four of the cubes are used and the designs are simple. In the last four trials, nine cubes are used and the designs are simple. In the last four trials, nine cubes are used and the designs are more complex. The score is based on the number of trials correctly completed as well as the speed with which the task is completed. Reliability scores for this test have been provided by Wechsler (1955).

Digit-Symbol is also a subtest of the Wechsler Adult Intelligence Scale. It measures the subject's ability to manipulate figures and abstract symbols according to a predetermined code. Subjects are instructed to fill the blanks with the symbols that correspond to each number. Reliability scores for this test have also been provided by Wechsler.

Embedded figures have been extensively used in neurological research - particularly during World War II. The test assesses visual perception in masked conditions. The test consists of four sets of ten superimposed outlines of familiar objects. The score is the number of objects successfully named in the four sets. Standardization data for this test are provided elsewhere (Valciukas, in preparation).

The Santa Ana Dexterity Test consists of a metal board in which four rows of square holes are cut. Plastic pegs having a round head with a hemicircle painted black and the matching hemicircle painted white are fitted to the holes. The subject has to lift and rotate the peg 180 degrees. Scores are the number of pegs turned in 30 seconds. The test is first executed with the preferred hand and then with both hands. Standardization scores for this test have been provided by Hänninen (personal communication).

Selection procedures. Subjects were examined at random. Examiners did not know whether the subjects were secondary lead smelter workers or controls.

c. Results. Findings are reported in terms of (1) differences between the groups of lead exposed workers and controls; and (2) correlations between scores in performance tests and occupational, educational, physiological and biochemical parameters.

There was a significant difference in three performance tests (B.C., D.S., and E.F.) between secondary lead smelter workers and controls. Differences were not related to differences in educational background or age between the two groups. Mean and standard deviations for each group and value of t are reported in Table 19. There was no statistically significant difference between groups for dexterity tests with preferred hand or both hands.

Among secondary lead smelter workers, there was a significant, negative correlation between scores in three performance tests (B.D., D.S. and E.F.) and ZPP levels. There was also a significant, negative correlation between educational levels and ZPP levels.

Individual scores and functional relationships between these variables are depicted in Figs. 10,11,12 and 13. Correlation coefficients and probability values are shown in the figures.

A matrix of intercorrelation among behavioral tests and occupational, educational and biochemical variables is shown in Table 20.

All performance tests are significantly, negatively correlated with age but not with years of exposure. In all performance tests, correlation coefficients for blood lead versus tests scores were smaller than ZPP versus tests scores. However, two tests (B.D. and E.F.) do show significant, negative correlations with blood lead at a probability level of .05.

6. <u>Study of household contamination</u>

During a previous examination of secondary lead smelter workers by us, a study of the possible household contamination by lead brought home on workers' clothes, shoes, hair, etc. was undertaken. Approximately 30 homes were surveyed, including 10 control homes. Wipe samples of dust on the floor at the entrance most commonly used by the worker, or head of household were collected. Homes were generally well-maintained single family dwellings. Analysis was by nitric acid digestion, followed by flame atomic absorption.

A highly significant difference was found between the lead content of samples collected in the workers' homes and those collected in the homes of controls.

Similar studies were conducted among the homes of employees of the secondary lead smelter in Vernon. Twenty-two homes, including controls, were visited. Wipe samples were collected from the floor at the entrance most commonly used by the head of the household, settled dust was brushed from the door moldings into glassine envelopes, and paint chips were collected. Dust was also collected from the driveway or curbside, to assess the contribution from leaded gasoline.

These samples are currently being analyzed.

7. Discussion and Conclusions

The examination of this group of 111 secondary smelter workers with relatively long lead exposure, and 37 control workers, permit a number of useful observations.

The blood lead levels exceeded 60μg/100ml in 21 percent of the workers, and 80μg/100ml in only one case. This contrasted with history of elevated blood lead in the past, which was given by 56 percent of those examined. This suggests that levels of lead exposure had been recently reduced.

In accordance with the distribution of blood lead levels, zinc protoporphyrin levels exceeded 200μg in 31 percent of the workers.

18% had hemoglobin concentrations less than 14gm/100ml. This relatively low prevalence of anemia is consistent with blood lead and ZPP levels. Hemoglobin showed a strong correlation with ZPP values. It is noteworthy that no correlation was found between serum iron and ZPP levels. Thus, the increase in ZPP in these lead exposed workers was shown to be due to the enzyme inhibiting effects of lead and not due to iron deficiency.

There was good correlation between urinary delta aminolevulinic acid and ZPP; nevertheless there was better correlation between hemoglobin and ZPP than between hemoglobin and ALA-U.

Urinary coproporphyrin was found to be a less useful parameter than delta aminolegulinic acid or ZPP.

Symptoms possibly due to lead effects were found with higher prevalence in the lead-exposed than in the control group. The most prevalent were CNS symptoms, followed by muscle and joint pain, and then by gastrointestinal symptoms. The overall prevalence was less than in secondary lead smelter workers seen by us in other studies, with higher blood lead and ZPP levels.

Chelation therapy had not been excessively used in the past (19 percent of workers) and there were only isolated cases with repeated treatment. Change in job assignment to areas without lead exposure had been more frequently used (in 29 percent of workers), again in contrast to what we have sometimes observed in other circumstances. Peripheral neuropathy involving the extensor muscles of hands and/or fingers was found in 23 workers; there was a strong correlation with duration of lead exposure.

Hypertension was found in 11 lead exposed workers; the prevalence was different from that found in the control group only with regard to diastolic hypertension. 10 of the workers who had developed hypertension were black. No conclusions can be drawn from this limited experience.

Thus, while lead effects which develop over relatively short periods of time (CNS symptoms, muscle and joint pain, gastrointestinal symptoms) were found to be less prevalent in this population, and the laboratory indicators of lead absorbtion and lead effects were less abnormal, than in other secondary smelter workers studied by us, long term effects, particularly peripheral neuropathy (slight or moderate) were prominent.

As for psychological function tests, secondary lead smelter workers showed significantly poorer performances in tests of central nervous system higher functions as compared to controls. Differences were not found to be attributable to differences in age or educational background between the groups. The lower the educational level, the higher the ZPP levels in blood. It may be that workers with poorer schooling are assigned to dirtier jobs.

Performances in the dexterity test were not statistically different in lead exposed workers and controls.

Changes in performance in these tests are consistent with greater prevalence of central nervous system dysfunction among secondary lead smelter workers than in controls. Zinc protoporphyrin levels are significantly, negatively correlated with tests of central nervous system higher functioning but not with dexterity tests. ZPP levels seem to show a closer correlation with disturbances of higher function of the central nervous system than does the blood lead level.

The data obtained are consistent with recent improvement in lead exposure levels in the smelter (and with proper medical management of high blood lead levels). They indicate that improvements in exposure of lead smelter workers are possible, and emphasize the need for such improvements, in order to prevent long-term effects.

Table 1

Duration of lead exposure

	Number examined	Percent
Less than 1 year	23	21%
1 to 3 years	14	13%
3 to 10 years	31	28%
10.1 - 20 years	11	10%
20.1 - 30 years	31	28%
	110	

Table 2

Age distribution of lead exposed workers and controls

Age (years)	Lead exposed	Controls
Less than 30	26 - 24%	3 8%
31 - 50	52 - 48%	23 62%
Over 50	31 - 28%	11 30%
Total	109	37

Table 3

Central nervous system symptoms in lead smelter workers and controls

Symptom	Lead exposed workers	Percent	Controls	Percent
Fatigue	8	7.4%	1	2.9%
Nervousness	11	10.3%	2	5.7%
Sleep disturbance	8	7.4%	2	5.7%
Combinations of above	13	12.1%	-	0
Other	24	22.4%	2	5.7%
Total	64	59.8%	7	20%

Table 4

Blood lead levels and central nervous system symptoms

Blood lead level µg/100ml	Total number examined	CNS symptoms	
		Number	Percent
Less than 60	75	41	54.6%
60-80	19	12	63.1%
More than 80	1	1	

Table 5

Central nervous system symptoms and zinc protoporphyrin levels

ZPP µg/100ml	Total number examined	CNS symptoms Number	CNS symptoms Percent
Less than 100	37*	17*	45.9%
100-200	35	20	57%
201-500	31	18	58%
More than 500	3	3	61%

*Includes 3 retired workers

Table 6

Muscle and joint pain and blood lead levels

Blood lead µg/100ml	Total number examined	Muscle and joint pain Number	Percent
Less than 60	75	23	30.7%
60-80	19	9	47.4%
Over 80	1	0	

Table 7

Muscle and joint pain and/or soreness and ZPP levels

ZPP level µg/100ml	Total number examined	Muscle and joint pain	
		Number	Percent
Less than 100	37	11	29.7%
100-200	35	10	28.6%
201-500	30)	10)	
	) 31	)	35.5%
More than 500	1)	1)	

Table 8

Gastrointestinal symptoms

Symptom	Lead exposed workers (109)		Controls 36	
Loss of appetite	5	4.6%	2	5.6%
Weight loss	8	7.3%	1	2.8%
Loss of appetite and weight loss	11	10.1%	1	2.8%
Total	24	22%	4	11%

Table 9

Hypertension (systolic >150mm Hg and/or diastolic >95mm Hg) in secondary lead smelter workers and controls

Total number tested	Systolic and/or diastolic	Systolic hypert. (>150mm Hg)	Diastolic hypert. (>95mm Hg)
Lead exposed workers 103	11* (10.7%)	7(6.8%)	8(7.7%)**
Controls 35	3(8.6%)	3(8.6%)	1(2.8%)

*Mean duration of lead exposure 21.6 years, and mean age 50.6 years.
**Mean duration of lead exposure 23.5 years, and mean age 49.6 years

Table 10

Hypertension in lead exposed workers and length of exposure

Duration of lead exposure	Total Number Tested	Hypertension Number	%
Less than 3 years	37	1	2.7%
3-10 years	31	1	3.2%
10.1-20 years	11	1	9%
Over 20 years	31	8	26%

Table 11

Hypertension in lead exposed workers and age

Age	Total number tested	Hypertension Number	%
Less than 30	26	-	
31-50	52	6	11.5%
Over 50	31	5	16%

Table 12

Peripheral neuropathy in secondary lead smelter workers: duration of lead exposure

Duration of lead exposure	Total number examined	Extensor weakness	
		No.	%
Less than 10 yrs.	69	9	13.2%
10.1 - 20 yrs.	11	3	27.3%
Over 20 yrs.	30	11	36.7%
Total	109	23	21.3%

Table 13

Blood lead levels (μg/100ml) in secondary lead smelter workers

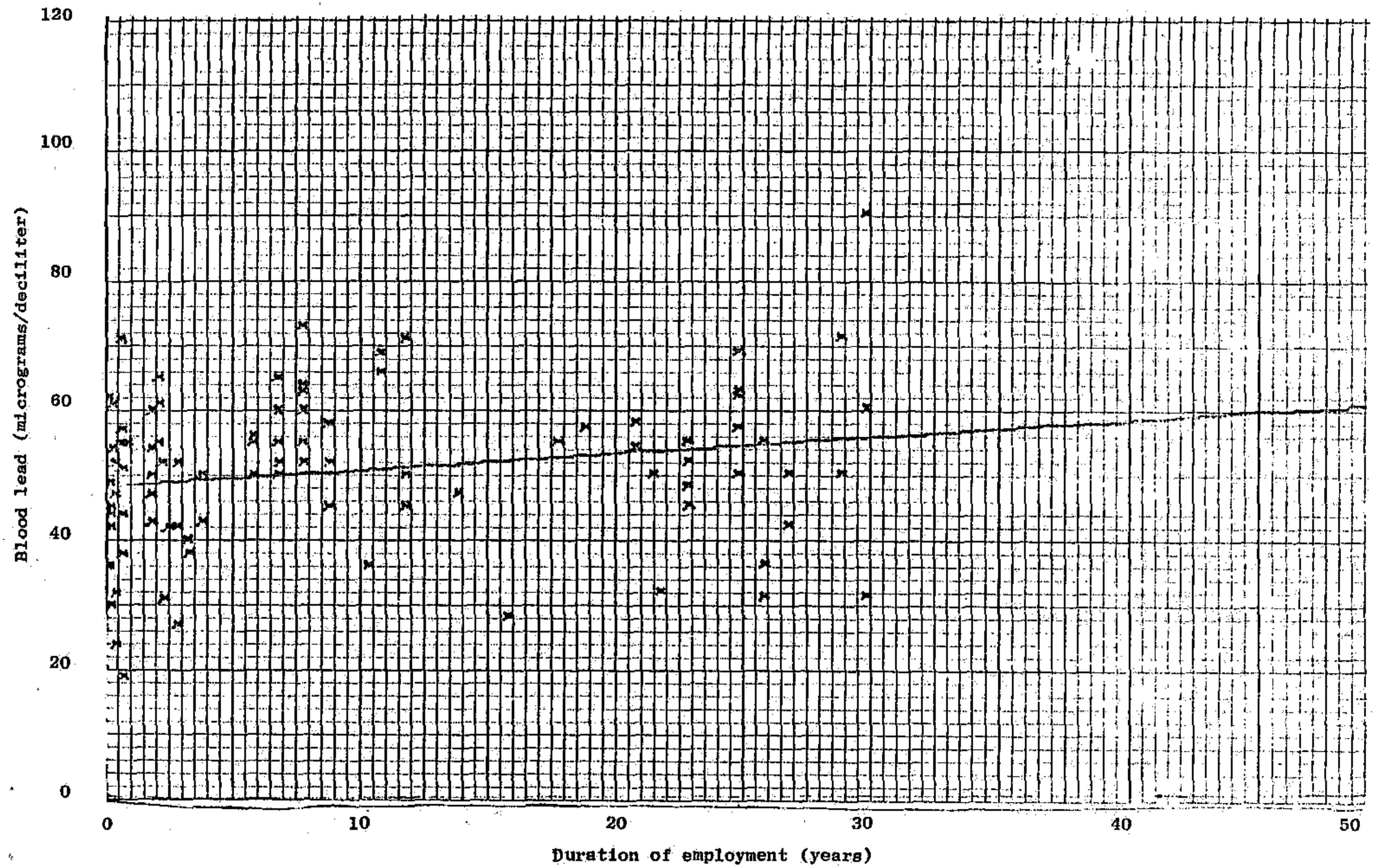
Blood lead levels μg/100ml	Lead exposed: Number of workers	Lead exposed: %	Controls: Number of workers	Controls: %
Less than 40	17	17%	34	94%
40 - 59	61	61%	2	6%
60 - 79	20	20%	---	
More than 80	1	1%	---	

Fig. 1

Blood lead levels of secondary lead smelter workers plotted against their years of employment and fitted with the least square linear regression line;

$r = 0.19$

Figure 1



Blood lead (micrograms/deciliter)
120
100
80
60
40
20
0
0
10
20
30
40
50
Duration of employment (years)

Table 14

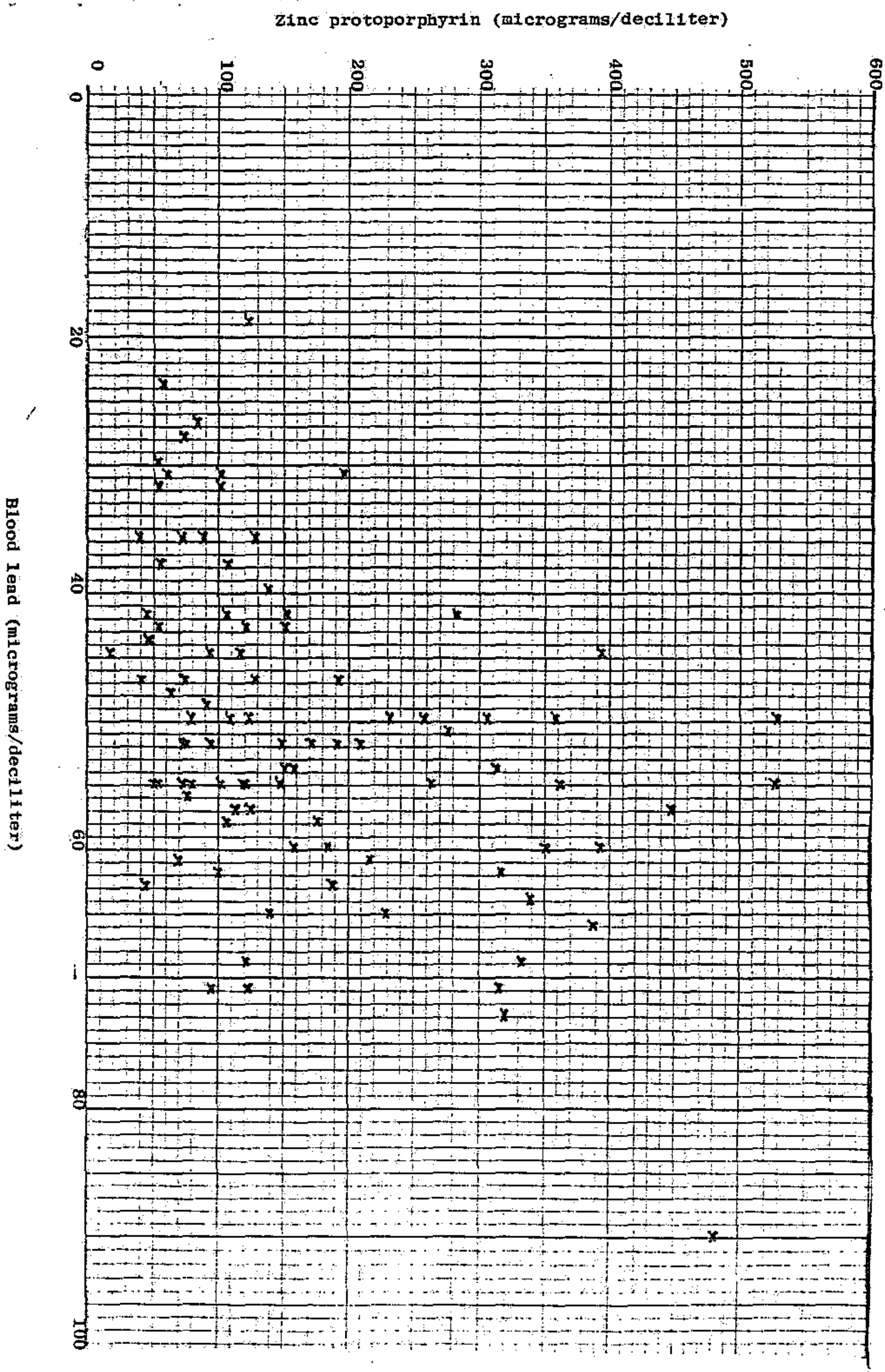
Zinc protoporphyrin levels in lead smelter workers and controls

	Lead exposed		Controls	
ZPP µg/100ml	Number of workers	%	Number of workers	%
Less than 100	36	32.7%	36	97.3%
100 - 200	40	36.7%	1	2.7%
201 - 500	31	28.2%	--	--
More than 500	3	2.7%	--	--
Total	110			

Fig. 2

Zinc protoporphyrin levels of secondary lead smelter workers plotted against their blood lead levels.

Figure 2



Zinc protoporphyrin (micrograms/deciliter)
0
100
200
300
400
500
600
Blood lead (micrograms/deciliter)
0
20
40
60
80
100

Table 15

Hemoglobin in secondary lead smelter workers

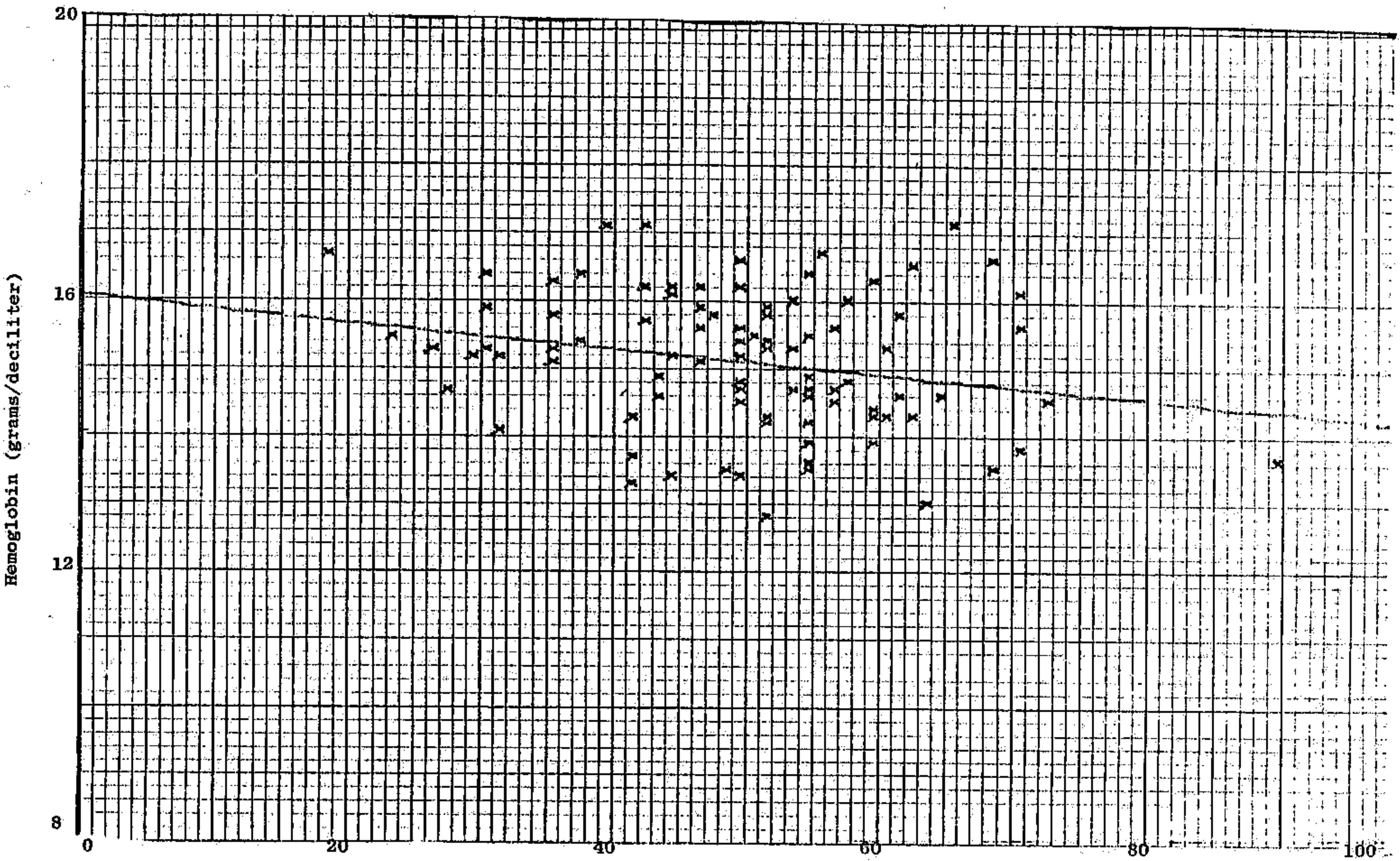
	Number examined	Hemoglobin gm/100ml: Less than 13		13 - 13.9		14 and over	
		No.	%	No.	%	No.	%
Lead smelter workers	109	1	0.9%	19	17.4%	89	81.6%
Controls	35	-		4	11.4%	31	88.6%

Fig. 3

Hemoglobin levels of secondary lead smelter workers plotted against their blood lead levels and fitted with the least square linear regression line;

$r = 0.23$

Figure 3



Blood lead (micrograms/deciliter)

Fig. 4

Hemoglobin levels of secondary lead smelter workers plotted against their zinc protoporphyrin levels and fitted with the least square linear regression line;

$r = 0.40$

Figure 4

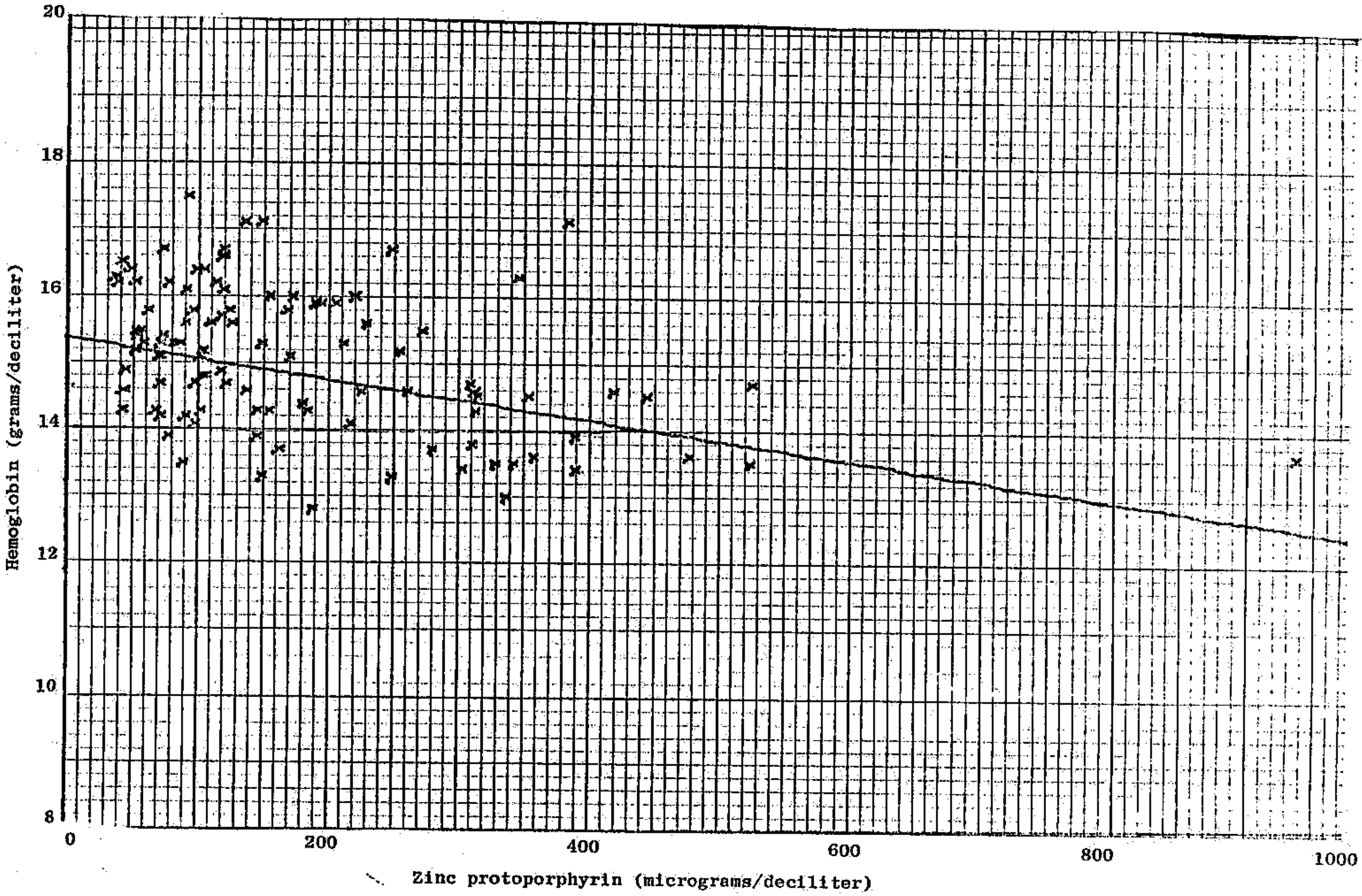

Hemoglobin (grams/deciliter)
20
18
16
14
12
10
8
0
200
400
600
800
1000
Zinc protoporphyrin (micrograms/deciliter)

Table 16

Hemoglobin and zinc protoporphyrin levels in secondary lead smelter workers

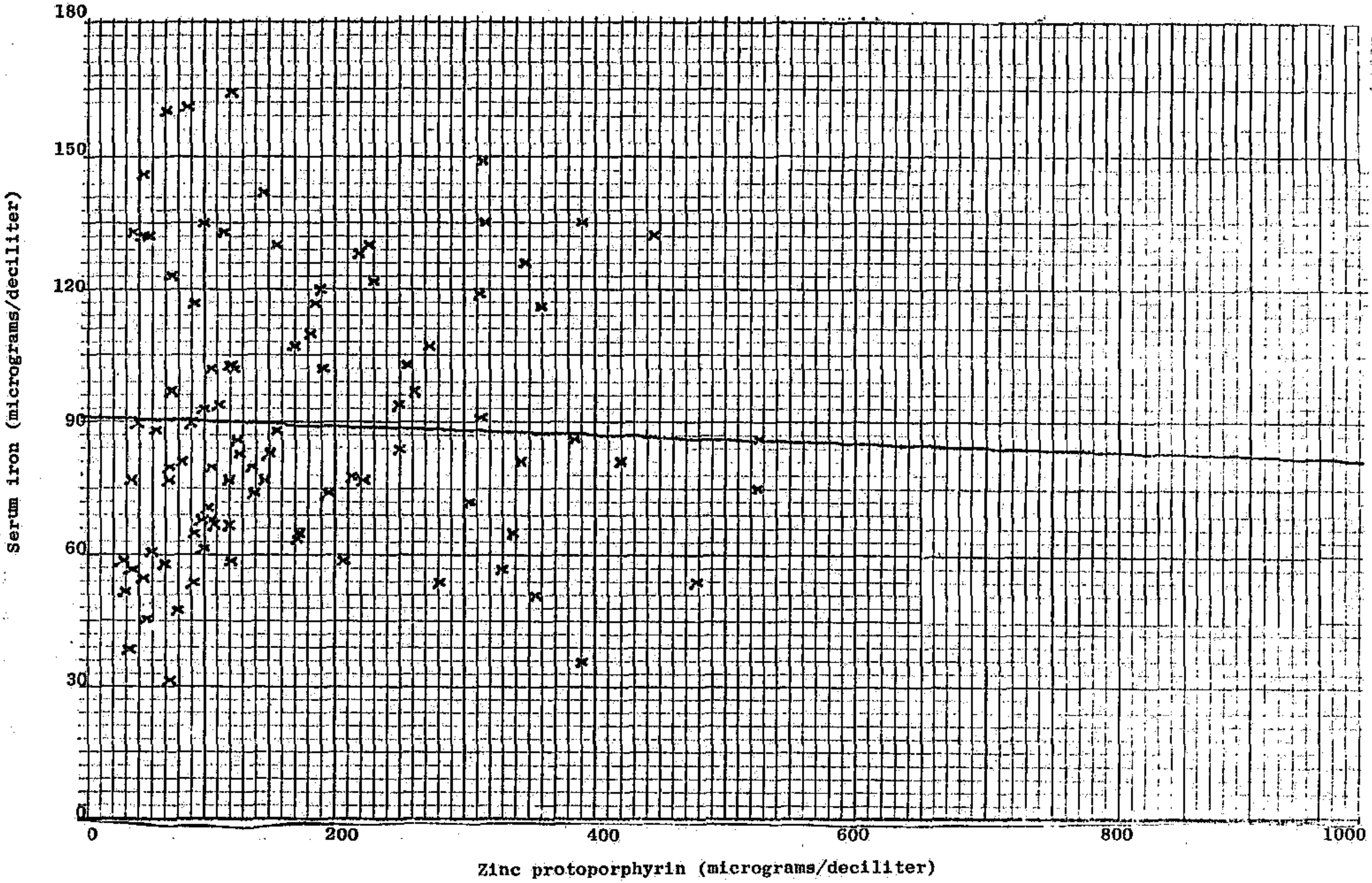
ZPP µg/100ml	Number examined	< 14gm/100ml No.	< 14gm/100ml %
Less than 100	36	2	5.6%
100 - 200	40	4	10%
201 - 500	31	12	38.7%
More than 500	3	2	66%

Fig. 5

Serum iron levels of secondary lead smelter workers plotted against their zinc protoporphyrin levels and fitted with the least square linear regression line;

$r = 0.038$

Figure 5



180
150
120
90
60
30
0
Serum iron (micrograms/deciliter)
0
200
400
600
800
1000
Zinc protoporphyrin (micrograms/deciliter)

Table 17

Urinary delta aminolevulinic acid in secondary lead smelter workers

ALA-Umg/1	Number of workers	Percent
Less than 6	70	74.2%
6.1 - 10	27	24.7%
Over 10	12	11.0%

Fig. 6

Urinary δ-aminolevulinic acid levels of secondary lead smelter workers plotted against their blood lead levels and fitted with the least square linear regression line; $r = 0.36$

Figure 6

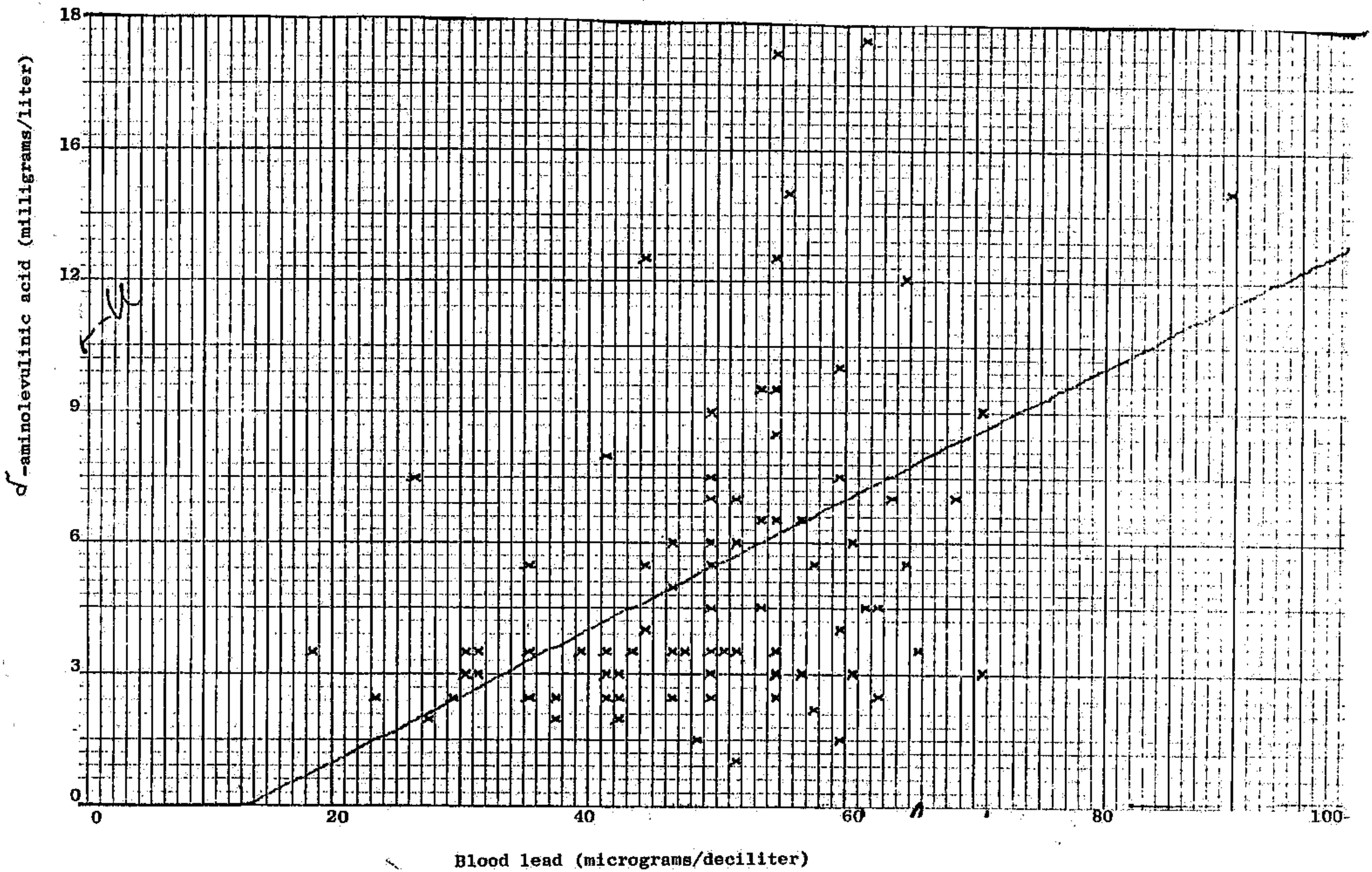
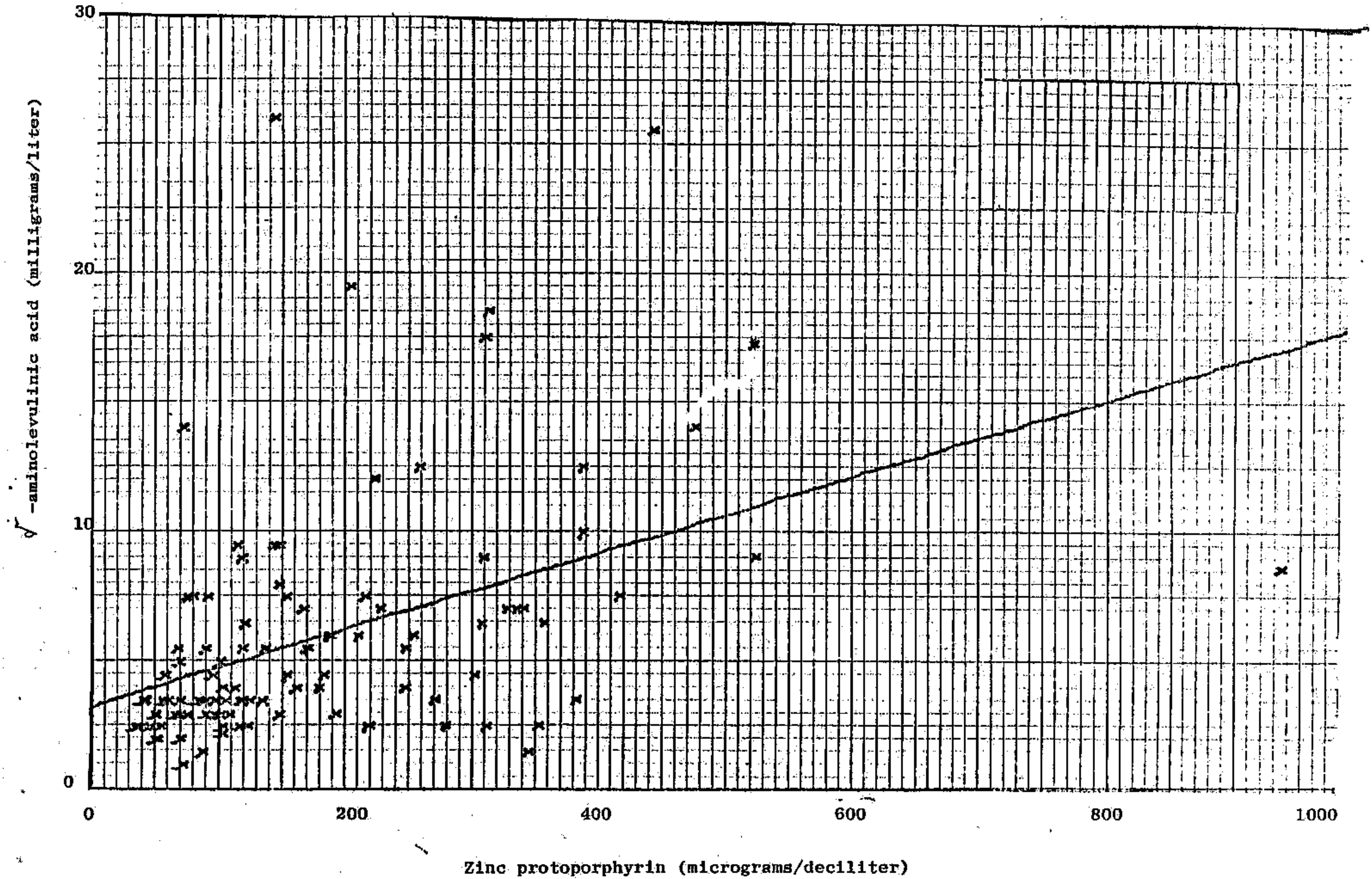

δ-aminolevulinic acid (milligrams/liter)
18
16
12
9
6
3
0
0
20
40
60
80
100
Blood lead (micrograms/deciliter)

Fig. 7

Urinary δ-aminolevulinic acid levels of secondary lead smelter workers plotted against their zinc protoporphyrin levels and fitted with the least square linear regression line: $r = 0.44$

Figure 7

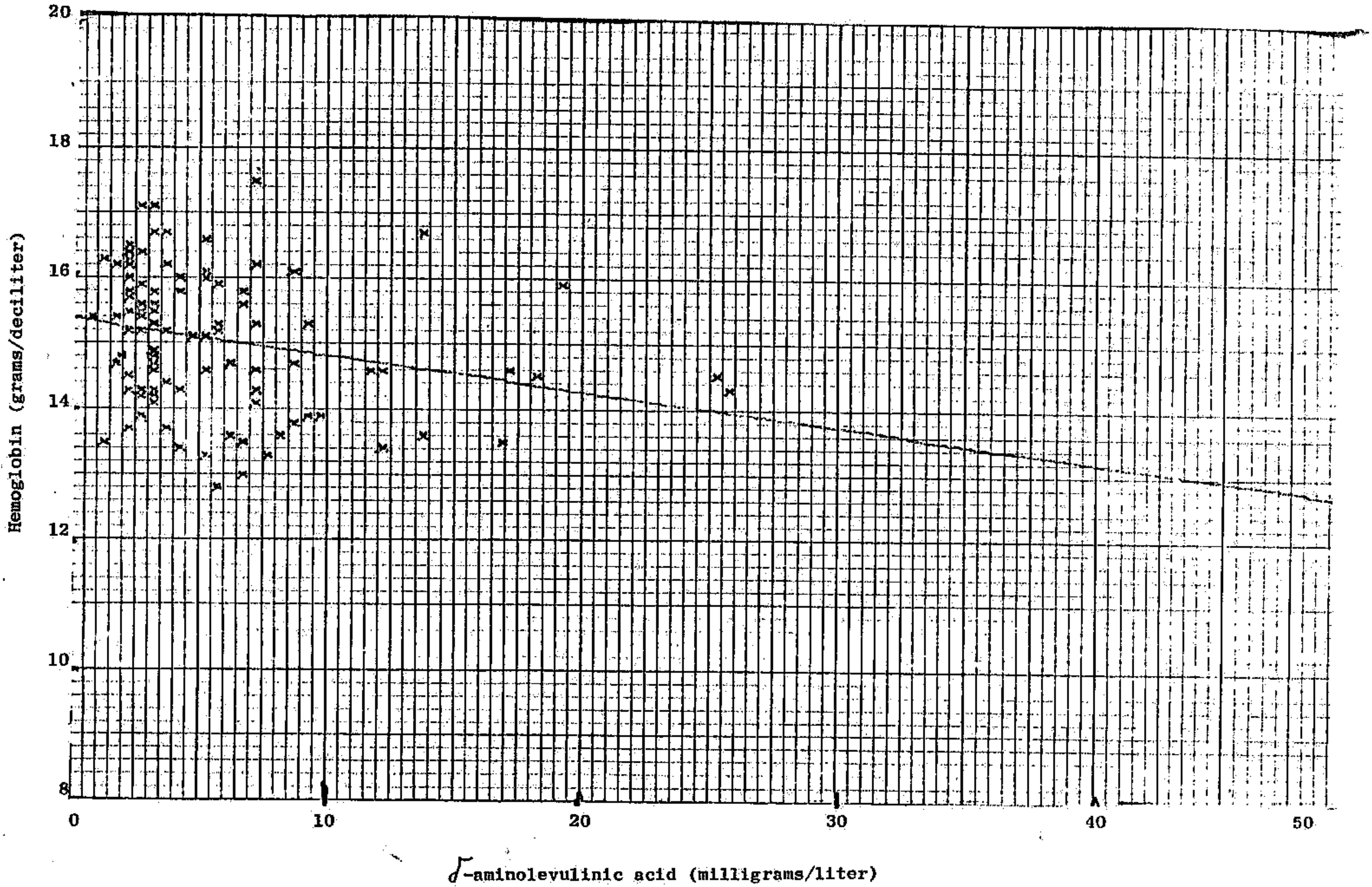


δ-aminolevulinic acid (milligrams/liter)
0
10
20
30
0
200
400
600
800
1000
Zinc protoporphyrin (micrograms/deciliter)

Fig. 8

Hemoglobin levels of secondary lead smelter workers plotted against their urinary δ-aminolevulinic acid levels and fitted with the least square linear regression line; $r = 0.25$

Figure 8



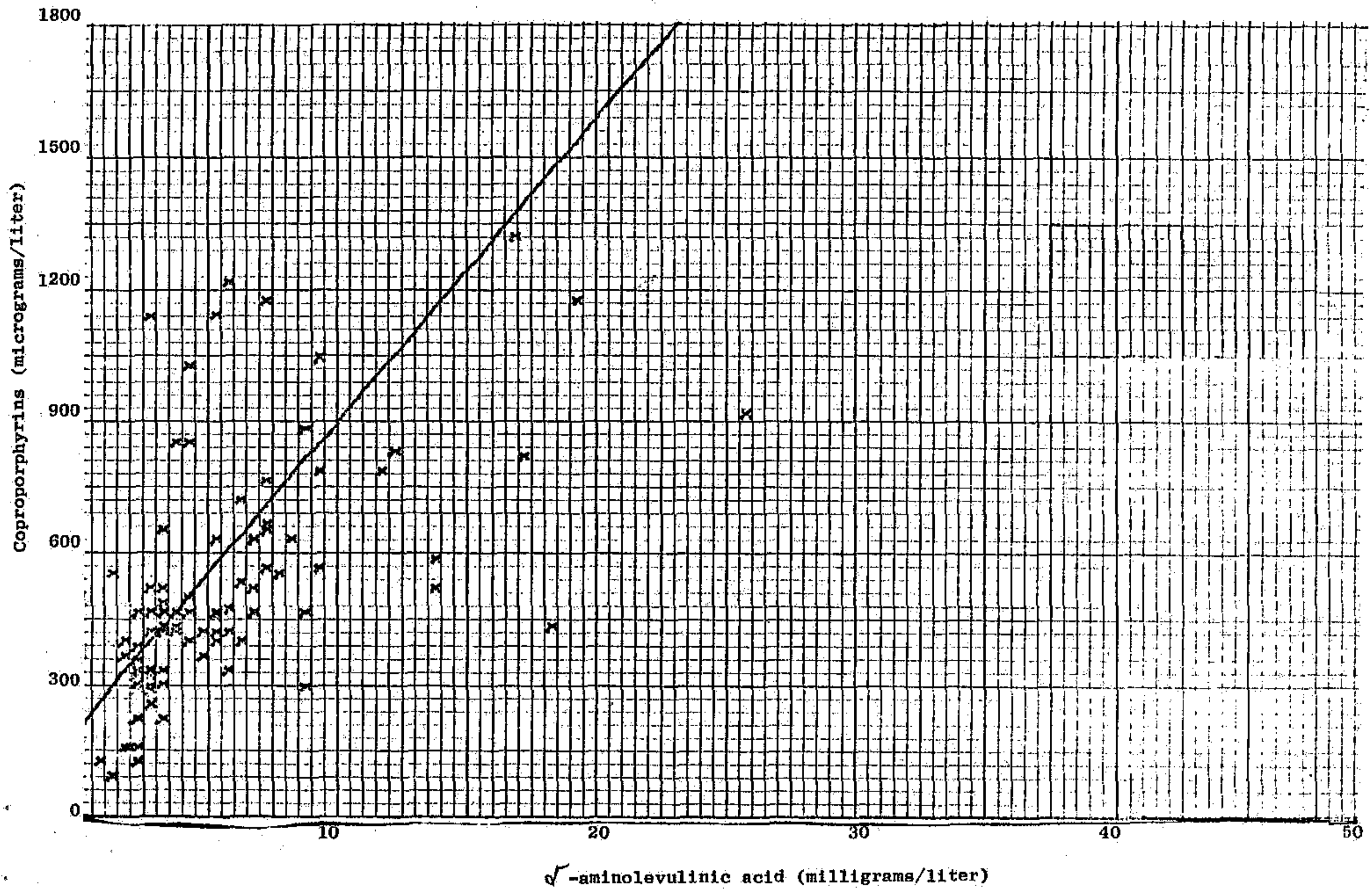
Hemoglobin (grams/deciliter)
20
18
16
14
12
10
8
0
10
20
30
40
50
δ-aminolevulinic acid (milligrams/liter)

Fig. 9

Urinary coproporphyrin levels of secondary lead smelter workers plotted against their urinary δ-aminolevulinic acid levels and fitted with the least square linear regression line;

$r = 0.62$

Figure 9



Coproporphyrins (micrograms/liter)
1800
1500
1200
900
600
300
0
10
20
30
40
50
δ-aminolevulinic acid (milligrams/liter)

Table 18

Educational Rating

1. No formal education. Quit after few years of grammar school. Does not know how to write or read.

2. Finished grammar school.

2.5 High school equivalent

3. Finished formal high school or trade school.

4. Associate degree in a junior college.

5. Finished college with a Bachelor's degree

6. Finished college with a Master's degree

7. Finished University with a Ph.D. degree

8. Doctoral working in his field.

Table 19

Behavioral Testing. Differences Between Groups

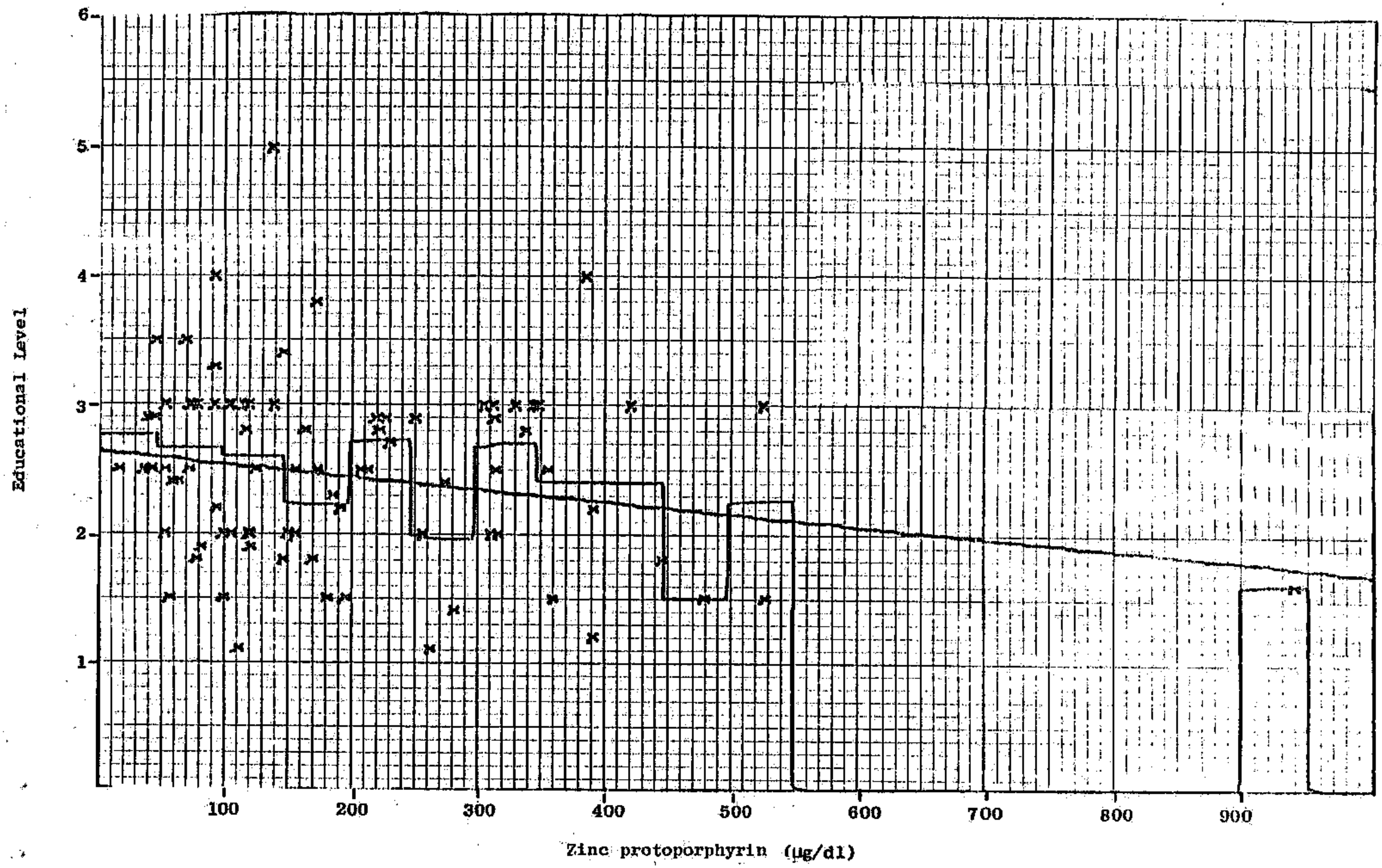
		N	$\bar{X}$	S.D.	t
Age	Control	25	44.8	11.3	0.76 (N.S.)
	S.L.S.W.	90	42.8	12.1	
Educ	Control	25	2.65	0.67	0.94 (N.S.)
	S.L.S.W.	86	2.50	0.69	
B.D.	Control	25	18.9	11.8	2.65 ($p < .05$)
	S.L.S.W.	86	12.7	9.3	
D.S.	Control	25	38.6	18.5	2.17 ($p < .05$)
	S.L.S.W.	89	31.8	12.9	
E.F.	Control	25	29.9	7.7	2.45 ($p < .05$)
	S.L.S.W.	90	26.1	6.6	
D.H.	Control	25	20.5	4.0	1.90 (N.S.)
	S.L.S.W.	90	19.0	3.9	
B.H.	Control	25	12.3	4.2	1.25 (N.S.)
	S.L.S.W.	86	11.4	3.4	

S.L.S.W. = Secondary Lead Smelter Workers

Fig. 10

Correlation between educational level and levels of zinc protoporphyrin (ZPP) among secondary lead smelter workers.

Figure 10



Educational Level
1
2
3
4
5
6
100
200
300
400
500
600
700
800
900
Zinc protoporphyrin (μg/dl)

Fig. 11

Correlation between Block Design test scores and levels of zinc protoporphyrin (ZPP) among secondary lead smelter workers.

Figure 11

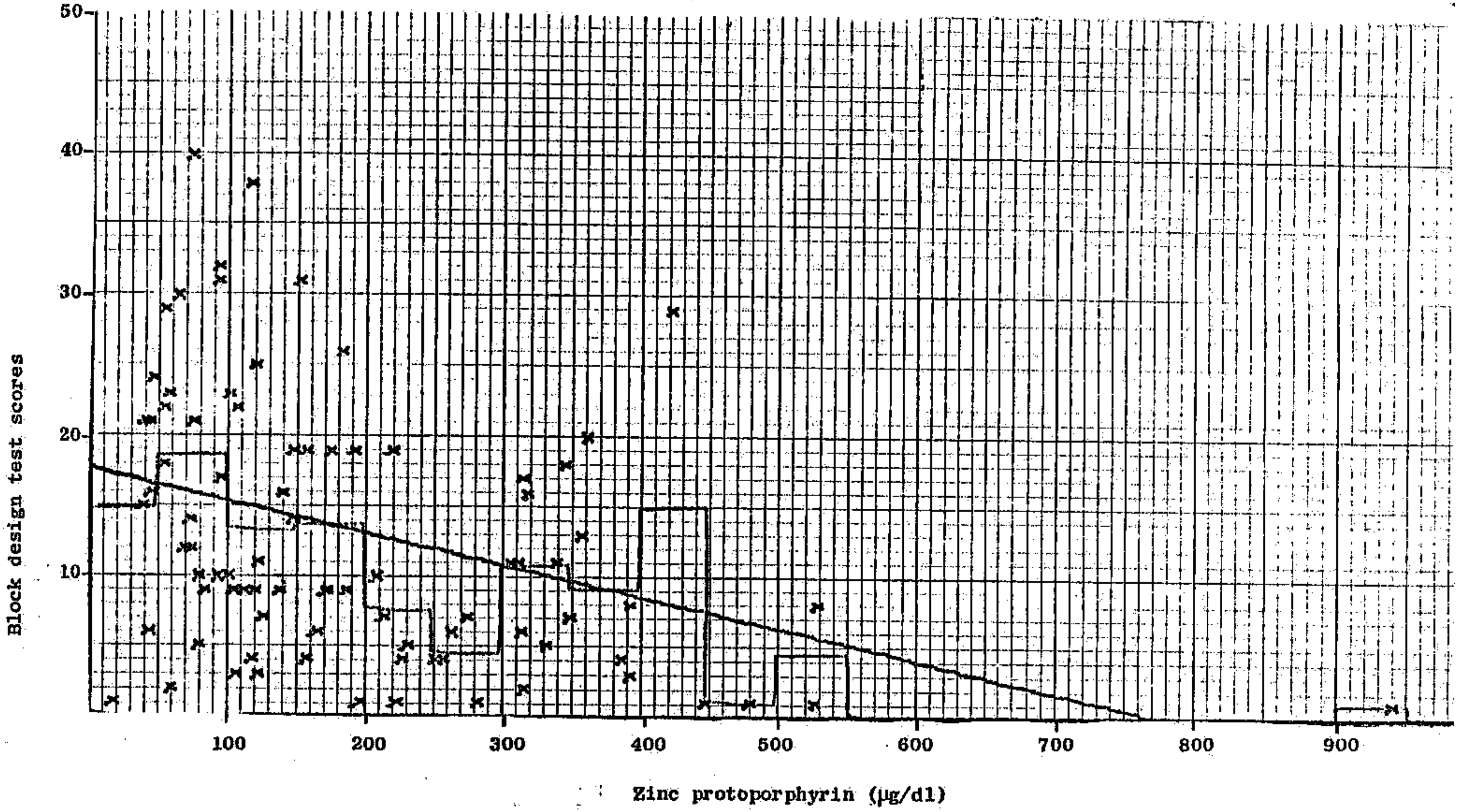
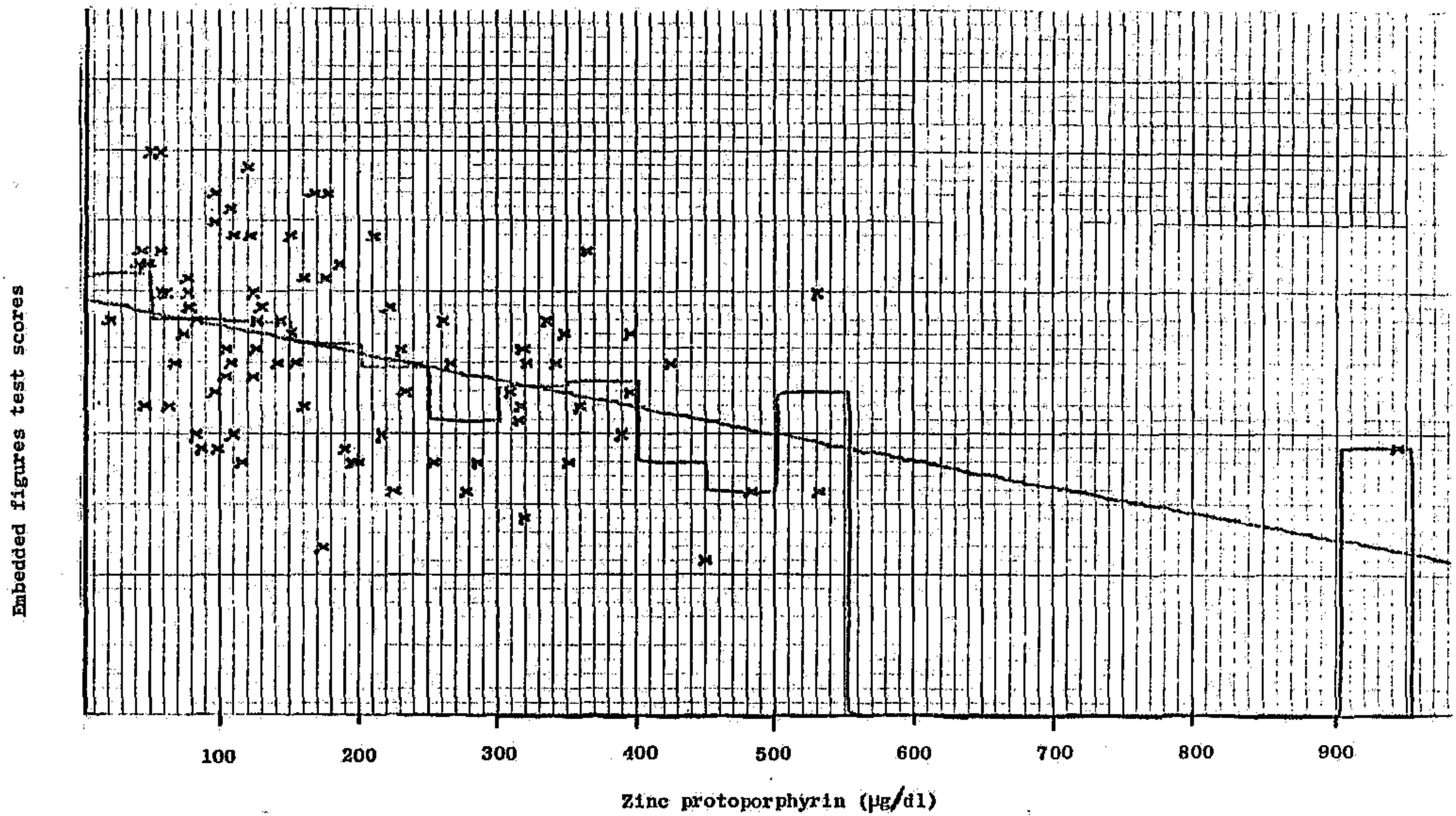

Block design test scores
50
40
30
20
10
100
200
300
400
500
600
700
800
900
Zinc protoporphyrin (µg/dl)

Fig. 12

Correlation between Digit-Symbol test scores and levels of zinc protoporphyrin (ZPP) among secondary lead smelter workers.

Figure 12



Embedded figures test scores
100
200
300
400
500
600
700
800
900
Zinc protoporphyrin (µg/dl)

Fig. 13

Correlation between Embedded Figures test scores and levels of zinc protoporphyrin (ZPP) among secondary lead smelter workers.

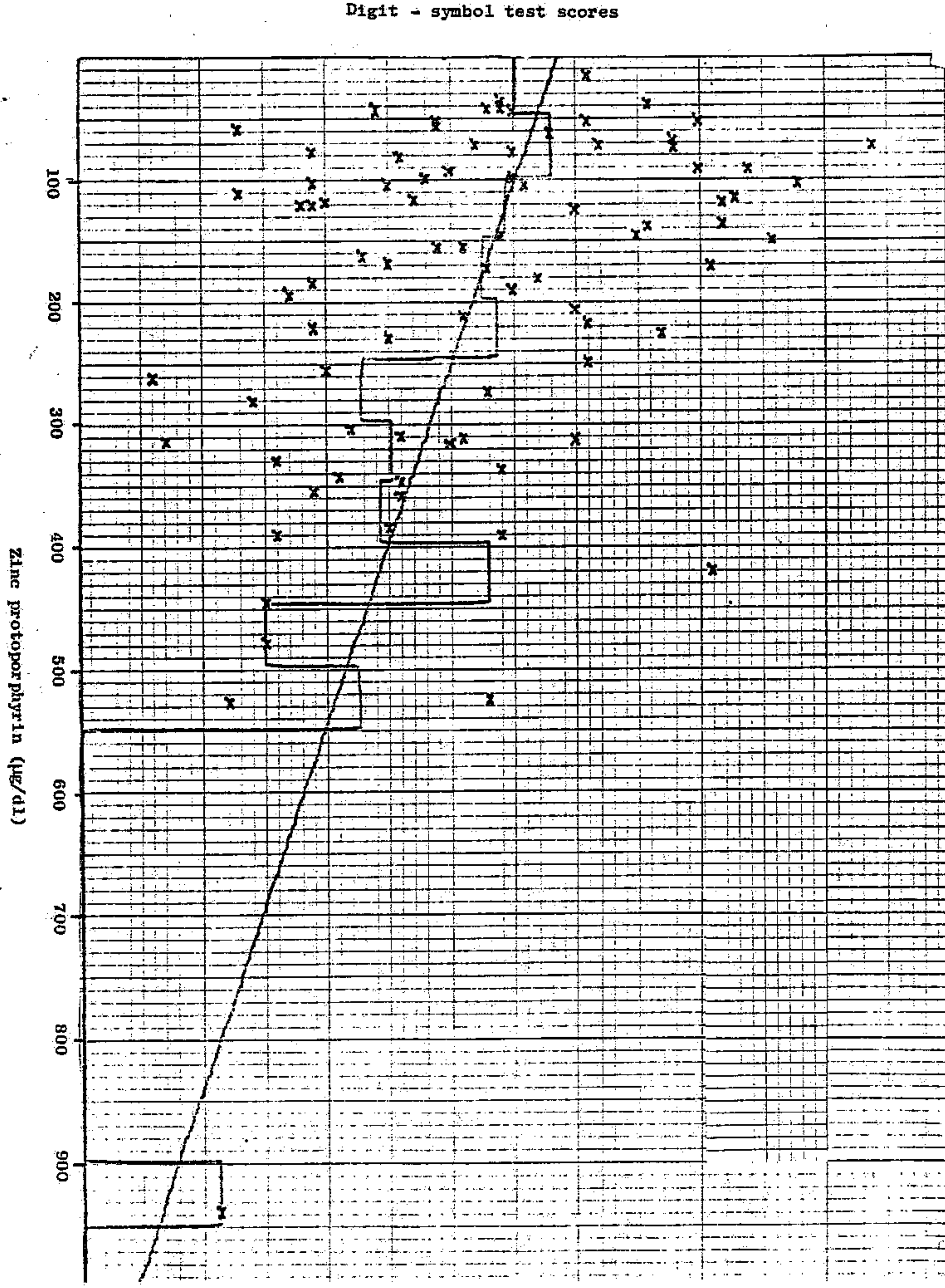

Digit - symbol test scores
100
200
300
400
500
600
700
800
900
Zinc protoporphyrin (µg/dl)

Figure 13

Table 20

Matrix of Intercorrelations Among Behavioral Tests and Occupational, Educational and Biochemical Variables

	Age	Educ.	B.D.	D.S.	E.F.	D.H.	B.H.	ZPP	Pb-B	Exp.
Age	X	-	-.29	-.52	-.42	-.33	-.20	-	-	-
Educ.		X	+.14	+.51	+.27	+.11	+.06	-.20	-.08	-
B.D.			X	+.61	+.51	+.44	+.47	-.37	-.24	-.12
D.S.				X	-	+.35	+.36	-.40	-.10	-
E.F.					X	+.30	-	-.42	-.22	-
D.H.						X	+.46	-.17	-.01	-
B.H.							X	-.17	-	-
ZPP								X	-	-
Pb-B									X	-
Exp.										X

$r = .20$; $p < .05$; $r = .27$; $p < .01$. Symbol - indicates data remain to be analyzed.