ELEMENT MIGRATION ACROSS GRANITIC DIKES

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THESIS

This is to certify that the

thesis entitled

Element Migration Across Granitic Dikes

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H. B. Stonehouse
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ABSTRACT

by Arthur Lifshin

This study was designed to examine the nature of diffusion patterns across an igneous contact zone, both in the intrusive and the country rock. Previous research indicates that diffusion plays an important role in such situations.

Continuous samples were taken from small granite dikes and the adjacent host rock. These samples were analyzed for both major and minor elements by emission spectrographic techniques. Concentration distrubutions were obtained and a generalized function was determined.

Three types of curves were observed: hyperbolic tangent, hyperbolic secant, and complex. Evidence from the complex curves indicates that the system is discontinuous at the contact. These curves cannot be used to describe the concentration distributions but, however, they can be used to describe the relative rates of diffusion on either side of the contact and through the contact itself. Further evidence from the curve types leads to the hypothesis that the contact acts as if it were a semipermeable barrier to diffusion of material across it.

A high-frequency and a low-frequency periodicity that is not related to sampling was found in the distribution. This is thought to be due to enhancement of normal variation in the rock by a non-equilibrium situation and by diffusion producing a high frequency periodicity. The low-frequency periodicity is thought to be caused by the barrier nature of the contact.

Solid-solid diffusion is rejected as the mechanism involved in igneous contact zone diffusion, leaving a form of fluid diffusion as the postulated mechanism. The amount of fluid is the main factor controlling the mechanism. With large amounts of fluid, the fluid is the active diffusing agent (hydrothermal ore deposits). With small amounts of fluid, diffusion occurs through a static fluid film surrounding the mineral grains which is a few molecules thick (granite contact zones). A matrix effect which was found appears to be due primarily to the texture of the host rock and secondarily to its composition. Increasing the width of the intrusive increases the thickness of the diffusion zone, but by a much smaller amount than the increased dike thickness.

ELEMENT MIGRATION ACROSS GRANITIC DIKES

by

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CHAPTER I

INTRODUCTION

Statement and Object:

Interactions between an intrusive body and its host rock constitute a major area within the field of igneous and metamorphic rocks which is replete with unsolved problems. One aspect, the interchange of material between the two rock bodies, is of major importance in understanding the chemical processes that occur during intrusion. Exchange processes may involve movements of fluids or fluidized materials or molecular diffusion. Contact phenomena probably involve combinations of these processes on several different scales. On the largest scale this interaction can be seen in veins proceeding from the main body of the intrusion and in similar phenomena. Smaller scale interactions are usually manifested by changes in gross mineralogy near contacts or, more subtly, slight intra-mineralic changes in composition.

This latter type of change may be due to molecular solid-solid diffusion, or to a fluidized molecular diffusion either by movement of the fluid itself or by the movement of molecules or ions through a fluid film surrounding the grains.

The determination of the nature of small scale transfer processes is the object of this research. Patterns of elemental variations across contacts of small dikes and the adjacent country rock will serve to limit the possible mechanisms for small scale transfer.

The primary objectives of this study are as follows:

1. To determine the extent of interchange of material between an intrusion and host rock.
2. To determine how the element distribution pattern resulting from the interchange differs for different elements.
3. From 1 and 2, to postulate mechanisms for element transfer that could result in the distributions observed.

Previous Work

Most of the studies in the area of diffusion in geological systems have focussed on wall rock alteration in mineral deposits. A few studies have been done on diffusion in contact metamorphic zones, diffusion in single crystals, or the theoretical basis of these phenomena.

Most of the experimental studies are of the diffusion of a single element into individual minerals. These studies are summarized by Fyfe, Turner, and Verhoogan (1958) and the values of the diffusion coefficients reported by them are exceedingly small (on the order of 10^{-6}).

Jensen (1964) investigated the mechanisms of solid-solid diffusion from a theoretical standpoint. Calculated activation energies for solid-solid diffusion by means of lattice defects agree with the activation energies from experimentally determined diffusion coefficients, suggesting that solid-solid diffusion probably occurs by movement of the ion through lattice defects in crystals. The values determined by Jensen and those reported by Fyfe, Turner and Verhoogan show the improbability of solid-solid diffusion as a mechanism in the transport of materials over distances greater than a few millimeters to one or two centimeters indicating that this type of diffusion is important only in the interchange of material between contiguous mineral grains and cannot be used to explain larger transport phenomena.

The interchange of material between an intrusive and its host rock has been reported for distances many times greater than appears to be possible through solid-solid diffusion. One possible process for these phenomena is the introduction of a fluid into the diffusion system either as a passive or active agent. In the case of the fluid acting as a passive agent, diffusion would occur within an intergranular fluid film and would yield diffusion coefficients somewhere between those of solid-solid diffusion and active fluid movement.

Mueller (1966) examined diffusion mechanisms from theory and published data in relation to the attainment of equilibrium in metamorphic rocks. He concluded that solid-solid diffusion is of major importance in the establishment of local equilibrium, but that it cannot be utilized in extensive material interchange. He asserts that extensive material interchange requires a fluid or vapor phase. He points out that any substance has a vapor pressure, and that this is enhanced by increased temperatures and fluids. This essentially agrees with Jensen's work and adds the idea of a vapor phase playing a role in the diffusion process to his conclusions.

Dennen (1951) investigated chemical variation in homogeneous rocks and in contact zones. His findings show that there are minor compositional variations even in the homogeneous rocks (Figure 1). The composition variations he found in contact rocks are seen to be completely different from those determined for the homogeneous rocks (Figure 2). The contact zone distribution curves show major depletion and enhancement of elements near the contacts which are of a different order of magnitude from the variations seen in the homogeneous rock. It should be noted that the zone of concentration variation in the contact zone rocks is too large to support solid-solid diffusion as a transport mechanism and that fluids must be involved. It should also be noted that the

Figure 1- Chemical Variation in a Homogeneous Rock (from Dennen)

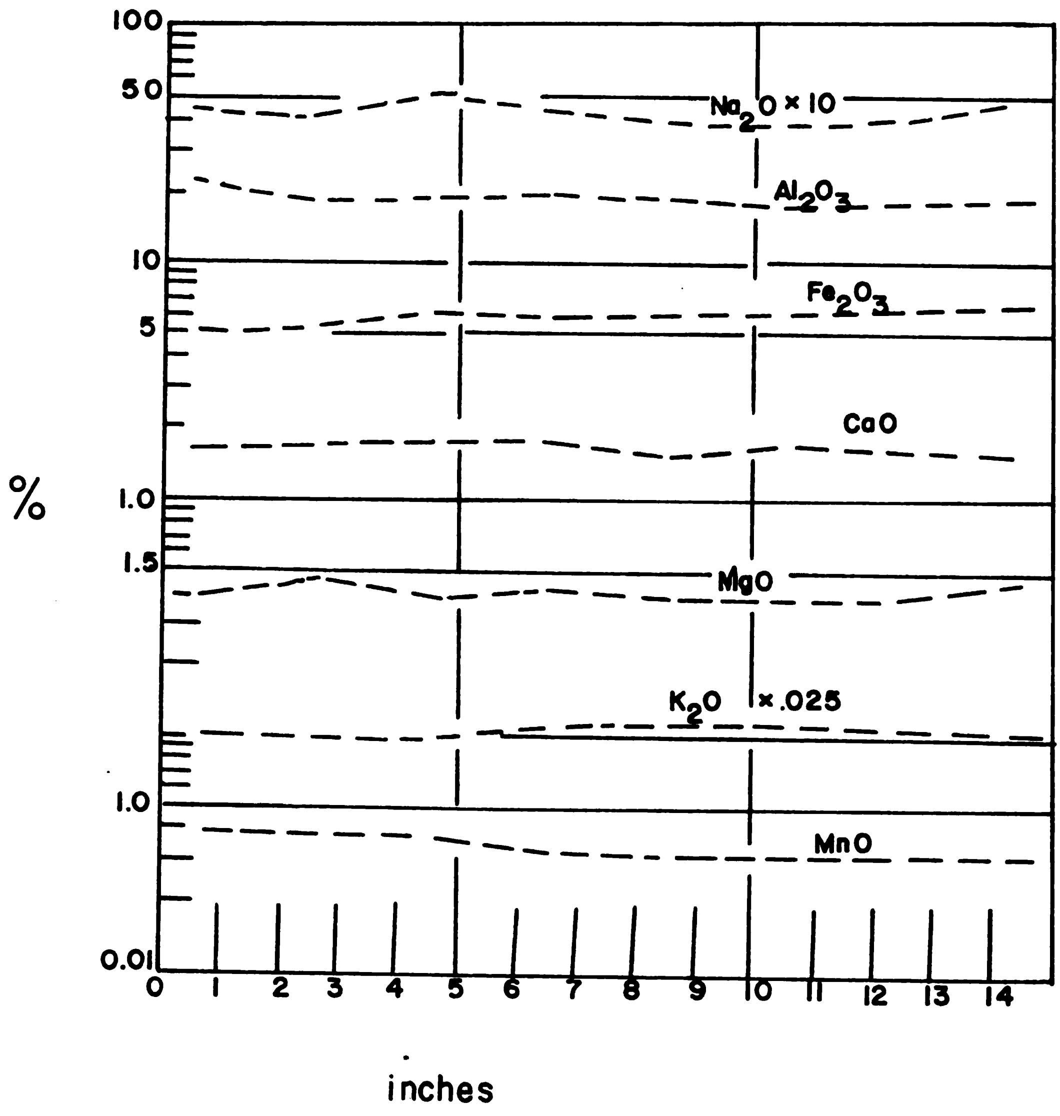
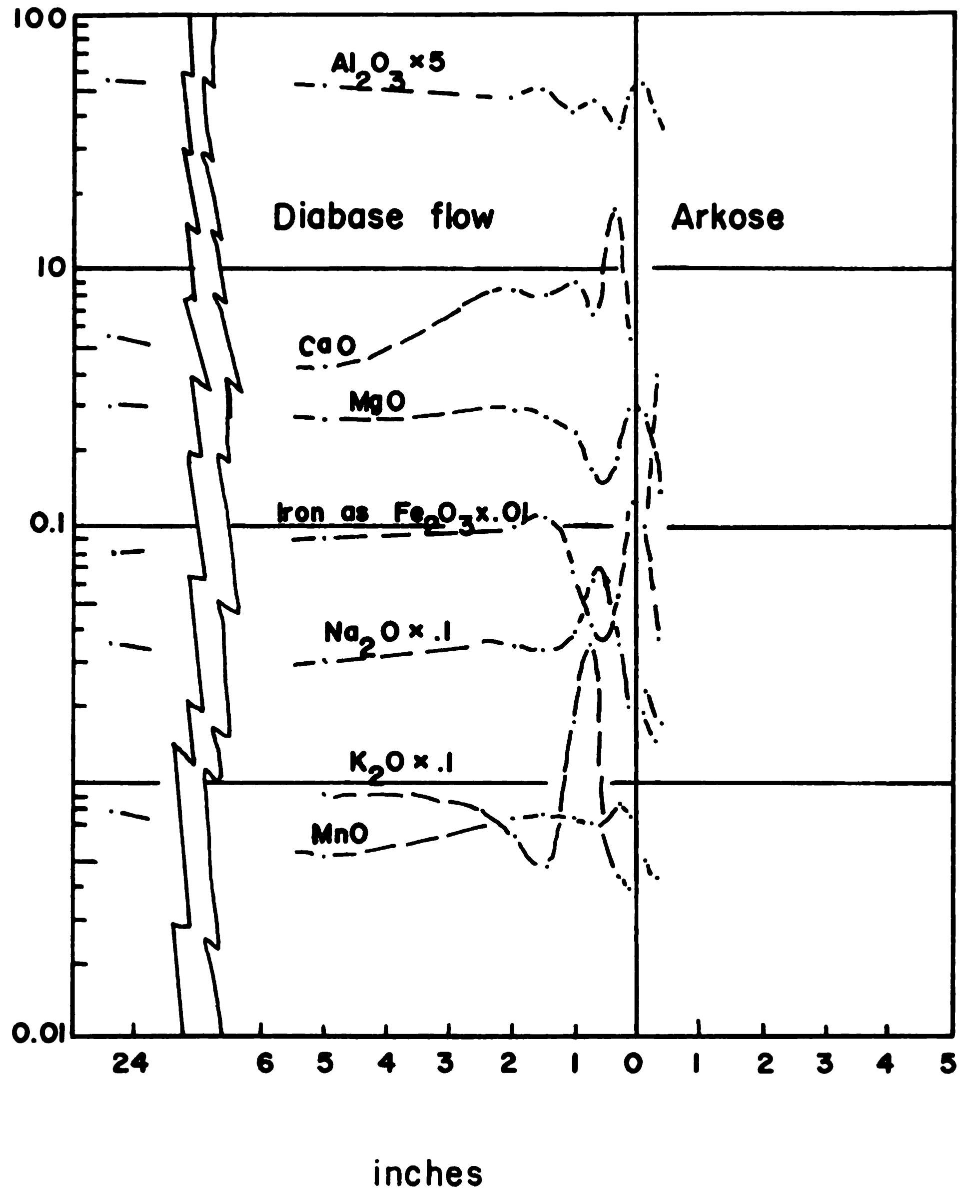


Figure 2 - Chemical Variation Across a Contact of the Medford Diabase Dike with Rhyolite (from Dennen, 1951)



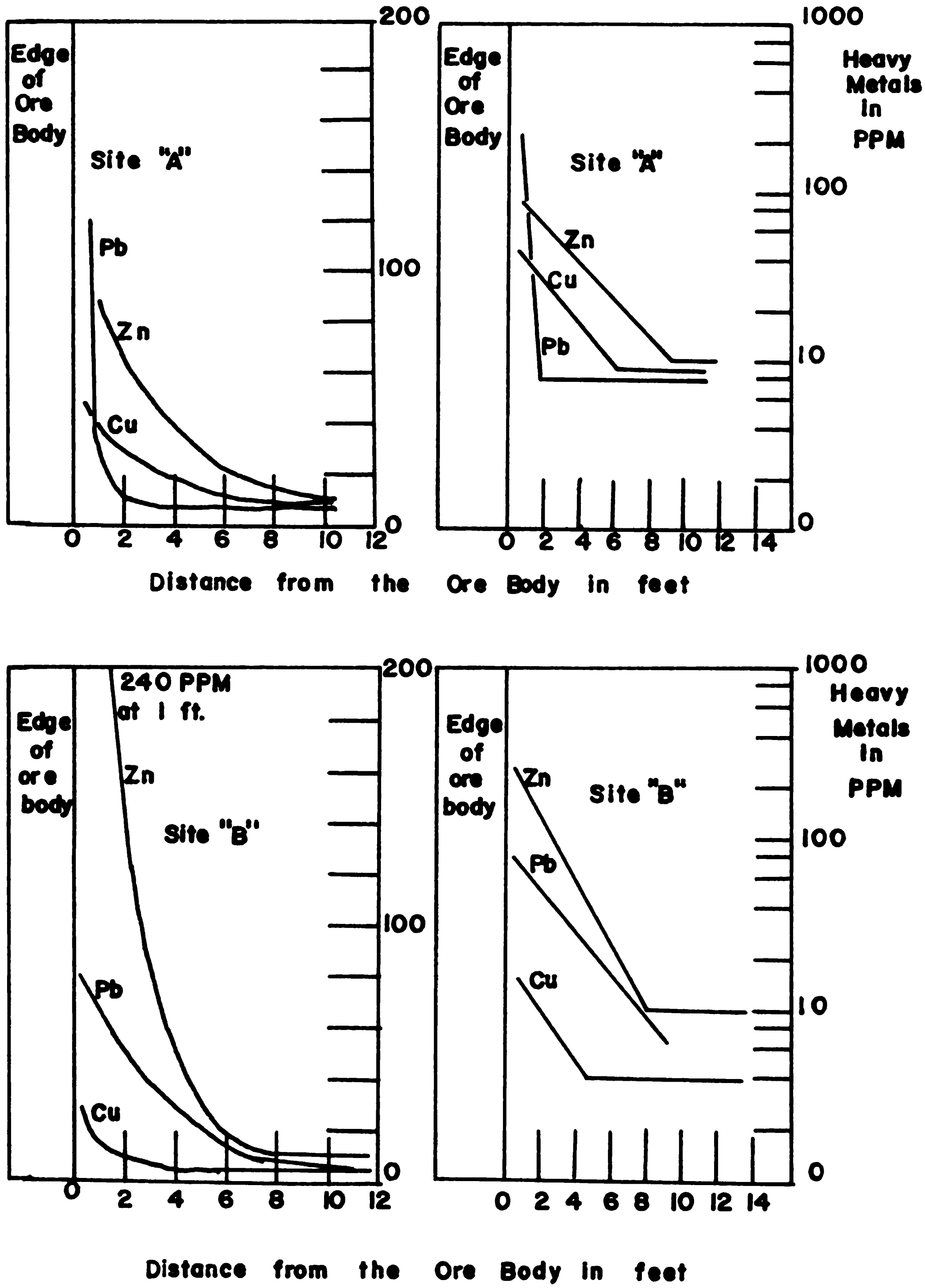
diabase-arkose contact curves and the granite-shale contact curves show a distinct periodicity in zone of concentration variation. This periodicity may be due to a variation in the rate of diffusion.

Woodard (1968) studied the compositional variation in the Cape Neddick Gabbro-Kittery Formation contact zone in Maine. He obtained composition distribution curves similar to those of Dennen's over similar distances.

Morris and Lovering (1952) investigated the distribution of metals in the wall rock of the Tintic District mines. Their distribution curves show a major increase in concentration near the ore vein with the element transfer zone (Figure 3) being from one to two orders of magnitude greater than those of Dennen's or Woodard's. The availability of fluids in these cases appear to be the critical difference. The "intrusion" is a hydrothermal vein which may be considered to be primarily an aqueous fluid in comparison to a granitic or a gabbroic magma. This leads to the assumption that material transfer has occurred primarily through liquid diffusion, where the major source of the fluid is in the "intrusive" itself. In magmatic intrusives, the width of the material transfer zone is much too large for solid-solid diffusion and seems to be too small for fluid diffusion, suggesting the possibility of diffusion of the ions through an effectively static fluid film.

Similar studies by Stonehouse (1954) at Sudbury; Ishikawa, Kuroda and Sudo (1962) in the Kuroko deposits of Japan; Fullagar, Brown and Hagner (1967) at the Ore Knob Deposits in North Carolina; and Wehrenberg and Silverman (1965) at Gilman, Colorado; have yielded results similar to those of Morris and Lovering. The distribution curves for both major and trace elements which were determined in these studies show major enhancement or depletion effects near the contact. The zone of concentration enhancement or depletion varies from about 5 feet in some of the Kuroko deposits to about 75 feet in some of the

Figure 3 - Heavy Metal Dispersion Pattern, Eureka Hill Mine, Tintic District, Utah (from Morris & Lovering, 1952)



Ore Knob deposits. The findings of these studies agree with the results of Morris and Lovering in respect to the material transfer and the thickness of the transfer zone, but like them do not agree with Dennen's and Woodard's studies on "normal" igneous contact zones.

Wehrenberg and Silverman (1965) ran a series of experiments in which zinc, in solution, was diffused through the Yule marble. Their resultant curves were comparable with the curves from the hydrothermal deposit studies, but they did not agree with the curves of either Dennen or Woodard. This is another indication that there are major differences between the two types of contact zones.

In the present study the writer is attempting partially to bridge the gap between diffusion theory and diffusion in a non-hydrothermal igneous contact zone in which the intrusion contains but little water. Empirical formulations that describe the real system will be obtained and these formulations will be related to current diffusion theory if possible.

Location and Geologic Setting

The samples for this study were taken from the igneous and matamorphic rocks in the Thomaston and Waterbury Quadrangles in Western Connecticut (Figure 4).

Gates (1951, 1954, 1968) mapped the Litchfield, Woodbury and Waterbury quadrangles and Cassie (1966) mapped the Thomaston Quadrangle in Connecticut. From their work in this area they have reported that there are two cycles of deformation in the country rock. The country rock sampled for this study is the regionally metamorphosed Hartland Formation.

The granites sampled are thought to be related to the Nonewaug Granite which is intrusive in the area. These Granites are reported by both Gates and Cassie to be post metamorphic and therefore not affected by the regional folding and metamorphism in the area.

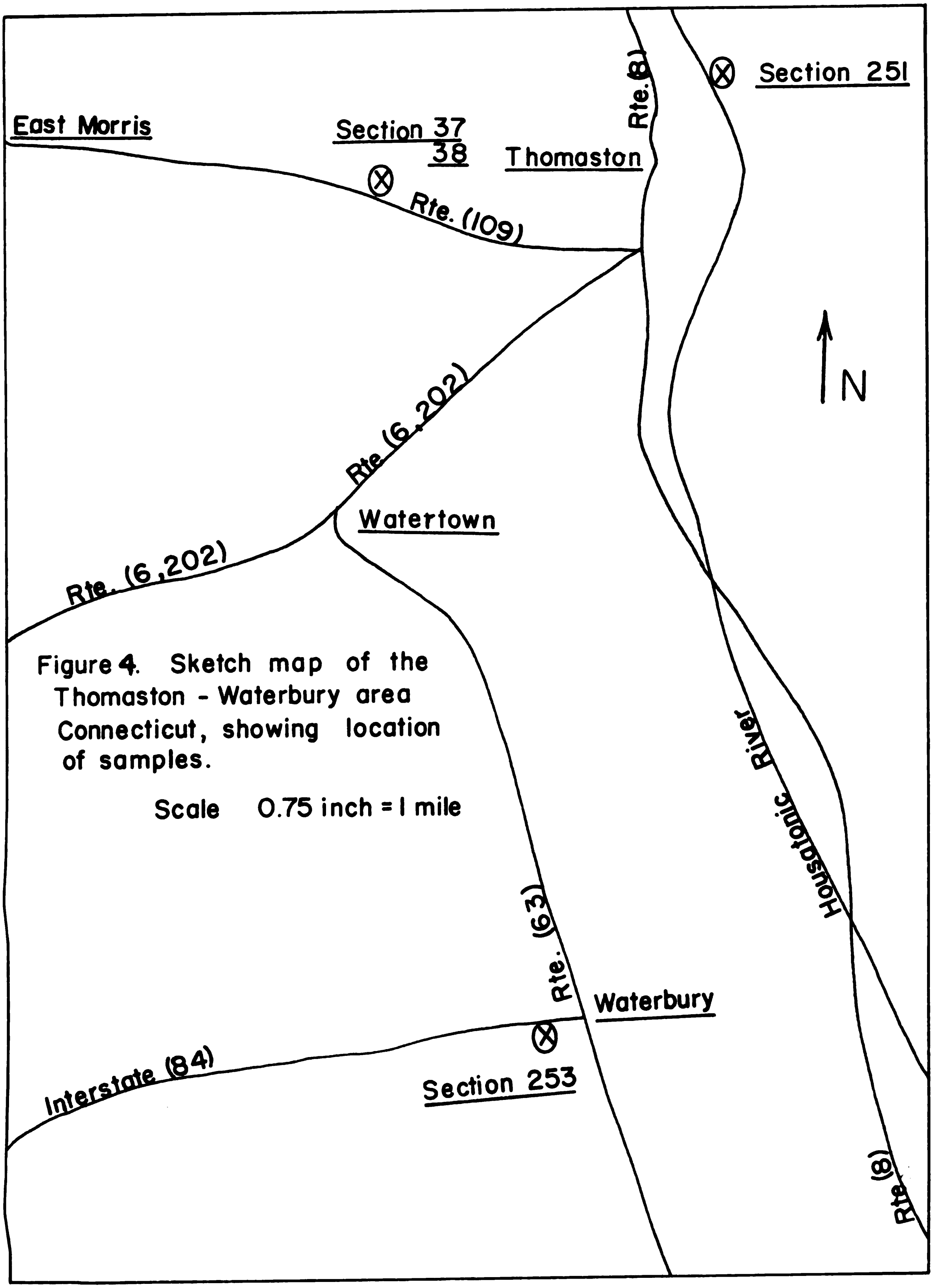


Figure 4. Sketch map of the Thomaston - Waterbury area Connecticut, showing location of samples.

Scale 0.75 inch = 1 mile

CHAPTER II

METHODS AND TECHNIQUES

Sampling

Continuous samples were taken in all cases. In the case of narrow width dikes (maximum width of about two feet), the samples were taken across the dike and into the host rock. For wider dikes, only that part of the dike near the contact and the adjacent horizon were sampled. The contact was defined as that plane which divides the two rock types and was seen as a line of abrupt mineralogical change. In either case care was taken so that only one horizon was sampled in the host rock. The term horizon was defined as a mineralogically homogeneous zone bounded by different mineralogies and probably represents one original homogeneous sedimentary unit.

Sample Description

Three separate dikes were sampled for this study. Their locations are shown in Figure 4 and the data concerning them is given in Table 1. The dikes are roughly an order of magnitude apart in thickness which yields the following thickness ratio: 1:6:120. The mineralogies of the dikes while similar, are sufficiently different to distinguish one from the other. None of the dikes showed chilled margins. Two separate sections were taken from the 12-inch wide dike in order to obtain a replicate sample. The host rock in these sections was chosen for its similarity.

The locations of the dikes are as follows:

Section 37 and 38 - On state route 109, 3.1 miles west of the intersection of state route 109 and US route 6. The outcrop

TABLE 1

SUMMARY OF THE DATA FOR THE GRANITE DIKES

Section	Width in inches	Quartz %	K-Feldspar %	Plagioclase %	An %	Muscovite %	Apatite %
37, 38	12	41.6	21.1	21.9	18	15.0	3.4
251	2	36.1	42.1	19.0	17	2.0	0.9
253	240	45.4	31.1	15.7	16	7.4	0.5

is on the east side of the road at the intersection of route 109 and a northeast trending side road.

Section 251 - By the Thomaston Dam Site on the Naugatuck River, approximately 100 yards east of the causeway bridge.

Section 253 - On interstate route 84 approximately 200 yards before the first Waterbury exit.

The host rock that was sampled was different for each dike. The only exception was section 37 and section 38 where similar rock types were sampled to provide a duplication. The data for the host rocks sampled are given in Table 2. Sections 37 and 38 are quartz-biotite schists. Section 251 is a quartz-biotite-hornblende schist and section 253 is a granite gneiss. The three sections provide enough differences in mineralogy and can be treated as different samples and not as a set of replications.

Sample Preparation

The field samples were sliced parallel to the contact by a diamond saw to yield sections of approximately 0.25 inches wide. These sections were then coarse ground in a Spex Mixer Mill with a high alumina ceramic canister and ball. An optimum grinding time of 45 minutes per sample was determined from a plot of grinding time versus emission line intensity. Four hundred milligrams of the sample were weighed out and mixed with 600 milligrams of graphite mix. Mixing was done on the Spex Mixer Mill using glass vials and plastic balls. Comparison with hand mixing and hand grinding using a mortar and pestle indicated that the mill was at least as good as the hand method.

Elements Selected for Analysis

The elements selected for analysis were chosen because of their position in the periodic table, and in the case of trace elements, their substitution

TABLE 2

SUMMARY OF THE DATA FOR THE HOST ROCKS

Section	Plagioclase %	An %	Quartz %	Biotite %	Muscovite %	Garnet %	Miscellaneous %	Miscellaneous %	Miscellaneous %
37	5.5	24	51.9	22.7	17.0	2.9	none	none	
38	5.0	25	50.2	25.3	16.4	3.2	none	none	
251	40.4	27	1.0	46.6	none	none	Hornblende 6.0	Sphene 5.7	Magnetite 0.4
253	27.2	16	38.0	4.0	none	1.0	K-Feldspar 29.6	Apatite 0.3	

for the major element concerned. In all cases the elements chosen had to fit the limitations of the analytical technique.

Elements were chosen to obtain a minimum of a full row on the periodic table and, where possible, to yield multiples in the columns. This decision was based on the assumption that the mobility of the diffusing ions would be dependent on a parameter that could be related to atomic number and/or atomic weight. Such parameters include ionic charge, ionic size, charge density, etc.

The second item, ionic substitution, follows a similar pattern except in this case ionic size and ionic charge are of primary importance.

The omission of aluminum and silicon as well as oxygen, sulfur and similar elements is due to the limitations of the analytic technique.

Spectrographic Analysis

All analyses for both major and minor elements were done by the writer using emission spectrographic techniques while at the Department of Geology, Michigan State University. The technique used was that of interrupted arc with internal standards. Palladium and indium were used as internal standards (Ahrens, 1950); graphite was added to the mixture for smoother burning. Table 3 gives the analytical conditions used and Table 4 the spectral lines measured.

External Standards

In order to obtain useful quantitative data external standards must be used. The intensity ratios of the unknowns are related to those of the external standards which are of known composition to obtain the concentration of the unknown. The following external standards were used in this study:

1. Standard sample rock G-1

TABLE 3

ANALYTICAL CONDITIONS FOR EMISSION SPECTROGRAPHIC ANALYSIS

Equipment:	Source unit - Applied Research Laboratories Multi-source-unit 4
	Spectrograph - Bausch and Lomb 2 meter dual grating
	Jarrel Ash Microphotometer
	Seidel calculating board, calibration curve from iron spectrum by two step filter method (Harvey, 1957)
Excitation:	Interrupted arc, 30 ohms 40 mfd 360 mh 15 seconds burn time sample positive
Electrodes:	0.242 inch graphite electrodes
Transmittance:	80% and 40% plus additional filtering to 27% and 14% on some lines by means of a split filter
Photography:	Plates - Eastman Kodak Spectrum Analysis No. 3
	Processing - Developer D 19 3-1/2 minutes Stop - 3% acetic acid 30 seconds Fixer - Kodak fixer 10 minutes Wash - running water 30 minutes

TABLE 4

SPECTROSCOPIC ANALYSIS LINES

Element	Line*	Element	Line
Barium	4554.03 Å	Lead	2833.06
Boron	2496.78	Magnesium	2781.42
		Magnesium	2802.69
Calcium	3007.00	Magnesium	2783.00
Calcium	3009.20		
Calcium	3158.60	Manganese	2801.06
Chromium	4274.80	Nickel	3012.00
Chromium	4344.51		
Chromium	4351.77	Palladium	3242.90
		Palladium	3404.00
Copper	3273.94	Palladium	3690.34
Gallium	2943.61	Potassium	4047.20
Indium	3258.56	Sodium	3302.99
Indium	3256.00		
		Titanium	3326.70
Iron	3011.48	Titanium	3361.00
Iron	3075.72		
Iron	3100.67	Vanadium	3183.41
Iron	3196.93	Vanadium	3183.98
Iron	3198.00		
Iron	3199.52	Zinc	3345.07
		Zirconium	3391.98

*Values of the spectroscopic lines are from the National Bureau of Standards Monograph 32

2. Standard sample rock W-1
3. Synthetic standards - Spectrographically pure compounds of various elements were mixed together to provide a base of average composition similar to the samples to be analyzed. Major elements of interest were varied within this base. Minor and trace elements were added as dilutions in graphite to cover the range of compositions of interest.

The working curves obtained from the synthetic standards were adjusted to the values of the standard rock samples G-1 and W-1 with a partial correction for the matrix effect.

Interrupted Arc

Interrupted arc is a technique whereby the arc, instead of being continuous, is mechanically interrupted by a rotary motor rotating at 60 cycles per second. The main effect of the interrupted arc is to lower the temperature of the sample in the arc. The interrupted arc was used in this study instead of the more commonly used continuous arc for the following reasons:

1. Reduction of CN emission and background over that of the continuous arc, probably due to the lower temperature of the interrupted arc.
2. Shorter arcing time per sample. In the present case, 15 seconds yielded consistant results with as good or better sensitivity than the 2 minutes or longer required of the continuous arc.

The disadvantages of this method appear to be an enhancement of the matrix effect of particle size on emission line intensity. Correction for the matrix effect was done as stated previously. The values of G-1 and W-1 were the recommended values of Fleischer and Stevens (1962). A correction for particle size was made by determining an optimum grinding time from a plot of grinding time versus emission line intensity.

Precision

All the samples were analyzed in triplicate, the standards were analyzed six separate times and two other samples were analyzed ten times. The maximum error for the standards are listed in Table 5.

TABLE 5

MAXIMUM ERROR DETERMINED FOR THE ANALYSIS OF THE STANDARDS

Element	Error in Percent Concentration
Barium	10%
Boron	10%
Calcium	9%
Chromium	10%
Copper	10%
Gallium	10%
Iron	7%
Lead	10%
Magnesium	8%
Manganese	7%
Nickel	10%
Potassium	8%
Sodium	9%
Titanium	10%
Vanadium	10%
Zinc	10%
Zirconium	9%

CHAPTER III

RESULTS

General Statement

An examination of the data curves (Appendix B) indicates the presence of gradients for most of the elements studied. In most of the curves, the observed gradients indicate the movement of material within the system studied. This is best seen in those curves which appear to be convergent or continuous at the contact (Figures 8, 10, 11, etc.). Other curves do not show material transfer although a gradient exists. This is seen in Figures 16, 21, 25, etc. In this last case, the concentration distribution on either side of the contact can best be described as a horizontal straight line.

Most of the curves have a periodicity which is superimposed upon the general trend of the distribution. Both a high frequency and a low frequency periodicity can be seen on the same curve. There is an order of magnitude difference in the two frequencies which indicates distinct differences between the two types.

Curve Descriptions

Examination of the patterns of the curve gradients indicates that they can be roughly grouped into three classes (Figure 5). The first class can be described as a generalized hyperbolic tangent (Figure 5a). The second class can be described as a generalized hyperbolic secant (Figure 5b). The third class is more complex as the curves are divergent at the contact (Figure 5c). Table 6 shows the breakdown of the elements into the major classes.

Figure 5- Three Classes of the Element Distribution Curves

Figure 5a- Class I Generalized Hyperbolic Tangent

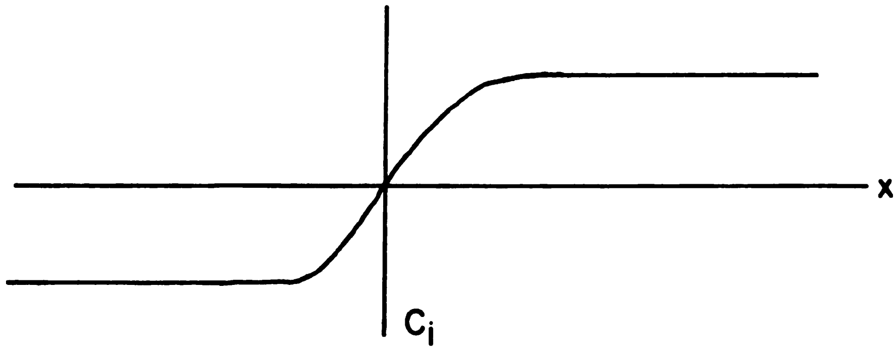


Figure 5b- Class II Generalized Hyperbolic Secant

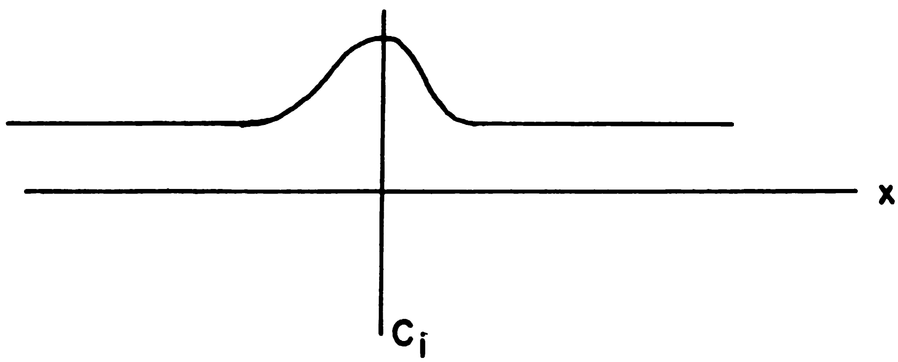


Figure 5c - Class III Complex, Divergent at the contact

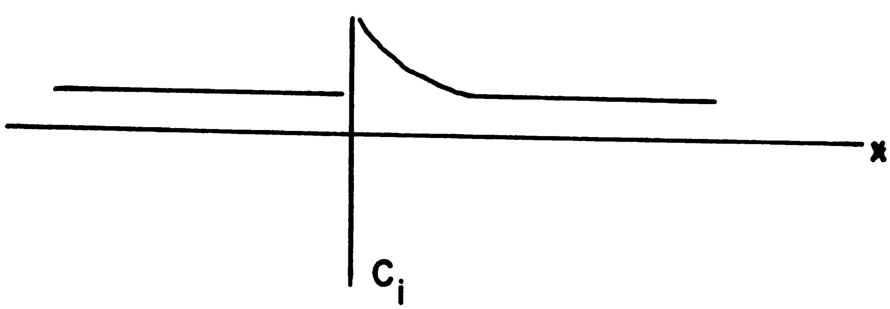


TABLE 6

BREAKDOWN OF THE VARIOUS ELEMENTS INTO THE THREE CURVE CLASSES

Section	Type I Hyperbolic Tangent	Type II Hyperbolic Secant	Type III Complex
37	K, Mg, Ca, Fe, Mn, Cu, B	Na, Ti, Ga, Pb	none
38	K, Mg, Ca, Fe, Mn, Cu, Pb, Ga, B	Na	Ti
251(1)	Na, Mg, Ca, Fe, Cr, V, Ti, Ga, Mn	K	none
251(2)	Na, Mg, Ca, Fe, Cr, V, Ti, Ga	K	Mn
253	K, Na, Ca, Cu, Ga, Pb	Mn	Mg, FeV, Ti

The greatest number of curves are of the type I (generalized hyperbolic tangent). This class of curves contains the straight line distributions which may be considered as an extreme form of the hyperbolic tangent. A few curves fit the type II classification (generalized hyperbolic secant). Six curves are in the type III class (complex).

The first two main curve classes can be further broken down into subgroups. The class III curves are all of the same form and hence there are no subgroups for this class. Figures 6 and 7 show the subgroups for the corresponding classes. Tables 7 and 8 show the element breakdown into the subclasses. It may be noted that while the subclasses are distinct from each other, they are all basically modifications of the same curves.

The general form of the curve for type I is the hyperbolic tangent which can be expressed as follows:

$$C_i = \tanh(\phi) = (e^{\phi} - e^{-\phi})(e^{\phi} + e^{-\phi}) \tag{3.1}$$

where C_i = concentration of element i

ϕ = some function of the distance from the contact

The three subgroups of the type I curve can be generated from the generalized hyperbolic tangent of type I by changing the function ϕ.

The type IIb curve is the inverse of the type IIa curve and can be generated by a rotation around the x axis. The hyperbolic secant can be expressed as follows:

$$C_i = \text{sech}(\phi) = (e^{\phi} + e^{-\phi})/2$$

where C_i = concentration of element i

ϕ = some function of the distance from the contact

Figure 6 - Generalized Curves for the Subclasses of the Class I Curves

Figure 6a - Class Ia Hyperbolic Tangent

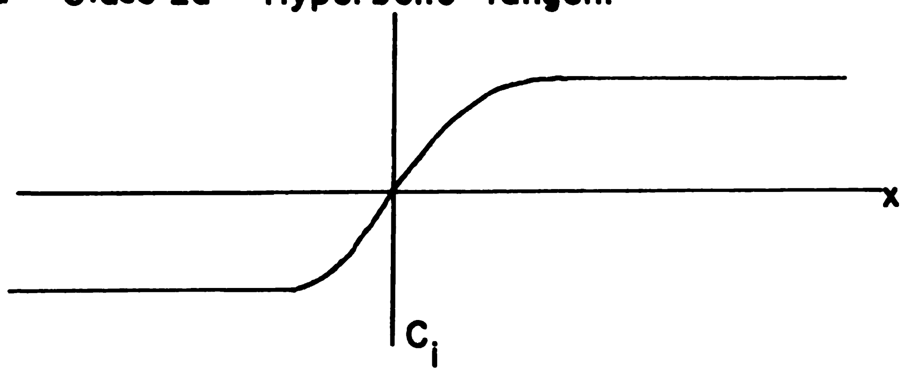


Figure 6b - Class Ib Straight line with gradient

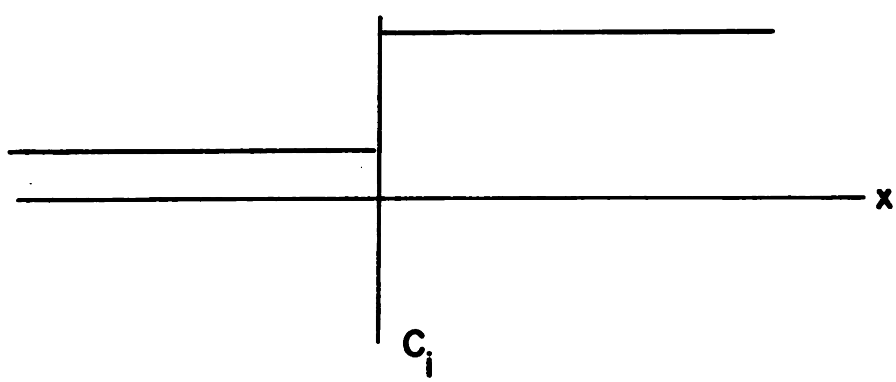


Figure 6c - Class Ic Straight line, no gradient

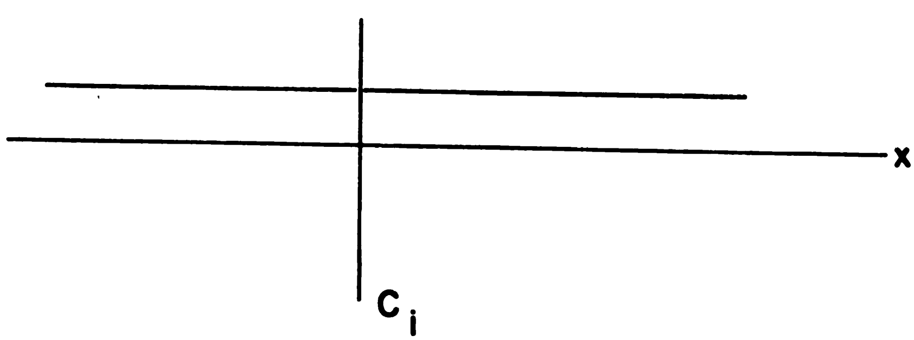


Figure 7 - Generalized Curve for the Subclasses of the Class II Curves

Figure 7a - Class IIa Hyperbolic Secant

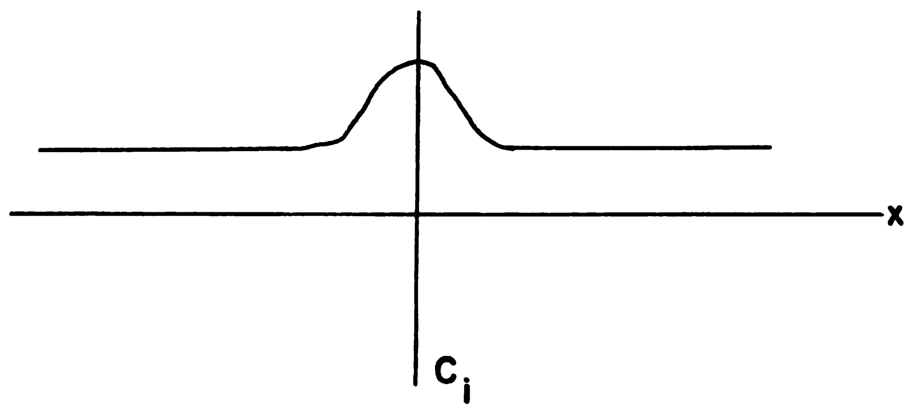


Figure 7b - Class IIb Inverted Hyperbolic Secant

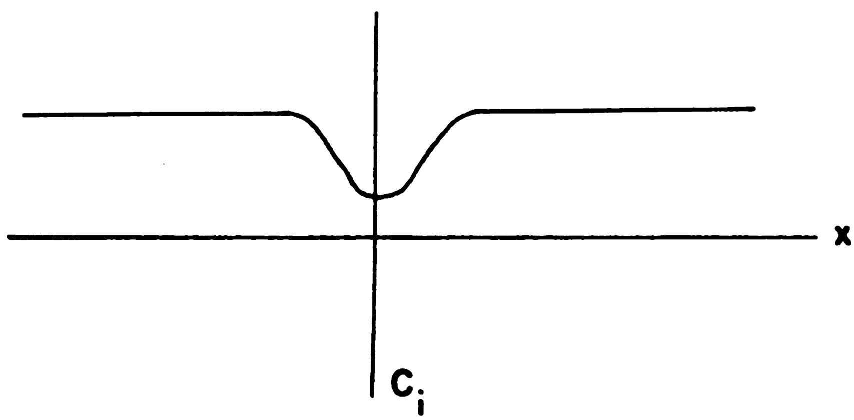


TABLE 7

BREAKDOWN OF THE VARIOUS ELEMENTS INTO THE SUBGROUPS OF TYPE I

Section	Ia	Ib	Ic
37	K, Mg, Ca, Cu, B	Fe, Mn	none
38	K, Mg, Fe, Mn, Ga, Pb, B, Cu	none	Ca
251(1)	Na, Mg, Fe, Ga, Ca, Mn	V, Cr, Ti	none
251(2)	Na, Fe, Ga	Ca, Mg, V, Ti, Cr	none
253	Ca, K	Pb	Na, Cu, Ga

TABLE 8

BREAKDOWN OF THE VARIOUS ELEMENTS
INTO THE SUBGROUPS OF TYPE II

Section	IIb	IIa
37		Ti, Ga
38	Na	none
251(1)	K	none
251(2)	K	none
253	none	Mn

The type III curve is the only curve that is divergent at the contact. A formulation for this type of curve would involve two separate functions, a decay curve on one side of the contact and a straight line on the other.

Distribution of the Elements in the Curve Types

The majority of the elements fall into the type I or hyperbolic tangent curves. These curves can be described as a growth or decay curve which would be expected in a diffusion system. A definite relationship appears between the Na and K curves for each section. Where the Na is in the type I groups the K is in the type II group and visa versa. This does not hold for section 253, probably due to the non-diffusion of the Na. The other elements in the type II curves do not show any distinct relationships with the type I curves. No obvious relationships appear for the type III curves, although this type of curve could be generated if diffusion occurred only on one side of the contact without material crossing the contact.

The type Ib and Ic curves are those that show no diffusion either with a gradient (Ib) or without one (Ic). Some relationships appear to exist between these and the type Ia curves, but these relationships are not consistent. The type Ia curves could be further subdivided but the resultant groupings would be superfluous since they would be due to modifications in the ϕ function.

The previous discussion is based on the assumption that the curves can be treated as continuous across the contact. The type III curves directly indicate this. If the reverse assumption is made, that the curves are discontinuous at the contact, the curve types then assume other meanings. The type I curves could be treated either way, but the Ib and Ic curves indicate a discontinuous function.

In the case of the type II curves, the contact is a point of high concentration (IIa) or low concentration (IIb) common to both sides. Under the assumption of continuity this is not easily explained. If one assumes a discontinuity, however, the situation can be explained by means of differing rates of diffusion on either side of the contact. It should also be noted that the physical system is itself discontinuous at the contact.

Under the assumption of discontinuity the system can still be treated as a growth or decay curve if each side of the contact is considered independently. In this case all of the curves can be treated either as a straight line or as a hyperbolic tangent. The breakdown into types I, II, and III curves can now be used to indicate relative mobilities within the system.

Specific Form of the Distribution

An approximate solution for the function ϕ in equation 3.1 was obtained by the following method.

1. The data was transformed such that;

$$C_e = \ln(C_i/C_o)/\ln(C_o/C_m) \tag{3.3}$$

where: C_e = resultant concentration of element i

C_i = actual concentration of element i

C_o = concentration of element i at its midpoint

C_m = minimum value of the concentration of element i.

This was done in order to fit the data to the +1 to -1 range of the hyperbolic tangent.

2. The values of ϕ corresponding to arctanh (C_e) were obtained from a table.

3. These values were then plotted against X, where $X = x - x_o$ and x_o is the distance from the contact corresponding to $C_i = C_o$.
4. A linear regression was performed on these variables and a generalized expression for ϕ was obtained.

The resultant expression for ϕ is:

$$C_e = \ln(C_i/C_o)/\ln(C_o/C_m) = \tanh(b(e^{kX} - 1)) \qquad (3.4)$$

Tables 9 to 12 show the values of the parameters for each section. There appear to be no definite relationships between b and k and atomic weight or atomic number. This may be due to the approximate nature of the data or to the small amount of data available.

Periodicity

As stated earlier, most of the curves show both a high and low frequency periodicity. A wavelength analysis of this periodicity was done by means of an autocorrelation program developed by D. Hill (Department of Geology, Michigan State University) on the CDC 3600 at Michigan State University. Comparison of the determined wavelengths with the sampling interval indicated the following.

1. The low frequency periodicity was not related to the sampling interval.
2. Of the high frequencies for a given curve, some are distinctly not related to the sampling interval while others may be related.

All of the high frequencies may be the result of the experimental procedure and may be viewed as noise within the data. This is not probable as the low frequency appears to be inherent in the system, and the high frequency

TABLE 9

PARAMETERS OF EQUATION (3.4) FOR SECTION 37

Element	x_o	C_o	C_o/C_m	b	k
Na (G)*	0.30	1.14	2	0.24	0.90
Na (S)**	0.60	0.99	2	1.22	0.49
K (G)	-0.30	2.98	2	-0.36	0.43
Mg (S)	0.90	1.20	2	0.35	0.99
Ti (G)	0.60	1628	2	-0.08	2.71
Ti (S)	0.55	4568	2	-0.11	5.70
Cu (G)	0.70	112	2	0.17	1.84
Cu (S)	1.25	40	4	-0.12	1.37
Ga (G)	-0.40	24	2	-0.11	2.21
Pb (S)	0.30	30	2	0.07	5.00

*(G) indicates that the values are for the granite part of the section.
**(S) indicates that the values are for the schist part of the section.

TABLE 10

PARAMETERS OF EQUATION (3.4) FOR SECTION 38

Element	x_o	C_o	C_o/C_m	b	k
Na (G)*	0.45	0.93	2	0.31	0.55
Na (S)**	0.75	0.50	2	0.25	2.28
K (S)	0.00	1.95	2	0.36	0.60
Fe (S)	0.25	3.87	2	0.35	0.47
Mg (G)	2.30	992	2	-0.24	0.83
Mg (S)	0.50	1.35	2	0.06	1.06
B (G)	-0.10	20	2	-0.09	2.31
B (S)	1.15	43.5	2	0.35	2.67
Cu (S)	0.95	238	2	0.14	2.08
Ga (G)	0.50	22	2	-0.16	0.52
Pb (G)	-0.10	31	2	0.01	2.10
Pb (S)	0.10	15	2	0.23	1.48
Ti (S)	0.95	204	2	-0.27	1.81
V (S)	0.70	980	2	-0.55	1.16
Zn (S)	0.35	86	2	0.30	0.85

*(G) indicates that the values are for the granite part of the section.
**(S) indicates that the values are for the schist part of the section.

TABLE 11

PARAMETERS OF EQUATION (3.4) FOR SECTION 251

Element	x_o	C_o	C_o/C_m	b	k
Na (S_i)*	0.00	3.70	2	-0.16	3.14
Na (S_2)**	-0.90	3.16	2	-0.54	0.20
K (S_i)	-0.20	1.01	2	0.22	0.89
K (S_2)	0.00	0.90	2	0.33	0.70
Mg (S_i)	0.10	0.23	2	0.34	1.79
Mn (S_i)	-0.40	1096	2	0.48	0.79
Mn (S_2)	0.00	2796	2	-0.29	1.10
Ni (S_i)	0.00	40	2	0.45	1.33
Ga (S_i)	-0.80	44	2	-0.01	5.99
Ga (S_2)	0.15	24	2	-0.07	29.90

*(S_i) indicates that the values are for the schist (1) part of the section.
**(S_2) indicates that the values are for the schist (2) part of the section.

TABLE 12

PARAMETERS OF EQUATION (3.4) FOR SECTION 253

Element	x_o	C_o	C_o/C_m	b	k
K (S)*	0.40	2.44	2	-0.54	0.20
Ca (S)	0.60	1.16	2	0.36	0.40
Fe (S)	0.50	3.14	2	-0.10	0.91
Ba (S)	1.40	60	2	-0.07	1.29
Cr (S)	1.20	84	2	-0.15	0.54
Ti (S)	0.90	1268	2	-0.18	1.80
V (S)	0.80	80	2	-0.21	1.73
Mn (G)**	3.70	346	2	-0.17	0.46
Mn (S)	2.60	790	2	-0.08	1.07

*(S) indicates that the values are for the schist part of the section.
**(G) indicates that the values are for the granite part of the section.

may be expected secondary and tertiary frequencies. Some of the higher frequencies may be due to inhomogeneity to be found in any rock.

Accurate analysis of the wavelengths of the periodicity was found to be impossible due to the variance in the x position of the points which is due to the thickness of the samples analyzed. There is some indication, however, from the analysis, that the wavelengths will correlate with atomic number or atomic weight. Further experimental work is needed to determine this with any degree of certainty.

Concentration Gradient

It would be expected that the driving force for the diffusion of an element would be the existence of an activity gradient within the system. Since it is not possible to determine the activities, the concentrations were used as a first approximation.

Unless the diffusion has resulted in the same concentration on both sides of the contact, differences in base level concentrations on either side of the contact should still appear. That the concentrations have not been equalized is shown by the mineralogical differences in the rocks on either side of the contact. With this in mind, t tests between the rock types for each element in each section were computed as a determination of differences in concentration (Walker and Lev, 1953). These values are presented in Tables 13 to 16.

The results of these t tests do not, in most cases, appear to be meaningful. Significant differences exist where there is no indication of diffusion from the curves and also the reverse. This may be due to the nature of the t test for this type of data, which seems doubtful. It is more probable that the concentrations, as a first approximation, are not linearly

TABLE 13

RESULTS OF t TEST BETWEEN SCHIST AND GRANITE FOR SECTION 37

Element	t
Na	0.92
K	10.75*
Mg	19.70*
Ti	3.82*
B	3.47*
Ga	6.68*
Ca	8.91*
Fe	19.00*
Mn	20.60*
Cu	11.40*
Pb	0.82
Zn, Ni, V, Zr	not determined

*indicates that the value is significant at 0.005.

TABLE 14

RESULTS OF t TEST BETWEEN SCHIST AND GRANITE FOR SECTION 38

Element	t
Na	8.16*
K	11.40*
Mg	29.10*
B	10.70*
Ga	7.90*
Ti	17.30*
Ca	2.11
Fe	26.10*
Mn	32.50*
Cu	87.40*
Pb	7.00*
Zn, Ni, V, Zr	not determined

*indicates that the value is significant at 0.005.

TABLE 15

RESULTS OF t TEST BETWEEN SCHIST AND GRANITE FOR SECTION 251

Element	t_1**	t_2***
Na	6.50*	7.30*
K	0.84	1.36
Mg	66.80*	24.70
V	15.60*	12.90*
Ga	6.20*	9.45*
Zr, Ni	not determined	not determined
Ca	13.70*	9.40*
Fe	29.20*	23.80*
Mn	17.60*	94.70*
Ti	56.50*	22.80*
Cr	28.80*	17.20*

*indicates that the value is significant at 0.005.
**t_1 refers to the schist (1)-granite part of the section.
***t_2 refers to the schist (2)-granite part of the section.

TABLE 16

RESULTS OF t TEST BETWEEN GRANITE AND GRANITE GNEISS FOR SECTION 253

Element	t
Na	1.30
K	24.30*
Mg	3.55*
Ti	4.30*
Pb	15.70*
Cu	3.70*
Ca	12.20*
Fe	12.50*
Mn	6.20*
V	11.00*
Ga	1.07
Ba, Cr	not determined

*indicates that the value is significant at 0.005.

related to the activities of the diffusing elements at the conditions under which the diffusion occurred.

Thickness of the Diffusion Zone

The thickness of the diffusion zone is, for the purposes of this section, operationally defined as that point where the hyperbolic tangent is effectively equal to one ($C_e = 0.999$). Table 17 shows the diffusion zone thicknesses for each element and each section.

The sections are arranged in order of increasing dike thickness. It should be noted that there is a tendency for the wider dikes to have wider diffusion zones for a given element. This may be due to the greater amount of fluid associated with the wider dikes. There is not enough data to determine what is the relationship between dike width and diffusion zone thickness. The matrix of the dike and host rock will also effect the diffusion zone width thereby making it difficult to determine such a relationship.

Comparisons within a single section are more fruitful. With partial and incomplete data, it can be seen that Ni and Mg are comparable in 251(1). In 251(2) Na and K are comparable and inverse. In section 38, Mg and Fe are comparable, Na and Ti are inverse. Ti and V in 253 are comparable. These comparable and inverse relationships of the thickness in a given section are to be expected from the known atomic parameters of these elements. It is to be expected that with more data other similar relationships will appear.

TABLE 17

THICKNESS OF THE DIFFUSION ZONE, IN INCHES,
FOR EACH ELEMENT IN EACH SECTION IN THE HOST ROCK

Element	Section 37	Section 38	Section 251(1)	Section 251(2)	Section 253
Na	1.82	1.46	0.58	2.10	none
K	none	2.20	1.71	2.00	2.60
Ca	none	none	none	none	3.90
Mg	2.27	3.10	0.88	none	none
Fe	none	3.13	none	none	3.14
Mn	none	none	1.02	1.37	5.03
B	none	4.03	none	none	none
Ga	none	none	0.30	0.24	none
Ti	1.25	1.48	none	none	1.82
Cu	2.71	1.96	none	none	none
Pb	0.82	1.23	none	none	none
Zr	none	none	none	none	none
Ni	none	none	0.89	none	none
V	none	2.51	none	none	1.81
Zn	none	2.11	none	none	none
Cr	none	none	none	none	5.83

CHAPTER IV

DISCUSSION

Nature of the Contact

The contact between the intrusive dike and the adjacent country rock is a mineralogical and textural discontinuity, which may act as a barrier to the free migration of elements from one rock type to the other.

When the various curves are examined, definite indications of material transfer across the contact appear in some of the curves (Figures 8, 10, 11, etc.) while other curves, show movement of material on one side of the contact only (Figures 16, 21, 25, etc.). The shape of the curves suggests that the distribution is discontinuous at the contact. The curve types described in the previous chapter probably indicate the relative mobility of an element on either side of the contact. Thus, the contact serves as a barrier to the free movement of material across it.

For a given element, the barrier can be considered to be permeable if it allows the free movement of material across it, and impermeable if it prevents such movement. If some elements can move freely across the barrier while others cannot, or if some element can cross it only with difficulty, then the barrier may be considered to be semipermeable. The mechanism of this barrier is not understood.

Two different hypotheses apply to the treatment of the contact as a barrier. The first hypothesis is that the contact is a physical barrier to diffusion. The second hypothesis asserts that the barrier nature of the contact is only apparent and the effect is due to the differing rates of diffusion on either side of the contact, which is to be expected since the material through which the diffusion is occurring is mineralogically and texturally different on either side of the contact. This would explain the need for different functions for a given element on either side of the contact in the same section. Either or both of the hypotheses will explain the type I curves (hyperbolic tangent).

The type Ia curves can be explained by the barrier nature of the contact and/or the differing diffusion rates on either side of it. At present it is not possible to determine how much of an effect the barrier nature of the contact has in this curve type. The difference in the curve on either side of the contact can be handled by changing the diffusion rates which will result in differing functions.

The term gradient as used below refers to both the concentration and temperature difference existing during the diffusion process. The use of concentration alone is due to lack of data on the temperature values.

The type Ib curves have a gradient and no movement of material across the contact. This can be explained by assuming a very low diffusion rate on either side of the contact and a very low permeability of the contact.

The type Ic curves require no further explanation beyond the statement that there is no gradient and no movement of material across the contact.

The type II curves (hyperbolic secant) can be explained by the assumption of a semipermeable contact which is effectively impermeable to the diffusion across it. The rate of diffusion on either side of the contact is now no longer of major importance to the argument. Since there is still a gradient across the contact, there will still be diffusion away from the high concentration side of the contact which will not be able to cross the contact and will, therefore, build up to a high concentration level near the contact. With a gradient established across the contact and the contact acting as a semipermeable barrier, a common high or low concentration point would form at the contact. If the higher side of the gradient is the side with the higher diffusion rate, there should be an increase in the concentration near the contact. This increase should develop at a faster rate than it can cross the contact. Since the diffusion on the opposing side of the contact is slow, movement of the transferred material away from the contact should also be slow resulting in a zone of increased concentration near the contact. Since both sides have concentrations increasing toward the contact, the contact should appear as a common high point as is seen in the type IIa curves.

An explanation for the type IIb curves is similar except that the side having the high diffusion rate is now the low concentration side of the gradient. In other words, material is removed from the area around the contact faster than it can be supplied which produces common low at the contact.

The type III curves (complex), however, can best be explained by the action of the contact as a physical barrier to diffusion. An explanation of the type III curves (complex) under the second hypothesis requires the assumption of a zero rate of diffusion for the element on the one side of the barrier. Section 253 has four curves in the type III group (complex), and since the rock types on either side of the contact are very similar (granite-granite gneiss), this assumption does not appear feasible. Similar arguments also apply to the exclusive use of the second hypothesis for the type II curves (hyperbolic secant).

In the light of the above discussion it is proposed that a rational explanation for the three curve groups lies in the combination of the two hypotheses into one. This results in the following statement: In considering interchange of material between an intrusive and its host rock by diffusion, the contact acts as a barrier to the free movement of material across it and the rock type on either side of the contact acts as a controlling factor in the diffusion process. This appears to be quite reasonable since the assumption of differing diffusion rates with differing matrices cannot easily be discarded, but as has already been shown, it is not a complete explanation. Introduction of a semipermeable barrier to diffusion in the contact adds the necessary conditions for the explanation of the three curve groups.

Periodicity

As stated previously, the low freqneucy and most of the high frequency periodicities are probably inherent in the diffusion system. No relationships were found between these periodicities and the sampling interval. Two factors may account for this periodicity. The first factor is the normal variation in composition to be found in any "homogeneous" rock, as reported by Dennen (Figure 1). The second factor is the semipermeable nature of the contact as discussed in the previous section.

Figure 1 (Dennen, 1951) shows element distributions for a homogeneous rock. It is evident that there are minor variations in composition, and that the variations are somewhat random in nature. If this rock system is isolated and the mobility of constituents is increased by increasing the temperature of the system so that material can move, the system would be expected to reach an equilibrium distrubution. If the increase in temperature is constant over the entire system, the resultant composition distribution expected is a straight line. If, however, the temperature increase varies over the system, the resultant composition distribution would reflect the temperature distrubution. Under this second set of conditions, the variations in composition already existing within the rock would be enhanced or depleted depending upon the distribution of the temperature field. In either case, in the absence of equilibrium, enhanced or depleted forms of the original compositional variations would still remain. If the system is under further stress, such as an anisotropic mass interchange (diffusion) parallel to the trend of the variations, these variations should be further enhanced. The system would be analogous to adding energy to one end of a standing wave.

The semipermeable nature of the contact would act to develop its own periodicity in the following manner. If material is diffusing out of the system and the contact is acting as a partial barrier to this diffusion, then an increase in the concentration of the diffusing element would be expected at or near the contact. This increase would tend to deplete the adjacent zone. The increase and depletion is basically a waveform although it is localized at the contact. If the conditions generating this waveform correspond with the conditions resulting in variations already present in the rock the variations will be enhanced thereby extending the waveform further into the rock away from the contact zone.

The combination of the two factors discussed above should result in a periodicity similar to that seen in the experimental curves. The low frequency periodicity being due to the semipermeable nature of the contact and the high frequency periodicity due to the stressing of the original compositional variation in the rock.

Factors Controlling Diffusion Rate

Of the numerous factors controlling the diffusion rate only two are evident from the results of this study. These are the "matrix" or bulk composition and the fluid content of the system. The matrix effect can be inferred from the values in Tables 9 to 12 (curve parameters) whereas the fluid effect is estimated from the published values of the diffusion coefficients (Fyfe, Turner & Verhoogan), the thickness of the diffusion zone as reported in this research (Table 17) and the diffusion zone thicknesses reported for wall rock alteration in hydrothermal vein deposits.

The effect of the matrix or bulk composition on the diffusion can be seen both in the thickness values of the diffusion zone and in the values of the distribution equation parameters. The values of b and k for any given element in any one section are different on either side of the contact. These values are also different from section to section, indicating that the matrix is a controlling factor in the diffusion rate. It is probable that the matrix effect, in the case of a fluid or of fluidized diffusion, is composed primarily of the grain size, orientation, etc., and secondarily the actual composition of the grains. If the relative importance of the various factors were known, it might be possible to assign numerical values to the matrix and thus apply it to the diffusion system to yield meaningful results. Further research is needed, however, before this can be done.

The fluids have a major effect on the diffusion system. If the system were completely dry, which would not be expected in these rocks, diffusion would have to be entirely solid-solid. The reported diffusion coefficients (Fyfe, Turner & Verhoogan 1958) indicate that solid-solid diffusion is not feasible for most geological systems. The rocks under consideration are not dry and do have a considerable amount of water in them as shown by the presence of muscovite in them.

If, instead of a dry system, a water bearing system is considered, two possibilities still remain. The first possibility is that the water or any other fluid, is in motion itself carrying the diffusing ions. The second case is where the water, or fluid, is static and simply serves as the medium through which the material diffuses. The first case is simple fluid diffusion and the second is a "fluidized" diffusion. It is probable that there is no sharp line dividing the two types of diffusion because the critical factor would appear to be the amount of water, or fluid, available and pore space and permeability. The values reported for the diffusion zone thicknesses in the studies on wall rock alteration in hydrothermal ore deposits are orders of magnitude greater than those reported for "normal" igneous intrusives. The hydrothermal deposits were formed from highly aqueous fluids and it is probable that the diffusion into the wall rock proceeded by fluid diffusion. In the systems studied in this research the amount of water available from the intrusive should be much less than in the hydrothermal deposits and the diffusion resulting from them should also be much smaller. The order of magnitude difference between the two cases, however, leads one to the conclusion that a mechanism of diffusion different from that operating in the hydrothermal deposits is responsible in this case. What is postulated is that the fluid acts as a static medium allowing the various ions to diffuse through it. By necessity this fluid would have to be a film, no more than a few molecules thick, surrounding the various mineral grains in the rock. This mechanism is somewhere between solid-solid diffusion on one end and liquid diffusion on the other. The resultant from this mechanism should lie somewhere between the other two and as the data indicates, it does.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was undertaken to determine the nature of diffusion in an igneous contact zone. The research that has been done in this area shows that diffusion plays an important role in contact zones. Contact alteration zones of the granite dikes in this study range up to only one or two feet, while wall rock alteration in hydrothermal ore deposits cited here show diffusion zones of up to two hundred feet wide, indicating that there are two different mechanisms involved. Data on solid-solid diffusion strongly suggests that it is not a feasible mechanism for most geological diffusion systems.

Continuous samples were taken from small granite dikes and the adjacent host rock. These samples were analyzed for both major and minor elements by emission spectrographix techniques. Concentration distributions were obtained and a generalized function was determined for them of the form: $C_e = \tanh\,(be^{(kx)} - b)$, where C_e is the element concentration (transformed), x is the distance from the contact less the distance to the zero point, and b and k are parameters of the equation.

The following three types of curves were observed; hyperbolic, tangent, hyperbolic secant, and complex. Evidence from the complex curves indicates that the system is discontinuous at the contact and that these curve types cannot be used to describe the concentration distributions. These curve types, however, can be used to describe the relative rates of diffusion on either side of the contact and through the contact itself. Further evidence from the curve types leads to the hypothesis that the contact acts as a semipermeable barrier to diffusion of material across it. This hypothesized process and the differing diffusion rates in the rocks on either side of the contact appears to result in the concentration distributions found.

A high and low frequency periodicity was found in most of the curves. Tests showed that this periodicity was not related to the sampling frequency except for a few of the high frequencies. Two hypotheses, either separately or together, yield an explanation of the periodicity. The first hypothesis is that the normal variations found in any homogeneous rock will be enhanced under a non-equilibrium system that is undergoing anisotropic stress (diffusion in one direction only) to yield a high-frequency periodicity. The second hypothesis is that the contact, by acting as a partial barrier to diffusion, causes the buildup of concentration at the contact with a subsequent depletion further away. This would generate a low-frequency periodicity. These processes, together, should produce a periodicity similar to that seen in the data curves.

The matrix or bulk composition of the rock through which the material is diffusing exerts a controlling effect on the rate of diffusion. Since the diffusion process postulated is a fluid or fluidized one, the matrix effect should be due to the texture of the host rock primarily and secondarily to its mineral composition.

By rejecting solid-solid diffusion as the mechanism involved in igneous contact zone diffusion, the mechanism must then be one of a fluid diffusion. Diffusion in wall rock alteration in hydrothermal ore deposits probably occurs with fluid movement as the active mechanism; the highly aqueous nature of the ore fluid and thickness of the resulting diffusion zones supports this hypothesis. The diffusion zone thicknesses in the granite contact zones studied are orders of magnitude smaller than those of the ore deposits indicating either very small amounts of water or a different mechanism. It is hypothesized that a different mechanism pertains to the diffusion zones in granite contact zones. That is, that a thin fluid film, perhaps only a few molecules thick, acts as a static medium through which the material diffuses. The controlling factor for these two mechanisms is the amount of water available to the system.

Further Research

Two separate research projects lend themselves as a continuation of this study. The first is an examination of the element concentration distribution in individual mineral grains as a function of distance from the contact. This would have the advantage of determining the effect, if any, of solid-solid and solid vapor diffusion in the system as well as determining the role of the various minerals in diffusion.

The second project is a laboratory experiment to determine the diffusion coefficients under controlled conditions and to determine the effect of the matrix and the width of the dike on the thickness of the diffusion zone. This would be done by putting an artificial melt into a rock and varying the times of the molten state, the amount of water in the melt, the temperature of the melt, the thickness of the melt and the rock type used.

Both of these projects should yield data to produce a more definitive statement of the processes of diffusion in an igneous contact zone.

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APPENDIX A

DATA TABLES

SPECTROGRAPHIC ANALYSES
SECTION 37

x in.	Na %	Ca %	K %	Fe %	Mg ppm
6.31	1.53	0.45	1.78	0.91	510
6.04	2.17	0.47	1.82	0.85	755
5.78	2.40	0.36	1.58	0.95	500
5.52	2.87	0.51	1.28	0.82	527
5.25	1.98	0.58	1.38	0.84	432
4.99	2.33	0.44	1.52	1.01	387
4.72	2.52	0.40	1.41	1.13	560
4.46	2.13	0.40	1.40	1.11	433
4.20	2.13	0.52	1.50	1.12	347
3.93	2.33	0.40	1.70	0.88	637
3.57	2.55	0.44	1.33	1.23	310
3.30	2.47	0.42	1.19	1.16	308
3.04	2.17	0.35	1.92	0.85	465
2.78	1.93	0.43	2.23	0.98	510
2.51	1.65	0.17	1.78	0.73	370
2.25	1.77	0.28	1.67	0.78	633
1.98	1.97	0.42	1.65	0.96	793
1.72	2.00	0.29	1.77	1.07	490
1.46	1.95	0.37	2.08	0.94	367
1.19	1.90	0.30	1.92	1.12	590
0.93	1.56	0.33	2.05	0.83	650
0.66	1.59	0.49	2.03	0.89	510
0.40	1.07	0.22	2.27	0.84	700
0.13	1.21	0.34	1.95	0.72	2750

Gr C Sch					Mg %
0.13	0.85	0.79	2.93	10.17	0.17
0.47	0.84	1.01	2.75	9.57	1.61
0.82	2.30	1.33	3.35	12.20	0.81
1.16	1.53	1.22	3.22	9.40	2.15
1.50	2.39	2.19	3.13	11.30	2.32
2.15	2.11	0.86	3.05	8.90	0.64
2.49	2.48	1.83	3.36	10.90	1.20
2.84	1.80	1.01	2.68	7.70	2.72
3.18	2.07	1.52	2.53	11.50	2.14
3.52	2.13	1.16	3.23	9.80	1.17
3.87	1.79	1.72	3.38	14.30	3.28
4.21	1.87	1.41	4.32	13.90	3.05
4.56	1.97	1.28	3.18	11.30	2.82
4.90	1.82	1.14	3.62	9.90	1.82
5.20	2.12	1.98	4.25	14.80	2.14

x in.	Mn ppm	Ti ppm	V ppm	B ppm	Cu ppm
6.31	73	763	n.d.	9	145
6.04	83	707	n.d.	8	112
5.78	72	833	n.d.	8	308
5.52	96	637	n.d.	8	193
5.25	80	713	n.d.	8	202
4.99	52	840	n.d.	7	260
4.72	47	993	n.d.	6	297
4.46	55	1050	n.d.	8	193
4.20	56	1000	n.d.	8	235
3.93	75	850	n.d.	7	285
3.57	71	977	n.d.	7	190
3.30	93	670	n.d.	7	273
3.04	106	640	n.d.	8	190
2.78	247	643	n.d.	9	132
2.51	141	490	n.d.	9	98
2.25	65	850	n.d.	8	160
1.98	71	813	n.d.	7	185
1.72	74	847	n.d.	7	220
1.46	69	967	n.d.	10	148
1.19	69	987	n.d.	8	175
0.93	67	1910	n.d.	8	134
0.66	96	837	n.d.	10	117
0.40	78	687	n.d.	9	43
0.13	670	5333	n.d.	11	163
Gr C Sch					
0.13	2883	7700	730	14	66
0.47	3683	5313	560	13	49
0.82	4033	2267	430	18	33
1.16	3117	1967	313	109	49
1.50	2987	2167	503	37	10
2.15	2530	1650	300	33	23
2.49	3050	2308	358	29	12
2.84	2757	1733	258	23	6
3.18	3767	2133	590	85	9
3.52	3017	1750	327	58	5
3.87	3583	2933	917	367	17
4.21	2300	3333	1017	247	6
4.56	2867	2650	677	133	9
4.90	3967	1933	457	142	8
5.20	4317	2433	1010	217	4

x in.	Ga ppm	Pb ppm	Zn ppm	Zr ppm	Ni ppm
6.31	12	51	n.d.	n.d.	n.d.
6.04	15	52	n.d.	n.d.	n.d.
5.78	12	54	n.d.	n.d.	n.d.
5.52	16	35	n.d.	n.d.	n.d.
5.25	12	72	n.d.	n.d.	n.d.
4.99	11	64	n.d.	n.d.	n.d.
4.72	11	61	n.d.	n.d.	n.d.
4.46	12	59	n.d.	n.d.	n.d.
4.20	13	78	n.d.	n.d.	n.d.
3.93	12	58	n.d.	n.d.	n.d.
3.57	13	115	n.d.	n.d.	n.d.
3.30	11	84	n.d.	n.d.	n.d.
3.04	9	59	n.d.	n.d.	n.d.
2.78	13	91	n.d.	n.d.	n.d.
2.51	9	43	n.d.	n.d.	n.d.
2,25	11	59	n.d.	n.d.	n.d.
1.98	14	84	n.d.	n.d.	n.d.
1.72	12	66	n.d.	n.d.	n.d.
1.46	13	50	n.d.	n.d.	n.d.
1.19	10	44	n.d.	n.d.	n.d.
0.93	13	46	n.d.	n.d.	n.d.
0.66	14	54	n.d.	n.d.	n.d.
0.40	18	35	n.d.	n.d.	n.d.
0.13	17	35	n.d.	n.d.	n.d.
Gr C Sch					
0.13	20	28	141	263	41
0.47	22	32	160	333	42
0.82	20	55	203	220	52
1.16	17	58	189	160	31
1.50	15	70	161	215	41
2.15	16	49	154	169	41
2.49	18	67	144	215	40
2.84	12	52	120	227	38
3.18	24	67	166	228	43
3.52	19	50	130	215	34
3.87	23	92	155	268	63
4.21	20	47	188	218	46
4.56	22	60	144	237	46
4.90	16	45	122	298	41
5.20	27	64	191	202	52

SPECTROGRAPHIC ANALYSES
SECTION 38

x in.	Na %	Ca %	K %	Fe %	Mg %
15.45	0.99	0.63	4.25	8.70	3.43
14.95	1.13	0.47	3.67	8.30	3.37
14.64	0.91	0.41	4.17	10.70	3.15
14.34	1.12	0.48	3.98	8.00	3.05
13.84	1.35	0.52	4.75	8.40	2.97
13.45	1.10	0.49	3.87	7.60	2.72
12.89	1.23	0.50	3.60	6.60	2.18
12.35	0.79	0.33	4.07	6.20	2.10
11.74	0.61	0.24	3.78	5.90	2.15
11.20	1.35	0.39	3.98	6.80	2.58
10.67	1.13	0.34	5.30	7.00	2.75
10.20	0.57	0.17	3.55	6.60	2.68
9.84	0.68	0.23	3.13	6.60	2.23
9.30	0.75	0.32	3.70	9.20	1.77
9.22	1.04	0.48	3.98	9.00	3.52
8.88	1.13	0.42	4.25	7.30	2.90
8.55	1.06	0.46	3.43	8.10	2.37
7.99	0.78	0.55	4.15	9.20	2.57
7.55	0.80	0.39	3.93	7.90	2.65
7.05	0.93	0.44	3.25	8.00	3.52
6.30	0.93	0.43	3.72	7.60	2.57
5.77	0.98	0.43	3.65	9.30	2.72
5.05	0.92	0.61	3.73	8.10	3.40
4.80	0.92	0.42	4.37	8.40	2.20
4.77	1.01	0.41	3.83	5.60	1.78
3.94	1.08	0.37	3.63	7.60	2.03
3.54	1.06	0.41	3.70	6.80	2.40
2.98	1.06	0.47	4.02	7.20	1.88
2.54	1.55	0.52	3.50	6.70	2.05
1.98	1.19	0.47	2.27	6.90	2.20
1.76	0.95	0.45	3.45	6.30	1.75
1.65	1.00	0.47	2.63	4.60	1.43
1.43	0.79	0.50	3.57	5.80	1.57
1.04	0.61	0.45	2.85	3.90	1.28
0.79	0.55	0.30	3.08	4.20	1.27
0.54	0.38	0.41	2.92	6.00	1.34
0.35	0.28	0.22	2.22	3.90	1.30

Sch
C
Gr

x in.	Na %	Ca %	K %	Fe %	Mg ppm
Sch C Gr					
0.35	0.82	0.30	2.37	0.49	1683
0.74	1.32	0.43	2.33	0.34	1383
1.13	1.14	0.51	2.12	0.32	1507
1.28	1.40	0.31	2.57	0.34	1767
2.01	1.33	0.33	2.58	0.38	1250
2.11	1.45	0.28	2.80	0.52	1467
2.34	1.31	0.23	2.05	0.48	830
2.39	1.57	0.24	2.13	0.40	967
2.74	1.52	0.29	2.77	0.37	837
3.11	1.76	0.31	1.98	0.32	610
3.35	1.77	0.37	1.80	0.53	660
3.78	2.15	0.41	2.15	0.47	610
4.11	2.67	0.46	1.35	0.61	342
4.34	2.47	0.45	1.30	0.63	450
4.56	1.88	0.28	1.38	0.76	393
5.11	2.00	0.49	1.35	0.58	395
5.65	1.10	n.d.	2.75	n.d.	377
6.07	1.65	0.38	2.05	0.71	427
6.18	2.22	0.43	1.87	0.60	377
6.90	2.05	0.50	1.77	0.75	413
7.15	2.19	0.52	1.05	0.23	343
7.40	2.28	0.55	n.d.	0.24	507
7.65	2.53	0.53	1.24	0.37	370
7.90	1.55	0.32	1.33	0.27	265
8.51	1.85	0.29	2.85	0.27	1025
8.90	1.73	0.27	2.52	0.37	723
9.65	1.30	0.41	3.08	0.43	733
10.57	1.70	0.34	2.50	0.64	870
10.90	1.83	0.28	1.93	0.35	510
11.29	2.12	0.42	1.85	0.45	500
11.65	0.95	0.28	2.18	0.33	227
11.90	1.09	0.31	1.12	0.[illegible]4	260

x in.	B ppm	Cu ppm	Ga ppm	Pb ppm	Ti ppm
15.54	99	483	15	31	1923
14.95	97	687	24	36	2067
14.64	132	447	24	30	2883
14.34	61	530	23	37	2367
13.84	58	335	28	33	2133
13.45	102	530	23	33	2250
12.89	61	362	20	31	1742
12.35	68	430	28	28	1758
11.74	31	417	21	25	1967
11.20	33	340	19	29	1908
10.67	33	333	19	26	1975
10.20	34	500	29	29	2225
9.84	28	427	18	22	2242
9.30	136	497	19	22	2267
9.22	139	423	26	31	2533
8.88	67	453	22	32	2017
8.55	136	480	23	29	2092
7.99	153	580	23	32	2750
7.55	107	530	21	32	2217
7.05	63	467	20	29	2067
6.30	78	338	18	27	1750
5.77	95	388	22	27	2042
5.05	84	733	23	36	2400
4.80	100	433	28	31	1633
4.77	130	430	18	29	1483
3.94	70	655	25	27	2075
3.54	109	523	22	37	1917
2.98	113	467	20	35	1475
2.54	108	590	19	35	1875
1.98	110	440	22	28	1788
1.76	108	444	18	30	1780
1.65	42	283	14	26	1375
1.43	86	185	17	26	1967
1.04	30	277	14	30	1130
0.79	25	177	20	22	1533
0.54	37	113	17	23	5567
0.35	13	373	18	19	1690

Sch
C
Gr

0.35	17	102	13	28	310
0.74	14	77	21	39	128
1.13	29	58	16	25	293
1.28	11	51	19	33	122
2.01	11	49	17	24	112
2.11	15	208	24	35	145

x in.	B ppm	Cu ppm	Ga ppm	Pb ppm	Ti ppm
2.34	11	39	16	27	111
2.39	11	29	18	36	137
2.74	17	24	18	36	113
3.11	8	87	14	48	85
3.35	8	293	15	58	142
3.78	7	148	15	66	99
4.11	10	243	13	72	138
4.34	8	148	11	65	101
4.56	6	240	10	52	109
5.11	9	188	10	74	119
5.65	12	n.d.	5	56	67
6.07	11	102	10	50	93
6.18	8	383	9	69	82
6.90	10	223	10	73	105
7.15	n.d.	23	11	75	75
7.40	n.d.	27	14	75	67
7.65	n.d.	85	11	n.d.	89
7.90	12	700	15	89	84
8.51	10	107	17	57	124
8.90	12	109	14	48	88
9.65	12	59	11	46	99
10.57	12	303	14	42	150
10.90	9	178	14	80	92
11.29	7	160	12	60	95
11.65	13	13	7	39	64
11.90	11	38	5	49	63

x in.	V ppm	Mn ppm	Zr ppm	Zn ppm	Ni ppm
15.45	527	3633	101	196	45
14.95	403	2750	85	205	51
14.64	593	2983	97	197	44
14.34	430	2617	54	144	48
13.84	450	2813	107	223	49
13.45	437	2380	86	201	51
12.89	413	2117	78	179	56
12.35	500	2787	80	147	43
11.74	677	2833	113	188	44
11.20	607	2193	77	174	47
10.67	650	2850	89	157	43
10.20	463	2983	66	159	37
9.84	860	2317	86	185	32
9.30	743	2667	71	121	31
9.22	617	3117	107	233	50
8.88	333	2883	78	178	46
8.55	443	3217	73	162	46
7.99	773	2567	102	179	47
7.55	407	2533	69	187	45
7.05	480	2967	101	193	56
6.30	420	2433	78	167	45
5.77	427	2617	85	169	31
5.05	667	3967	44	183	33
4.80	277	3050	61	115	22
4.77	257	3233	84	135	26
3.94	395	3600	75	205	39
3.54	315	2587	71	170	32
2.98	370	2400	115	137	31
2.54	285	3450	55	137	29
1.98	415	3350	93	190	32
1.76	438	2447	76	140	32
1.65	377	2708	86	118	35
1.43	753	2433	68	140	34
1.04	200	1900	82	129	33
0.79	420	2067	93	100	31
0.54	1667	2600	146	140	35
0.35	1220	1967	70	99	35
Sch C Gr					
0.35	n.d.	81	n.d.	n.d.	n.d.
0.74	n.d.	68	n.d.	n.d.	n.d.
1.13	n.d.	417	n.d.	n.d.	n.d.
1.28	n.d.	257	n.d.	n.d.	n.d.
2.01	n.d.	182	n.d.	n.d.	n.d.
2.11	n.d.	65	n.d.	n.d.	n.d.

x in.	V ppm	Mn ppm	Zr ppm	Zn ppm	Ni ppm
2.34	n.d.	129	n.d.	n.d.	n.d.
2.39	n.d.	267	n.d.	n.d.	n.d.
2.74	n.d.	155	n.d.	n.d.	n.d.
3.11	n.d.	142	n.d.	n.d.	n.d.
3.35	n.d.	257	n.d.	n.d.	n.d.
3.78	n.d.	130	n.d.	n.d.	n.d.
4.11	n.d.	60	n.d.	n.d.	n.d.
4.34	n.d.	56	n.d.	n.d.	n.d.
4.56	n.d.	56	n.d.	n.d.	n.d.
5.11	n.d.	53	n.d.	n.d.	n.d.
5.65	n.d.	390	n.d.	n.d.	n.d.
6.07	n.d.	520	n.d.	n.d.	n.d.
6.18	n.d.	90	n.d.	n.d.	n.d.
6.90	n.d.	57	n.d.	n.d.	n.d.
7.15	n.d.	162	n.d.	n.d.	n.d.
7.40	n.d.	67	n.d.	n.d.	n.d.
7.65	n.d.	70	n.d.	n.d.	n.d.
7.90	n.d.	215	n.d.	n.d.	n.d.
8.51	n.d.	106	n.d.	n.d.	n.d.
8.90	n.d.	83	n.d.	n.d.	n.d.
9.65	n.d.	99	n.d.	n.d.	n.d.
10.57	n.d.	83	n.d.	n.d.	n.d.
10.90	n.d.	75	n.d.	n.d.	n.d.
11.29	n.d.	65	n.d.	n.d.	n.d.
11.65	n.d.	151	n.d.	n.d.	n.d.
11.90	n.d.	160	n.d.	n.d.	n.d.

SPECTROCHEMICAL ANALYSES
SECTION 250

x in.	Na %	K %	Ca %	Fe %	Mg %
1.33	3.29	1.89	0.41	0.36	0.066
0.95	2.58	1.63	0.34	0.29	0.056
0.57	2.99	1.82	0.39	0.27	0.066
0.19	2.93	4.87	0.22	0.13	0.039
Gr C Sch					
0.18	1.73	0.80	6.90	7.60	0.12
0.55	1.80	0.87	8.50	8.27	0.11
0.92	1.42	0.87	11.50	8.10	0.15
1.19	1.75	0.88	8.00	7.53	0.17
1.56	1.65	0.85	9.40	9.47	0.21
1.93	0.95	0.85	9.87	9.57	0.15
2.30	1.65	0.90	6.93	7.50	0.15
2.67	1.87	0.98	10.53	7.67	0.14
3.04	1.77	0.93	6.27	6.40	0.14
3.41	1.48	1.07	6.60	7.60	0.14
3.88	1.47	0.95	7.13	7.37	0.14
4.25	1.42	0.93	5.87	6.30	0.12
4.62	1.73	0.76	8.77	7.73	0.11
4.99	1.06	0.72	8.43	7.33	0.14
5.46	1.48	0.98	6.53	7.30	0.17
5.83	1.15	0.97	6.97	7.50	0.13
6.20	1.80	0.84	9.63	7.63	0.15
6.57	1.57	0.76	5.60	6.70	0.25
6.94	2.02	0.67	6.00	7.73	0.24
7.31	1.43	0.90	7.67	5.90	0.12
7.68	1.87	0.83	6.10	6.33	0.14
8.05	1.10	0.82	8.05	7.95	0.16
8.42	1.35	0.82	10.90	11.10	0.21
8.79	1.83	0.71	7.00	7.50	0.20
9.11	1.28	1.22	5.53	8.83	0.37
9.38	2.22	1.01	7.27	7.37	0.78
9.65	2.15	0.77	7.77	7.27	0.35
9.92	2.43	0.90	8.17	7.37	0.81
10.15	1.88	0.68	5.83	6.10	0.32
10.46	2.37	0.64	8.40	7.13	0.31
10.73	2.12	0.76	9.73	7.40	0.39
11.00	1.62	0.78	7.43	6.63	0.35
11.27	1.65	0.83	6.43	6.03	0.30
11.54	2.12	0.86	8.97	7.97	0.37
11.81	2.45	0.86	6.07	6.57	0.71
12.08	2.33	0.82	9.40	7.47	0.37
12.35	1.77	1.64	5.10	6.70	0.35

x in.	Na %	K %	Ca %	Fe %	Mg %
12.62	2.45	1.60	7.40	8.43	0.92
12.89	1.73	1.49	4.77	6.60	0.40
13.16	1.63	1.12	5.40	6.47	0.31
13.43	1.40	1.03	5.70	6.00	0.35
13.70	1.90	1.00	6.67	8.20	0.62
13.97	1.83	1.07	8.27	7.30	0.31
14.24	1.63	1.35	4.27	5.67	0.36
14.51	1.62	1.16	4.90	5.97	0.33
14.78	1.77	1.41	6.40	6.63	0.28
15.05	2.18	1.12	10,37	9.40	0.65
15.31	1.80	1.41	10.30	8.67	0.36
15.59	2.22	0.86	8.93	7.97	0.20
15.86	1.83	1.23	9.93	9.03	0.33
16.13	1.88	0.85	10.67	8.03	0.14
16.40	2.50	1.03	9.83	7.13	0.83
16.67	1.68	1.09	10.93	8.27	0.44
16.94	1.15	1.17	11.10	7.55	0.44
17.21	1.73	1.24	9.00	7.10	0.14
17.48	1.77	0.82	12.97	9.77	0.16
17.75	1.73	0.98	14.13	9.13	0.17
18.02	2.28	0.96	12.93	7.93	0.33
18.29	2.00	0.56	9.70	8.73	0.20
18.56	1.58	0.60	9.97	7.16	0.30
18.81	1.27	0.83	9.47	11.65	0.32
19.06	1.41	0.82	8.97	9.90	0.36
19.33	2.48	0.62	9.23	12.17	0.13
19.60	1.06	0.98	9.60	10.03	0.29
19.87	0.81	0.73	7.07	8.87	0.29
20.14	1.03	0.72	7.40	8.67	0.27
20.41	1.16	0.76	5.47	7.17	0.18
20.68	1.33	0.73	6.97	8.20	0.49
20,95	0.95	0.89	7.23	8.80	0.29
21.22	1.00	0.82	8.20	8.73	0.22
21.49	1.23	1.05	7.87	8.53	0.30
21.80	1.19	1.00	8.40	8.77	0.26
22.03	1.06	1.02	7.07	8.90	0.26
22.40	1.37	0.74	6.30	8.80	0.39
22.57	2.02	0.76	6.17	6.97	0.18
22.84	1.18	1.01	7.53	8.00	0.25
23.11	1.48	0.86	11.07	10.25	0.39
23.42	0.95	0.92	6.53	8.50	0.25
23.65	1.33	0.76	5.40	8.00	0.18
23.93	1.00	0.85	8.00	9.00	0.31
24.20	1.00	0.87	6.43	8.57	0.24
24.51	1.43	0.77	6.00	8.30	0.24
24.74	1.04	0.86	7.10	8.90	0.28
25.01	1.04	0.98	7.60	8.97	0.25
25.28	1.19	0.98	9.40	10.07	0.29

x in.	Na %	K %	Ca %	Fe %	Mg %
25.55	1.47	0.86	9.23	9.47	0.22
25.82	1.57	0.87	9.00	8.80	0.35
26.09	1.53	0.69	8.20	8.97	0.44
26.36	1.18	0.98	8.13	8.87	0.25
26.63	1.27	0.78	7.80	7.23	0.17
26.91	1.66	1.00	12.93	9.40	0.44
27.40	1.59	1.17	7.37	8.13	0.43
27.89	1.45	0.53	9.40	9.93	0.22
28.38	1.44	1.00	8.23	8.13	0.42
28.87	1.48	1.06	9.10	8.53	0.41
29.36	1.28	0.90	8.07	8.13	0.21
29.85	1.63	0.90	8.13	7.20	0.39
30.34	1.56	0.84	7.27	7.60	0.49
30.83	1.48	0.85	7.13	7.50	0.40
31.32	1.68	0.86	7.40	7.17	0.24
31.81	1.48	1.01	8.23	8.33	0.57
32.30	1.80	1.10	7.33	8.97	0.44
32.79	1.26	1.05	9.40	8.70	0.22
33.28	1.39	1.01	7.83	8.33	0.52
33.77	1.53	0.86	8.17	7.87	0.31
34.26	2.13	1.10	8.93	11.53	0.67
34.75	1.78	0.80	9.47	7.27	0.49
35.24	1.78	0.81	7.03	6.40	0.29
35.73	2.09	0.96	7.40	7.90	0.46
36.22	1.52	0.83	6.60	8.03	0.48
36.70	1.47	1.07	10.97	9.38	0.28
37.17	1.28	1.04	11.83	10.33	0.26
37.64	1.41	0.91	11.13	9.17	0.26
38.11	1.70	0.79	10.43	9.17	0.19
38.58	1.13	0.88	7.83	7.80	0.17
39.05	1.90	0.73	12.97	9.33	0.18
39.52	2.40	0.69	8.97	7.57	0.13
39.99	1.85	0.84	10.90	7.40	0.17
40.46	1.70	0.79	10.67	7.30	0.17
40.93	1.75	0.79	8.87	6.37	0.21
41.40	1.73	0.79	9.13	6.83	0.15
42.01	1.68	1.09	7.70	6.53	0.27
42.76	1.37	1.53	10.43	6.70	0.17
43.51	1.82	1.19	11.90	9.03	0.50
44.26	1.68	0.93	7.43	7.47	0.29
44.88	1.83	0.75	7.50	6.93	0.33
45.37	1.97	0.86	7.63	7.50	0.30
45.86	0.62	0.75	7.17	7.70	0.13
46.35	1.51	0.76	7.43	7.57	0.39
46.84	1.50	0.72	6.57	6.97	0.29
47.33	1.37	0.84	9.67	9.20	0.36
47.82	1.32	0.80	8.47	8.47	0.38
48.31	1.34	0.80	8.67	8.93	0.53

x in.	Na %	K %	Ca %	Fe %	Mg %
48.79	1.40	0.70	9.47	8.80	0.47
49.28	1.48	0.83	8.90	7.43	0.42
49.77	1.48	0.89	9.40	10.33	0.57
50.26	1.41	0.93	7.87	8.67	0.60
50.77	1.66	0.84	8.30	8.60	1.67
51.30	1.68	0.75	6.93	9.15	1.03
51.83	1.41	0.85	8.10	8.43	1.58
52.32	1.59	0.78	11.53	9.17	1.92
52.76	1.37	0.72	11.87	6.30	0.77
53.20	1.53	0.84	11.77	8.57	0.72
53.64	1.30	0.75	9.30	8.90	0.80
54.08	1.80	0.80	11.47	8.80	1.39
54.52	1.53	0.67	9.53	9.10	0.84
54.96	1.52	0.77	11.90	10.03	1.71
55.40	1.68	0.73	10.67	9.15	0.85
55.84	1.38	0.69	7.27	8.95	0.81
56.28	1.68	0.80	7.57	7.80	0.92
56.72	1.56	0.78	8.93	8.20	1.17
57.16	1.35	0.73	9.00	8.13	1.70
57.60	1.52	0.63	7.00	7.70	0.89
58.09	1.53	0.76	7.93	8.23	1.06
58.63	1.49	0.69	7.83	8.37	1.62
59.17	1.67	0.69	7.30	8.45	0.85
59.71	1.88	0.75	8.50	9.50	1.52
60.15	1.75	0.69	8.33	8.17	1.05
60.79	1.43	0.77	7.80	8.10	1.05
61.33	1.44	0.76	7.53	8.10	0.92
61.79	1.43	0.64	8.37	7.70	0.94
62.17	1.17	0.73	8.80	9.50	1.01
62.52	1.27	0.82	8.17	8.00	0.64
62.88	1.11	0.83	9.17	9.40	0.73
63.60	1.23	0.63	9.13	10.00	1.05
63.96	1.42	0.69	6.57	7.80	1.01
64.32	1.85	0.71	7.57	6.87	0.99
64.68	1.53	0.68	7.17	7.80	0.90
65.04	1.53	0.64	7.27	9.65	1.19
65.40	1.58	0.72	7.87	7.85	1.02
65.76	1.65	0.79	10.03	7.80	0.87
66.12	1.66	0.74	6.87	7.60	0.94
66.48	1.81	0.80	7.63	7.07	0.51
66.84	1.64	0.78	8.47	8.45	1.11
67.20	1.77	0.77	7.80	8.15	0.95
67.56	1.71	0.82	7.17	7.60	1.00
67.92	1.81	0.78	6.07	6.40	1.04

x in.	B ppm	Cu ppm	Ga ppm	Ti ppm	V ppm
1.33	n.d.	22	12	188	4
0.95	n.d.	5	12	162	5
0.57	n.d.	3	10	183	4
0.19	n.d.	9	15	152	5
Gr C Sch					
0.18	97	143	34	8200	1013
0.55	126	178	42	7267	1050
0.92	83	133	30	9133	1013
1.19	99	102	23	7100	977
1.56	133	187	44	7833	840
1.93	137	205	34	8600	1373
2.30	85	97	28	6500	847
2.67	92	11	23	6600	900
3.04	81	37	23	5200	743
3.41	78	n.d.	32	7267	787
3.88	80	82	19	6433	813
4.35	73	153	19	5367	533
4.62	120	137	39	5400	827
4.99	110	104	27	6267	907
5.46	76	6	16	4800	720
5.83	126	83	33	6800	820
6.20	96	29	26	6100	983
6.57	88	21	15	4750	550
6.94	135	53	25	5733	710
7.31	64	15	14	4467	497
7.68	75	230	23	6167	697
8.05	132	105	31	7250	715
8.42	178	n.d.	28	6400	750
8.79	103	190	30	6533	743
9.11	74	163	25	5533	827
9.38	89	77	25	6100	783
9.65	94	72	20	5467	703
9.92	82	82	20	5500	767
10.15	77	62	19	5167	547
10.46	90	77	24	5300	820
10.73	77	45	16	5900	797
11.00	77	70	15	5467	700
11.27	75	81	12	4767	647
11.54	115	109	44	6067	937
11.81	76	97	21	5650	610
12.08	86	108	26	5300	1143
12.35	64	45	19	6800	870
12.62	64	48	28	9100	1000
12.89	69	50	23	6100	730

x in.	B ppm	Cu ppm	Ga ppm	Ti ppm	V ppm
13.16	80	42	21	6067	593
13.43	80	7	16	4567	707
13.70	112	35	32	6667	1037
13.97	96	48	30	6633	967
14.24	65	14	17	4800	583
14.51	67	51	18	5067	680
14.78	79	44	29	4967	800
15.05	126	n.d.	70	7400	1473
15.31	99	175	38	7500	1633
15.59	140	103	38	9250	977
15.86	124	101	44	n.d.	1230
16.13	145	78	37	6000	1053
16.40	75	67	39	6300	817
16.67	85	31	39	7800	1263
16.94	137	80	30	9167	857
17.21	79	31	27	6967	1183
17.48	207	39	41	9350	1187
17.75	106	17	36	9300	1600
18.02	98	30	36	8050	1250
18.29	168	13	29	9900	1043
18.56	208	5	28	7500	700
18.81	119	n.d.	12	5700	713
19.06	97	2	11	4367	683
19.33	130	51	38	7000	867
19.60	123	n.d.	24	4600	543
19.87	144	2	20	5700	463
20.14	132	5	21	5333	433
20.41	98	2	20	4533	387
20.68	114	2	22	5717	607
20.95	153	7	17	5850	593
21.22	125	2	12	4050	567
21.49	94	2	13	3983	570
21.80	140	7	21	3450	477
22.03	102	3	18	5000	623
22.40	126	4	14	4717	567
22.57	93	n.d.	27	4967	663
22.84	133	n.d.	19	5017	540
23.11	122	3	11	6167	790
23.42	88	2	19	4317	500
23.65	108	3	25	4950	413
23.93	103	2	21	5583	617
24.20	110	n.d.	21	5800	553
24.51	112	2	17	4733	523
24.74	94	3	21	4383	600
25.01	99	7	17	5567	653
25.28	149	2	25	5500	653
25.55	118	5	16	5067	813
25.82	113	n.d.	10	6633	743

x in.	B ppm	Cu ppm	Ga ppm	Ti ppm	V ppm
26.09	123	2	23	5167	620
26.36	91	3	19	5767	560
26.63	78	3	17	6833	627
26.91	133	11	16	9850	667
27.40	99	8	15	7850	570
27.89	163	11	29	9800	543
28.38	104	6	17	9150	563
28.87	101	7	14	9250	523
29.36	80	8	15	6833	510
29.85	98	11	12	8400	717
30.34	71	6	14	7900	517
30.83	88	6	16	8600	427
31.32	90	2	12	5700	580
31.81	100	5	16	5800	500
32.30	105	3	15	6250	673
32.79	122	8	35	4633	513
33.28	106	4	15	5800	603
33.77	99	6	11	6133	583
34.26	78	8	15	7550	1063
34.75	121	6	16	8350	603
35.24	87	9	14	6267	490
35.73	97	10	14	6550	553
36.22	101	21	14	6500	693
36.70	108	23	16	7567	637
37.17	162	14	26	7900	773
37.64	148	21	25	7067	623
38.11	149	23	26	6333	723
38.58	79	25	13	5450	477
39.05	124	43	27	7267	933
39.52	101	68	21	7733	620
39.99	117	27	25	6767	867
40.46	87	18	17	7200	637
40.93	76	13	17	6233	443
41.40	103	16	28	6517	480
42.01	84	12	14	8100	547
42.76	84	16	21	5233	470
43.51	124	7	13	5052	577
44.26	105	3	11	6833	510
44.88	99	4	10	5767	530
45.37	106	6	18	6100	610
45.86	106	5	22	6300	610
46.35	98	2	15	4700	507
46.84	98	5	13	4783	443
47.33	108	3	9	5500	660
47.82	109	2	11	5950	477
48.31	125	2	13	7350	500
48.79	110	n.d.	16	7767	567
49.28	101	4	10	6533	563
49.77	101	3	12	6400	607

x in.	B ppm	Cu ppm	Ga ppm	Ti ppm	V ppm
50.26	91	4	14	5775	483
50.77	111	3	13	8850	557
51.30	91	7	10	7667	500
51.83	109	4	14	8550	513
52.32	113	3	17	7100	640
52.76	132	3	14	6967	857
53.20	110	3	12	7767	680
53.64	128	4	15	7633	743
54.08	118	n.d.	13	7500	767
54.52	114	2	12	6133	690
54.96	114	2	17	7067	840
55.40	128	3	11	6800	817
55.84	114	3	13	6133	607
56.28	101	3	14	6300	523
56.72	106	5	11	6700	547
57.16	116	1	12	5967	643
57.60	111	n.d.	7	5167	487
58.09	111	2	10	6550	690
58.63	98	3	12	6767	563
59.17	111	4	10	6717	620
59.71	98	3	15	6050	600
60.15	107	n.d.	14	6033	660
60.79	100	2	14	5067	487
61.33	111	4	6	5500	547
61.79	113	5	12	6253	523
62.17	119	2	13	7367	687
62.52	87	13	19	8800	580
62.88	97	2	14	7200	647
63.60	123	1	14	6567	697
63.96	88	2	11	5367	507
64.32	89	2	10	6033	620
64.68	91	6	11	5617	597
65.04	99	3	12	6267	977
65.40	94	4	12	6967	653
65.76	112	35	16	6133	647
66.12	77	29	16	4600	520
66.48	89	33	20	4633	563
66.84	83	31	17	5300	657
67.20	80	7	15	4217	637
67.56	90	8	13	4267	630
67.92	79	43	17	4033	433

x in.	Zn ppm	Cr ppm	Ba ppm	Zr ppm	Ni ppm
1.33	n.d.	15	n.d.	n.d.	n.d.
0.95	n.d.	13	n.d.	n.d.	n.d.
0.57	n.d.	11	n.d.	n.d.	n.d.
0.19	n.d.	15	n.d.	n.d.	n.d.
Gr C Sch					
0.18	108	770	272	215	180
0.55	178	1240	171	188	172
0.92	103	1453	285	152	150
1.19	83	1073	237	134	132
1.56	153	947	197	164	155
1.93	108	967	263	203	190
2.30	106	690	195	171	128
2.67	97	897	228	127	128
3.04	106	478	207	140	86
3.41	94	1106	290	157	120
3.88	76	843	227	143	109
4.35	89	733	228	119	83
4.62	143	573	160	181	120
4.99	102	492	195	132	98
5.46	80	523	160	113	83
5.83	117	673	240	142	99
6.20	111	680	178	110	88
6.57	76	525	260	108	108
6.94	n.d.	677	n.d.	n.d.	59
7.31	75	527	167	101	80
7.68	87	618	250	131	73
8.05	91	797	205	155	98
8.42	143	917	178	179	148
8.79	85	563	163	147	105
9.11	97	1160	235	130	97
9.38	95	1300	375	129	77
9.65	73	890	188	133	71
9.92	79	1033	345	118	82
10.15	87	840	268	126	59
10.46	75	960	205	142	66
10.73	63	807	207	135	60
11.00	59	843	212	114	55
11.27	51	747	185	108	59
11.54	143	800	202	153	85
11.81	86	1000	282	124	83
12.08	97	697	217	133	76
12.35	74	1367	273	140	81
12.62	100	1390	410	192	141
12.89	73	1300	258	120	100

x in.	Zn ppm	Cr ppm	Ba ppm	Zr ppm	Ni ppm
13.16	92	1003	248	139	100
13.43	60	618	185	108	78
13.70	130	467	173	141	126
13.97	101	933	293	163	134
14.24	71	983	263	89	101
14.51	66	830	197	115	115
14.78	68	797	177	103	118
15.05	126	957	172	145	111
15.31	59	1110	202	135	140
15.59	n.d.	1703	n.d.	n.d.	107
15.86	137	1170	268	194	203
16.13	n.d.	797	n.d.	n.d.	147
16.40	73	1075	135	107	167
16.67	73	1233	173	116	147
16.94	94	1417	280	153	178
17.21	60	1700	232	145	138
17.48	n.d.	1683	n.d.	n.d.	102
17.75	85	1847	265	170	139
18.02	84	1927	405	150	155
18.29	n.d.	1197	n.d.	n.d.	86
18.56	n.d.	1163	n.d.	n.d.	72
18.81	79	853	423	122	95
19.06	65	1040	467	134	96
19.33	n.d.	977	n.d.	n.d.	85
19.60	163	813	195	152	106
19.87	122	683	158	157	105
20.14	117	853	177	148	103
20.41	133	458	127	104	80
20.68	147	567	143	121	93
20.95	120	710	160	147	95
21.22	124	830	157	146	102
21.49	92	980	217	113	110
21.80	177	780	142	127	105
22.03	132	1057	158	125	98
22.40	101	773	128	122	93
22.57	117	397	150	130	81
22.84	102	1289	183	137	105
23.11	60	1563	507	160	132
23.42	129	900	157	109	95
23.65	178	463	123	123	80
23.93	125	1210	200	134	95
24.20	125	510	138	164	107
24.51	118	463	128	123	98
24.74	129	913	143	108	91
25.01	146	950	190	150	115
25.28	175	1003	220	181	125
25.55	107	1073	205	150	112
25.82	54	1100	530	157	125

x in.	Zn ppm	Cr ppm	Ba ppm	Zr ppm	Ni ppm
26.09	155	597	128	122	105
26.36	120	987	205	140	99
26.63	98	917	192	148	95
26.91	82	1657	365	260	143
27.40	85	2150	570	177	111
27.89	n.d.	1173	n.d.	n.d.	68
28.38	87	1917	540	193	107
28.87	75	2467	635	187	108
29.36	88	1370	307	153	96
29.85	79	1817	500	218	104
30.34	90	1337	n.d.	168	116
30.83	90	1510	410	147	105
31.32	82	1007	430	172	77
31.81	83	1800	440	123	102
32.30	71	2383	435	155	111
32.79	149	780	177	135	87
33.28	88	1767	360	158	101
33.77	71	1460	420	178	90
34.26	78	2450	370	192	150
34.75	80	1750	n.d.	262	119
35.24	101	1507	370	155	73
35.73	72	1983	500	139	105
36.22	90	1560	325	170	108
36.70	90	1583	292	150	105
37.17	153	1500	280	198	133
37.64	158	1750	217	218	133
38.11	153	1950	198	203	132
38.58	88	1117	218	101	93
39.05	117	1267	207	207	118
39.52	100	665	183	160	85
39.99	135	1793	238	198	98
40.46	72	1753	317	143	87
40.93	82	1087	215	105	77
41.40	110	1183	182	117	87
42.01	86	1433	710	127	84
42.76	68	957	207	69	72
43.51	95	807	192	105	130
44.26	78	1850	625	170	97
44.88	75	1217	435	127	93
45.37	84	1047	195	137	113
45.86	104	593	167	125	122
46.35	98	1167	275	98	123
46.84	102	1017	285	91	117
47.33	67	1423	325	168	140
47.82	77	1800	380	142	127
48.31	86	1463	283	300	142
48.79	142	1350	265	133	105
49.28	88	1433	570	167	95

x in.	Zn ppm	Cr ppm	Ba ppm	Zr ppm	Ni ppm
49.77	90	1673	305	187	148
50.26	78	1700	370	133	123
50.77	85	1707	395	192	142
51.30	84	1683	530	178	99
51.83	114	2057	515	203	137
52.32	104	2217	n.d.	153	155
52.76	95	1917	547	182	157
53.20	87	1687	302	170	145
53.64	108	1750	563	192	178
54.08	79	1833	395	163	145
54.52	87	1117	450	133	132
54.96	100	1700	237	113	168
55.40	66	2033	547	172	132
55.84	97	1340	357	158	125
56.28	91	1450	395	120	117
56.72	72	1417	310	117	133
57.16	70	960	385	160	128
57.60	71	1413	367	145	122
58.09	75	1107	410	157	117
58.63	80	1020	345	132	118
59.17	70	1650	547	205	113
59.71	89	1300	345	140	138
60.15	80	1157	320	117	110
60.79	78	1240	277	122	108
61.33	65	1783	487	155	110
61.79	96	1667	533	170	118
62.17	96	1717	603	182	111
62.52	78	1133	248	148	91
62.88	78	1700	313	167	92
63.60	102	1417	550	162	122
63.96	70	1650	600	128	93
64.32	69	1317	490	142	88
64.68	61	1783	633	118	90
65.04	55	1440	480	143	121
65.40	58	1750	723	145	101
65.76	77	1417	473	130	88
66.12	60	1153	412	103	84
66.48	95	820	175	118	80
66.84	60	1167	460	97	97
67.20	56	1023	373	95	96
67.56	51	1667	430	110	113
67.92	65	1110	380	98	81

x in.	Mn ppm
1.33	760
0.95	563
0.57	572
0.19	215
Gr	
C	
Sch	
0.18	3400
0.55	2725
0.92	2683
1.19	3493
1.56	2433
1.93	3700
2.30	2525
2.67	2425
3.04	2683
3.41	2458
3.88	2367
4.35	2225
4.62	2400
4.99	3200
5.46	2900
5.83	2750
6.20	2383
6.57	5667
6.94	2500
7.31	2100
7.68	2650
8.05	3400
8.42	3700
8.79	2167
9.11	2533
9.38	2967
9.65	2350
9.92	3200
10.15	2067
10.46	2217
10.73	2800
11.00	2433
11.27	2217
11.54	2900
11.81	2717
12.08	2783
12.35	2283
12.62	2750
12.89	2600

x in.	Mn ppm
13.16	1800
13.42	2333
13.70	2000
13.97	2117
14.24	2200
14.51	2067
14.78	2467
15.05	2733
15.31	3333
15.59	2650
15.86	2850
16.13	1700
16.40	3383
16.67	3167
16.94	3100
17.21	2467
17.48	2167
17.75	3300
18.02	3567
18.29	2100
18.56	3217
18.81	3550
19.06	4167
19.33	2450
19.60	3350
19.87	3950
20.14	2200
20.41	2350
20.68	2867
20.95	3400
21.22	1867
21.49	2600
21.80	3183
22.03	3067
22.40	2883
22.57	2467
22.84	2900
23.11	5367
23.42	2517
23.65	2467
23.93	3183
24.20	3100
24.51	3367
24.74	3317
25.01	3217
25.28	3750
25.55	2433
25.82	4333

x in.	Mn ppm	x in.	Mn ppm
26.09	2633	48.31	3233
26.36	2617	48.79	3483
26.63	2250	49.28	3083
26.91	3383	49.77	3783
27.40	2817	50.26	3450
27.89	2483	50.77	3617
28.38	3050	51.30	3167
28.87	2950	51.83	3333
29.36	2700	52.32	3567
29.85	3050	52.76	4267
30.34	3633	53.20	2533
30.83	2933	53.64	4687
31.32	2783	54.08	3167
31.81	3500	54.52	4433
32.30	2783	54.96	2933
32.79	3050	55.40	3400
33.28	2800	55.84	4433
33.77	2517	56.28	3200
34.26	3033	56.72	3517
34.75	3283	57.16	3033
35.24	2883	57.60	4150
35.73	2100	58.09	2883
36.22	2800	58.63	4383
36.70	3150	59.17	4300
37.17	3917	59.71	3367
37.64	3850	60.15	2983
38.11	3050	60.79	3333
38.58	2017	61.33	3967
39.05	3050	61.79	4783
39.52	2883	62.17	3067
39.99	3217	62.52	3333
40.46	2433	62.88	2817
40.93	3050	63.60	3467
41.40	2733	63.96	4517
42.01	3217	64.32	2850
42.76	2583	64.68	4800
43.51	3800	65.04	5000
44.26	2583	65.40	4417
44.88	3750	65.76	4533
45.37	2700	66.12	5533
45.86	3700	66.48	2850
46.35	3233	66.84	5850
46.84	2933	67.20	4450
47.33	3000	67.56	5000
47.82	3433	67.92	5233

SPECTROCHEMICAL ANALYSES
SECTION 251

x in.	Na %	K %	Ca %	Fe %	Mg %
4.84	1.93	2.43	1.47	7.40	0.40
4.77	1.73	2.38	1.52	9.17	0.50
4.50	1.93	2.10	1.88	9.03	0.55
4.23	1.65	2.18	1.43	8.77	0.39
3.98	1.57	1.95	1.31	7.03	0.43
3.69	2.03	1.69	2.42	11.00	0.57
3.44	1.83	1.94	1.71	8.37	0.39
3.24	1.62	1.78	1.33	7.67	0.44
3.07	2.17	1.67	2.47	9.90	0.48
2.83	1.93	1.97	1.18	8.60	0.39
2.38	1.88	2.10	1.26	8.30	0.41
1.80	1.90	1.72	1.28	7.77	0.36
1.29	1.95	1.40	1.70	8.67	0.38
1.02	2.42	1.08	1.77	7.83	0.40
0.77	2.05	1.47	1.26	7.43	0.45
0.57	2.05	1.35	2.17	10.53	0.34
0.32	2.13	1.35	1.50	7.63	0.40
0.17	3.13	1.25	1.16	9.57	0.26
Sch C Gr					
0.15	3.22	1.33	0.24	0.86	0.027
0.50	3.78	1.94	0.33	0.88	0.021
0.77	2.82	3.75	0.27	0.58	0.016
0.96	3.52	2.85	0.23	0.75	0.024
1.15	3.45	1.80	0.29	0.86	0.025
1.34	2.90	1.70	0.34	0.87	0.033
1.56	2.58	1.11	0.29	0.90	0.034
Gr C Sch					
0.11	2.18	1.18	1.68	9.17	0.38
0.35	2.05	1.13	4.50	5.90	0.39
0.79	1.82	1.09	4.70	6.40	0.36
1.06	2.27	1.31	6.23	7.07	0.29
1.33	1.87	1.41	8.00	7.63	0.35
1.53	2.13	1.55	6.00	7.87	0.46
1.70	1.55	1.92	4.00	7.80	0.34
1.89	2.18	1.40	4.70	7.03	0.45
2.16	1.55	1.59	3.27	6.63	0.39
2.43	2.12	1.94	7.27	7.80	0.42

x in.	Na %	K %	Ca %	Fe %	Mg %
2.93	1.22	1.64	2.63	5.50	0.33
3.45	2.37	1.78	5.60	7.00	0.39
3.75	1.05	1.86	2.10	5.73	0.29
4.00	1.12	1.91	1.67	4.77	0.30
4.25	1.75	1.97	3.93	7.33	0.39
4.52	1.32	1.65	4.00	6.63	0.38
4.77	1.32	1.58	5.27	7.00	0.35
5.10	2.10	1.68	7.87	8.47	0.43

x in.	Mn ppm	V ppm	Ti ppm	Zr ppm	Ni ppm
4.84	1883	923	6800	187	82
4.77	2017	1133	5967	238	81
4.50	2900	1057	10000	133	90
4.23	1967	950	5900	227	67
3.98	1817	737	8800	238	63
3.69	2717	1050	8200	243	100
3.44	2033	917	n.d.	197	73
3.24	2033	703	6400	202	75
3.07	2750	1510	6200	208	91
2.83	1817	540	7633	128	65
2.38	1700	650	7800	160	58
1.80	1433	733	6433	192	64
1.29	2067	910	n.d.	175	84
1.02	2033	917	7467	137	70
0.77	2300	683	6467	165	64
0.57	1800	1283	10000	147	74
0.32	1817	763	5867	137	68
0.17	1600	843	7933	207	52
Sch C Gr					
0.15	360	21	1493	n.d.	n.d.
0.50	430	14	800	n.d.	n.d.
0.77	365	9	687	n.d.	n.d.
0.96	397	10	1110	n.d.	n.d.
1.15	265	15	1030	n.d.	n.d.
1.34	375	34	1037	n.d.	n.d.
1.56	301	31	1120	n.d.	n.d.
Gr C Sch					
0.11	2517	613	8800	n.d.	78
0.50	1917	257	7400	n.d.	51
0.79	1783	300	5700	n.d.	51
1.06	1783	460	6400	n.d.	57
1.33	1583	483	7033	n.d.	69
1.53	2067	517	6300	n.d.	58
1.70	1383	487	6600	n.d.	53
1.89	1383	433	7500	n.d.	50
2.16	1317	373	6533	n.d.	52
2.43	1650	700	8500	n.d.	77
2.93	1333	277	5800	n.d.	44
3.45	1592	480	7000	n.d.	55
3.75	1083	320	5900	n.d.	61

x in.	Mn ppm	V ppm	Ti ppm	Zr ppm	Ni ppm
4.00	1117	283	4767	n.d.	47
4.25	1233	557	7767	n.d.	71
4.52	1483	290	6567	n.d.	74
4.77	1300	387	6767	n.d.	80
5.10	1867	643	7233	n.d.	85

x in.	Ga ppm	Cr ppm
4.84	24	1427
4.77	31	1383
4.50	25	1573
4.23	30	1230
3.98	17	1480
3.69	24	1633
3.44	18	1667
3.24	19	1340
3.07	22	1470
2.83	16	1167
2.38	24	1270
1.80	18	1310
1.29	21	1353
1.02	19	1063
0.77	20	993
0.57	35	1087
0.32	20	1150
0.17	25	1427
Sch		
C		
Gr		
0.15	32	13
0.50	52	10
0.77	44	21
0.96	46	11
1.15	38	10
1.34	43	13
1.56	33	13
Gr		
C		
Sch		
0.11	30	1233
0.50	10	1000
0.79	11	1520
1.06	14	1954
1.33	13	2240
1.53	13	2434
1.70	14	1826
1.89	11	1740
2.16	15	1134
2.43	12	1694
2.93	9	1280
3.45	12	1654
3.75	14	1526

x in.	Ga ppm	Cr ppm
4.00	9	1480
4.25	12	1500
4.52	10	1706
4.77	14	1880
5.10	18	2460

SPECTROCHEMICAL ANALYSES
SECTION 253

x in.	Na %	K %	Ca %	Fe %	Mg %
23.90	2.15	3.65	0.80	0.34	0.20
23.70	2.83	5.27	0.53	0.29	0.24
23.30	3.10	4.32	0.84	0.37	0.22
22.90	2.38	3.57	0.76	0.32	0.23
22.50	2.83	3.47	0.76	0.26	0.19
22.10	2.85	3.80	0.75	0.34	0.22
21.70	2.87	3.92	0.66	0.34	0.23
21.55	2.20	3.97	0.66	0.35	0.30
21.35	2.74	3.68	0.79	0.44	0.32
21.05	2.37	4.17	0.71	0.37	0.34
20.75	2.36	4.38	0.79	0.32	0.31
20.50	3.05	4.02	0.75	0.35	0.24
20.30	2.65	3.77	0.78	0.47	0.26
19.95	2.73	3.85	0.71	0.45	0.30
19.70	2.10	3.77	0.54	0.32	0.26
19.50	2.41	3.63	0.52	0.35	0.23
19.25	2.53	4.08	0.65	0.35	0.24
19.00	2.63	3.58	0.71	0.33	0.25
18.75	2.28	3.58	0.63	0.32	0.31
18.32	2.75	3.48	n.d.	n.d.	n.d.
17.89	2.40	3.78	0.69	0.45	0.27
17.47	2.43	4.03	0.51	0.25	0.18
17.05	2.71	5.52	0.63	0.28	0.31
16.63	2.90	3.62	0.83	0.33	0.22
16.21	2.55	4.32	0.54	0.51	0.33
15.79	3.15	4.67	0.49	0.45	0.44
14.84	2.20	3.27	0.72	0.24	0.22
14.54	2.17	3.98	0.58	0.30	0.19
14.29	2.53	3.98	0.62	0.31	0.22
13.79	2.40	4.07	0.61	0.34	0.39
13.39	2.47	3.48	0.65	0.29	0.31
13.04	2.58	3.23	0.62	0.27	0.26
12.79	2.47	2.98	0.96	0.25	0.28
12.44	2.95	3.82	0.87	0.28	0.23
12.04	2.64	3.57	0.78	0.24	0.18
11.74	2.82	3.33	0.90	0.27	0.19
11.49	2.58	3.68	0.96	0.24	0.17
11.09	2.80	3.48	0.77	0.23	0.21
10.74	2.47	3.80	0.65	0.23	0.24
10.14	2.12	3.27	0.77	0.29	0.21
9.89	2.73	3.38	0.77	0.27	0.20
9.39	2.53	3.30	0.78	0.32	0.25
8.74	2.50	3.15	0.63	0.21	0.15
8.39	2.50	3.03	0.52	0.22	0.20
7.94	2.20	2.97	0.85	0.21	0.14

x in.	Na %	K %	Ca %	Fe %	Mg %
7.54	2.70	3.23	0.94	0.29	0.24
7.19	3.10	3.28	1.02	0.24	0.17
6.84	2.80	2.98	0.86	0.22	0.13
6.49	2.40	3.83	0.68	0.27	0.22
6.19	2.78	4.00	0.84	0.25	0.26
5.94	2.73	4.70	0.83	0.21	0.17
5.64	2.92	3.28	0.80	0.24	0.23
5.39	2.80	3.38	0.90	0.27	0.26
4.24	2.83	2.65	0.50	0.16	0.12
3.84	2.90	3.08	0.58	0.21	0.14
3.14	2.80	2.68	0.65	0.31	0.22
2.84	3.33	2.92	0.46	0.23	0.17
2.54	2.55	3.15	0.70	0.21	0.21
2.24	3.00	3.00	0.44	0.18	0.14
2.04	2.90	2.53	0.52	0.29	0.13
1.74	2.78	2.78	0.54	0.23	0.17
1.39	3.15	2.90	0.57	0.22	0.21
1.19	2.83	2.83	0.64	0.22	0.15
0.89	2.75	2.12	0.66	0.21	0.08
0.44	2.45	2.77	0.56	0.25	0.10
0.15	2.67	4.13	0.36	0.14	0.11

Gr
C
Sch

0.15	2.65	1.57	0.69	3.17	0.62
0.44	2.38	1.78	0.87	3.33	1.80
0.73	2.63	1.80	1.35	2.53	1.52
1.02	2.82	1.97	1.27	2.60	1.30
1.31	2.30	1.80	1.94	2.77	1.59
1.60	2.23	1.60	2.70	2.77	1.82
1.89	3.10	1.43	2.15	1.32	0.64
2.18	2.65	1.32	1.95	1.75	1.30
2.43	2.50	1.67	1.53	2.15	1.34
2.72	2.47	1.32	1.47	1.73	1.01
3.01	2.75	1.48	1.93	1.95	0.45
3.30	2.33	1.28	1.92	1.77	1.08
3.70	2.83	1.53	1.98	1.77	0.16
4.10	2.78	1.53	2.10	1.62	0.16
4.45	2.60	1.30	2.35	1.88	0.22
4.75	2.60	1.37	2.50	1.80	0.19
5.30	2.28	1.38	n.d.	n.d.	n.d.
6.15	2.23	1.23	2.43	1.45	n.d.
6.85	2.98	1.10	2.20	1.21	n.d.
7.15	2.50	1.10	2.80	1.08	0.11
7.55	2.93	1.49	2.45	1.95	0.22
8.10	2.70	1.62	2.80	1.90	0.21

x in.	Na %	K %	Ca %	Fe %	Mg %
8.65	2.83	1.43	2.65	1.73	0.16
9.40	1.83	1.12	1.80	1.17	0.13
10.13	2.26	1.28	1.55	1.28	0.14
10.86	2.22	1.04	2.05	1.40	0.13
11.59	2.60	0.94	n.d.	n.d.	n.d.
12.32	2.67	0.96	2.03	0.96	0.09
13.05	2.43	1.05	n.d.	n.d.	n.d.
13.78	2.92	1.08	2.25	0.96	0.13

x in.	Ba ppm	Cr ppm	Ti ppm	V ppm	Mn ppm
23.90	n.d.	n.d.	517	6	227
23.70	n.d.	n.d.	427	7	214
23.30	n.d.	n.d.	517	10	245
22.90	n.d.	n.d.	487	6	153
22.50	n.d.	n.d.	480	4	150
22.10	n.d.	n.d.	507	8	167
21.70	n.d.	n.d.	600	4	190
21.55	n.d.	n.d.	437	6	152
21.35	n.d.	n.d.	827	5	162
21.05	n.d.	n.d.	553	5	150
20.75	n.d.	n.d.	633	3	142
20.50	n.d.	n.d.	528	8	153
20.30	n.d.	n.d.	643	7	168
19.95	n.d.	n.d.	760	12	185
19.70	n.d.	n.d.	497	3	133
19.50	n.d.	n.d.	597	7	145
19.25	n.d.	n.d.	473	8	227
19.00	n.d.	n.d.	563	3	190
18.75	n.d.	n.d.	600	5	170
18.32	n.d.	n.d.	n.d.	n.d.	n.d.
17.89	n.d.	n.d.	575	5	183
17.47	n.d.	n.d.	457	6	162
17.05	n.d.	n.d.	503	7	157
16.63	n.d.	n.d.	477	7	198
16.21	n.d.	n.d.	740	5	215
15.79	n.d.	n.d.	750	4	180
14.84	n.d.	n.d.	527	8	138
14.54	n.d.	n.d.	600	4	138
14.29	n.d.	n.d.	613	6	155
13.79	n.d.	n.d.	553	7	138
13.39	n.d.	n.d.	630	6	170
13.04	n.d.	n.d.	500	4	129
12.79	n.d.	n.d.	570	15	170
12.44	n.d.	n.d.	410	9	162
12.04	n.d.	n.d.	457	7	156
11.74	n.d.	n.d.	720	7	156
11.49	n.d.	n.d.	410	5	150
11.09	n.d.	n.d.	393	4	127
10.74	n.d.	n.d.	477	4	139
10.14	n.d.	n.d.	473	4	184
9.89	n.d.	n.d.	527	7	136
9.39	n.d.	n.d.	560	11	162
8.74	n.d.	n.d.	243	5	338
8.39	n.d.	n.d.	367	7	227
7.94	n.d.	n.d.	223	4	248
7.54	n.d.	n.d.	307	8	202
7.19	n.d.	n.d.	302	5	190
6.84	n.d.	n.d.	252	4	160

x in.	Ba ppm	Cr ppm	Ti ppm	V ppm	Mn ppm
6.49	n.d.	n.d.	380	7	153
6.19	n.d.	n.d.	417	6	153
5.94	n.d.	n.d.	302	8	166
5.64	n.d.	n.d.	497	3	166
5.39	n.d.	n.d.	353	5	158
4.24	n.d.	n.d.	183	7	270
3.84	n.d.	n.d.	242	6	325
3.14	n.d.	n.d.	240	4	400
2.84	n.d.	n.d.	193	3	473
2.54	n.d.	n.d.	222	6	393
2.24	n.d.	n.d.	203	4	360
2.04	n.d.	n.d.	213	7	547
1.74	n.d.	n.d.	172	10	390
1.39	n.d.	n.d.	277	17	467
1.19	n.d.	n.d.	212	5	487
0.89	n.d.	n.d.	n.d.	5	447
0.44	n.d.	n.d.	215	5	510
0.15	n.d.	n.d.	257	4	178

Gr
C
Sch

x in.	Ba ppm	Cr ppm	Ti ppm	V ppm	Mn ppm
0.15	46	80	1080	51	1800
0.44	61	96	1610	69	1533
0.73	58	77	1497	73	1117
1.02	54	93	1027	51	1267
1.31	62	76	1580	66	1080
1.60	55	77	1933	81	820
1.89	24	42	417	23	593
2.18	30	54	513	38	663
2.43	29	72	817	53	963
2.72	31	56	733	30	747
3.01	42	66	703	37	770
3.30	27	52	730	34	610
3.70	39	56	800	48	520
4.10	29	55	625	40	543
4.45	28	61	570	51	763
4.75	17	53	425	45	660
5.30	50	43	n.d.	n.d.	387
6.15	47	37	920	30	420
6.85	23	29	593	19	243
7.15	25	34	555	25	323
7.55	30	56	870	49	540
8.10	34	64	750	56	630
8.65	38	46	825	44	497
9.40	17	31	435	27	313
10.13	21	38	450	33	387

x in.	Ba ppm	Cr ppm	Ti ppm	V ppm	Mn ppm
10.86	24	32	562	29	413
11.59	21	31	n.d.	n.d.	263
12.32	19	26	420	19	309
13.05	25	38	n.d.	n.d.	233
13.78	17	31	380	21	327

x in.	Cu ppm	Ga ppm	Pb ppm
23.90	6	20	48
23.70	6	20	63
23.30	9	22	62
22.90	10	21	52
22.50	7	18	48
22.10	14	26	64
21.70	21	17	55
21.55	17	22	56
21.35	29	16	41
21.05	19	17	59
20.75	13	25	64
20.50	27	19	53
20.30	18	22	51
19.95	11	21	52
19.70	19	19	51
19.50	12	20	47
19.25	10	18	50
19.00	12	19	48
18.75	12	18	55
18.32	n.d.	n.d.	n.d.
17.89	21	20	60
17.47	5	22	68
17.05	13	27	66
16.63	6	19	54
16.21	29	21	56
15.79	10	21	59
14.84	n.d.	16	55
14.54	n.d.	16	40
14.29	4	18	47
13.79	5	21	48
13.39	6	17	48
13.04	6	19	45
12.79	21	18	40
12.44	5	21	55
12.04	4	16	39
11.74	8	17	49
11.49	5	18	38
11.09	3	19	46
10.74	9	16	43
10.14	n.d.	17	47
9.89	8	17	38
9.39	10	19	42
8.74	5	22	49
8.39	3	21	42
7.94	7	19	61
7.54	5	26	59
7.19	4	19	54
6.84	6	23	57

x in.	Cu ppm	Ga ppm	Pb ppm
6.49	3	19	52
6.19	n.d.	20	48
5.94	4	22	60
5.64	n.d.	18	47
5.39	n.d.	19	46
4.24	4	21	60
3.84	9	21	52
3.14	12	19	54
2.84	4	23	59
2.54	9	21	51
2.24	4	21	48
2.04	9	22	56
1.74	4	18	47
1.39	9	23	55
1.19	6	24	55
0.89	6	17	55
0.44	6	22	47
0.15	7	17	46
Gr C Sch			
0.15	7	20	36
0.44	6	20	34
0.73	5	21	34
1.02	4	20	29
1.31	4	19	30
1.60	5	21	29
1.89	3	18	34
2.18	n.d.	17	28
2.43	4	19	28
2.72	6	19	31
3.01	3	17	28
3.30	7	16	29
3.70	4	16	31
4.10	n.d.	17	28
4.45	4	33	33
4.75	5	24	29
5.30	n.d.	n.d.	n.d.
6.15	3	13	27
6.85	4	17	30
7.15	11	22	36
7.55	11	21	45
8.10	13	24	41
8.65	10	21	42
9.40	7	16	32
10.13	7	14	27

x in.	Cu ppm	Ga ppm	Pb ppm
10.86	10	14	27
11.59	n.d.	n.d.	n.d.
12.32	4	15	29
13.05	n.d.	n.d.	n.d.
13.78	4	20	31

x in.	Cu ppm	Ga ppm	Pb ppm
10.86	10	14	27
11.59	n.d.	n.d.	n.d.
12.32	4	15	29
13.05	n.d.	n.d.	n.d.
13.78	4	20	31

APPENDIX B

DATA CURVES

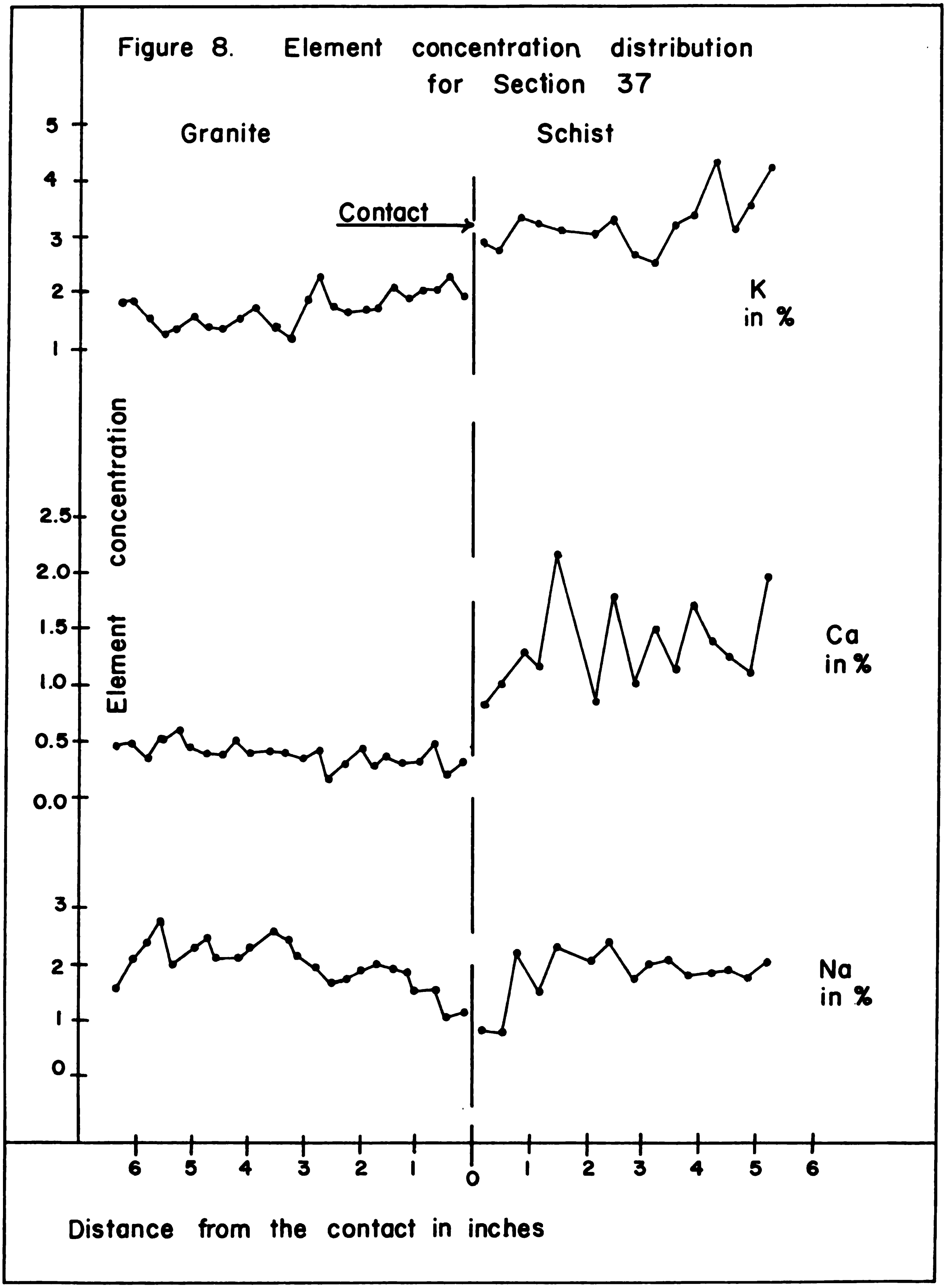


Figure 8. Element concentration distribution for Section 37
Granite
Schist
Contact
K in %
Ca in %
Na in %
Element concentration
5
4
3
2
1
2.5
2.0
1.5
1.0
0.5
0.0
3
2
1
0
6
5
4
3
2
1
0
1
2
3
4
5
6
Distance from the contact in inches

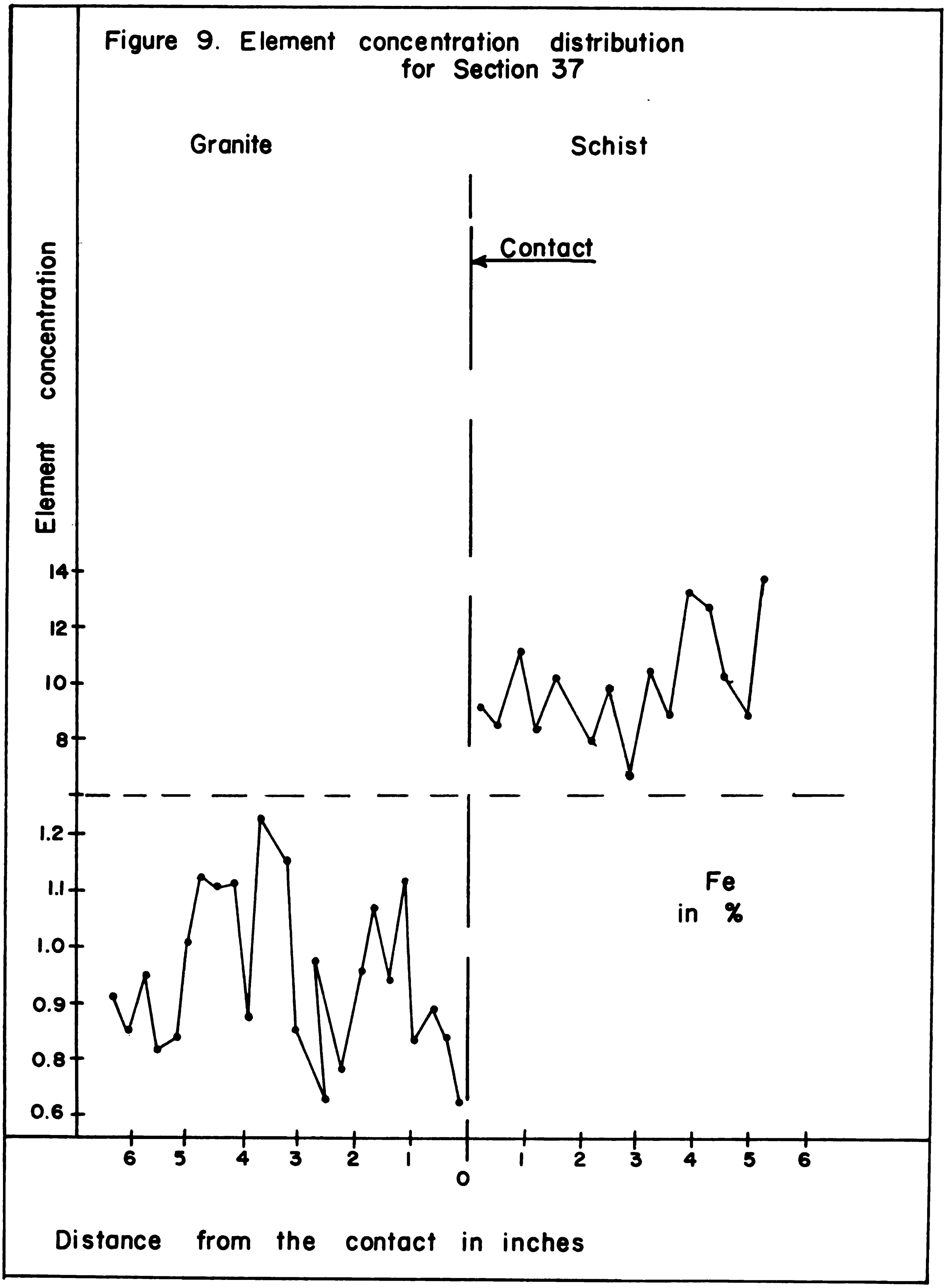


Figure 9. Element concentration distribution for Section 37
Granite
Schist
Contact
Element concentration
14
12
10
8
1.2
1.1
1.0
0.9
0.8
0.6
Fe
in %
6
5
4
3
2
1
0
1
2
3
4
5
6
Distance from the contact in inches

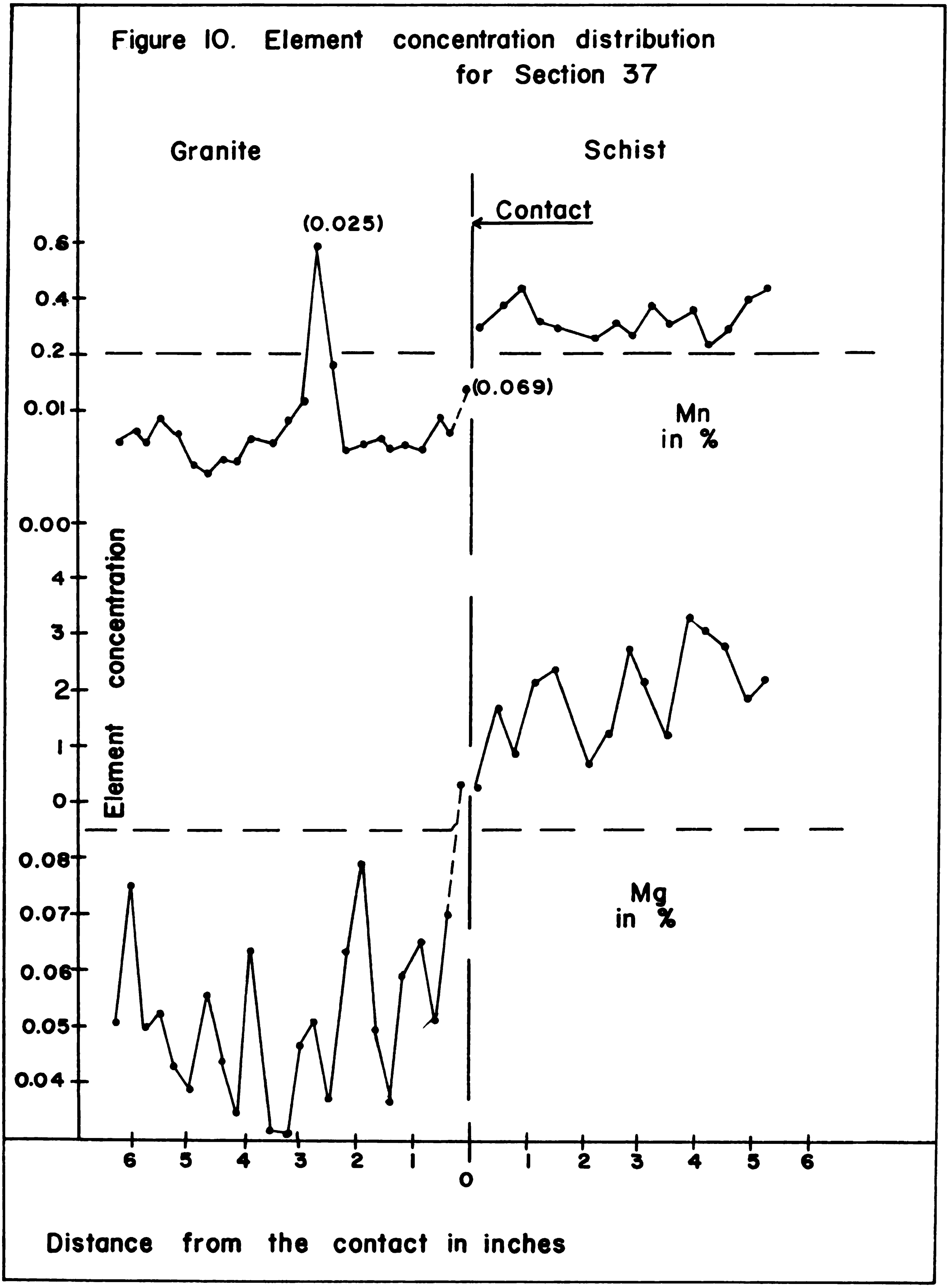
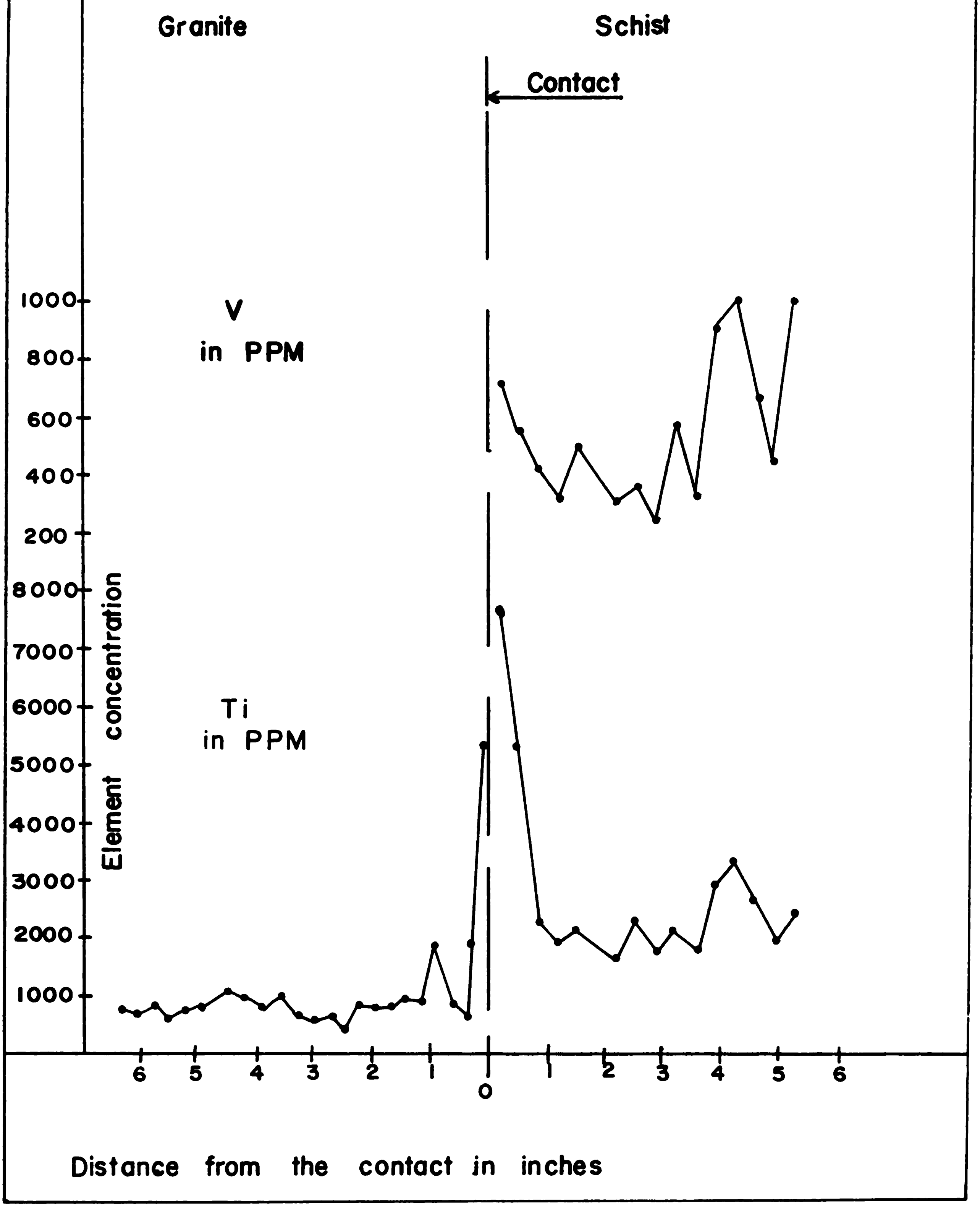


Figure 10. Element concentration distribution for Section 37
Granite
Schist
Contact
(0.025)
(0.069)
Mn in %
Mg in %
Element concentration
0.6
0.4
0.2
0.01
0.00
4
3
2
1
0
0.08
0.07
0.06
0.05
0.04
6
5
4
3
2
1
0
1
2
3
4
5
6
Distance from the contact in inches

Figure 11. Element concentration distribution for Section 37



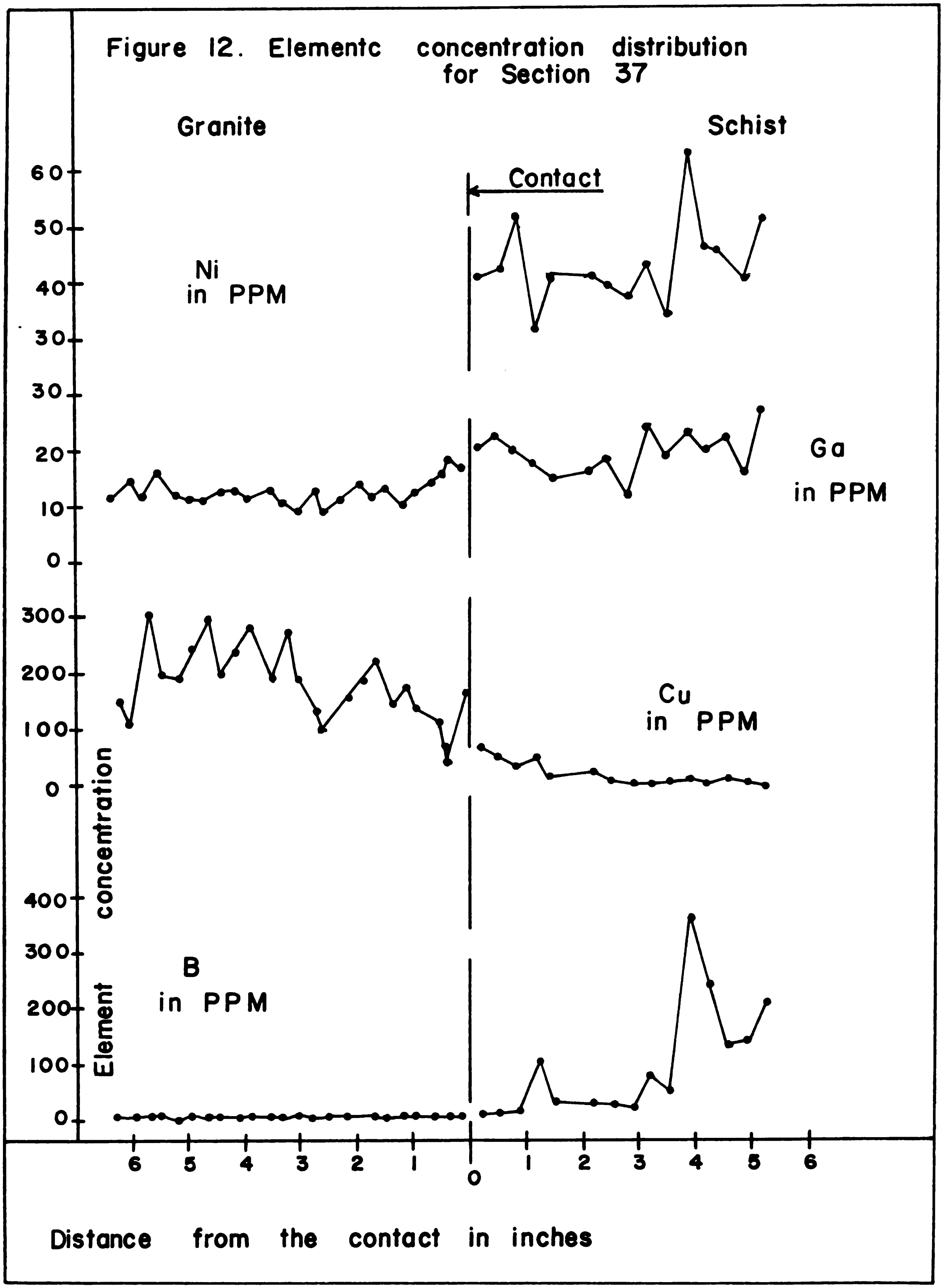


Figure 12. Elementc concentration distribution for Section 37
Granite
Schist
Contact
Ni in PPM
Ga in PPM
Cu in PPM
B in PPM
Element concentration
60
50
40
30
30
20
10
0
300
200
100
0
400
300
200
100
0
6
5
4
3
2
1
0
1
2
3
4
5
6
Distance from the contact in inches

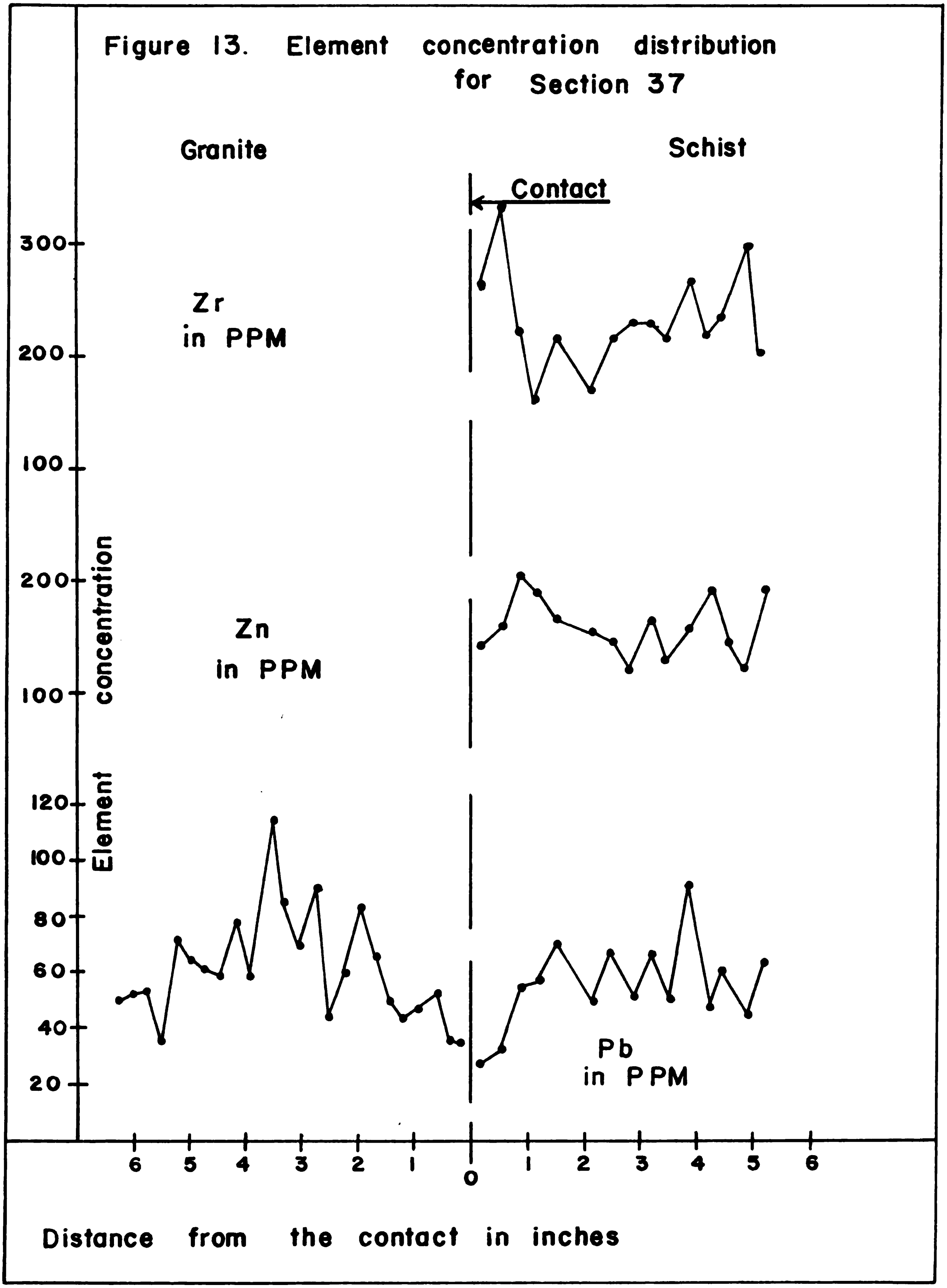


Figure 13. Element concentration distribution for Section 37
Granite
Schist
Contact
Zr in PPM
Zn in PPM
Pb in PPM
Element concentration
300
200
100
200
100
120
100
80
60
40
20
6
5
4
3
2
1
0
1
2
3
4
5
6
Distance from the contact in inches

Figure 14. Element concentration distribution for Section 38

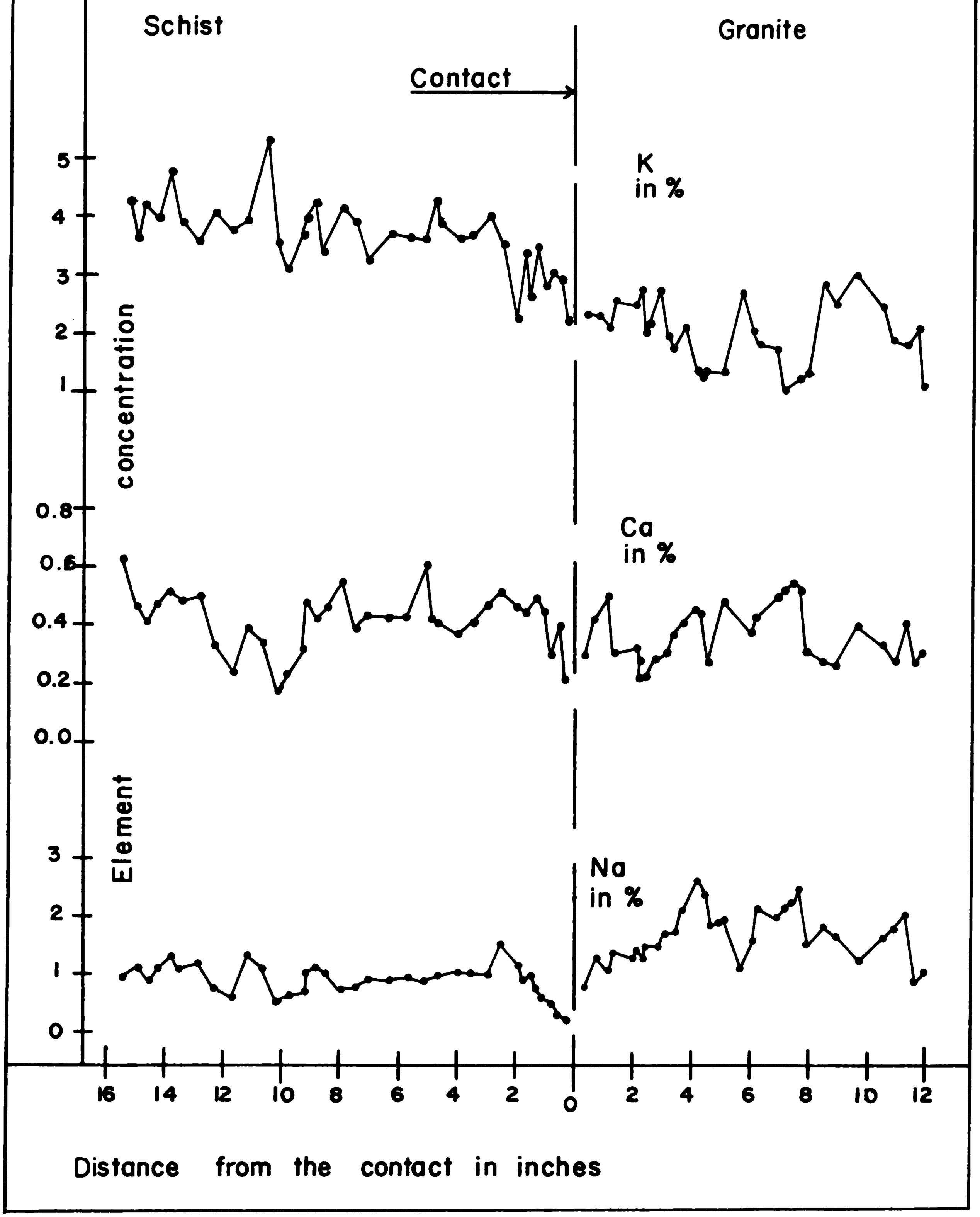
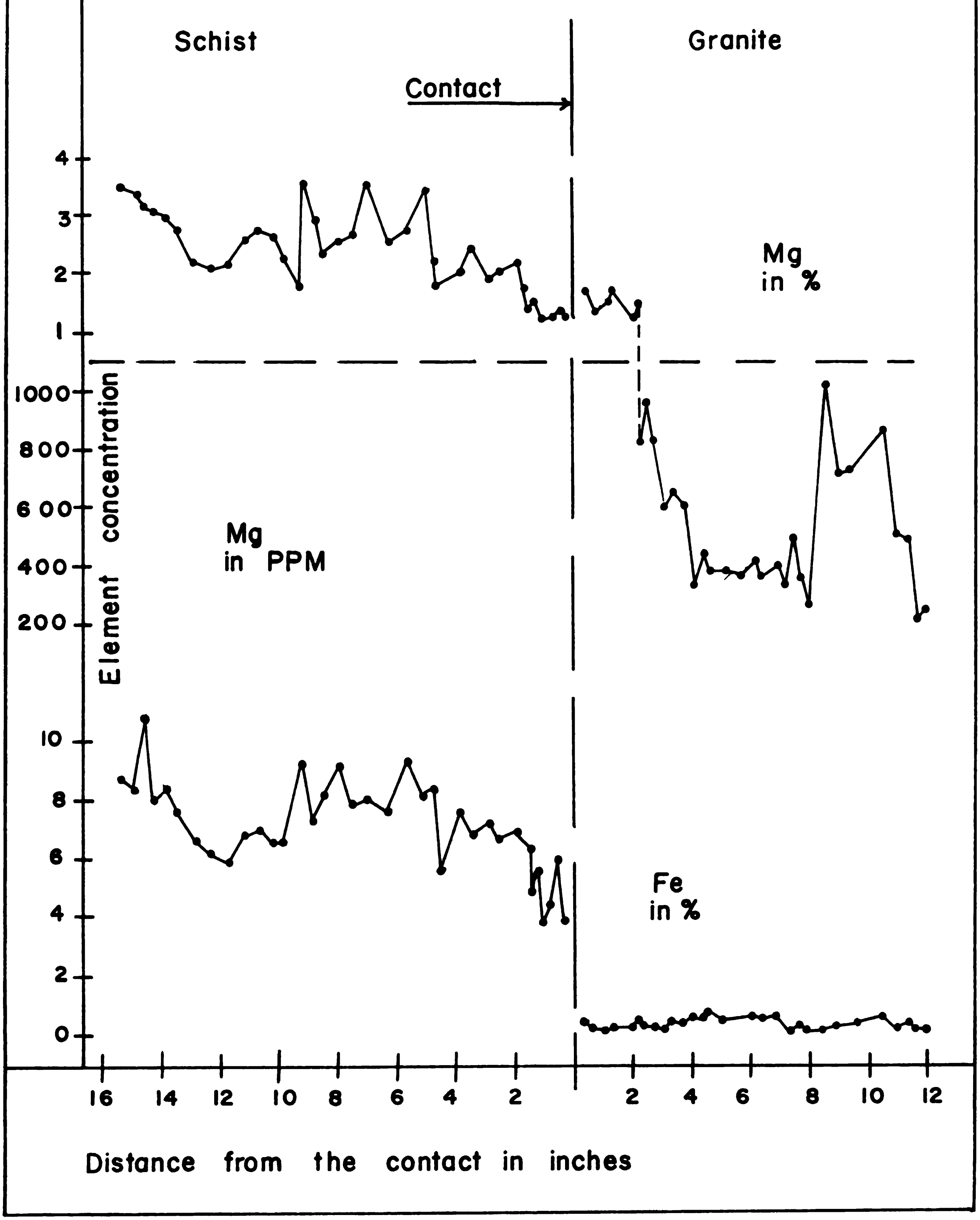


Figure 15. Element concentration distribution for Section 38



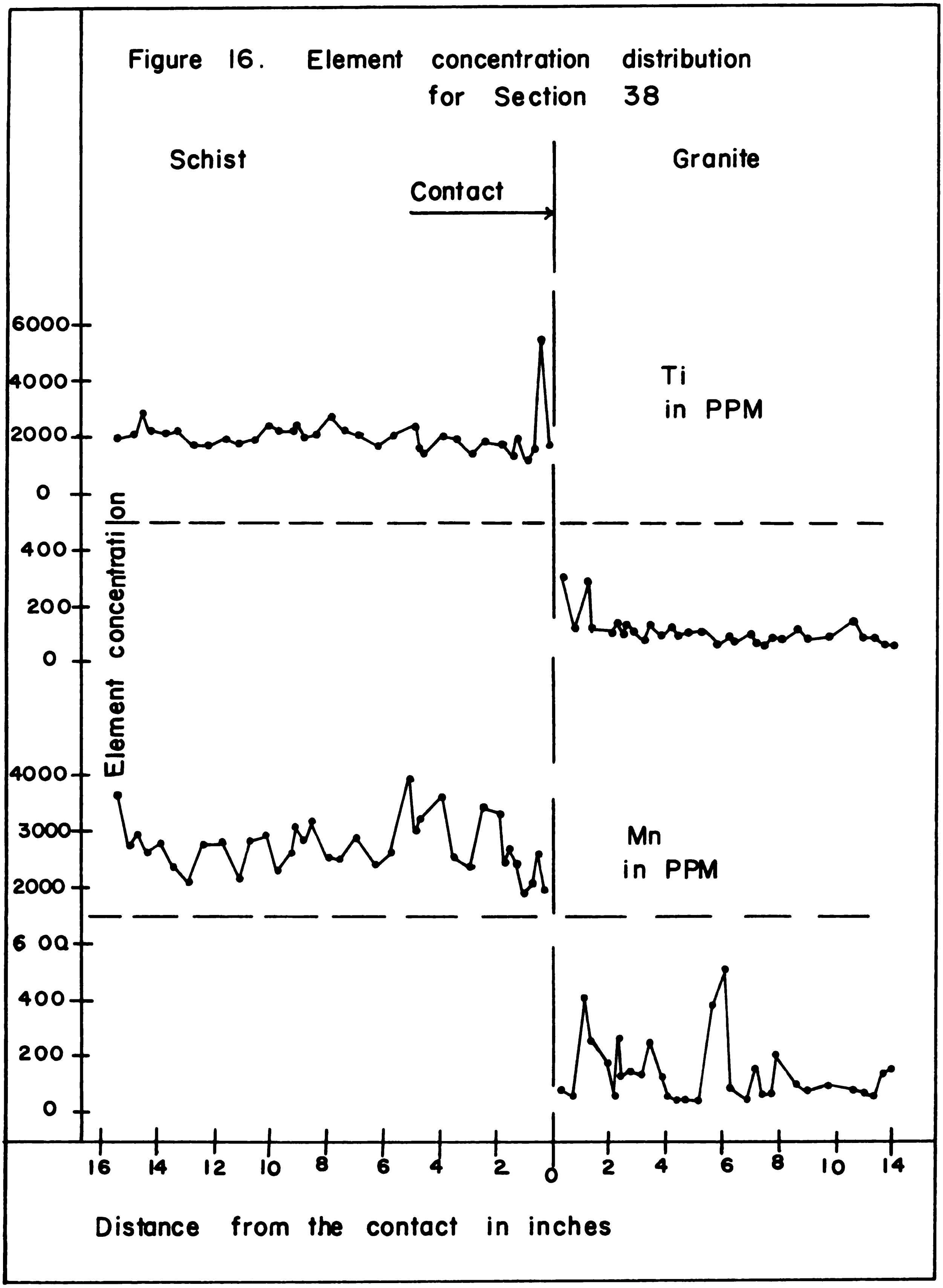


Figure 16. Element concentration distribution for Section 38
Schist
Granite
Contact
Ti
in PPM
Mn
in PPM
Element concentration
6000
4000
2000
0
400
200
0
4000
3000
2000
6 00
400
200
0
16
14
12
10
8
6
4
2
0
2
4
6
8
10
14
Distance from the contact in inches

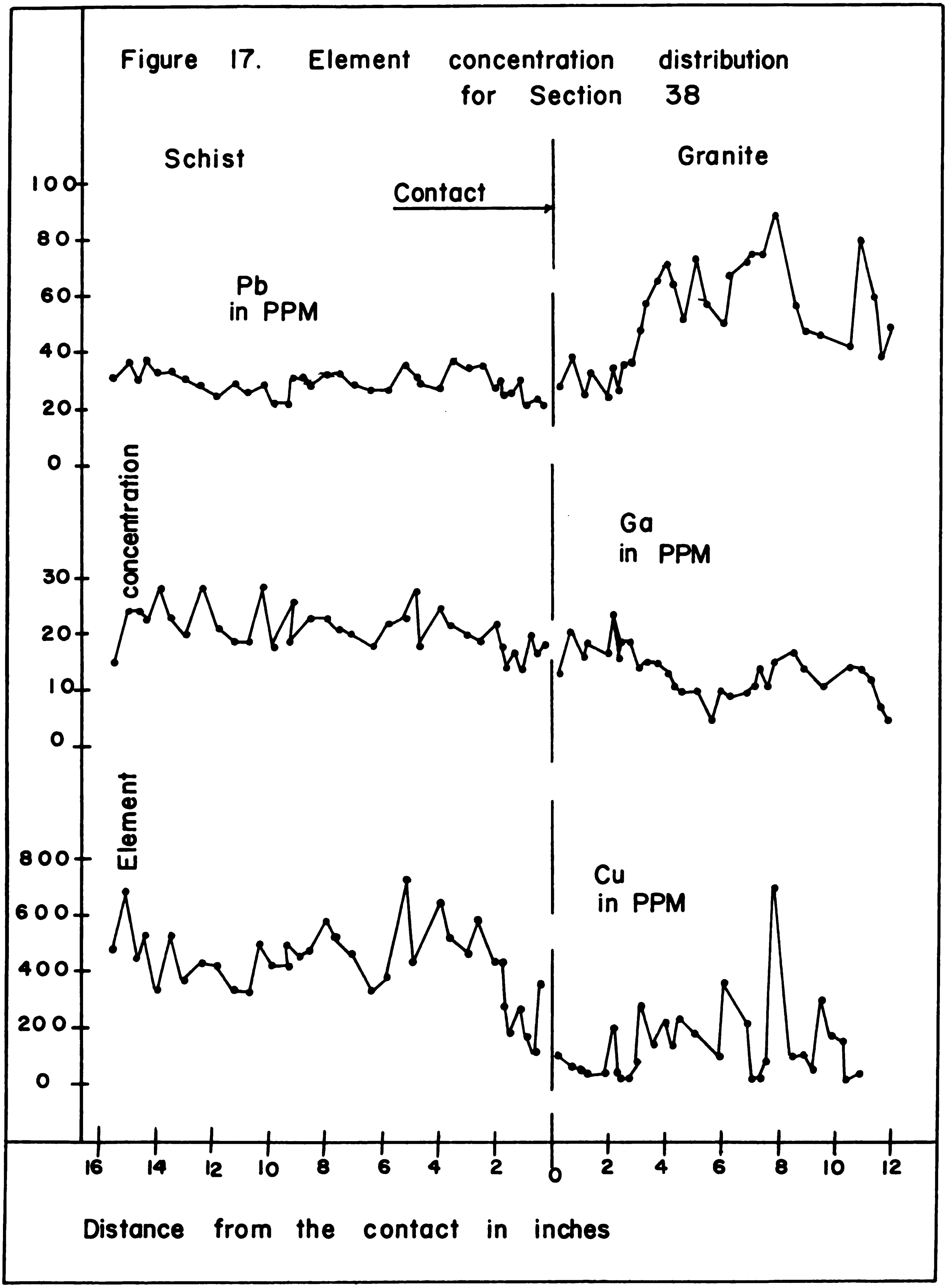
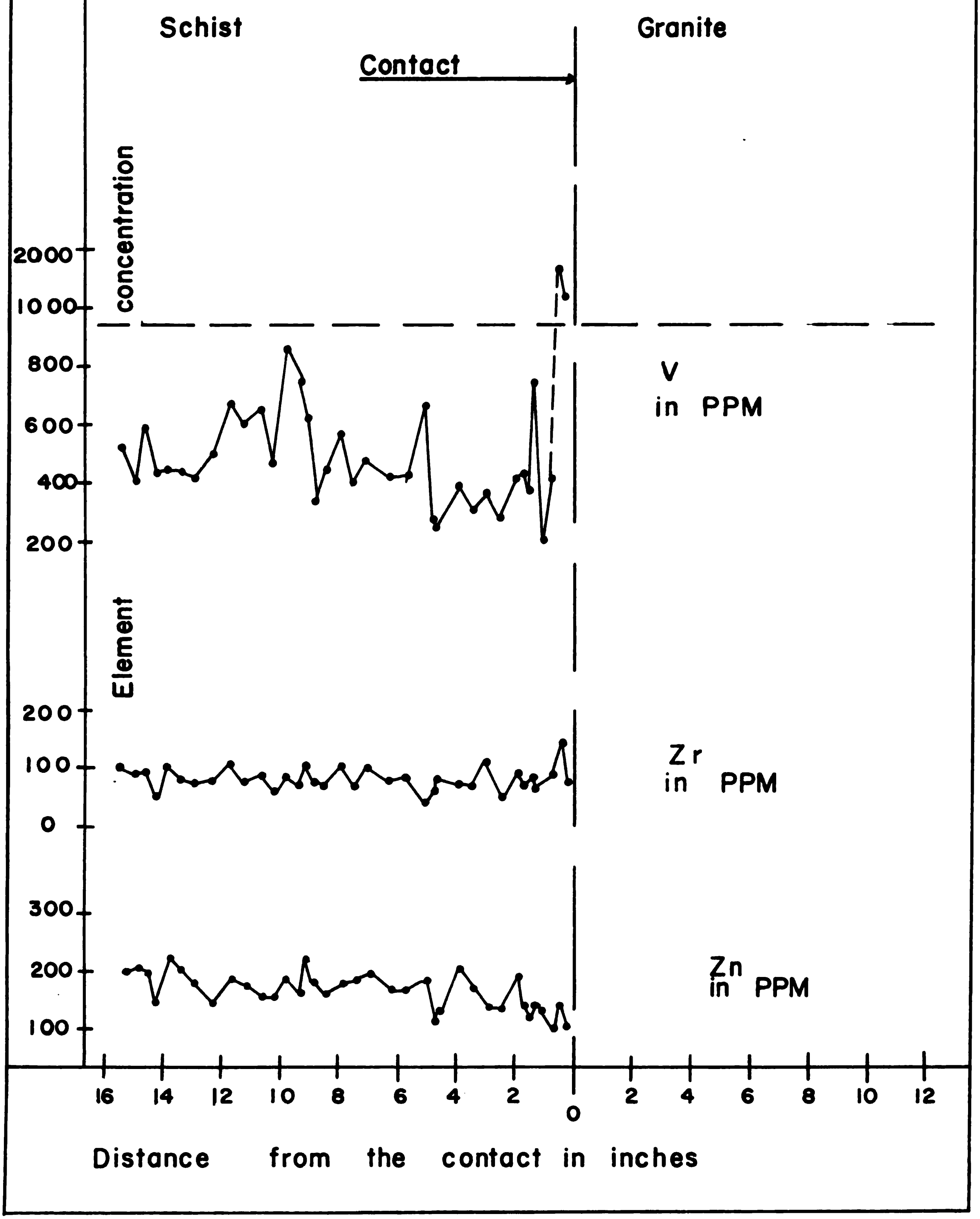


Figure 17. Element concentration distribution for Section 38
Schist
Granite
Contact
Pb in PPM
Ga in PPM
Cu in PPM
Element concentration
100
80
60
40
20
0
30
20
10
0
800
600
400
200
0
16
14
12
10
8
6
4
2
0
2
4
6
8
10
12
Distance from the contact in inches

Figure 18. Element concentration distribution for Section 38



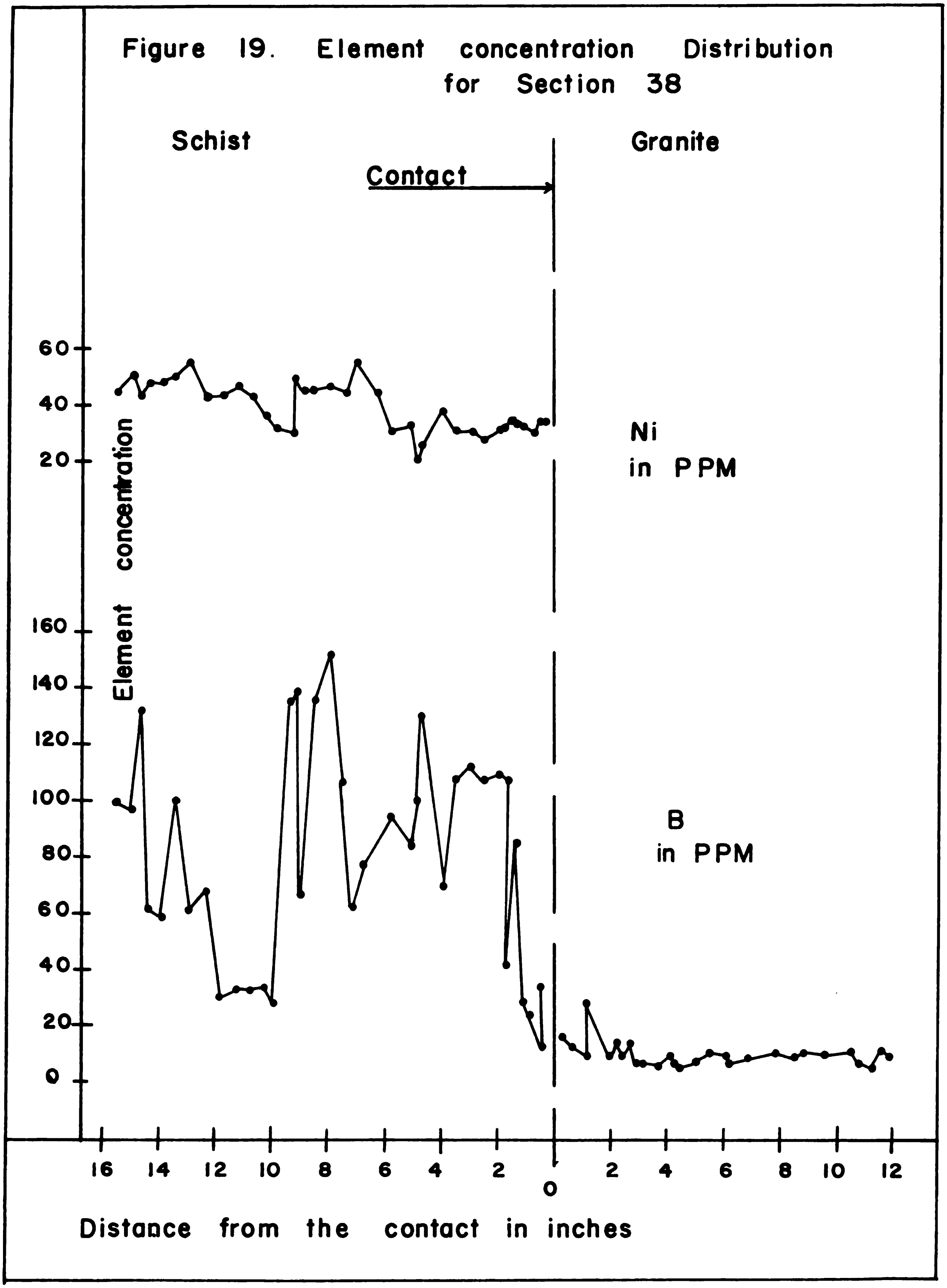
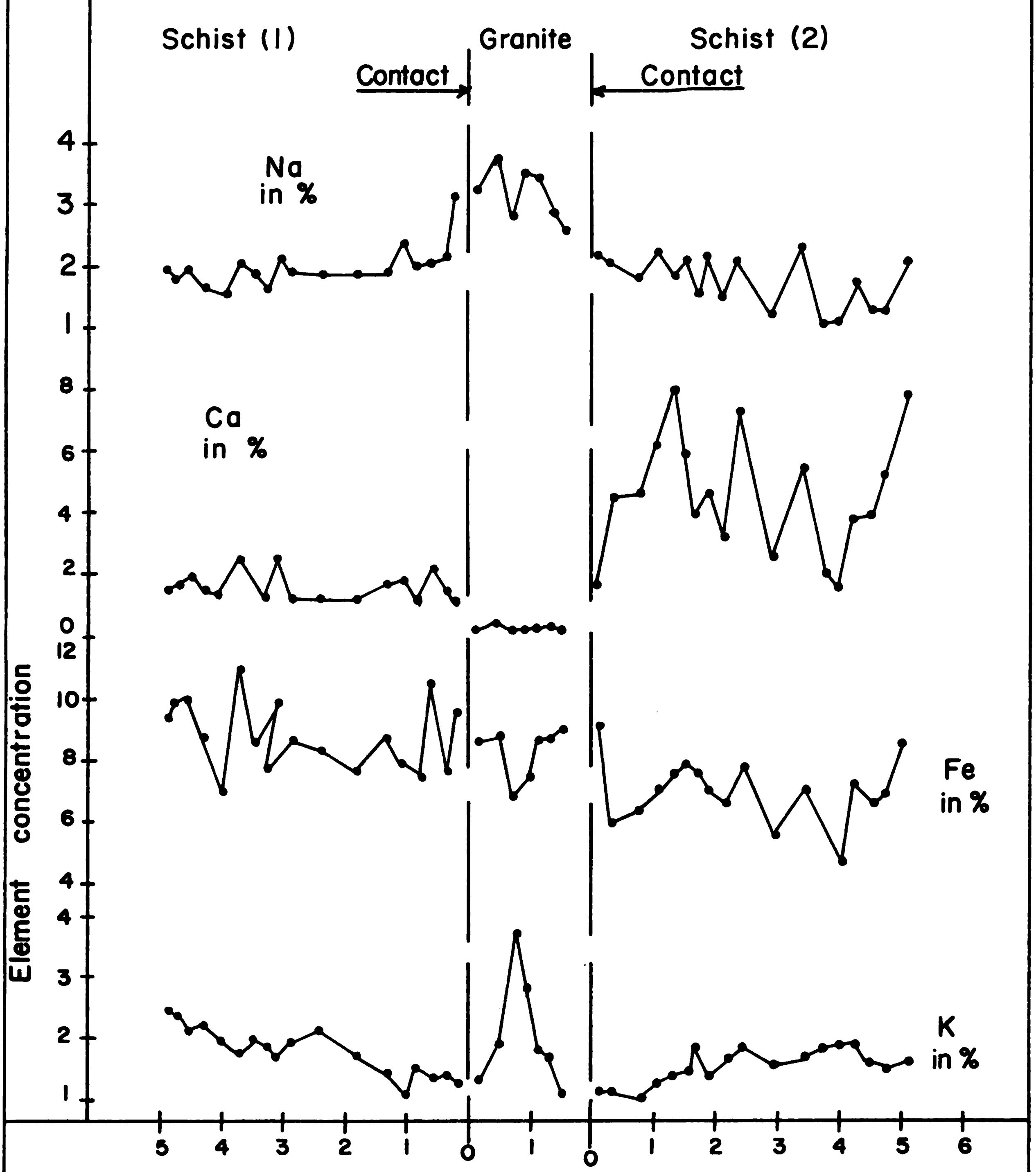


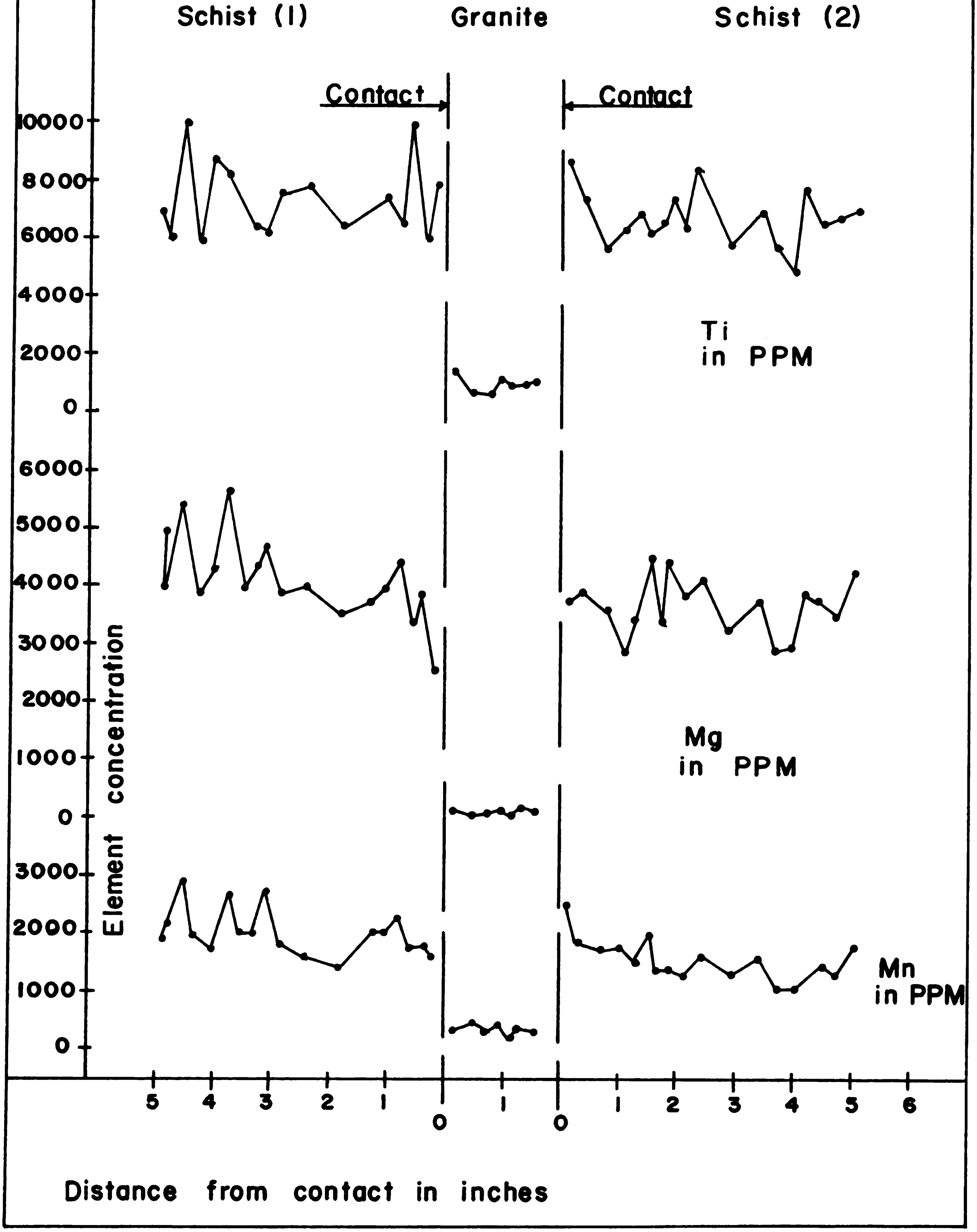
Figure 19. Element concentration Distribution for Section 38
Schist
Granite
Contact
Ni in PPM
B in PPM
Element concentration
60
40
20
160
140
120
100
80
60
40
20
0
16 14 12 10 8 6 4 2 0 2 4 6 8 10 12
Distance from the contact in inches

Figure 20. Element concentration distribution for Section 251



Distance from the contact in inches

Figure 21. Element concentration distribution for Section 251



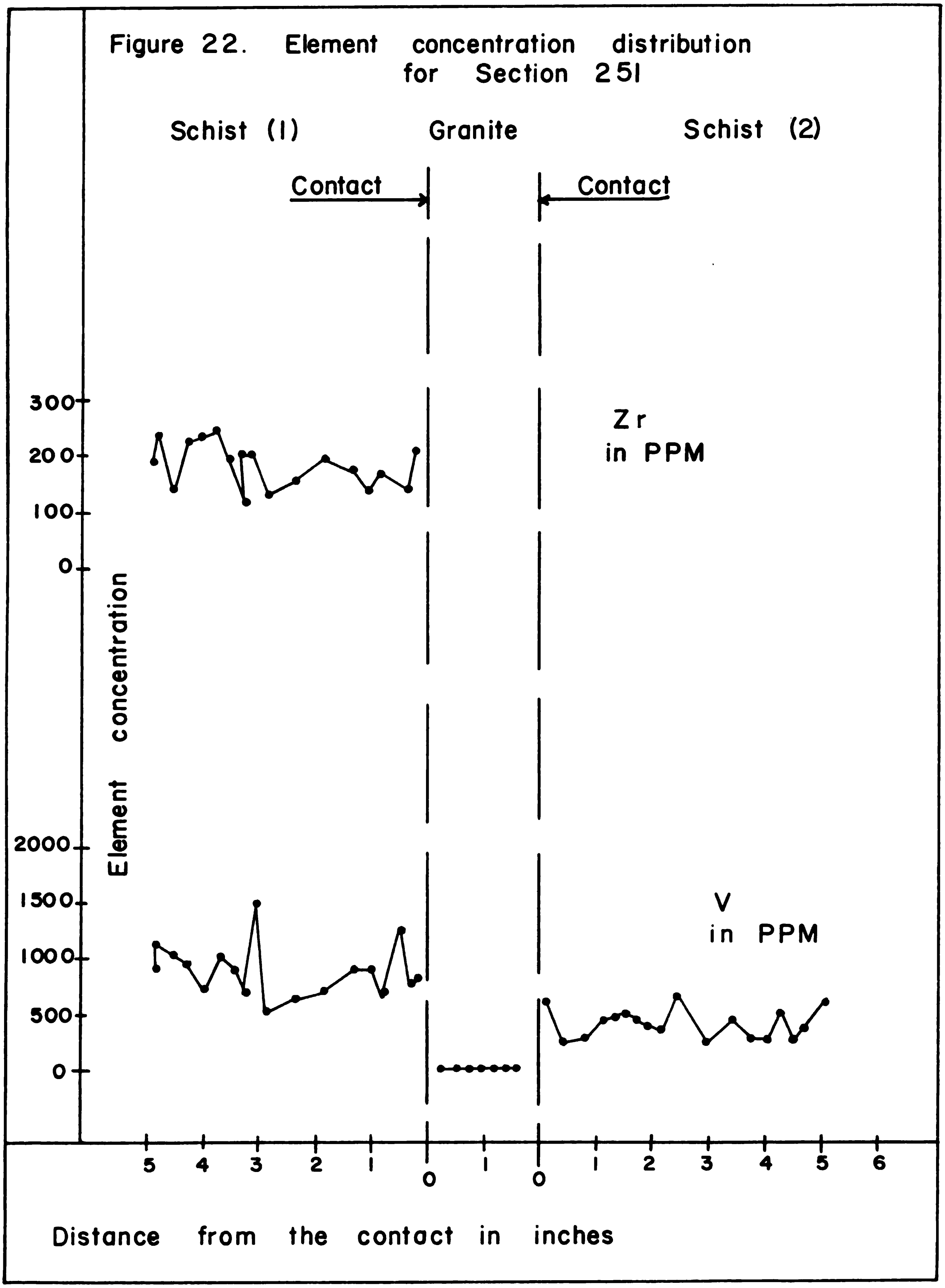


Figure 22. Element concentration distribution for Section 251
Schist (1)
Granite
Schist (2)
Contact
Contact
Zr in PPM
V in PPM
Element concentration
300
200
100
0
2000
1500
1000
500
0
5
4
3
2
1
0
1
0
1
2
3
4
5
6
Distance from the contact in inches

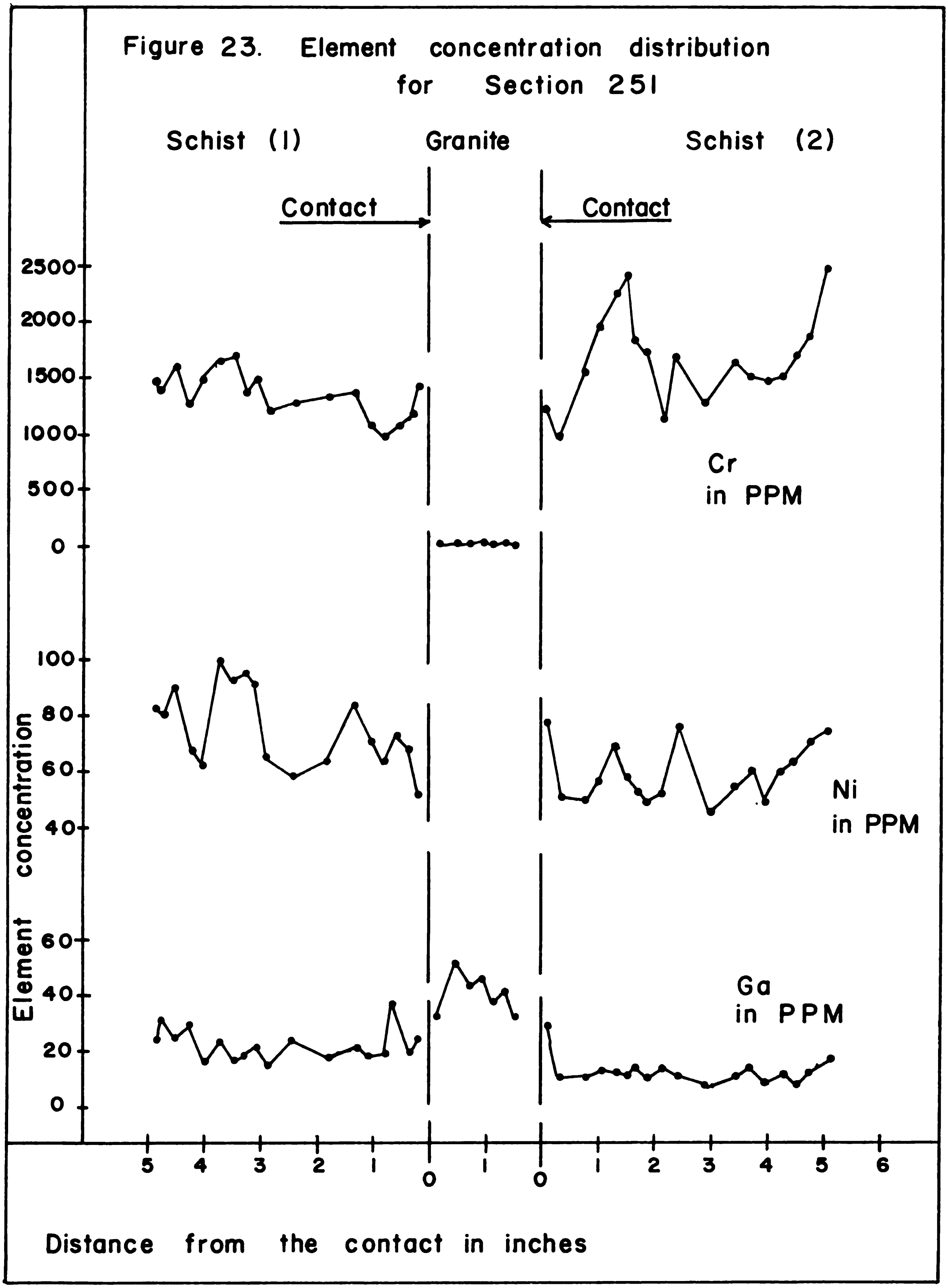


Figure 23. Element concentration distribution for Section 251
Schist (1)
Granite
Schist (2)
Contact
Contact
2500
2000
1500
1000
500
0
Cr in PPM
100
80
60
40
Ni in PPM
60
40
20
0
Ga in PPM
Element concentration
5
4
3
2
1
0
1
0
1
2
3
4
5
6
Distance from the contact in inches

Figure 24. Element concentration distribution for Section 253

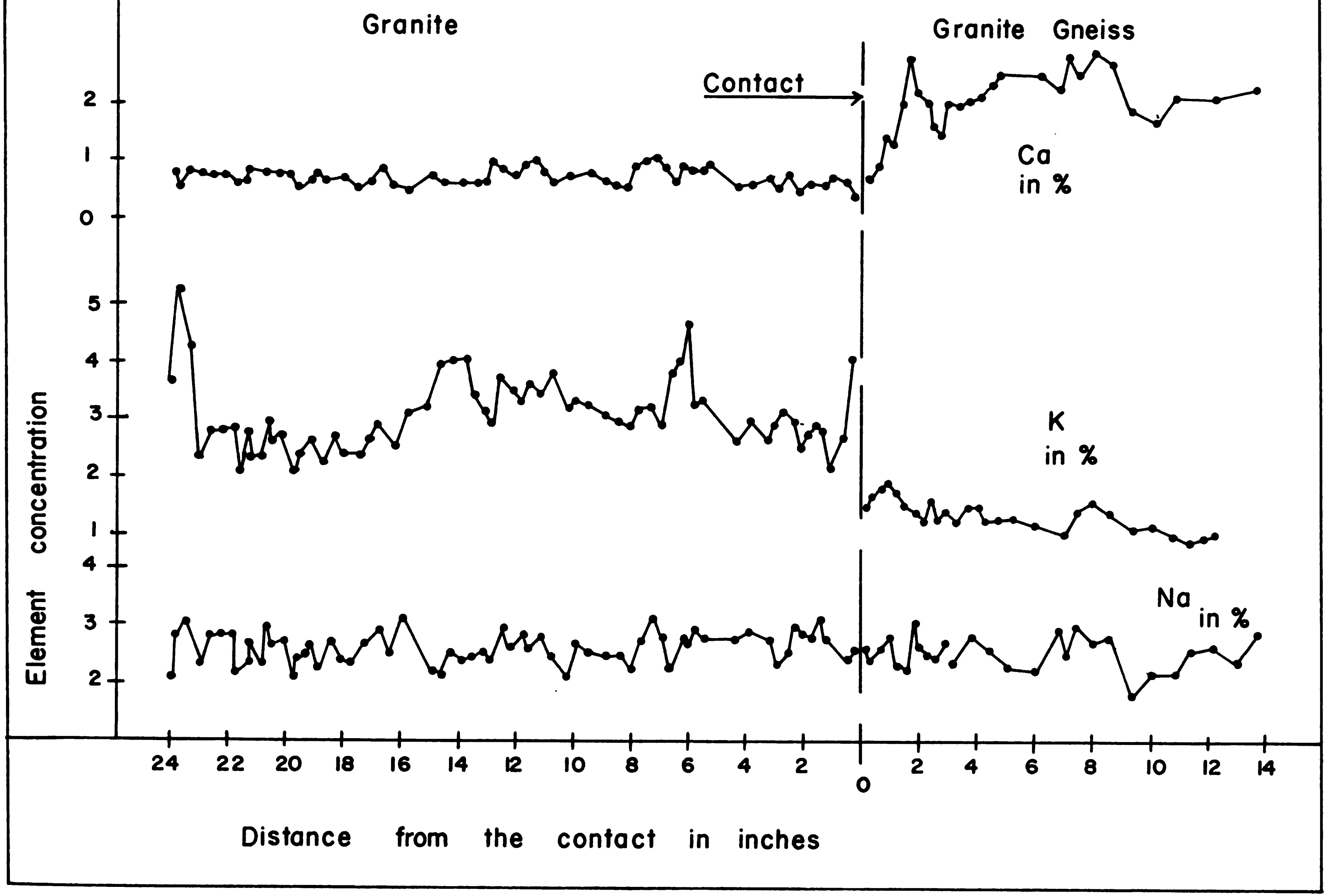


Figure 25. Element concentration distribution for Section 253

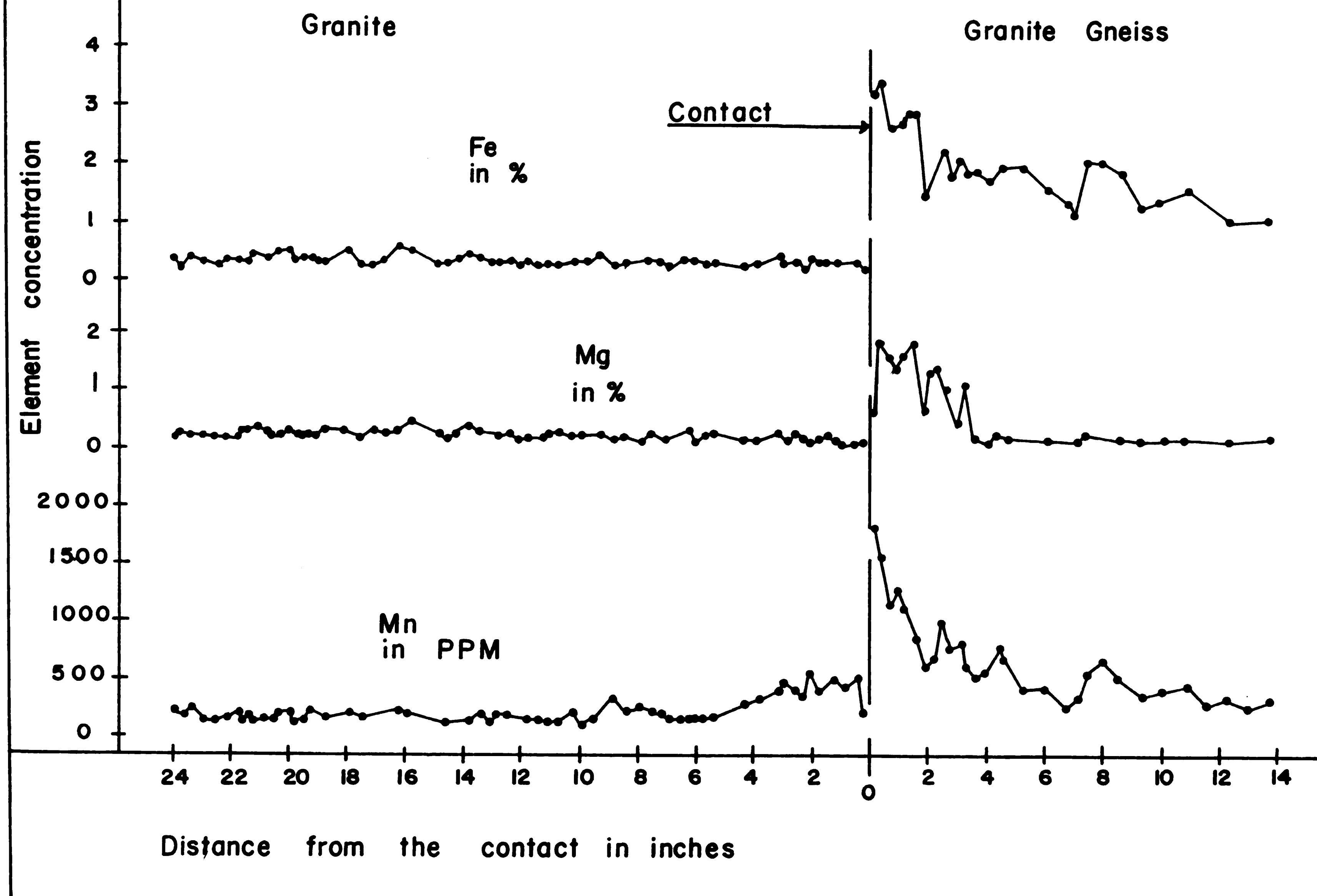


Figure 26. Element concentration distribution for Section 253

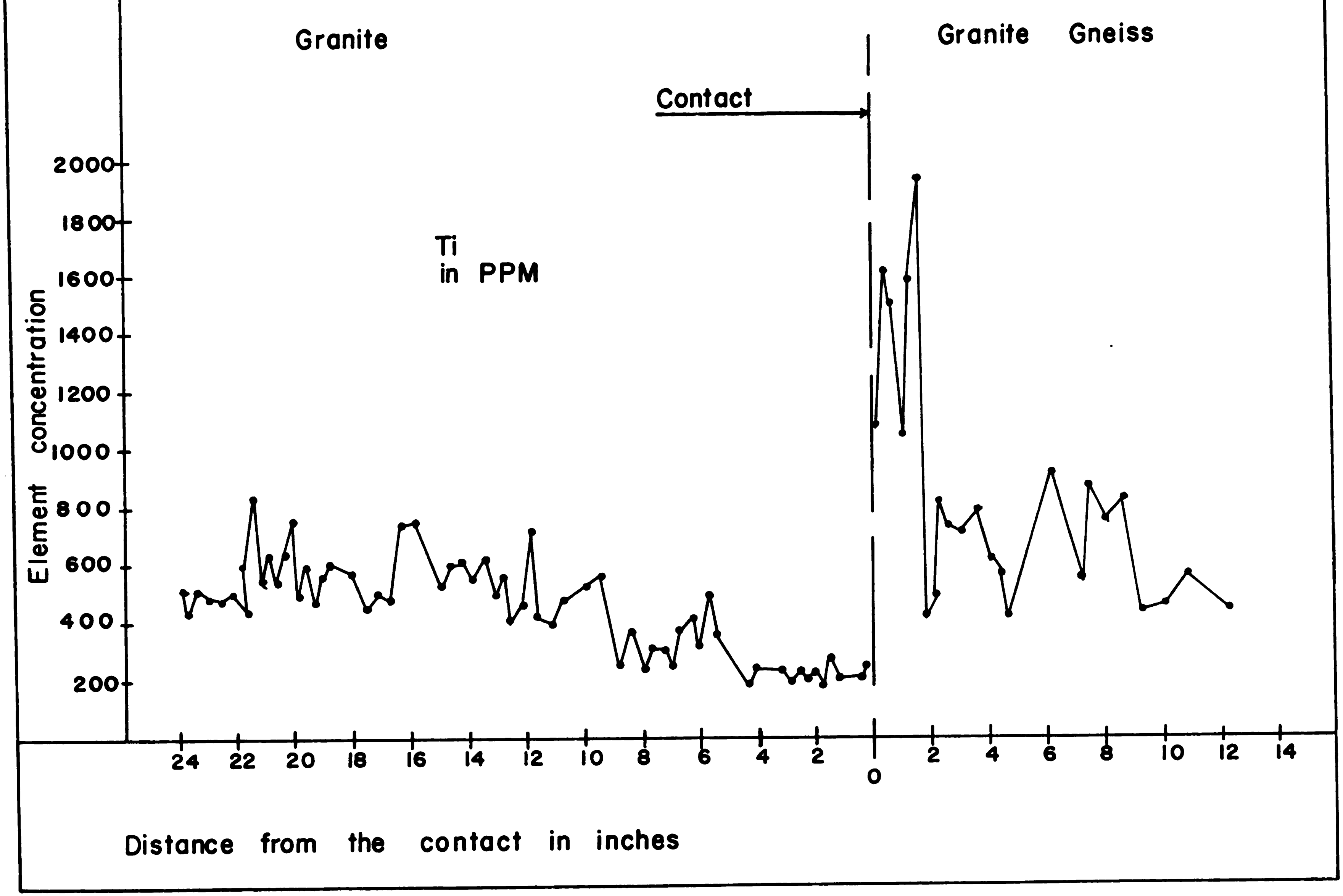


Figure 27. Element concentration distribution for Section 253

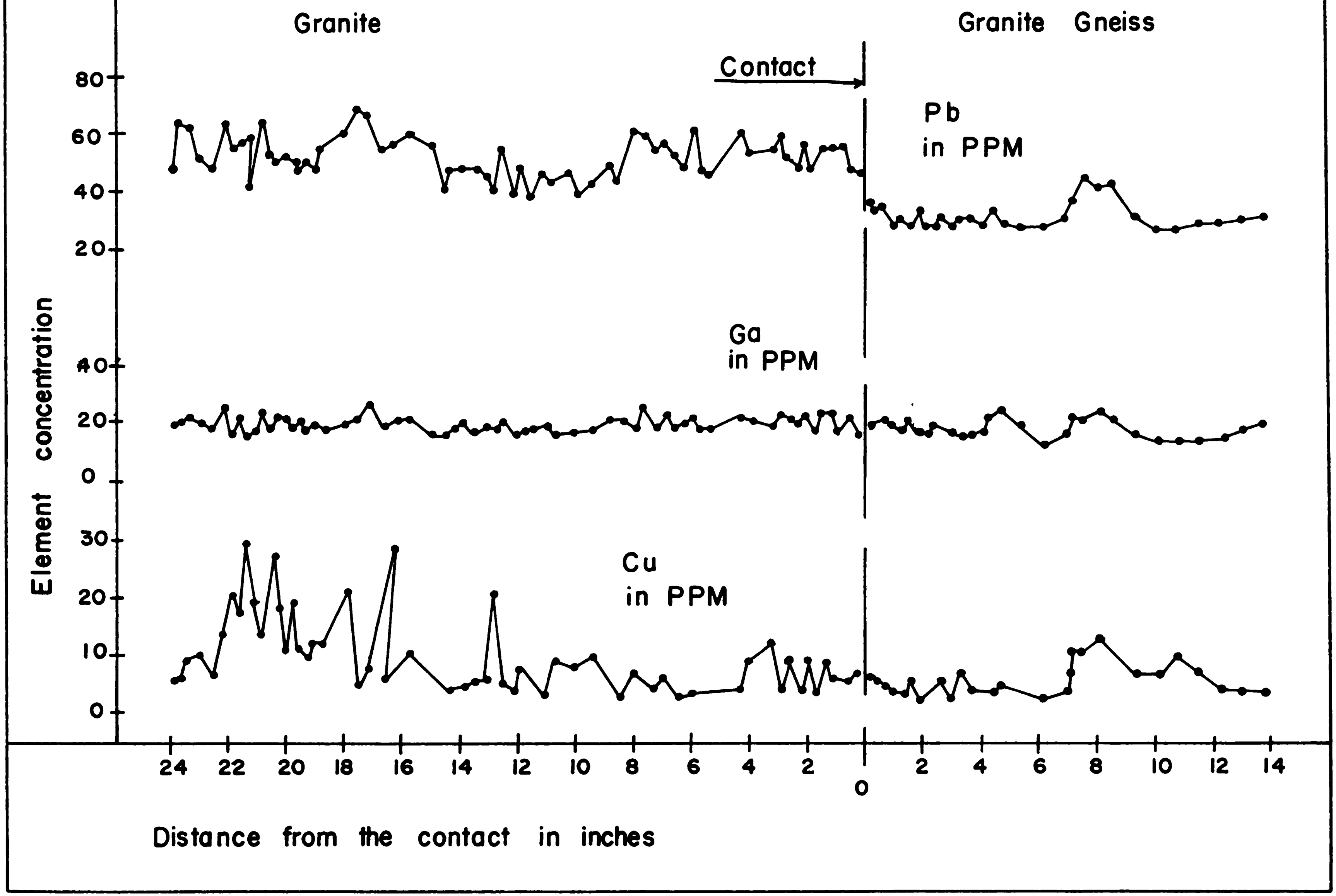
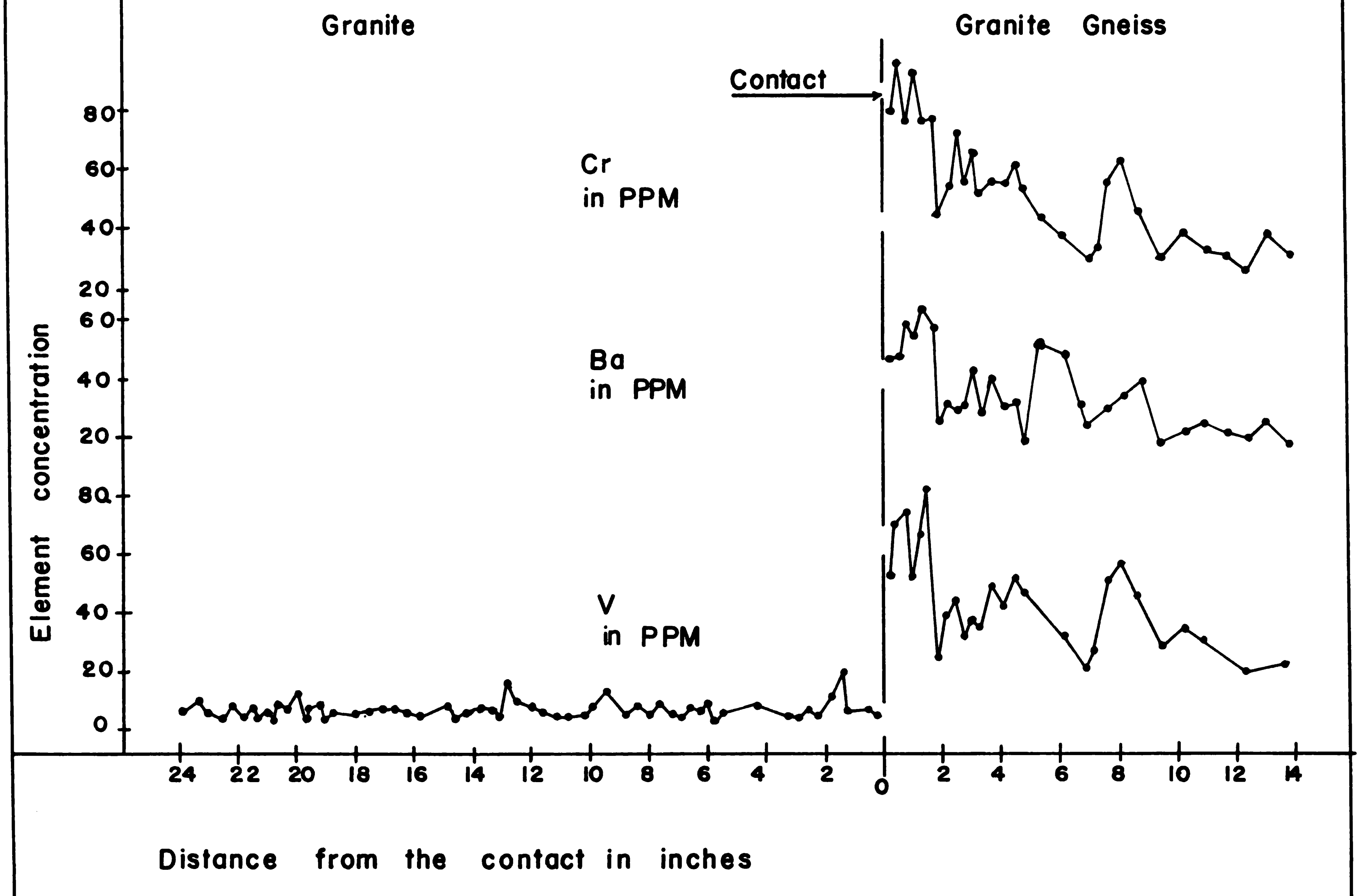


Figure 28. Element concentration distribution for Section 253



APPENDIX C

DIFFUSION THEORY

APPENDIX C

Diffusion Theory

Fick's second law of diffusion can be stated as follows (Jost, 1960):

$$\frac{\partial c}{\partial t} = D\left[\frac{\partial^2 c}{\partial x^2}\right] \tag{A.1}$$

where

C = concentration
t = time
x = distance
D = diffusion coefficient

Equation (A.1) assumes that D is a constant. If we look at the system after diffusion has taken place and there is no further movement of material, then equation (A.1) reduces to

$$O = D\left[\frac{\partial^2 c}{\partial x^2}\right] \tag{A.2}$$

The solution of equation (A.2) is of the form:

$$C = (C_o + C_1 x)\ D \tag{A.3}$$

Therefore a plot of C versus x should be linear. Since equation (3.4) which describes C as a function of x in nonlinear, equation (A.3) does not apply and the assumption of constant D is not valid for this case.

If we assume that D is some function of C (D = f(C)) and since equation (3.4) defines C as a function of x, C = G(x), then D can be defined as a function of x, D = D(x), and equation (A.1) becomes:

$$\frac{\partial c}{\partial t} = D(x)\left[\frac{\partial^2 c}{\partial x^2}\right] + \left[\frac{\partial (D(x))}{\partial x}\right]\left[\frac{\partial c}{\partial x}\right] \tag{A.4}$$

In the system under consideration, a dike intrusive into country rock, the boundary conditions for equation (A.4) are as follows:

Dike	Contact	Host Rock
at $x = 0$	at $x = 0$	at $x = 0$
$t = 0$	$t = 0$	$t = 0$
$C = 0_1$	$C = C_1$	$C = C_2$

The system under consideration is further complicated by anisotropy, multiple components, multiple phases and a multiplicity of grains. The solution of equation (A.4) under the above conditions has not been reported.

If we look at equation (A.4) at $t = t_{final}$, then $\frac{\partial c}{\partial t} = 0$, and

$$0 = D(x)\left[\frac{\partial^2 c}{\partial x^2}\right] + \left[\frac{\partial (D(x))}{\partial x}\right]\left[\frac{\partial c}{\partial x}\right] \tag{A.5}$$

Equation (3.4) describes $C = f(x)$ at $t = t_{final}$. Substituting equation (3.4) into equation (A.5) yields:

$$0 = \frac{\partial (D(x))}{x} + D(x)\left[1 - (2be^{(kx)})\ \mathrm{Tanh}\ (be^{(kx)} - b)\right] \tag{A.6}$$

A solution that fits equation (A.6) is of the form:

$$D(x) = e^{w} \tag{A.7}$$

where $w = G(x)$

Substituting equation (A.7) into equation (A.6) and solving for (w) yields:

$$x = \left[(2/k)\ln(\mathrm{Cosh}(be^{(kx)} - b)) \right] - x \qquad (A.8)$$

Substituting equation (A.8) into equation (A.7) results in:

$$D(x) = e\left[\frac{2}{k} \ln(\mathrm{Cosh}(be^{(kx)} - b) \right] - x \qquad (A.9)$$

The solution of D is valid only under the following conditions:

$$t = t_{final} \quad \text{and} \quad C = \tanh(be^{(kx)} - b)$$

This is because there is no reason to assume that equation (3.4) is a general solution of equation (A.5) and also because equation (3.4) is not valid at $t \neq t_{final}$. A general solution of equation (A.5) would involve C as a function of both distance and time, $C = F(x, t)$, and would result in a solution for D involving distance and time or concentration and time, $D = G(x, t)$ or $D = H(C, t)$. This solution would also have to take into account the barrier nature of the contact. A solution for the type of system under consideration at the present is not possible.