FACTORS AFFECTING THE HORIZONTAL DISTRIBUTION OF VERTICAL WORM TUBES IN THE THOROLD SANDSTONE

FACTORS AFFECTING THE HORIZONTAL DISTRIBUTION OF VERTICAL WORM TUBES IN THE THOROLD SANDSTONE

By
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A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the Requirements
for the Degree of
Bachelor of Science

McMaster University
April 1974

Title: Factors Affecting the Horizontal Distribution of Vertical Worm Tubes in the Thorold Sandstone

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Number of Pages: viii, 95

ACKNOWLEDGEMENTS

The writer wishes to sincerely thank Dr. M.J. Risk for his time and patience in directing this work and reviewing this manuscript. Thanks also to D.R. Kobluk who assisted in the technical aspects of this experiment; to Mrs. M. Yeo who typed the final draft; to Miss D. Vasko who typed the rough drafts; and to Miss M.A. Vasko who did the drafting of the figures.

Amoco Canada Petroleum Company Ltd. kindly performed porosity and permeability tests and did thin section work; Consumers' Gas Ltd. graciously supplied drill cores for additional samples. Thanks go to both corporations.

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ABSTRACT

101 samples of Thorold sandstone were collected from 12 geographically distinct regions along the Niagara Escarpment. The average number of vertical worm tubes in each region was determined as was clay content, organic matter, burrow diameter, interburrow distance, mean grain size, sorting, quartz proportion, distance from shore, porosity, and the sandstone/shale ratio. Stepwise linear regression and principal component analysis were used to investigate relationships between the variables. The number of worm tubes can be predicted by clay content, organic matter, distance from the shore, and porosity, a model which explains 62% of the observed variation. All 11 variables accounted for 99.9% of the variation. Distance from shore can be predicted by organic matter, burrow diameter, mean grain size, and the sandstone/shale ratio, a model which explains 94% of the variation. All 11 variables accounted for 99.9% of the variation. Organisms living in the Thorold evidently reacted to environmental parameters in a similar fashion to modern tidal flat organisms.

INTRODUCTION

Introduction

Numerous workers have shown that a relationship exists in the marine habitat between diversities and densities of organisms and environmental parameters. The bulk of the evidence comes from studies on recent marine communities in shallow lagoons or on recent mud flats. The purpose of this investigation is to determine if recent models of environmental control of animal populations can be used to deduce the factors which correlate with the horizontal distribution of vertical worm tubes in a Silurian sandstone from southern Ontario and northern New York State. If these factors can be isolated, then this study will demonstrate that methods currently used in marine biological studies can be applied to the ancient.

Schafer (1972), Eltringham (1971), Newell (1970), and Hughes et al. (1972) have shown how environmental parameters affect the zonation of organisms in intertidal regions. Hughes identified the fauna and sieved the sediment as well as measured the distance from the shore in St. Margaret's Bay, Nova Scotia. The sediment and distance measurements were correlated with the various species of polychaetes and echinoderms by applying both principal component and Q mode factor analysis. He found that five components explained 70% of the total variance.

Statistical analysis of variance has been used by many workers in various studies. Griffiths (1958) used multiple stepwise regression techniques to evaluate the relationship between petrology and porosity;

Field (1971) used factor analysis to produce species groups of Australian benthic invertebrates which can be correlated with environment parameters. Roback et al. (1969) studied the fauna of a large river on the eastern United States coast and observed changes in the type and diversity of fauna, as well as changes in the environment due to increased urbanization, and attempted to relate the two. Stephenson et al. (1970) used statistical analysis to reduce their data, to arrange sample sites into groups with similar characteristics, to assign specific species to certain groups, and to establish a site-group, species-group correlation. Stephenson (1971) grouped fauna according to environmental factors using principal component analysis. Rhoads et al. (1972) grouped sampled fauna into sediment-related fossil assembleges, but used no statistical or numerical methods to group the fauna.

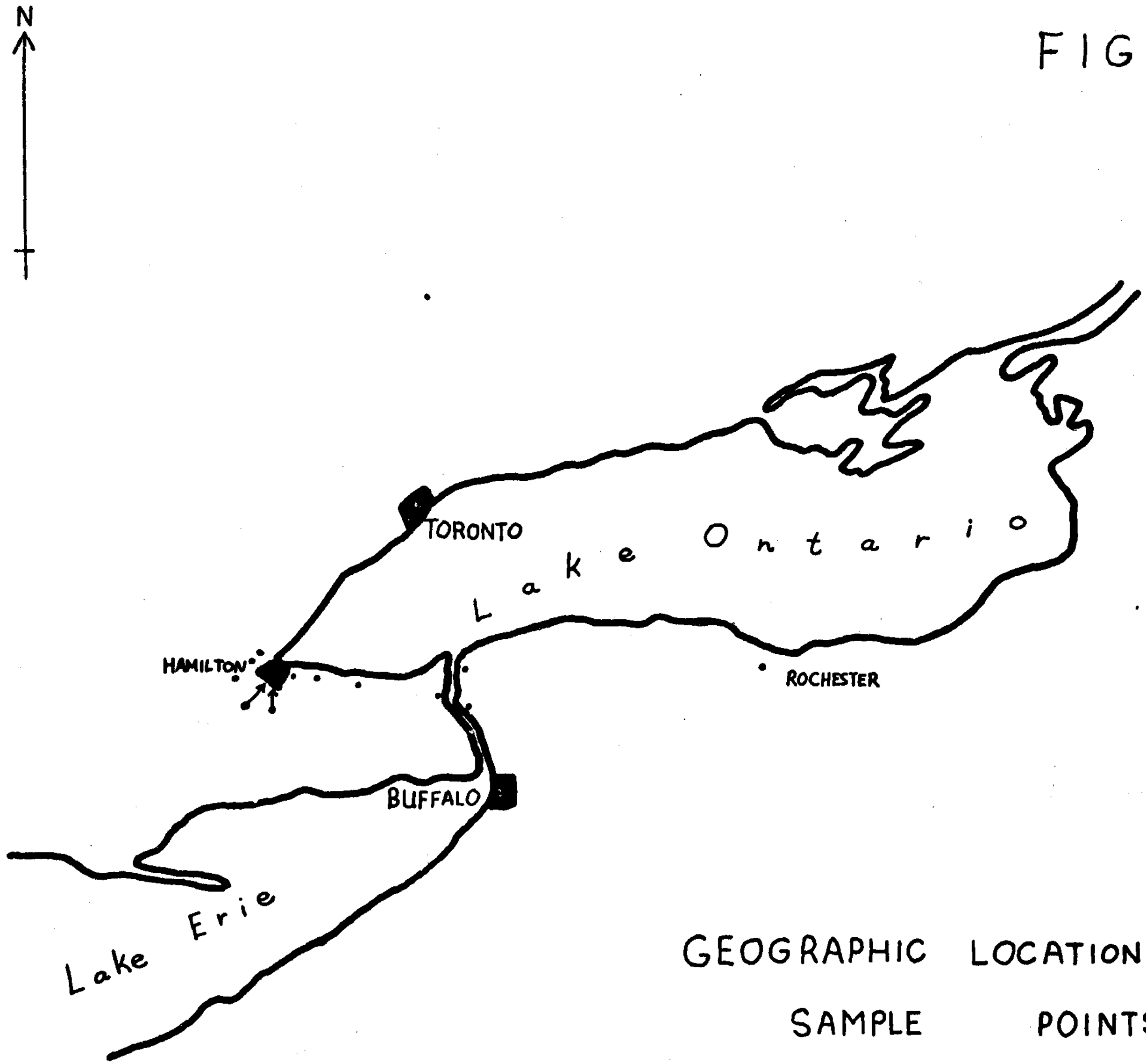
The principles of interpretation and analysis enumerated by the above studies will be incorporated in the present study, which attempts to determine the relationship between organisms inhabiting vertical tubes and the paleoenvironmental parameters (presumably reflected in substrate lithology).

Study Area

The Thorold sandstone, considered to be a Silurian intertidal mud flat (Martini, 1971), is a good parallel with the present environment because of the availability of information on research into animal-environment relationships on modern intertidal mud flats.

The Thorold sandstone has been assigned to the Medina Formation of the Lower Silurian Clinton Group. It conformably grades into the Grimsby sandstone below, marked by a colour change from green to red; the Thorold is unconformably overlain by the Reynales limestone. It ranges in thickness from approximately 4.9 m. around Hamilton, Ontario, to about .3 m. just east of the Lockport area, but can be traced a total of 203.2 km. from Clappison's Corners, Ontario, in the west to Fulton, New York, in the east, with no lateral breaks. The Thorold is exposed all along the Niagara Escarpment and is easily accessible in several areas. However, in some areas it is covered, especially to the southwest. The Thorold is exposed in the Niagara Gorge following a north-south line perpendicular to the trend east-west along the escarpment face. All sample sites used were those selected by Martini (1966) for his sedimentological study of the Medina Formation.

FIG. 1



GEOGRAPHIC LOCATION OF SAMPLE POINTS

• SAMPLE POINT

SCALE 1" = 50 mi.

STATISTICAL APPROACH

Sample Design

The sampling procedure used in this study was determined by two factors: the type of analysis to be performed and the cost-efficiency [1.] in terms of data collection. The analysis used here requires that systematic samples be taken along a line or grid when using stepwise regression and principal component analysis (Kummel and Raup, 1965). These two types of variance analysis explain variation as distributions and occurrences of organisms. The author adopted a stratified systematic sampling strategy with starting points randomly determined, necessarily modified by the occurrence of covered intervals.

The above sampling procedure was carried out on both a regional and local scale. The entire extent of the exposed Thorold along the transect was divided into ten eastwardly increasing strata [2.] with one sample point in each stratum. The Niagara Gorge permitted sampling both north and south of the Niagara Escarpment, giving some indication of variation perpendicular to the transect. On a regional scale, the Thorold was sampled at twelve exposures (sample points). At each of the twelve locations (sample points) the site was divided

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1. Cost-efficiency is a sampling term which indicates how many samples must be taken in order to approximate the mean of the population at a given probability level. It also indicates how much it will cost in time and money to collect these samples.
2. Strata is used here in a statistical rather than a geological sense.

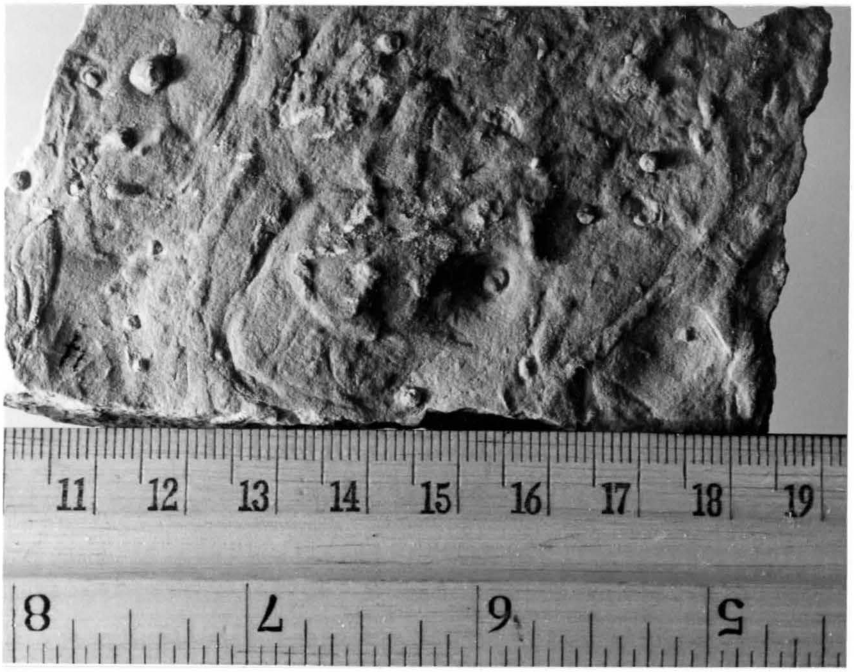

Plate 1: A typical sample slab of Thorold sandstone showing vertical worm tubes. If this specimen was larger, the number of strata that the outcrop would be divided into would be reduced.

into a specific number of equal strata. The number of strata used was inversely related to the surface area of the sample slabs (see Plate 1.); a large number of strata was used when the slab surface area was small and a smaller number was used when the slabs were large in area. In all cases, an attempt was made to sample a total of 0.2 sq. m. slab area. After the number of strata at each sample point was decided upon, a point in the first stratum was randomly selected; the relative position of the sample point within each succeeding stratum was the same as the first. The samples were taken along a diagonal line stretching from the base of the first incremental column to the top of the last. This monitored changes in tube population densities during the deposition of the Thorold at each sample point. The final average value for each of the variables using this scheme should be representative of the entire Thorold at each location.

A result of the stratified systematic sampling design used in this study is an increase in the efficiency of obtaining an estimate of the mean of the particular population under investigation. Snedecor and Cochran (1967) show that in a case such as this study, stratified systematic sampling allows an accurate estimate of the mean to be produced with fewer samples.

Statistical Procedure

The variables to be used in this analysis fall into three groups: the distribution and occurrence of vertical worm tubes, lithology and mineralogy of the containing rock, and a geographic measure of position on the presumed Silurian mud flat. Once these variables have been established and measured, their variance will be compared by means of linear regression, stepwise regression and principal component analysis, using the UCLA Biomedical Computer program package.

For examination of the behavior of a dependent variable and one independent variable, a computer programme for simple linear regression was employed. This programme determines the standard deviation of both the dependent and independent variables, the correlation coefficient, the Y intercept of the regression line, the slope of the line, and the standard error of estimate.

The stepwise regression programme (BMDO2R) calculates linear regression equations in a sequential method. The variable which has the highest simple correlation coefficient with the dependent variable is the variable used in the first equation. In each succeeding step, all the variables which have not been added to the equation are partialled on those that have been added. The next variable entered into the equation is the variable with the highest partial correlation coefficient, thus the variable which most greatly reduces the chi-square goodness of fit value, and if added would produce the highest F value. When the F value falls below a specific minimum value, the variable is rejected since it does not contribute to the explanation of the variance of the dependent variable. The programme also allows variables to be forced into the equation (assuming that the F value is too low for further computation) and also allows the regression line to be forced through the origin. As a final result, one is able to determine how much of the observed variation in the dependent variable is explained by the variation among the independent variables. This will provide some idea of how important each variable is in explaining variation of the dependent variable.

Many of the independent variables which are selected as being valid controlling influences on the dependent variable are in fact not independent but are auto-correlated. The principal component analysis programme (BMDO1M) is designed to recoordinate interdependent variables (x1, x2, x3 ... xn) so that within the context of the new coordinate system, they become independent components (y1, y2, y3 ... yn). The total number of variables equals the total number of new components and the total variance is preserved in the transformation. The resulting components comprise all the original variables, each variable having a certain importance or factor loading. In many studies, (King, 1966; Moser & Scott, 1961), the number of original variables could be reduced by 80% to a few components. This programme derives the principal components of standardized data and rank orders in each case. Principal component analysis is used when the variables used in stepwise regression are not independent.

These three computer programmes should be competent to isolate those variables or factors which explain the bulk of the variation in worm distribution in the Thorold sandstone.

PETROGRAPHY AND DIAGENESIS

The Thorold sandstone is a white to light green, fine grained, dense orthoquartzite. It consists of interbedded sands and shales with the sandstone/shale ratio increasing in an eastward direction (Bolton, 1957). In thin section the grains are subrounded to subangular; the sediment becomes dominently subangular closer to the sediment source. Quartz overgrowths are common throughout the Thorold. The grain surface below the overgrowths is frequently marked by a dusty iron oxide coat, the overgrowth often showing signs of being reworked. The presence of sericite indicates alteration of potassium feldspars; this is reinforced by cases in which feldspar is in transition to sericite. The sericite appears to be "squeezed" around quartz grains often appearing as if the quartz and sericite were reacting. Rims of goethite surround quartz grains and are found in the surrounding matrix as small spherules. Some calcite cement was also found in the sandstone. Accessory minerals included biotite, chlorite, zircon, tourmaline, magnetite and plagioclase feldspars. X-ray diffraction analysis showed that montmorillonite, chlorite, illite, goethite, quartz and calcite are very common in the Thorold, with rare dolomite. Quartz makes up 60% - 70% of the sandstone by visual estimate, with an error of ± 5% as indicated by Dennison and Shea (1966). Goethite and clays each make up approximately 15%.

Martini (1971) concluded that the Thorold is a second cycle sediment on the basis of abundant quartz, chert grains, submaturity of the sandstone, the presence of only the most stable heavy minerals, and reworked quartz overgrowths. He believes the Thorold is the reworked top of the subsiding Grimsby delta.

The usual sorting, compaction and reworking processes took place, as can be seen in thin section. Quartz grains were cemented by secondary silica and calcite, which reduced permeability and total porosity. Dolomite occasionally replaces the calcite cement. Post-depositional diagenetic changes occurred, but do not appear to have significantly altered the texture or mineralogy of the sediment. Tectonic processes were not of major significance in the geologic history of the region and the Thorold in particular, but did cause a regional 5° dip of the beds to the south west.

Most thin sections from the study area show aligned quartz extinction, suggesting a regional stress, such as a tilting of the beds after lithification. Such a force would also tend to explain any preferred pressure solution direction.

VARIABLES

Introduction

Eleven variables were chosen as possibly related to environmental conditions necessary for the organisms to survive (Storer et al., 1968; MacGinitie and MacGinitie, 1968; Ager, 1963). Each variable is indicative of some environmental process or condition. As any one variable (environmental condition) changes, worm burrow population should also change. The eleven variables are listed below, and the method used to quantify each is also described.

Worm Burrow Population Density

Each sample slab was thoroughly washed to ensure that no mudballs were mistaken for burrows. The number of vertical tubes was counted on each slab and the area of the slab was measured. The sum of the burrows and the sum of the area were calculated. The total number of burrows within the sampled area was readjusted to a square meter so that all population densities were based on one square meter.

Clay Fraction

X-ray diffraction analysis identified at least three clay minerals and sometimes four. The area under the curve of each clay mineral primary peak was measured using a planimeter; the areas for each clay mineral were summed and the area was expressed as a percent of the total summed area for all minerals.

Organic Fraction

One sample from each of the twelve sample points was crushed to a fine powder (< 50 μ). A weighed quantity of sandstone powder was placed in a beaker to which was added a volume of 15% H_2O_2. The hydrogen peroxide oxidized any organic residue present. After the reaction had gone to completion, the sample was filtered using the finest filter paper available, and the sample was dried. The sample was weighed and the difference in weight expressed as a percent of the original sample. There does exist the possibility that the sample was contaminated by foreign organic matter or that organic acids have entered the rock from external vegetation.

Burrow Diameter

The outside diameter of each burrow was measured using a pair of caliphers and a steel rule divided into mm. units. Where the number of burrows of each sample exceeded thirty, a grid pattern was superimposed on the slab and a sample of 30 burrows was counted using a systematic design.

Interburrow Distance

The distance between the centre of one burrow and its nearest neighbour was measured using caliphers and a rule. When the number of burrows exceeded thirty, only those burrows included in the sample measured were used to determine the nearest neighbour distance. If the edge of the sample was closer to a given burrow than another burrow, that burrow was ignored.

Mean Grain Size

A petrographic microscope was used to measure thirty quartz grains excluding any overgrowths from one thin section from each sample point. Again, a grid pattern was employed to select the grains.

Sorting

The standard deviation of the mean grain size was used as an expression of the degree of sorting of the sediment in the thin section.

Quartz Fraction

X-ray diffraction analysis was used to determine the percent quartz at each sample point.

Distance from the Shore

Using the isopach maps from Martini (1966 and 1971), the suspected shore line was sketched onto large scale maps. The shortest distance from each sample point to the shore was measured in miles using the appropriate scale.

Porosity

The porosity and permeability of a specimen from each sample point was determined using standard industrial techniques. These measurements were made in the laboratories of Amoco Canada Ltd., Calgary, Alberta. The value for each specimen is expressed in percent terms.

Sandstone/Shale Ratio

The thickness of the sandstone beds and the shale beds were measured in the field. The ratio of the total thickness of each was taken. These sample points which had no shale beds were assigned a ratio of 9999.99, which is the largest number that can be entered into the programme.

Environmental Significance of the Variables

There are at least four major factors which affect worms: food, community interaction, substrate type and the condition of the water. The worms under investigation are either filter feeders (probably) or deposit feeders. If they are deposit feeders then they should be most abundant where the organic content of the sediment is high, relatively speaking. The organic residue within the sandstone would give a direct measure of the available food. However, because of the reactive nature of organics, this measure may not be valid due to processes of decomposition and diffusion (Berner, 1971). Clays which have a reactive surface often bind organics to the grain surface. Deposit feeding organisms ingest the clays to remove the organics for nutrition. If these organisms are filter feeders, then there should be little or no correlation with either the organic content or the clay content of the sediment.

The second factor is community interaction. The organisms, for unknown reasons, may need to live in clusters or be separated by some distance. This spacing may be a function of competition for food. The diameter of the burrow is a function of the size of the animal, or a function of the species of worm which constructs the burrow.

The nature of the substrate is reflected by the mean grain size, sorting, quartz fraction, porosity, and sandstone/shale ratio. The degree of compaction of the surface sediment is to some extent reflected by the grain size; that is, small grains form a harder substrate than large grains. Sorting is indicative of the porosity of the sediment, a well sorted sediment being more porous than one which is poorly sorted. It has been shown that particular combinations of mean grain size and sorting are suggestive of particular environments (Blatt et al. 1972). The quartz fraction reflects the amount of non-argillaceous, particulate matter in the substrate. Porosity indicates the degree of compaction that has occurred and measures the degree of secondary cementation in the sandstone. This measure may not be valid since the primary cementation cannot be accurately estimated, and thus the extent of diagenesis before cementation cannot be determined. The sandstone/shale ratio is an indication of the rate of sedimentation and also the substrate type.

The distance from the shore reflects such conditions as current velocity, wave energy, salinity, and turbidity. This measure is a "catch all" term for many environmental conditions.

TABLE 1

X_1	number of worm burrows per meter
X_2	clay content
X_3	organic content
X_4	burrow diameter
X_5	mean grain size
X_6	sorting
X_7	quartz fraction
X_8	distance from shore
X_9	porosity
X_{10}	sandstone/shale ratio

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	9	1926918.073	214102.008	36.092
RESIDUAL	1	5932.056	5932.056	

VARIABLES IN EQUATION

VARIABLE	COEFFECIENT	STD. ERROR	F TO REMOVE
(CONSTANT	-7325.16317)		
2	-91.21529	11.44885	63.4763 (2)
3	-931.23507	80.72833	133.0659 (2)
4	1276.52456	155.21317	67.6396 (2)
5	-11043.71655	1153.41399	91.6769 (2)
6	602.11304	130.79811	21.1911 (2)
7	-16.42405	6.07490	7.3094 (2)
8	68.02949	5.01266	184.1866 (2)
9	-87.51133	8.91237	96.4143 (2)
10	.09172	.01718	28.5102 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER

F-LEVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	MULTIPLE RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	8		.4194	.1759	.1759	1.9212	1
2	9		.5725	.3277	.1518	1.8065	2
3	2		.6956	.4838	.1561	2.1165	3
4	3		.7987	.6378	.1540	2.5522	4
5	4		.8410	.7074	.0695	1.1878	5
6	5		.8822	.7783	.0709	1.2792	6
7	10		.9650	.9313	.1530	6.6791	7
8	6		.9872	.9745	.0432	3.3896	8
9	7		.9985	.9969	.0224	7.3094	9

LIST OF RESIDUALS

CASE NUMBER	Y X(1)	Y COMPUTED	RESIDUAL	X(8)	X(9)	X(2)	X(3)	X(4)
1	448.4000	427.4842	20.9158	156.0000	12.7000	27.0000	2.1400	4.1000
2	434.2000	434.0408	.1592	155.0000	10.5000	19.0000	3.4500	2.9000
3	1659.5000	1646.1928	13.3072	150.0000	7.6000	16.0000	1.3300	3.6000
4	668.2000	665.4299	2.7701	149.0000	6.1000	19.0000	2.9000	3.3000
5	128.3000	113.6987	14.6013	148.0000	15.8000	15.0000	2.5000	3.6000
6	650.4000	690.1119	-39.7119	138.0000	11.5000	21.0000	2.5100	4.1000
7	210.2000	258.1165	-47.9165	125.0000	9.4000	21.0000	.7400	3.6000
8	115.5000	104.7940	10.7060	111.0000	7.3000	20.0000	2.3300	4.6000
9	284.2000	299.5625	-15.3625	112.0000	5.3000	24.0000	2.1000	5.8000
10	190.7000	165.3573	25.3427	115.0000	6.4000	27.0000	.8500	4.2000
11	320.9000	305.7113	15.1887	81.0000	8.7000	17.0000	.8800	4.8000

FINISH CARD ENCOUNTERED
PROGRAM TERMINATED

19.

TABLE 2

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	9	5775.634	641.737	503.382
RESIDUAL	1	1.275	1.275	

VARIABLES IN EQJATION

VARIABLE	COEFFECIENT	STD. ERROR	F TO REMOVE
(CONSTANT	103.43175)		
1	.01462	.00108	184.1866 (2)
2	1.33822	.15942	70.4604 (2)
3	13.69191	.54846	623.2155 (2)
4	-18.79403	1.46929	163.6151 (2)
5	162.58926	7.85457	428.4883 (2)
6	-8.87585	1.67599	28.0465 (2)
7	.24243	.08443	8.2442 (2)
9	1.28142	.14443	78.7142 (2)
10	-.00135	.00023	35.3046 (2)

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER

F-LEVEL OR TOLERANCE INSUFFICIENT FOR FURTHER COMPUTATION

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	4		.7106	.5050	.5050	9.1818	1
2	5		.8173	.6680	.1630	3.9288	2
3	3		.9205	.8473	.1793	8.2228	3
4	10		.9699	.9407	.0934	9.4475	4
5	1		.9838	.9678	.0271	4.2152	5
6	9		.9912	.9824	.0146	3.3092	6
7	2		.9968	.9935	.0112	5.1827	7
8	6		.9990	.9980	.0044	4.3280	8
9	7		.9999	.9998	.0018	8.2442	9

LIST OF RESIDUALS

CASE NUMBER	Y X(8)	Y COMPUTED	RESIDUAL	X(4)	X(5)	X(3)	X(10)	X(1)
1	156.0000	156.2908	-.2908	4.1000	.1700	2.1400	1.0200	448.4000
2	155.0000	155.0008	-.0008	2.9000	.0700	3.4500	1.1000	434.2000
3	150.0000	150.1494	-.1494	3.6000	.1600	1.3300	1.0900	1659.5000
4	149.0000	149.0549	-.0549	3.3000	.0800	2.9000	1.9300	668.2000
5	148.0000	148.2446	-.2446	3.6000	.1400	2.5000	1.8400	128.3000
6	138.0000	137.3760	.6240	4.1000	.0700	2.5100	7.3300	650.4000
7	125.0000	124.3306	.6694	3.6000	.1300	.7400	7.9300	210.2000
8	111.0000	111.1771	-.1771	4.6000	.0500	2.3300	10.3300	115.5000
9	112.0000	111.7827	.2173	5.8000	.2800	2.1000	9999.9900	284.2000
10	115.0000	115.3782	-.3782	4.2000	.1300	.8500	88.0000	190.7000
11	81.0000	81.2147	-.2147	4.8000	.1000	.8800	9999.9900	320.9000

FINISH CARD ENCOUNTERED
PROGRAM TERMINATED

TABLE 3

BATCH CREATED 04/15/74 TODAY IS 04/16/74

BMD01M - COMPONENT ANALYSIS - REVISED SEPTEMBER 12, 1969
HEALTH SCIENCES COMPUTING FACILITY,UCLA

PROBLEM CODE BMD01M
NUMBER OF VARIABLES 10
NUMBER OF CASES 11
NUMBER OF VARIABLES ADDED 0
NUMBER OF TRANSGENERATION CARD(S) -0
NUMBER OF VARIABLE FORMAT CARD(S) 1

VARIABLE FORMAT IS
(4F6.2,6X,6F6.2)

CORRELATION COEFFICIENT MATRIX

1.0000	-.3173	-.0186	-.2940	.0616	-.0290	.0508	.4194
-.3173	1.0000	-.1658	.3582	.3340	-.1169	-.3406	-.0661
-.0186	-.1658	1.0000	-.3199	-.2584	.5271	.0467	.5859
-.2940	.3582	-.3199	1.0000	.5461	-.4665	.1144	-.7106
.0616	.3340	-.2584	.5461	1.0000	-.2502	-.0771	-.0498
-.0290	-.1169	.5271	-.4665	-.2502	1.0000	.2339	.3289
.0508	-.3406	.0467	.1144	-.0771	.2339	1.0000	-.1403
.4194	-.0661	.5859	-.7106	-.0498	.3289	-.1403	1.0000
-.1622	-.2435	.2649	-.3857	-.1552	.1241	.0685	.4451
-.1840	-.0022	-.2686	.7682	.4935	-.1348	.1352	-.7102

-.1622	-.1840
-.2435	-.0022
.2649	-.2686
-.3857	.7682
-.1552	.4935
.1241	-.1348
.0685	.1352
.4451	-.7102
1.0000	-.3444
-.3444	1.0000

EIGENVALUES

3.5822624	1.5577291	1.3369052	1.1435364	.9558874	.6493582
.5078754	.2140699	.0522760	.0001059		

CUMULATIVE PROPORTION OF TOTAL VARIANCE

.36	.51	.65	.76	.86	.92	.97	.99
1.00	1.00						

21.

TABLE 4

EIGENVECTORS

1	2	3	4	5	6	7	8
.1497	.0542	.7546	.2667	.1149	.0139	.0410	.5215
-.1933	.5189	-.3718	.1546	.2017	.4895	.0677	.3969
.3281	-.1060	-.3238	.4056	.0783	-.3801	.5768	.0062
-.4809	-.0705	-.1069	.1720	-.1152	-.0208	.3799	.2409
-.2876	.2272	.1072	.5952	-.3665	.0526	-.2440	-.4392
.2801	-.2833	-.3131	.3710	.3719	.0833	-.5581	.1363
.0085	-.6351	.0703	.1440	-.1386	.6676	.2393	-.0909
.4384	.2904	.0867	.3378	-.1611	.0708	.0994	-.1272
.2756	-.0300	-.2303	-.1187	-.7791	-.0025	-.1771	.4428
-.4146	-.3018	-.0319	.2646	-.0440	-.3936	-.2172	.2838

1	2
.1130	.1852
-.2535	.1568
-.0326	.3568
.5632	-.4355
.1354	.3033
.3438	-.1094
-.1961	.0421
-.2550	-.6928
.0863	.1179
-.5977	-.1567

EIGEN VALUE CHECK MATRIX

3.5823	.0016	-.0002	.0000	.0006	.0001	.0002	-.0000
.0016	1.5577	.0000	.0000	-.0000	.0003	-.0001	.0000
-.0002	.0000	1.3369	-.0000	.0001	-.0003	.0001	-.0000
.0000	.0000	-.0000	1.1435	.0000	.0000	-.0000	-.0000
.0006	-.0000	.0001	.0000	.9559	-.0000	.0000	.0000
.0001	.0003	-.0003	.0000	-.0000	.6494	.0000	-.0000
.0002	-.0001	.0001	-.0000	.0000	.0000	.5079	.0000
-.0000	.0000	-.0000	-.0000	.0000	-.0000	.0000	.2141
-.0000	-.0000	.0000	.0000	.0000	.0000	-.0000	-.0000
.0000	.0000	-.0000	-.0000	.0000	-.0000	.0000	.0000

-.0000	.0000
-.0000	.0000
.0000	-.0000
.0000	-.0000
.0000	.0000
.0000	-.0000
-.0000	.0000
-.0000	.0000
.0523	.0000
.0000	.0001

RANK ORDER OF EACH STANDARDIZED CASE ORDERED BY SIZE OF EACH PRINCIPAL COMPONENT SEPARATELY

TABLE 5

RESULTS

All variables were entered into the BMDO2R programme. It was apparent that interburrow distance was the dominant variable, accounting for 62% of the variation in burrow density. However, it is intuitively obvious that a large number of burrows within a given area tend to be closer than a few scattered over the same area. It was decided to remove the variable to see how important it is to the regression model. It was also noted that the standard error of estimate was very large because of the data from Webster's Falls. Webster's Falls was the most poorly sampled point (one biased sample of a small area). It was decided to remove the Webster's Falls data from the matrix. After these modifications, the data matrix contains 10 variables and 11 cases.

The BMDO2R programme was run again using the new data matrix. The 10 variables explained 99.69% of the variance. Thus, interburrow distance is inessential to the model. However, the standard error of estimate was too large for many variables to contribute significantly to the explained variation. Distance from the shore, porosity, clay fraction, and organic fraction explain 62% of the variation with distance from the shore having $p > .05$ and the clay fraction $p > .10$. All the variables entered after this point are not significant because their standard error of estimate is too large. It should be noted that the lack of significance may not be a function of a wide scatter of points about the model line but may be a result of the small number of sample points. The regression equation which describes the variation of the dependent variable, the population density of worm burrows, with the variation in the independent variables are:

$$X_1 = -7025.16 - 91.22\, X_2 - 931.24\, X_3 + 68.03\, X_8 - 87.51\, X_9$$

where X_2 = clay content
X_3 = organic fraction
X_8 = distance from the shore
X_9 = porosity
X_2 confidence level 10%
X_8 confidence level 5%

The same data matrix was run using BMDO2R but designating distance from the shore as the dependent variable. Four variables: burrow diameter, mean grain size, organic fraction, and sandstone/shale ratio, explain 94% of the variation in distance, multiple R = .9985 ($p > .05$). These four variables are all significant above the 5% level (t test). The remaining five variables explain another 5% of the variation, but the regression coefficients are not significant. Total explained variance is 99.98%. The regression equation which describes the variation of the dependent variable, the distance from the shore, with the variation in the independent variables are:

$$X_8 = 103.43 + 13.69\, X_3 - 18.79\, X_4 + 162.59\, X_5 + .001\, X_{10}$$

where X_3 = organic fraction
X_4 = burrow diameter
X_5 = mean grain size
X_{10} = sandstone/shale ratio
X_3, X_4, X_5, X_{10}, confidence level 5%

In order to determine which variables are contributing to explained variance through correlation with another independent variable, BMDO1M was run using 10 variables and 11 cases.

Principal component analysis showed that 86% of the total variance could be explained using only 5 components. Component one explained 36% of the variation, with all variables except the quartz fraction equally contributing to the component. An additional 15% was accounted for by component two, dominated by the quartz and clay fraction variables; to a lesser extent the organic fraction, mean grain size, sorting, distance from the shore, and the sandstone/shale ratio contributed to the component. Component three explained another 14% of the variation. It consisted of a heavy factor loading on burrow density with all other variables except quartz fraction, distance from the shore, and the sandstone/shale ratio equally important to the component. Component four explains an additional 11% with equal loadings on all variables except mean grain size, which is more heavily loaded. Component five accounts for another 10%, which is dominated by porosity with equal contributions from all other variables except the organic fraction and the sandstone/shale ratio.

Examining all the components, it is apparent that all variables contribute equally to the explanation of variance with one different variable in components two to five being only slightly more dominant than the rest.

Interpretation of Results

Stepwise regression analysis shows that only two of the variables are significant above the 10% level of confidence in the worm burrow model: distance from the shore and the clay fraction. The correlation matrix indicates that these two variables are not autocorrelated. There are many ecological implications of the distance variable. As distance increases so does the population of worm burrows. It would appear that the organisms inhabiting the tubes prefer quiet waters with slow sedimentation rates. Eltringham (1971) notes that polychaetes on modern tidal flats are scarce on the high energy zone close to the shore but increase as one moves away from shore. This observation is consistent with the model established for the Thorold. Kellerhals and Murray (1969) have also found the same relationship on the Fraser River delta. The sediment type reflects quiet water. As distance increases, the amount of argillaceous material also increases. Eltringham (1971) noticed that certain species of worms prefer a particular substrate. In Kames Bay, he found that changes in the fauna could be related to changes in the substrate. Newell (1970) shows that some polychaetes seek a sediment type containing a certain quantity or species of bacteria. He concludes that on the modern flats substrate surface texture, surface contours, surface angle, surface albedo, grain size and porosity, and current strength are important considerations in analysing polychaete population densities. The first four factors are relatively constant throughout the Thorold, but grain size and porosity and current strength vary. Grain size and porosity show no correlation with distance and there is no accurate means of measuring paleocurrent velocity. Grain size and porosity have been altered by diagenesis; they may have once been highly correlated with distance as modern sediments are today. The ease with which an organism can burrow is related to the grain size and the porosity of the sediment. The largest densities occur far from shore in the Thorold where grain size was probably originally small and compaction loose. The same situation occurs in the Bay of Fundy (D. Craig, personal communication.

Current strength varies with distance from the shore but does not do so directly. Offshore and longshore currents combine to produce complex water current systems.

These currents act as importers of fresh organic material. The morphology of the tubes indicates that the organisms were probably filter feeders or surface feeders scraping organic material from the sediment surface. In such a case, currents would be extremely important in food supply. If current and wave energy were high, sediment as well as organic matter would be in suspension resulting in a clogged feeding apparatus and removing organic films from the sand grains (Newell, 1970). The maximum densities occur where these conditions are most beneficial to the animal. Some animals have a wide tolerance level explaining the gradation from near shore to far shore environments (Schafer, 1972). The same relation was found by Sanders (Purdy, 1964). He found that the relative abundance of filter feeders and suspension feeders varied with the sediment texture; deposit feeders were found associated with the finest grain size, while filter feeders were associated with the coarsest. The association of filter feeders and coarse grain size is through current velocity. Filter feeders require microorganisms and organic material to be suspended in order to be consumed and high current velocities (relative to clay and silt settling velocities) suspend the organic material.

Salinity changes slightly, decreasing in the near shore environment. Eltringham (1971) shows that the most normal marine conditions are far from shore. These organisms found in the Thorold apparently preferred the normal salinity offshore.

In summary, distance from the shore as it applies to population densities includes considerations of energy zonation, substrate zonation, grain size and porosity, current strength, and salinity. These conditions apply to modern marine intertidal areas and these same conditions adequately explain the distribution of organisms on the Thorold.

The second significant variable in this model is the clay content. Population density is inversely related to the clay content of the substrate.

The distance from shore model contains four variables with a confidence level above 5%: burrow diameter, mean grain size, organic fraction, and sandstone/shale ratio. Distance and burrow diameter are inversely related. The smaller burrows far from shore may be a function of the compaction of the sediment; the walls of the vertical burrows do not slump inward. Also there is the possibility that another species inhabits distal regions.

Mean grain size is directly related to distance from the shore. This same relationship was found by Purdy (1964). Stronger tidal and offshore currents rework the sediment and deposit sediment with grain sizes larger than near shore sediment.

The residual organic fraction is inversely related to distance from the shore. This is expected since most organic material is supplied from the land and would decrease away from the shore as currents dwindled. The amount of organic material is related to the amount of clay; the surface of the clay is chemically reactive and readily binds organic material to its surface.

The sandstone/shale ratio is inversely related to distance: the farther offshore, the more argillaceous material present. The sandstone/shale ratio is highly autocorrelated with burrow diameter suggesting that different species are associated with different types of substrates.

A final note: the population density of *Arthrophycus alleghenesis*, a deposit feeder, varies inversely with the density of vertical burrows. This relation may be due to competition but is more likely related to food supply, the deposit feeders requiring high organic content in the sediment and filter feeders not needing this organic content.

Sources of Error

Sampling errors are always inherent in any statistical analysis. A modified systematic design was used; any regularly occurring population changes would not have been included in the sample. Measurements from X-ray diffraction analysis may depend upon the correct positioning of the base line. The figures given for the clay fraction represent the upper limit of clay content within the sample, and is probably less than 10%. Determination of the organic fraction involved many reactions, each of which would add to the measurement error. Purdy (1964) points out that organic matter in the sediment is modified by post depositional processes. All size measurements were subject to the usual operator error of one half of the distance of the smallest scale division.

The entire study used 101 samples from 12 geographically distinct areas. The final result was 11 cases or sample points which is too small.

CONCLUSIONS

The following conclusions can be made:

1. Burrow population density may be predicted by 4 variables:

X_8	distance from the shore	exceeds the 5% confidence level.
X_2	clay fraction	exceeds the 10% confidence level.
X_3	organic fraction	
X_9	porosity	

The model is:

$$X_1 = -7025.16 + 68.03\ X_8 - 87.51\ X_9 - 91.22\ X_2 - 931.24\ X_3$$

2. Distance from the shore can be predicted by 4 variables:

X_4	burrow diameter	
X_5	mean grain size	all variables exceed the 5% confidence level.
X_3	organic fraction	
X_{10}	sandstone/shale ratio	

The model is:

$$X_8 = 103.43 - 18.79\ X_4 + 162.59\ X_5 + 13.69\ X_3 - .001\ X_{10}$$

3. Principal component analysis shows that there is no one dominating variable; most variables are equally loaded in the first five components. However, many variables are not significant due to a wide scatter of points and a small size.

4. Although the sample size is small, the variables

chosen for the model are capable of accounting for 99.98% of the variation in the distance from shore and 99.69% of the variation in burrow population density. In each case, only four easily obtained measurements are needed to determine the distance from shore or the number of burrows per square meter.

Economic Significance

The distance from shore model is a very useful predictive tool. By using standard laboratory techniques the closest distance from any point in the surface of an intertidal mudflat or delta to the shore can be calculated. This is extremely useful in determining the position of ancient shore lines and hence possible hydrocarbon reservoirs.

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Appendices

<u>Key</u>

Station 1	Rock Chapel, Ontario
Station 2	Sydenham Road, Dundas, Ontario
Station 3	Webster's Falls, Dundas, Ontario
Station 4	Jolly Cut, Hamilton, Ontario
Station 4A	Sherman Access, Hamilton, Ontario
Station 4B	Kenilworth Access, Hamilton, Ontario
Station 5	Bruce Trail, Grimsby, Ontario
Station 6	Ball's Falls, Vineland, Ontario
Station 7	Niagara Gorge, Niagara Falls, Ontario
Station 8	Niagara Glen, Niagara Falls, New York
Station 9	Lewiston, New York
Station 10	Rochester, New York

Appendix I

Population Characteristics

Station 1

Sample No.	Area (cm².)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	29.25	16	0.40	0.90
			0.30	1.00
			0.40	0.70
			0.30	0.80
			0.40	1.00
			0.35	1.20
			0.30	0.60
			0.30	1.50
			0.30	
			0.45	
			0.25	
			0.35	
			0.40	
			0.35	
			0.40	
			0.40	
2.	108.00	5	0.60	5.20
			0.30	3.55
			0.45	4.30
			0.60	5.20
			0.30	5.30
3.	56.00	0	----	----
4.	49.00	15	0.40	0.40
			0.35	0.90

			0.35	1.50
			0.40	0.90
			0.40	0.90
			0.40	1.00
			0.40	1.20
			0.20	1.20
			0.20	
			0.35	
			0.30	
			0.30	
			0.35	
			0.30	
			0.40	
5.	109.25	0	----	----
6.	69.38	3	0.30	1.00
			0.30	0.90
			0.30	0.90
7.	92.50	3	0.40	4.30
			0.55	3.40
			0.40	3.40
8.	180.00	6	0.45	2.95
			0.40	2.95
			0.40	4.15
			0.55	3.60
			0.35	5.60
			0.45	7.10
9.	30.00	2	0.45	2.75
			0.40	2.75

10.	22.75	0	----	----
11.	30.00	1	0.45	----
12.	19.13	0	----	----
13.	15.00	0	----	----
14.	27.00	2	0.50	2.05
			0.40	2.05
15.	52.25	0	----	----
16.	27.00	3	0.60	0.90
			0.30	0.90
			0.60	0.90
17.	128.25	6	0.80	0.80
			0.45	0.80
			0.45	1.10
			0.60	
			0.40	
			0.40	
18.	360.00	1	0.50	----
	Σ = .1405 sq. m.	63	$\bar{x}$ = 0.41	$\bar{x}$ = 2.17
			σ^2 = 0.01	σ^2 = 2.77
			σ = 0.11	σ = 1.66

Population Density = 448.4

Station 2

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	152.75	6	0.45	0.90
			0.25	2.35
			0.25	
			0.35	
			0.30	
			0.40	
2.	112.50	0	----	----
3.	45.00	5	0.40	2.15
			0.55	
			0.40	
			0.40	
			0.40	
4.	56.00	32	0.20	0.75
			0.20	0.75
			0.20	0.70
			0.20	0.70
			0.20	0.50
			0.20	
			0.20	
			0.20	
			0.15	
			0.15	
			0.15	
			0.15	

			0.15	
			0.15	
			0.15	
			0.15	
			0.15	
			0.15	
			0.15	
			0.15	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
			0.10	
5.	42.25	1	0.30	----
6.	63.00	1	0.25	----
7.	118.75	2	0.40	6.10
			0.45	
8.	112.50	1	0.35	----
9.	286.00	14	0.80	2.15
			0.60	1.90
			0.45	1.45

			0.45	2.60
			0.55	2.20
			0.30	
			0.30	
			0.30	
			0.30	
			0.30	
			0.20	
			0.20	
			0.30	
			0.30	
10.	324.00	13	0.45	2.15
			0.40	1.70
			0.55	2.15
			0.35	1.70
			0.35	0.90
			0.40	0.90
			0.30	0.90
			0.30	0.90
			0.20	
			0.60	
			0.30	
			0.30	
			0.30	
11.	337.50	12	0.40	0.70
			0.30	0.70
			0.40	1.65
			0.45	1.20
			0.40	1.70
			0.30	1.20
			0.50	1.35

			0.35	1.65
			0.40	
			0.70	
			0.45	
			0.40	
12.	288.75	2	0.40	----
			0.25	----
13.	157.50	2	0.70	----
			0.70	----
	Σ = .2097 sq. m.	91	$\bar{x}$ = 0.29	$\bar{x}$ = 1.56
			σ^2 = 0.03	σ^2 = 1.07
			σ = 0.16	σ = 1.04

Population Density = 434.2

Station 3

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	157.50	3	0.25	0.60
			0.45	
			0.35	
	Σ = .0016 sq.m.	3	$\bar{x}$ = 0.35	$\bar{x}$ = 0.60
			σ^2 = 0.01	
			σ = 0.08	

Population Density = 1875.0

Station 4

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	442.00	7	0.15	1.75
			0.25	1.75
			0.10	1.75
			0.80	1.75
			0.30	
			0.35	
			0.25	
2.	340.00	2	0.50	4.80
			0.40	4.80
3.	130.00	0	----	----
4.	510.00	0	----	----
5.	154.00	6	0.30	1.30
			0.60	1.30
			0.50	1.60
			0.40	1.60
			0.30	3.10
			0.20	
6.	160.00	8	0.60	2.15
			0.35	1.90
			0.40	1.90
			0.40	
			0.30	

			0.30	
			0.30	
			0.20	
8.	132.00	0	----	----
9.	150.00	3	0.40	3.40
			0.40	3.40
			0.40	
10.	754.00	440	$\hat{\bar{\bar{X}}}$	$\hat{\bar{\bar{X}}}$
			0.60	0.90
			0.40	0.65
			0.35	0.50
			0.50	0.50
			0.40	0.80
			0.40	0.60
			0.40	0.75
			0.30	0.35
			0.40	0.50
			0.40	0.50
			0.30	0.45
			0.30	0.95
			0.40	0.45
			0.30	0.55
			0.40	0.50
			0.45	0.80
			0.30	1.20
			0.40	0.60
			0.25	0.50
			0.30	0.95
			0.40	0.85
			0.35	0.60

0.45	0.80
0.35	0.85
0.35	0.95
0.30	1.70
0.40	0.65
0.35	0.40
0.35	0.70
0.35	0.40
0.25	1.60
0.40	0.30
0.30	0.60
0.35	0.60
0.40	0.80
0.35	0.60
0.30	0.40
0.25	0.60
0.30	0.70
0.30	
0.35	
0.25	
0.40	

Σ = .2772 sq.m. 460 $\bar{x} = 0.36$ $\bar{x} = 1.19$

$\sigma^2 = 0.01$ $\sigma^2 = 1.03$

$\sigma = 0.11$ $\sigma = 1.01$

Population Density = 1659.5

<u>Station 4A</u>

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	319.00	0	----	----
2.	155.00	3	0.50	----
			0.30	----
			0.30	----
3.	48.00	1	0.20	----
4.	30.00	1	0.35	----
5.	55.00	0	----	----
6.	28.00	15	0.40	0.85
			0.40	0.40
			0.35	0.55
			0.30	0.60
			0.25	0.90
			0.20	0.55
			0.25	0.50
			0.45	
			0.35	
			0.35	
			0.35	
			0.25	
			0.30	
			0.50	
			0.40	

7.	350.00	4	0.45	----
			0.30	----
			0.40	----
			0.40	----
8.	432.00	0	----	----
9.	121.00	82	$\bar{X}$	$\bar{X}$
			0.40	0.65
			0.40	1.15
			0.45	0.50
			0.40	0.70
			0.25	0.70
			0.55	0.60
			0.30	0.60
			0.20	0.90
			0.30	0.70
			0.20	1.15
			0.40	0.60
			0.45	0.50
			0.20	0.50
			0.30	0.70
			0.25	0.80
			0.40	0.90
			0.35	
10.	115.50	1	0.40	----
11.	25.00	0	----	----
12.	30.00	2	0.30	0.50
			0.50	0.50
13.	27.00	0	----	----

14.	21.00	0	----	----
15.	24.00	10	0.15	0.80
			0.35	0.70
			0.30	0.30
			0.40	0.30
			0.15	
			0.30	
			0.20	
			0.20	
			0.30	
			0.30	
	Σ = .1781 sq.m.	119	$\bar{x}$ = 0.33	$\bar{x}$ = 0.65
			σ^2 = 0.01	σ^2 = 0.05
			σ = 0.10	σ = 0.21

Population Density = 668.2

Station 4B

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	418.00	0	----	----
2.	374.00	3	0.40	----
			0.25	----
			0.35	----
3.	135.00	6	0.30	3.40
			0.30	
			0.25	
			0.45	
			0.40	
			0.50	
4.	170.00	0	----	----
5.	72.50	1	0.80	----
6.	120.00	1	0.45	-----
7.	145.00	4	0.40	----
			0.40	----
			0.30	----
			0.40	----
8.	225.00	0	----	----
9.	56.00	9	0.40	0.60

			0.25	0.60
			0.30	1.10
			0.30	0.90
			0.25	
			0.20	
			0.30	
			0.25	
			0.50	
10.	504.00	10	0.40	1.70
			0.20	1.70
			0.30	2.05
			0.50	2.05
			0.50	0.60
			0.30	0.60
			0.20	
			0.40	
			0.40	
			0.40	
11.	585.00	2	0.30	----
			0.40	----
	Σ = .2805 sq.m.	36	$\bar{x}$ = 0.36	$\bar{x}$ = 1.39
			σ^2 = 0.01	σ^2 = 0.79
			σ = 0.12	σ = 0.89

Population Density = 128.3

Station 5

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	1968.00	128	$\hat{\bar{X}}$	$\hat{\bar{X}}$
			0.55	0.60
			0.40	1.50
			0.50	0.50
			0.40	0.70
			0.40	0.80
			0.30	1.20
			0.40	0.35
			0.30	0.55
			0.35	1.60
			0.40	0.95
			0.35	0.50
			0.30	1.30
			0.20	1.40
			0.50	0.60
			0.70	0.60
			0.40	0.55
			0.40	0.50
			0.35	
			0.65	
	Σ = .1968 sq.m.	128	$\bar{x} = 0.41$	$\bar{x} = 0.85$
			$\sigma^2 = 0.02$	$\sigma^2 = 0.17$
			$\sigma = 0.12$	$\sigma = 0.41$

Population Density = 650.4

Station 6

Sample No.	Area (cm.^{2})	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	1530.00	20	0.40	4.70
			0.40	3.70
			0.30	1.30
			0.30	1.30
			0.40	2.70
			0.20	2.70
			0.40	3.30
			0.25	5.40
			0.30	1.30
			0.25	1.30
			0.30	5.30
			0.40	5.30
			0.35	
			0.35	
			0.45	
			0.30	
			0.30	
			0.30	
			0.30	
			0.40	
2.	420.00	19	0.30	3.50
			0.40	1.90
			0.50	1.65
			0.40	1.65
			0.25	1.65
			0.40	1.50

			0.30	1.50
			0.30	1.70
			0.30	1.70
			0.30	0.75
			0.30	0.85
			0.20	
			0.40	
			0.30	
			0.40	
			0.30	
			0.35	
			0.50	
			0.60	
3.	475.00	13	0.30	2.30
			0.40	2.90
			0.30	2.70
			0.35	1.60
			0.45	2.80
			0.25	1.60
			0.65	3.00
			0.60	
			0.30	
			0.45	
			0.40	
			0.50	
			0.45	
4.	60.00	2	0.40	----
			0.30	----
6.	132.00	1	0.40	----

$\leq$ = .2617 sq.m. 55 $\bar{x}$ = 0.36 $\bar{x}$ = 2.45

σ^2 = 0.01

σ = 0.10

Population Density = 210.2

Station 7

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	323.00	5	0.40	1.80
			0.40	
			0.50	
			0.40	
			0.40	
2.	120.00	0	----	----
3.	32.00	0	----	----
4.	84.00	0	----	----
5.	102.00	0	----	----
6.	170.00	8	0.50	1.40
			0.40	3.20
			0.40	3.50
			0.60	3.10
			0.50	
			0.50	
			0.50	
			0.50	
7.	180.00	0	----	----
8.	67.50	0	----	----
9.	70.00	1	0.40	----

10.	28.00	0	----	----
11.	36.00	0	----	----
	Σ= .1212 sq.m.	14	$\bar{x}$ = 0.46 σ^2 = 0.00 σ = 0.07	$\bar{x}$ = 2.60 σ^2 = 0.88 σ = 0.94

Population Density = 115.5

Station 8

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	4164.00	0	----	----
2.	931.00	0	----	----
3.	1306.00	6	0.70	----
			0.50	----
			0.90	----
			0.50	----
			0.50	----
			0.50	----
4.	1241.00	267	$\hat{\bar{\bar{X}}}$	$\hat{\bar{\bar{X}}}$
			0.45	1.30
			0.30	1.30
			0.60	1.30
			0.40	0.70
			0.60	1.10
			0.70	1.70
			0.35	1.70
			0.40	0.90
			0.50	1.40
			0.70	1.30
			0.80	1.30
			0.45	1.70
			0.70	1.70
			0.60	0.60
			1.00	0.60

			0.50	2.20
			0.90	2.20
			0.60	1.50
			0.90	1.50
			0.50	1.70
			0.40	1.10
			0.40	1.10
			0.40	1.20
			0.40	0.90
			0.30	0.90
			0.30	2.40
			0.40	0.70
			0.50	0.70
			0.40	0.80
			0.40	1.10
5.	1016.00	14	0.90	3.00
			1.00	3.00
			0.70	7.90
			0.90	2.60
			0.70	2.60
			0.40	2.50
			0.40	2.50
			0.70	3.00
			0.50	3.00
			0.70	
			0.60	
			0.90	
			0.70	
			0.70	
6.	1306.00	14	0.80	9.20
			0.70	9.20

			0.80	7.20
			0.90	1.60
			0.90	1.60
			0.70	2.70
			0.70	5.00
			0.80	
			0.70	
			0.50	
			0.70	
			0.50	
			0.40	
			0.50	
7.	909.00	8	0.40	2.20
			0.60	2.20
			0.30	2.20
			0.40	1.30
			0.40	1.30
			0.30	
			0.30	
			0.40	
	Σ = 1.0873 sq.m.	309	$\bar{x}$ = 0.58	$\bar{x}$ = 2.24
			σ^2 = 0.04	σ^2 = 4.01
			σ = 0.19	σ = 2.00

Population Density = 284.2

Station 9

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	785.00	2	0.50	----
			0.30	----
2.	168.00	3	0.30	2.20
			0.40	
			0.40	
3.	124.00	2	0.40	----
			0.40	----
4.	352.00	6	0.60	5.10
			0.50	
			0.40	
			0.50	
			0.40	
			0.50	
5.	398.00	13	0.40	0.90
			0.40	0.90
			0.40	4.00
			0.40	1.50
			0.40	1.50
			0.60	1.50
			0.60	1.50
			0.35	
			0.50	
			0.50	

			0.40	
			0.50	
			0.35	
6.	88.00	4	0.60	1.10
			0.50	1.10
			0.30	
			0.30	
7.	150.00	0	----	----
8.	66.00	0	----	----
9.	176.00	14	0.60	0.50
			0.40	0.50
			0.40	1.10
			0.40	1.10
			0.50	2.40
			0.40	2.40
			0.40	0.40
			0.35	0.40
			0.40	1.20
			0.40	
			0.40	
			0.40	
			0.30	
			0.30	

Σ = .2307 sq.m.	44	$\bar{x} = 0.42$	$\bar{x} = 1.57$
		$\sigma^2 = 0.01$	$\sigma^2 = 1.43$
		$\sigma = 0.09$	$\sigma = 1.19$

Population Density = 190.7

Station 10

Sample No.	Area (cm^2)	No. of Burrows	Diameter (cm.)	Nearest Neighbour Distance (cm.)
1.	187.00	6	0.60	1.50
			0.60	1.30
			0.40	1.30
			0.40	
			0.50	
			0.40	
	Σ = .0187 sq.m.	6	$\bar{x}$ = 0.48	$\bar{x}$ = 1.37
			σ^2 = 0.01	σ^2 = 0.01
			σ = 0.01	σ = 0.12

Population Density = 320.9

Appendix II

Grain Size Analysis

Station 1

0.20	0.12	0.23
0.13	0.17	0.12
0.20	0.10	0.10
0.20	0.20	0.17
0.15	0.17	0.20
0.25	0.15	0.10
0.10	0.30	0.10
0.20	0.10	0.05
0.20	0.20	0.15
0.10	0.25	0.25

$\bar{x} = 0.165$

$\sigma = 0.059$

$\sigma^2 = 0.0035$

Station 2

0.10	0.06	0.12
0.10	0.06	0.04
0.10	0.10	0.04
0.06	0.08	0.03
0.08	0.07	0.05
0.07	0.08	0.09
0.10	0.09	0.06
0.15	0.06	0.07
0.05	0.04	0.03
0.04	0.09	0.06

$\bar{X} = 0.072$

$\sigma = 1.47$

$\sigma^2 = 2.17$

Station 3

0.08	0.06	0.05
0.06	0.08	0.03
0.05	0.08	0.09
0.05	0.12	0.09
0.07	0.10	0.04
0.15	0.09	0.06
0.06	0.17	0.04
0.05	0.08	0.04
0.04	0.06	0.09
0.05	0.05	0.04

$\bar{x} = 0.071$
$\sigma = 0.033$
$\sigma^2 = 0.001$

Station 4

0.15	0.20	0.17
0.12	0.25	0.20
0.20	0.23	0.25
0.12	0.09	0.05
0.15	0.12	0.15
0.12	0.23	0.15
0.20	0.23	0.06
0.23	0.22	0.20
0.09	0.17	0.15
0.12	0.10	0.15

$\bar{x} = 0.162$
$\sigma = 0.056$
$\sigma^2 = 0.003$

Station 4A

0.09	0.08	0.05
0.15	0.10	0.03
0.20	0.03	0.06
0.03	0.02	0.15
0.04	0.12	0.03
0.04	0.09	0.01
0.02	0.06	0.22
0.04	0.13	0.06
0.12	0.05	0.06
0.06	0.06	0.05

$\bar{x} = 0.075$
$\sigma = 0.053$
$\sigma^2 = 0.003$

Station 4B

0.15	0.14	0.15
0.25	0.10	0.23
0.17	0.12	0.09
0.10	0.13	0.06
0.17	0.25	0.10
0.12	0.15	0.14
0.06	0.14	0.25
0.14	0.20	0.12
0.20	0.13	0.04
0.09	0.18	0.10

$\bar{x} = 0.142$
$\sigma = 0.056$
$\sigma^2 = 0.003$

Station 5

0.12	0.07	0.08
0.06	0.06	0.06
0.09	0.09	0.06
0.09	0.12	0.05
0.06	0.05	0.04
0.06	0.05	0.05
0.06	0.06	0.04
0.06	0.10	0.08
0.05	0.11	0.08
0.05	0.09	0.04

$\bar{x} = 0.069$
$\sigma = 0.023$
$\sigma^2 = 0.001$

Station 6

0.06	0.11	0.05
0.11	0.25	0.12
0.18	0.10	0.15
0.25	0.06	0.20
0.06	0.08	0.12
0.25	0.08	0.33
0.08	0.06	0.20
0.12	0.07	0.08
0.20	0.05	0.17
0.25	0.04	0.15

$\bar{x} = 0.134$
$\sigma = 0.077$
$\sigma^2 = 0.006$

Station 7

0.05	0.08	0.03
0.03	0.10	0.03
0.04	0.09	0.05
0.04	0.06	0.02
0.06	0.04	0.02
0.08	0.08	0.15
0.02	0.03	0.02
0.03	0.06	0.02
0.03	0.02	0.15
0.02	0.01	0.05

$\bar{x} = 0.050$
$\sigma = 0.036$
$\sigma^2 = 0.001$

Station 8

0.25	0.23	0.40
0.22	0.35	0.20
0.23	0.15	0.30
0.35	0.32	0.25
0.40	0.30	0.35
0.50	0.15	0.30
0.25	0.35	0.20
0.30	0.25	0.27
0.30	0.25	0.10
0.25	0.50	0.20

$\bar{x} = 0.282$
$\sigma = 0.092$
$\sigma^2 = 0.009$

Station 9

0.10	0.20	0.12
0.11	0.12	0.15
0.17	0.05	0.25
0.15	0.08	0.10
0.10	0.12	0.15
0.15	0.06	0.15
0.15	0.17	0.23
0.25	0.25	0.10
0.05	0.10	0.10
0.12	0.10	0.05

$\bar{X} = 0.133$
$\sigma = 0.058$
$\sigma^2 = 0.003$

Station 10

0.10	0.05	0.15
0.17	0.08	0.17
0.09	0.05	0.10
0.05	0.20	0.06
0.10	0.05	0.06
0.10	0.04	0.10
0.09	0.10	0.10
0.12	0.12	0.15
0.15	0.10	0.04
0.06	0.17	0.20

$\bar{X} = 0.104$
$\sigma = 0.047$
$\sigma^2 = 0.002$

Appendix III

Sandstone/Shale Ratio
Distance From Shore
Organic Fraction
Quartz Fraction
Clay Fraction

Sandstone/Shale Ratio

Station	Ratio
1	1.02
2	1.10
3	1.20
4	1.09
4A	1.93
4B	1.84
5	7.33
6	7.93
7	10.33
8	999.99
9	88.00
10	999.99

Distance from Shore Line

Station	Miles
1	156.0
2	155.0
3	156.0
4	150.0
4A	149.0
4B	148.0
5	138.0
6	125.0
7	111.0
8	112.0
9	115.0
10	81.0

Organic Content

Station	Percent
1	2.14
2	3.45
3	3.15
4	1.33
4A	2.90
4B	2.50
5	2.51
6	0.74
7	2.33
8	2.10
9	0.85
10	0.88

Quartz Fraction

Station	Percent
1	60.0
2	63.0
3	64.0
4	63.0
4A	51.0
4B	57.0
5	54.0
6	61.0
7	69.0
8	59.0
9	48.0
10	62.0

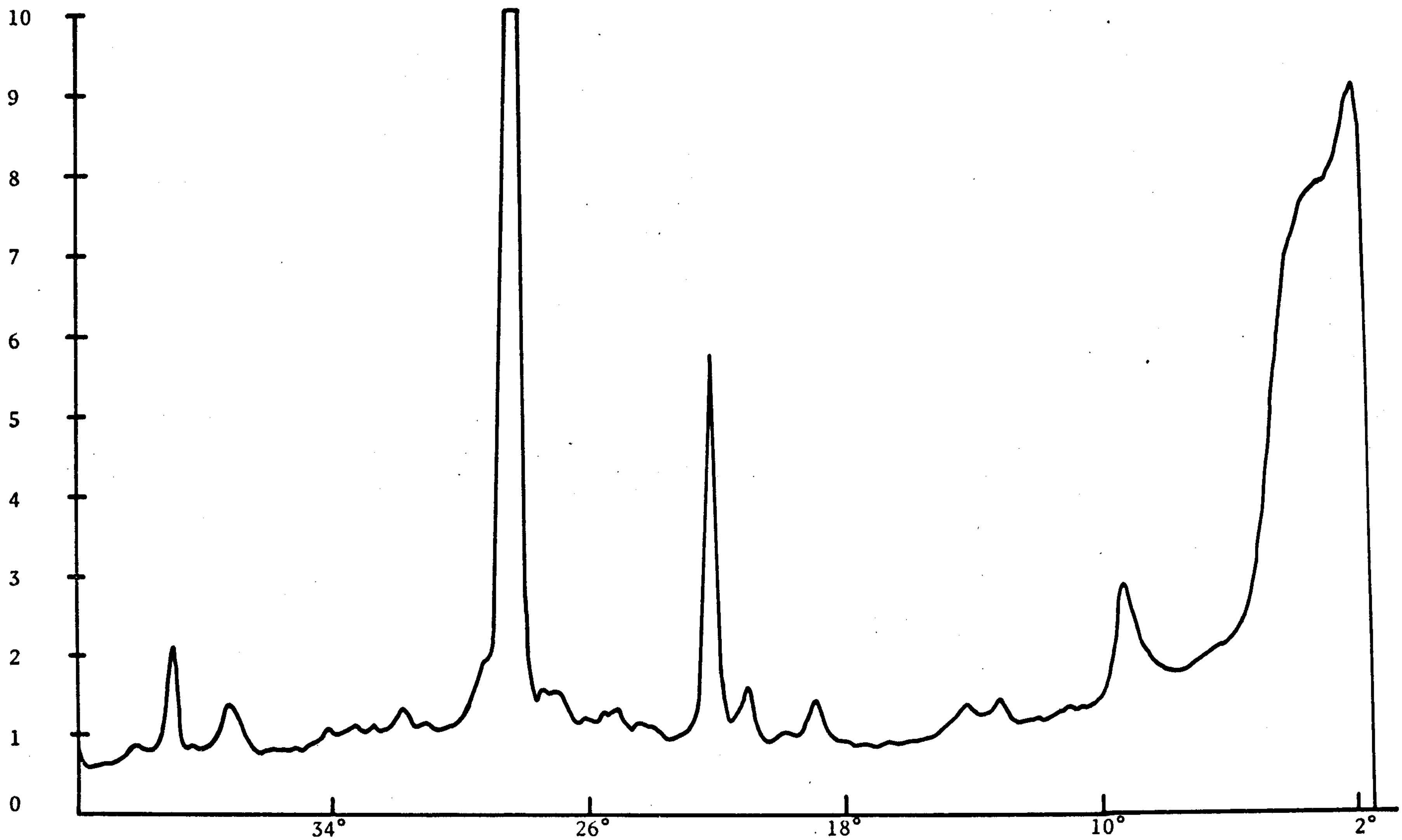
Porosity

Station	Percent
1	12.7
2	10.5
3	14.3
4	7.6
4A	6.1
4B	15.8
5	11.5
6	9.4
7	7.3
8	5.3
9	6.4
10	8.7

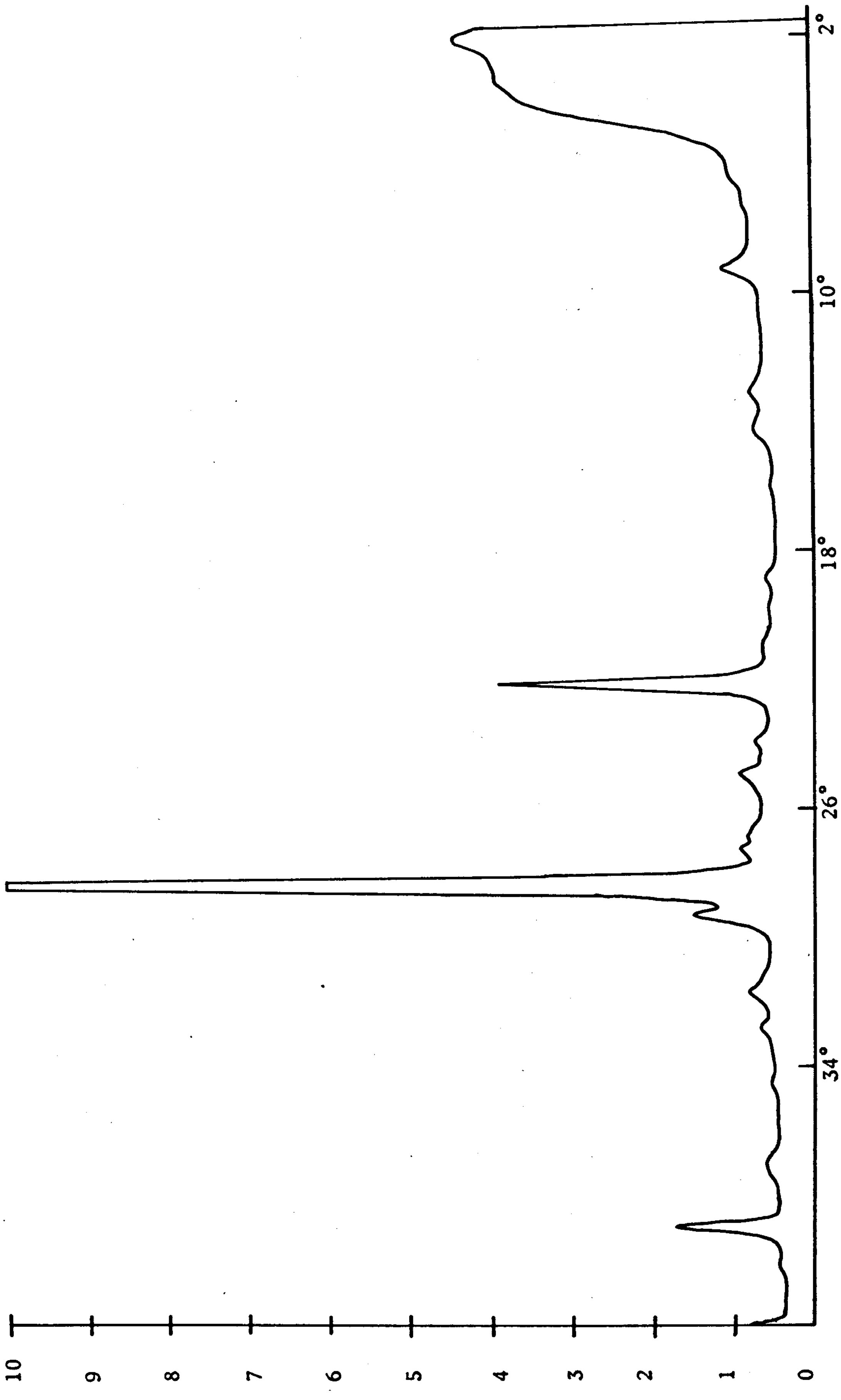
Appendix IV

Mineral Content
From X-Ray Analysis

STATION 1



STATION 2



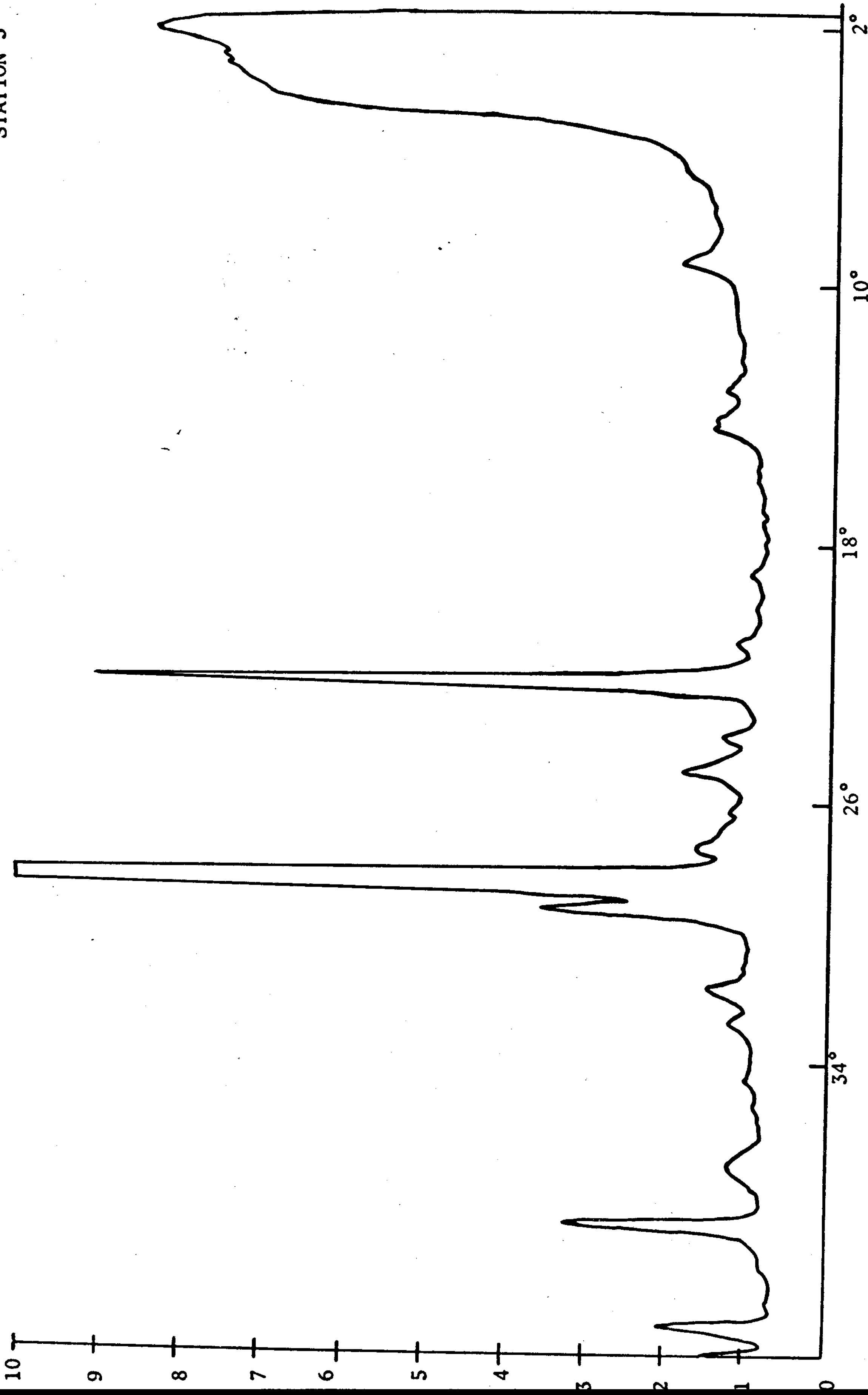
Station 1

	Absolute Amount	Proportion
montmorillonite	0.90	
illite	0.48	
chlorite	0.08	
unknown clay	0.12	
total clay	1.58	0.27
goethite	0.71	0.12
quartz	3.53	0.60
dolomite	0.07	0.01
Total Minerals	5.89	

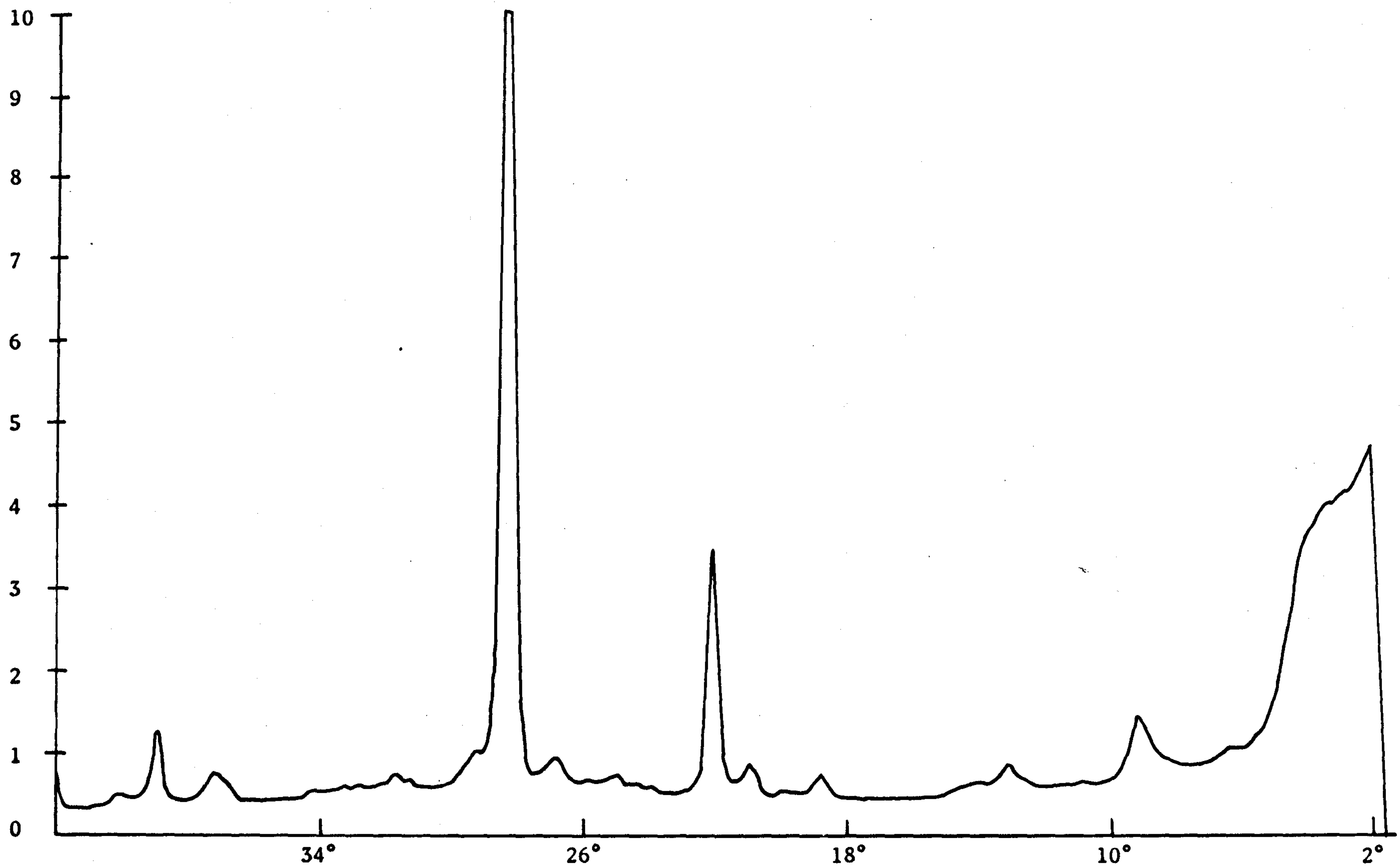
Station 2

	Absolute Amount	Proportion
montmorillonite	0.43	
illite	0.08	
chlorite	0.06	
unknown clay	0.07	
total clay	0.64	0.19
goethite	0.50	0.15
quartz	2.15	0.63
calcite	0.08	0.02
dolomite	0.03	0.01
Total Minerals	3.40	

STATION 3



STATION 4

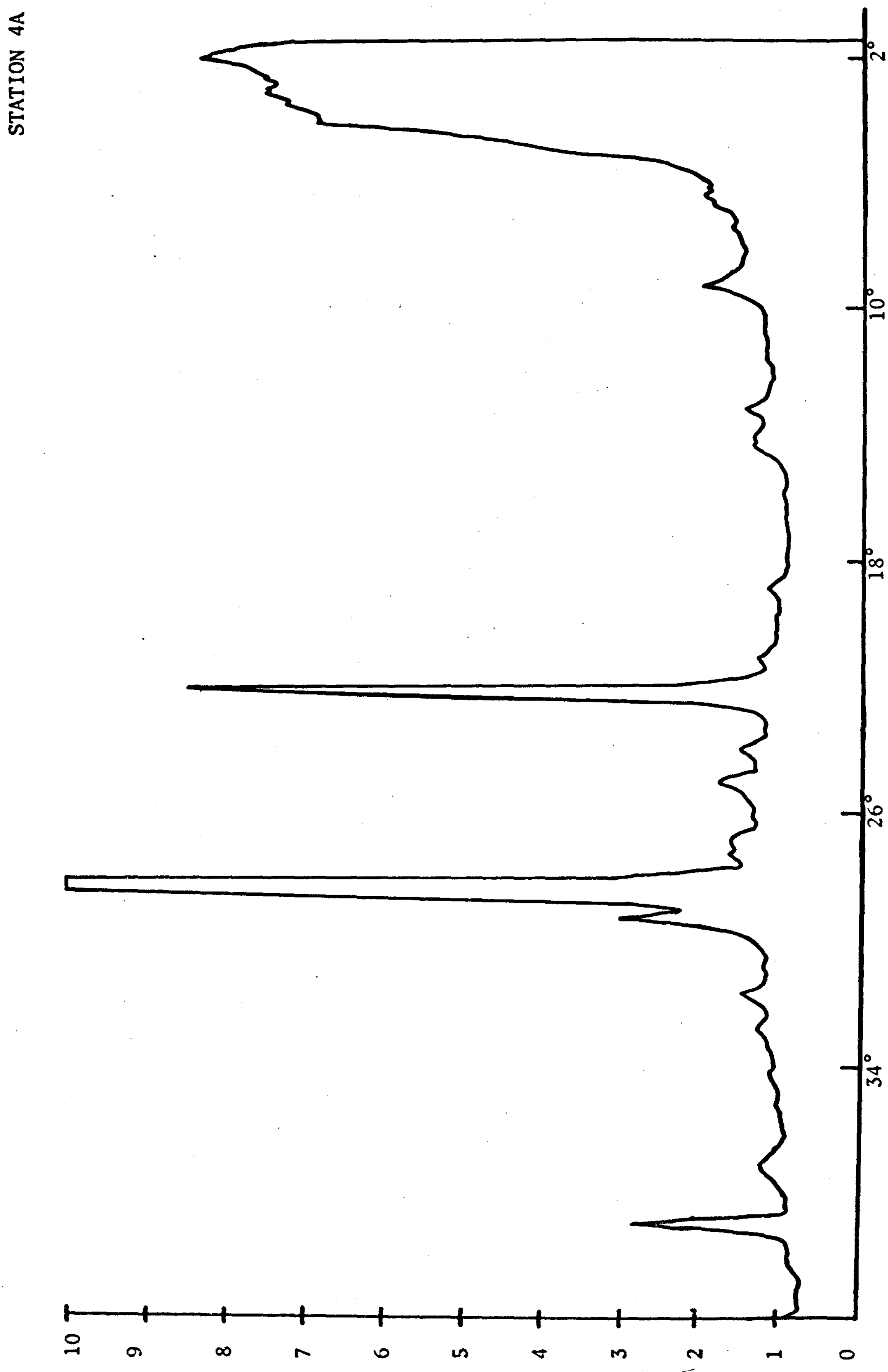


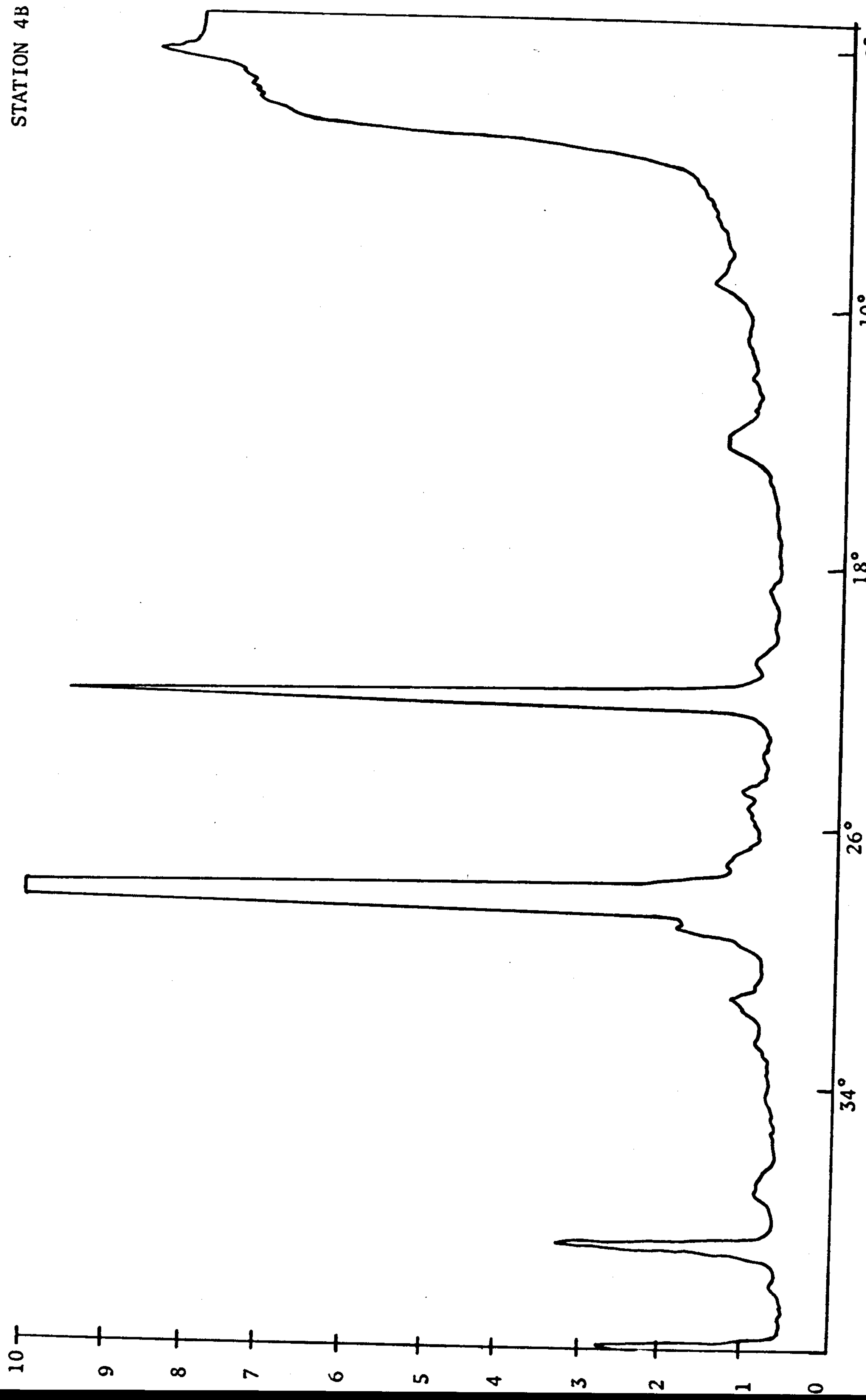
Station 3

	Absolute Amount	Proportion
montmorillonite	0.73	
illite	0.18	
chlorite	0.08	
unknown clay	0.20	
total clay	1.19	0.14
goethite	1.20	0.14
quartz	5.37	0.64
calcite	0.56	0.07
dolomite	0.12	0.01
Total Minerals	8.44	

Station 4

	Absolute Amount	Proportion
montmorillonite	0.22	
illite	0.24	
chlorite	0.08	
total clay	0.54	0.16
goethite	0.46	0.14
quartz	2.13	0.63
calcite	0.17	0.05
dolomite	0.07	0.02
Total Minerals	3.37	


STATION 4A
2°
10°
18°
26°
34°
0
1
2
3
4
5
6
7
8
9
10

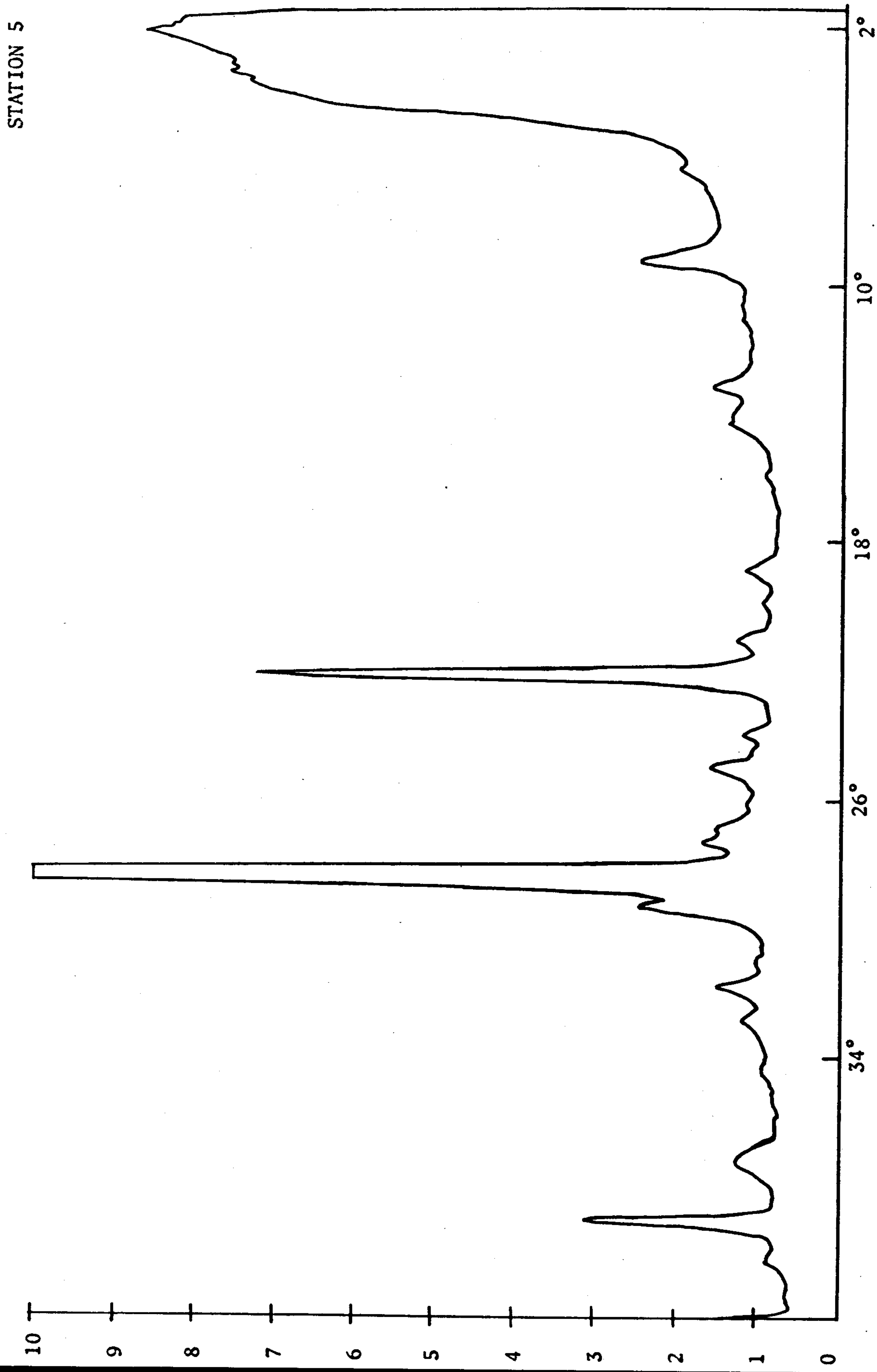

STATION 4B
10
9
8
7
6
5
4
3
2
1
0
2°
10°
18°
26°
34°

Station 4A

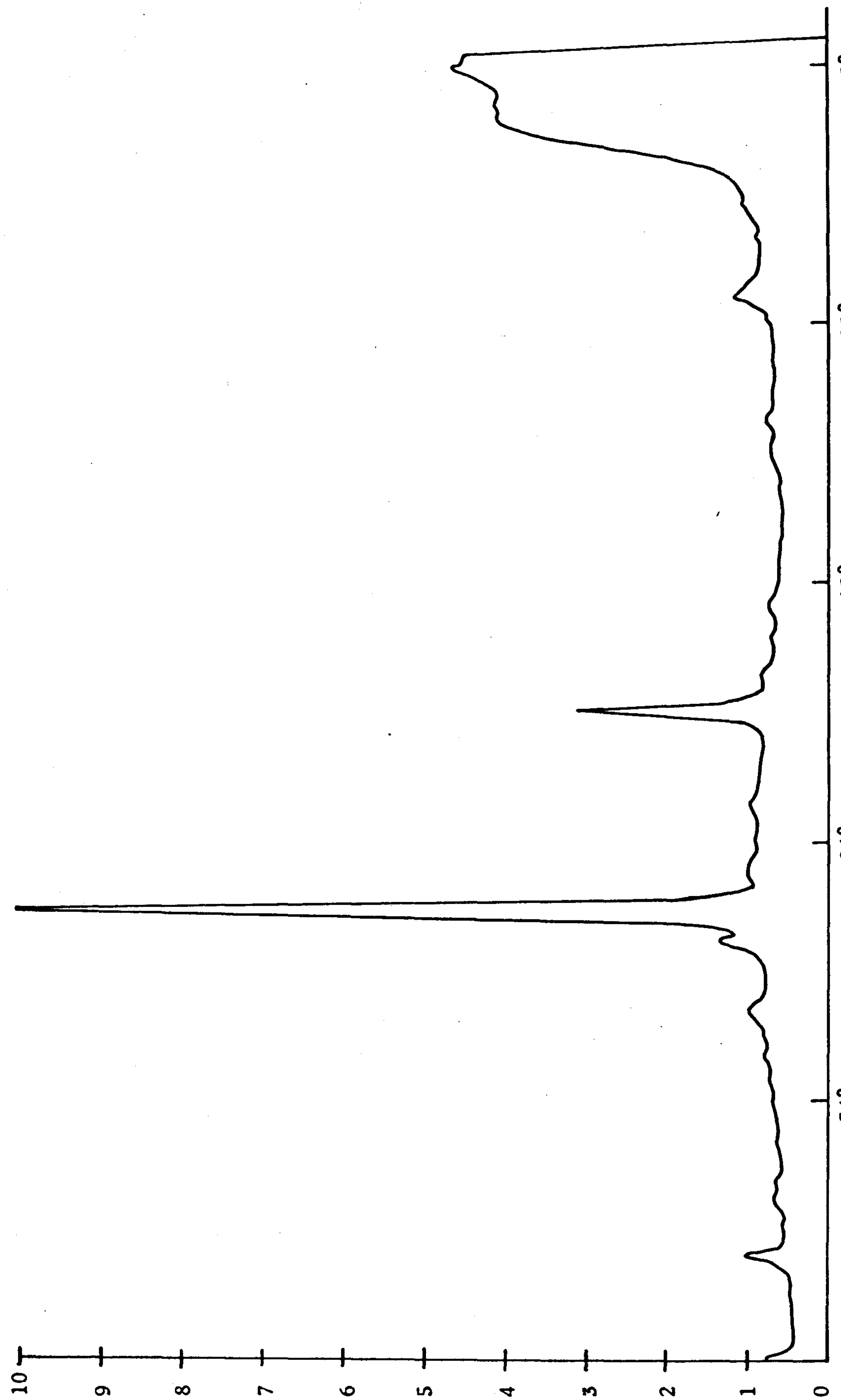
	Absolute Amount	Proportion
montmorillonite	0.61	
illite	0.20	
chlorite	0.11	
unknown clay	0.15	
total clay	1.07	0.19
goethite	1.15	0.21
quartz	2.81	0.51
calcite	0.42	0.08
dolomite	0.06	0.01
Total Minerals	5.51	

Station 4B

	Absolute Amount	Proportion
montmorillonite	0.65	
illite	0.12	
chlorite	0.21	
total clay	0.98	0.15
goethite	1.33	0.21
quartz	3.60	0.57
calcite	0.32	0.05
dolomite	0.10	0.02
Total Minerals	6.33	


STATION 5
2°
10°
18°
26°
34°
0
1
2
3
4
5
6
7
8
9
10

STATION 6



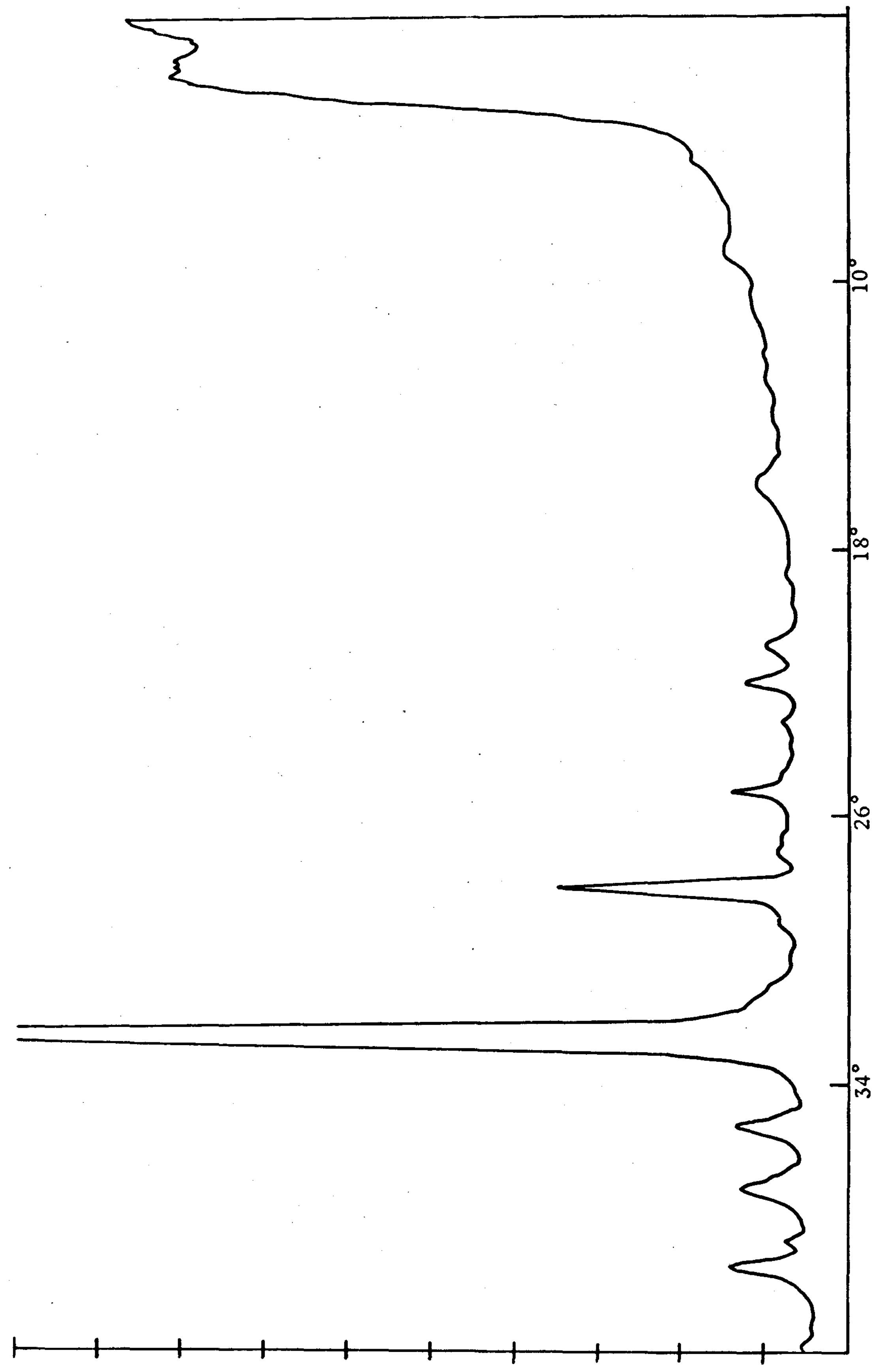
Station 5

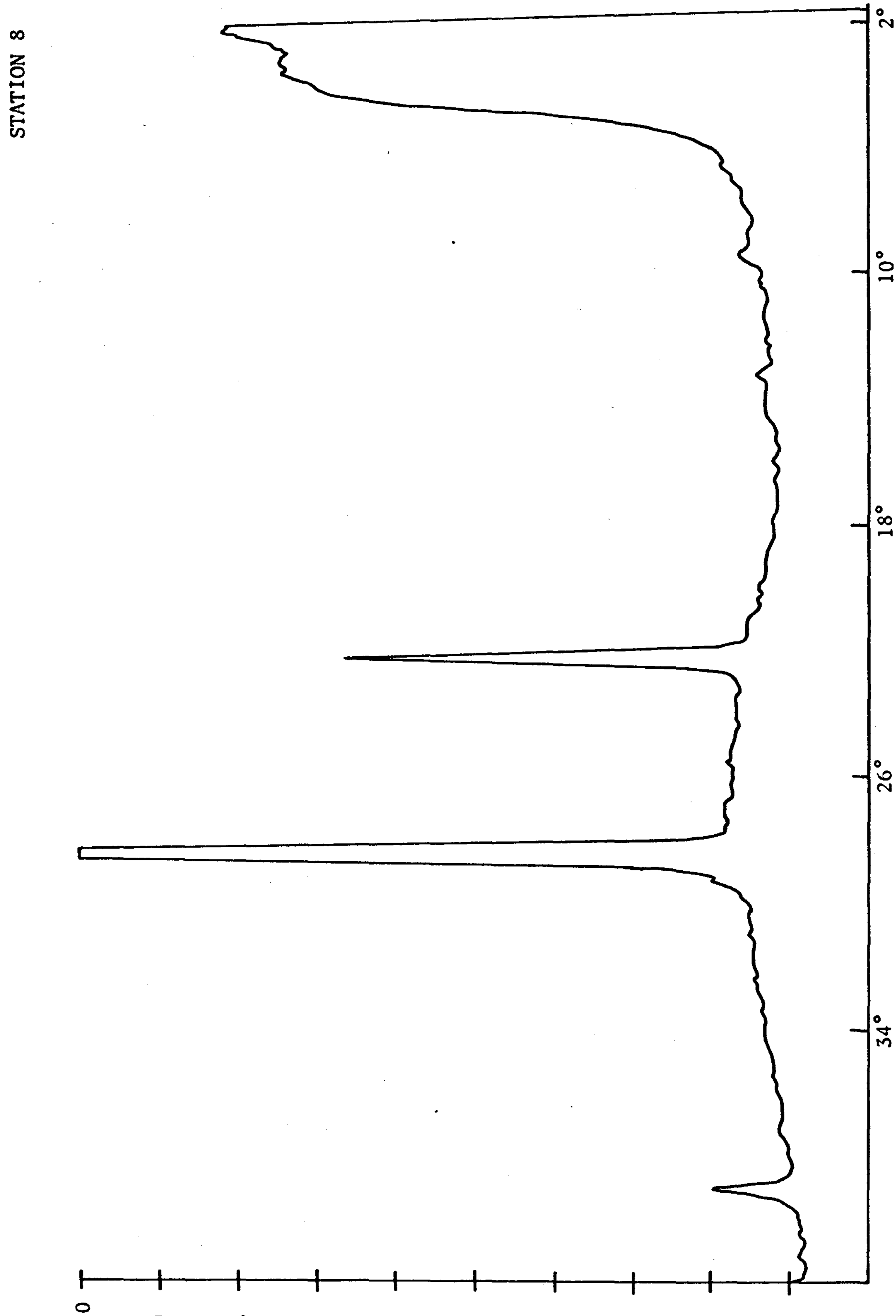
	Absolute Amount	Proportion
montmorillonite	0.65	
illite	0.33	
chlorite	0.17	
unknown clay	0.13	
total clay	1.28	0.21
goethite	0.99	0.16
quartz	3.29	0.54
calcite	0.40	0.07
dolomite	0.15	0.02
Total Minerals	6.11	

Station 6

	Absolute Amount	Proportion
montmorillonite	0.39	
illite	0.08	
chlorite	0.02	
total clay	0.49	0.21
goethite	0.31	0.14
quartz	1.39	0.61
calcite	0.08	0.04
dolomite	0.01	0.00
Total Minerals	2.28	

STATION 7




STATION 8
2°
10°
18°
26°
34°
0
1
2
3
4
5
6
7
8
9
10

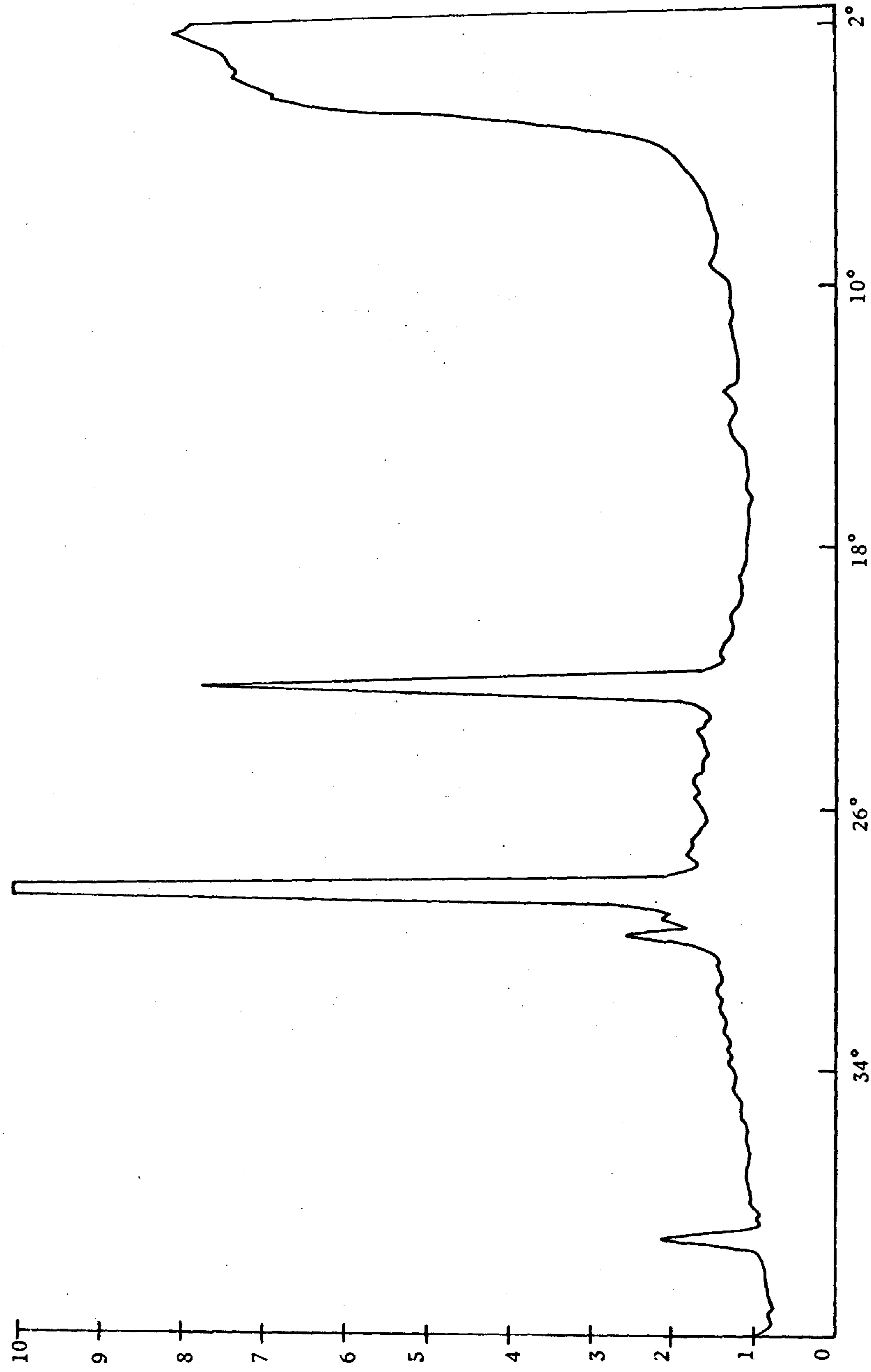
Station 7

	Absolute Amount	Proportion
montmorillonite	1.07	
illite	0.12	
chlorite	0.13	
total clay	1.32	0.20
goethite	0.48	0.08
quartz	4.35	0.69
dolomite	0.19	0.03
Total Minerals	6.34	

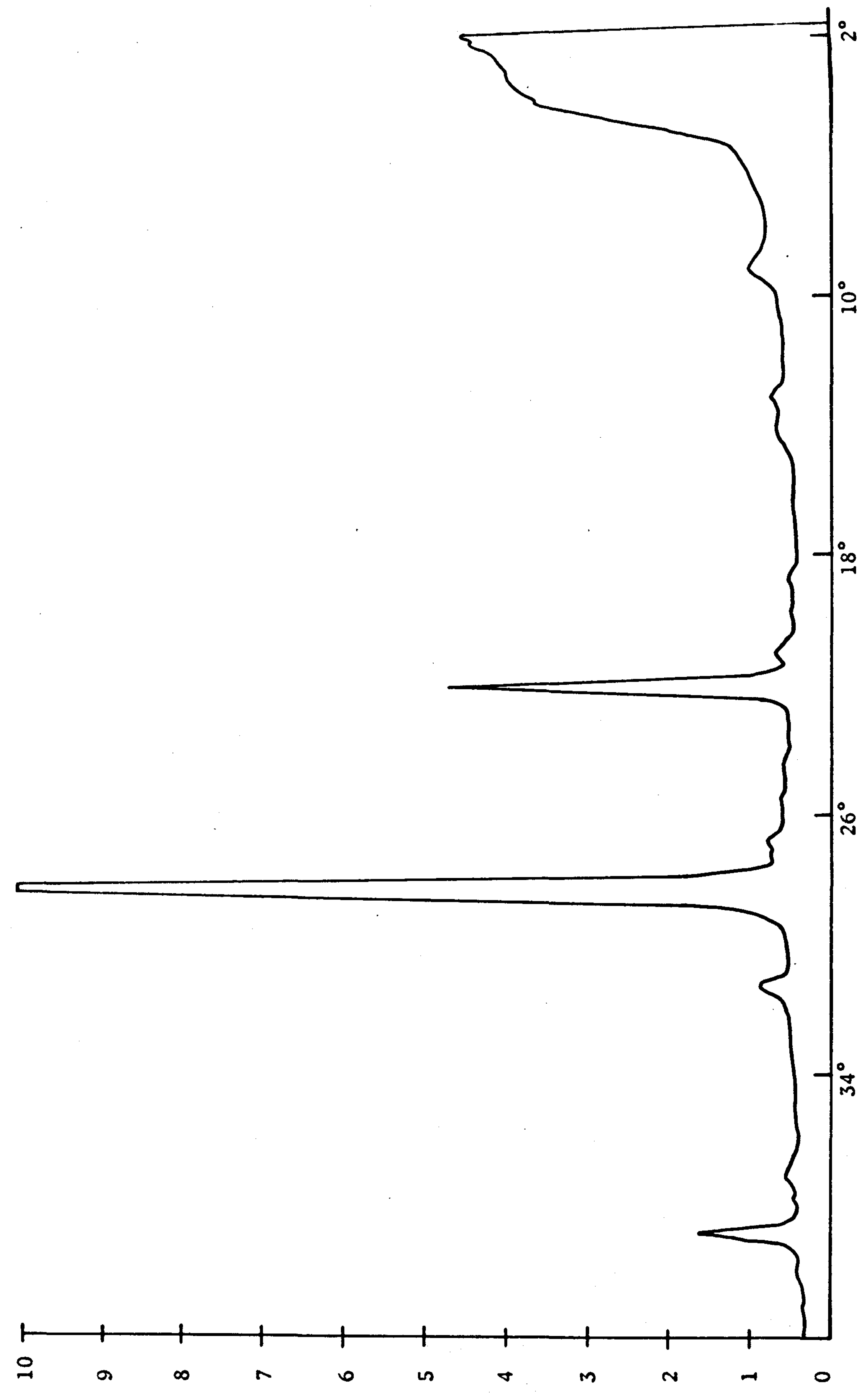
Station 8

	Absolute Amount	Proportion
montmorillonite	0.99	
illite	0.06	
chlorite	0.05	
unknown clay	0.07	
total clay	1.17	0.24
goethite	0.75	0.15
quartz	2.87	0.59
calcite	0.06	0.02
Total Minerals	4.85	

STATION 9



STATION 10



Station 9

	Absolute Amount	Proportion
montmorillonite	1.30	
illite	0.07	
chlorite	0.03	
unknown clay	0.04	
total clay	1.44	0.27
goethite	1.12	0.21
quartz	2.60	0.48
calcite	0.11	0.02
dolomite	0.14	0.02
Total Minerals	5.41	

Station 10

montmorillonite	0.49	
illite	0.12	
chlorite	0.05	
total clay	0.66	0.17
goethite	0.60	0.16
quartz	2.37	0.62
dolomite	0.18	0.05
Total Minerals	3.81	

Modified Data Matrix

Station	Worm Burrows	Clay Fraction	Organic Fraction	Burrow Diameter	Mean Grain Size	Sorting	Quartz Fraction Grains	Distance From Shore	Porosity	$\frac{ss}{sh}$ Ratio
1	448.4	27.0	2.14	4.10	.17	.06	60.0	156.0	12.7	1.02
2	434.2	19.0	3.45	2.90	.07	1.47	63.0	155.0	10.5	1.10
4	1659.5	16.0	1.33	3.60	.16	.06	63.0	150.0	7.6	1.09
4A	668.2	19.0	2.90	3.30	.08	.05	51.0	149.0	6.1	1.93
4B	128.3	15.0	2.50	3.60	.14	.06	57.0	148.0	15.8	1.84
5	650.4	21.0	2.51	4.10	.07	.02	54.0	138.0	11.5	7.33
6	210.2	21.0	.74	3.60	.13	.08	61.0	125.0	9.4	7.93
7	115.5	20.0	2.33	4.60	.05	.04	69.0	111.0	7.3	10.33
8	284.2	24.0	2.10	5.80	.28	.09	59.0	112.0	5.3	9999.99
9	190.7	27.0	.85	4.20	.13	.06	48.0	115.0	6.4	88.00
10	320.9	17.0	.88	4.80	.10	.05	62.0	81.0	8.7	9999.99