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COPPER, ZINC AND LEAD DISTRIBUTION IN THE ROCKS NEAR REVELSTOKE, B.C.

by

ROBERT NORMAN MATTHEWS

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A dissertation submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
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Copper, zinc and lead distribution
in the rocks near Revelstoke, B.C.

ABSTRACT

This thesis is concerned with the variation of trace copper, zinc and lead content in rocks forming a portion of the Hadrynian to Devonian sequence east of Revelstoke, B.C. Eighty-nine trace copper, zinc and lead determinations are presented. In addition, five whole rock analyses of granitic rocks were prepared.

The results were arranged according to changing lithostratigraphy, lithology and metamorphic type and statistically treated to determine trends of enrichment or impoverishment, if any. Of the lithostratigraphic units the Lardeau Group showed the greatest concentration of copper, zinc and lead. The phyllites of the Lardeau Group have the highest content of these trace elements of any major rock within the unit.

Pelitic rocks in the study area regardless of their stratigraphic position have a higher trace metal content than psammitic rocks.

The trace copper, zinc and lead content of metamorphic rocks varies. Generally rocks of higher metamorphic grade are depleted in trace copper, zinc and lead compared with their lower grade equivalents.

The results of this study, contrasted with some literature data, failed to establish any clear correlation amoung trace copper, zinc and lead abundances in rocks and the distribution of actual ore occurrences.

SECTION 1

INTRODUCTION

Statement of Problem

This study based on quantitative analyses of trace copper, zinc and lead in rocks near Revelstoke, B.C. is concerned with the changing geochemistry of these elements in regard to the changing stratigraphy, lithology and metamorphic grade of their hosts. Metal distribution patterns around the zinc and lead deposits are not a concern of this study.

The study area is located within the Revelstoke Mining Division. The area is characterized by two mountain ranges, the Selkirks and the Monashees. The Selkirk Mountains in the east consist of a complexly deformed section of quartzites, phyllites and limestones. The Monashee Mountains contain the Shuswap metamorphic complex, an area of high grade metamorphics. The major type of mineralization is that of zinc and lead vein, replacement and other deposits.

Location and Access

The study area is located in southeastern British Columbia. Its boundaries are approximately those of Glacier National Park on the east and the city of Revelstoke on the west (Figure 1). The prime access routes in the area are the Trans-Canada Highway and Provincial Road 23 (which runs parallel to the Columbia River and intersects the Trans-Canada Highway at Revelstoke). Logging roads, old mining roads and walking trails provide further access routes.

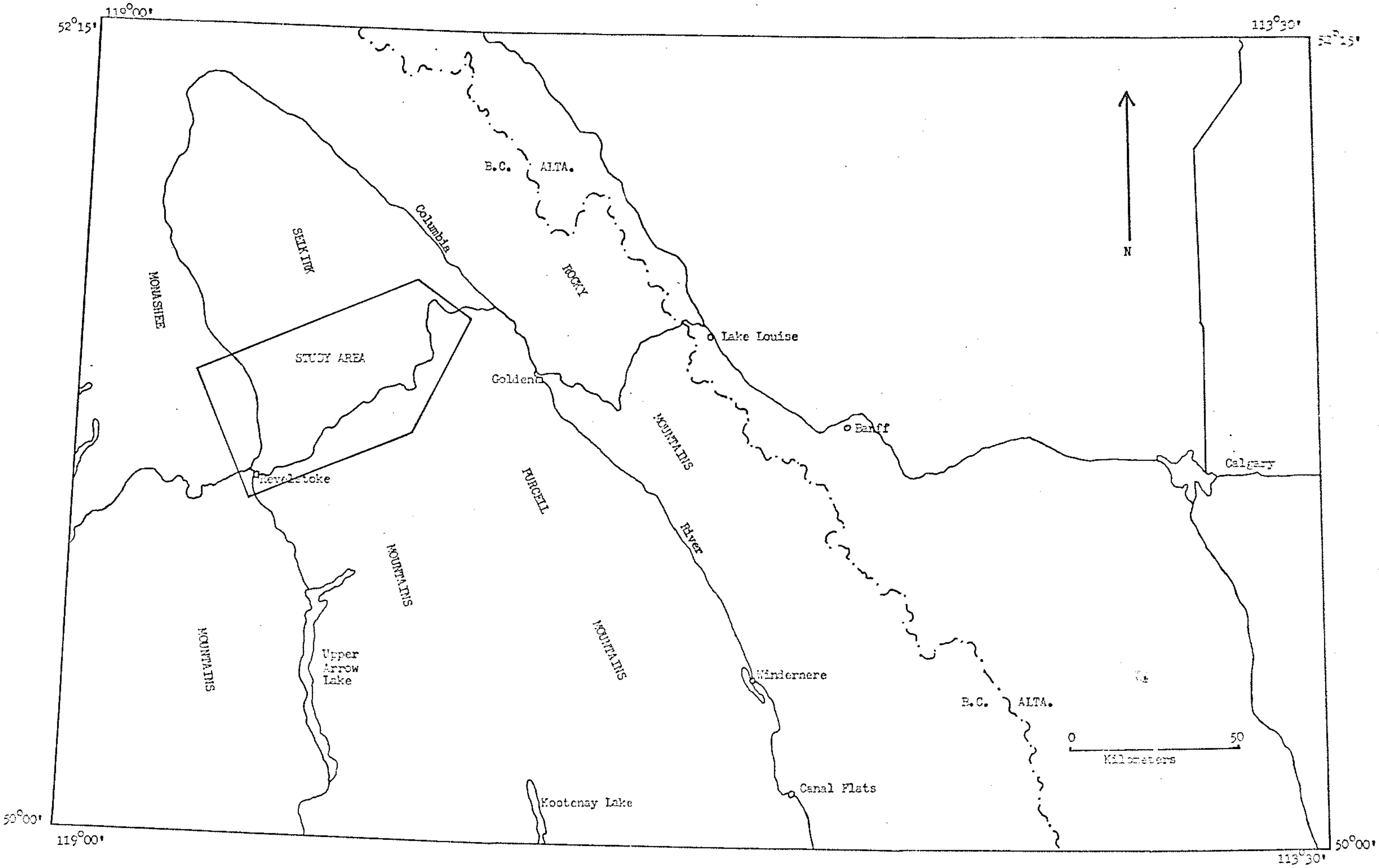

Figure 1. Location of Study Area

Previous Work

Little published information is available on the geochemistry of the rocks in the study area. The author is unaware of any published trace element data. Data on the metal content in some of the ore deposits have been published in Wheeler (1963, 1965).

Dawson (1898) published a report on the geology along the Canadian Pacific Railway in the vicinity of Revelstoke. Walker and Bancroft (1929) produced a report on the Lardeau Map area. The western and northern Selkirk ranges were mapped by Gunning (1929) and Fyles (1960). Wheeler (1963, 1965) mapped the Rogers Pass Map Area and the Big Bend Map Area. Ross (1968) studied the structural geology near Albert Canyon. Fyles (1970) published a preliminary report on the zinc and lead deposits in the Jordan River area near Revelstoke. Gilamn (1972) described the geology of the Clachnacudainn Salient east of Revelstoke.

Reports on age dating (K-Ar) on intrusive rocks from the area were published by Lowden (1963), Gabrielse and Reesor (1964) and by Wanless (1972).

Thompson (1972) and Zwanzig (1973) have produced Ph.D. theses on the geology in the vicinity of this study area.

Scope of the Study

The field work was carried out during two summer seasons (1973, 1974). Total time spent in the field was approximately 2 months. The purpose of the field work was to collect rock samples for chemical analysis. Eighty-nine samples were selected for analysis from the material collected (for a description of sample locations see the

Appendix). The samples were selected such that all the lithostratigraphic units and major lithologic and metamorphic types were included for analysis.

The laboratory work by the author was done in the laboratories at the Department of Earth Sciences, University of Manitoba and it included all phases of trace element analysis from crushing samples to dissolving the rock material and operating the atomic absorption spectrophotometer. The author was assisted during these operations by the technical staff of the Department of Earth Sciences. All eighty-nine samples were analyzed for their copper, zinc and lead content by atomic absorption. From the eighty-nine samples, five whole rock analyses of granitic rocks were produced by the Earth Science technical staff using atomic absorption and x-ray spectrophotometric methods.

Acknowledgements

I wish to thank several people and agencies who have helped to make this project possible.

B.P. Minerals Ltd. of Vancouver assisted the author during the first field season. The author was on the company payroll during this period. The company also assisted in transportation costs.

Parks Canada, Western Region, provided a collectors permit so that material could be removed from the two national parks in the study area (Glacier and Revelstoke National Parks).

The author's advisor, Dr. P. Laznicka, has provided assistance both while in the field and with the reading of the manuscript.

The author's parents have also provided financial and personal support.

SECTION 2

GENERAL GEOLOGY

General Statement

The study area includes two geological regions. The sequence of the Selkirk Mountains underlie the eastern section of the study area while the Shuswap metamorphic complex lies to the west of the Selkirks (Wheeler, 1963, 1965). The Selkirk Mountains sequence comprise a section of limestones, grits, shales, phyllites and schists ranging in age from Hadrynian to possibly Devonian (Douglas, 1970). The Shuswap complex contains rocks ranging in age from Aphebian to early Mesozoic which are metamorphosed to upper almandine - amphibolite facies (Douglas, 1970). Both geological provinces form part of the Omineca Crystalline Belt (Wheeler, 1970).

Stratigraphy

The supracrustal rocks of the Selkirk and Monashee Mountains (Shuswap Complex) may rest on the Hudsonian crystalline basement of Early Proterozoic (Aphebian) metamorphic and plutonic rocks that extends under the Interior Plains from the Churchill Province of the Canadian Shield (Price, 1971). The basement rocks may emerge again as tongues of remobilized granitoid gneiss that occur in the cores of "gneiss domes" in the Shuswap metamorphic complex (Price, 1971). Douglas (1970) maintains that nowhere in the cores of the domes has an ancient crystalline basement been identified.

The oldest component of the miogeosynclinal-platform assemblage

TABLE 1

Table of Lithostratigraphic Units

Era	Period	Shuswap Complex	Selkirk Mountains
Mesozoic	Middle Jurassic	Intrusive rocks -porphyritic hornblende granite to granodiorite	Intrusive rocks -porphyritic hornblende granite to granodiorite
Intrusive Contact			
Paleozoic	Cambrian to Devonian	Fringe Zone -paragneiss riddled with pegmatite	Lardeau Group -extensive fine clastic sequence, ranges from phyllite through limy sequences to quartzite
	Lower Cambrian	Mantling Zone -paragneiss with some nepheline syerite gneiss, quartzite and marble	Badshot Formation -light and gray limestone, dolomite and phyllite
			Hamill Group -quartzite, argillite and schist
Proterozoic	Hadrynian	Core Zone -mixed gneisses and migmatitic granitoid gneisses	Horsethief Creek Group -slate, phyllite, grit; quartz-pebble conglomerate; limy metasediments

is the Late Proterozoic (Hadrynian) Windermere Super Group represented in the study area by the Horsethief Creek Group (Price, 1971). Subsequent Paleozoic sedimentation resulted in the development of the Hamill Group, the Badshot Formation and the Lardeau Group, all of Cambrian age. Rocks ranging in age from the Proterozoic to early Mesozoic comprise the Shuswap metamorphic complex (Douglas, 1970).

Description of the Lithostratigraphic Units[1]

Shuswap Metamorphic Complex

The Shuswap metamorphic complex consists of rocks comprising a great range in ages (Proterozoic to Mesozoic). It occupies the western portion of the map area (Figure 2). Only a portion of the entire complex is included, this being the Frenchman's Cap Dome west of the Columbia River and the Clachnacudainn Salient east of the Columbia River (Gilman, 1972).

The core of the Frenchman's Cap Dome is composed of mixed gneisses and migmatitic granitoid gneisses (Wheeler, 1965). Surrounding the core is a mantle of metasedimentary gneisses and schists and locally nepheline syenite gneiss. This zone is fringed with metasedimentary gneisses cut by pegmatites.

According to Wheeler (1966) the earliest structures in the complex are warps and isoclinal recumbent folds developed along east-west axes. The early structures have been redeformed producing northerly trending folds and lineations resulting in a structural pattern of domes and depressions. In the course of the redeformation the cores of the domes moved upward as diapirs and perhaps eastward as well (Wheeler, 1966).

[1] See geological map (Figure 2).

No evidence has been found in the Frenchman's Cap Dome for an unconformity between the core gneisses and the base of the metasedimentary gneisses and schists (Wheeler, 1970). Furthermore, Ross (1968) has shown that an unconformity does not exist between the outer metasedimentary fringe of the Shuswap complex and the sediments of the Western Kootenay Arc.

The metamorphic grade of the rocks within the Shuswap complex are generally in the upper amphibolite facies (Wheeler, 1970). A metamorphic aureole extends into and under the adjacent Kootenay Arc. The transition from the amphibolite facies to the greenschist facies is located in the vicinity of Albert Canyon. Metamorphism of the Shuswap complex probably took place in mid-Jurassic time (Wheeler, 1970).

Attempts have been made to correlate units within the Shuswap complex with units in the Kootenay Arc. The paragneiss of the Shuswap complex contains a lower quartzite, calc-silicate gneiss, marble and schist sequence that is generally similar, though not in detail, to the Lower Cambrian Hamill Quartzite-Badshot Limestone succession in the Kootenay Arc (Wheeler, 1970). This same observation has been made by Ross (1968) and by Reesor and Moore (1971).

Horsethief Creek Group

Overlying the Hudsonian crystalline basement is the Horsethief Creek Group (Wheeler, 1963), a part of the Late Proterozoic (Hadrynian) Windermere Super Group. The Horsethief Creek Group underlies the map area on the extreme eastern boundary and dips under the Hamill Group on the western edge near the headwaters of the Illecillewaet River. Total thickness of the Group is close to 1800 meters (Evans in Wheeler, 1963).

The Horsethief Creek Group has been divided into four map units by Evans (In Wheeler, 1963). The lowermost unit consists principally of quartzose and feldspathic grits, sandstone and some varicoloured quartz-pebble conglomerate and has a total thickness of 900 meters. Overlying this is a 300 meter section of grey and green slate which is succeeded by a limestone unit 200 meters thick. An upper shale unit 300 meters in total thickness completes the section.

Many westward dipping north-south trending fault zones cut the Horsethief Creek Group in the vicinity of Quartz Creek. One of these fault zones forms part of the boundary with the overlying Hamill Group. A possible disconformity exists between the two groups along the remainder of the contact (Wheeler, 1963).

The Horsethief Creek Group is thought to be an equivalent of the Windermere Super Group and therefore is viewed to be Hadrynian in age (Wheeler, 1963). The group can probably be correlated with the Precambrian Miette Group of the western ranges of the Rocky Mountains (Price and Simony, 1971).

Hamill Group

The Hamill Group (Wheeler, 1963) outcrops in a north-south trending belt across the map area (Figure 2). The Group extends from the boundary with the Horsethief Creek Group in the east to the vicinity of Bostock Creek in the west. A second small outcrop belt is found near the conjunction of the Tangier River and the Trans-Canada Highway. The total thickness of the Group is 250 meters (Wheeler, 1963).

The Hamill is composed predominantly of pure metaquartzite with some zones of schist (Wheeler, 1963). Towards the east and the

Dogtooth Range the Hamill Group consists of two metaquartzite units separated by an argillaceous unit. The Group undergoes a facies change in a westward direction grading into an orthoquartzite.

The Hamill Group is faulted at several places especially along its boundaries. An easterly dipping overturned syncline bisects the outcrop pattern of the Hamill Group.

The Hamill Group is separated from the underlying Horsethief Creek Group by a possible disconformity (Okulitch, in Wheeler, 1963). Much of the boundary is a fault contact, however, with the competent Hamill Group quartzites having slid over the underlying weak slates of the Horsethief Creek Group (Wheeler, 1963).

Metamorphic recrystallization has affected much of the Hamill Group especially in the eastern part of the Shuswap metamorphic complex. The metaquartzite contains in addition to quartz the assemblage of muscovite, biotite, plagioclase and potash feldspar (Wheeler, 1965).

The Hamill Group is of Lower Cambrian age (Price, 1971). It occupies the same stratigraphic position as the quartzites of the Gog Group of the Western Main Ranges of the Rocky Mountains.

Badshot Formation

The Badshot Formation is exposed in the Ventigo syncline west of the summit of Rogers Pass, in the limbs and the core of an anticline northeast of Woolsey Creek. The thickness section measured by Wheeler (1963) was 300 meters.

The lithologic components of the Badshot Formation include light and dark grey metalimestone locally interbedded with buff metadolomite and phyllite. The presence of Archeocyathids made this formation one of the most significant of the Kootenay Arc (Ross, 1970).

Much of the Badshot Formation is severely deformed by folding or cut by faults. The Formation conformably overlies the Hamill Group.

The Badshot is Lower Cambrian in age (Price, 1971). It occupies a similar stratigraphic level to that of the Donald Formation in the adjacent Dogtooth Range (Price and Simony, 1971).

Lardeau Group

The Lardeau Group in the study area consists of the Index and Broadview Formations (Price, 1971). The Lardeau Group is exposed in the study area primarily in the core of the Illecillewaet syncline and to a lesser extent in the core of the Ventigo syncline. Zwanzig (1973) estimates that there is about 3000 meters of Lardeau in this area of which the upper 1000 meters are Broadview Formation.

The lower Lardeau Group consists of lustrous phyllites and slates, black carbonaceous slates and phyllites, calcareous slates, phyllites and metasiltstones. Dark metalimestones and pale metaquartzite are also present. Andalusite-bearing schists and gneisses and quartz schists are found adjacent to the granitic stocks which intrude the Index Formation along the Tangier River. A gradational contact exists between the Lardeau Group and the underlying Badshot Formation (Wheeler, 1963).

The upper part of the Lardeau Group (Broadview Formation) consists of quartz-mica and quartz-chlorite schists, micaceous and chloritic metaquartzite locally gritty and feldspathic (Wheeler, 1963). There is a gradational contact between the upper and lower sections of the Lardeau (Wheeler, 1963).

The Lardeau Group has undergone contact metamorphism adjacent to the granitic stocks that have intruded the weak rocks of the Lardeau. It has also been regionally metamorphosed with the highest grade rocks adjacent to the Shuswap metamorphic complex and part of its mantle (Thompson, 1972).

The exact age of the Lardeau Group is uncertain but it certainly postdates the Lower Cambrian Badshot Formation. Wheeler (1970) places its upper limit as pre-Milford (Mississippian).

Intrusive Rocks

Granitic plutons of various sizes outcrop in the study area. They intrude the Lardeau Group in the Illecillewaet syncline and the Clachnacudainn Salient of the Shuswap metamorphic complex. The plutons consist of porphyritic hornblende granite characterized by phenocrysts of potash feldspar and sodic plagioclase (Wheeler, 1963). In some of these bodies a crude concentric foliation is revealed by the arrangement of hornblende crystals (Wheeler, 1963). The plutons which are exposed in the Tangier River area, have been dated as Middle Jurassic at 168 m.y. (K-argon on biotite, Lowden, 1963) and 164 m.y. (K-argon on hornblende, Wanless et al, 1972).

Gilman (1972) reports a grey gneiss that varies in composition from granodiorite to quartz diorite. It is exposed near the mouth of Woolsey Creek but is otherwise overlain by units of the Lardeau and Hamill Groups (Zwanzig, 1973). The upper contact may be faulted or intrusive (Zwanzig, 1973). The origin of the rock is uncertain (Zwanzig, 1973) but the gneiss may represent a large, highly deformed intrusive body or it may be a tectonic wedge of Hudsonian basement rocks (Ross, 1970).

Economic Geology

The most important mineral deposits in the area are the lead-zinc deposits which occur in the Lardeau Group and in the Badshot Formation. Many of these deposits have been worked in the past but none are in production today. Minor copper and gold showings also occur in the map area but are of little significance.

Vein and replacement deposits are the normal mode of occurrence for the lead-zinc deposits (Wheeler, 1963, 1965). The limestones of the Badshot Formation act as a host for replacement deposits (Wheeler, 1965). A summary of the major deposits is given in Table 2. The locations are plotted in Figure 3.

Structurally the deposits are associated with the flanks of the major synclinal structure (Illecillewaet) in the study area.

TABLE 2

Description of Ore Deposits[2]

Name of Ore Deposit	Metals	Habit	Sulphides	Comments
Mastodon	Zn, Cd, Pb, Ag	Replacement	Sphalerite, galena	In Lower Cambrian limestone and dolomite.
Lead King	Zn, Pb	Replacement	Sphalerite, galena	In Lower Cambrian dolomite.
Little Slide	Zn, Pb, Cu	Vein and Replacement	Sphalerite, galena, chalcopyrite	In quartz and limestone.
J and L	Zn, Pb, Cu, Au, Ag	Vein and Replacement	Sphalerite, galena, arsenopyrite, pyrite, chalcopyrite	Along a shear zone at or near a schist/limestone contact (Lardeau).
A and E	Zn, Pb	Vein and Replacement	Pyrite, sphalerite, galena, pyrrhotite	Partly in limestone or marble.
Woolsey Mine	Zn, Pb, Cu	Vein	Pyrite, sphalerite, galena, chalcopyrite, pyrrhotite	Developed in quartz vein.
Lanark Mine	Pb, Ag, Au	Vein	Pyrite, sphalerite, galena, copper	Developed in quartz vein at contact of Lardeau limestone and overlying slate.
Snowflake and Regal	Pb, Zn, Ag, Cu, Sn, W	Vein	Galena, sphalerite, pyrite, chalcopyrite, scheelite, stannite	In graphitic, siliceous schist and limestone of the Lardeau Group.
Allco	Ag, Pb, Zn, Au	Vein and Replacement	Galena, sphalerite pyrite	In post Lower Cambrian limestone (Lardeau Group) near contact with overlying slate.
George	Zn, Pb	Vein	Pyrite, sphalerite, galena	Developed in quartz vein.

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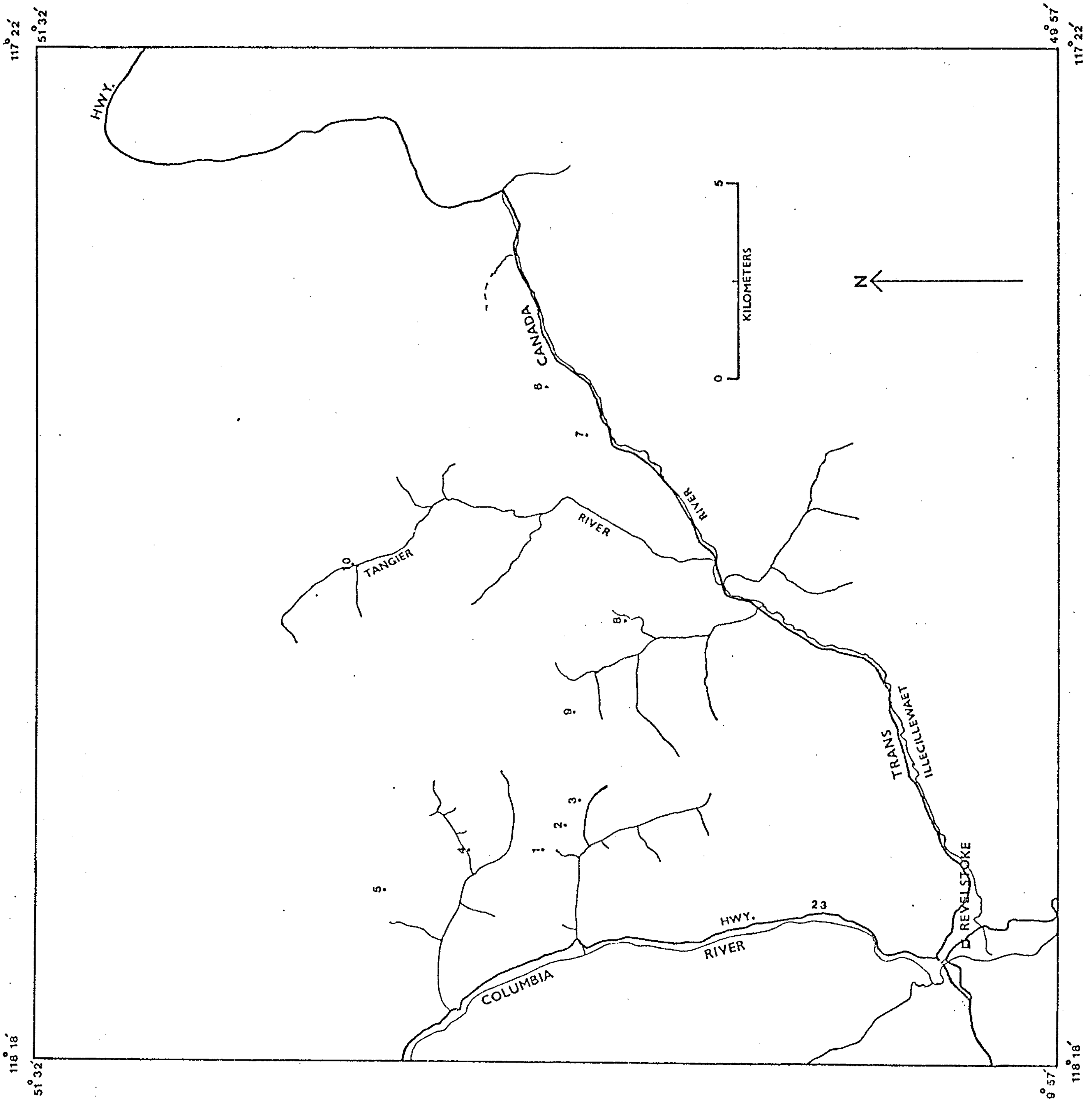
[2] Compiled from Wheeler (1963, 1965) and B.C. Dept. of Mines *Mineral Deposit* - *Land Use Maps*

Figure 3.

Location of ore deposits.



SECTION 3

ANALYTICAL TECHNIQUES, RESULTS AND STATISTICAL EVALUATION

Copper, zinc and lead concentrations were measured by atomic absorption. Whole rock analyses were obtained by atomic absorption and x-ray fluorescence spectrophotometric methods. The precision was estimated to be ±15 parts per million (ppm) for copper, zinc and lead concentrations (oral communication, University of Manitoba, Department of Earth Sciences technical staff). Consequently the results are only semi-quantitative.

Eighty-nine samples were analyzed for the three trace metals. Five of the samples were analyzed for total element content. Sample descriptions and locations are listed in the Appendix.

Samples were prepared for trace metal analysis by means of a hydrofluoric-sulphuric acid dissolution. The analyses were performed on a Perkin-Elmer 303 atomic absorption spectrophotometer.

Results

Copper, zinc and lead concentrations for the eighty-nine rock samples are listed in Table 3. Whole rock analyses for five rock samples are listed in Table 4. Locations and sample descriptions are listed in the Appendix.

TABLE 3

Trace Metal Content of the Rock Samples (in ppm)

No. of Sample	Cu	Zn	Pb	No. of Sample	Cu	Zn	Pb	No. of Sample	Cu	Zn	Pb
1	13	41	0	31	29	40	5	61	12	1	0
2	12	52	18	32	34	48	9	62	9	5	9
3	55	79	3	33	19	3	0	63	11	33	18
4	42	66	7	34	19	1	0	64	9	31	19
5	25	1900	400	35	8	5	0	65	19	65	11
6	25	7720	17	36	15	5	0	66	35	69	14
7	62	74	0	37	12	7	0	67	10	64	15
8	28	83	7	38	5	1	9	68	15	35	14
9	123	78	11	39	35	55	18	69	14	0	0
10	37	109	15	40	11	2	2	70	14	5	15
11	20	70	43	41	35	81	7	71	10	12	2
12	41	135	11	42	9	126	2	72	11	40	6
13	18	11	0	43	17	11	8	73	31	36	0
14	4	18	11	44	10	96	7	74	42	35	0
15	60	355	0	45	12	73	17	75	29	64	41
16	10	48	0	46	8	46	27	76	97	300	0
17	63	5	0	47	22	53	0	77	75	350	12
18	7	37	0	48	35	74	6	78	92	365	12
19	17	44	0	49	26	64	11	79	26	109	16
20	4	5	0	50	18	23	0	80	6	1	0
21	43	136	9	51	31	45	9	81	44	86	0
22	4	57	0	52	12	114	10	82	6	21	0
23	25	94	18	53	28	67	20	83	6	6	2
24	22	65	5	54	83	54	16	84	23	58	0
25	7	9	0	55	6	5	7	85	31	99	18
26	36	118	3	56	6	1	0	86	27	113	12
27	15	105	5	57	12	27	46	87	9	108	0
28	12	52	11	58	43	103	15	88	47	111	10
29	19	240	2	59	40	68	7	89	20	86	0
30	21	73	0	60	16	4	0				

TABLE 4

Total Rock Chemistry (in %)

Sample No.	63	64	65	66	67
SiO_2	68.90	74.05	62.45	61.85	71.40
Al_2O_3	16.06	13.64	15.08	16.37	15.04
Fe_2O_3	2.46	1.04	6.26	6.47	2.00
FeO	-	-	-	-	-
MgO	0.95	0.38	2.18	1.63	0.16
CaO	2.30	1.38	4.80	5.30	0.63
Na_2O	2.88	3.04	3.20	4.66	3.50
K_2O	4.18	4.49	2.60	1.82	5.72
H_2O^+	0.55	1.30	1.53	0.85	0.58
CO_2	0.11	0.36	0.37	0.18	0.20
TiO_2	0.30	0.26	0.69	0.74	0.25
P_2O_5	0.25	0.11	0.32	0.33	0.09
MnO	0.04	0.06	0.13	0.17	0.14
Total	99.99	100.11	99.61	99.37	99.71

Samples 5 and 6 display a zinc and lead content that is one to two orders of magnitude larger than that for other samples. Neither sample is included in the calculations as these two samples appear to be affected by an adjacent mineral deposit.

Statistical Evaluation

The trace metal data have been grouped on the basis of lithology and metamorphic type (see next section). Comparisons between populations are made by plotting the average concentrations. Histograms (number of samples versus ppm) have been drawn to display the trace metal distribution.

The density distribution patterns of histograms for geological data are often assumed to be of the normal pattern (Till, 1974). Ahrens (1954a, b) recognized that some trace element data display a log normal density distribution pattern. Kock and Link (1970) indicate that some geological data have a negatively skewed (mirror-image to a log-normal pattern) density distribution pattern.

Populations can be compared by constructing a null hypothesis (Mendenhall, 1974). Suchan hypothesis is a statement of no difference (Downie and Heath, 1965). The hypothesis usually takes the position that the mean of sample A is equal to the mean of sample B. This assertion merely states that as far as the trait being measured is concerned, the two samples come from the same population (Downie and Heath, 1965). The null hypothesis is stated so that it can be tested. The confidence level for accepting a null hypothesis in this study is 5% or less. If the null hypothesis is rejected then the two samples are said to represent two distinct populations and that the sample means differ significantly (Downie and Heath, 1965).

Common parametric statistical tests for the comparison of populations cannot be used as such tests require that the distribution of the population is known (usually normal) and that the variances of the population being compared are equal or of a known ratio (Till, 1974). Neither of the conditions are met by the results of the study.

Populations are compared in this study by a non-parametric test which does not require prior knowledge of the above two conditions (Till, 1974). The non-parametric statistic that has been used is the Mann-Whitney U test. It has been applied as described by Downie and Heath (1965).

The Mann-Whitney U statistic tests the hypothesis that the two samples in question both come from the same population. The statistic is a one tailed test, with the alternative hypothesis being that one sample contains higher values than the other (Till, 1974).

The next section displays the trace element data graphically. A later section will compare the populations using the Mann-Whitney U statistic.

SECTION 4

TRACE ELEMENT DISTRIBUTION

The data has been assembled according to recognizable groupings, these being lithostratigraphy, lithology and metamorphic type. The number of samples in each grouping is indicated in parenthesis on the variation diagrams.

Trace Metal Distribution as Related to Lithostratigraphy

Figure 4 displays the average copper, zinc and lead content of the lithostratigraphic (map) units. Copper displays some variance between lithostratigraphic units. The range for copper is from 15 ppm for the Badshot Formation to 34 ppm for the Lardeau Group. Zinc content varies greatly between the units. The Badshot Formation has an average value of 4 ppm versus 82 ppm for the Lardeau Group. Lead values are quite constant from one unit to the next. The Badshot Formation has almost zero lead content. Granites have an average of 13 ppm.

Figures 5 to 7 are histograms representing number of samples versus metal content. Most of the histograms for copper show a log-normal distribution. Copper values for the Badshot Formation may have a log-negative distribution. Zinc histograms are generally normally distributed. The Hamill and Horsethief Creek Groups appear to be log-normal. Zinc values have a large variation in sample values within population groupings. Lead values appear to be distributed in a log-normal pattern. Little variation is observed between lead values from the same population.

Trace Metal Distribution in Specific Rock Types, as Related to Lithostratigraphy

Siltstones are common to both the Horsethief Creek and Lardeau Groups (Price, 1971). Copper shows almost no difference in content between these two units (Figure 8). The average zinc content varies considerably from 42 ppm for the Horsethief Creek Group to 58 ppm for the Lardeau Group. Lead varies only slightly between two units.

The histograms for copper and lead distribution are log-normal. The zinc isotope for the siltstones of both units has a normal distribution.

Phyllites and slates are common to four of the lithostratigraphic units (Horsethief Creek, Hamill and Lardeau Groups and the Shuswap paragneiss). Rock samples from the Shuswap paragneiss have the lowest average copper content (22 ppm). The Lardeau Group phyllites and slates have the highest average copper content (37 ppm).

Zinc values are very divergent between units. The Hamill Group has an average zinc content of 50 ppm whereas the average zinc content for the Lardeau is 110 ppm. Lead values vary between units only to a small degree (a range of 8 ppm).

The copper content of samples of phyllites and slates appear to show a log-normal distribution except for the Hamill Group which may have a log-negative pattern. Zinc values apparently have two distribution patterns (normal and log-normal). Lead values for all four units are distributed log-normally.

Trace Metal Distribution in Common Rock Types

The trace metal values of different rock types were compared. The rocks represent all stratigraphic units. This comparison was made to observe the trace metal values of the common rock types in the area.

Rock samples of phyllites have the highest copper values. Shales and phyllites have the highest zinc content. Trace lead values do not appear to be selectively concentrated in any of the rock types.

The three trace metals have a normal and log-normal histogram distribution. Zinc values are highly variable within populations. There were few anomalous lead values.

Trace Metal Distribution in Regionally Metamorphosed Rocks and their Pre-metamorphic Equivalents

The mantling paragneiss of the Shuswap complex in the vicinity of Albert Canyon represents a regionally metamorphosed section of the Selkirk Mountains Sequence (Ross, 1968). Rock samples of relatively unmetamorphosed rocks from the Selkirk Sequence are compared with samples of the paragneiss for their copper, zinc and lead content.

Copper displays some variation between rock types of different metamorphic gradient (Figure 18). Saltes and phyllites have a moderately higher average copper content than do schists and gneisses (33 to 22 ppm). Shales and siltstones are also higher in copper content than schists and gneisses (Figure 18). Zinc values are the highest in shales and siltstones (82 ppm). Slates and phyllites have a zinc content of 77 ppm and schists and gneisses have 63 ppm. Lead once again shows little variation between populations.

The histograms (Figures 19) for copper are distributed log-normally. All of the zinc histograms display a log-normal distribution pattern. The variation between samples from a single population is quite large. Lead values are also distributed log-normally. Lead values show little variability within one population.

Distribution of Trace Metals in Contact Metamorphosed Rocks

The copper, zinc and lead content of rock samples of the Lardeau phyllites that have undergone contact metamorphism adjacent to the granite plutons has been determined. Figure 22 is the histogram of the copper, zinc and lead values for these rocks.

Copper may be normally distributed. Its average value is 53 ppm. Copper values show a large variation between sample points. Zinc values appear to be normally distributed as well as having a large average value of 203 ppm (Figure 22). A large variation is observed between sample points. Lead values appear to be log-normal in distribution. The average value for lead is 15 ppm.

Summary of the Distribution

Generally the zinc content of the samples exceeded the copper content. Copper tended to be in greater abundance than lead.

The histogram distribution diagrams for copper, zinc and lead usually are log-normal or normal. A few plots may have been log-negative.

Copper and zinc showed a wide variation between populations. Lead varied very little from one population to the next. Within a single population zinc values have a large variation from one sample point to another. Copper values show only moderate scatter. Lead values have little variation between sample points.

Section 4 compared the average metal values of one population to another. The significance of the distinction made between populations will be tested statistically in the next section. Published data will be used to compare the results of this study.

Figure 4

Trace Cu, Zn, Pb Content in Rocks,
as Related to Lithostratigraphy

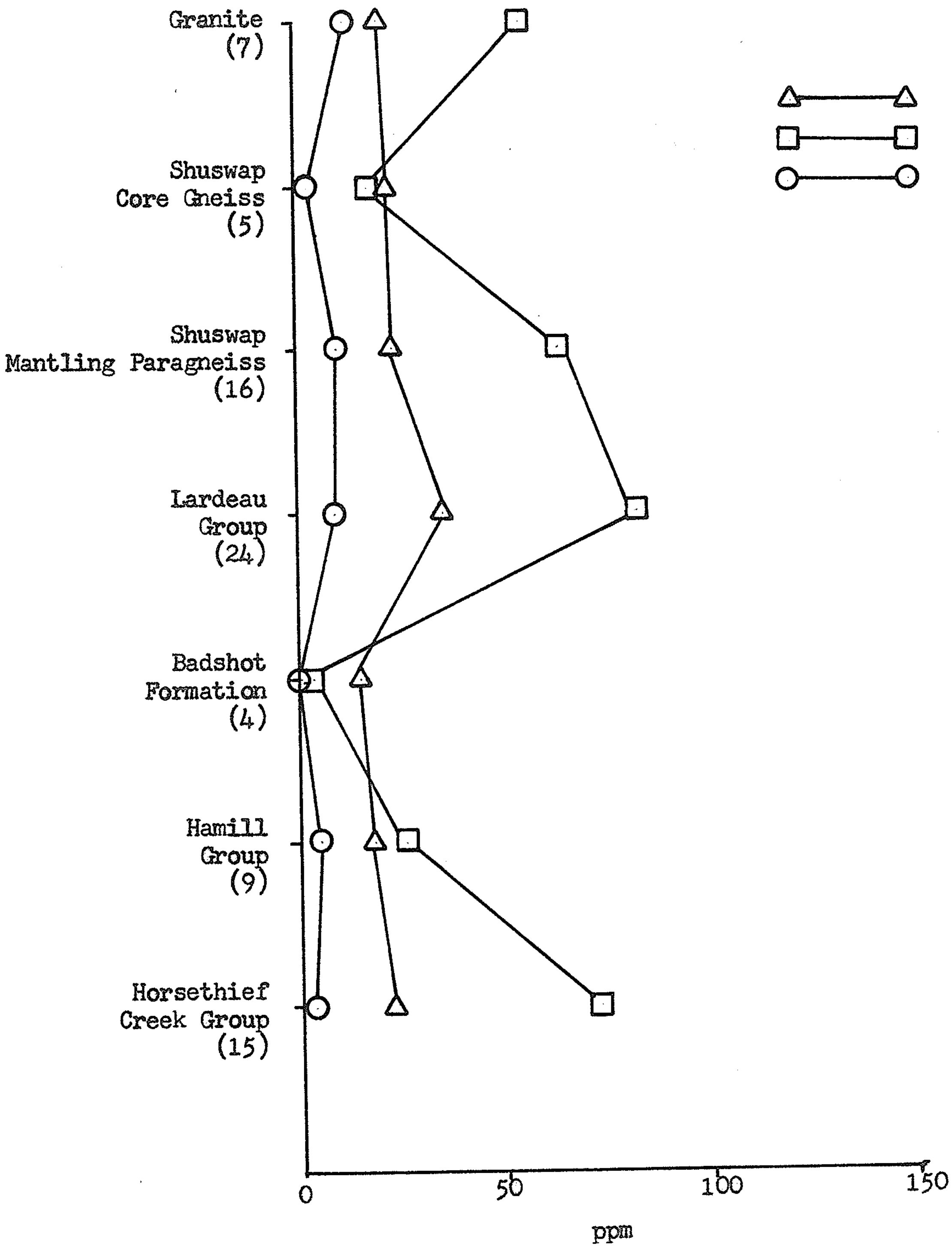


Figure 5 Trace Copper Content in Rocks, as Related to Lithostratigraphy

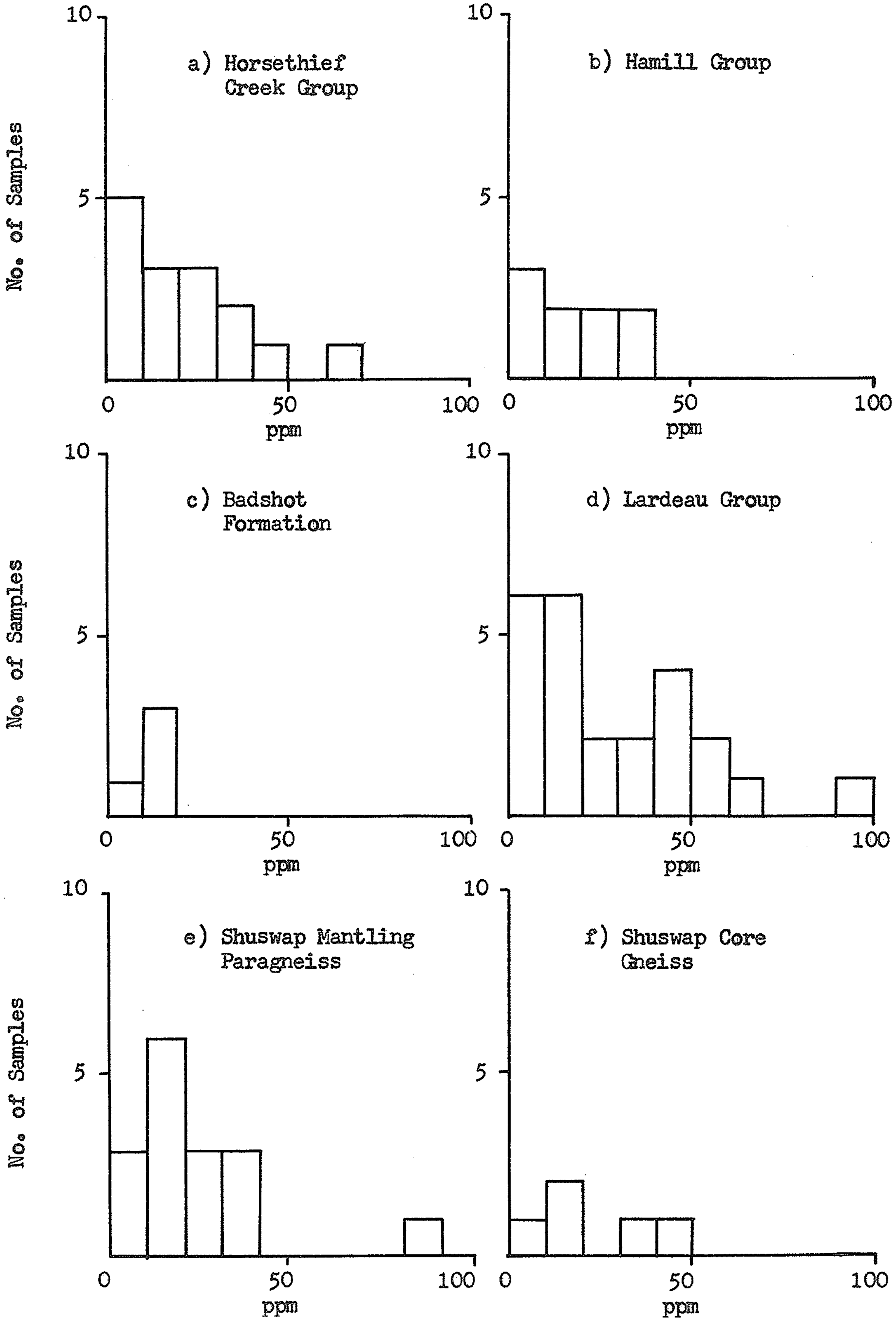


Figure 5 (cont) Trace Copper Content in Rocks, as Related to Lithostratigraphy

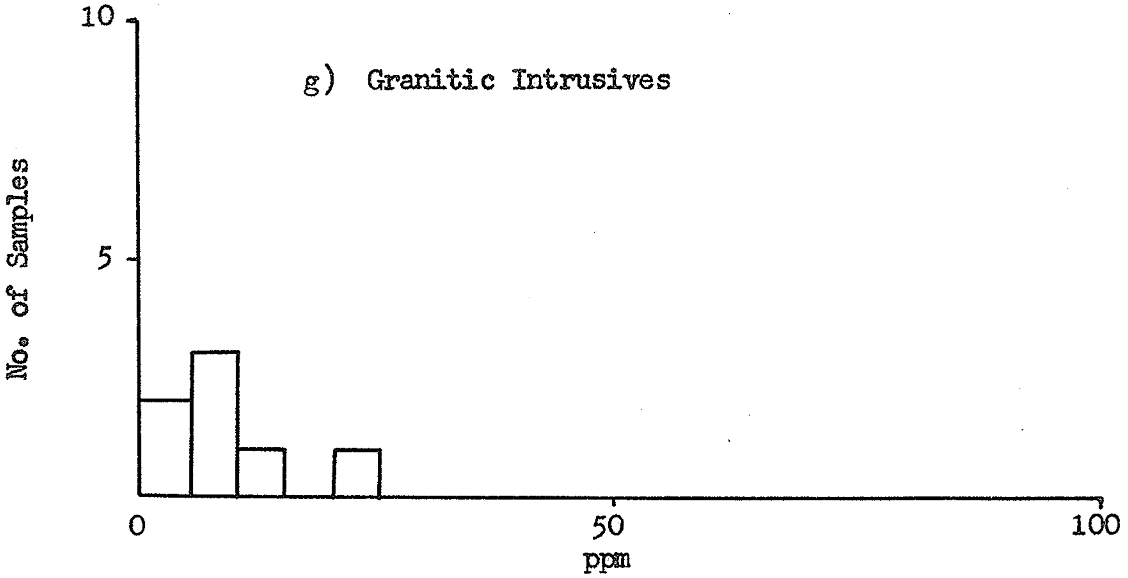


Figure 6 Trace Zinc Content in Rocks, as Related to Lithostratigraphy

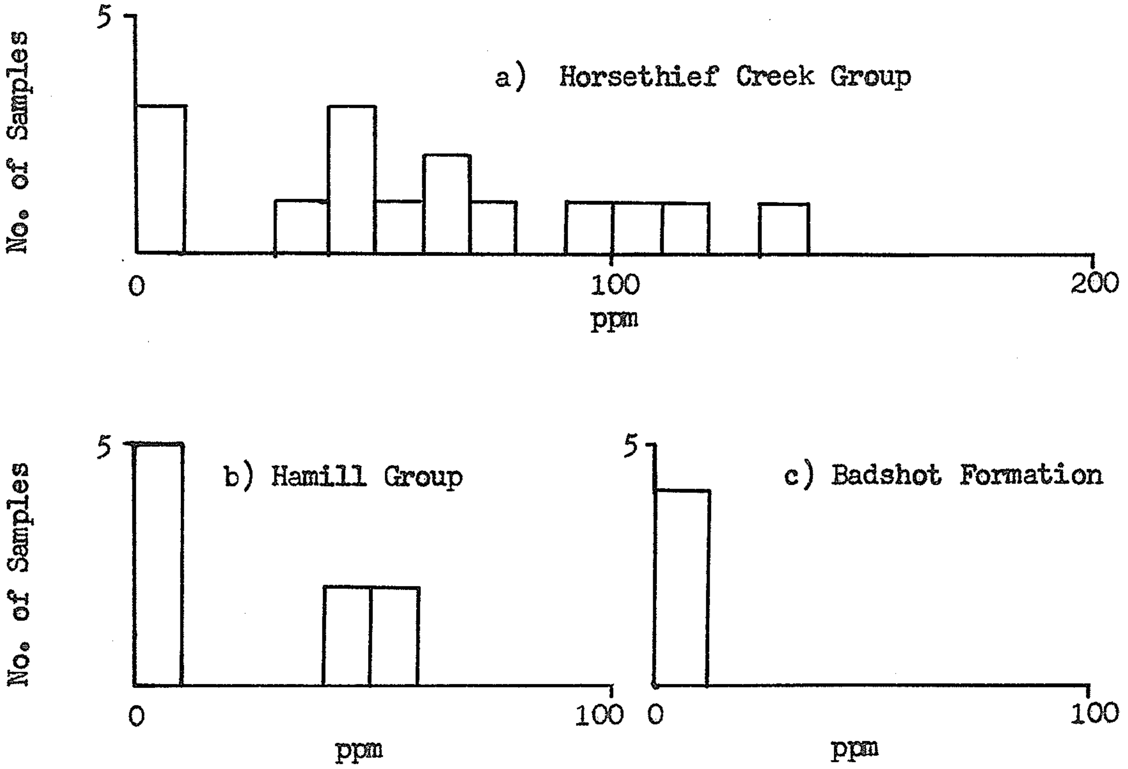


Figure 6 (cont) Trace **Zinc** Content in Rocks, as Related to Lithostratigraphy

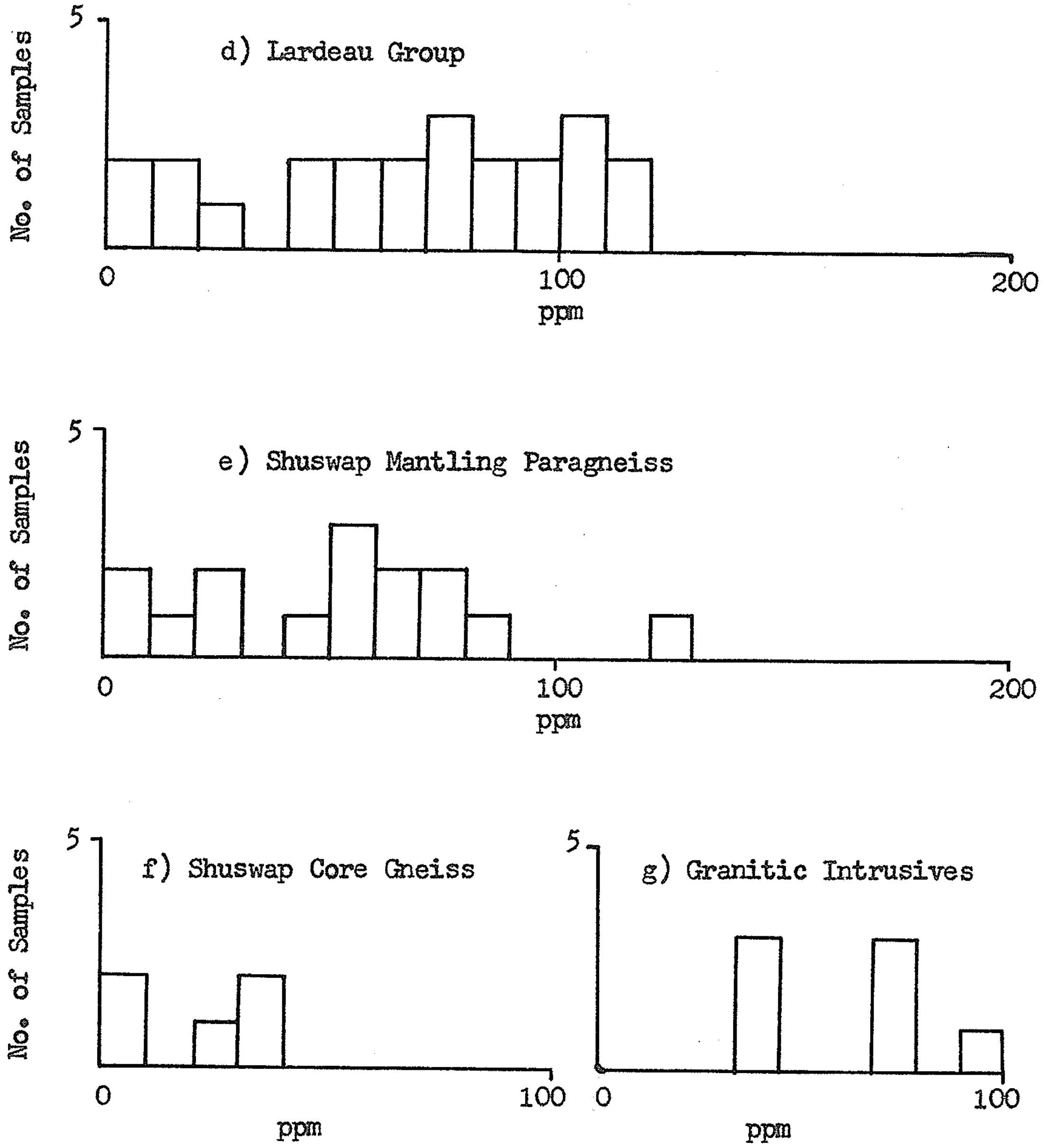


Figure 7 Trace Lead Content in Rocks, as Related to Lithostratigraphy

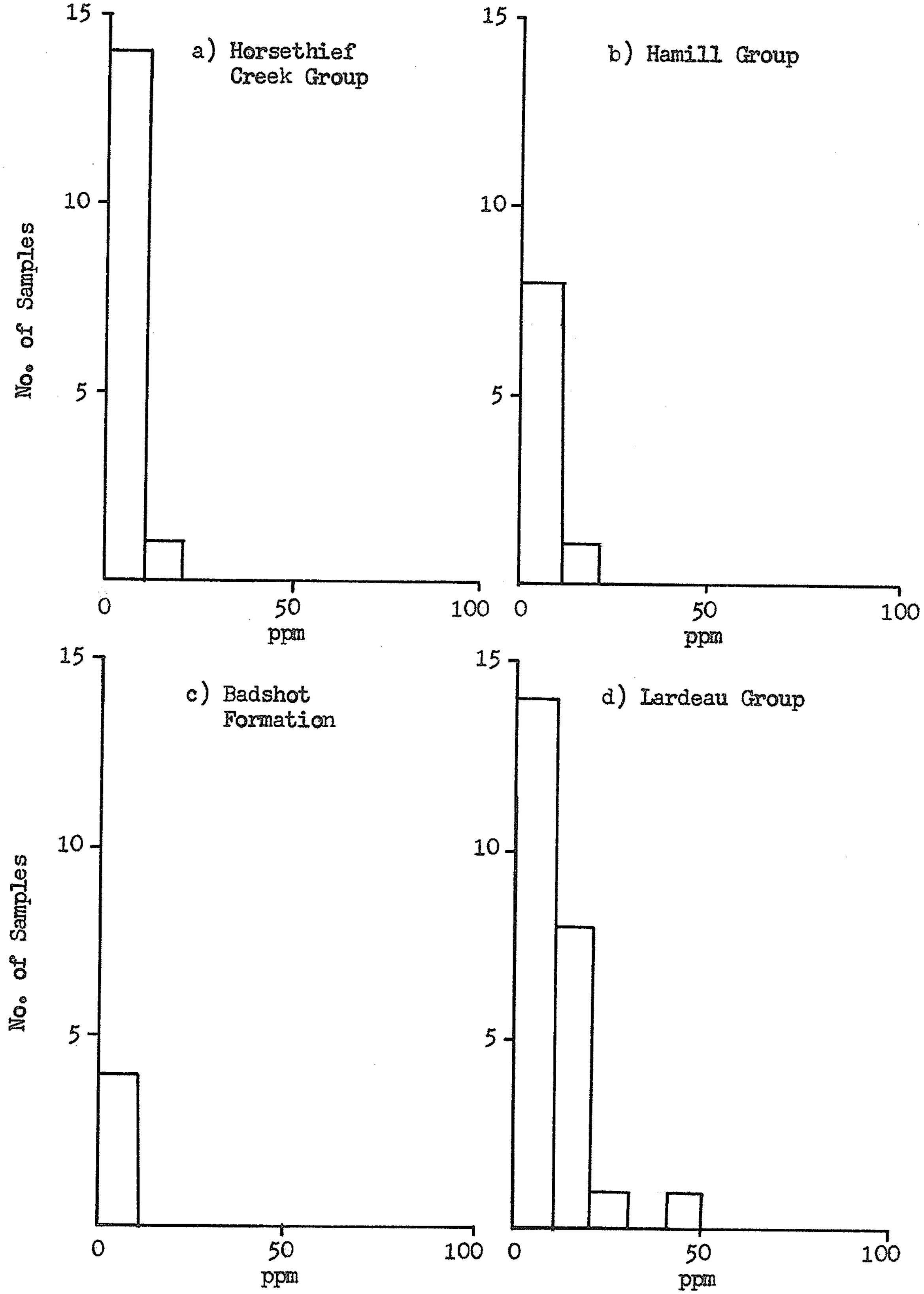


Figure 7 (cont) Trace Lead Content in Rocks, as Related to Lithostratigraphy

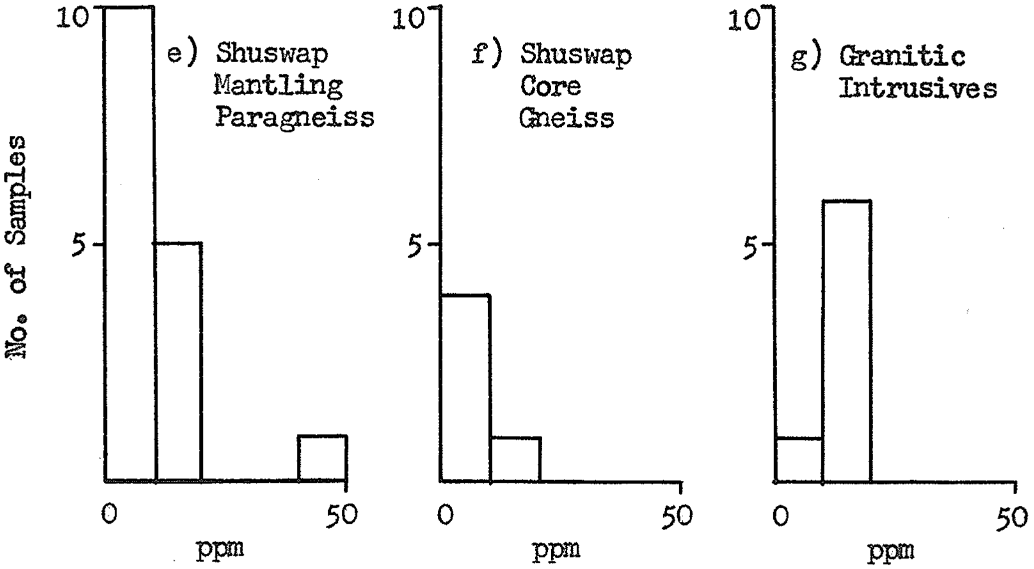


Figure 8 Trace Cu, Zn, Pb Content in Rocks, as Related to Lithostratigraphy

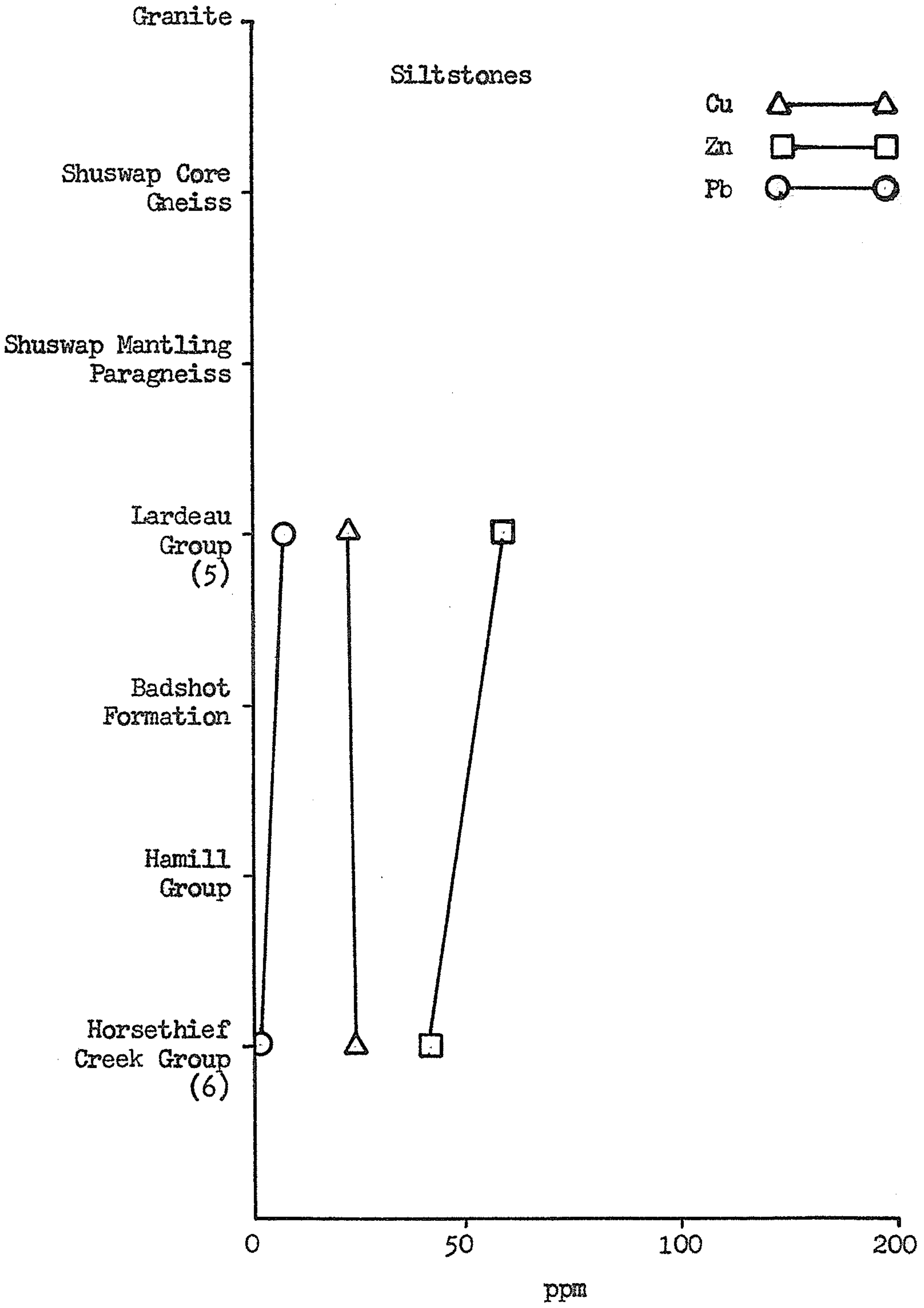


Figure 9 Trace Cu, Zn, Pb Content in Rocks, as Related to Lithostratigraphy

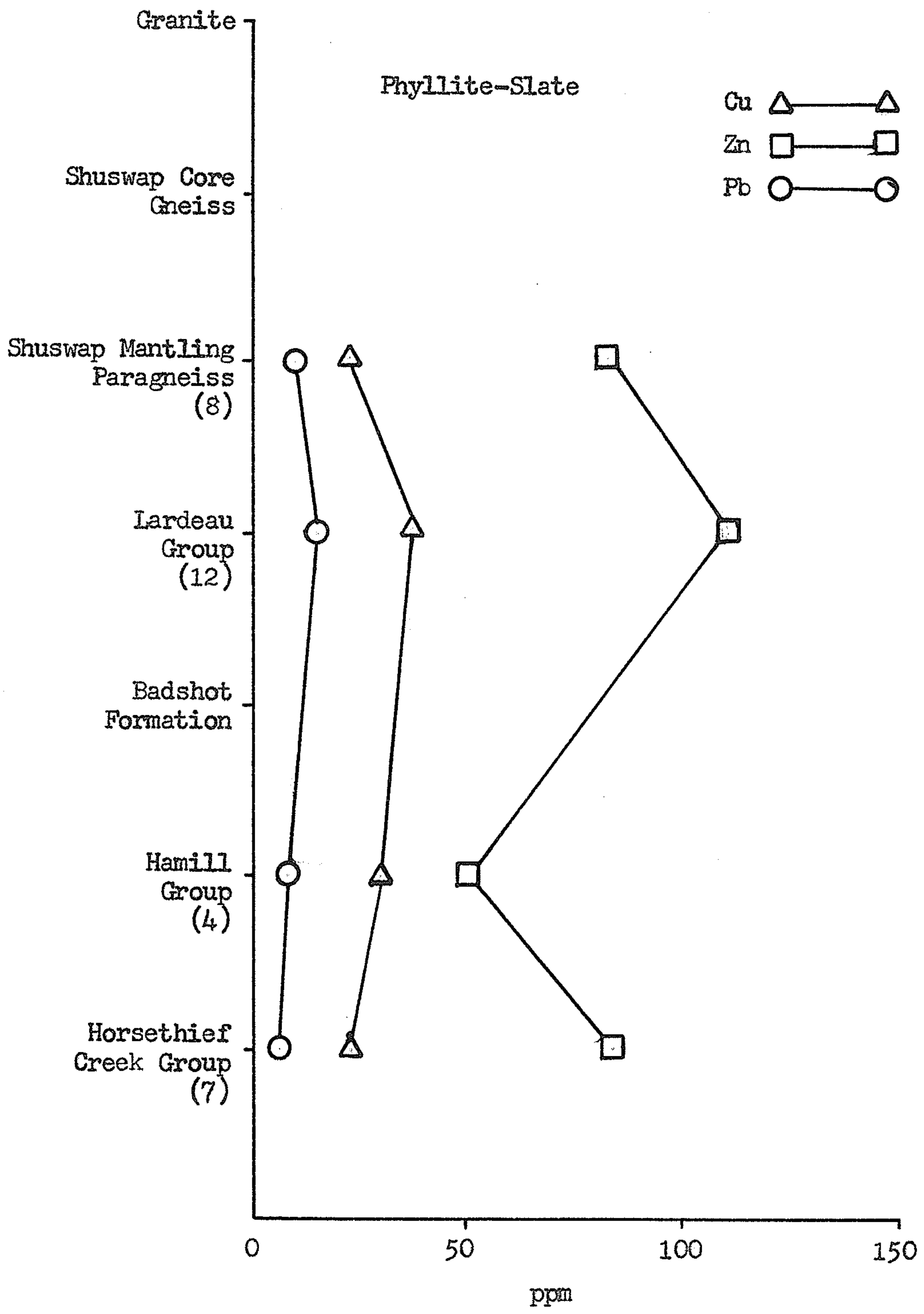


Figure 10 Trace Metal Content in Siltstones, as Related to Lithostratigraphy

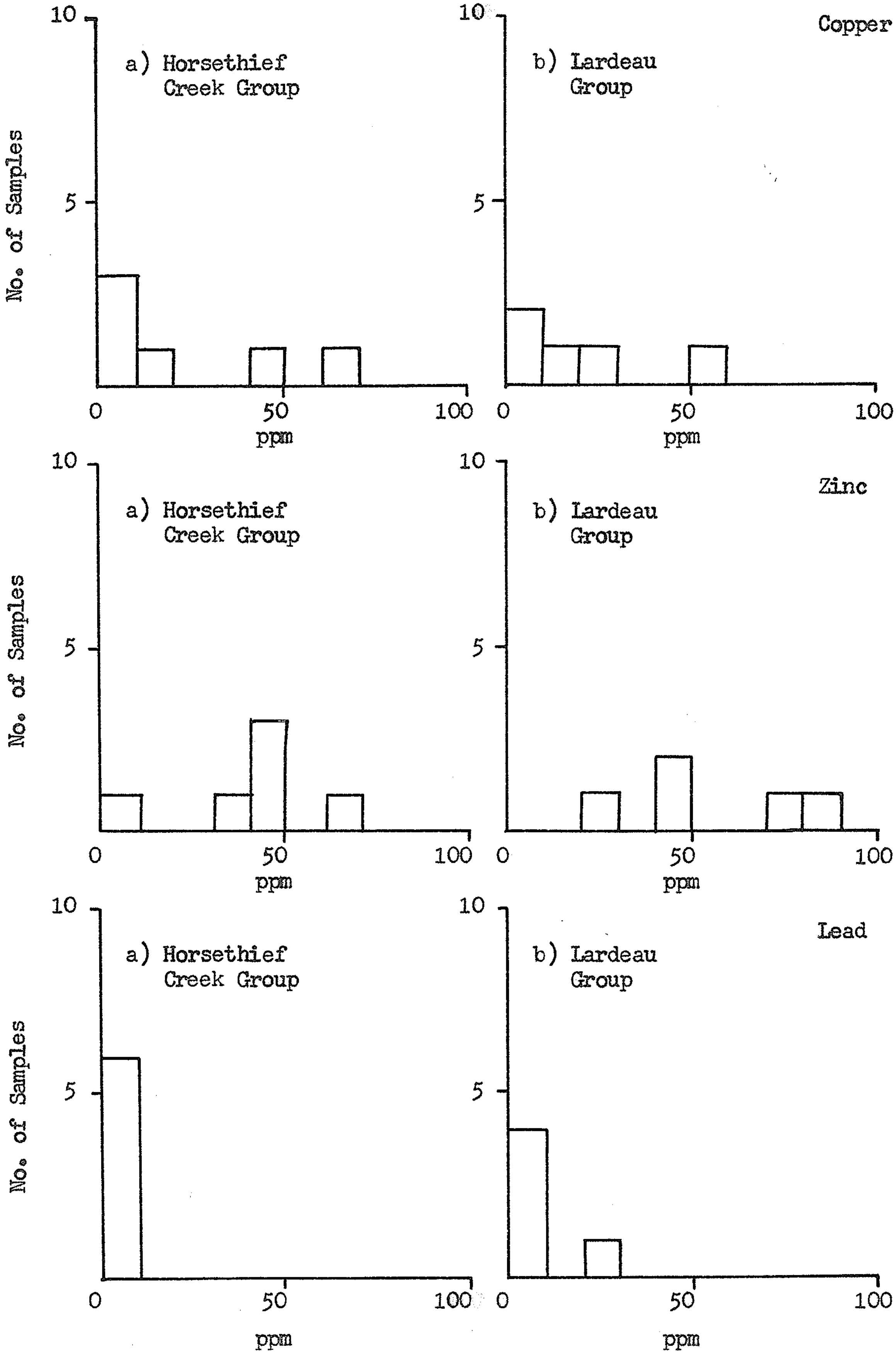
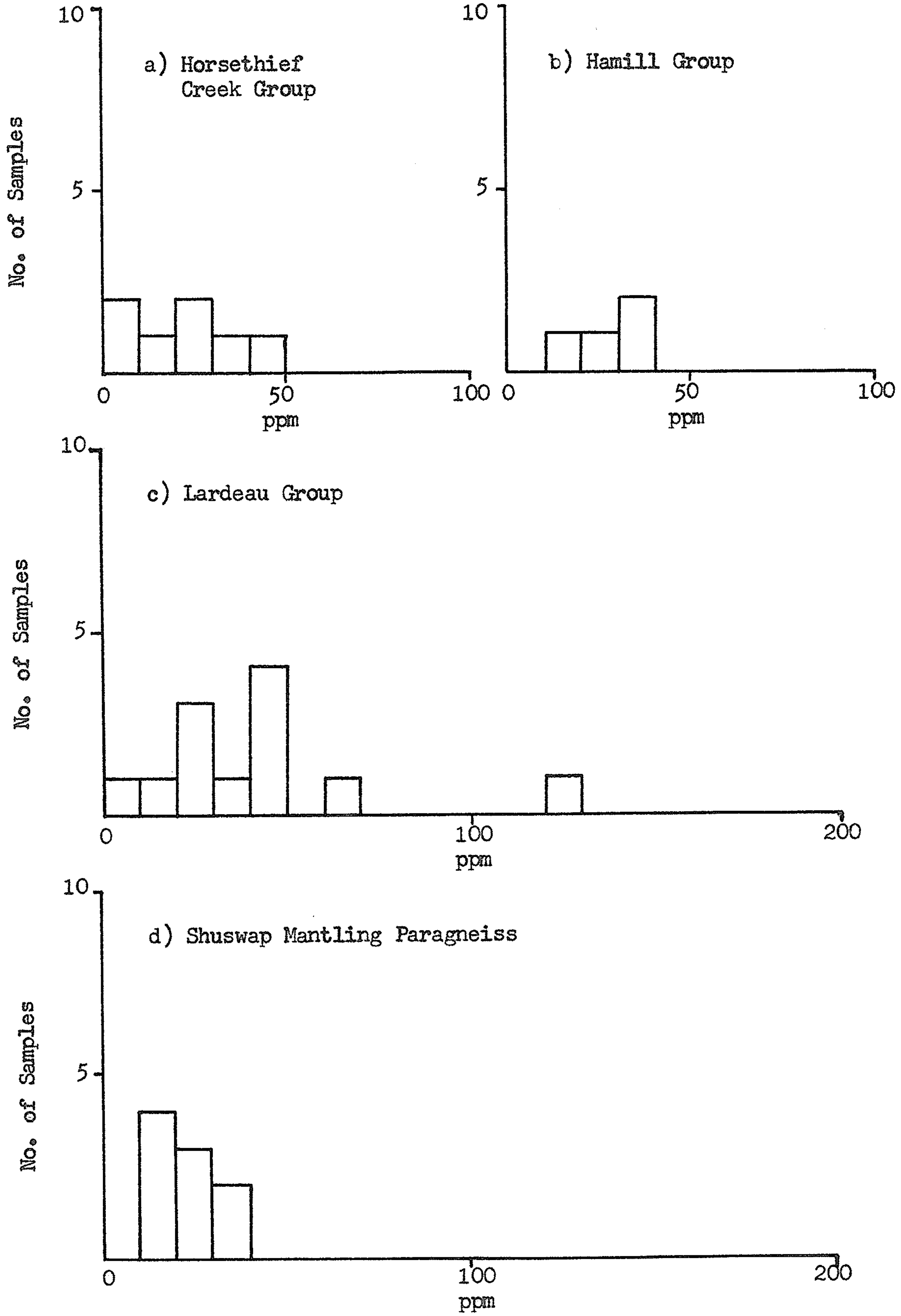


Figure 11 Trace Copper Content in Phyllites and Slates, as Related to Lithostratigraphy



as Related to Lithostratigraphy

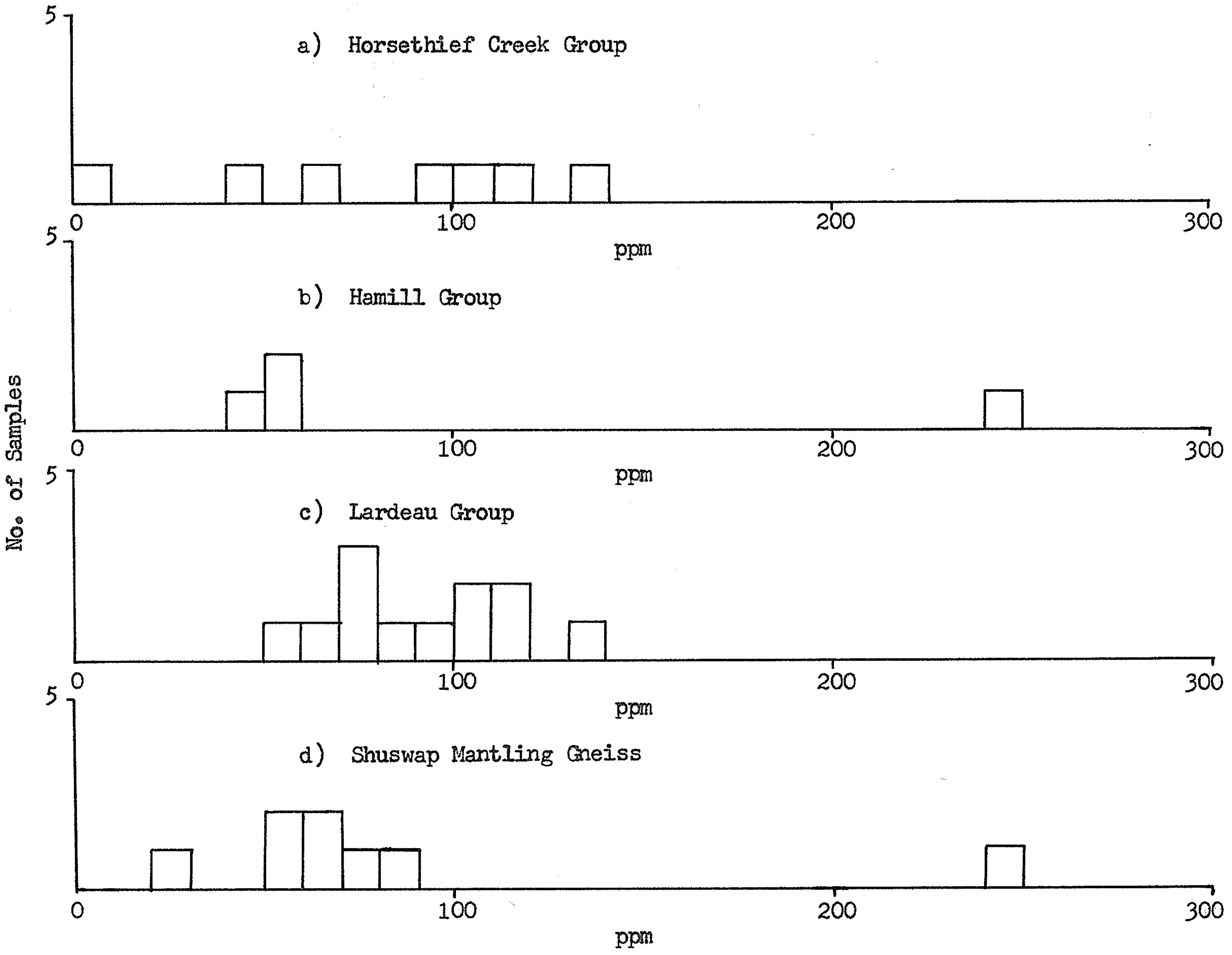


Figure 13 Trace Lead Content in Phyllites and Slates, as Related to Lithostratigraphy

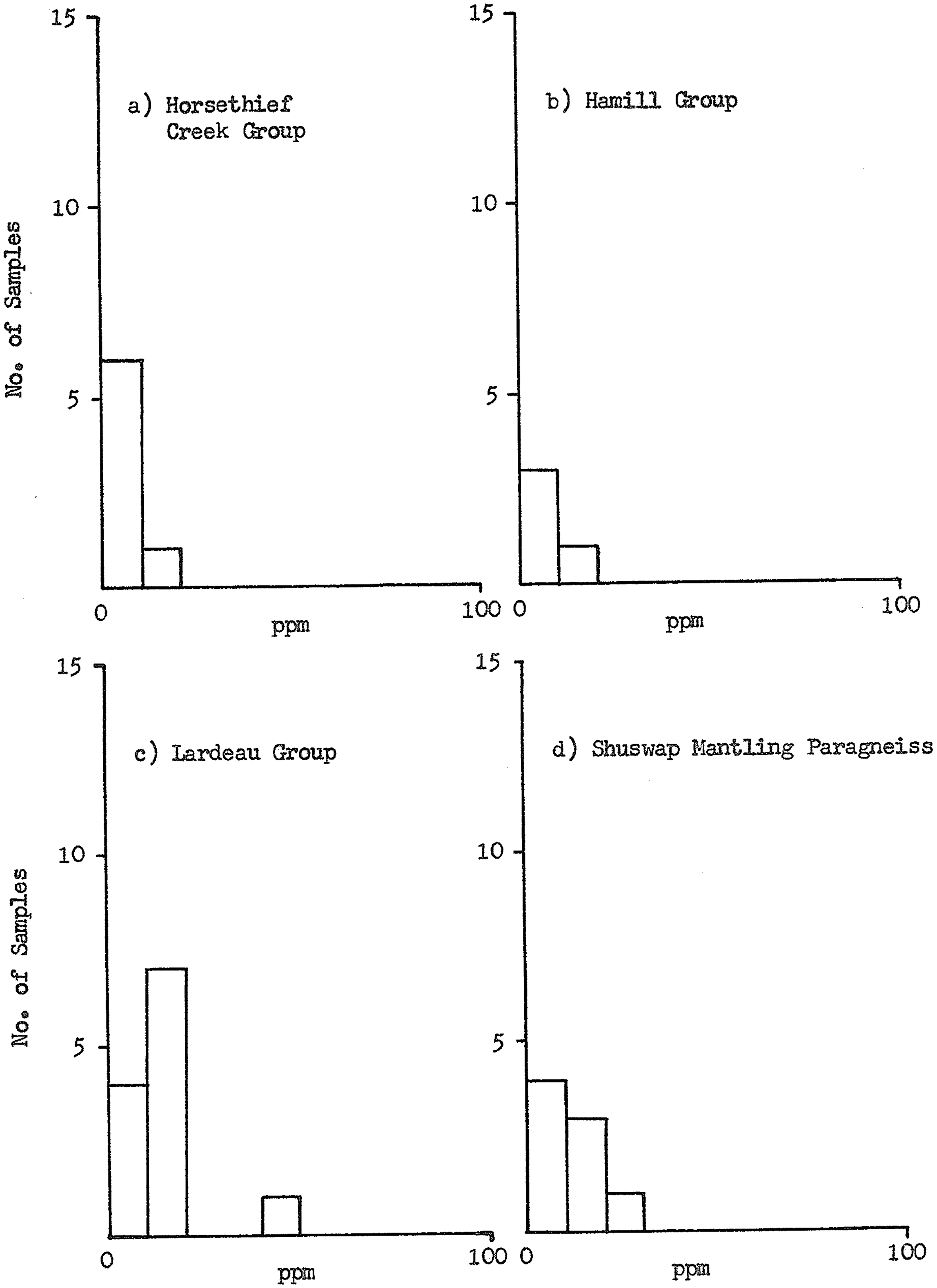


Figure 14 Trace Metal Content as Related to Lithology

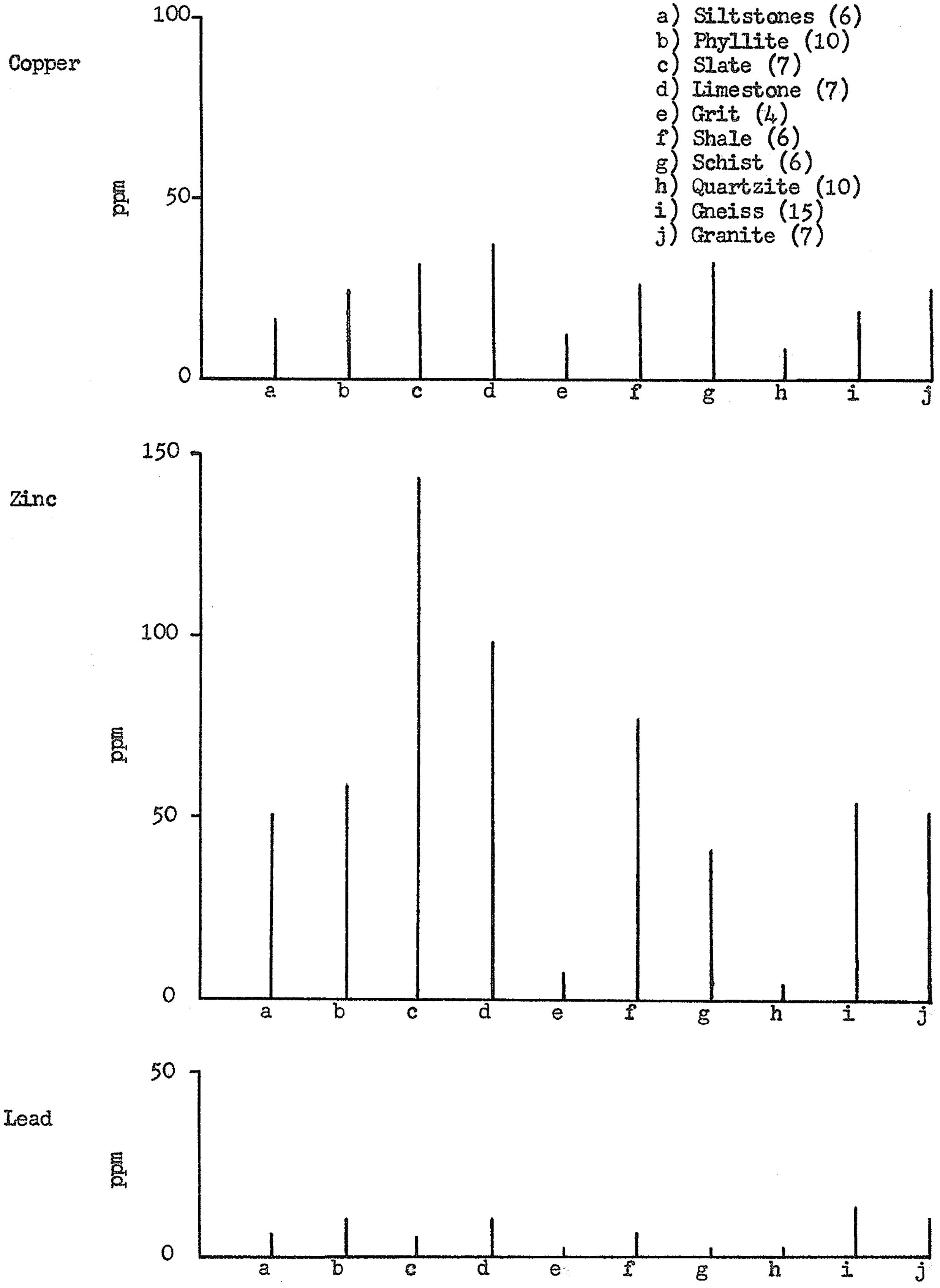


Figure 15 Trace <u>Copper</u> Content
as Related to Rock Type

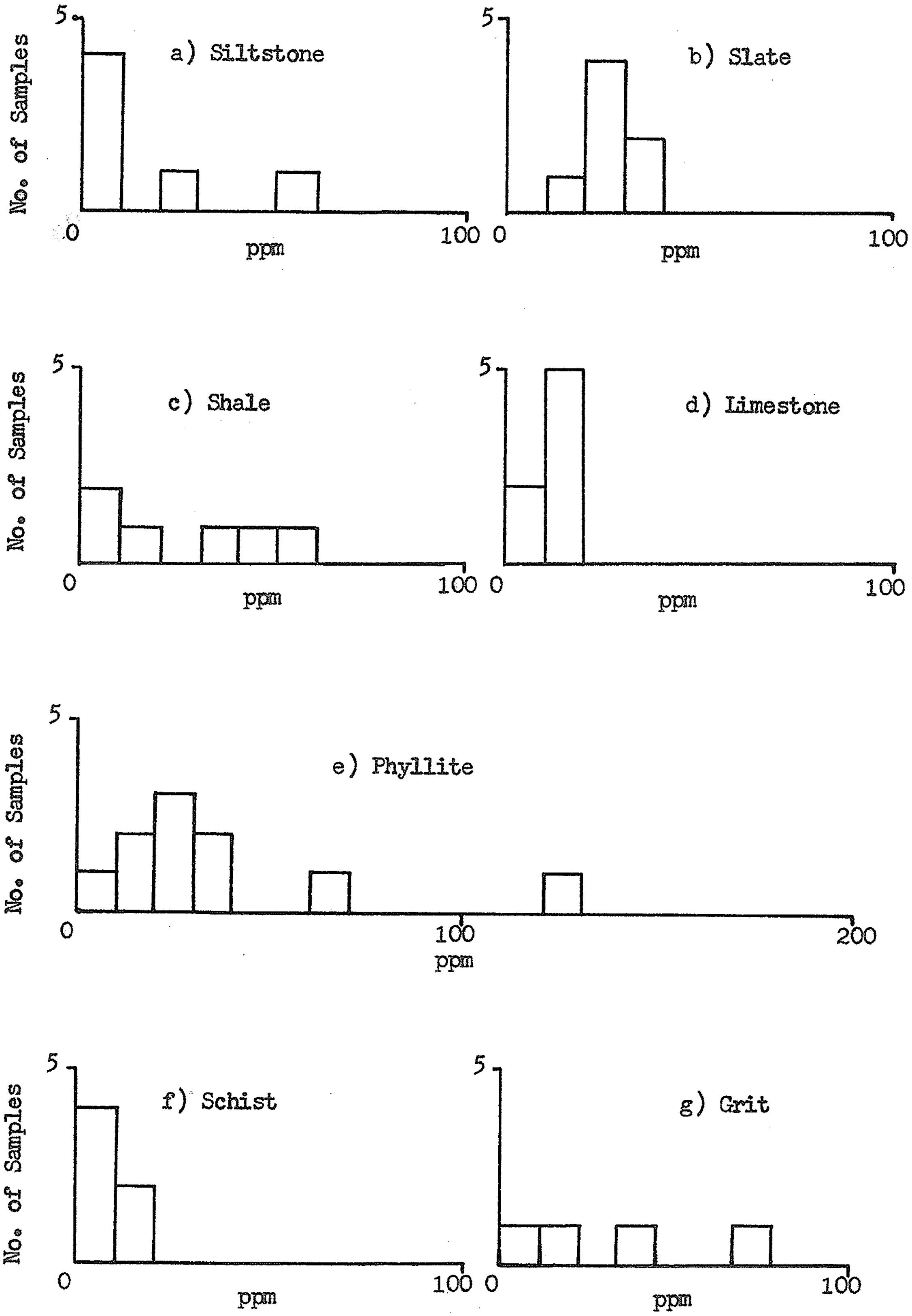


Figure 15
(cont)

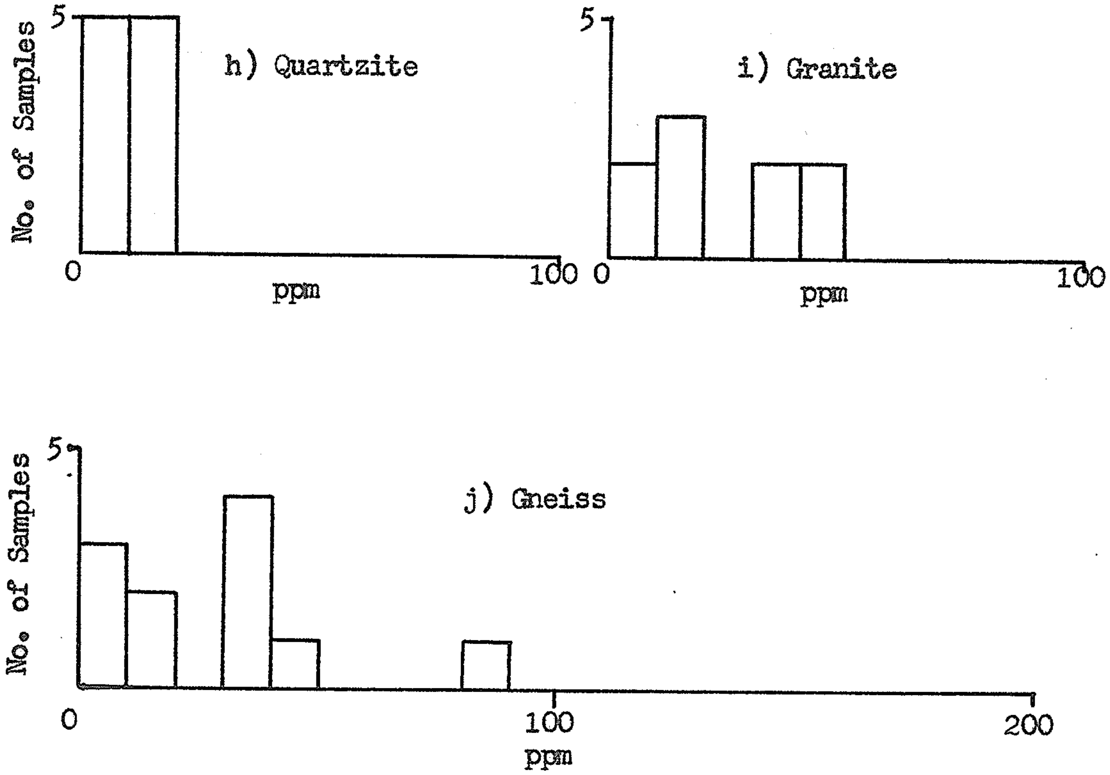


Figure 16

Trace Zinc Content,
as Related to Rock Type

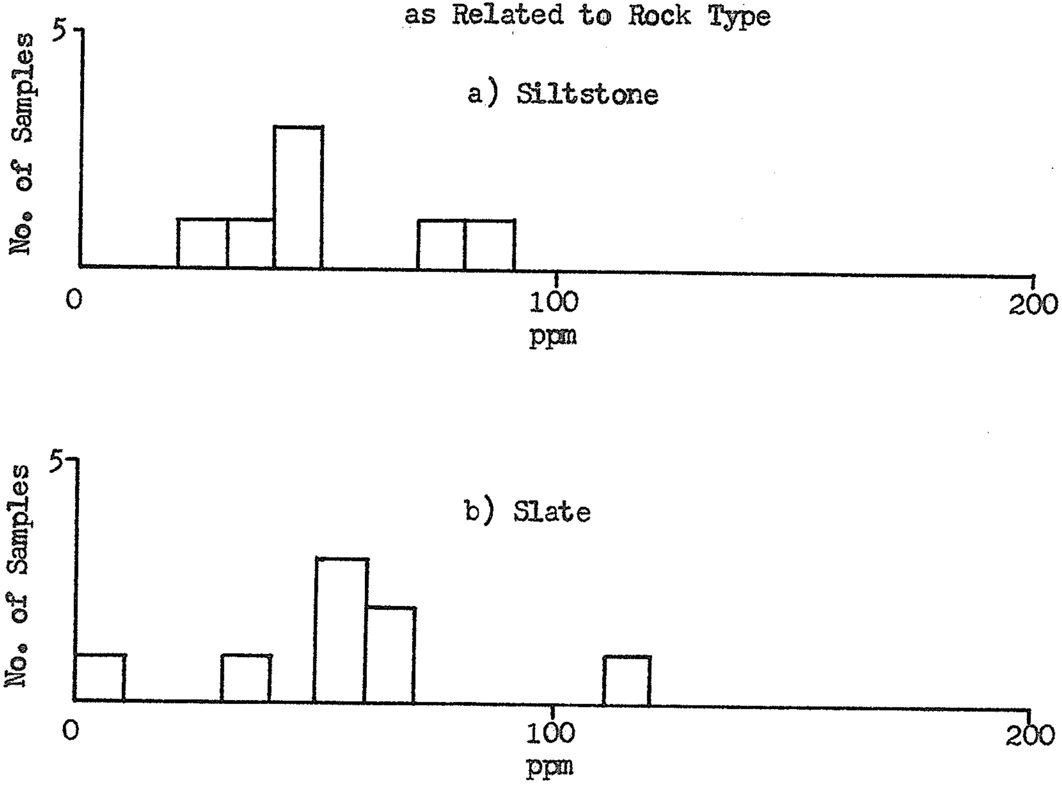


Figure 16
(cont)

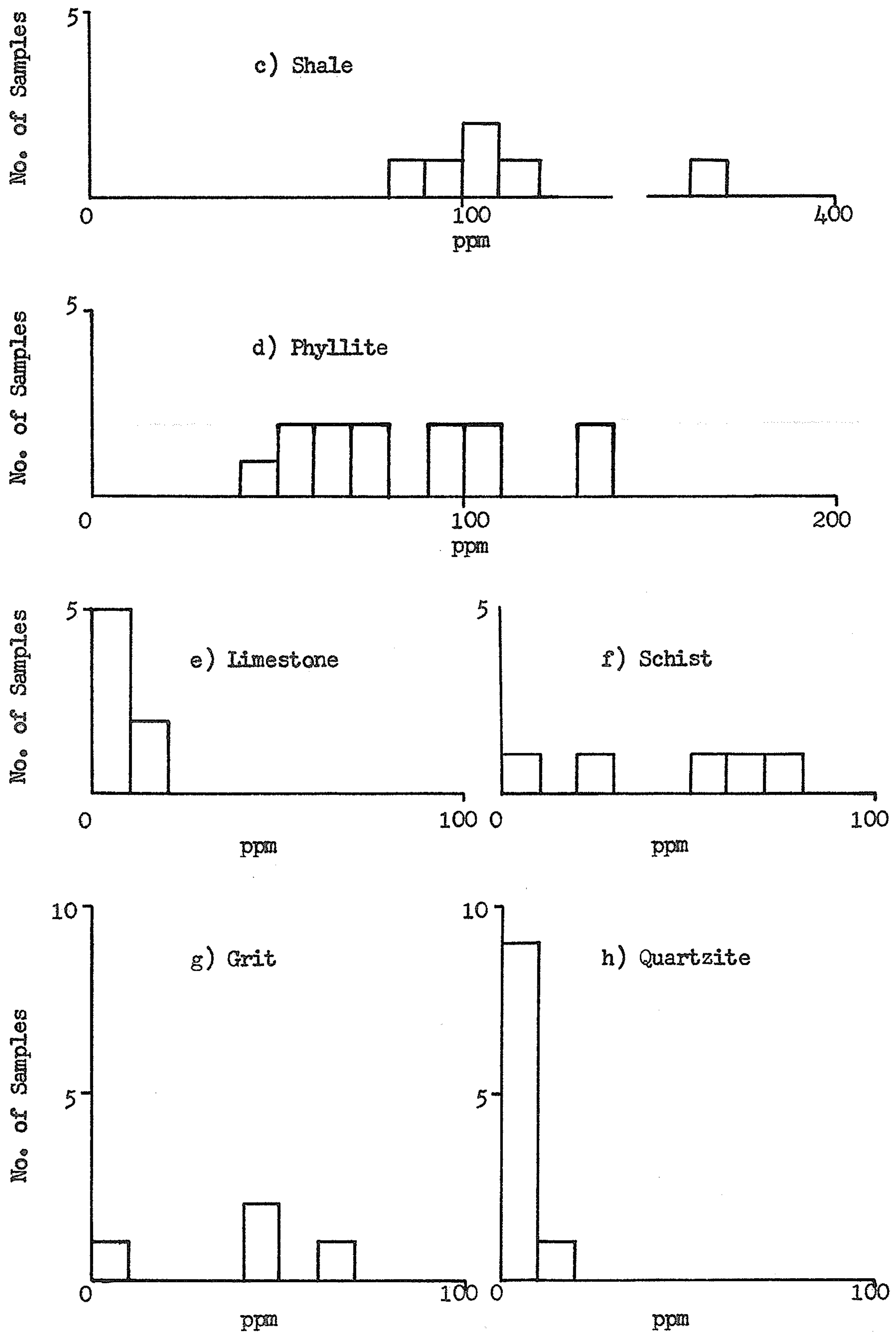


Figure 16
(cont)

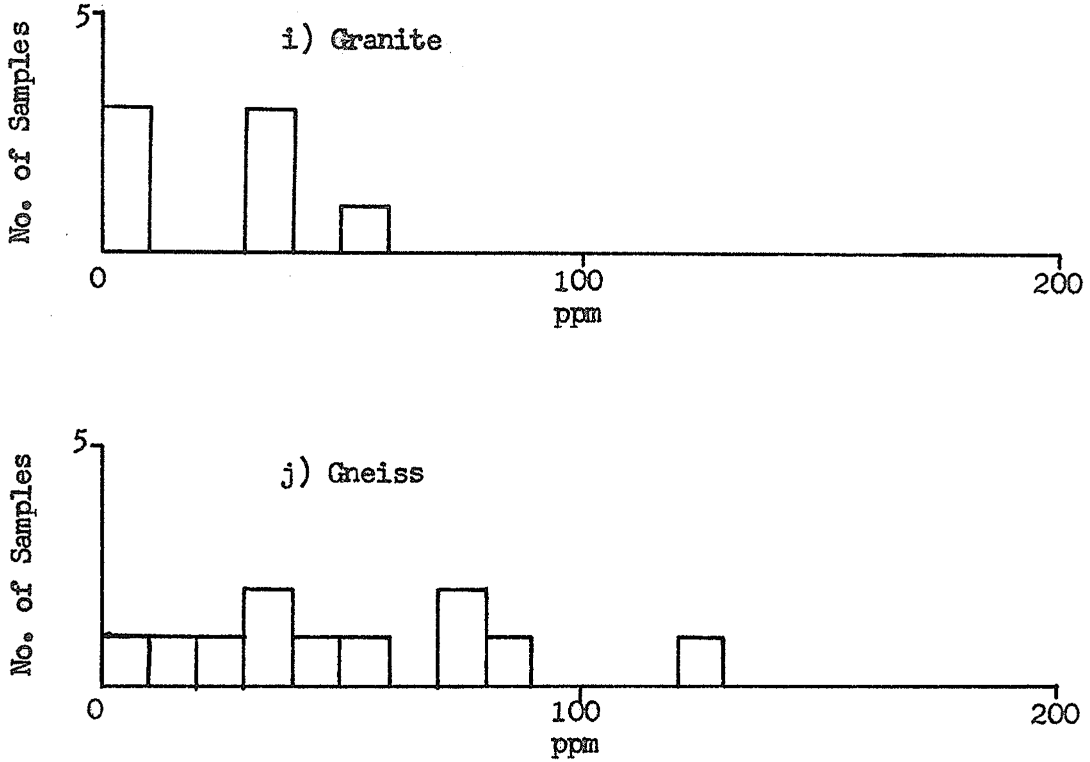


Figure 17 Trace Lead Content, as Related to Rock Type

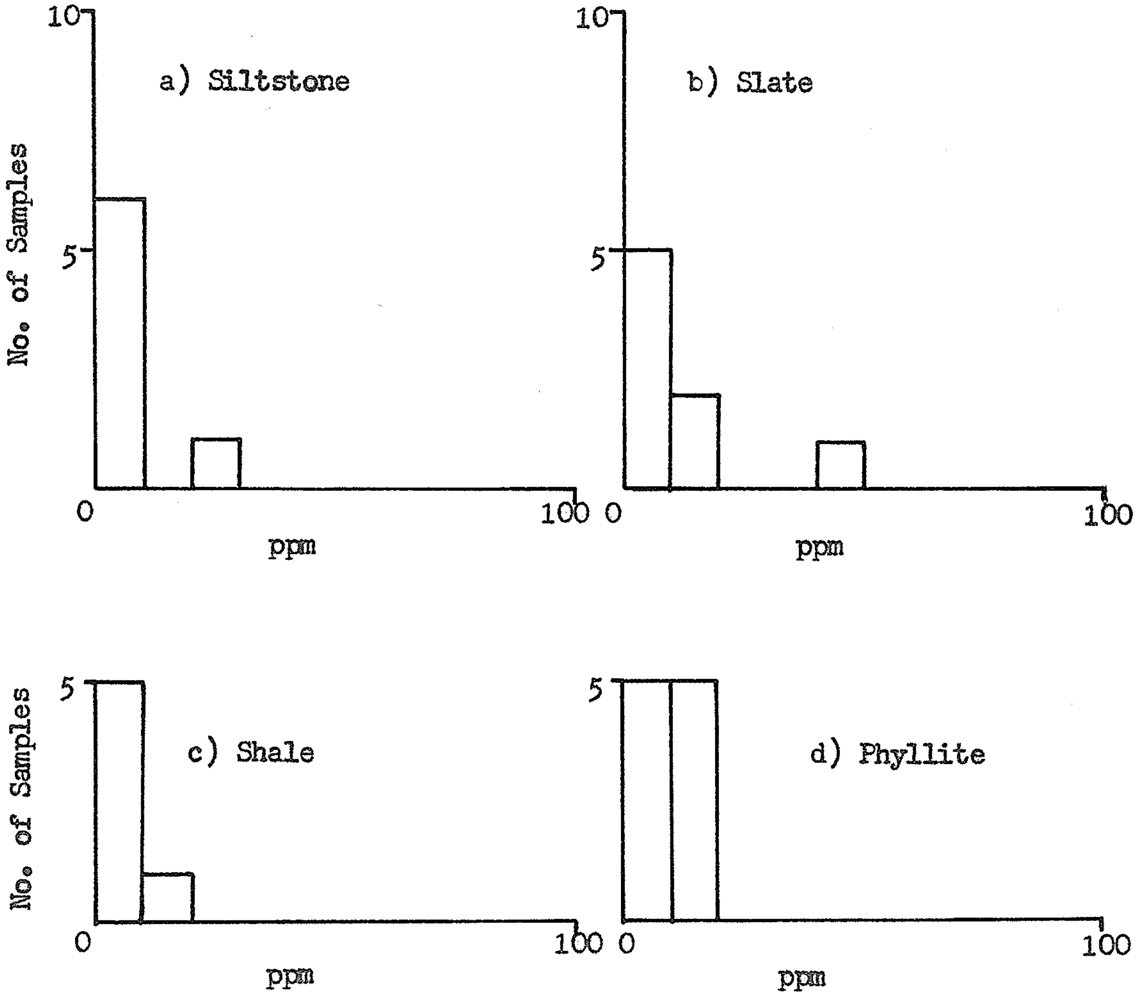


Figure 17
(cont)

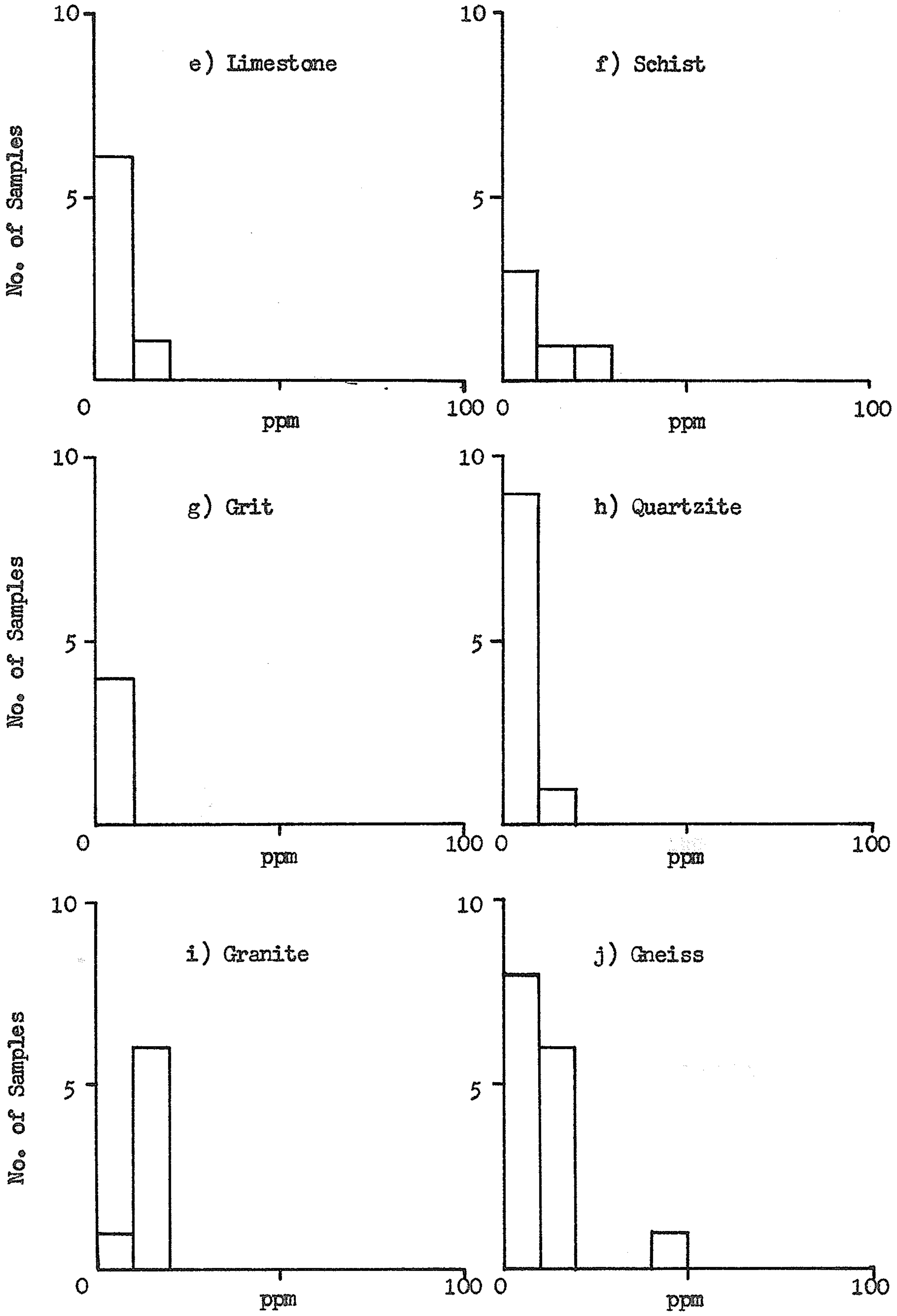


Figure 18 Trace Cu, Zn, Pb Content in Rocks as Related to the Intensity of Metamorphism

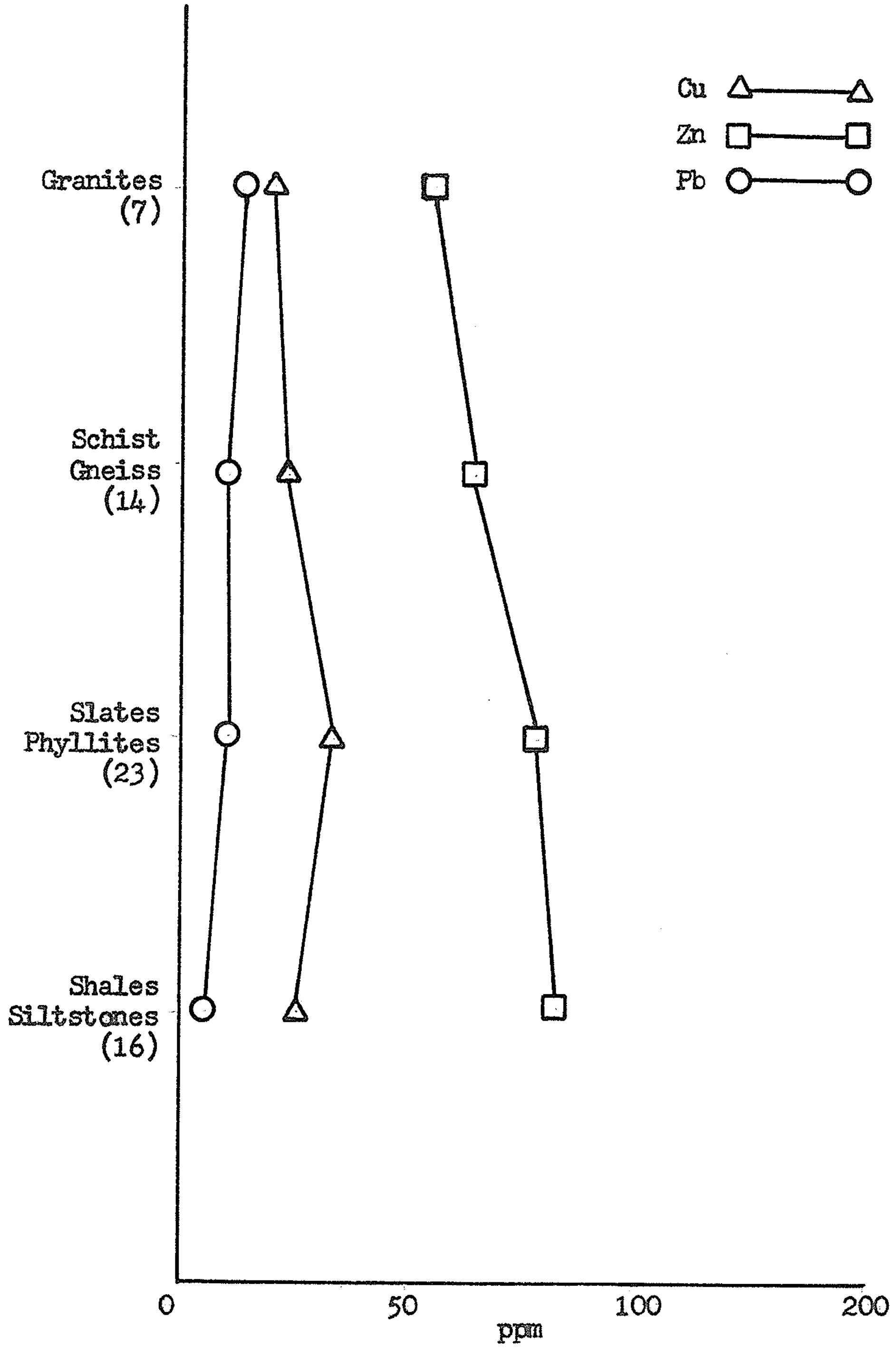


Figure 19 Trace Copper Content in Rocks, as Related to Intensity of Metamorphism

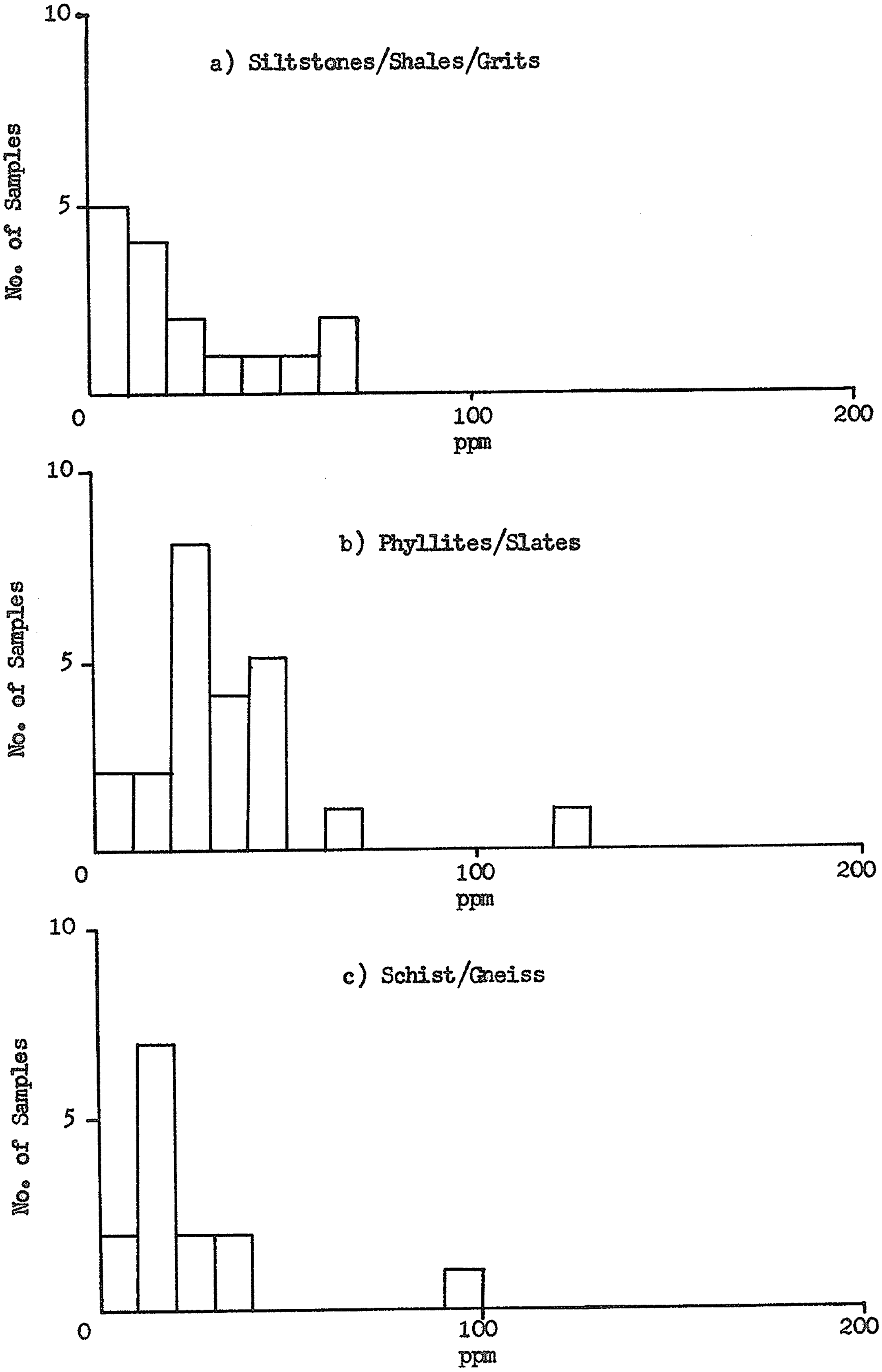


Figure 20 Trace Zinc Content in Rocks, as Related to Intensity of Metamorphism

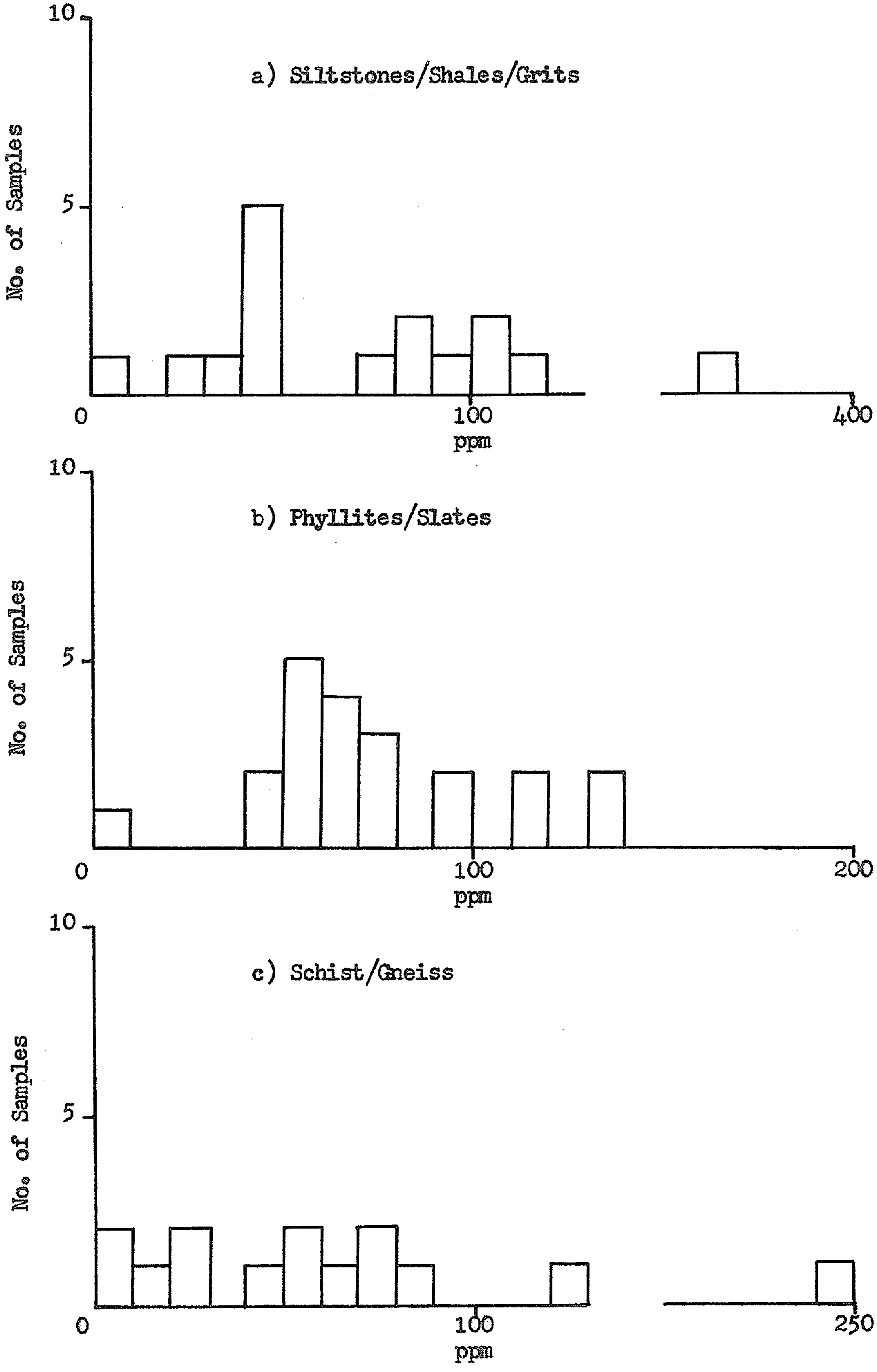


Figure 21 Trace Lead Content in Rocks, as Related to Intensity of Metamorphism

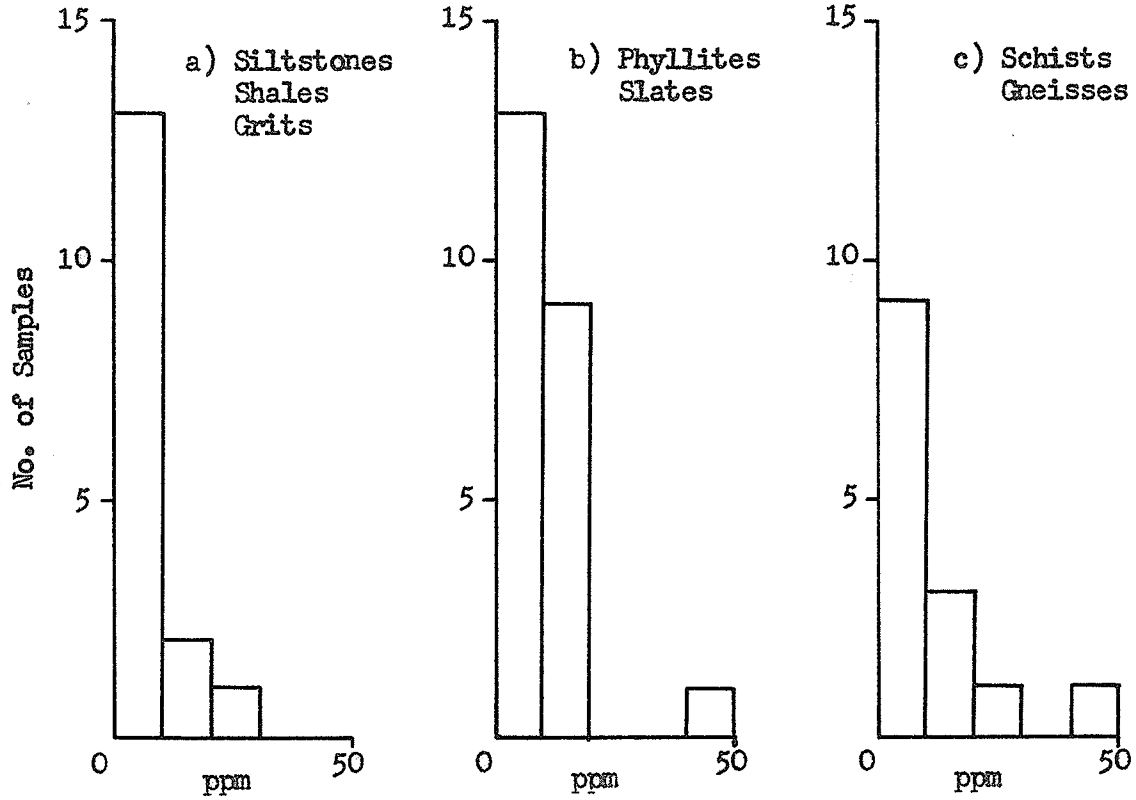


Figure 22 Trace Metal Content of Contact Metamorphic Rocks

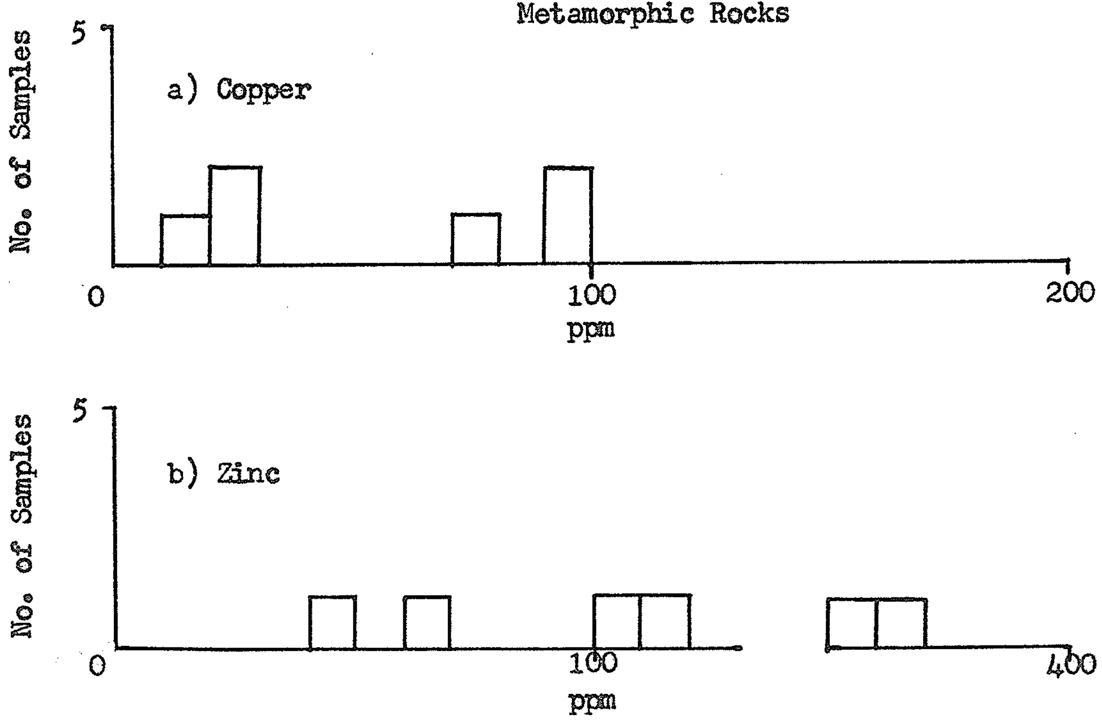
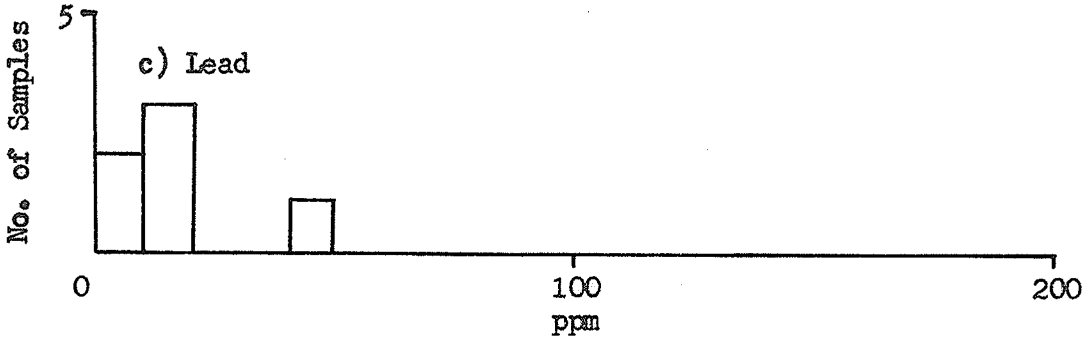


Figure 22
(cont)



SECTION 5

DISCUSSION

Introduction

The previous section noted some variations in trace metal values between populations. This section will subject those variations to a statistical analysis, the Mann-Whitney U statistics (see Section 3), to determine the significance of the noted variations. Where applicable literature results are compared with the results of this study.

Lithostratigraphy

In the previous section it was observed that the Lardeau Group had the highest average copper and zinc values of any lithostratigraphic unit. It also had a high lead value. The significance of the higher isotope values for the Lardeau with those of the Horsethief Creek and Hamill Groups will be tested statistically.

The null hypothesis that both groups of data are from the same population should not be rejected when the copper values for the Lardeau and Horsethief Creek Groups are compared. Application of the Mann-Whitney U statistics indicate that there is a 16% chance that the two samples are from the same population. However, for zinc the hypothesis can be rejected as there is only a 5% chance of both samples representing the same population. For lead the rejection of the null hypothesis is even more plausible; there is only a 2% chance that both samples are from the same population.

Comparing samples from the Lardeau with those of the Hamill results in a rejection of the null hypothesis for copper and zinc but not lead. The chance of both samples (Lardeau and Hamill) being from the same population was 1% for copper, 1% for zinc and 16% for lead.

In summary it appears that the zinc content of the Lardeau Group is significantly different than that of the Horsethief Creek and Hamill Groups. The copper content of the Lardeau is not convincingly different than that of the Horsethief Creek Group but it is likely higher than the Hamill. The lead content of the Lardeau is most probably higher than that of the Horsethief Creek Group but may not be different than that of the Hamill Group.

The metal content of the Lardeau phyllites and siltstones is shown in Figure 8. For copper and zinc the null hypothesis that the two sets of samples represent the same population can be rejected in all but 1% of possible cases. For lead the hypothesis is also rejected; there is only a 6% chance that both samples represent the same population.

This analysis indicates that for the Lardeau Group the three trace metal elements are higher in phyllites than in siltstones. This may explain why the Lardeau Group has a higher copper, zinc and lead content than other lithostratigraphic units as the Lardeau Group is characterized by large sections of phyllites.

<u>Lithology</u>

Figure 14 indicates the average abundance of copper, zinc and lead in a number of different rock types. The trace metal content of the psammites (siltstones and grits) are compared in this section with that of the pelites (shales and phyllites).

If the null hypothesis proposes that the two sets of samples, psammites and pelites, represent the same population then the hypothesis can be rejected for copper, zinc and lead. There is only a 4% chance in the case of copper, 1% for zinc and 2% for lead that the two sets of samples represent the same population. This data would indicate that copper, zinc and lead are more concentrated in the pelitic rocks rather than the psammites.

Wedepohl (1969) has accumulated from the geological literature a large amount of trace element data. His data indicates that copper is found in lower concentrations in sandstones than in argillaceous (pelites) rocks. Of the argillaceous rocks, Wedepohl (1969) indicates that those higher in bituminous material often have higher copper concentrations. Vine and Tourtelot (1970) determined an average copper value of 70 ppm from 779 samples of black shales which exceeds the average value for non-bituminous shales (20-40 ppm copper) (Wedepohl, 1969).

Wedepohl (1969) reports that a composite sample of 10 quartzites contained 23 ppm zinc. He also points out that argillaceous rocks are higher in zinc than are psammites. A general average of zinc in argillaceous rocks, low in bituminous matter, seems to be close to 100 ppm zinc (Wedepohl, 1969). Much higher accumulations are reported from black shales (Vine and Tourtelot, 1970) up to a frequency maximum of 200 ppm zinc (Wedepohl, 1969).

Wedepohl (1969) indicates that the average lead content of 924 sands and sandstones was 10 ppm lead. Pelites contain the highest proportions of the lead contained in sediments (Wedepohl, 1969). The listed averages of lead in non-bituminous argillaceous rocks is about 22 ppm lead (Wedepohl, 1969). Data on lead in bituminous shales indicates a slightly higher average lead content, than that of non-bituminous shales, of 24 to 29 ppm.

The extensive literature on the abundance of trace elements in rocks as compiled by Wedepohl (1969) indicates that copper, zinc and lead are found in greater concentrations in pelitic rocks over psammites. Of the pelitic rocks those higher in bituminous matter like black shales show a greater average content in copper, zinc and lead. The data obtained in this study is in general accord with the cited literature results. The pelites of this study do show higher concentrations of copper, zinc and lead than do the psammites.

Metamorphic Rocks

Figure 18 indicates the average abundance of copper, zinc and lead in rocks of varying metamorphic intensity. This section will evaluate the significance of the variation shown between those populations.

Slates and phyllites have a higher average copper content than do schists and gneisses (Figure 18). Application of the Mann-Whitney U statistics indicate that there is only a 1% chance that the two sets of samples represent the same population.

Similarly the zinc content of shales and siltstones exceed that of schists and gneisses (Figure 18). However the application of the statistic indicates that there is an 18% chance that the two sets of samples represent the same population. There is an even greater chance (35%) that the zinc content of the phyllites and slates and that of the schists and gneisses represent the same populations. Zinc does not seem to vary appreciably from one metamorphic rock type to another.

The average lead content of slates and phyllites is equal to that of schists and gneisses (Figure 18). Both exceed the average for shales and siltstones (Figure 18). Application of the Mann-Whitney U statistics indicate that for lead there is only a 1% chance that the samples of siltstones and shales are from the same population as that for phyllites and slates. Similarily there is only a 5% chance that for lead the samples from the siltstones and shales are from the same population as the schists and gneisses. Therefore the difference in lead values as displayed in Figure 18 is thought to be significant. The diagram indicates an increase in lead content with the onset of metamorphism.

Wedepohl (1969) states that the majority of schists and gneisses contain less than 25 ppm copper which is less than the average copper concentration of the majority of greywackes and shales (30 ppm and 35 ppm copper). That is the metamorphic rocks have a lower copper content than non-metamorphic rocks of similar bulk composition. The results of this study for copper are consistent with the data compiled by Wedepohl (1969).

Wedepohl (1969) notes that there is a slight difference in average zinc concentration in favour of schists and gneisses over shales and greywackes. The results of Engel and Engel (1960,a,b) and Van de Kamp (1970) indicate that the available data is inconclusive concerning the movement of zinc during metamorphism. Certainly the statistical analysis of the data available to this study is also inconclusive as to the relative difference in zinc values between metamorphic and non-metamorphic rocks.

Wedepohl (1969) points out that the average lead value for 2846 samples of gneisses and schists is 17 ppm lead. This value falls between those quoted earlier for psammites and pelites. The data from this study would indicate that there is a small but significant increase in the lead content of samples when they are initially metamorphosed.

A few of the samples collected for the study have been thermally metamorphosed. The histograms for these samples are drawn in Figure 22. When these thermally metamorphosed rocks are compared statistically to similar rocks that have not been thermally metamorphosed there is little difference between the samples. There is a 26% chance that in the case of copper both the thermally and non-thermally metamorphosed samples are from the same population. For zinc the possibility is 32% and for lead it is 35%. The evidence is far from conclusive that the thermally and non-thermally metamorphosed samples represent two distinct populations. It would appear that both rock types have similar copper, zinc and lead values.

Wedepohl (1969) does not list averages for the copper content of thermally metamorphosed rocks. He, however, indicates that several workers have not observed any appreciable change in copper concentrations across a magmatic contact. Data for zinc concentrations around intrusive bodies is not available from Wedepohl's (1969) compilation. The data for lead is similar to that cited for copper (Wedepohl, 1969).

SECTION 6

DEPOSIT TYPE AND ROCK TYPE IN SOME B.C. LEAD-ZINC DEPOSITS

Table 5 is a contingency table which organizes two characteristics, deposit type and rock type, of 110 lead-zinc deposits located in south-eastern British Columbia. The data was derived from the B.C. Department of Mines and Petroleum Resources Mineral Deposit - Land Use Maps for NTS Sheets 82G, K, L, M and N.

Chi-square correlation analysis is used to establish a possible significance of the observed association between rock type (i.e. host rock) and deposit type. A similar study on some characteristics of British Columbia molybdenite occurrences was published by Peach and Renault (1965).

Chi-square analysis requires that the data be organized into a contingency table consisting of rows and columns. The total number of categories or cells in which entries can be made is equal to the number of rows multiplied by the number of columns.

Siegel (1956) in Till (1974) states that chi-square tests may be used powerfully if fewer than 20 percent of the cells have an expected frequency less than five and if no cell has an expected frequency of less than 1. To satisfy this requirement the number of deposit types in Table 5 are reduced to two and the number of rock types to three. Choosing just three rock types required the elimination of the categories for intrusives, pegmatites, and volcanics. A total of 101 deposits remain for chi-square analysis.

TABLE 5

OBSERVED FREQUENCIES OF DEPOSIT TYPE AND ROCK TYPE IN LEAD-ZINC DEPOSITS OF SOUTHEASTERN BRITISH COLUMBIA

	Rock Type						
Deposit Type	Intrusions	Pegmatites	Volcanics	Sediments	Metamorphics	Sediments & Metamorphics	Totals
Replacements	0	0	0	12	3	3	18
Comformable Mineralization	0	0	0	1	7	0	8
Vein	5	0	2	21	19	11	58
Vein and Replacement	0	0	0	10	7	5	22
Vein in Shear Zone	1	0	1	0	2	0	4
Totals	6	0	3	44	38	19	110

Table 6 represents the deposits that were chosen for the chi-square analysis. The three columns for rock type are sedimentary, metamorphic and one column when both metamorphic and sedimentary rocks are the host rocks. The data is treated as dichotomous in deposit type. All deposits are considered as being either vein deposits or non-vein deposits (i.e. replacement and comformable mineralization rows in Table 5). The figures outside of parentheses in Table 6 are the observed frequencies and the figures in parentheses are the expected or theoretical frequencies.

TABLE 6

CONDENSED CONTINGENCY TABLE OF ROCK TYPE VERSUS DEPOSIT TYPE FOR THE LEAD-ZINC DEPOSITS OF SOUTHEASTERN BRITISH COLUMBIA

	Rock Type		
Deposit Type	Sedimentary	Metamorphic	Sedimentary & Metamorphic
Non-Vein Deposits	13 (11.3)	10 (9.76)	3 (4.88)
Vein Deposits	31 (32.7)	28 (38.2)	16 (14.28)

Overall Confidence Level (50%) - Too Low to Accept

In order to test whether or not there is a correlation between rock type and deposit type a null-hypothesis (independence of rock type and deposit type) was adopted. The 95 percent confidence level was selected as the lower limit for rejecting the hypothesis. Expected frequencies F, satisfying the null-hypothesis, were computed according to the relation:

$$F = \frac{\text{rock type frequency X deposit type frequency}}{\text{total number of deposits}}$$

These frequencies were compared with the observed frequencies by means of the usual chi-square formula (Till, 1974). Confidence in the degree of association of the deposit characteristics was established by reference to standard statistical tables in Mendenhall (1971).

Analysis of these associations does not permit us to reject the hypothesis that rock type and deposit type are independent of one another. The analysis indicates that there is a 50 percent chance that the hypothesis is valid.

The result obtained is not consistent with that obtained by Peach and Renault (1965) for B.C. molybdenite occurrences. That study indicated that there is very possibly a connection between deposit type and rock type.

SECTION 7

CONCLUSIONS

1. The Lardeau Group shows the greatest concentration of copper, zinc and lead of any of the lithostratigraphic units.
2. The phyllites of the Lardeau Group have higher metal concentrations than Lardeau Group siltstones. The dominance of phyllite in the Lardeau Group may account for the overall high metal values obtained for the Lardeau.
3. The pelitic rocks of the study area have larger trace metal values than do the psammitic rocks.
4. Metamorphic rocks are quite variable in their metal content. Copper is concentrated in slates and phyllites. Zinc does not appear to have been concentrated in any particular metamorphic rock. Trace values are higher in metamorphic rocks compared with non-metamorphic rocks. Contact metamorphic rocks do not appear to be enriched in the three trace metals (copper, zinc and lead) over similar rocks.
5. A dependence between rock type and deposit type cannot be established for a series of southeastern British Columbia lead and zinc deposits.

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APPENDIX

Sample Locations and Descriptions

Table 7 contains a brief description of each sample as well as its lithostratigraphic unit. Samples can be located in Figure 23.

Five samples (#53, #60, #63, #64 and #80) fall outside the boundaries of Figure 23. The five samples are from locations along the Columbia River north of the map area. Samples #53, #60, #63 and #80 are located near the mount of the Goldstream River. Sample #64 is from Downie Creek.

TABLE 7

Sample Description

Sample No.	Lithostratigraphic Unit	Description of Sample
1	Lardeau Group	Silty phyllite
2	" "	Silvery grey phyllite
3	" "	Black carbonaceous shale
4	" "	Silvery grey carbonaceous shale
5	" "	Buff coloured slate
6	" "	Grey carbonaceous slate
7	" "	Silvery grey phyllite
8	" "	Carbonaceous phyllite
9	" "	Silvery grey carbonaceous phyllite
10	" "	Black carbonaceous phyllite
11	" "	Andalusite bearing phyllite
12	" "	Silvery carbonaceous phyllite
13	" "	Black carbonaceous shale
14	" "	Black limestone
15	" "	Black carbonaceous shale
16	Horse Thief Creek Group	Black phyllite
17	" "	Coarse grained metasandstone
18	" "	Coarse grained siltstone
19	" "	Coarse grained metasandstone
20	" "	Fine grained siltstone
21	" "	Quartz, muscovite phyllite
22	" "	Silvery phyllite

Sample No.	Lithostratigraphic Unit	Description of Sample
23	Horsethief Creek Group	Black phyllite
24	" "	Silvery phyllite
25	" "	Grey slate
26	" "	Grey slate
27	" "	Black phyllite
28	Shuswap Paragneiss	Quartz-biotite schist
29	" "	Biotite schist
30	Horse Creek Group	Garnet-biotite muscovite schist
31	Hamill Group	Rusty brown green slate
32	" "	Black phyllite
33	Badshot Formation	Grey carbonaceous limestone
34	" "	Grey limestone
35	Hamill Formation	Quartz-mica schist
38	" "	Pale green quartzite
39	" "	Quartzite
40	" "	Light brown quartzite
41	Shuswap Paragneiss	Muscovite gneiss
42	" "	Quartz-biotite gneiss
43	" "	Quartzite
44	Lardeau Group	Black shale
45	Shuswap Paragneiss	Fine grained shale
46	Lardeau Group	Silty phyllite
47	Shuswap Paragneiss	Black slate
48	" "	Quartz-biotite-garnet gneiss
49	" "	Silvery slate
50	" "	Biotite muscovite schist
51	" "	Calcareous gneiss
52	" "	Brownish metasiltstone
53	" "	Biotite-muscovite schist
54	" "	Quartz-feldspar-biotite gneiss
55	" "	Grey dolomite
56	" "	Pink quartzite
57	" "	Quartz-feldspar gneiss
58	Lardeau Group	Black phyllite
59	Horse Creek Group	Quartzite
60	Badshot Formation	Limestone
61	Lardeau Group	Quartz vein material
62	Lardeau Group	Quartz vein material
63	Granite	Granite to granodiorite
64	"	Granite to granodiorite
65	"	Porphyritic granite
66	"	Porphyritic granite
67	"	Porphyritic granite
68	"	Porphyritic granite
69	Shuswap Core Gneiss	White quartzite
70	" " "	White quartzite
71	" " "	Quartz-muscovite-biotite gneiss

Sample No.	Lithostratigraphic Unit	Description of Sample
72	Lardeau Group	Calcareous metasandstone
73	Shuswap Core Gneiss	Quartz-biotite-muscovite gneiss
74	" " "	Grey gneiss
75	Lardeau Group	Metagreywache
76	" "	Argillaceous metaquartzite
77	" "	Slate
78	" "	Slate
79	" "	Black slate
80	Badshot Formation	Dolomite
81	Granite	Porphyritic granodiorite
82	Lardeau Formation	Grey siltstone
83	Hamill Group	Quartzite
84	Hamill Group	Slate
85	Lardeau Group	Silvery slate
86	" "	Black carbonaceous slate
87	" "	Black phyllite
88	" "	Black phyllite
89	" "	Black phyllite

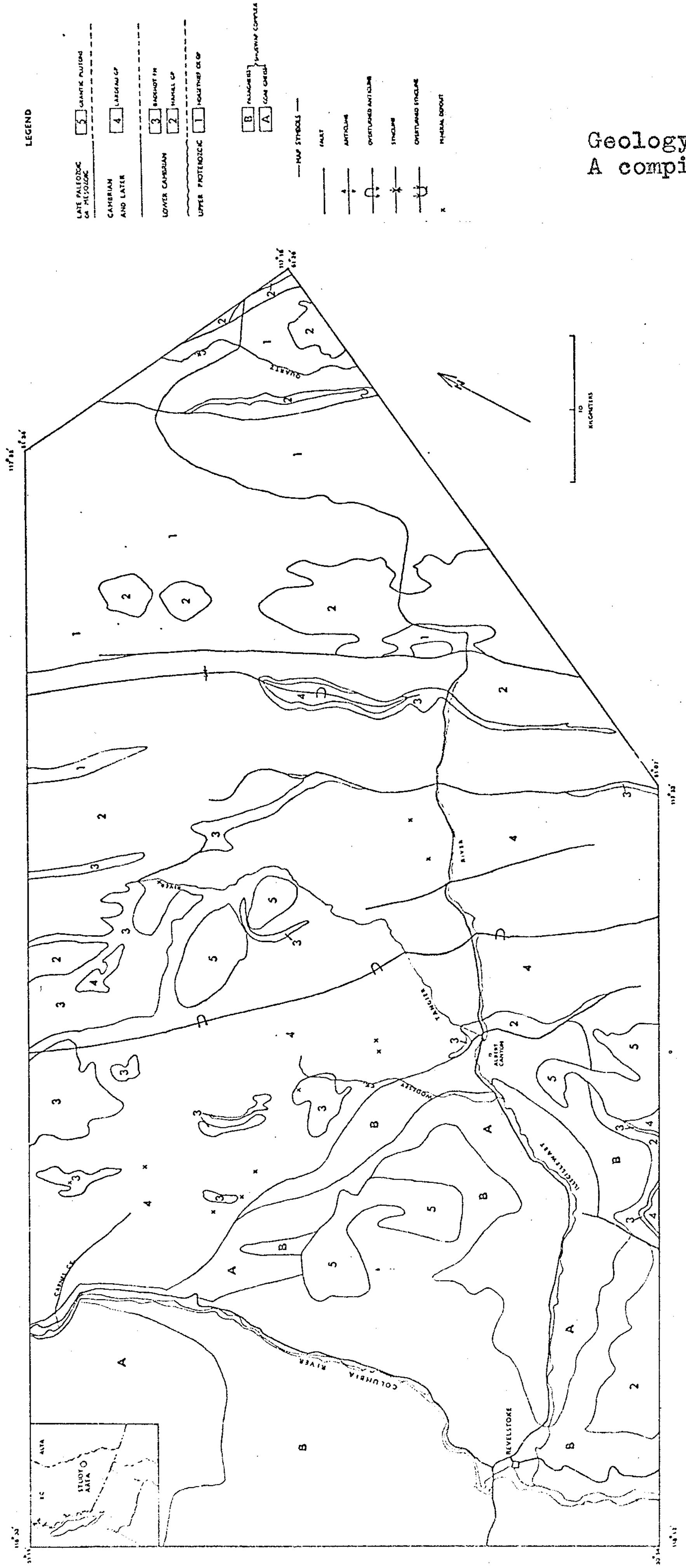

Figure 2

Geology of the study area.
A compilation map.

Figure 23

Sample location map.