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A fault-controlled Pb - Zn occurrence in Essex and Kent counties, Ontario.

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NL-339 (3/77)

A FAULT-CONTROLLED Pb - Zn OCCURRENCE
IN ESSEX AND KENT COUNTIES
ONTARIO.

by

Robert Karl Phelps

A Thesis
Submitted to the Faculty of Graduate Studies through the
Department of Geology in Partial Fulfillment of the
Requirements for the Degree of
Master of Science at the
University of Windsor

Windsor, Ontario

1978

ABSTRACT

This study is an investigation of the Pb - Zn abundances in the Lower Paleozoic rocks of Southwestern Ontario, in Essex and Kent Counties. Rock samples from PreCambrian to Upper Ordovician formations were collected from 30 drill holes in the study area. A total of 330 determinations for Zn, Cu, Pb, Ni, Cr, Mn, Fe, Ca, and Mg on 30 sample sites were made by atomic absorption. The data indicate a geochemical anomaly pattern, which can be related to the existence of regional faults penetrating the Paleozoic sequence, from the PreCambrian basement. It is suggested that upward migration of mineralizing fluids along fault zones is responsible for the observed geochemical dispersion patterns. The metals were probably derived locally from the PreCambrian basement, and have been eluted by deep circulating groundwaters.

DEDICATION

This manuscript is dedicated to my wife Sandra, who has been a constant source and well of compassion and enthusiasm throughout this investigation.

ACKNOWLEDGMENTS

I sincerely acknowledge the assistance and helpful criticism of my thesis advisors, Drs. M. W. Davis, and A. Turek, during the course of this study.

INTRODUCTION.

Essex and Kent Counties form the western portion of Southern Ontario, lying between latitudes 42° 00' N. and 42° 36' N. and 81° 45' W. to 83° 15' W. longitude. This land area comprises some 4400 square kilometres (1700 square miles), the boundaries of which are shown in Figure 1.

This study was undertaken to establish the abundances of base metal content in Essex and Kent Counties. In this respect, it is an extension of earlier work by Delevault and Warren (1961), which is a more general geochemical study of various Paleozoic formations of Eastern and Central Ontario. Emphasis has been placed on the abundances of Zn, Cu, and Pb because these metals can achieve concentrations of economic value, particularly in carbonate rocks. Moreover, these carbonate rocks are a major source of industrial stone, agricultural lime, and food preservatives such as $CaCl_2$, for which only very low concentrations of base metals are permissible.

Pb - Zn mineralization is well known in Southern Ontario. Liberty (1971) discussed the occurrences in the Bruce and Niagara Peninsulas and attributed their origin to biogenic activity. While concentration by organic activity is a possible mechanism, other processes must also be considered. Metal concentration can occur

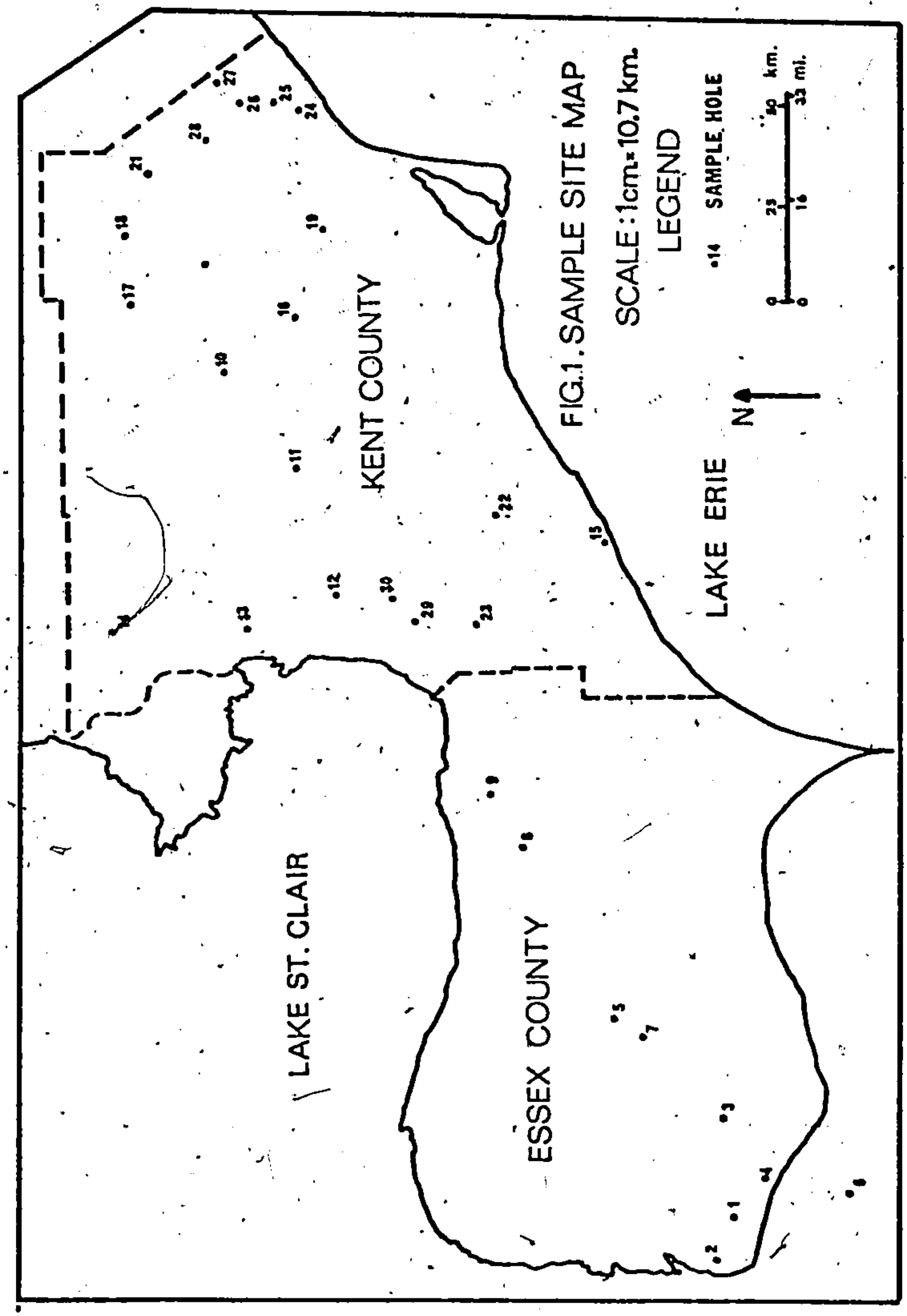


FIG.1. SAMPLE SITE MAP

SCALE: 1cm = 10.7 km.

in normal sedimentary sequences by ion exchange in clay minerals, with subsequent dispersion and distribution during diagenesis. Mineralization may also occur from groundwater percolating through permeable rock formations, joints, faults, and fractures.

Therefore, the objective of this study is to evaluate the role of these processes on the basis of new geochemical analytical work, completed in the course of this investigation.

GENERAL STRATIGRAPHY

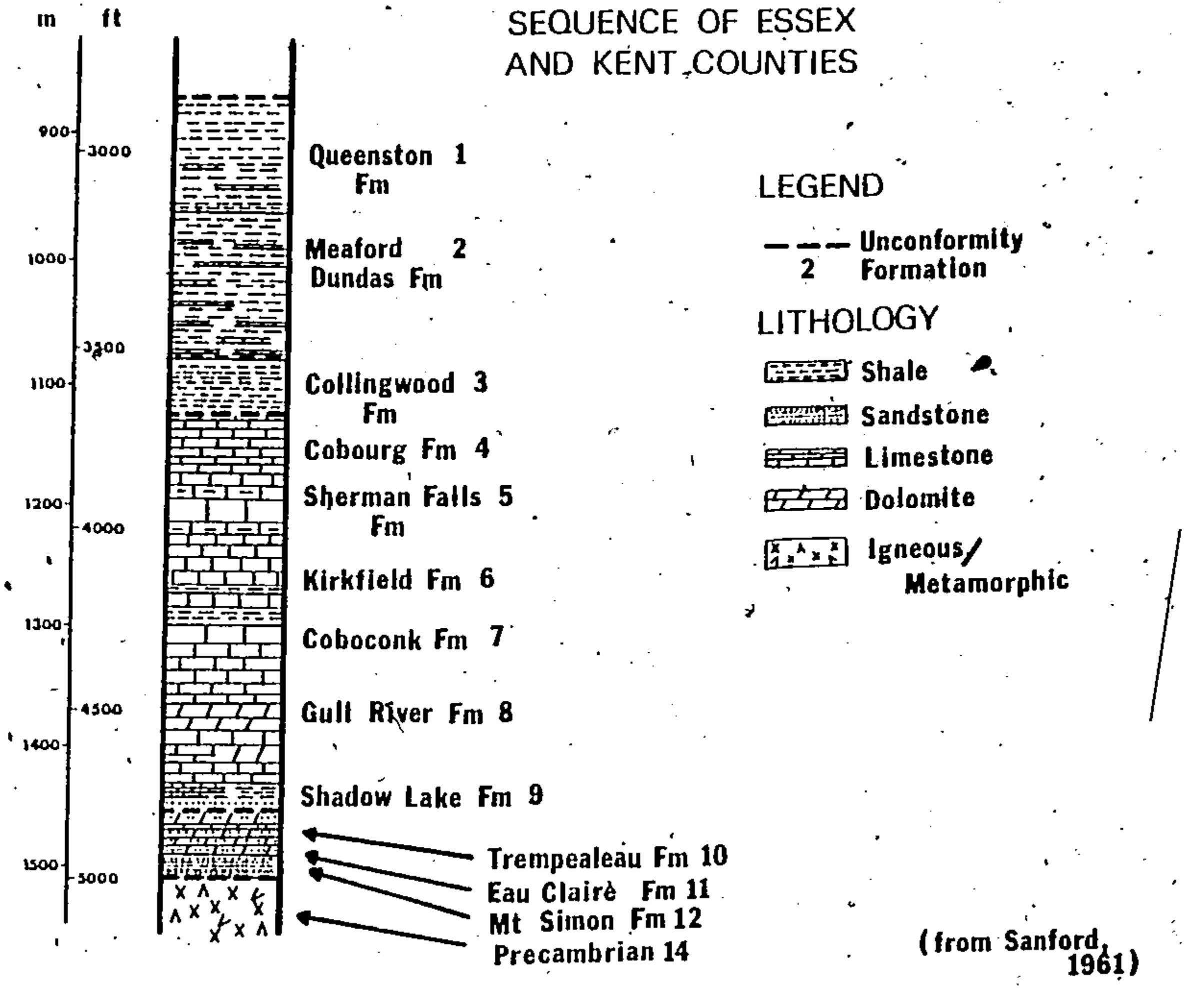
The bedrock of Essex and Kent Counties consists of about 1100 metres (3100 feet) of Cambrian to Upper Devonian sediments, underlain by the PreCambrian basement, belonging to the Grenville Province of the Canadian Shield (Stockwell, 1965) .

The following is a brief description of the studied formations of the area, relevent to the discussion of metal distribution. This stratigraphic sequence is illustrated in Figure 2.

PreCambrian Basement

The PreCambrian basement rocks of Essex and Kent Counties are quartz rich metamorphic rocks, mainly impure meta - quartzites and gneisses. Drill core and chip samples from petroleum exploration indicate a predominance of quartz over K - feldspar and biotite. Chloritization in the more impure gneisses appears to be local, although it may be extensive. Age determinations for the basement rocks of Southwestern Ontario, as reported by Tilton (1960), indicate a radiometric K - Ar age range from 1750 ± 40 Ma. to 950 ± 30 Ma. Wanless et al. (1964) published two other age determinations. The first is a K - Ar biotite age, GSC 63 - 111, from Burford Township, Brant County,

FIG.2. STRATIGRAPHY OF THE LOWER PALEOZOIC SEQUENCE OF ESSEX AND KENT COUNTIES



(from Sanford, 1961)

at 920 ± 40 Ma. The second is another K - Ar age determination for sample GSC 63,-112, from Romney Township, Kent County, with an age of 895 ± 40 Ma.

Cambrian Formations

Unconformably overlying the PreCambrian basement, is a sequence of predominantly clastic sediments of Cambrian age. In southwestern Essex County, this sequence is well developed and consists of :

Trempealeau Formation : sandstone with sandy dolomite lenses throughout.

Eau Claire Formation : partially dolomitized sandstone.

Mt. Simon Formation : clean quartzose sandstone.

Elsewhere, in the study area, only the Trempealeau Formation is well defined.

The Cambrian formations are conformable to each other, but unconformable to underlying and overlying beds. In Essex County, thicknesses range from 100 to 140 metres (300 to 400 feet). In Kent County, these thicknesses diminish to 0 to 50 metres (0 to 150 feet), due to post - Cambrian uplift and erosion.

Towards the Allegheny Basin of New York and Pennsylvania, the three clastic formations are succeeded by the Little Falls and Theresa Formations, both of which are fine grained sandy dolomites. Within the study area however, these two formations are absent (Brigham, 1971).

Ordovician Formations

The succeeding sequence of sediments is of Early Middle to Late Ordovician in age. It consists mainly of a thick sequence of clastics and carbonates, called the Black River and Trenton Groups, from the original classification of Kay (1942). The following stratigraphic description is taken from Sanford (1961).

Black River Group

Lower Ordovician sediments are not found in the study area, having been eroded away in the post - Cambrian uplift. The oldest member of the Black River Group is the Shadow Lake Formation, consisting of a pyritiferous, multicoloured shale to argillaceous limestone. This formation is certainly variable in thickness, from 0 to 15 metres (0 to 50 feet), due to irregularities in the Cambrian surface.

The succeeding Gull River Formation is a thickly bedded lithographic buff coloured limestone, ranging in thickness from 15 to 125 metres (50 to 410 feet). It is flat lying and thickens towards the northwest.

The top of the Black River Group is composed of

Coboconk Formation, a buff, fine grained limestone, with minor chert. This formation varies in thickness from 40 to 50 metres (130 to 165 feet) in the study area.

Trenton Group

The oldest member of the Trenton Group is the Kirkfield Formation, which is an argillaceous limestone with interbedded shale. Average thicknesses are in the range of 40 to 50 metres (130 to 165 feet) in Essex and Kent Counties.

The Kirkfield Formation is succeeded by the Sherman Fall Formation, which is an argillaceous limestone, with minor dolomite lenses. Numerous shale stringers are present. The upper 7 metres or so are characterized by " birdseye structures " . Thicknesses of this formation range from 27 to 38 metres (90 to 125 feet) .

The youngest member of the Trenton Group is the Cobourg Formation. This is an argillaceous to clean porous limestone. Along fault and fracture patterns or where porosity is quite high, dolomite replaces limestone as the rock type. This formation is more porous than the other members of the group. Its thickness averages 34 metres (115 feet) .

Generally, the members of the Black River and Trenton Groups are conformable to each other. According to Liberty (1971) , these sediments mark a period of nearly uniform shallow water carbonate development.

Upper Shales Group

The Trenton Group is succeeded unconformably by members of the so-called " Upper Shales " Group, principally the Collingwood, Meaford - Dundas, and Queenston Formations (Kay, 1942) . These formations have an overall thickness ranging from 200 to 360 metres (660 to 1180 feet), thickening to the southeast.

The oldest member of the " Upper Shales " Group is the Collingwood Formation, which is a highly bitumenous, putrid - black shale, indicative of euxinic conditions. The average thickness of this formation in the study area is 30 metres (100 feet) .

Overlying the Collingwood Formation is the Meaford - Dundas Formation, consisting of intercalated gray shales and limestones. Thicknesses vary from 80 to 115 metres (260 to 380 feet), thickening to the southeast. This formation is indicative of marine muddy conditions, with some carbonate formation (Liberty, 1969) .

The youngest member of this group is the Queenston Formation, consisting of a typical brick - red shale, mottled green throughout. Locally, it is calcareous with minor limestone lenses. In Essex and Kent Counties, this formation ranges in thickness from 90 to 120 metres (300 to 400 feet) .

Overlying the Queenston Formation is a thick sequence of carbonates and evaporites of Silurian age, which includes the Salina Group. This group consists of over 300 metres (1000 feet +) of intercalated carbonates and evaporites. Further carbonate formations succeed the Salina Group into the Middle Devonian. The post - Ordovician formations are unconformable to the Queenston Formation.

FAULT PATTERNS IN ESSEX AND KENT COUNTIES

In the study area, there are three prominent faults, which are significant as possible conduits for the upward migration of fluids containing Zn, Cu, and Pb. The faults also provide structural traps for the accumulation of petroleum in the Cambrian and Ordovician sediments. For example, the Dover Field, first discovered in 1917, produces from the Middle Ordovician Sherman Fall Formation. The trap for oil accumulation occurs on a limb of a faulted syncline. The Clearville oil and natural gas field, discovered in 1963, is a Cambrian based producer in southeastern Kent County. Here the main production occurs on the uplifted block between two parallel faults.

Figure 3 illustrates the main structural elements of the study area. The following description of the fault zones and their effect on local stratigraphy is largely taken from Brigham (1971) .

The Dover Fault (strike N 72° W., dip 60° S.) occurs in Dover East and Dover West Townships, Kent County. It is a steeply dipping reverse fault, with displacement varying from 25 to 35 metres (80 to 115 feet). Structurally, the rift occurs on the southern limb of a small syncline, and can be traced to the

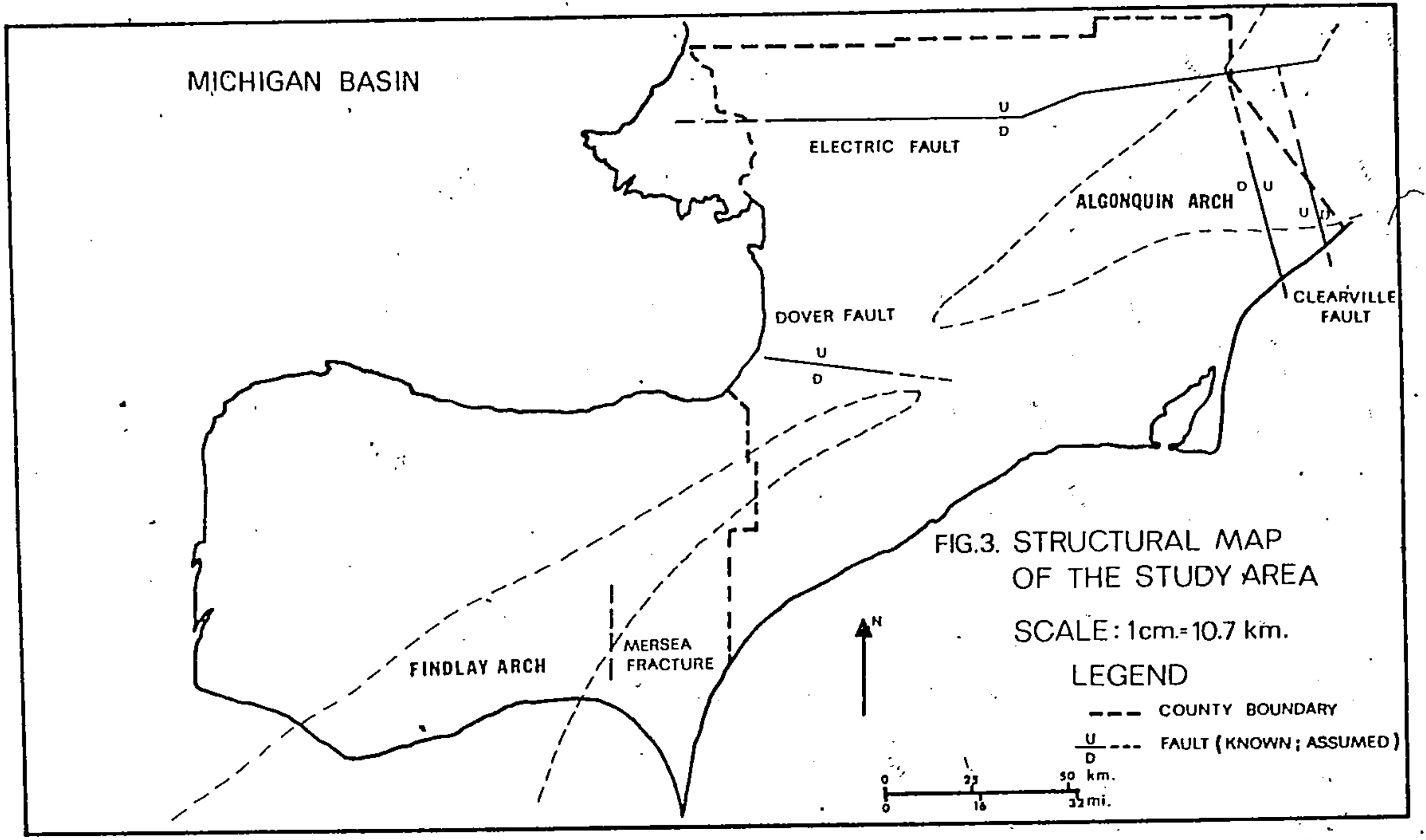


FIG.3. STRUCTURAL MAP OF THE STUDY AREA

SCALE: 1cm.=10.7 km.

PreCambrian basement. Age of movement appears to be post - Ordovician in age, probably Devonian.

The Clearville Fault is really a fault block, located in Orford Township, Kent County. The two parallel faults are normal in character, striking N 11° W., with vertical dips. The western fault, called the Clearville Fault, has a vertical displacement of from 40 to 60 metres (130 to 200 feet). some 8 kilometres (4.8 miles) east of the main fault, is a small rift with vertical displacement ranging from 7 to 15 metres (25 to 50 feet). Movement along the two faults may have occurred in post - Ordovician time, coinciding with leaching of the Salina Group, according to Brigham (1971) .

The most extensive fault is the Electric Fault, which extends across the northern portion of Kent County. This fault strikes east - west , and dips vertically. Vertical displacements along this fault vary from 92 to 101 metres (300 to 340 feet) . The western end of the Electric Fault is assumed to be somewhere in Lake St. Claire, since no trace can be found on the Michigan side (Stonehouse et al., 1973). The eastern terminus is in the Wiley Field of Elgin County (Sanford, 1961) . The tectonic stimulus which generated the Electric Fault may have been regional adjustment to basinal subsidence, or leaching of the Salina B Salt Unit, as suggested by Brigham (1971) .

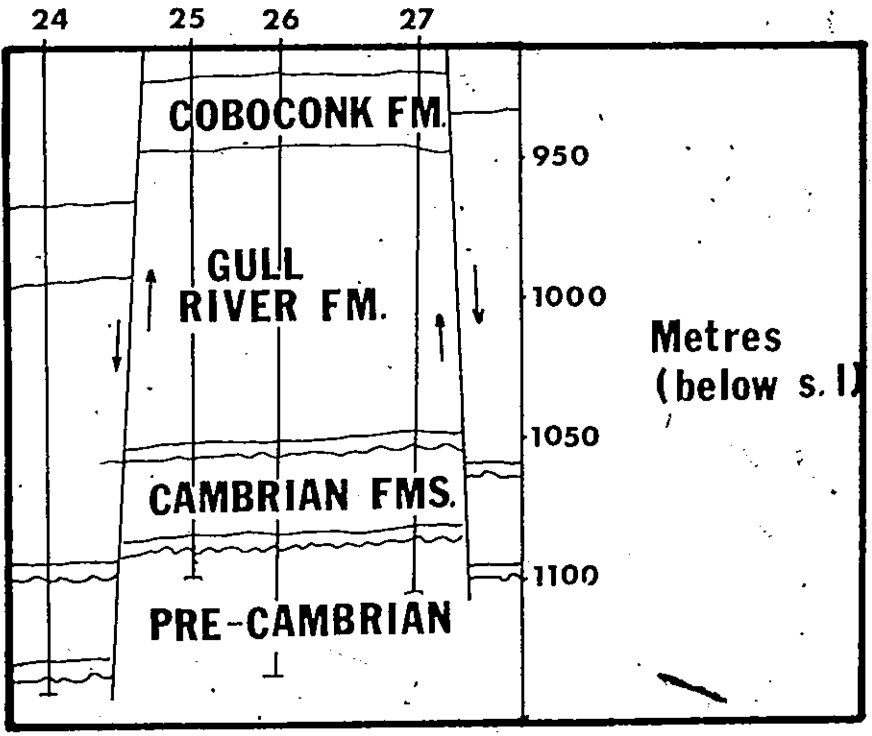


FIG. 4. CLEARVILLE FAULT BLOCK

Scale 1 in.=5 km.

There appears to be some evidence of faulting in Essex County. Correlation of drill holes " Imperial Mersea 280 N.T.R. " and " Imperial Mersea 287 N.T.R. " in the Mersea Field, indicate a rapid closure on the Cambrian and Ordovician contour lines. A considerable shortening in the thickness of the Collingwood Formation is associated with this closure (Sanford, 1961) . Some shearing and secondary mineralization can be seen in available core samples, which lends credence to the theory of possible faulting.

This faulting cannot be traced to the PreCambrian basement surface, and appears to affect only Ordovocian sediments. This feature has been called the " Mersea Fracture " and its relationship to the faults of the study area can be seen in Figure 3. The shortening of shortening of strata may also be due to stratigraphic readjustment on a regional basis, or salt leaching.

Other faults, outside of Essex and Kent Counties include the eastern extension of the Electric Fault into Elgin County, as well as the east - west trending faults of Dawn and Moore Townships, Lambton County.

SAMPLING AND ANALYTICAL PROCEDURES

In Essex and Kent Counties, several thousand drill holes have been put down in connection with oil and natural gas exploration, as well as gas storage. A good portion of these wells reach the Ordovician and Cambrian sediments. From these, some thirty drill holes were chosen for the study. The selected holes penetrate the PreCambrian basement to depths of 20 feet or more, and cover the Cambro - Ordovician sequence without sample loss.

Material from the thirty sample sites was in the form of chip samples, each vial representing a ten foot section of each target formation. Since this material was obtained from a government repository, only a small amount of sample could be taken. In order to maximize this limited quantity of material, a composite bulk sample for each formation was made up as follows. The target formation was divided into three sub - units of uniform thickness. Chip samples were taken from each vial containing a typical lithology of each sub - unit. The composite sample was then obtained by blending the three sub - unit samples.

The composite samples were then crushed to - 180 mesh size, using a shatter box and screen. About 2.0 g of the powder was then weighed out to 0.1 g into a 100 ml beaker and ignited for five minutes at 500° C. on a

Bunsen burner. This destroyed any natural hydrocarbons present in the sample, which would interfere with the analysis of some elements . (In particular, Zn concentrations are enhanced in atomic absorption using an air / acetylene flame, due to the formation of proteins, which absorb in the Zn wavelength region.) After cooling the sample, is was then reweighed and digested in 10 ml of aqua regia (1 part HNO_3 and 3 parts HCl) on a hot plate for one hour. Care was taken not to allow the sample to go to dryness. Following digestion, the sample was then filtered through Wattman #4 filter paper into a 100 ml volumetric flask, the filtrate washed with dilute HCl (2.5N) and triple distilled water, and the solution was made up to volume with triple distilled water. It was then transferred to plastic bottles for storage.

The solutions were analysed by atomic absorption using a Varian Techtron AA - 5 intrument. The following elements were determined :

Zn, Cu, Pb, Ni, Cr, Mn, Fe, Ca, Mg .

All analytical data are reported in parts per million and given in Appendix A.

Standards used in the analyses were prepared from Fisher ionic standards. In the preparation of the working standards, a " buffer " solution containing 48% Ca and 15% Mg by weight was used. This was done to approximate expected Ca and Mg levels in the carbonates, thus **negating** any matrix or non-atomic absorption interference.

Use of the atomic absorption technique is well established in geochemical exploration studies. The precision of analysis in the department has been reported by Turek et al. (1976). Most elements are determined to ± 5 %. However, Cr and Ni concentrations are very low, and the error factor may be as much as ± 50 %. Therefore, interpretation of this data must be made cautiously.

MAP ANALYSES

The concentrations of Zn, Cu, and Pb in the Lower Paleozoic sequence of the study area were plotted as geochemical contour maps to show their spatial variations and associations between metals. These three elements are of prime economic interest. The other six analysed elements may have some bearing on variations in Zn, Cu, and Pb. However, these metals and their significance in the overall metal dispersal patterns will be dealt with at length in the section concerning factor analysis.

The Lower Paleozoic sequence was divided into 5 groups, based on lithologic similarity, as follows :

Group 1	Upper Shale Group	: Gray marine to euxinic shales and minor limestones of the Queenston, Meaford - Dundas, and Collingwood Formations.
Group 2	Trenton Group	: Mainly argillaceous to clean limestones and minor shales of the Cobourg, Sherman Fall, and Kirkfield Formations.
Group 3	Black River Group	: Argillaceous to clean limestones of the Coboconk and Gull River Formations.
Group 4	Shadow Lake Group	: Calcareous shales and sandstones of the Shadow Lake and Trempealeau Formations.
Group 5	PreCambrian Group	: Igneous and metamorphic rocks of the basement.

Figures 5, 6, and 7 are cumulative geochemical contour maps of Zn, Cu, and Pb concentrations in Essex and Kent Counties. Anomalous metal concentrations occur in proximity to the Clearville and Dover Faults; however, this relationship is not as obvious in proximity to the Electric Fault.

This initial finding warrants further investigation. The study area was broken up into four regions, based on location relative to fault zones. Three regions were established, each covering an area of 3080 metres (10,000 feet) on either side of the fault zone, and a fourth region taking in the area outside of these boundaries. These regions are defined as follows :

1. Clearville Fault Region : Sites 24, 25, 26, 27, and 28.
2. Dover Fault Region : Sites 29, and 30.
3. Electric Fault Region : Sites 13, 14, 17, 18, 19, and 21.
4. Outside Region : Sites 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16, 19, 20, 22, and 23.

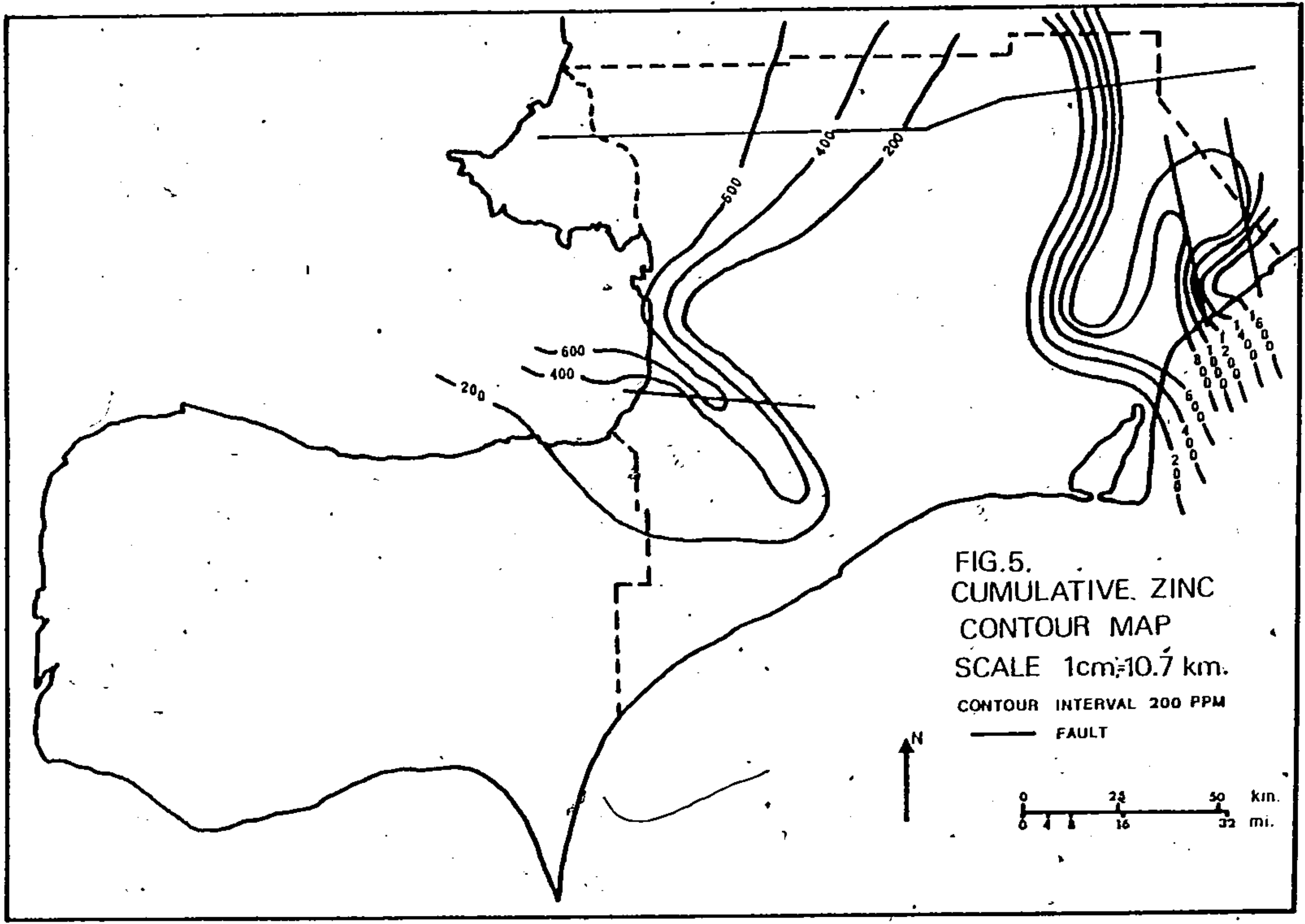


FIG.5.
CUMULATIVE ZINC
CONTOUR MAP
SCALE 1cm=10.7 km.

CONTOUR INTERVAL 200 PPM

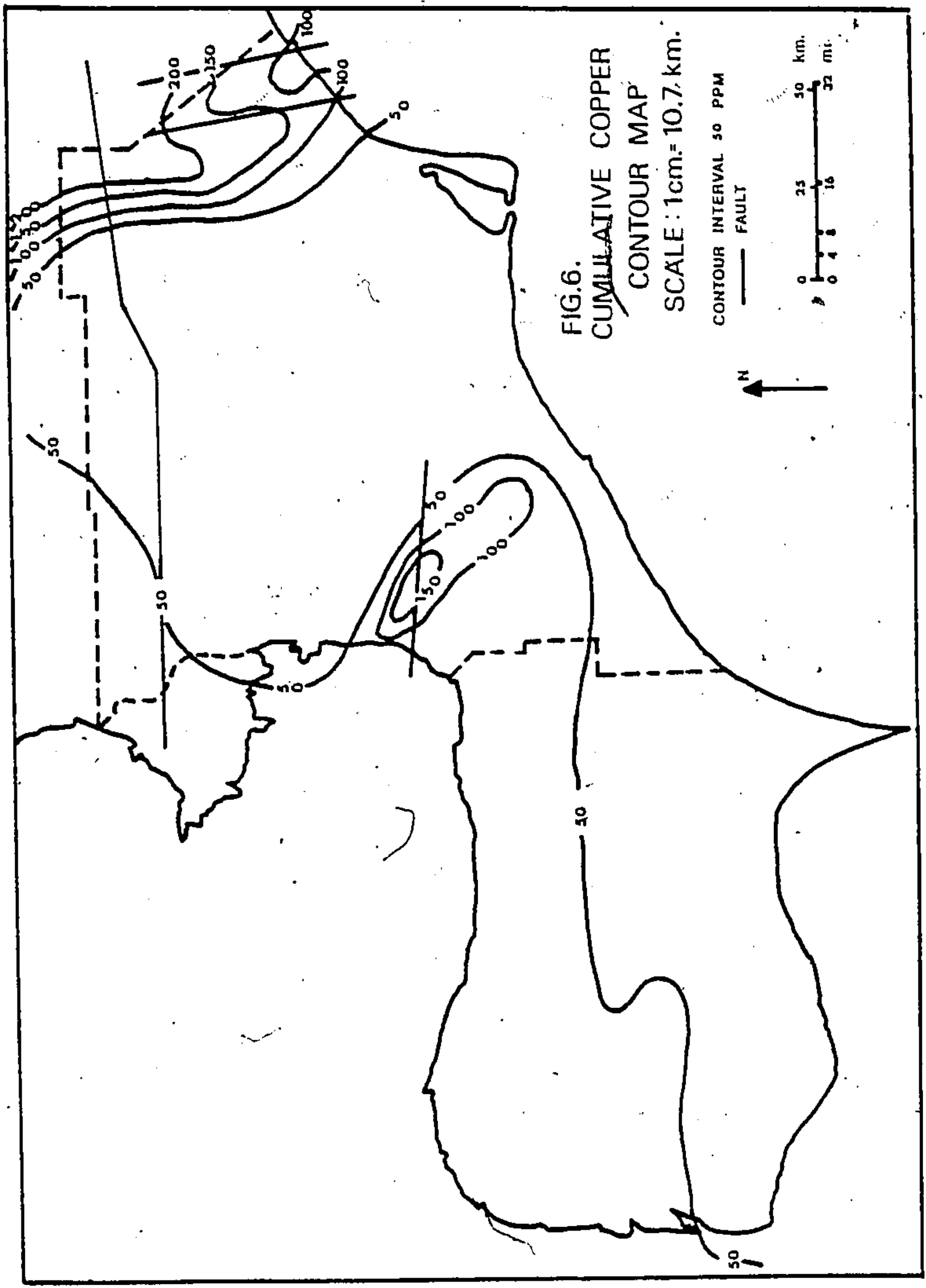


FIG.6.
CUMULATIVE COPPER
CONTOUR MAP
SCALE : 1cm.= 10.7 km.

CONTOUR INTERVAL 50 PPM
— FAULT

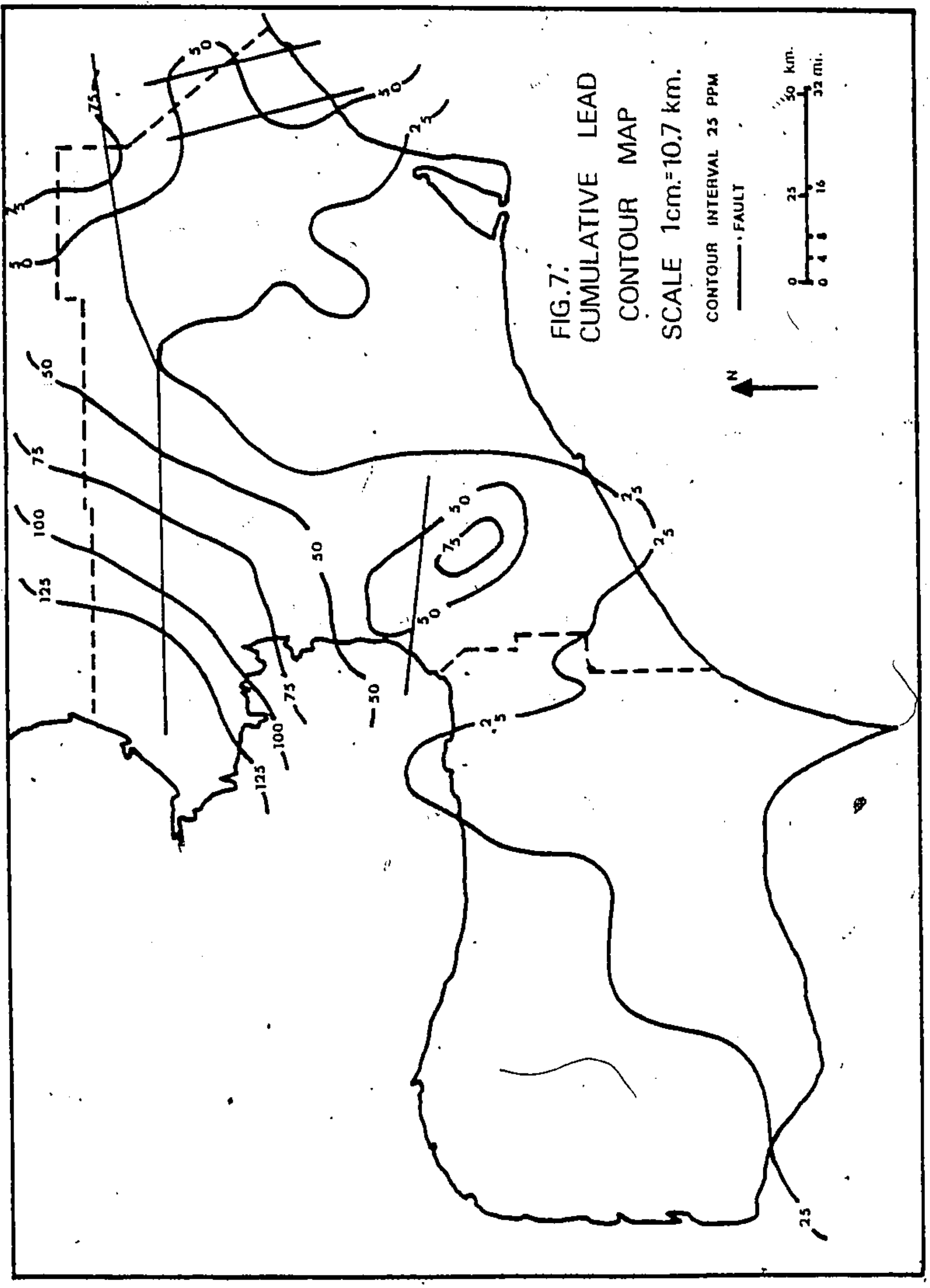


FIG.7. CUMULATIVE LEAD CONTOUR MAP

SCALE 1cm.=10.7 km.

Zinc

Figure 8 gives the distribution of Zn vs. the 5 stratigraphic groups for each of the four regions. The Outside Region shows a gradual decrease in Zn toward Group 5. Minor enrichment of Zn occurs in the lower group.

The fault regions show a different Zn distribution, in comparison to the Outside Region. Plots for the Dover and Electric Fault Regions are erratic. In the Dover Fault Region, Zn decreases to Group 3, and increases thereafter. The Electric Fault Region shows a similar pattern, except that Zn content decreases to Group 4, and increases thereafter. The Clearville Fault Region plot shows an enrichment in Zn content through to Group 5.

Copper

Figure 9 is the plot of Cu vs. the stratigraphic groups for each of the four regions. The Outside and Electric Fault Regions have similar trends, with decreasing Cu content to Group 4, and a sharp increase into Group 5.

The Dover Fault Region shows a decrease in Cu to Group 3, and a sharp increase thereafter to Group 5. In the Clearville Fault Region, there is a sharp increase in Cu to Group 3, and a decrease through to Group 5.

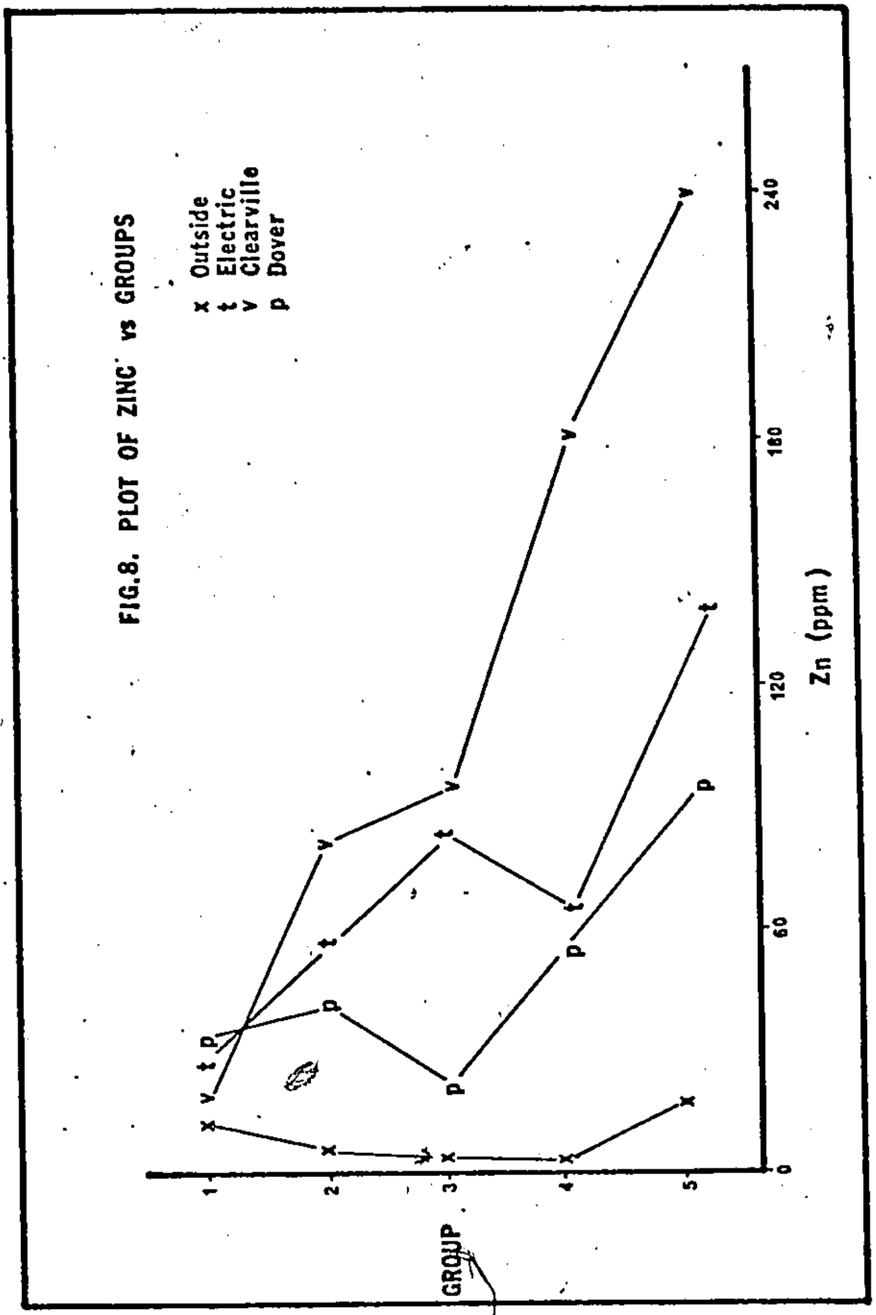


FIG.8. PLOT OF ZINC vs GROUPS

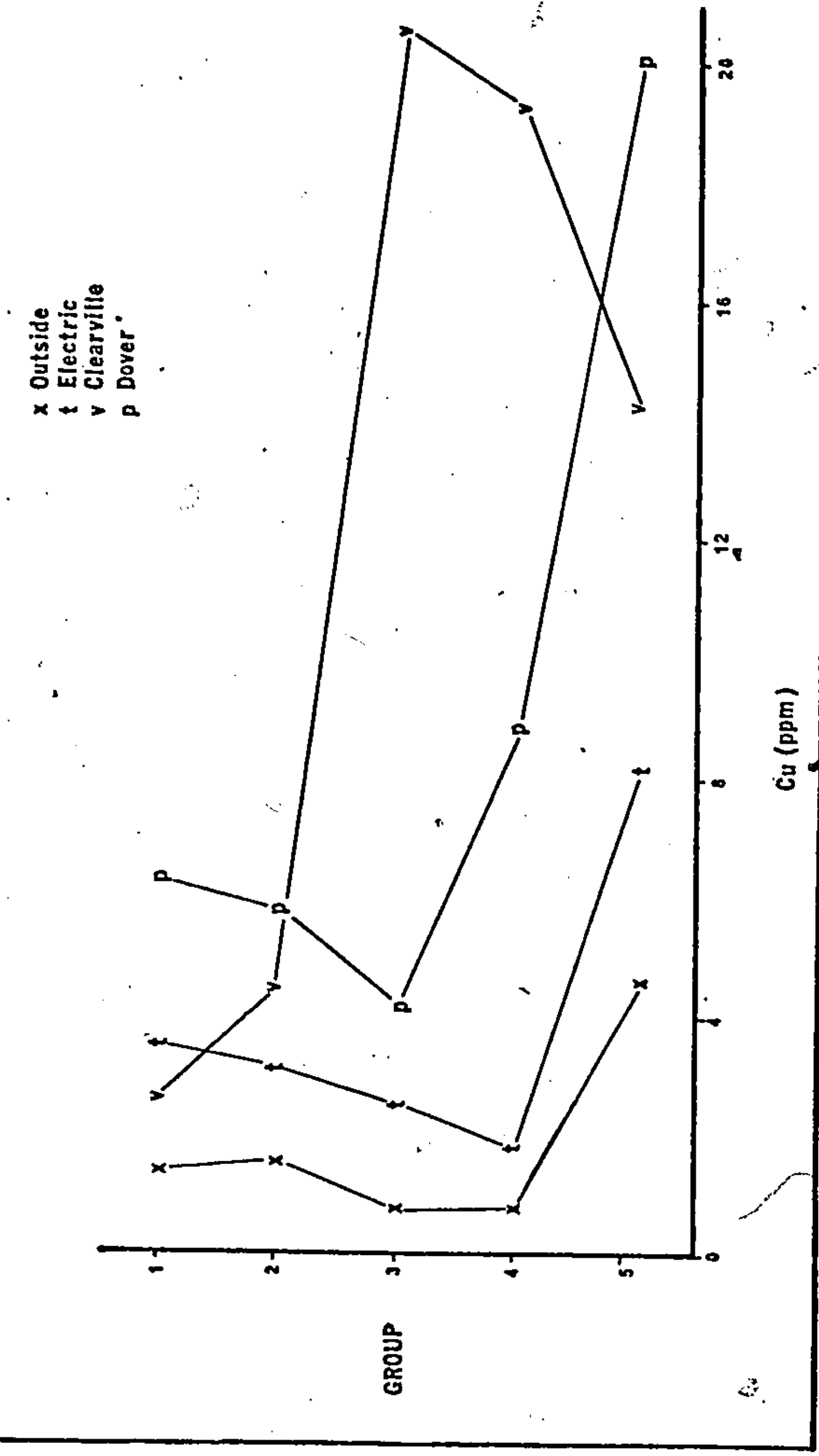


FIG.9. PLOT OF COPPER vs GROUPS

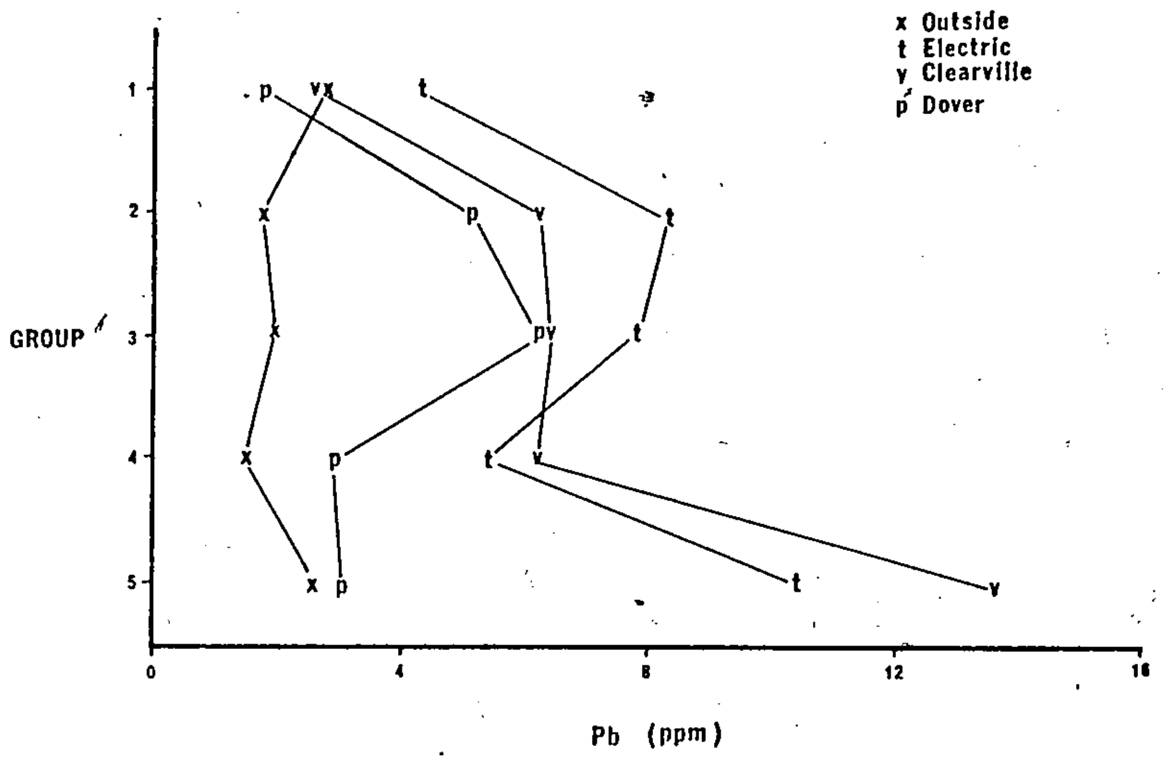
Lead

Figure 10 is the plot of Pb vs. the five stratigraphic groups for the four regions. The Outside Region shows a decrease in Pb to Group 4, and an increase thereafter into Group 5.

The three fault regions all show increases in Pb content to Group 2. From this point, the patterns become divergent. In the Dover and Clearville Fault Regions, Pb content increases to Group 3, with this trend more pronounced in the Dover Fault Region. In the Electric Fault Region, Pb concentrations decrease to Group 3. The three fault regions all show a decrease in Pb from Group 3 to Group 4, and a subsequent increase thereafter into Group 5.

The data presented above and illustrated in Figures 8, 9, and 10 all show an apparent variation in metal content due to stratigraphic and structural controls. The relative concentrations of Zn, Cu, and Pb should then be examined in order to better understand the metal patterns seen.

FIG.10. PLOT OF LEAD vs GROUPS



TERNARY DIAGRAMS

Ternary diagrams of Zn, Cu, and Pb for the sample holes were drawn in order to display these metals' relative variability. Since large amounts of variation can occur in the metal concentration of a certain series of formations, the ternary diagram gives some insight into the underlying trends in the data. Krumbein and Sloss (1963) indicate that such plots can then point to other more detailed and rewarding methods of data analysis.

Data for these diagrams were generated by taking the sum of the concentrations of Zn, Cu, and Pb for each sample, and taking each value as a decimal portion of the whole. For example :

Values for Zn, Cu, and Pb concentrations for a certain formation may be as follows.

Metal	Initial Concentration
Zn	9.7 ppm
Cu	3.7 ppm
Pb	1.6 ppm
Total	15.0 ppm

Zn value for the ternary diagram = 9.7 / 15.0 = 0.647
Cu value for the ternary diagram = 3.7 / 15.0 = 0.246
Pb value for the ternary diagram = 1.6 / 15.0 = 0.106
0.999

These data values will be referred to a " Q " values.

Ternary diagrams have found a wide use in geology. In geochemistry, such diagrams are well suited to show the chemical composition of three components of various rocks, as well as the relations between the three metals. The generated data was also plotted on vertical variograms, which a shown beside the ternary diagrams.

A significant variation in metal content was observed between the fault regions and the outside region in the preceeding analysis. A certain degree of variation in metal concentrations was observed when fault regions were compared to each other. In order to further examine this variation, a further division of the study area, as set out in the initial map analysis was made, in order to evaluate any relations between metal content in the country rock and the faults. This division is as follows:

a) Clearville Fault Region : The sample hole is located within 154 metres (500 feet) of a fault zone. Only one hole (# 25) is in this category.

b) Clearville Fault Periphery Region : The sample hole is located outside of the fault zone, but within 3080 metres (10,000 feet) of the fault. Holes # 24, 26, 27, and 28 are in this category.

Dover Fault Periphery Region : The sample hole is classified on the criteria stated above. Holes # 29 and 30 are in this category.

Electric Fault Periphery Region : The sample hole was classified as in the case of the Clearville Fault Periphery Region. Holes # 13, 14, 17, 18, and 21 are in this category.

c) Outside Region : All holes that are located away from the faults. A total of 18 holes are in this category.

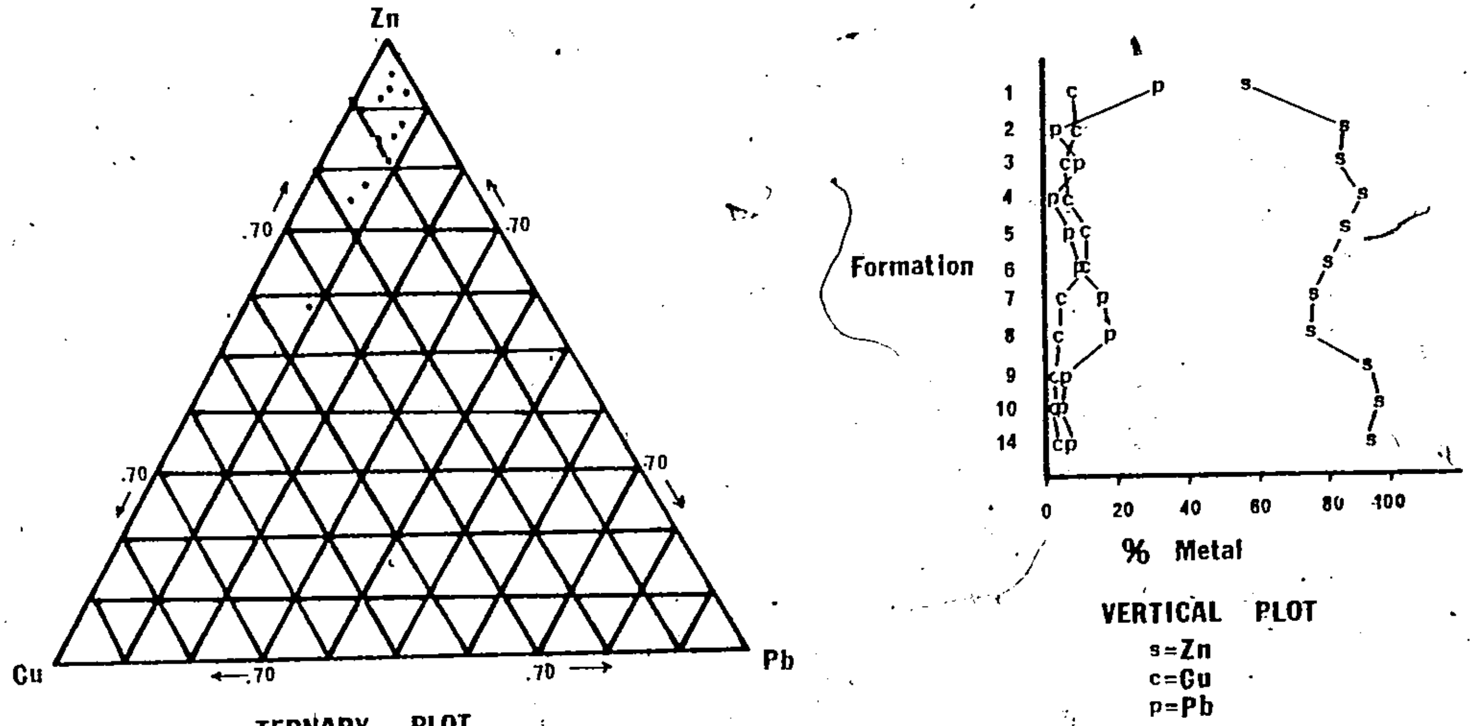
Clearville Fault Region

Figures 11 a) and 11 b) are the ternary diagram and variogram for the Clearville Fault Region respectively. The ternary diagram illustrates a tightly clustered pattern in the Zn portion of the plot. Zn is the most important metal, with Q averaging 0.85 . This is followed by Cu (Q = 0.10) and Pb (Q = 0.05).

The vertical plot is highly variable with Zn concentrations increasing to Group 5. Pb and Cu content both decrease to Group 5. Pb concentrations are the inverse of Zn, while Cu shows little relationship to the other metals.

Clearville Fault Periphery Region

Figures 12 a) and 12 b) are the ternary diagram and variogram for the Clearville Fault Periphery Region. The ternary diagram is a tightly clustered pattern, with Zn the dominant metal (Q = 0.80), followed by Cu (Q = 0.10) and Pb (Q = 0.05) .



TERNARY PLOT

VERTICAL PLOT

FIG:11. TERNARY AND VERTICAL PLOT OF Zn:Cu:Pb FOR THE CLEARVILLE FAULT REGION

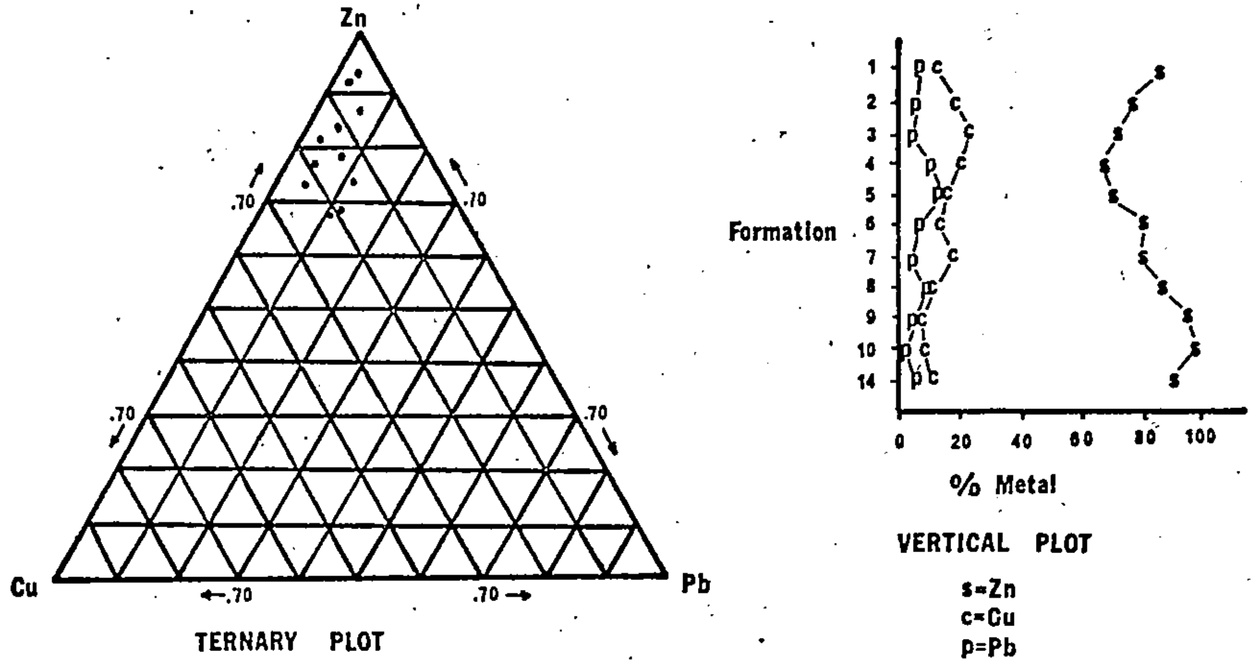


FIG.12.TERNARY AND VERTICAL PLOT OF Zn:Cu:Pb FOR THE CLEARVILLE PERIPHERY REGION

The variogram is not as erratic as that of the Clearville Fault Region. Zn concentrations increase, while Cu content decreases toward Group 5. Pb content shows two distinct patterns. From Groups 1 to 3, Pb behaves similarly to Zn, while in Groups 4 and 5, this metal behaves comparably to that of Cu.

Dover Fault Periphery Region

Figures 13 a) and b) are the ternary diagram and vertical variogram for the Dover Fault Periphery Region. The ternary diagram shows two populations of data. One population is found in the upper three stratigraphic groups, and the other group in the lower two groups. The overall pattern is more scattered than the Clearville Fault Periphery Region. Zn is the dominant metal (Q = 0.70), followed by equal portions of Cu and Pb (Q = 0.15 in both cases). However, the two populations are not very distinct.

The variogram shows that Zn concentrations decrease toward Group 5. In Groups 4 and 5, this decrease is more pronounced. Cu concentrations increase toward Group 5. Pb content decreases toward Group 5, but there is no apparent relationship between Zn and Pb.

Electric Fault Periphery Region

Figures 14 a) and b) are the ternary diagram and

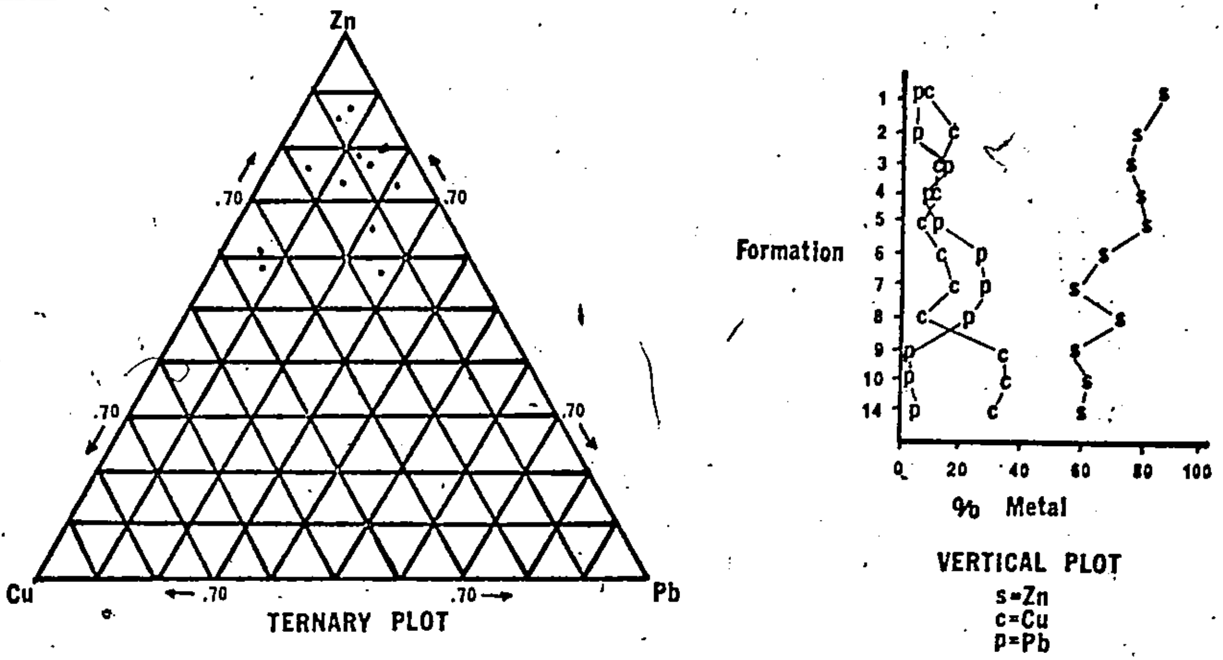


FIG.13.TERNARY AND VERTICAL PLOT OF Zn:Cu:Pb FOR THE DOVER PERIPHERY REGION

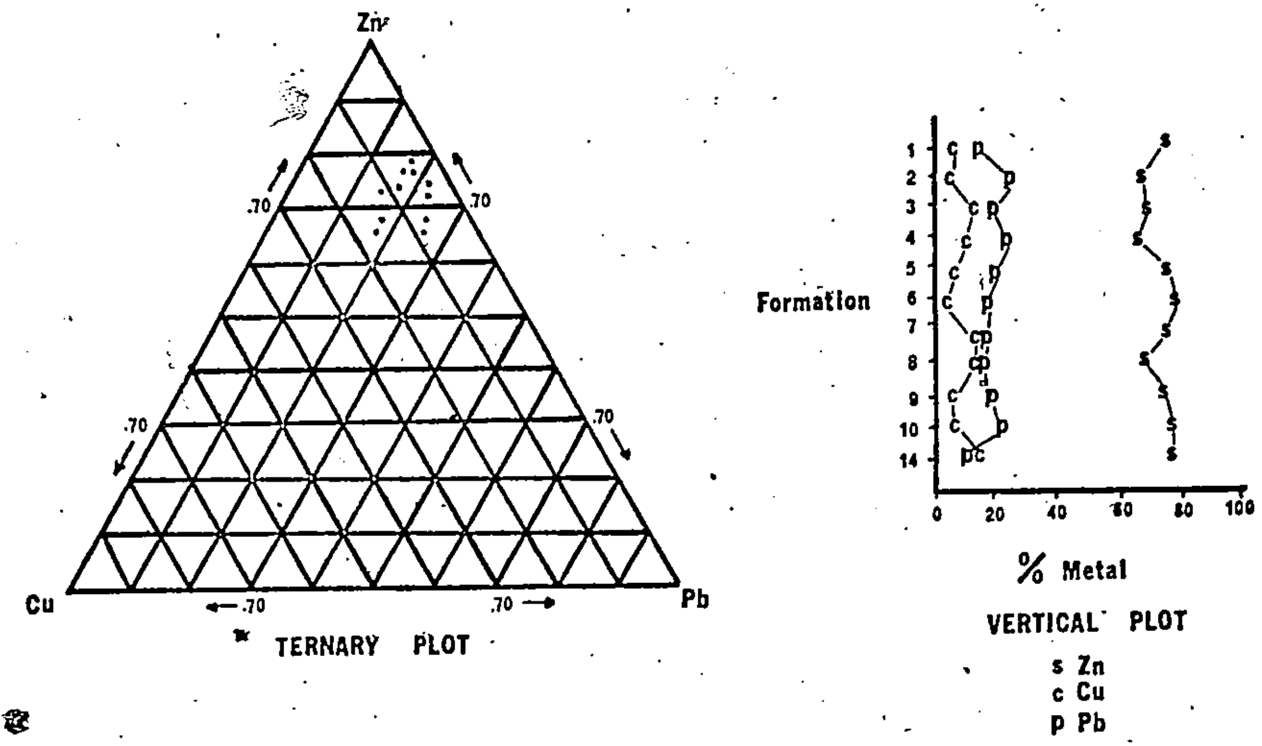


FIG.14. TERNARY AND VERTICAL PLOT OF Zn:Cu:Pb FOR THE ELECTRIC PERIPHERY REGION

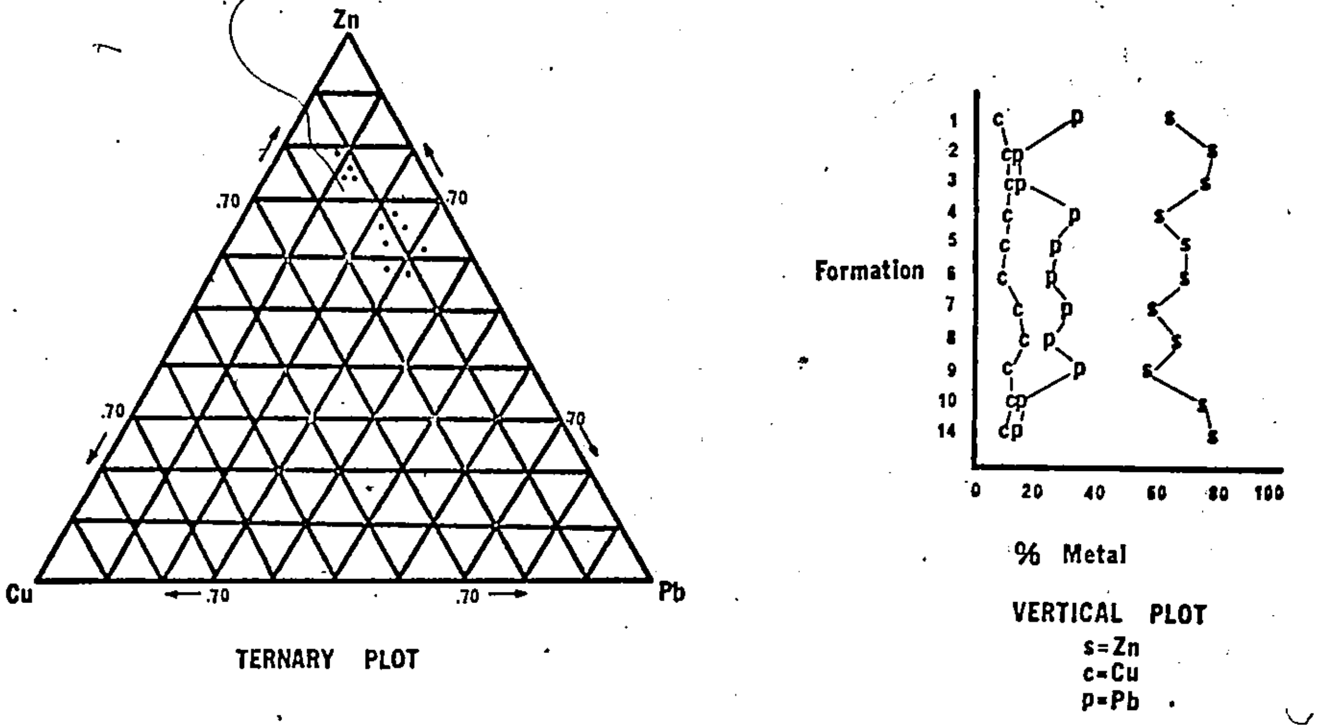
variogram for the Electric Fault Periphery Region. The ternary diagram shows that Zn is the dominant metal (Q = 0.70) in a tightly clustered pattern. This is followed by Pb (Q = 0.20), and finally Cu (Q = 0.10).

The variogram shows that Zn concentrations decrease while Cu content increases toward Group 5. However, Pb concentrations are constant throughout the five groups.

Outside Region

Figures 15 a) and b) are the ternary diagram and vertical variogram for the Outside Region. The ternary plot indicates the presence of two populations of data, as is the case in the Dover Fault Periphery Region plot. However, in the Outside Region, these populations are now quite distinct. The upper population, representing Groups 1, 2, and 3 show dominant Zn (Q = 0. 60), followed by Pb (Q = 0.27). The lower cluster, representing Groups 4 and 5, has a higher Zn content (Q = 0.78), but a much lower Pb content (Q = 0.11). In both clusters, Cu is the least abundant metal (Q = 0.11).

The vertical plot is highly variable with Zn concentrations increasing to Group 5. Cu content is constant throughout the five groups, while Pb concentrations decrease to Group 5.



TERNARY PLOT

VERTICAL PLOT

FIG.15.TERNARY AND VERTICAL PLOT OF Zn:Cu:Pb FOR THE OUTSIDE AREA

All ternary diagrams show a dominance of Zn over Cu and Pb. Only in the Clearville Fault and Fault Periphery Region, is Cu dominant over Pb. In the Dover Fault Periphery and Outside Regions, there is evidence of two populations of data, which are stratigraphically controlled.

CORRELATION COEFFICIENTS

The variograms of the preceeding analysis show possibly related trends of Zn - Cu - Pb variation throughout the stratigraphic sequence. In order to determine and test the validity of these proposed relationships, correlation coefficients for the three metals were determined. The correlation coefficient is a measure of the degree of association between two variables. Its values range from - 1.0 to + 1.0 , indicating a perfectly negative to positive relationship respectively.

Tables 1 to 5 list the arithmetic means, and Tables 6 to 10 contain the correlation coefficients for Zn, Cu, and Pb of each formation, in the five regions.

Three interesting correlations emerge from this analysis. Zn and Pb show a positive correlation in all five regions, with " r " values ranging from 0.61 to 0.82. There is a positive correlation between Zn and Cu in the

TABLE 1

MEANS FOR Zn, Cu, AND Pb FOR THE OUTSIDE REGION

Formation	Zn	Cu	Pb
Queenston	9.6	1.2	4.4
Meaford Dundas	11.5	1.9	1.9
Collingwood	14.1	1.3	1.4
Cobourg	5.5	0.9	2.4
Sherman Fall	8.7	1.4	1.7
Kirkfield	6.6	1.4	1.9
Coboconk	5.5	0.9	1.7
Gull River	4.9	0.8	2.4
Shadow Lake	4.0	0.4	1.4
Trempeauleau	3.6	1.3	1.6
PreCambrian	49.8	4.6	9.1

TABLE 2

MEANS FOR Zn, Cu, AND Pb FOR THE CLEARVILLE FAULT REGION

Formation	Zn	Cu	Pb
Queenston	20.3	11.6	2.4
Meaford Dundas	22.6	1.2	2.0
Collingwood	18.6	2.0	1.1
Cobourg	83.5	2.1	5.4
Sherman Fall	79.3	5.1	8.1
Kirkfield	60.2	7.5	6.4
Coboconk	87.5	17.1	6.4
Gull River	106.7	25.1	5.8
Shadow Lake	383.2	27.3	7.1
Trempeauleau	489.2	11.1	5.9
PreCambrian	527.4	14.1	13.6

TABLE 3

MEANS FOR Zn, Cu, AND Pb FOR THE CLEARVILLE PERIPHERY REGION

Formation	Zn	Cu	Pb
Queenston	76.1	9.4	3.2
Meaford Dundas	65.7	18.7	1.5
Collingwood	63.8	19.6	1.9
Cobourg	57.1	6.4	3.7
Sherman Fall	44.2	7.2	4.5
Kirkfield	113.2	6.1	4.6
Coboconk	147.2	8.7	6.3
Gull River	128.2	7.1	8.0
Shadow Lake	132.6	11.8	3.3
Trempeauleau	148.2	10.5	2.3
PreCambrian	207.9	18.2	4.4

TABLE 4

MEANS FOR Zn, Cu, AND Pb FOR THE DOVER PERHIPHERY REGION

Formation	Zn	Cu	Pb
Queenston	39.9	3.7	1.7
Meaford Dundas	36.9	9.8	1.8
Collingwood	15.5	6.1	2.3
Cobourg	53.7	9.0	2.9
Sherman Fall	38.8	4.7	5.3
Kirkfield	27.1	5.9	6.7
Coboconk	19.4	5.8	6.4
Gull River	22.5	2.5	6.2
Shadow Lake	39.2	5.1	3.4
Trempealeau	74.1	11.7	2.6
PreCambrian	94.7	20.6	3.0

TABLE 5

MEANS FOR Zn, Cu, AND Pb FOR THE ELECTRIC PERIPHERY REGION

Formation	Zn	Cu	Pb
Queenston	18.4	2.3	2.5
Meaford Dundas	28.4	3.3	6.1
Collingwood	32.6	4.9	5.8
Cobourg	35.9	3.4	11.5
Sherman Fall	34.0	1.5	5.8
Kirkfield	106.9	1.4	8.7
Coboconk	69.0	1.9	6.9
Gull River	91.4	3.1	8.7
Shadow Lake	71.6	2.0	7.4
Trempealeau	62.6	1.5	3.5
PreCambrian	138.0	8.2	10.3

TABLE 6

CORRELATION COEFFICIENTS FOR THE OUTSIDE REGION

Metal	Zn	Cu	Pb
Zn	1.0	0.238	0.691
Cu		1.00	0.480
Pb			1.000

TABLE 7

CORRELATION COEFFICIENTS FOR THE CLEARVILLE FAULT PERIPHERY REGION

Metal	Zn	Cu	Pb
Zn	1.000	0.384	0.671
Cu		1.000	0.542
Pb			1.000

TABLE 8

CORRELATION COEFFICIENTS FOR THE DOVER FAULT PERIPHERY REGION

Metal	Zn	Cu	Pb
Zn	1.000	0.414	0.611
Cu		1.000	0.424
Pb			1.000

TABLE 9

CORRELATION COEFFICIENTS FOR THE ELECTRIC FAULT PERIPHERY REGION

Metal	Zn	Cu	Pb
Zn	1.000	0.424	0.648
Cu		1.000	0.448
Pb			1.000

TABLE 10

CORRELATION COEFFICIENTS FOR THE CLEARVILLE FAULT REGION

Metal	Zn	Cu	Pb
Zn	1.000	0.667	0.822
Cu		1.000	0.844
Pb			1.000

Clearville Fault Region only. Here, an " r " value of 0.67 is recorded. Cu and Pb show a positive correlation only in the Clearville Fault and Fault Periphery Regions, with " r " values of 0.84 and 0.52, respectively.

DISCRIMINANT ANALYSIS

Discriminant analysis was performed to determine the presence of individual populations within the sample data. Briefly, this method of analysis classifies an individual data point into a group, for which its estimated probability density is greatest. The computational procedure evaluates the linear function, corresponding to each of the groups. It then assigns the individual data point to the group for which the calculated density value is greatest. In this way, the linear function is used an an index of discrimination between groups or populations of data. An excellent rendition of theory and practice can be found in Anderson (1958), and Anderson et al. (1965).

In general, the five regions can be placed into three categories : Fault, Fault Periphery, and Outside. From this, the following category pairs were developed:

Case I	Fault : Fault Periphery
Case II	Fault Periphery : Outside
Case III	Fault : Outside

TABLE 11

MEANS AND STANDARD DEVIATIONS FOR CASE I

Metal	Fault Mean	Fault Per. Mean	Difference	Fault Std. Dev.	Fault Per. Std. Dev.
Zn	170.77	79.53	91.24	252.53	98.39
Cu	11.73	10.24	1.49	14.62	14.14
Pb	5.75	5.69	0.06	6.61	7.64

TABLE 12

THRESHOLD AND ANOMALY VALUES FOR CASE I

	Fault			Fault Periphery		
	Zn	Cu	Pb	Zn	Cu	Pb
Mean	170.77	11.73	5.75	79,53	10.24	5.69
Threshold	675.83	40.97	18.97	276.31	38.52	20.07
Anomaly	928.36	55.59	25.58	374.70	52.66	28.61

Case I Fault : Fault Periphery

Table 11 contains category means for Zn, Cu, and Pb, as well as standard deviations and differences between the means. From this, one can see that anomalous differences occur only for the Zn category means.

Table 12 lists the threshold and anomaly values for Case I. In this instance, the anomaly values for the Fault category were compared with actual Zn, Cu, and Pb concentrations in the fault hole. Anomalous Zn concentrations occurred in the Shadow Lake, Trempealeau, and PreCambrian Formations of hole # 25.

Overall ranking of the two categories indicate only metal concentrations of the Shadow Lake, Trempealeau, and PreCambrian Formations of the Fault category are separate from the main body of values. This differentiation occurred for the metal pairs Zn : Cu , and Zn : Pb.

Very little difference exists between the Fault and Fault Periphery categories. There are no Pb or Cu concentrations exceeding the threshold limits set out in Table 12. Only Zn concentrations in the Shadow Lake, Trempealeau, and PreCambrian Formations of hole # 25 are anomalous. This is due in part to the proximity of the PreCambrian basement.

TABLE 13

MEANS AND STANDARD DEVIATIONS FOR CASE II

Metal	Fault Per. Mean	Outside Mean	Difference	Fault Per. Std. Dev.	Outside Std. Dev.
Zn	79.53	10.46	68.84	98.39	10.20
Cu	10.24	2.35	7.86	14.14	2.89
Pb	5.69	2.87	2.77	7.64	2.47

TABLE 14

THRESHOLD AND ANOMALY VALUES FOR CASE II

	Fault Periphery			Outside		
	Zn	Cu	Pb	Zn	Cu	Pb
Mean	79.34	10.24	5.69	10.46	2.35	2.87
Threshold	276.31	38.52	20.97	30.86	5.24	5.34
Anomaly	374.70	52.66	28.61	41.06	8.13	7.81

Case II Fault Periphery : Outside

Table 13 lists the category means for Zn, Cu, and Pb as well as standard deviations and differences between the category means for this case. There are significant differences between the category means for all three metals.

Table 14 contains the threshold and anomaly values for Case II . The anomaly values for the Outside category were compared to the Zn, Cu, and Pb concentrations of the Fault Periphery . Anomalous concentrations of Zn and Cu in the Fault Periphery category consistently occur. As older formations are penetrated, the number of sample holes with anomalous Zn and Cu content increase markedly. In the PreCambrian Formation, over 50% of all sample holes show anomalous concentrations.

Anomalous Pb concentrations occur in the Fault Periphery category, in the Kirkfield, Coboconk, and Gull River Formations of the Dover Fault Periphery Region only.

Ranking of the two categories for the metal pairs Zn : Cu and Zn : Pb show that 75% of the Fault Periphery values are distinct from the Outside values. The remainder of the Fault Periphery values form a transition zone between the two categories.

Ranking of values for the metal pair Cu : Pb indicates that very few Fault Periphery values are separate from the Outside category values.

TABLE 15

MEANS AND STANDARD DEVIATIONS FOR CASE III

Metal	Fault Mean	Outside Mean	Difference	Fault Std. Dev.	Outside Std. Dev.
Zn	170.77	10.68	160.08	252.53	10.20
Cu	11.52	2.36	9.35	14.62	2.89
Pb	5.75	2.91	2.83	6.61	2.47

TABLE 16

THRESHOLD AND ANOMALY VALUES FOR CASE III

	Fault			Outside		
	Zn	Cu	Pb	Zn	Cu	Pb
Mean	170.77	11.73	5.75	10.46	2.35	2.87
Threshold	675.83	40.97	18.97	30.86	5.24	5.34
Anomaly	928.36	55.59	25.58	41.06	8.13	7.81

Case III Fault : Outside

The validity of using the Fault category, based on only one hole is questionable. However, results from analysis of this case indicate that its usage is justified.

Table 15 contains the category means, standard deviation, and differences between means for Zn, Cu, and Pb. Again, there are significant differences between Zn, Cu, and Pb means for the two categories.

Table 16 lists the threshold and anomaly values for this case. Except for Formations 1, 2, and 3 (see Figure 2), all Zn and Cu values in the Fault category exceed the anomaly values of the Outside category. The upper three formations form a transition zone between the two categories. Anomalous Pb concentrations are seen only in the Cobourg, Gull River, and PreCambrian Formations of the Fault category.

Ranking of the metal pairs Zn : Cu and Zn : Pb illustrate the same pattern as above. Ranking the metal pair Cu : Pb indicates that only Formations 1, 2, and 3 of the Fault category are distinct from the Outside category.

Step - wise discriminant analysis was then performed on the data, in order to generate canonical variables, which will indicate the presence of one or more populations in the data.

The plot of canonical variables for Zn, Cu, and Pb in the three categories is seen in Figure 16.

The plot indicates that two separate populations occur in the study area; one comprised of the Fault and Fault Periphery categories, and the other formed from the Outside category. The development of two populations is also seen in the distinct differences found in the ranking of various cases.

Results of discriminant analysis suggest several mechanisms, which may influence metal distribution in these rocks. The anomalous Zn concentrations in the Shadow Lake, Trempealeau, and PreCambrian Formations of the Fault category are due to the influence of the PreCambrian basement. The presence of residual brines with high concentrations of Zn may be locally important as well.

Zn and Cu concentrations show a definite separation between the Fault and Outside categories. On the other hand, the separation of Pb concentrations in these two categories is not as distinctive. This may be due to an overall lack of Pb in the original metal supply, or selective leaching of Pb after diagenesis.

The similarity of the Fault and Fault Periphery categories, as a whole, indicates lateral migration of metals by groundwaters. Metal concentrations tend to be uniform and continuous in beds of good porosity and permeability. Since there is little difference between

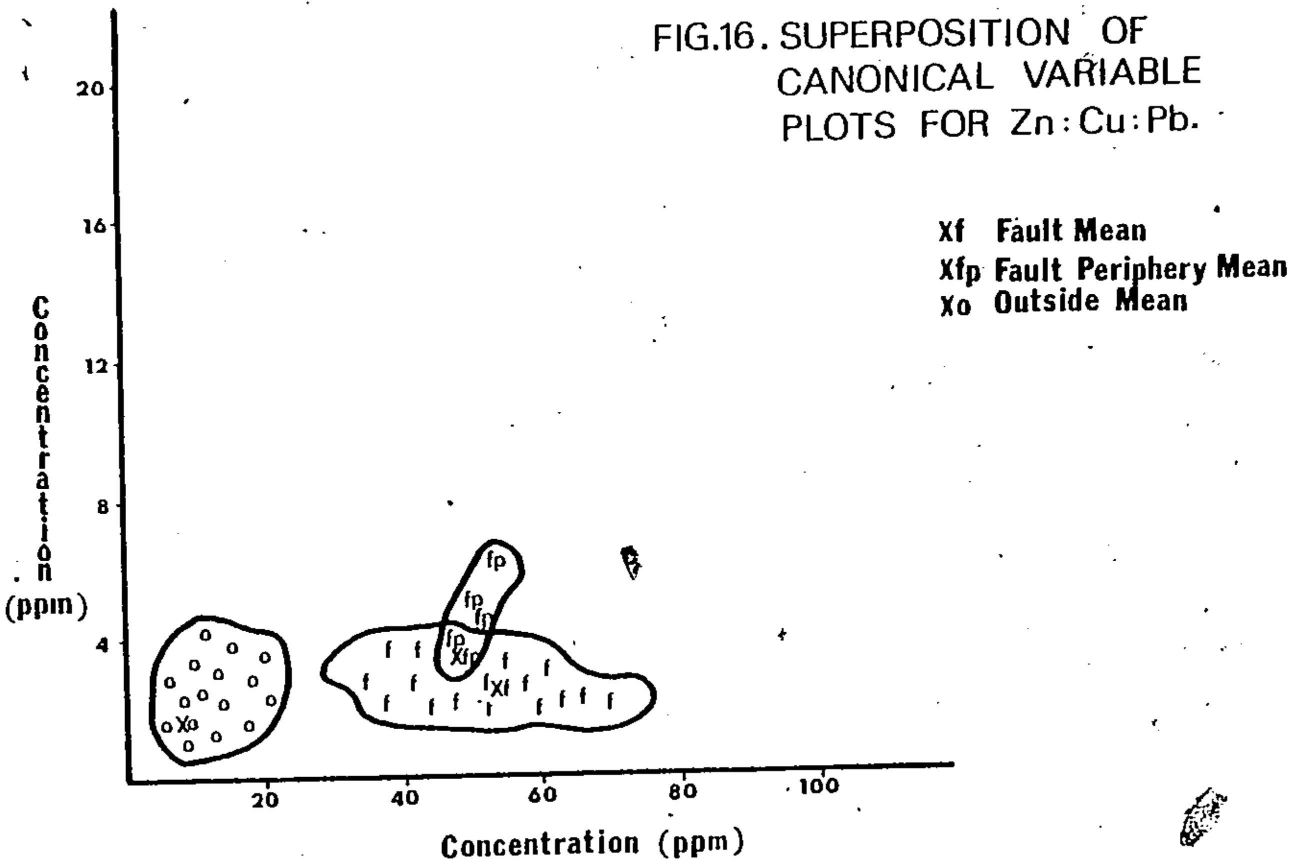


FIG.16. SUPERPOSITION OF CANONICAL VARIABLE PLOTS FOR Zn:Cu:Pb.

the Fault and Fault Periphery categories, porosity and permeability is high enough to allow for lateral migration of metals away from the fault. A good example of this is in the Cobourg Formation of the Clearville Fault Region. In hole # 25, the porosity of this formation exceeds 10%. The Cobourg Formation is highly dolomitized and possesses good horizontal permeability. Little difference can be seen in the Zn and Cu concentrations between holes # 24 and # 25.

Different lithologies have certain affinities for Zn, Cu, and Pb. Marine shales, such as the Meaford.- Dundas Formation, attract significant concentrations of Zn and Cu, with minor Pb. The average content of these metals for this type of lithology is 33.0 ppm Zn, 6.9 ppm Cu, and 2.7 ppm Pb. Organic - rich shales, such as the Collingwood Formation also contain large concentrations of Zn and Cu, with minor Pb. Average metal content for this lithology is 38.9 ppm Zn, 6.8 ppm Cu, and 2.5 ppm Pb. Carbonate rocks tend to attract higher concentrations of Zn and Pb than do shales . Average metal content of carbonates is 57.5 ppm Zn, 4.0 ppm Cu, and 7.6 ppm Pb. Shales appear to have a stronger affinity for Cu than do carbonates. In general, these two lithologies are not very distinctive, because carbonate rocks include a variable amount of shale.

Clastic sediments, such as sandstones and arkoses show a high concentration of Zn and Cu, but not Pb. Average metal contents for this lithology include 70.4 ppm Zn, 6.3 ppm Cu, and 3.1 ppm Pb. The high concentrations of Zn and Cu reflect the influence of the PreCambrian basement. The low affinity for Pb is somewhat puzzling. The PreCambrian basement has a fair amount of K - feldspar as a constituent mineral. According to Helgeson (1964), this mineral serves as a source of Pb in various clastic sediments, such as arkoses and sandstones. The low concentrations of Pb in the clastic sediments of the study area indicate that any available Pb is easily complexed and carried off. It may also mean that local sandstones contain little K - feldspar, or K - feldspar which is low in Pb .

LATERAL MIGRATION OF METALS ACROSS THE CLEARVILLE FAULT ZONE

Lateral variation studies were done in order to examine the variation in Zn, Cu, and Pb with respect to both lateral and vertical components. Figures 17 to 20 illustrate the lateral variation of these metals across the Clearville Fault block, in terms of stratigraphic groups. The location of holes # 24, 25, 26, and 27 can be seen in Figure 1.

Table 17 lists the average concentrations of Zn, Cu, and Pb in various types of carbonate rocks, from Hawkes and Webb (1962).

Figures 17 to 20 show the distribution of Zn, Cu, and Pb stratigraphically. As one examines each group in turn, it becomes apparent that Zn is the most abundant and variable metal, followed by Cu and Pb. This variability is due to the relative mobilities of the three metals in various environments.

Overall enrichment of Zn along the fault zone occurs initially, in the Trenton Group, where Zn concentrations are from 2 to 4 times as high as the limits set out in Table 17. In the Shadow Lake - PreCambrian composite Groups, Zn is enriched some 10 times. In all groups, Cu and Pb concentrations fall within the limits, as set out in Table 17.

TABLE 17

AVERAGE CONCENTRATIONS OF Zn, Cu, AND Pb FOR SEDIMENTARY ROCKS

Metal (ppm)	Limestone	Sandstone	Shale	Black Shale
Zn	4 - 20	5 - 20	50 - 300	100 - 1000
Cu	5 - 20	10 - 40	30 - 150	20 - 3000
Pb	5 - 10	10 - 40	30 - 150	20 - 400

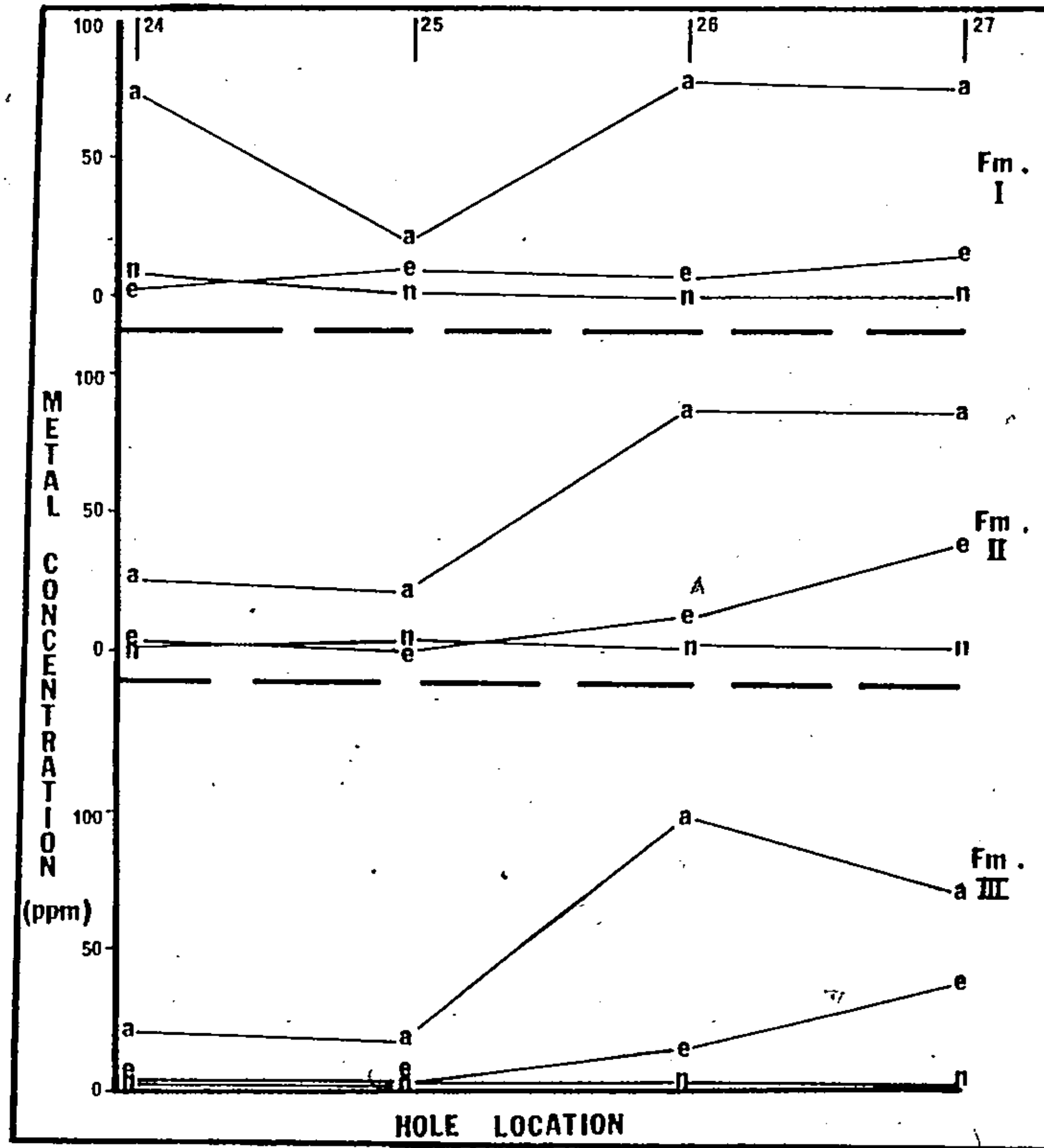


FIG.17: VARIATION OF Zn,Cu,AND Pb ACROSS THE CLEARVILLE FAULT ZONE (Upper Shales)

KEY

I = Queenston Fm.
II = Meaford-Dundas Fm.
III = Collingwood Fm.

a = Zn.
e = Cu.
n = Pb.

FIG. 18. VARIATION OF Zn, Cu, AND Pb ACROSS THE CLEARVILLE FAULT ZONE (TRENTON GROUP)

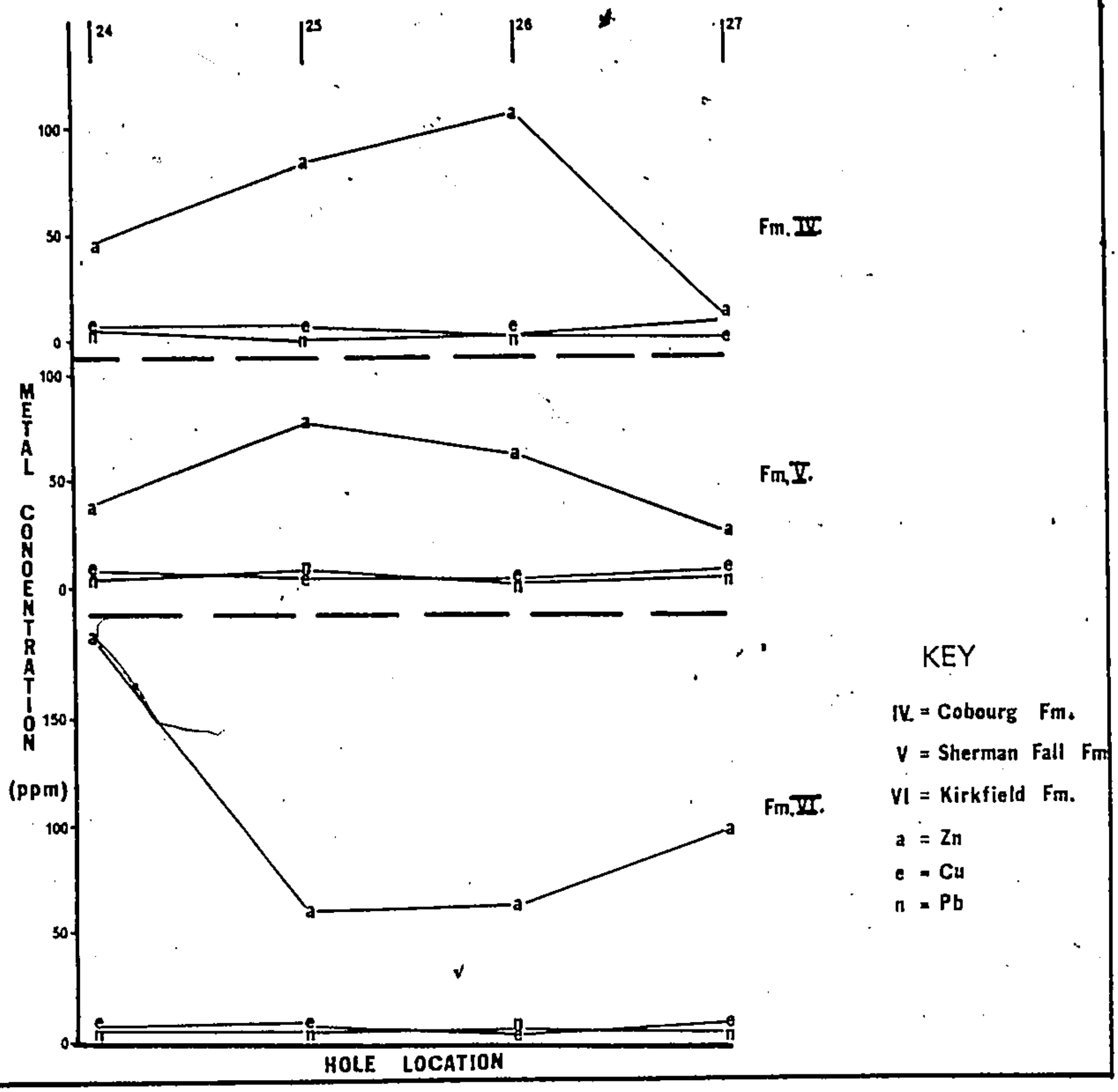


FIG. 19. VARIATION OF Zn, Cu, AND Pb ACROSS THE CLEARVILLE FAULT ZONE (Black River Grp.)

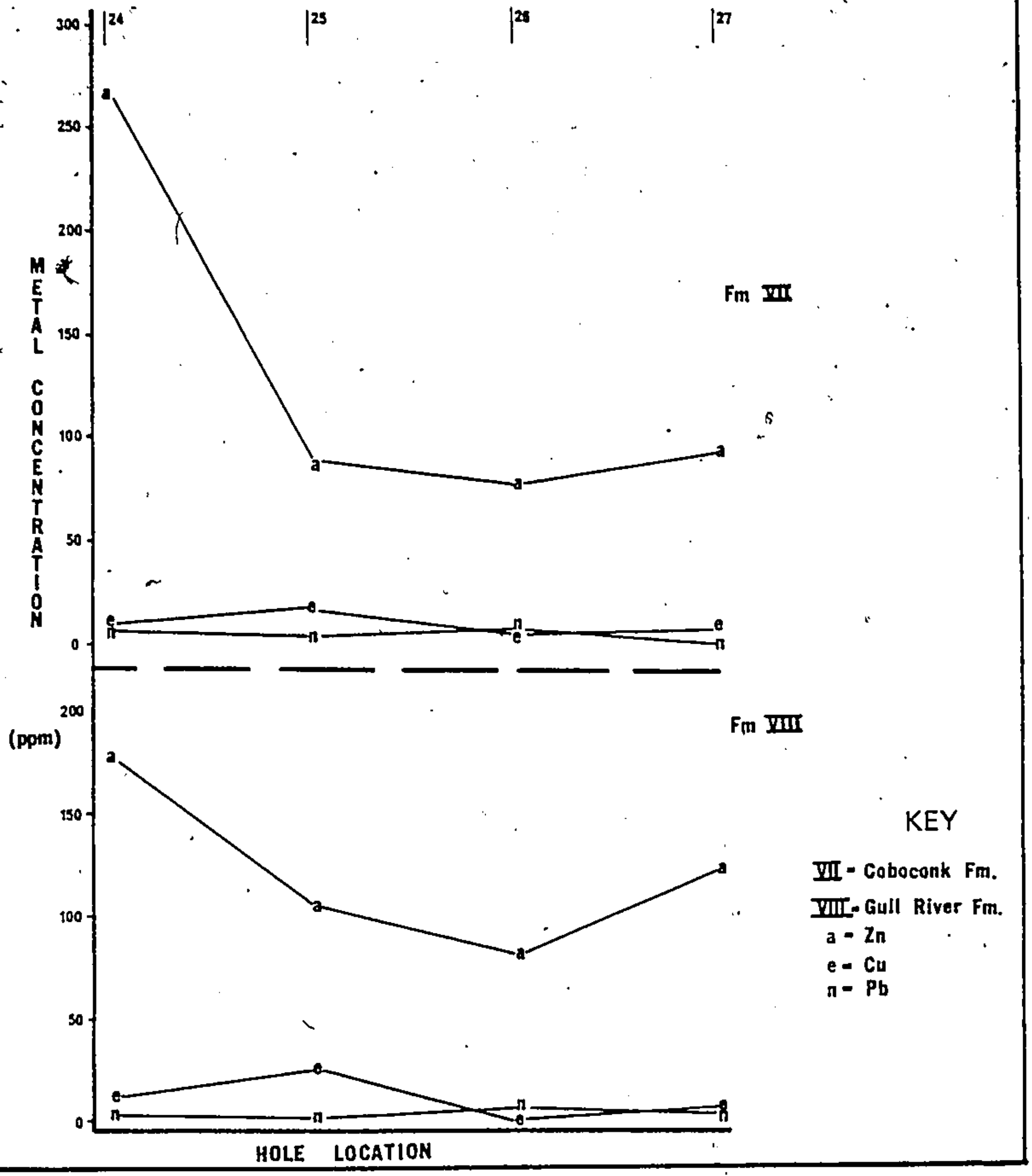
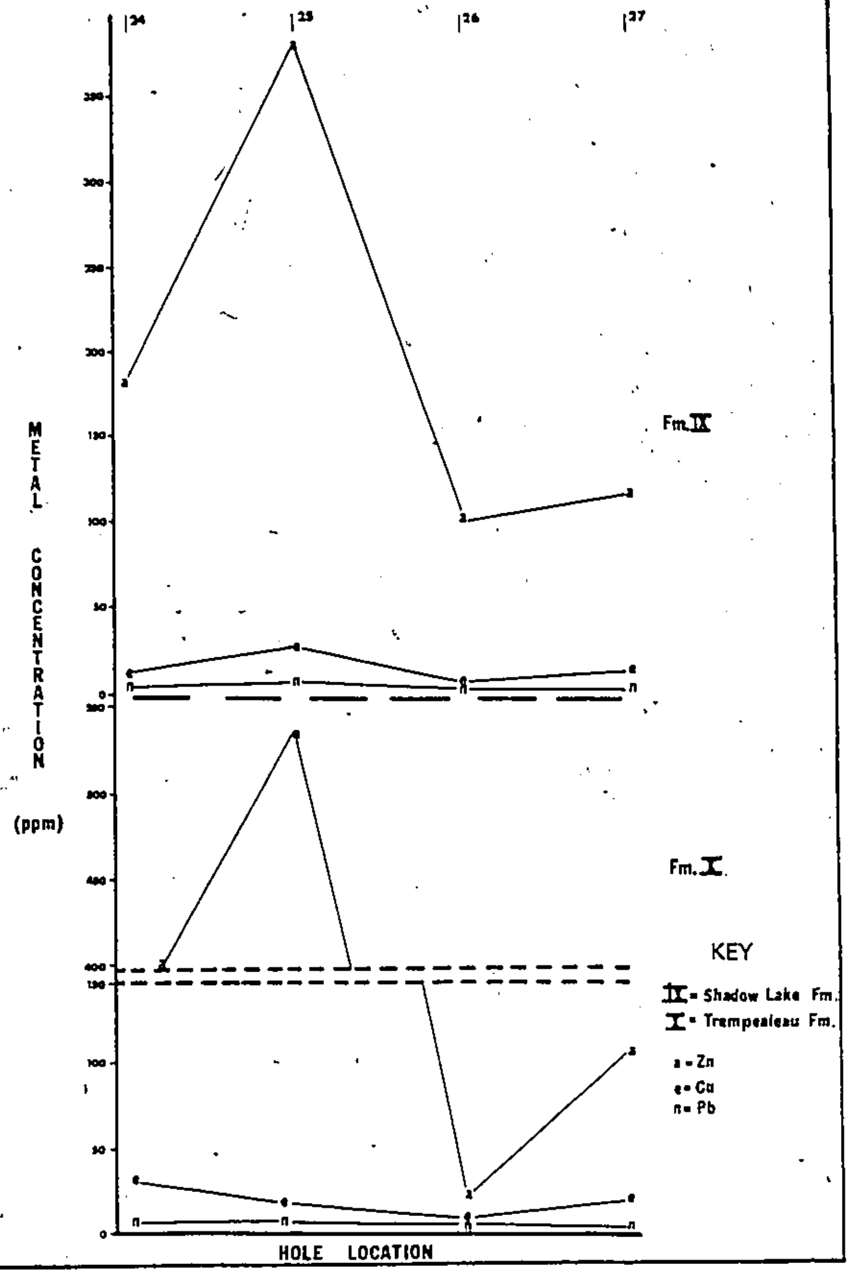


FIG. 20 VARIATION OF Zn Cu AND Pb ACROSS THE CLEARVILLE FAULT ZONE (Shadow Lake Grp.)



The Upper Shales, Trenton, and Black River Groups appear to have their metal distribution patterns controlled by local micro-environments. Each lithologic group represents a vertical and lateral geochemical barrier to migrating metal complexes. Therefore, these lithologic groups present a very complex geochemical picture.

On the other hand, the Shadow Lake and PreCambrian Groups show the overall influence of the PreCambrian basement on Zn and Cu concentrations. This is especially apparent when hole # 25 is compared to surrounding holes.

The presence of the Clearville Fault plays an important part in the distribution of metals in the fault block. In the lower stratigraphic groups, the fault provides a ready conduit for the upward migration of metals from the basement. Lateral migration of metals is not great from the fault into surrounding areas, except in the Cambrian clastic rocks. In the upper three groups however, local micro-environments of deposition appear to be of importance. Lateral migration from the fault into surrounding areas is better, since metal concentrations appear to be more uniform.

FACTOR ANALYSIS

Since statistical analysis and correlations between two variables tells us little about the causal connection between them, further analysis was required. By employing factor analysis, we are able to study the intercorrelations between all analysed elements and delineate the number of causal factors which help to explain the observed data patterns.

Several applications of factor analysis to problem solving in geology have been made in the last twenty years. Among these, are works by Imbrie and Van Andel (1964),as well as Klovan (1966) and McCammon (1967) .

The first portion of factor analysis, according to Klovan (1966), involves an algebraic solution to the question about the total number of factors required to represent all correlations. This constitutes the so-called " R Mode " type of analysis. Here attention is paid to the correlation coefficients between the variables. The initial starting point of factor analysis is a matrix representing the correlation coefficients for all variable pairs. This matrix contains all information concerning variable relationships.

The second portion of this analysis is the " Q Mode." section, in which the correlation coefficient matrix is transformed into a factor matrix, by employing the

" method of principle components " . The resulting variable factor matrix undergoes further transformation or rotation, thereby yielding a factor score matrix. This matrix tells us how much a factor or causal influence affects each variable's behaviour. This factor is a hypothetical component, governed by the following empirical formula:

$$f \leqq n - \text{delta}$$

f = no. of factors
n = no. of variables
delta = a triangular number (1, 3, 6, 9, ...) which does not exceed n in value.

In this study, nine variables were analysed and their intercorrelations were reduced algebraically to three factors by the above metioned rule. Further analysis of any non - change correlations may yield a smaller number of factors, than generated by the formula. In this case, two factors may account fo[illegible]he bulk of variation in various relationships, rather than three factors generated algebraically. This reduction occurs in analysis of the fault zone.

This mode of analysis is followed by a closer examination of the associations of variables, represented by each factor.

As is the case in discriminant analysis, there are three potential categories in the study area, namely the Fault, Fault Periphery, and Outside categories.

In the Outside category, 209 samples for 19 holes were evaluated. The squared multiple correlations for each variable are not significant, except that of Fe ($r^2 = 0.54$) . A numerical measurement of the overall sampling adequacy of this category was then completed to ensure a good representation of the group. This is known as the Mean Sampling Adequacy (MSA). For the Outside category, this value is 0.66, which is fair for the overall number of samples.

Before matrix transformation, three factors explained 58.0% of the total variance. After transformation and rotation, Factors 1, 2, and 3 accounted for 52.9% of the total variance. This leaves some 47% of the remaining variation to be explained by the other six minor factors.

In the Fault Periphery category, 110 samples for 10 holes were analysed. The squared multiple correlations of each variable again are not significant, except that of Cr and Mn ($r^2 = 0.997$ in both cases) . The MSA for this category is 0.51, which is some 15% lower than the MSA for the previous category. This may be accounted for by a 45% reduction in the total sample size.

Initial factor analysis indicates that some 58.8% of the variance seen is explained by three factors. After rotation, Factors 1, 2, and 3 explained 57.8% of the total variance of the factor matrix. This leaves 41.2% of the remaining variation to be explained by the other six factors. These three factors account for some 6% more of the overall variance, as compared with the Outside category.

The Fault category contains a sum total of 11 samples for one hole. The squared multiple correlations for all variables are significant for the first time. In all cases, r^2 values are greater than 0.50 . However, the MSA is understandably low at 0.38 , which may be explained by the small sample size.

Initial factor analysis of this category indicates that only two factors are dominant, and explain 72.6% of the total variation in the unrotated matrix, and a resulting 58.0% of the variation after rotation. This indicates that there is some control on variation exercised by a small number of factors. It may also indicate that a distorted picture is developing, due to a lack of sample data.

Tables 18, 19, and 20 list the factor scores for each metal under study in all three categories. Bar graphs of the data were then drawn to further evaluate any interrelationships between various elements. These are seen in Figures 21, 22, and 23.

The bar graphs and tables show several interesting relationships. A number of metal sets are discussed and examined in more detail.

TABLE 18

FACTOR SCORE COEFFICIENTS FOR CASE I

Variable	Factor 1	Factor 2	Factor 3
Zn	0.245	0.088	-0.054
Cu	-0.106	0.489	0.209
Pb	0.322	0.054	0.242
Ni	0.434	-0.121	0.041
Cr	0.409	-0.206	-0.065
Mn	-0.152	0.397	-0.012
Fe	0.091	0.317	-0.084
Ca	-0.052	-0.097	0.464
Mg	0.102	0.123	0.640

TABLE 19

FACTOR SCORE COEFFICIENTS FOR CASE II

Variable	Factor 1	Factor 2	Factor 3
Zn	-0.046	0.201	0.284
Cu	0.048	0.379	-0.068
Pb	0.000	-0.089	0.378
Ni	0.075	0.081	0.385
Cr	0.489	0.081	-0.009
Mn	0.490	0.027	-0.015
Fe	-0.009	0.382	0.163
Ca	-0.006	-0.386	0.191
Mg	-0.088	-0.173	0.330

TABLE 20

FACTOR SCORE COEFFICIENTS FOR CASE III

Variable	Factor 1	Factor 2
Zn	0.061	0.401
Cu	0.238	0.067
Pb	0.159	0.283
Ni	-0.044	0.311
Cr	0.000	0.000
Mn	-0.232	0.085
Fe	-0.191	0.079
Ca	0.177	-0.315
Mg	0.254	0.054

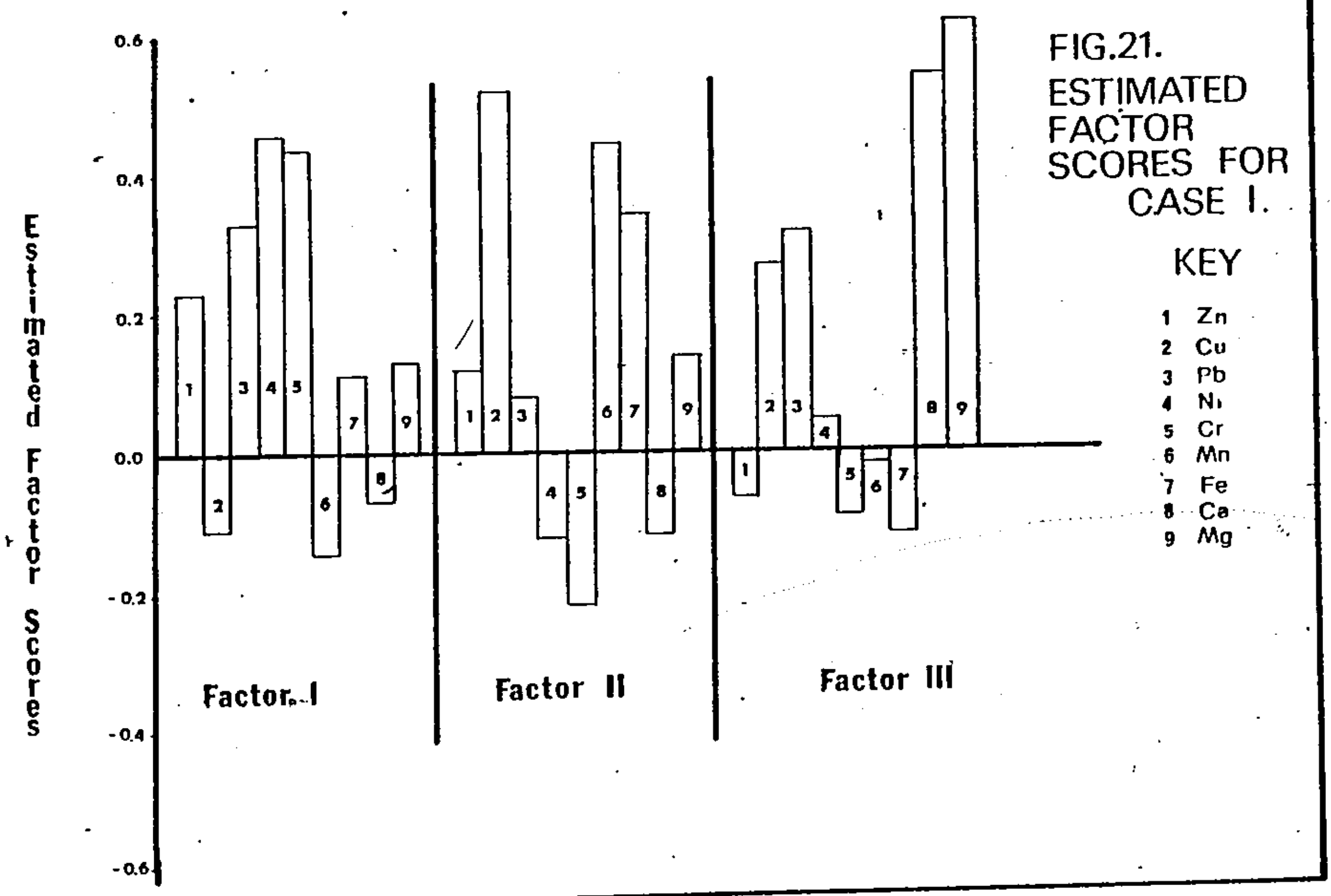


FIG.21. ESTIMATED FACTOR SCORES FOR CASE I.

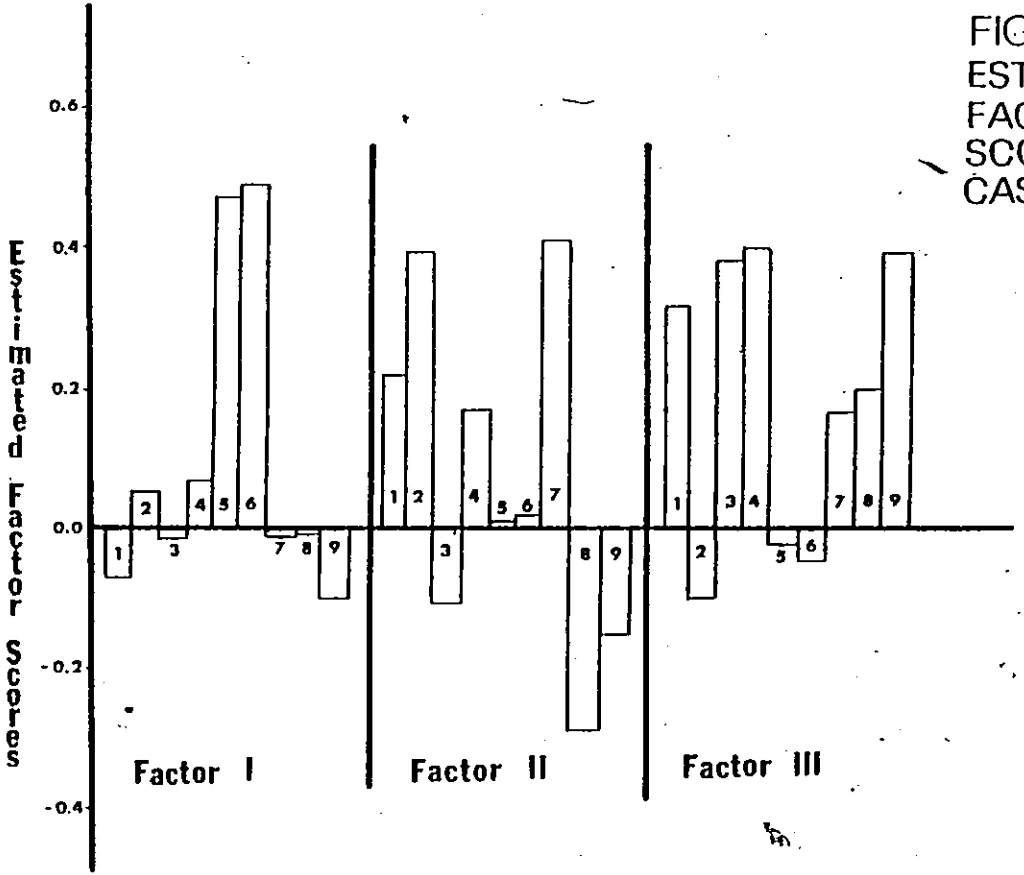


FIG.22. ESTIMATED FACTOR SCORES FOR CASE II

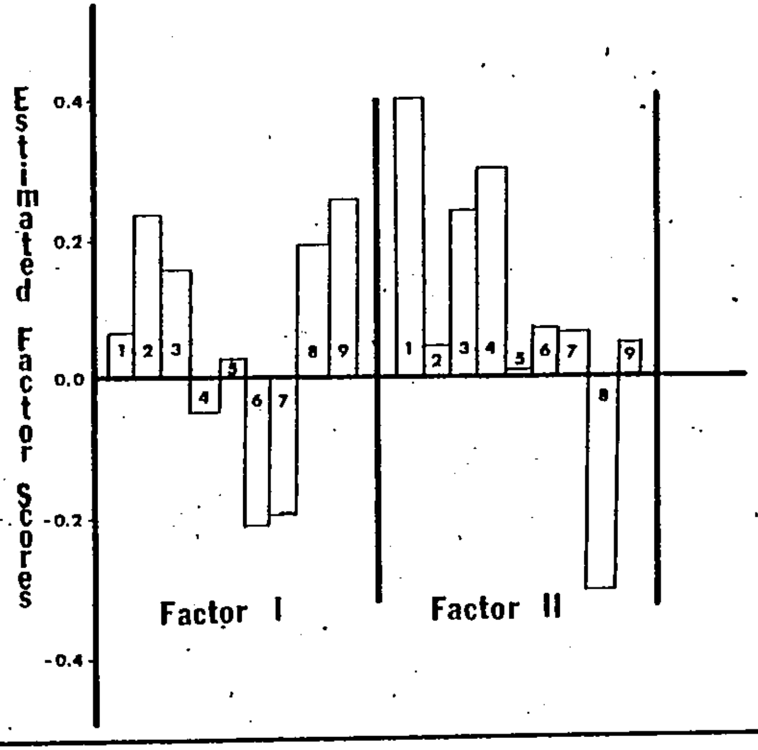


FIG.23.
ESTIMATED FACTOR
SCORES FOR
CASE III

Zn - Pb - Ni

Since these metals are chalcophile in nature, they are thought to behave in a similar manner. The trend +Zn + Pb +Ni is dominant in the Fault and portions of the Fault Periphery categories. This indicates that overall enrichment of these metals is due to the presence of the major faults. The second trend of +Zn +Pb -Ni is prevalent in the Outside and parts of the Fault Periphery categories and indicate the normal distribution of these metals away from the fault zones. Therefore, it appears the Ni enrichment occurs in association with major fault zones, and is derived from the PreCambrian basement.

Ni - Cr

Association of these two metals in mafic to ultramafic rocks is well known. The trend +Ni -Cr is dominant in the Fault and Fault Periphery categories. The trend +Ni +Cr is found in the Outside category. These two trends indicate that in the fault zones, Cr appears not to be related to Ni, and is probably not derived from the basement. In the Outside category, the strong association of Ni and Cr reflects the normal association of these metals. However, this discussion should be treated with caution, since concentrations of Cr and to some extent, Ni are quite low.

Ni - Fe - Mn

In the Fault and Fault Periphery categories, the dominant trend is +Fe +Mn +Ni. In the Outside category, the trend of +Fe +Mn -Ni is found in conjunction with the first trend. In the fault zone, Ni is affected by the presence of the scavenger oxides of Fe and Mn, as well as the presence of the PreCambrian basement. In the Outside category, the presence of Fe and Mn is not as noticeable. However, since little Ni is present, it would be difficult to draw any conclusions.

Cr - Mn - Fe

In the Fault and Fault Periphery categories, the trend +Fe +Mn +Cr is dominant. In the Outside category, however, the trend of +Fe +Mn -Cr is found. Away from the fault zones, Cr is only partially affected by the presence of Fe and Mn, whereas Ni is not. In the Fault category, Cr is strongly tied up with Fe and Mn.

There is a dichotomy in Cr : Mn and Cr : Fe in the various categories. Where Fe is low, there is no relationship between Cr and Mn. Therefore, it appears that both Ni and Cr are affected more by the presence of Fe than by Mn.

Zn - Cu - Pb

Since the metals of this set are strongly chalcophile in nature, it is expected that they should behave similarly. In the Outside category, the dominant trend is +Zn +Pb -Cu. In the Fault and Fault Periphery categories, the trend +Zn +Pb +Cu is important. In the latter case, the strong association of all metals indicates a possible influx of Cu from the basement, which may obliterate the pattern seen in the Outside category.

Mn - Fe - Cu

In the Outside and Fault categories, the dominant trend is +Fe +Mn +Cu. This indicates that Cu is partially controlled by the presence of Fe and Mn. However, an influx of Cu from the basement may alter this pattern and yield a distorted picture.

Ca - Mg

In the Outside category, there is a dominant trend of +Ca +Mg , which illustrates the natural association of these metals in carbonate rocks. In the Fault category, the trend +Mg -Ca is dominant. This trend indicates the dolomitization of the carbonates occurs along the fault zones. In the Fault Periphery category, both trends appear.

Following this analysis, the average estimated factor scores for each of the categories were found and plotted in Figure 24. From this, a general model was patterned.

In terms of average scores, the basement rocks exhibited the highest values (1.7+), followed by the shales (0.55), the Cambrian clastic rocks (0.40), and finally , the carbonates of the Trenton and Black River Groups (0.25) .

The carbonate rocks show highly divergent factor scores, due to the variation in their lithologic composition. The shales and PreCambrian rocks tend to show the least variation, due to a minimum in compositional make up. However, differences in estimated factor scores for different portions of the PreCambrian basement may mirror the gradual change in lithology from Essex to Kent Counties.

This factor analysis substantiates earlier findings based on the analysis of Zn, Cu, and Pb. It also introduces the effect of the other analysed metals on the distribution of Zn, Cu, and Pb. Several metal associations become apparent. Ni is removed from the PreCambrian basement, and introduced into overlying rocks along the fault zones. In other areas, Cu, Ni, and Cr appear to be affected by the presence of Fe and Mn. Ca and Mg relationships are typical for carbonates and for dolomitized zones .

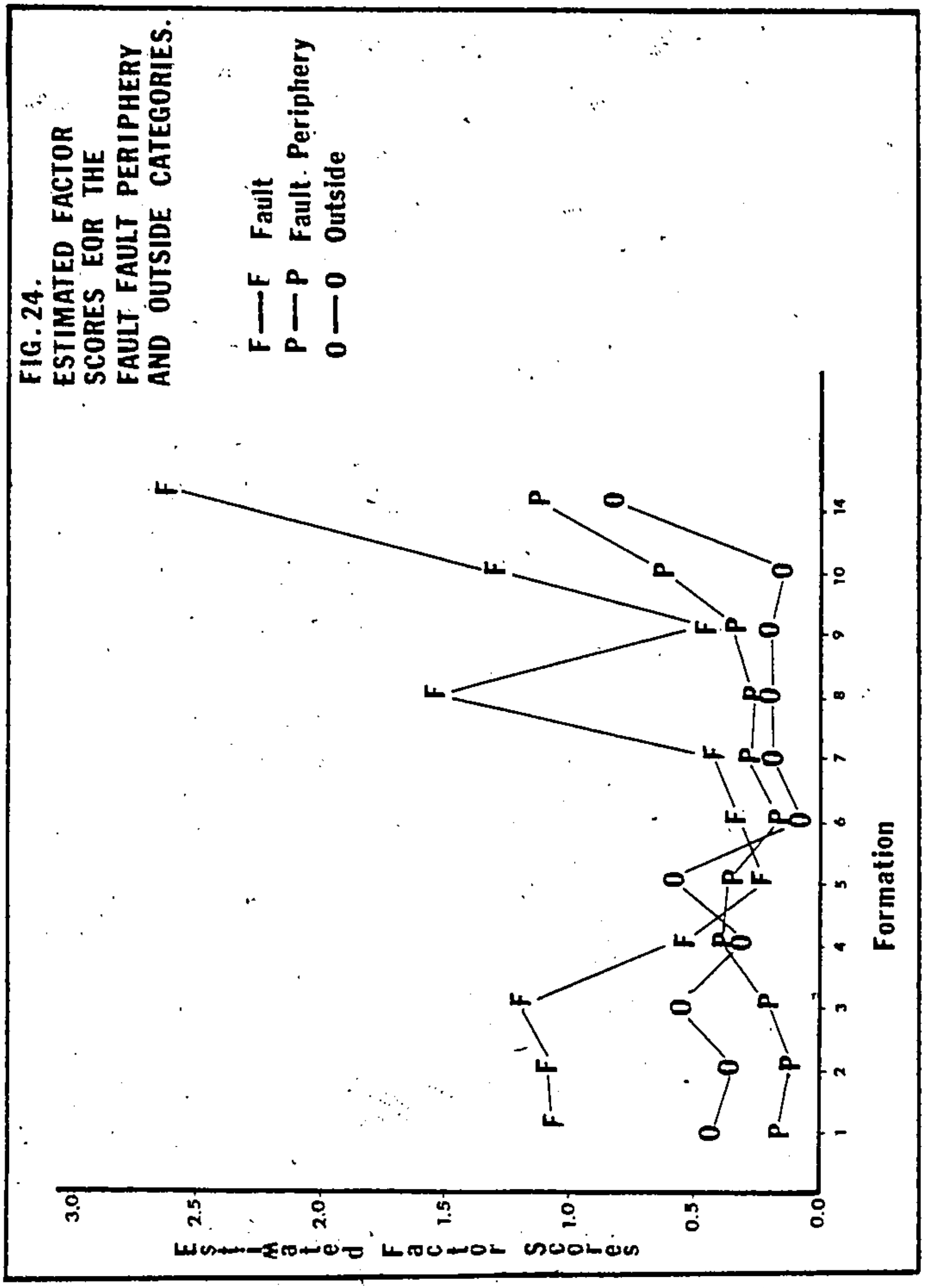


FIG. 24.
ESTIMATED FACTOR SCORES FOR THE FAULT FAULT PERIPHERY AND OUTSIDE CATEGORIES.

MAJOR Pb - Zn DEPOSITS IN CARBONATE STRATA

Deposits of Pb and Zn are common in carbonate rocks. Examples from North America include the Pine Point deposit of Canada (Campbell, 1965), and the Tri State deposits of the midwestern United States (Heyle, 1964) ; both of which are Devonian in age. Ordovician Pb - Zn deposits occur in the Knox Group in Tennessee and Kentucky (Hoagland, 1964). European examples range from Devonian to Carboniferous in age, and include the deposits in the Calcareous Alps of Austria (Schneider, 1966) and France (Amstutz, 1964), as well as large occurrences in Poland (Berce, 1964), as well as those in the Western Carpathian Mountains of Czechoslovakia (Duhovnik, 1964).

An extensive survey of Pb - Zn deposits in carbonate rocks was completed by Sangster and Lancaster (1976), who classify them into two groups. The first is called the stratabound type of occurrence, created after the formation and diagenesis of the carbonate host rock. Examples of this type include the deposits of Tennessee and Kentucky, as well as the Sardinian deposits (Zuffardo, 1964).

The second type of occurrence is the stratiform type, formed during deposition of the carbonate rocks.

Examples of this type include the occurrences in the Mackenzie Mountains of northern British Columbia, Canada (MacQueen, 1976), as well as the low grade deposits of the western Carpathian Mountains (Duhovnik, 1964).

Both Heyle (1974) and MacQueen (1976) have studied and compiled the general characteristics of the North American " Mississippi Valley " type deposits. No direct comparison can be made between their findings and the occurrences in Essex and Kent Counties ; however, both the ore deposits and local anomalies occur in carbonate rocks, with Zn : Pb ratios greater than 10 : 1. Porosity and permeability characteristics in the host rock as well as the presence of fault / fracture / joint patterns play important roles in the metal enrichment of the ore deposits and the local occurrences. There is an association of metal enrichment with shale - carbonate interfaces, such as the Collingwood - Cobourg boundary. Petroleum is present in several of the North American ore deposits, as well as some of the anomalous Zn concentrations in Essex and Kent Counties. For example, hole # 23 is an oil producer, and exhibits high concentrations of Zn and Pb.

Jackson and Beales (1967) discuss a general " Mississippi Valley " type deposit, formed through the interaction of normal diagenetic processes on sedimentary sequences upon burial. There is some connection between this type of deposit - forming process and the anomalous Zn concentrations within the study area. We should therefore use this model closely to examine the initial sources, migration, and processes of deposition, which affect the local metal dispersal pattern.

Sources

The original source of all metals is the interior of the earth (Helgeson, 1964). Secondary sources are quite variable and could have included basement rocks, shale formations, evaporite deposits, as well as petroleum accumulations. Carbonate rocks, excluding the host rocks, may also have been considered as a potential source of metals.

The basement rocks of the study area are metamorphic in character. An intermediate rock (probably a meta - diorite) occurs in the Clearville Fault area. According to Helgeson (1964), an ore anomaly can occur if the source rock contains as little as 3.0 ppm Zn, over a terrain of 100 square kilometres. Table 21 lists the average concentrations of metals in igneous and metamorphic rocks, based on a study by Vinogradov (1962).

The presence of shale formations in the stratigraphic column may have been a source of metals. Table 17 lists common concentrations of Zn, Cu, and Pb in marine and euxinic shales, from Hawkes and Webb (1962). From this table, it can be seen that euxinic shales have higher concentrations of metals than do normal marine

TABLE 21

AVERAGE ABUNDANCES OF ELEMENTS IN THE PRINCIPAL ROCK TYPES

Metal (ppm)	Ultrabasic	Basic	Intermediate	Acidic	Schist
Zn	31.0	130.0	72.0	61.0	81.0
Cu	21.0	110.0	35.0	24.0	47.0
Pb	1.1	8.8	15.0	21.0	21.0

shales. The Collingwood Formation, which is about 30 metres (100 feet) of black euxinic shale, may have served as a local source of metals. During the formation of this lithology, Zn, Cu, and Pb ions were trapped in the lattice structure of the clay minerals, as well as components in organo - metallic complexes. During lithification, a portion of the metals were expelled and carried away by circulating groundwaters.

Evaporites as well, contain large concentrations of metal ions, in the form of chloride complexes. According to Barton (1964) , leaching of evaporites could release these metal complexes into ciculating groundwaters, to be deposited elsewhere under favourable conditions. However, the Lower Paleozoic sequence of the study area lacks any large scale evaporite deposit. Minor amounts of gypsum occur in the Kirkfield and Coboconk Formations only. The largest accumulation of evaporites occurs in the Upper Silurian Salina Group, where over 340 metres (1000 feet +) of gypsum, halite, and sylvite are found. Leaching of this evaporite sequence by percolating groundwaters could deposit the required metals into the underlying Lower Paleozoic sequence, only if faults or fractures are present to allow for this downward movement. Such a process could have conceivably occurred in the Clearville and Electric Faults, since both can be found interrupting Middle Devonian strata.

The presence of petroleum in the study area may have constituted a local source of metals, in locations removed from any known fault zone. This would account for high concentrations of metals around hole # 23 in Kent County, for instance. Columbo (1967) states that very low concentrations (0.003 ppm) of metals can be derived from the breakdown of organo - metallic complexes. The two main types of compounds, which have a strong affinity for metals, are the phenol and prophyrin groups. Zn and Cu form unstable complexes in these two groups, which are easily destroyed with pressure and time. Small amounts of Zn and Cu (0.003 ppm) are then released into migrating brine waters, which are constantly being expelled.

Carbonate rocks could have been another potential source of metals. Table 17 lists the average concentrations of Zn, Cu, and Pb in carbonate rocks. Zn and Pb are tied up in the calcite lattice structures of limestones. Dolomitization of these limestones causes a shrinkage of these lattice structures, which results in the expulsion of Zn and Pb. These two metals are then complexed and carried off by formation waters. Since the process of dolomitization can occur early in the diagenetic cycle, the metal content of carbonates is generally too low to be important sources in later metal enrichment.

L

Migration

Given a series of potential sources of Zn, Cu, and Pb, the actual migration from source to host strata is important. In order to better comprehend the controls which affect the dispersal of Zn, Cu, and Pb , a brief look at the geochemical characteristics of these metals is in order.

Zinc

Zn is the most mobile element in the metal set Zn : Cu : Pb . Primarily, Zn in concentrated in the mafic fraction of acidic igneous rocks, and is easily leached out by acidic groundwaters, or by absorption onto crystal chlorite or magnetite.

In the sedimentary cycle, Zn is found in the shale fraction, with some enrichment in carbonate rocks. Enrichment in shales is due to the affinity of Zn ions for positions in the clay mineral lattice structure, as well as adsorption onto $Fe_2O_3 \cdot nH_2O$, and MnO_2 . These scavenger oxides are found in organic debris or as precipitated minerals, within the shales.

Carbonates show some concentration of Zn, which is due to the presence of a small shale fraction. Small amounts of Zn are tied up in the calcite lattice structure. During dolomitization, the influx of Mg ions causes the easing out of Zn into circulating groundwaters.

Zn is transported by hydrothermal solutions as chloride complexes. The assimilation of Zn into these solutions is directly proportional to the temperature of the fluid, according to Barnes and Cymanske (1967).

Zn can be either complexed by the chloride of bisulphide ion. At high temperatures (300° C. +), Zn is easily taken up in slightly acidic to neutral brines, which are rich in chlorides, according to Helgeson (1964). In this instance, the bisulphide ion concentration is very low.

In weak alkaline solutions (pH range from 7.0 to 8.5), Zn is complexed by bisulphide ions. Barnes and Cymanske (1967) state that, at a pH of 8.2, Zn forms ($Zn(HS)_3^{-2}$ ions, in H_2S saturated waters. In this case, chloride ion concentrations are low.

Low concentrations of Zn can be found in the hemins, chlorins, and porphyrins of oil field brines. Zn bonding in these organo - metallic complexes is weak, and easily destroyed by the application of pressure and / or time, The Zn ion is released and taken up by either the chloride or bisulphide ion, dependent upon their respective concentrations, as well as the pH and Eh of the solution.

Copper

Like Zn, Cu is derived **from** mafic igneous and metamorphic rocks. The leaching of hornblende and pyroxene by acidic waters yield appreciable concentrations of Cu for transport.

In sediments, Cu is mainly concentrated in the black shales, due to adsorption by clay minerals. Some scavengering by Fe and Mn oxides is also important.

Cu concentrations in carbonate rocks are low and can be attributed to the presence of shales or organic matter in the rock.

Transportation of Cu is achieved mainly by chloride complexing in a fairly acidic environment, with low concentrations of bisulphide ions. According to Helgeson (1964) , the solubility of Cu is more temperature dependent than is Zn. Its solubility is also limited by the presence of sulphides, carbonates, and sulphates, which have low solubilities in natural groundwaters.

Where the chloride ion concentration is low, in alkaline conditions, Cu can be complexed by the bisulphide ion. In this instance, $Cu(HS)_4^{-2}$ ions are formed. However, this form of complexing is most insignificant in the overall transportation picture of Cu.

Low concentrations of Cu can be found in the chlorins and phenols of oil field brines. Like Zn, Cu complexing with organic compounds are unstable and easily destroyed. This yields free Cu ions for complexing and subsequent transport.

3

Lead

According to Hawkes and Webb (1962), Pb is the least mobile of the metal set Zn : Cu : Pb . Initial concentrations of Pb are found in the felsic igneous rocks. Its abundance is directly related to the amount of K - feldspar in the source rock. Helgeson (1964) states that there are large concentrations of Pb linked together in the K - Al sheets, in the feldspar lattice. Granites and granodiorites, therefore, may yield as much as 20 ppm Pb, since these rocks contain an appreciable amount of K - feldspar.

In sediments, Pb is concentrated in the black shale fraction, due to adsorption by clay minerals, scavengering Fe and Mn oxides, as well as the presence of organic chelating compounds. High concentrations of Pb in clastic sediments are proportional to the presence and amount of K - feldspar. In carbonate rocks, Pb concentrations are low due in part to the initial meagre amount of this metal in seawater.

Transportation of Pb in solution is strictly pH dependent. In acidic mine waters, Barnes and Cymanske (1967) state that chloride complexing is most important. However, from slightly acidic to neutral conditions, complexing by sulphide ions becomes increasingly important. In this region, the complex is $PbS \cdot nH_2S$. In alkaline conditions, bisulphide complexing of Pb is important. According to Helgeson (1964), the complex here is $Pb(HS)_3^-$.

Organic complexing of Pb is minor in nature. In the hemins, according to Columbo (1967), Pb forms very weak bonds, surpassed only by Zn.

Causes of Ore Deposition

Thus far, an examination of potential sources, and the geochemical character of the metals, with further application to Essex and Kent Counties has been done. There are several methods of inducing the deposition of Zn, Cu, and Pb in the steady state. Therefore, we shall look at some of these mechanisms, that appear to be important with respect to local metal patterns. The following description is based upon the theoretical work of several researchers, including Helgeson (1964), and Barnes and Cymanske (1967).

Cooling of Ore Solutions

Ore deposits can be formed by the cooling of brine solutions. As the heated brine migrates from the depths, the loss of heat to the surrounding country rock increases the stability of the sulphide phase, and lowers the activity product constants of Zn, Cu, and Pb. This will tend to induce precipitation of these metals as sulphides at specific temperatures. Further concentration and enrichment of sulphides can occur by leaching and redeposition of the sulphide phase.

Mixing of Brines

The mixing of brines with connate waters can induce ore deposition. This intermingling of waters increases the hydrogen ion concentration, which in turn lowers the pH of the solution, as well as the activity constants of the three metals, according to Helgeson (1964). This will create a tremendous change in the environment of the metal species and induce deposition. This process is directly dependent upon the solubility product (S.P.) of the existing metal complex. The mixing of the heated brines with cool connate waters also reduces the temperature of the brine, which hastens a change in the chemical environment.

Alteration of the Wall Rock

Alteration of the wall rock by ascending heated brines involves a transfer of hydrogen ions from the outside into the brine, and a concomitant removal of alkali ions from the brine into the wall rock. This exchange of material will alter the geochemical character of the brine, and change the state of the solution. Since the steady state of the brine is fragile, specific metal species will come out of solution as soon as their solubility products are exceeded. Greater concentrations of sulphides are deposited in areas, where more surface area of wall rock is presented to the brine.

Presence of Oxidizing Metal Species

Exposure of the brine to Fe and Mn oxides, as well as their carbonate form, will promote deposition of Zn, Cu, and Pb. The oxidation of a metal species tends to release hydrogen ions, which lower the pH of the solution. Reaction of the hydrogen ions with available S^{-2} and HS^{-} ions decrease the activity states of the stronger complex forming metals and thereby induce deposition. This process is common at watertable interfaces, where an anerobic groundwater is being oxidized, forming a low grade metal enrichment zone.

DISCUSSION AND CONCLUSIONS

A review of the main aspects of the analysis, and a discussion of their implications, is now in order.

Map analysis indicates that anomalous concentrations of Zn are found around fault zones. This can be seen particularly in the strata of holes # 29 and 30 of the Dover Fault, holes # 13, 14, and 21 of the Electric Fault, and holes # 24, 25, 26, and 27 of the Clearville Fault.

The discriminant analysis similarly indicates that twp major data populations exist in the study area. One comprises the Fault and Fault Periphery Regions; the other comprises the Outside Region. The results of factor analysis of all nine elements, though complex, also suggest that fault zone processes affecting metal distribution are different from those of the Outside category.

The ternary diagrams imply some stratigraphic control of metal concentrations. Data for the Clearville Fault and Fault Periphery Regions, as well as for the Electric Fault Periphery Region, are tightly clustered on the ternary plots. However, the Dover Fault Periphery Region indicates some separation between the upper shales and carbonates, and the lower clastics and basement. This pattern becomes much more pronounced in the

Outside Region. In this case, the two data clusters are distinguished by an increase in Zn, and a corresponding decrease in Pb, in the lower stratigraphic groups.

The correlation coefficients indicate that there is a positive relationship between Zn and Pb concentrations. In the Electric Fault, there is a positive Zn : Cu correlation, and in the Clearville Fault area positive correlations between Zn : Cu and Cu : Pb.

These results support a theory of metal emplacement along fault zones by ascending saline brines. The source of metals associated with the fault zones is the PreCambrian basement. Concentrations of Zn, Cu, and Pb greater than 5.0 ppm, found in acid igneous rocks, are generally viewed as sufficient to create an ore deposit (Helgeson, 1964) . The variable concentrations of these metals in the basement of the study area are most likely due to variations in lithology, but may also indicate that various faults (in particular the Clearville Fault) extend into the basement and provide zones of primary enrichment .

The raw data and correlations indicate that the initial brines were rich in Zn, with some Cu and Pb. The generally low concentrations of Cu suggest a slightly acidic brine (pH range from 5.5 to 7.0). Cu concentrations are significant in the Clearville area, where it would seem that the basement rocks contain more Cu.

The ternary plots show that, in addition to fault zone enrichment through the stratigraphic column, there is an overall enrichment of Zn, and to some extent, Pb in the lower clastic sediments. This is due to the fact that these sediments are derived in situ. Metals such as Pb in K - feldspar, may then be released from these secondary sources for the enrichment of younger sediments.

The study of metal distribution across the Clearville Fault block also indicates the overriding influence of the PreCambrian basement on metal concentration patterns in the lower sediments. However, the variable metal content in the upper shales and carbonates reflects a complex geochemical history for each group, incompletely masked by fault controlled enrichment. Local enrichment of metals may occur when connate waters are expelled from shales into adjoining carbonate formations. Similarly, the enrichment of Zn in the Black River Group and older sediments may indicate late stage Zn deposition, initiated by dolomitization. Another minor source of anomalous metal concentrations in this general framework of events is the breakdown of organic materials, such as in the region of hole # 23. Yet another curious pattern of metal distribution occurs in the Cobourg Formation, which contains zones of iron staining. Analysis of the stained zones shows a two to five fold increase in Zn and Cu, relative to non-stained areas, suggesting enrichment due to the scavengering properties of iron.

The features which characterize Zn concentrations along fault zones also appear in the surrounding peripheral areas, though they are not as well developed. Although discriminant analysis classifies the peripheral regions with the fault, rather than with the outside areas, lateral migration of fluids from the fault zone outward is noticeably limited by porosity and permeability. A high effective permeability occurs only in the Cobourg Formation, and only the Cobourg Formation has porosity values in excess of 10 %. All other carbonate formations have porosities ranging from 3.0 to 5.0 %. (Sanford, 1961).

The chemical processes responsible for the observed metal patterns may be elucidated by observations of present day groundwater in the study aree. At depths of 1300 metres (4000 feet), brines exist in the PreCambrian basement and Cambrian clastic sediments. Average flow rates in holes # 24, 25, 26, and 27 in the Clearville area are in the vicinity of 48 gallons / hour. These waters are decidedly acidic in character, with pH values ranging from 4.0 to 5.0 . Any available Zn, Cu, or Pb is leached from the basement, forming chloride complexes, in situ. At high lithostatic pressures, the brines are quite warm, with temperatures averaging 300°C. Under these conditions, Zn is appreciably more mobile than Cu or Pb.

Studies of groundwater resources indicate the dominance of chloride over bisulphide ions at depth, and the reverse of this in the upper carbonates. The presence of bisulphide ion is due to the breakdown of organic material by anerobic bacteria, releasing HS^- and S^{-2} ions. The brine solution is thought to partially buffered by the host carbonates ; this fixes the lower limit of the pH of the solution from 4.5 to 6.5, dependent upon the amount of free sulphur present. The upper limits are set by the presence and concentrations of alkaline species in the groundwater. This has been set at approximately 8.5 to 9.0 .

We may now suggest a geologic environment of deposition for the local Pb - Zn occurrence. The depositional setting was one of low temperature (60 to 100° C.) and low pressure (2.0 atm.) . Conditions ranged from marginally oxidizing to reducing in nature, with Eh values ranging from 0.00 to - 0.05 , ~~The~~ pH conditions varied from 6.0 to 10.0 .

Upward migration of the heated brine from the basement occurred in response to a decreasing pressure gradient, developed from the PreCambrian into the Middle Ordovician sediments. This pulsating movement probably coincided with major tectonic events in the region , according to Lockett (1947). The ascent of the brines immediately caused an increase in the original volume per unit mass of the fluid, with a concomitant transfer of heat.

Mass exchanges of material from the wall rock to the brine also occurred, which Barton (1964) felt would sufficiently decrease the mobility of the Zn and Pb ions in solution. Further changes in the chemical character of the brine occurred when the saline fluids mixed with connate waters of the carbonates, rich in HS^- ions. Deposition of metal ions was then initiated, when the solubility product (S.P.) of the most immobile metal (in this case , Pb) was reached and exceeded.

As the brine further cooled and was diluted, the stability of the metal complexes changed, with the deposition of Zn and Pb in the sulphide phase. In this case, the original chloride complexes of Zn and Pb became unstable, and ionic Zn and Pb then complexed with available HS^- ions. Once the solubility products of these new complexes were reached, the deposition of Zn and Pb in the form of disseminated sulphides began. This general sequence of events in low grade ore metal enrichment is envisioned for the Silurian prospects of Lambton County, as well as the disseminated Zn deposits of the Bruce and Niagara Peninsulas, Ontario.

A modern day example of Pb - Zn enrichment in currently taking place in Southern Ontario. In the Vinemount Quarry of Stelco (Hamilton), located on the outskirts of Vinemount, Ontario, Haynes and Mostaghel (1977) report the formation of a galena : sphalerite showing from subsurface seepage.

The author visited the showing, located on the northern wall of the quarry, which bottoms in the Middle Silurian Amabel Formation. A well developed series of joints penetrates this formation in the quarry, and the showing occurs along one of the main joints.

The mineralogy is quite simple. The main portion of the occurrence is a brown rust-coloured mass of oxidized pyrite and $Fe_2O_3 \cdot nH_2O$. In places, the iron oxide is covered with a mass of brilliant to dull green patches, which Haynes and Mostaghel (1977) report consists of microcrystalline galena. Honey-brown aggregates of crystals also occur in the iron gossan, which has been identified as sphalerite. According to Haynes and Mostaghel (1977), the iron gossan has a concentration of 3400 ppm Pb and 600 ppm Zn. Chemical analysis of the brines indicate a 20% excess of salts and contains 50 ppm Zn and 7.6 ppm Pb. The brines are rich in bisulphide ions, since H_2S gas bubbles freely in place.

The mechanics of formation of this occurrence appear to be simple . The upward migration of reducing brines meets an oxidizing barrier, which is the watertable. The subsequent oxidation of iron releases hydrogen ions, which lowers the activity constants of the complexed Zn and Pb ions. Deposition of the two metals in in the sulphide phase, as galena and sphalerite. The residual salinity in excess of local groundwaters indicates the possible mixing of two types of water at the watertable oxidation barrier. The initial source of the metals and their complexes could have been the PreCambrian basement or Lower Paleozoic clastic rocks. It may also be associated with the Upper Silurian Bertie Akron Formation, which has a high concentration of Pb, according to Delevault and Warren (1961).

In conclusion, there is a definite enrichment of Zn along the Clearville, Electric, and Dover Faults of the study area. Of the three metals under study, Zn is the most mobile, followed by Cu, and then Pb.

The influence of the fault on the lateral pattern of metal distribution is restricted by the lack of effective porosity and permeability in the carbonate host rock. Away from the fault zone, little influence can be seen in the existing metal patterns.

The formation of a Pb - Zn anomaly in Essex and Kent Counties is explained by the general principles of formation of the " Mississippi Valley " type deposit. In this case, upward migration of heated saline brines along fault zones are cooled and diluted, causing deposition of metal sulphides in overlying host rocks.

Where the metal distribution pattern is not directly influenced by the fault zone, a two-fold control is seen. Local anomalies are created by shale dewatering on a local to regional basis, as well as the destruction of organic compounds by bacteria, in oil-rich zones.

Any enrichment in the lower Cambrian clastic sediments clearly is influenced by the presence of the PreCambrian basement.

To further substantiate the mechanisms for metal emplacement outlined in this study, additional examination and a more detailed scrutiny of each formation is required. However, the ground work has been laid, and extended in some cases, which may yield a better understanding of the processes, which control low temperature sedimentary ore enrichment.

APPENDIX A

WELL HOLE NAMES AND GEOCHEMICAL DATA.

The following appendix contains a list of sample hole names and the corresponding geochemical data. All concentrations are given in parts per million (ppm).

Name	Sample Number
C.B. Lewis, Dr. King # 1	1
Imperial Delhi Home C.W.P. 271 N.T.R.	2
C.W.P. Colchester # 1	3
Imperial Oil # 732-Harvest Submarine Colchester # 9	4
S.S.P.C. Gosfield N. # 1	5
Amerada Hess # 1	6
C.W.P. Malden # 1	7
Brett Rochester 8-16-VI	8
Tilbury N. 6-3	9
Angelus Chatham Gore # 1	10
Home et al. Chatham Gore N.W. 6 - II	11
Imperial Oil Dover II-IV-E	12
Norbla Oil Peterkin # 1	13
Norbla Oil # 6	14
Imperial Bluewater # 728	15

Name	Sample Number
Imperial Oil # 812	16
Imperial Oil Farrell # 1	17
Imperial Oil Zone 4-3-4	18
United Reef # 1	19
Zenmac # 6	20
British American Moravian I.R. 25	21
Palomino Buxton Raleigh I-3-X	22
Tilbury East 1-7-3-IV	23
Lynwood Securities # 1	24
Tobacco Road # 5	25
Imperial Oil # 808	26
Imperial Oil # 829	27
Central Pipeline Earl Duart # 1	28
Patterson # 1	29
Patterson # 2	30

SAMPLE DATA.

HOLE NUMBER 1

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP018001	8.3	1.8	3.3	0.5	0.1	814.9	9705.4	49386.2	24996.4
RKP018002	9.0	1.3	1.5	0.9	0.1	447.8	20293.4	31883.2	21387.5
RKP018003	6.9	1.8	0.5	1.0	0.1	334.4	12881.7	11918.7	12961.2
RKP018004	6.0	1.5	3.2	1.3	0.1	816.1	9264.3	312110.9	31994.4
RKP018005	6.8	1.0	4.3	0.8	0.1	160.4	1244.5	338277.6	21199.5
RKP018006	7.2	1.1	4.2	0.7	0.1	164.2	777.8	249146.5	19321.4
RKP018007	8.4	1.1	4.3	0.5	0.1	78.7	1466.7	271191.5	19329.5
RKP018008	7.2	1.1	4.2	0.9	0.1	65.3	1688.9	329191.4	21221.4
RKP018009	6.9	0.8	2.2	1.2	0.1	86.3	6176.4	41918.5	24791.2
RKP018010	12.3	1.1	3.7	1.2	0.1	206.5	8161.7	109110.6	19886.5
RKP018014	26.1	2.4	7.6	1.0	0.1	668.7	15881.2	15881.2	27991.2

SAMPLE DATA.

HOLE NUMBER **2**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP007001	12.7	6.3	2.3	0.4	0.1	1838.9	11516.3	57987.6	40314.2
RKP007002	15.3	6.3	1.4	0.1	0.1	1128.4	14513.6	29933.2	21989.0
RKP007003	6.7	18.9	0.2	0.3	0.1	1100.4	22028.7	12114.7	18354.2
RKP007004	6.0	16.8	4.3	0.9	0.1	452.3	8267.3	287914.5	35968.7
RKP007005	5.3	4.2	3.3	1.0	0.1	98.6	4873.2	319964.2	32984.4
RKP007006	6.0	3.4	3.4	1.1	0.1	37.1	3873.2	228779.1	32918.4
RKP007007	5.3	4.2	5.5	1.0	0.1	36.6	3970.4	309114.2	36649.2
RKP007008	6.7	5.1	4.1	0.9	0.1	24.6	2372.6	299877.4	30785.4
RKP007009	19.3	2.2	4.2	1.2	0.1	167.4	28952.7	20989.2	21989.6
RKP007010	7.2	5.3	4.0	1.0	0.1	12.2	18462.7	10417.4	63056.8
RKP007014	14.7	2.5	1.6	0.9	0.4	584.3	60481.3	37954.7	21256.4

SAMPLE DATA.

HOLE NUMBER 3

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP019001	10.2	0.7	3.7	0.5	0.1	585.1	3366.2	49297.2	23119.1
RKP019002	21.1	2.7	1.7	0.8	0.1	635.3	10357.6	32876.5	22964.3
RKP019003	36.6	2.9	2.8	1.3	0.1	458.7	43689.5	12831.2	14211.5
RKP019004	9.9	0.8	5.4	1.2	0.1	218.9	3020.3	9000.3	29112.4
RKP019005	9.5	0.8	3.3	1.3	0.2	56.8	782.3	329663.2	22311.4
RKP019006	12.6	0.7	3.6	1.2	0.1	143.2	143.2	254912.4	19211.3
RKP019007	9.4	0.6	3.2	1.3	0.1	92.6	869.7	283889.5	24221.4
RKP019008	9.1	0.6	3.0	1.3	0.1	164.2	1652.7	329914.7	24711.2
RKP019009	5.9	0.6	9.2	1.1	0.1	176.8	1139.2	42919.8	29112.4
RKP019010	21.1	0.8	3.0	1.0	0.1	113.7	3064.2	10900.1	21226.7
RKP019014	23.1	1.8	3.4	0.9	0.1	250.8	4531.2	36291.2	21221.4

SAMPLE DATA.

HOLE NUMBER 4

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP001001	8.3	1.3	1.9	1.3	0.1	394.6	5261.4	67914.2	23647.8
RKP001002	10.4	2.1	2.4	2.4	0.2	494.6	19214.4	39647.3	22146.3
RKP001003	14.6	2.4	3.6	2.1	0.4	294.4	14413.2	16981.5	14614.7
RLP001004	7.2	1.3	3.4	0.9	0.0	327.6	394.4	311462.1	30464.1
RKP001005	7.9	2.0	2.9	0.6	0.0	291.4	291.4	299916.5	32619.7
RKP001006	7.4	1.4	2.7	0.4	0.0	241.4	1113.4	289462.4	29118.6
RKP001007	9.2	0.8	0.1	4.4	0.0	246.2	982.2	249118.4	29621.4
RKP001008	5.9	1.6	3.4	0.4	0.0	189.6	1714.7	300146.5	30118.2
RKP001009	8.3	1.9	3.9	0.9	0.0	194.4	1276.3	332294.6	31916.2
RKP001010	5.4	1.8	1.2	0.4	0.0	218.6	4312.4	21546.2	12461.2
RKP001014	4.9	1.9	4.3	2.4	0.2	561.4	17946.4	53691.4	30618.9

SAMPLE DATA.

HOLE NUMBER 5

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP002001	7.4	0.9	1.9	1.3	0.1	250.0	2755.6	61351.1	23455.1
RKP002002	3.7	2.4	1.0	1.3	0.1	334.4	8503.6	34987.1	20523.6
RKP002003	9.9	2.4	1.2	1.4	0.1	150.5	14889.8	8621.2	11727.7
RKP002004	6.8	0.9	3.5	1.6	0.1	100.3	844.3	299186.5	27853.4
RKP002005	6.7	0.9	2.8	1.2	0.1	143.2	1200.2	345612.0	27441.6
RKP002006	9.2	0.8	0.1	4.4	0.0	246.2	983.4	259118.4	29621.6
RKP002007	5.4	1.2	3.6	1.6	0.1	133.9	1233.8	299872.2	26868.5
RKP002008	6.6	0.9	2.2	1.4	0.1	136.4	1075.6	329114.2	34911.2
RKP002009	6.5	1.0	3.1	1.6	0.1	668.9	1246.1	49549.2	18057.4
RKP002010	5.9	1.3	1.3	1.6	0.1	292.6	7444.4	99549.2	19857.4
RKP002014	4.5	0.9	0.4	1.4	0.1	397.1	4254.3	8297.6	30785.6

SAMPLE DATA.

HOLE NUMBER 6

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP004001	8.6	0.9	1.8	2.4	0.4	491.6	5394.6	69347.1	24913.5
RKP004002	10.4	2.1	2.1	2.6	0.6	499.6	18241.9	38749.2	22916.7
RKP004003	14.6	2.1	3.1	2.4	0.4	312.4	22646.3	19423.8	14913.5
RKP004004	7.8	0.9	1.9	0.8	0.0	381.2	9894.3	306614.2	31244.5
RKP004005	9.2	1.2	1.8	0.6	0.0	299.6	496.2	299481.4	32749.8
RKP004006	6.3	1.3	1.8	1.0	0.0	243.2	1011.4	299149.3	29934.5
RKP004007	7.4	1.2	2.4	1.3	0.0	184.3	1646.2	310200.6	32146.5
RKP004008	8.2	0.8	3.2	1.4	0.0	199.2	1391.2	322629.5	34919.5
RKP004009	6.4	0.6	1.9	1.9	0.4	1046.5	10463.2	49214.6	14624.5
RKP004010	1.4	0.4	1.4	1.4	0.0	211.4	4791.2	22613.5	13992.2
RKP004014	17.9	1.1	2.4	3.6	0.5	1796.4	19983.2	57214.2	39646.1

SAMPLE DATA.

HOLE NUMBER 7

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP003001	7.9	1.2	1.9	1.2	0.3	291.4	4941.3	64913.2	22946.1
RKP003002	9.2	2.4	1.8	1.1	0.1	413.2	8634.2	38746.3	21413.2
RKP003003	12.4	2.4	1.6	1.4	0.1	194.6	12464.2	14641.2	13471.2
RKP003004	6.9	0.9	3.8	0.8	0.0	247.6	389.6	301414.2	28714.2
RKP003005	7.1	1.1	2.9	0.6	0.0	231.4	291.4	299642.3	31212.4
RKP003006	6.7	0.9	2.9	1.0	0.0	142.4	1493.6	271412.5	27918.6
RKP003007	5.3	1.4	3.8	1.4	0.0	194.6	1836.4	299496.5	24914.6
RKP003008	7.2	1.2	2.4	1.3	0.0	193.4	1776.4	321431.5	31141.2
RKP003009	6.5	1.0	3.2	1.8	0.1	714.2	7491.2	42144.6	14134.8
RKP003010	5.4	1.4	1.4	1.7	0.0	214.6	4241.8	21213.8	11941.2
RKP003014	14.9	1.4	2.6	1.6	0.4	1493.6	14941.7	49174.3	31914.2

SAMPLE DATA.

HOLE NUMBER 8

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP011001	11.4	7.4	2.4	0.4	0.0	927.4	11624.2	57919.6	37134.2
RKP011002	12.4	7.3	1.6	0.4	0.0	1124.8	13215.4	31943.2	20191.4
RKP011003	8.3	9.2	1.4	0.3	0.0	1121.5	22183.5	32471.6	11318.6
RKP011004	6.9	3.2	0.9	0.8	0.0	452.4	4213.4	294832.1	29491.6
RKP011005	4.7	4.2	2.1	1.2	0.0	321.2	994.2	319446.5	93484.2
RKP011006	5.9	3.4	2.4	1.1	0.0	416.3	1132.5	289416.2	11346.2
RKP011007	6.7	5.2	3.1	1.0	0.0	421.4	1321.4	309941.6	12944.6
RKP011008	4.3	5.2	2.4	0.8	0.0	221.5	1891.4	319964.1	83449.2
RKP011009	16.2	2.3	5.4	1.3	0.1	4164.2	9832.4	21446.2	11345.2
RKP011010	7.1	3.6	4.2	0.9	0.1	184.3	1094.2	10471.5	8263.1
RKP011014	16.8	12.4	1.6	0.8	0.2	939.8	17945.4	59174.1	37424.1

SAMPLE DATA.

HOLE NUMBER 9

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP015001	12.6	6.2	1.9	1.3	0.0	1026.4	14625.3	58636.3	38371.2
RKP015002	13.4	7.3	1.9	1.3	0.1	1424.4	15196.5	32419.8	22319.6
RKP015003	13.4	7.3	2.0	1.3	0.1	1424.3	16011.3	35767.5	12419.4
RKP015004	6.9	4.6	0.8	0.8	0.1	612.4	11241.3	299461.1	31226.4
RKP015005	4.9	4.9	1.4	0.4	0.0	328.6	947.3	320943.5	95694.5
RKP015006	6.2	3.4	1.3	0.2	0.0	514.6	2514.6	329541.5	12416.5
RKP015007	7.4	4.6	2.4	0.8	0.0	429.6	1631.4	319919.5	14456.3
RKP015008	8.9	6.2	0.8	0.2	0.1	196.3	642.3	325134.2	16471.2
RKP015009	6.4	1.7	3.8	1.4	0.0	6943.2	10894.7	22319.4	11341.2
RKP015010	11.2	4.2	0.9	0.8	0.8	819.4	1131.2	9844.3	8156.4
RKP015014	17.9	16.2	2.4	3.2	0.5	4726.4	22646.3	56349.7	39624.3

SAMPLE DATA.

HOLE NUMBER **10**

FORMATION	ZN	CU	PB	NI	CP	MN	FE	CA	MG
RKP027001	8.2	0.9	3.2	0.9	0.1	491.3	6839.5	52918.2	21291.4
RKP027002	14.3	0.9	1.9	0.9	0.1	436.4	8246.5	29337.6	18961.5
RKP027003	12.6	1.3	1.4	1.3	0.2	289.3	8911.4	11386.5	22911.4
RKP027004	3.4	0.8	2.3	0.7	0.1	194.6	4291.6	239914.5	31291.5
RKP027005	8.2	1.2	0.1	0.6	0.1	89.6	491.4	322114.6	23244.1
RKP027006	6.2	1.6	1.8	0.9	0.1	104.6	832.4	238776.4	24391.3
RKP027007	4.2	0.8	1.6	0.3	0.1	89.6	439.4	289462.5	24139.7
RKP027008	3.8	0.6	0.9	0.2	0.1	141.5	546.3	309114.6	20112.4
RKP027009	1.8	0.4	1.3	1.3	0.1	238.5	899.6	49972.4	21861.4
RKP027010	3.2	1.2	1.4	0.6	0.1	89.1	128.6	9962.3	17611.5
RKP027014	46.2	3.4	8.9	2.6	0.2	801.2	12911.4	29114.6	29386.1

SAMPLE DATA.

HOLE NUMBER **11**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP028001	9.6	1.2	4.1	0.9	0.0	526.4	7124.6	57941.1	20193.2
RKP028002	11.4	1.9	1.9	0.9	0.1	494.3	8192.3	31918.5	17181.4
RKP028003	13.2	1.3	1.4	1.5	0.0	321.2	9198.4	13491.2	22991.2
RKP028004	4.9	0.9	2.4	0.8	0.1	204.6	4248.6	299186.5	32194.7
RKP028005	8.9	1.4	1.7	0.6	0.1	94.9	546.3	311483.2	31812.5
RKP028006	6.4	6.4	1.9	0.1	0.1	122.4	947.6	247764.2	27446.5
RKP028007	2.2	0.9	1.7	0.4	0.1	94.6	583.5	299483.5	25891.3
RKP028008	2.9	0.8	2.4	0.4	0.2	183.7	894.6	310492.5	21491.2
RKP028009	3.0	0.4	1.4	0.8	0.1	294.6	9347.6	53471.2	23986.5
RKP028010	3.6	1.2	1.6	0.1	0.0	98.5	1147.4	8946.5	18741.2
RKP028014	39.2	4.6	9.1	1.2	0.2	706.5	17941.3	29934.5	31856.7

SAMPLE DATA.

HOLE NUMBER **12**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	[illegible]
RKP029001	6.4	0.4	4.9	0.9	0.1	696.5	7938.6	63831.2	27913.4
RKP029002	10.3	0.2	5.3	1.2	0.1	389.2	9932.4	23609.8	19386.6
RKP029003	11.2	1.0	2.6	2.4	0.2	542.3	10446.7	12341.4	24918.7
RKP029004	7.2	0.8	0.9	0.9	0.1	203.6	5381.2	10026.7	33611.2
RKP029005	6.8	0.9	1.3	0.8	0.1	82.6	436.5	321002.5	29184.5
RKP029006	6.5	0.6	0.9	0.6	0.1	81.9	422.9	249917.6	38611.2
RKP029007	4.9	1.1	1.5	0.3	0.1	102.1	538.4	283214.5	32918.2
RKP029008	2.9	0.9	1.4	0.2	0.1	98.9	382.4	325997.6	31218.7
RKP029009	1.9	0.3	0.9	1.0	0.3	294.6	728.6	39987.6	21841.2
RKP029010	0.9	0.1	0.9	0.4	0.2	41.1	99.9	10914.3	18761.4
RKP029014	41.6	7.6	15.4	2.0	0.5	704.6	14986.5	40911.3	28181.3

SAMPLE DATA.

HOLE NUMBER **13**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP040001	18.9	1.3	1.2	0.6	0.1	342.7	14999.3	59837.2	29253.1
RKP040002	26.7	2.6	1.4	0.6	0.2	326.0	21616.5	27033.6	25654.3
RKP040003	30.6	2.6	1.1	0.9	0.1	217.6	3166.5	9988.5	26570.4
RKP040004	45.2	1.6	16.3	8.1	0.5	172.4	3219.7	49114.5	70548.7
RKP040005	35.6	1.2	11.2	4.3	0.6	151.6	4675.6	318811.3	67458.6
RKP050006	109.0	1.2	16.8	3.4	1.9	543.3	8161.4	212264.5	49258.7
RKP040007	75.1	1.4	12.0	1.3	1.9	256.3	3088.1	229183.5	46649.9
RKP040008	180.9	1.2	11.2	15.9	0.8	105.6	5690.7	299894.4	82460.0
RKP040009	74.5	1.7	16.3	15.3	0.9	417.9	18334.5	21011.8	27496.3
RKP040010	87.7	1.6	10.7	12.3	0.2	710.6	13356.7	12413.5	64136.5
RKP040014	101.0	5.3	15.6	14.5	0.9	473.5	29385.6	18358.7	52743.6

SAMPLE DATA.

HOLE NUMBER **14**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP038001	26.6	3.8	1.3	1.3	0.1	821.1	10961.1	42911.3	33081.5
RKP038002	24.8	4.9	1.8	1.4	0.1	638.1	14911.2	21987.6	27983.4
RKP038003	22.6	10.6	1.9	1.2	0.1	311.4	8641.3	10446.9	29891.0
RKP038004	38.9	8.3	1.9	2.0	0.1	99.8	1928.7	258311.2	52918.9
RKP038005	28.6	2.2	1.3	1.9	0.1	342.8	2861.5	309146.5	54911.2
RKP038006	100.9	1.8	1.2	1.4	0.4	391.8	8312.6	329821.4	47912.4
RKP038007	81.2	4.4	1.2	1.7	0.2	142.6	4961.2	249864.5	152918.6
RKP038008	29.8	8.0	8.6	1.9	0.7	183.9	6386.5	294416.5	77892.3
RKP038009	64.4	1.9	8.9	2.1	0.2	682.1	12113.6	29831.3	24911.3
RKP038010	88.3	1.8	2.9	2.4	0.2	90.9	14624.6	12308.7	52966.7
RKP038014	211.4	11.6	18.6	4.9	0.4	490.8	10644.5	52388.8	53826.5

SAMPLE DATA.

HOLE NUMBER **15**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP022001	6.2	0.9	0.5	0.4	0.0	792.3	6936.2	59381.2	22971.2
RKP022002	14.7	1.3	0.9	1.0	0.1	8432.5	10491.2	24621.3	22911.2
RKP022003	22.6	1.9	1.5	2.4	0.1	647.5	3826.4	12191.4	29106.5
RKP022004	6.2	0.9	2.4	0.9	0.1	432.1	2921.4	1446.5	22976.5
RKP022005	8.4	0.7	1.4	0.7	0.1	122.4	1047.3	329982.3	21291.5
RKP022006	9.2	0.8	0.1	4.4	0.0	246.2	982.4	249118.7	29621.4
RKP022007	4.4	0.8	0.9	0.2	0.1	1099.4	629.8	279991.2	31992.3
RKP022008	2.2	0.4	0.9	0.1	0.0	137.7	297.6	321012.4	31621.4
RKP022009	9.7	1.3	1.3	1.4	0.2	346.2	3249.3	41988.5	31989.6
RKP022010	7.2	0.9	0.3	0.6	0.1	91.9	322.9	11211.6	21291.9
RKP022014	21.3	3.6	2.5	2.1	0.1	641.3	12421.6	39964.6	22691.3

SAMPLE DATA.

HOLE NUMBER 16

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP023001	4.9	0.9	3.6	0.7	0.1	691.4	5121.4	59368.4	27981.2
RKP023002	12.9	0.4	3.9	0.4	0.1	939.2	10918.7	29381.2	22638.1
RKP023003	13.6	1.9	4.2	0.9	0.0	521.4	7918.6	9914.3	22911.4
RKP023004	7.9	0.9	1.3	0.4	0.1	391.2	1129.8	312271.4	29688.5
RKP023005	2.9	1.2	0.9	0.1	0.1	104.9	712.9	329141.6	32614.5
RKP023006	1.4	0.8	0.1	0.1	0.0	147.6	1461.2	251887.6	40891.2
RKP023007	1.9	0.8	1.0	0.1	0.0	109.9	910.9	291146.8	26382.4
RKP023008	0.9	0.7	0.6	0.1	0.1	162.9	2923.5	319994.4	34914.7
RKP023009	2.4	1.2	1.6	0.2	0.2	183.3	4129.8	43364.5	29189.7
RKP023010	1.2	0.9	0.1	0.2	0.1	109.4	209.1	10964.6	20914.7
RKP023014	12.4	2.5	2.4	1.2	0.1	310.2	16891.3	49113.2	39224.4

SAMPLE DATA.

HOLE NUMBER **17**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP030001	7.2	0.6	4.9	1.2	0.1	734.6	8324.5	61618.4	19413.2
RKP030002	11.2	0.2	5.4	1.5	0.1	421.4	10842.4	29841.2	18462.3
RKP030003	14.2	1.8	2.7	1.2	0.1	641.2	11387.6	11984.3	23814.6
RKP030004	6.4	1.2	1.2	0.9	0.1	342.4	1084.7	309914.4	38164.5
RKP030005	6.2	1.1	1.4	0.7	0.1	93.6	549.8	321918.6	30941.2
RKP030006	4.5	0.8	1.9	0.6	0.2	99.4	441.2	254918.7	26412.4
RKP030007	4.9	1.4	1.5	0.4	0.2	131.4	424.4	283219.5	25194.2
RKP030008	2.9	0.8	1.8	0.3	0.1	120.4	424.3	321442.4	21019.6
RKP030009	2.4	0.3	1.2	1.2	0.2	398.5	6732.5	29994.3	24836.7
RKP030010	1.2	0.2	1.4	0.9	0.1	98.2	440.4	13194.6	19846.7
RKP030014	32.4	8.4	14.2	1.9	0.4	809.4	19484.5	31914.5	32185.6

SAMPLE DATA.

HOLE NUMBER 18

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP035001	10.4	1.2	4.9	1.2	0.1	698.4	4966.4	42918.4	29183.4
RKP035002	29.3	2.7	1.9	0.9	0.1	938.6	9949.8	19219.3	26181.5
RKP035003	38.9	2.8	2.9	1.1	0.1	492.6	4296.6	7943.3	21325.4
RKP035004	9.9	1.3	6.9	1.3	0.1	218.9	2091.2	291164.5	39186.5
RKP035005	12.4	0.9	3.3	1.1	0.1	72.9	649.8	329412.3	39811.3
RKP035006	12.9	0.6	3.6	0.9	0.1	123.6	1294.5	289114.3	32918.5
RKP035007	6.4	0.4	3.2	0.8	0.1	99.9	832.5	300912.3	39146.5
RKP035008	12.4	0.6	9.4	1.8	0.2	154.9	1291.3	329641.2	32186.5
RKP035009	4.9	2.7	2.6	1.2	0.2	172.3	1989.6	29836.6	27168.5
RKP035010	12.1	0.9	2.9	1.3	0.1	103.6	221.4	12369.8	26184.5
RKP035014	40.4	8.9	4.9	1.9	0.3	212.9	13861.4	52911.3	47811.2

SAMPLE DATA.

HOLE NUMBER **19**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP036001	19.4	2.6	1.9	1.2	0.1	793.9	9299.9	47182.4	29146.2
RKP036002	32.6	2.8	2.4	1.3	0.1	472.3	14688.7	23142.4	27142.2
RKP036003	38.4	3.9	1.1	1.2	0.1	324.8	4939.7	9462.3	24626.4
RKP036004	49.9	2.4	1.5	1.3	0.1	183.6	2899.6	279114.2	49152.5
RKP036005	49.8	1.3	1.5	2.0	0.1	151.9	4896.5	308216.7	53621.3
RKP036006	204.6	1.5	1.6	1.7	0.2	482.6	9938.7	232181.4	41990.5
RKP036007	102.9	1.9	1.3	1.4	0.1	387.9	5081.3	249184.5	44691.2
RKP036008	142.6	2.6	1.8	2.6	0.1	109.8	6492.3	298371.2	72149.7
RKP036009	79.3	1.7	1.9	1.4	0.1	499.8	11926.7	29563.4	24183.4
RKP036010	62.4	1.9	1.4	2.1	0.1	200.9	12644.3	12911.5	41291.4
RKP036014	198.6	6.9	2.2	4.6	0.3	389.9	29499.8	59381.2	49371.2

SAMPLE DATA.

HOLE NUMBER **20**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP037001	6.4	0.9	5.9	1.2	0.1	832.9	6911.9	48911.2	23146.2
RKP037002	13.2	1.4	1.6	1.6	0.2	638.5	21309.8	22602.3	26411.3
RKP037003	21.3	2.4	2.8	1.3	0.1	391.1	4926.7	9417.6	24981.7
RKP037004	2.7	1.9	3.9	1.6	0.3	99.8	1191.8	300027.8	32146.5
RKP037005	8.4	0.9	4.9	1.2	0.1	64.2	896.5	328046.5	31911.7
RKP037006	6.6	0.6	3.9	1.0	0.1	122.6	1124.5	279341.5	29114.6
RKP037007	3.8	1.2	2.9	0.8	0.1	120.1	849.5	319001.3	32134.5
RKP037008	6.9	1.8	0.9	1.4	0.2	88.6	831.2	329565.4	32811.5
RKP037009	4.8	1.9	4.6	1.3	0.2	291.5	1914.8	29161.5	34221.4
RKP037010	10.2	0.9	0.9	1.3	0.1	48.1	87.5	19034.5	29814.6
RKP037014	45.6	2.6	12.9	9.8	0.2	209.1	4911.2	49302.5	31020.3

SAMPLE DATA.

HOLE NUMBER 21

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP017001	43.7	15.9	1.1	0.8	0.1	823.6	11268.9	52976.7	39114.2
RKP017002	60.8	16.4	2.0	1.0	0.1	791.3	12499.8	22918.7	26214.4
RKP017003	64.4	18.7	3.2	1.2	0.1	493.8	14644.4	9812.4	29113.5
RKP017004	62.2	28.1	4.3	1.2	0.1	286.3	8944.5	289112.4	47911.2
RKP017005	91.9	7.0	6.9	2.5	0.2	391.9	12935.9	310001.4	46218.6
RKP017006	93.3	4.7	6.6	3.4	0.3	300.6	12911.4	288791.2	59876.5
RKP017007	147.1	4.6	5.0	8.3	0.3	389.5	14644.3	218821.4	71228.3
RKP017008	132.8	2.4	5.9	10.4	0.4	289.1	10001.4	264691.4	89236.5
RKP017009	88.2	43.1	3.7	11.9	0.4	498.4	7443.5	21911.4	99146.2
RKP017010	58.9	39.7	2.8	12.2	0.4	768.6	8291.6	11918.2	39118.5
RKP017011	110.3	37.5	29.3	14.4	0.4	439.8	42961.4	31911.7	49312.5

SAMPLE DATA.

HOLE NUMBER **22**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP012001	54.7	12.6	3.6	0.6	0.1	446.9	6982.8	7201.2	29336.5
RKP012002	66.7	25.3	2.7	0.5	0.1	359.2	11791.2	21218.4	23966.5
RKP012003	45.3	16.8	4.2	1.3	0.1	293.9	10938.7	45312.4	10879.7
RKP012004	20.0	6.3	8.2	2.0	0.1	197.3	6491.9	291914.2	38319.2
RKP012005	14.7	4.2	9.0	3.7	0.2	199.3	7321.9	329112.4	49221.4
RKP012006	10.7	6.3	9.1	7.0	0.3	146.3	6430.4	219986.5	36224.5
RKP012007	24.0	6.3	8.4	9.9	0.3	293.8	5389.2	244891.2	43221.4
RKP012008	40.7	6.3	8.5	11.6	0.4	102.9	2949.6	308911.2	42973.4
RKP012009	72.7	2.3	6.2	12.4	0.4	921.6	7430.1	22998.6	83826.3
RKP012010	17.4	8.4	5.3	8.4	0.2	122.9	3846.1	10987.1	99324.2
RKP012014	46.0	29.5	5.4	12.7	0.7	399.2	16911.2	41998.6	53721.4

SAMPLE DATA.

HOLE NUMBER **23**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP010001	12.6	9.3	1.4	0.6	0.0	1126.4	13493.6	60919.3	39646.2
RKP010002	11.3	7.4	1.2	0.7	0.0	1462.9	14941.7	33161.2	22134.5
RKP010003	9.2	11.2	1.5	1.3	0.0	1313.2	19838.7	32214.7	14621.2
RKP010004	8.3	1.3	8.6	0.8	0.0	596.7	5632.2	289456.2	93941.2
RKP010005	6.7	2.1	2.4	0.4	0.0	420.4	1096.4	319994.2	13621.5
RKP010006	7.4	2.2	0.9	0.3	0.0	816.4	1091.2	306442.1	13419.2
RKP010007	5.4	4.1	1.2	1.2	0.0	522.3	9367.3	319048.2	11245.3
RKP010008	5.4	2.4	0.9	0.9	0.0	367.4	638.2	327112.2	93146.9
RKP010009	11.2	4.1	2.9	0.7	0.0	4998.9	10961.2	20146.5	12640.3
RKP010010	8.9	3.6	1.4	1.1	0.0	287.3	921.3	8291.4	7241.9
RKP010014	17.9	11.2	1.9	2.4	0.5	4296.5	21426.5	63197.4	39624.4

SAMPLE DATA.

HOLE NUMBER **24**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP039001	20.3	1.2	2.3	1.4	0.0	699.6	10878.5	61387.8	32961.2
RKP039002	22.6	2.0	2.0	2.2	0.0	595.1	10635.4	29837.6	27911.2
RKP039003	19.6	2.1	1.1	1.3	0.1	397.1	17964.5	29998.7	29113.5
RKP039004	83.5	5.1	5.4	1.1	0.0	367.8	3190.9	229186.7	62911.3
RKP039005	79.3	7.5	8.1	1.7	0.1	195.6	5319.2	231103.7	52961.5
RKP039006	60.2	17.1	6.4	1.4	0.0	223.3	5955.6	209912.7	52911.3
RKP039007	87.6	25.1	6.4	1.7	0.1	147.6	4063.6	212914.7	61785.4
RKP039008	106.7	27.3	5.8	1.4	0.2	123.9	1083.6	226634.5	32314.3
RKP039009	383.7	11.1	7.1	1.6	0.0	667.2	2552.9	48304.5	39291.5
RKP039010	489.2	14.3	5.0	1.6	0.1	277.6	4893.2	10905.6	69113.2
RKP039014	527.8	16.3	13.6	2.0	0.3	334.9	12975.4	12201.5	69114.3

SAMPLE DATA.

HOLE NUMBER **25**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP008001	73.1	4.3	8.5	0.4	0.1	1029.4	8734.9	53871.2	40492.6
RKP008002	25.5	3.5	2.0	0.2	0.1	819.4	17411.2	29886.5	16892.3
RKP008003	21.1	2.6	1.2	2.0	0.1	376.1	12193.2	7618.3	23405.5
RKP008004	47.0	5.1	6.3	1.7	0.2	221.5	16308.2	23119.7	66321.3
RKP008005	40.1	9.2	5.0	1.6	0.4	213.2	17911.3	319891.2	34286.3
RKP008006	177.6	7.5	6.1	7.6	0.1	104.5	13944.6	219971.2	35382.4
RKP008007	269.3	10.4	5.9	10.1	0.1	250.8	20478.2	239987.6	49224.3
RKP008008	177.9	12.4	4.8	5.9	0.4	208.9	7822.3	279947.8	42928.5
RKP008009	177.2	13.4	4.0	6.1	0.6	547.5	19477.4	41912.4	91982.3
RKP008010	321.1	17.6	4.8	3.0	0.8	167.1	22640.6	89994.3	4386.4
RKP008014	299.0	21.9	7.3	12.1	1.3	425.5	49389.8	3998.7	69291.4

SAMPLE DATA.

HOLE NUMBER **26**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP020001	79.3	8.3	0.5	0.1	0.1	464.2	8246.3	59877.2	29886.2
RKP020002	86.3	12.4	1.3	0.4	0.1	398.7	9483.4	29911.4	22914.3
RKP020003	99.3	16.3	2.2	0.4	0.1	426.4	10479.6	12416.6	31699.7
RKP020004	107.6	2.4	2.8	0.8	0.1	227.4	11244.5	286944.5	47391.2
RKP020005	64.6	2.9	2.9	0.2	0.1	249.2	4746.5	319294.3	52966.5
RKP020006	63.9	3.7	4.7	1.1	0.1	221.6	3829.5	211482.2	41210.6
RKP020007	70.6	6.2	8.3	2.4	0.1	198.4	2479.8	249977.6	63911.2
RKP020008	82.7	1.8	9.2	2.9	0.2	102.9	1044.5	289984.6	89391.2
RKP020009	102.4	7.9	4.2	1.0	0.1	392.6	4246.7	20949.6	69381.2
RKP020010	118.2	2.1	2.6	0.4	0.2	99.4	921.7	10914.5	50112.4
RKP020014	193.7	12.4	4.2	2.5	0.4	399.6	17286.5	34911.2	41039.2

SAMPLE DATA.

HOLE NUMBER **27**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP009001	76.0	15.7	1.1	1.2	0.1	794.1	7552.9	52961.3	42913.2
RKP009002	85.3	39.8	1.1	1.1	0.1	618.5	17886.9	22318.5	29145.2
RKP009003	70.7	39.8	2.2	0.9	0.1	622.7	18307.3	6998.5	27862.1
RKP009004	16.7	11.7	4.5	2.4	0.1	639.4	14558.7	282114.2	49381.6
RKP009005	28.0	9.4	6.1	2.9	0.1	483.2	15111.2	309112.4	39226.4
RKP009006	98.0	7.0	7.6	0.2	0.3	208.6	14933.4	329112.7	54911.5
RKP009007	92.6	9.4	4.2	0.3	0.3	342.7	19555.7	217776.5	72911.4
RKP009008	124.4	7.0	6.7	8.0	3.5	104.5	536.6	271187.4	86981.4
RKP009009	117.8	14.1	2.3	1.4	0.4	229.8	5955.6	21988.5	96211.4
RKP009010	105.9	11.7	2.9	11.3	0.5	1003.4	20374.3	9949.6	52618.4
RKP009014	131.0	20.2	4.5	12.4	0.4	334.5	44469.3	39981.2	49663.3

SAMPLE DATA.

HOLE NUMBER **28**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP014001	62.6	12.6	0.8	0.6	0.1	493.6	7249.6	44983.2	32911.4
RKP014002	74.3	22.6	1.2	0.9	0.1	397.2	9398.5	31383.2	27941.2
RKP014003	89.9	29.7	1.2	1.2	0.1	329.4	12741.3	9918.6	22638.5
RKP014004	32.6	8.6	2.4	0.4	0.1	199.6	8498.6	299116.6	30211.4
RKP014005	34.7	9.2	3.2	0.3	0.1	207.6	4237.6	332144.6	38618.6
RKP014006	39.4	9.8	4.6	1.9	0.1	244.9	3291.4	221871.4	21119.4
RKP014007	49.2	7.4	4.1	2.9	0.2	296.2	4276.3	262884.3	22646.5
RKP014008	97.6	7.0	0.9	3.2	0.3	109.6	896.5	329994.4	19183.4
RKP014009	119.5	14.6	2.9	4.7	0.5	422.7	3893.4	39387.6	20184.5
RKP014010	64.6	7.6	0.9	0.1	0.6	86.2	1021.9	10874.5	20091.2
RKP014014	139.6	13.9	4.9	2.9	0.3	324.8	14933.5	27983.4	31148.2

SAMPLE DATA.

HOLE NUMBER **29**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP013001	9.0	1.1	0.6	0.6	0.0	438.9	4041.5	91332.4	27911.3
RKP013002	17.7	2.6	0.9	0.5	0.0	355.2	11273.5	31887.6	23962.1
RKP013003	8.2	2.2	1.0	0.6	0.0	246.6	10635.4	7109.5	19289.4
RKP013004	14.9	1.0	3.6	0.8	0.0	113.6	20845.6	278321.4	19296.4
RKP013005	17.6	1.0	5.0	0.6	0.0	168.4	1244.4	311812.3	22183.9
RKP013006	6.8	1.2	3.5	1.1	0.1	122.1	1155.6	241283.6	28266.5
RKP013007	5.7	0.9	4.4	0.9	0.1	193.7	1000.2	290611.3	27911.4
RKP013008	10.9	0.8	3.6	0.3	0.2	126.9	666.5	328222.4	18621.4
RKP013009	46.3	1.3	2.6	1.3	0.2	694.1	18080.4	41392.4	22966.3
RKP013010	74.9	1.0	1.7	1.1	0.2	629.9	12549.6	10789.5	21411.9
RKP013014	79.9	1.1	0.4	0.8	0.5	585.9	9572.5	22917.2	21221.4

SAMPLE DATA.

HOLE NUMBER **30**

FORMATION	ZN	CU	PB	NI	CR	MN	FE	CA	MG
RKP016001	70.7	6.3	2.0	1.0	0.1	862.9	9261.3	52987.2	43926.5
RKP016002	56.0	17.0	2.6	0.9	0.1	791.3	11911.2	31981.3	38299.4
RKP016003	22.7	9.9	3.6	0.9	0.1	498.6	14691.2	9799.5	42962.3
RKP016004	92.7	17.0	2.3	1.3	0.2	387.9	9279.5	283911.4	52966.5
RKP016005	60.0	8.8	5.6	2.4	0.1	299.6	8911.2	319186.5	39291.4
RKP016006	47.3	10.5	9.9	1.4	0.1	254.9	9219.5	299877.6	38296.5
RKP016007	33.1	10.7	8.4	1.1	0.1	307.5	8311.2	229832.5	46512.4
RKP016008	34.1	11.0	6.5	1.4	0.1	191.9	4321.4	299947.6	48391.2
RKP016009	32.2	8.8	5.1	2.7	0.2	647.9	6938.2	11942.3	64911.2
RKP016010	73.3	22.3	3.6	3.0	0.1	167.4	7286.9	82910.6	79832.4
RKP016014	109.2	40.3	5.6	7.4	1.0	791.2	22969.7	99833.7	32118.7

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