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Sand texture and depositional environments in Essex County, Ontario.

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SAND TEXTURE AND DEPOSITIONAL ENVIRONMENTS IN ESSEX COUNTY, ONTARIO

by

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ABSTRACT

Graphic measures, moment measures, stepwise discriminant analysis, and R-Mode factor analysis have been used to find the most effective technique to differentiate the depositional environments (shallow agitated, foreshore, backshore, dune and glacial) of I68 randomly collected samples . Neither moment measures nor graphic measures have reliably discriminated the various environments of deposition. However, the sample statistics, especially the mean and skewness parameters, exemplified the relationship between sand texture (grain-size) and depositional environments.

The multivariate technique have shown greater effectiveness. Stepwise discriminant analysis classified 78.57I% of the samples in their true depositional settings; with the misclassified sampled being a consequence of variation in the intensity of energy producing forces (storms, waves, wind, etc.). Although R-Mode factor analysis identified four sand populations, with each population reflecting variations in size distributions and energy producing forces, no clear-cut distinction is shown between glacial, shallow agitated, and foreshore samples.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont'd)

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

Repeated attempts have been made by sedimentologists to derive statistical methods for interpreting depositional sedmentary environments from the grain size of sediments. Many studies have used textural parameters based on the size frequency distribution of sands to discriminate between , or , identify depositional environments.

Despite various shortcomings, after the poineering contributions of Udden (1919), a number of workers (for example, Mason and Folk 1958; Friedman 1961; Shepard and Young 1961; Chappell 1967; Hails 1967; Miola and Weiser 1968; Anan 1969; Greenwood 1969), have tried to differentiate beach and dune sands by their sedimentological characteristics. Other studies have tried to differentiate the various depositional sub-environments of beach sediments (e.g. Duane 1964; Klovan 1966; Hails and Hoyt 1969). Doeglas (1964, 1968), Passega (1957, 1964), Sahu (1964), Visher (1969), Jones (1971), Allen et al (1972) and Williams (1973) , have sampled one or more environments and attempted to use the analysed data to discriminate between the processes of deposition by using various statistical methods.

Whereas each study dealt with a specific area , different workers have proposed a number of statistical methods for interpreting depositional environments from grain size data. The varied results of these methods are in some cases in direct contrast, in others in close agreement with each other. Solohub and Klovan (1970) evaluated the techniques proposed by Passega (1957), Mason and Folk (1958), Friedman (1961), Sahu (1964) , and Klovan (1966) and found only the method proposed by Klovan

(1966) to be reliable in identifying the depositional environments of sediments. From this study, it is apparent that the sensitivity of statistical methods should be further evaluated.

Objectives of the study

This study deals principally with the analysis of samples of clastic sediments collected from known depositional sedimentary environments. In relation to grain-size data , various statistical methods proposed for interpreting depositional environments are evaluated. This empirical approach further serves the important function of determining whether the grain-size of a clastic sediment is a measure of the energy of the depositing medium, and the energy of the basin of deposition. In particular , sedimentation processes in modern environments can be explained. Although proposed statistical methods are not criticised , nor new ones proposed, conclusions are drawn as to the usefulness of statistical parameters calculated from grain-size distributions to differentiate environments of deposition.

Development of Grain-Size Distribution Studies

Identification of the environment of deposition has been the principal objective of the textural study of sand. Folk (1966) has summarised previous studies (1914-1964) which have been claimed to be effective in separating environments of sand deposition. The literature on the techniques and interpretation of grain-size is rapidly expanding with increasing emphasis placed on multivariate statistics.

Although it can be argued that the use of complex parameters should be used for proper environmental determination simpler techniques used by other workers have also been claimed to achieve reliable results. In 1957 , Folk and Ward showed in a plot of Inclusive Graphic Skewness measure against the Inclusive Graphic Standard Deviation that beach and river sands fall, for the most part into separate groupings, which are related to the environments of deposition.

In the following year , Mason and Folk (1958) demonstrated that beach sands are generally negatively skewed and dune and eolian flat sands are positively skewed. Friedman (1961) using moment measures, reached a similar conclusion, but his samples were collected from widely spaced locations. Furthering his work on beach and river sands Friedman (1962, 1965, 1967) found that correlations exist between textural parameters and the environments of deposition. In 1962 , Friedman claimed that a normal uni-modal distribution is rather unusual in beach environments and suggested that the average sand deposit is in fact more skewed and peaked than the corresponding normal curve. Friedman (1967) listed ten possible statistical parameters that could be used as environmental indicators , but commented that mean grain size is not too meaningful for an environmental distinction.

Giles and Pilkey (1965) collected 50 pairs of samples from beaches and dunes and compared these with samples from rivers in the vicinity. From their analysis they concluded that both beach and dune sands appeared to be derived from nearby rivers, and also from sediment in the adajacent area , namely shelves.

Separate studies by Chappell (1967) and Hails (1967) indicated that skewness is the best parameter for distinguishing between beach and dune sands. Chappell analysed samples collected from the west coast of New Zealand and found that the beach and dune sands were bimodal , containing two logarithmic normal populations 1 ϕ unit apart . Using the moment method he found that the beach sands are generally negatively skewed, Hails who worked in eastern Australia collected 1500 samples from various beaches , dunes , barrier and fluvial deltaic plains and found that by using moment measures beach and dune sands could be differentiated in terms of their environments of deposition. 81% of the beach samples were negatively skewed , while all the dune samples showed a positive skewness.

A number of other studies (e.g. Anan 1969 ; Hails and Hoyt 1969 ; Passega and Byramjee 1969 ; Visher 1969) suggested the use of simpler techniques for environmental analysis. Anan using both moment measures and Folk and Ward Graphic measures presented scatter plots of various measures plotted against each other . His plot of skewness against kurtosis , using moment measures , also provides an effective means of differentiating sand types . His results indicated that the dunes sands have positive skewness values. Hails and Hoyt concluded that skewness appears to be a significant statistical parameter after analysing sediments from a series of six Pleistocene and one recent barrier island and the intervening lagoonal marsh deposits. Their results showed that 70% of the barrier island samples were negatively skewed , while 90% of the dune samples showed positive skewness.Passega and Byramjee suggested the use of C/M diagrams and other plots.

These are : F/M
L/M
and A/M which are used for environmental analysis

where M is the median
C is the 1 percentile
and F,L and A are the percentages by weight in the samplesof the grains , finer than 125, 31, and 4u , respectively.

The results of Passega and Byramjee indicate that these plots are effective to distinguish environments of deposition (particularly turbidity curent deposits). Visher related the shape of grain-size curves to the mode of transportation of sediments and found that different energy levels influence different transport conditions. He further claimed that the characteristics of the individual grain size distribution curves provide a basis for an environmental classification.

Two other studies have confirmed that skewness is sensitive to the environment. Jones (1971) concluded that the sign of skewness is significant after textural analyses of 120 bay samples and 15 beach samples from a portion of southern Cardigan Bay. The work of Williams (1973) on beach sediments enabled him to conclude that mean, standard deviation , skewness and kurtosis values calculated by central moment measures can be usefully utilised in order to differentiate between various beach zones. According to Williams the most important parameter was the mean ; the skewness and kurtosis values for the bulk of the samples indicated that they came from non-normal distributions.

The application of multivariate statistical techniques to objectively define depositional environments is on the increase . Sahu (1964) used the technique of linear discriminant functions and a combination of other parameters to satisfactorily differentiate depositional mechanisms. Klovan (1966) applied Q-mode factor analysis to identify depositional environments in terms of grain-size distributions. He analysed sediments collected from Barataria Bay on the Mississippi Delta and found that the different energy conditions dominated the characteristics of the sediments. The factor analysis technique showed that the first factor (current energy dominant) accounted for 77.22% of the sums of squares , the second (gravitational energy dominant) for 14.34 percent and the third (surf energy dominant) for 5.81 percent , totalling 97.46 percent in terms of the loading of the samples on the first three factors. His results can be considered to be both geographically and geologically meaningful in terms of the resultant groups of sediments. A similar study was done by Visher (1965) who demonstrated that flow regime may control the range of grain size of the saltation and suspension populations and the approximate position of the truncation between the two populations.

Another multivariate technique, linear discriminant analysis , was used by Greenwood (1969) to differentiate between dune and wave deposited sands from a number of different areas. The results of his analysis of 112 samples at quarter phi intervals showed that multiple discriminant analysis could be effectively used in classifying sediments of unknown origin and of varied mineralogical composition. The sign of skewness was found to be significant as an environmental indicator, followed in order by the mean size , standard deviation and the kurtosis. Other workers (Beall,1970; Solohub and Klovan, 1970) have used the Q-mode factor analysis technique for grouping grain -size data into meaningful factors which are significant in their geologic context. Beall (1970) working in a fluviodeltaic complex found that the factor groupings of the textural facies had environmental significance. Solohub and Klovan(1970) evaluated a number of statistical methods from samples collected in a lacustrine setting and found only Q-mode factor analysis to be more meaningful than other methods of textural analysis.

In addition to the use of Q- mode factor analysis , Allen et al (1972) postulated the use of R- mode factor analysis. Claiming to have used R-mode factor analysis for the first time their results showed that this technique determines the relative environmental importance of each sand population in a determined area. They further claimed that each sand population can be associated with specific transport conditions.

Reasons for setting up Hypotheses

This brief review of the literature has shown that various statistical methods have been proposed for interpreting depositional environments from grain-size data. Certain workers (e.g. Chappell, 1967; Miola and Weiser, 1968) have suggested that the graphic measures are not very useful in distinguishing between beach and coastal dune sands. Further , Davis and Ehrlich (1970) and Williams (1973) prefer the use of formal central moment measures.

It is the opinion of Shepard and Young (1961) that textural parameters are not environmentally sensitive and cannot be used to differentiate between modern beach and coastal dune sands and between beach and river sands .Further Folk and Ward (1957) and McCammon (1962) have pointed out the limitations of moment measures. Although Folk(1966) claimed the moment measures to be mathematically elegant yet he claimed that these measures have serious drawbacks which make it really not much superior to the percentile - intercept methods.

Solohub and Klovan (1970), found that the technique of Passega (1957), Mason and Folk (1958), Friedman (1961), and Sahu (1964) cannot reliably identify the true depositional environments of sediments collected in a lacustrine setting. They claimed that only Q-mode factor analysis identified sediments in their true depositional settings. Greenwood (1969) on the other hand showed the importance of multiple discriminant analysis to differentiate sediments collected from a number of different areas. Further Allen et al (1972) demonstrated the effectiveness of R-mode factor analysis to differentiate sand populations collected collected from depositional settings.

It can therefore be seen that many sedimentologists have conflicting opinions as to the environmental sensitivity of the statistical methods used to identify depositional environments of sediments. As such , this research seeks to establish a working method for differentiating sands collected from a number of known depositional environments.

Hypotheses

Based on these considerations the following hypotheses are postulated :

1. There exists a relationship between sand texture and depositional environments.
2. Several methods, namely Graphic Measures, Central Moment Measures, Step-Wise Discriminant Analysis, and Factor Analysis can be used to differentiate depositional environments on the basis of the grain-size distribution of sands.
3. Grain-size distributions cannot identify depositional environments on a universal basis, but only at the local geographic level.

Definitions

Texture:

Texture includes the shape, roundness, surface features, grain-size, and fabric of the components, principally the detrital ones, of a sand stone (Pettijohn, Potter and Siever, 1972, p.68). This study uses only one aspect of texture, that is grain-size.

Depositional sedimentary environment:

Shepard and Moore (1955, p. 1488) defined a sedimentary environment as " a spatial unit in which external physical, chemical, and biological conditions and influences affecting the development of a sediment are sufficiently constant to form a characteristic deposit."

This study is concerned with depositional sedimentary environments, that is, under what hydrodynamic conditions a given sediment is deposited.

Graphic measures;

Graphic statistical parameters have been discussed by a number of workers (Doeglas, 1946; Folk and Ward, 1957; Mason and Folk, 1958). The basic two-dimensional form of the co-ordinates for a graph is derived from a frequency table; the independent variable x, grain-size in this case, is plotted along the abscissa; and the dependent variable y, the percentage frequency, is plotted on the ordinate axis.

There are four main grain-size parameters;

1. Mean Size

Mean size (M_z) reflects the overall average size of the sediment as influenced by source of supply, environment of deposition, etc. and is found by:

$$M_z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where $\phi 16$ is the phi diameter at the 16th percentile of the distribution.

2. Standard Deviation

Inclusive standard deviation (σ_I) is a measure of sorting given by:

$$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

3. Skewness

Skewness (SK_I) measures the symmetry of the distribution by the formula:

$$SK_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

4. Kurtosis

Kurtosis (K_G) measures the normality of a distribution by by comparing the sorting in the central part of the curve with the sorting in the tails. The formula used is ;

$$K_G = \frac{\phi 95 - \phi 5}{2.44 * (\phi 75 - \phi 25)}$$

Moment measures

In mathematical statistics it is common practice to describe a frequency distribution in terms of moment measures. In general the first four moments provide an adequate description of a distribution which when converted to the proper form are referred ~~to~~ as the mean , standard deviation , skewness and kurtosis. The method of moment allows the entire frequency distribution to be considered , rather than a few selected percentiles. Formulae to calculate these parameters are:

1. Mean

Mean ($\bar{x}$) - First Moment

$\bar{x}_\phi = 1/100 \sum fm\phi$ where f is grade-size frequency and $m\phi$ is the mid-point of each grade-size in phi units

2. Standard deviation

Standard Deviation (σ_ϕ) - Second Moment

$$\sigma\phi = (\sum f[m_\phi - \bar{x}_\phi]^2 / 100)^{1/2}$$

3. Skewness

Skewness ($\alpha 3_\phi$) - Third Moment

$$\alpha 3_\phi = (1/100)\, \sigma_\phi^{-3} \sum f(m_\phi - \bar{x}_\phi)^3$$

4. Kurtosis

Kurtosis ($\alpha 4_\phi$) - Fourth Moment

$$\alpha 4_\phi = (1/100)\,\sigma_\phi^{-4} \sum f(m_\phi - \bar{x}_\phi)^4$$

Discriminant analysis

Discriminant analysis involves the computation of a set of functions for the purposes of classifying an individual into one of several groups. The use of the step wise procedure results in an optimal set of variables being selected, and provides an efficient way for discriminating between populations or classifications , and for assigning new observations to established classes with a minimum probability of error. A good mathematical account of this technique can be found in texts by Cooley and Lohnes (1971) and by Van De Geer (1971). Davis discusses the application of this technique in the geological context in great detail in 1973.

Factor analysis

Simply stated , factor analysis attempts to create a minimum number of new variables which are linear combinations of the original ones, such that the new variables contain the same amount of information as the original (Klovan, 1968). There are five stages of factor analysis considered by Krumbein and Graybill (1965). In the first interest is focused on the relations among variables. This is the R-mode of factor analysis , where the correlation matrix is used. The 'R' according to Davis (1973) refers to the symbol for multiple correlation.

A second purpose of factor analysis is to examine relations among the individuals or samples , rather than the variables themselves. This is the Q-mode of factor analysis which helps to arrange a number of samples into a meaningful order so the relationship between one sample and another may be deduced (Davis , 1973). Two very simple accounts of these two aspects of factor analysis are given by Cooley and Lohnes (1962) and Cattell (1965). Further,Harman (1967) discusses the application and concepts of modern factor analysis in great detail.

CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

Site and Situation of Essex County

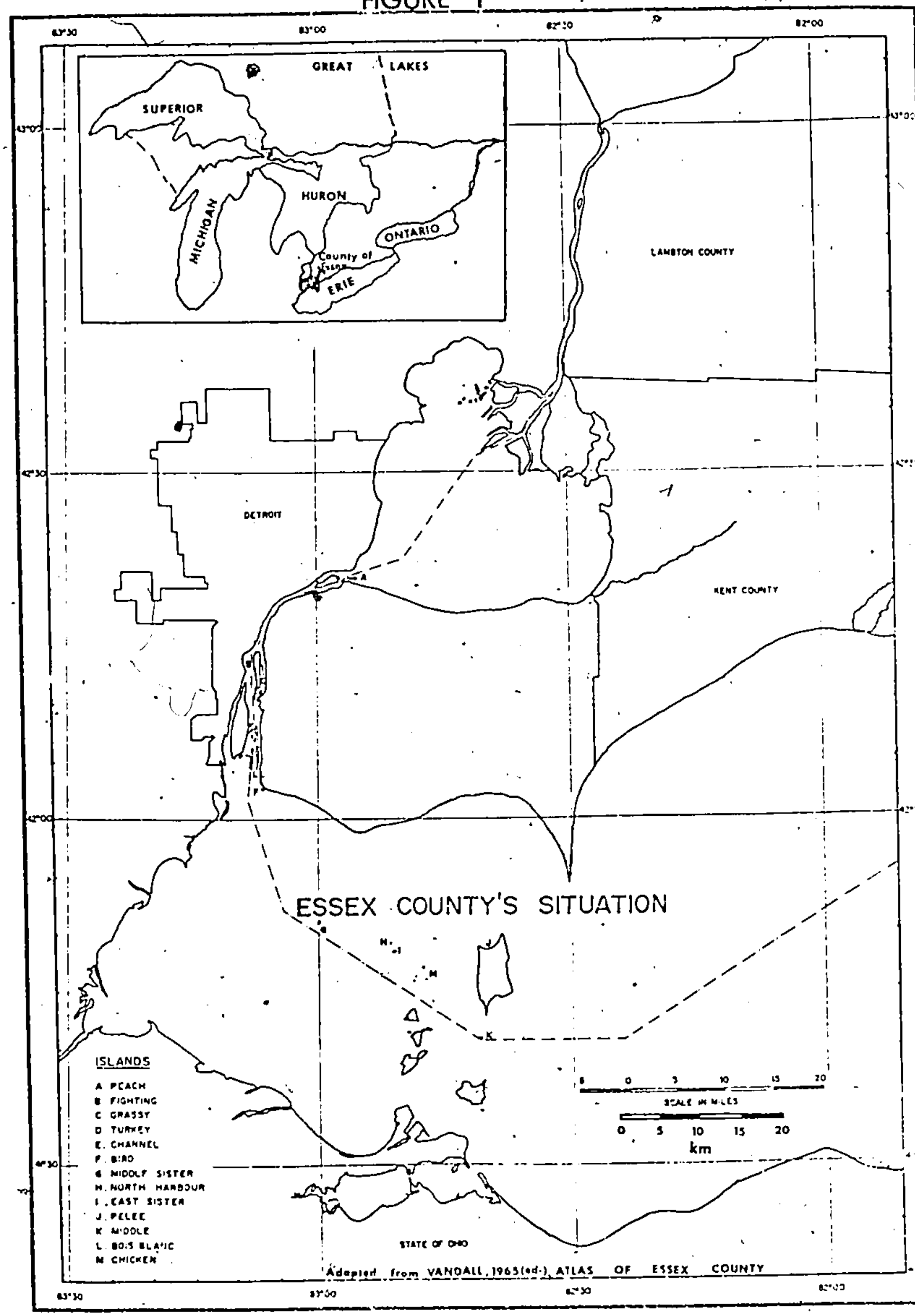
Essex county which occupies part of the south - western peninsula of Ontario covers an area of about 1654 Km^2. Extending below the 42nd parallel and west of longitude 82 degrees (Figure 1), it reaches an elevation of approximately 228.65 meters.

Regional Geology

A general description shows that the peninsula of south-western Ontario is separated from the Ottawa-Quebec lowland by the Precambrian rocks of the Frontenac Arch. The peninsula itself is underlain by a south-west trending Precambrian basement high (the Algonquin Arch) from which Cambrian, Ordovician, Silurian, and Devonian rocks dip north-westerly into the Michigan Basin and south-westerly into the Allengheny Trough (Poole, et al, 1970). The intervening Algonquin Arch consisted of a broad elongated structure that maintained some degree of subsidence during the Palaeozoic. Cambrian and Lower Ordovician sediments thin toward it, and as a result of slight uplift are bevelled and overlapped by Middle Ordovician sediments.

The nearly flat-lying Palaeozoic strata , resting upon the uneven surface of the Precambrian rocks underlying this area range in age from late Cambrian to late Devonian (Sanford and Brady , 1955). The youngest Cambrian rocks in south-western Ontario , the Little Falls Formation , lie beneath Lake Erie graditionally overlying the Theresa Formation. They consist of tan , finely crystalline dolomite, 100 feet (30.5 m) thick at the international boundary (Poole , et al 1970).

FIGURE 1


GREAT LAKES
SUPERIOR
MICHIGAN
HURON
ONTARIO
ERIE
County of Essex
LAMBTON COUNTY
DETROIT
KENT COUNTY
ESSEX COUNTY'S SITUATION
ISLANDS
A PEACH
B FIGHTING
C GRASSY
D TURKEY
E CHANNEL
F BIRD
G MIDDLE SISTER
H NORTH HARBOUR
I EAST SISTER
J PELEE
K MIDDLE
L BOIS BLANC
M CHICKEN
SCALE IN MILES
0 5 10 15 20
km
STATE OF OHIO
Adapted from VANDALL, 1965 (ed.) ATLAS OF ESSEX COUNTY

General Geology of Essex County

The area is underlain by Middle Devonian limestone, dolomite , and shale and by Upper Silurian dolomite. Rocks of the Bass Island Formation (dolomite), Detroit River group (dolomite, limestone and sandstone), Dundee Formation (limestone), and Hamilton Formation (shale and limestone) can be found at various levels in different parts of the county (Sanford , 1969; Vagners , 1971).

Mantling the bedrock in parts of the county is a thick layer of Quaternary sediments which can be divided into Pleistocene and Recent (Holocene). According to Vagners (1971) sediments deposited during the Pleistocene Epoch consist of non- stratified drift (i.e. till) and stratified drift (i.e. sand and gravel of glacio-fluvial origin, loam of fluvial origin , and , gravel , sand , silt , and clay of glacio- lacustrine or lacustrine origin). Deposits of the Holocene Epoch include alluvial loam , lacustrine sand and gravel , palustrine peat , and eolian sand.

The tills formed by glacial action as described by Hough (1958) and Prest (1968) range from a few meters thick in some bedrock highlands to at least 91.95 meters thick in some bed rock depressions and interlobate areas. Dreimanis (1961) and Goldwait , et al (1965) claimed that most of the tills were probably deposited during the last (Wisconsin) ice age , as the glaciers entered southern Ontario from the Canadian Shield.

The Recent (Holocene) sediments described by Vagners (1971)are the alluvium found in the flood plains of the larger creeks and rivers , and the beach sands along the Lake Erie shoreline. These deposits , it can be claimed , are constantly modified by wind , wave , current , fluvial and other actions.

A Brief Account of the Physiography of Essex County

Essex County occupies the western part of the St. Lawrence physiographic region. Standing between the basins of Lake Erie and Lake St. Clair , the surface is essentially a till plain overlying the Cincinatti Arch , a low swell in the bedrock of the area (Chapman and Putnam , 1973). The county lacks significant relief , the surface rising gradually from 176 meters at Lake St. Clair to approximately 154-190 meters above sea level in the central part of the county. This fairly flat environment which falls southward to the level of Lake Erie is broken by small morainic hills in the vicinity of Kingsville and Leamington . West of Leamington , a till moraine of approximately 226-228 meters forms the highest part of the county. Point Pelee , a cuspate land form , adds variability to the topography of the area.

The low gradient , and slight variation in elevation are the principal factors controlling the drianage patterns of the county . Small creeks and streams originating in the centre of the county flow northward into Lake St. Clair, southward into Lake Erie , and Westward into the Detroit River .

Point Pelee

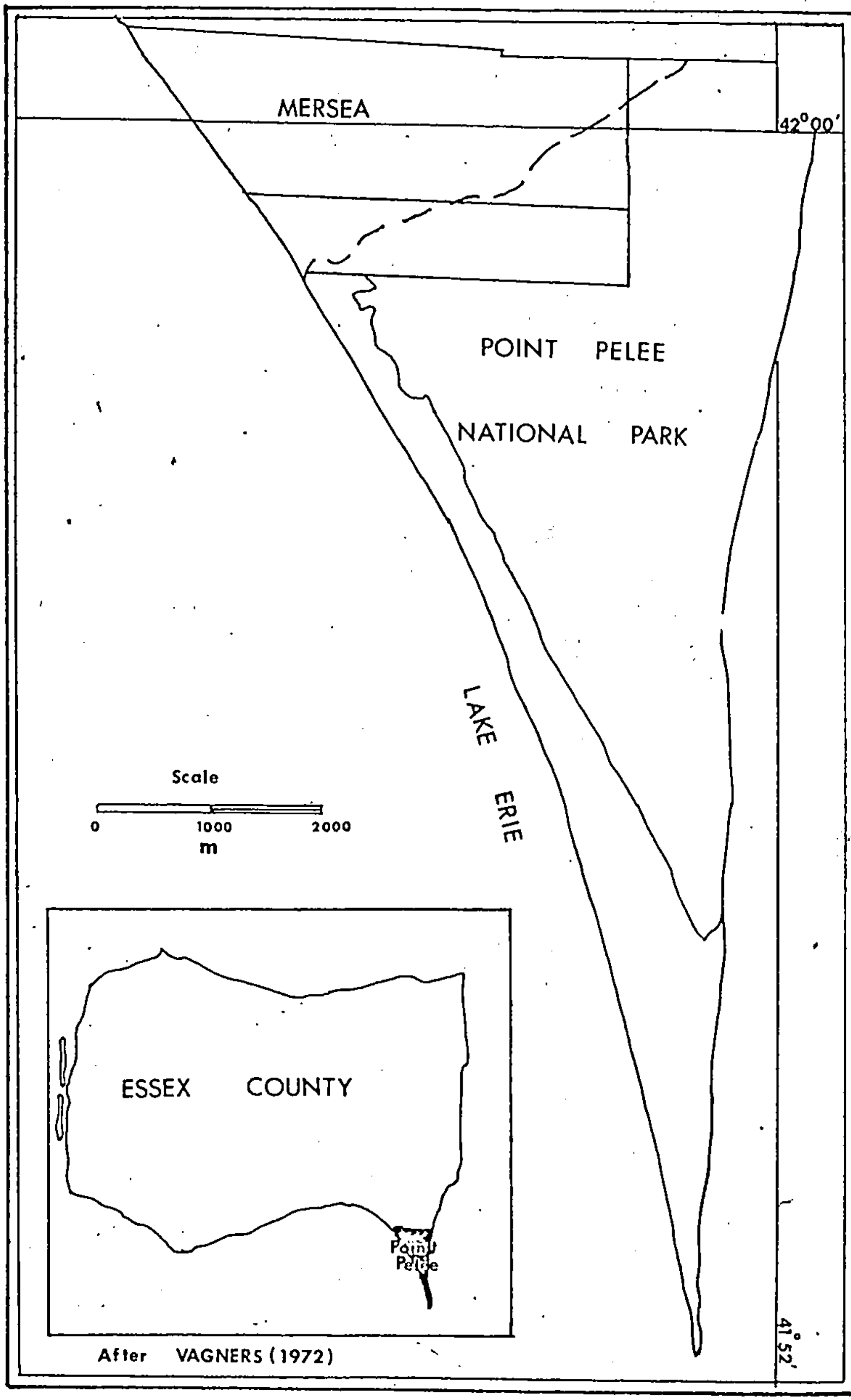
Point Pelee, a cuspate landform or spit (quasi-symmetrical or arrow head in shape), is a part of Essex County (Figure 2). Occupying an approximate area of 15.5 Km^2 , it extends about 12 Km southward from the north shore of Lake Erie. Point Pelee is a dynamic feature which experiences significant changes in the patterns of accretion and erosion over time (Kindle , 1933; Coakley,et al 1973).

Area Sampled

After making a detailed study of the geological and topographical maps of the county , and making three preliminary

FIG·2

SITUATION OF POINT PELEE



After VAGNERS (1972)

field investigations , the sand deposits in the county were mapped and the sampling sites selected (Figure 3). These sites represent a wide range of environments. Special emphasis was placed on topographic expression , provenance , and availability , type of sediments , and energy (wave , wind , current, etc.) level of each area. Preliminary work indicated that each selected site showed a variation in sediment type (field study of sediments with 2^4X hand lens) and energy levels (computation of the fetch distances for sites A to E). On a general basis the sediments collected at these six localities can be placed into five broad depositional environments . These are;

1. Shallow agitated environment:

   Zone constantly under the action of low water swash . This zone is part of the nearshore zone.

11. Foreshore Environment:

   This zone is part of the beach which extends to the limit of high water swash.

111. Backshore Environment:

   This zone is above the limit of the swash , and is not under the forces of wave action.

1V. Dune Environment:

   Zone controlled by wind action . Wind erosion and deposition are the dominant processes.

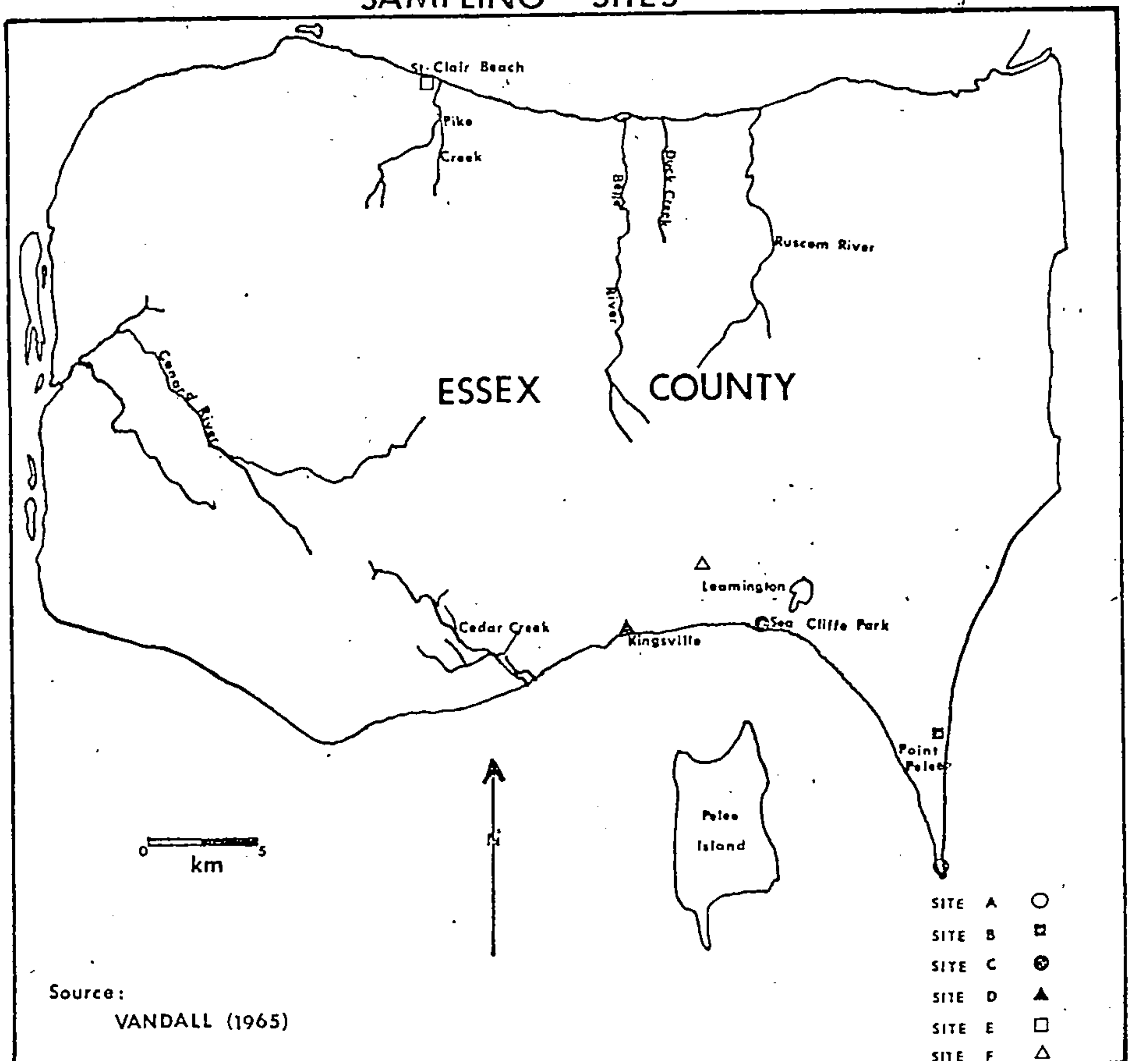
V. Glacial Environment:

   In general the glacial environment indicates the fluvio-glacial origin of sediments . Ice was once the dominant geological agent.

The shallow agitated, foreshore , and backshore environments are represented at localities A , B , C , D , and E (Figure 3).

FIG·3

SAMPLING SITES



Source:
VANDALL (1965)

These environments vary in dimension and physical characteristics at each of the selected sites. Field investigations show that the first three localities have a mixture of sand (fine , medium , and coarse) and gravel ; medium sand at site D , and a mixture of sands and gravel at site E. Sampling locality F represented a heterogenuous deposit (an area of till and gravel or gravelly sand). Fairly developed eolian environments occur at sampling localities A and C , with traces of wind blown material present at the extreme backshore of sites B and D (Figure 3).

The physical processes and the factors governing them (currents , waves , water depth , wind , etc.) at the sites of deposition will be discussed after statistical analysis of the grain-size data .

CHAPTER THREE

METHODOLOGY

Sampling Procedures

The samples chosen for the present study had to be representative of the size of grains of sand making up the beach , eolian and glacial sediments in Essex County . Discussions on the problem of sampling (geologic populations) are given by Krumbien (1953, 1954, 1960)and Koch and Link (1970). Studies on the problem of sampling sediments include those by Krumbien and Slack (1956) and Griffiths (1955,1967).

Having studied the geological maps (Vagners , 1971), three preliminary field investigations were carried out , whereby a total of 34 pairs of spot samples were taken from the various sand deposits in Essex County. Laboratory analysis (sieving) showed variation in the grain-size distribution of each sample. The mean-size of the samples reflected variation in relation to various sub-environments of deposition.

As exemplified in the geologic literature , a simple random sampling plan was evolved ; the objectives being the analyses of the samples to lead to generalisations about the population , and to provide factual information on the association between specific environments and types of grain-distributions.

Sampling Designs

The six sampling sites chosen represented parts of large depositional units . Field procedures involved mapping and measuring the length and width of each selected locality. The dimensions of each selected site are:-

Site A - 110 meters long and 45 meters wide at the widest point of the area. A profile study done at this site confirmed the results of G. Berynk[1] (1974) that both the east and west beaches of Point Pelee (site A) show significant differences in slope values .

Site B - 100 meters long and 40 meters wide at the widest point. A well marked berm is characteristic of this beach.

Site C - 100 meters long and 45 meters wide at the widest point. This beach has a wide foreshore environment (21 meters wide).

Site D - 100 meters long and 35 meters wide at the widest point . The beach sediment is medium - grained sand , but a large variation in mean size was found after the spot samples were analysed .

Site E - 100 meters long and 30 meters wide . Beach gradient at this site was less than 3^{o}.

Site F - 85 meters long and 70 meters wide . This deposit is part of the Leamington moraine.

Preliminary field investigations and laboratory analyses necessitated that two designs be employed . The choice of the of the first design was dictated by the variable nature of the sand deposits and the shape of Site A . Krumbien and Slack (1956) carried out beach sampling experiments at Illinois Beach on Lake Michigan and reported that beaches with highly variable deposits are most efficiently sampled by using the superimposed grid method . The reliability of the second design is the same as that of the first in that its use is jus-

[1] Berynk , G. , (1974), Sediment distribution around Point Pelee, Unpbl. Bsc. Thesis , Dept. of Geology , University of Windsor.

tified on beaches with fairly stable characteristics. Further this design can be employed in areas where the sedimentary deposits are fairly homogeneous . These designs ensured that the number of samples collected at each site adequately represented the population sampled . 38, 28, 24, 29, 18, and 31 samples were collected at Site A, B, C, D, E and F respectively.

At Site A, the first sampling plan was employed. The area was first drawn and a sampling frame which ensured a random spacing of samples was then decided on . This was done by using the intersections of squares on a superimposed grid . A random sample of 51 squares enclosed within the study area were then chosen , and 38 squares were drawn randomly from which samples were taken. Random numbers were read from a table of random numbers (Rand Corporation , 1958). The location of each of these samples is shown in Figure 4. This design was then transferred to the field , where with stakes , tape measure, measuring rod and a die , the samples were taken .

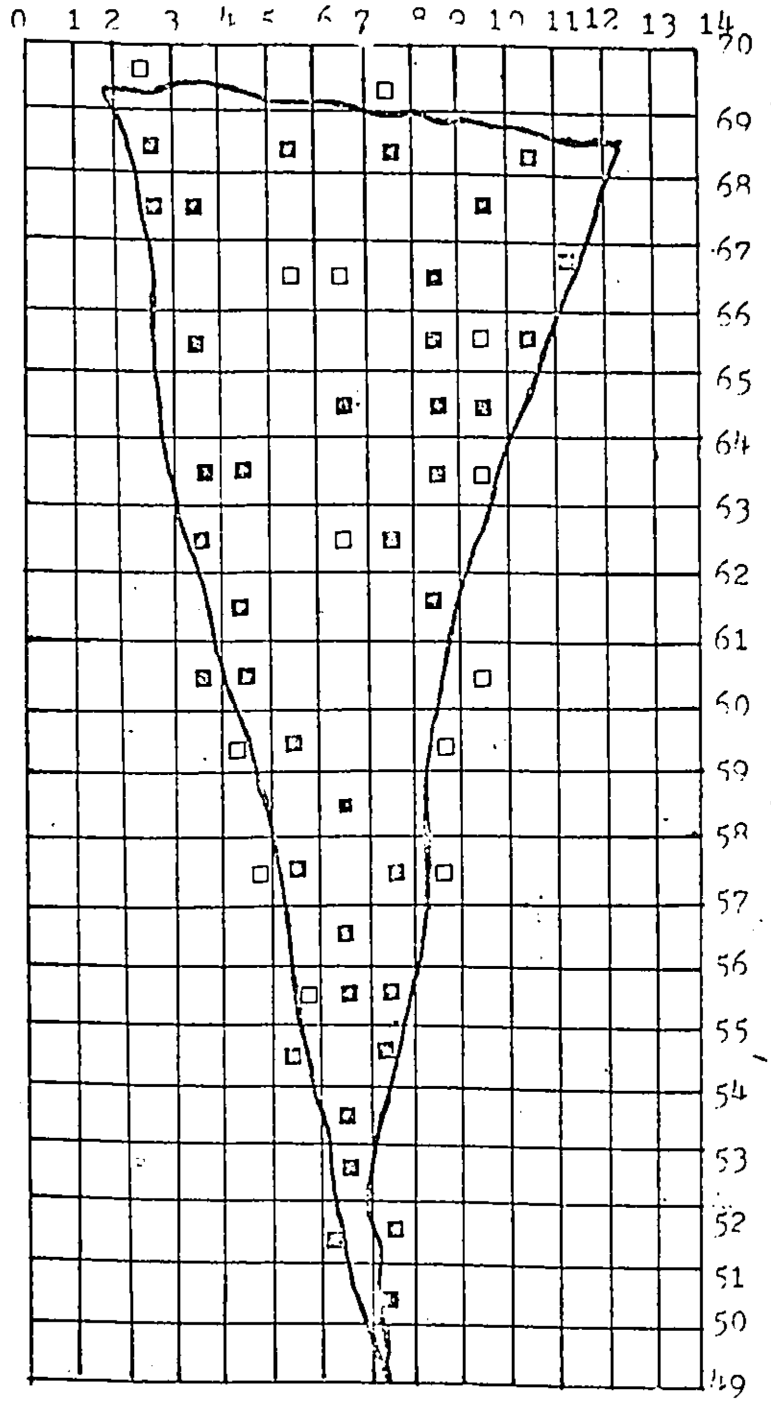
In the second plan , samples were distributed randomly over the selected sites. These were selected by using a table of random numbers that defined the X-and Y- co-ordinates of the samples. In this design the sampling points generated are typical of randomly spaced points , in that some tendency for clustering occurs. This design was employed in the field at Sites B , C , D , E and F; using the same material as at Site A.

Sample Collection and Preparation

In the field approximately 1000 grams of sediments were collected from each of the sampling points. The upper two cetimeters of sediments were scooped up with a six inch garden shovel from the foreshore, backshore, dune and glacial environments . In the shallow agitated zone samples were collected by using a simple "scoop" grabber . All samples were carefully labelled , and each was placed in a durable water-proof plastic bag. Bags were secured and placed in ordinary cardboard

FIG·4

SAMPLING DESIGN AT SITE A



□ GRID SQUARES ORIGINALLY SELECTED BUT NOT SAMPLED
■ RANDOMLY SAMPLED SQUARES

cartons.

On the same day of collection , all samples were dried in electric ovens for twelve hours at 100°C . In some cases samples collected from the shallow agitated zone were dried for 20 hours. Samples were then split according to the method proposed by Muller, 1967 (Appendix One). All sediments coll-ected from the glacial deposits, and seven samples collected from the shallow agitated zones were disaggregated by using a mortar and rubber pestle.

Sieve Analysis and Determination of Grain-Size

Muller (1967) shows that different measurement techniques apply to widely different size ranges. In addition the choice of method depends both on the degree of consolidation and the objectives of the study (Pettijohn et al , 1965; Griffiths, 1967). Folk, 1966 has reviewed the standard methods (sieving , se-ttling tube , pipette , hydrometer , microscopic and grain counting) used in sediment studies . For this research the sieving method was followed. Folk (1966 , p. 75) says that "si-eving is probably most accurate for general analysis of sand and gravel , and the time required for analysis is intermedi-ate. " Using 100 grams of sediment from each sample , grain-size analysis with subdivisions based in ½phi intervals, (a $\log_2$ transformation of the diameter in millimeters of the se-diment size) proposed by Krumbein (1934), were performed.

On Tyler screens (-2.0 ∅ ; -1.5 ∅ ; -1.0 ∅ ; -0.5 ∅ ; 0.0 ∅ ; 0.5 ∅ ; 1.0 ∅ ; 1.5 ∅ ; 2.0 ∅ ; 2.5 ∅ ; 3.0 ∅ ; 3.5 ∅ ; 4.0 ∅) and pan , all samples were sieved on Ro-Tap shaker for 15 minutes . The retent of each sieve was weighed on a Mettler Precision Balance to 0.01 grams.

Computation and Presentation of Results

The results of the 168 grain-size analyses were computed with the aid of an electronic calculator and a digital computer.

The results are presented in the following manner:-

The samples are considered to be from "unknown" depositional environments. Each statistical technique to be tested is applied to the results of these analysed samples . The results are then compared to see if the techniques provide factual information on the true depositional environments of the samples . An evaluation and discussion follows.

CHAPTER FOUR

STATISTICAL ANALYSES OF GRAIN-SIZE DATA

Introduction

One of the chief aims of grain-size analysis is to find the grain-size frequency from which statistical parameters can be derived. As mentioned in Chapter One a number of workers have discussed the presentation and evaluation of the results of mechanical analysis. The application of some of these techniques are demonstrated in this paper.

Graphic Measures

a/ Cumulative Curves

One of the chief graphic devices used to display sedimentological data is the cumulative curve. This shows the percentage proportion of the sediment which has a greater grain size than a particular value. Cumulative curves are commonly plotted with the cumulative frequency represented on a probability scale. This is designed so that a Normal (or Gaussian) frequency distribution will plot as a straight line.

The cumulative curves of the 168 samples (Appendix 4 , pp. 92 to I32) clearly show that a number of the samples collected from the shallow agitated, foreshore , backshore , and dune areas approach normality . In some cases the "curves" appear to be made up of two or more straight line segments. These segments can be interpreted as parts of several Normal distributions mixed together . Spencer (1963) has shown that most grain-size frequency curves can be broken down into complex mixtures of two or three fundamental log-normally distributed populations. However he has not considered the 'break of slope' characteristic of the curves for sands from the glacial environment . These curves are distinctly bimodal and are in some cases trimodal.

b/ Component Population Analysis using Cumulative Curves

The application of cumulative curves as an aid in component population analysis for distinguishing the depositional environments is clearly demonstrated by Visher (I969). This technique uses the cumulative curves to delimit truncated phi-normal distributions. Using the log-normal components ($\phi = -\log_2$ mm) of the cumulative curves various sediment populations can be identified. Visher determined three basic populations (traction, saltation, and suspension) of sediment transport. These three populations (Appendix 2) are reflected in samples collected from the shallow agitated zone, foreshore zone, backshore zone and the dune environment. Similar populations have been identified by Moss(I964), Upchurch (I970) and Greenwood (I972).

The cumulative curves for the samples collected from the shallow agitated zone(Appendix 4) reflect similar characteristics to the distributions obtained by Visher (I969, Appendix 3A). These samples in nearly all cases reflect a poorly sorted traction population and a saltation population of coarse (-Iϕ - 0.0 ϕ) and slightly less coarse materials. Significantly, some samples (for example 23 and 42) fail to reflect any distinct traction population. This can be due to the rapid variation of energy present in this zone which transport out or transport in material of various size ranges, or to the source area of the sediments or the complication of other factors (for example current velocity, shoreline geometry, and sedimentation rates).

With only a few exceptions(for example samples 27, 49, 67, and II7, Appendix 4) samples from the foreshore and backshore environments reflect similarities in curve shape to those obtained by Visher (I969, Appendix 3B). The fore shore samples in nearly all cases demonstrate the development of two saltation populations, with a good sorting of fine materials in the first population and a second population of better sorted finer materials. Both Visher (I969) and Greenwood (I972) attribute the presence of two saltation populations with the swash-back-wash action of the waves.It is also evident that some of the backshore samples (for example 37, 70, and II9) reflect a variable percentage of suspended material greater than 2.5 phi.

Samples from the dune environment (Appendix 4) demonstrate the influence of wind processes. Characteristics of the curves (Appendix 3C) are similar to those postulated by Visher (I969). These include: I/ a poorly sorted coarse sliding or rolling population;

2/a very well sorted saltation population with a size population ranging from approximately 2.0 to 3.5 phi;

and 3/ a variable percentage of the suspension population. Significantly some samples(for example I7, 24 and 83) illustrate the presence of a small percentage of coarse material which may indicate possible bed rolling .Although Bagnold (I954) discusses the general lack of competence of wind processes to move a coarse population by surface creep it will be discussed that the existence of this coarse population can be due to one or more physical or climatalogical processes.

The glacial samples (Appendix 4) show a considerable range of material (-02.00 phi to 04.00 phi). Doornkamp and King (I97I) claim that the different size range of materials that can be found in a glacial environment clearly demonstrate the different processes which once acted and now active in such an environment. The curves illustrate quite well the bimodal and in some instances the trimodal characteristics which are typical of sediments from a glacial environment.

The characteristics displayed by the individual grain-size distribution curves can only provide a general basis for environmental discrimination. The unusual shape of some of the curves representing samples from the shallow agitated, foreshore, and backshore environments can be the result of several influencing factors which will only be subjectively discussed. Visher (1969) rightly claims that attempts should not be made to use precise limits for the slopes and truncation points to determine different sand populations, and thus individual environments.

Graphic Statistics

One method widely used to compare different environments of deposition is graphic statistics. The graphic method involves reading selected percentiles off the cumulative size-frequency curve plotted on probability paper. The ones that have been used are the 5, 16, 25, 50, 75, 84 and 95 % coarser figures. Using these values it is possible to describe the sediment in terms of median, mean, sorting, skewness, and kurtosis. The parameters described in Chapter One have been used by Mason and Folk (1958) to differentiate sands on Mustang Island on South Texas Gulf Coast. They suggested that the best means of differentiating sands from the beach, dune, and eolian environments is by plotting skewness against kurtosis because the geological processes at work have their greatest effect on the tails of the size distribution curves. According to their investigation , beach sands form normal curves, dune sands are positively skewed but still mesokurtic, and eolian flat sands are positively skewed and leptokurtic.

The data for the graphical parameters have been read off the cumulative curves (Appendix 4), and the median, mean, standard deviation, skewness, and kurtosis were calculated using a computer program (Appendix 5).

The computed graphical statistical parameters (Table I) are shown in a plot of skewness against kurtosis for the samples as "unknowns" (Figure 5A) and for the samples as "knowns" (Figure

TABLE ONE

GRAPHIC PARAMETERS

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT
FA 1	0.97	1.03	0.49	0.09	1.09
MA 2	-0.03	-0.28	0.31	0.04	0.85
MA 3	-0.35	-0.35	0.32	0.05	0.87
FA 4	0.70	0.67	0.64	-0.05	1.06
FA 5	0.87	0.92	0.49	0.08	1.14
FA 6	0.66	0.60	0.59	-0.14	0.94
MA 7	0.39	0.41	0.00	-0.86	-1.24
FA 8	0.38	0.37	0.51	-0.05	0.94
MA 9	-0.39	-0.45	0.19	4.71	0.08
NA 10	1.18	1.11	0.57	-0.12	0.85
FA 11	0.61	0.59	0.55	-0.08	0.91
SA 12	1.55	1.55	0.61	-0.02	1.01
MA 13	-0.67	-0.32	-0.07	65.61	0.01
FA 14	1.21	1.09	0.67	-0.32	1.09
MA 15	-0.43	-0.44	0.17	43.49	0.01
SA 16	0.78	0.67	0.65	0.00	0.82
NA 17	1.33	1.27	0.57	-0.17	0.85
SA 18	0.47	0.50	0.41	0.20	0.81
FA 19	0.18	0.17	0.37	-0.04	0.95
NA 20	2.08	2.03	0.48	-0.22	1.44
NA 21	1.40	1.40	0.52	-0.05	1.07
NA 22	1.61	1.56	0.57	-0.16	0.88
MA 23	-0.44	-0.41	0.21	0.20	0.85
NA 24	1.59	1.54	0.57	-0.12	0.96

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT
MA 25	-0.37	-0.15	0.00	-0.54	0.14
NA 26	1.52	1.43	0.72	-0.15	0.74
SA 27	0.84	0.85	0.78	-0.04	0.85
NA 28	1.00	1.01	0.59	0.00	0.97
SA 29	1.28	1.24	0.47	-0.12	0.99
MA 30	-0.32	-0.13	0.00	-1.11	-0.33
FA 31	0.46	0.35	0.66	-0.28	1.04
FA 32	0.80	0.78	0.53	-0.09	0.91
FA 33	0.68	0.66	0.64	-0.08	1.02
SA 34	1.32	1.33	0.50	0.00	0.97
MA 35	-0.33	-0.33	0.19	2.23	0.19
NA 36	1.43	1.42	0.45	-0.05	0.93
SA 37	0.60	0.60	~~0.51~~	-0.01	0.96
NA 38	1.37	1.38	0.54	0.00	-0.80
MB 39	-0.52	-0.21	0.03	-2.87	0.23
MB 40	-0.38	-0.30	0.47	0.23	0.91
MB 41	-0.31	-0.07	0.11	4.95	-3.13
MB 42	-0.17	-0.19	0.47	-0.02	0.99
MB 43	-0.19	-0.21	0.38	-0.05	0.79
MB 44	-0.19	-0.20	0.37	0.01	0.83
MB 45	-0.02	-0.01	0.24	0.11	0.98
FB 46	0.28	0.29	0.45	0.02	0.88
FB 47	0.24	0.18	0.54	-0.17	0.91

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT
FB 48	0.30	0.21	0.58	-0.19	1.01
FB 49	0.43	0.41	0.66	-0.02	1.18
FB 50	0.20	0.17	0.57	-0.02	0.78
FB 51	0.40	0.33	0.60	-0.08	0.96
FB 52	0.79	0.72	0.50	-0.23	0.94
FB 53	0.88	0.81	0.50	-0.22	0.84
FB 54	1.02	0.99	0.56	-0.05	1.21
FB 55	1.06	1.06	0.57	-0.06	0.95
FB 56	0.97	1.06	0.59	0.16	1.07
FB 57	1.32	1.22	0.76	-0.17	0.96
SB 58	1.64	1.60	0.57	-0.13	0.89
SB 59	1.35	1.33	0.67	-0.05	0.88
SB 60	1.21	1.19	0.57	-0.10	0.97
SB 61	1.16	1.16	0.63	-0.00	1.02
SB 62	1.42	1.37	0.65	-0.14	0.86
SB 63	1.62	1.51	0.47	-0.26	1.19
SB 64	1.66	1.67	0.49	0.03	1.07
SB 65	1.78	1.78	0.46	-0.03	1.43
SB 66	1.35	1.35	0.46	-0.01	0.90
MC 67	-0.37	-0.40	0.27	1.72	0.22
MC 68	-0.41	-0.42	0.24	2.19	0.19
MC 69	-0.27	-0.33	0.26	1.29	0.26
MC 70	-0.58	-0.54	0.25	2.11	0.30
MC 71	-0.18	-0.16	0.36	-0.02	1.13

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT
FC 72	0.23	0.27	0.58	0.18	1.31
FC 73	0.23	0.19	0.48	-0.11	0.89
FC 74	1.02	1.05	0.71	0.02	0.87
FC 75	0.86	0.85	0.49	-0.04	0.92
SC 76	1.67	1.62	0.58	-1.13	1.05
SC 77	0.10	0.74	0.61	1.25	1.06
SC 78	1.45	-1.42	0.65	-0.12	0.93
SC 79	1.73	1.67	0.43	-0.30	1.78
SC 80	1.21	1.17	0.37	-0.14	1.07
SC 81	1.42	1.43	0.46	-0.01	1.07
NC 82	1.37	1.42	0.49	0.12	0.96
NC 83	1.64	1.59	0.47	-0.24	0.88
NC 84	2.19	2.16	0.44	-0.17	0.95
NC 85	1.91	1.86	0.32	-0.22	1.09
NC 86	2.04	2.01	0.52	-0.17	1.09
NC 87	1.88	1.87	0.47	-0.01	1.02
FC 88	0.81	0.86	0.53	0.17	1.01
FC 89	0.69	0.64	0.58	-0.15	0.86
SC 90	0.81	0.73	0.50	-0.26	0.89
MD 91	-0.45	-0.42	0.40	0.08	0.89
MD 92	-0.32	-0.33	0.47	-0.04	0.91
MD 93	0.35	0.36	0.40	-0.04	1.02
MD 94	0.44	0.32	0.36	-0.19	0.67
MD 95	0.17	0.13	0.46	-0.14	0.89

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT.
FD 96	1.00	0.92	0.42	-0.19	1.14
FD 97	0.74	0.73	0.31	-0.04	1.01
FD 98	0.83	0.87	0.38	0.23	1.29
FD 99	1.16	1.14	0.38	-0.04	1.29
FD 100	1.10	1.08	0.39	-0.11	1.25
FD 101	1.13	1.14	0.42	0.06	1.42
FD 102	1.10	1.11	0.36	-0.03	1.08
FD 103	0.99	1.00	0.31	-0.02	1.30
FD 104	1.03	1.10	0.36	0.22	1.17
FD 105	1.04	1.13	0.37	0.37	1.09
FD 106	1.08	1.09	0.41	0.08	1.09
FD 107	1.10	1.10	0.38	0.06	1.13
FD 108	0.61	0.62	0.39	0.08	1.03
FD 109	0.94	0.85	0.47	-0.30	1.01
FD 110	1.10	1.11	0.29	-0.04	1.46
FD 111	1.11	1.09	0.34	-0.07	1.35
FD 112	1.13	1.12	0.38	0.01	1.08
SD 113	1.63	1.60	0.60	-0.03	1.10
SD 114	1.82	1.83	0.47	-0.04	1.10
SD 115	1.95	2.03	0.52	0.16	1.00
SD 116	1.82	1.85	0.43	0.15	1.16
SD 117	1.88	1.92	0.48	0.18	1.22
SD 118	1.97	1.93	0.44	-0.17	1.07
SD 119	1.84	1.90	0.43	0.17	1.22

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW	KURT
ME 120	0.30	0.29	0.46	-0.19	1.49
ME 121	0.28	0.16	0.70	-0.23	0.84
ME 122	0.47	0.83	0.41	7.63	2.71
ME 123	-0.26	-0.27	0.41	-0.10	0.90
ME 124	-0.33	-0.37	0.46	-0.10	0.95
ME 125	0.07	0.03	0.46	-0.13	1.11
FE 126	-0.13	0.08	0.19	1.56	0.26
FE 127	-0.34	-0.06	0.83	0.37	0.83
FE 128	-0.18	-0.25	0.55	-0.20	1.02
FE 129	-0.-4	0.02	0.55	0.11	1.05
FE 130	0.01	-0.03	0.56	-0.09	1.01
FE 131	0.29	0.28	0.46	-0.03	1.07
FE 132	0.51	0.60	0.33	0.37	1.18
FE 133	0.85	0.80	0.51	-0.10	0.89
FE 134	0.86	0.85	0.51	-0.03	1.07
FE 135	0.67	0.63	0.46	-0.09	1.05
FE 136	1.03	1.03	0.52	0.06	0.92
FE 137	1.10	1.13	0.58	0.14	1.01
GLF 138	-1.26	-1.27	0.21	-5.52	-0.15
GLF 139	-0.94	-0.99	0.39	2.32	0.16
GLF 140	-0.01	-0.00	1.09	0.51	0.48
GLF 141	-0.14	0.04	0.94	0.68	0.75
GLF 142	-1.05	-0.95	0.61	1.97	0.23
GLF 143	-0.34	-0.46	0.68	0.67	0.43

TABLE ONE (Cont'd)

SAMPLE IDN. AND NO.	MEDIAN DIAM.	MEAN DIAM.	STD. DEV.	SKEW.	KURT
GLF 144	0.01	0.09	1.00	0.54	0.47
GLF 145	0.50	0.33	1.12	0.22	0.60
GLF 146	-0.83	-0.93	0.45	1.52	0.33
GLF 147	-0.79	-0.62	0.84	1.04	0.63
GLF 148	-1.30	-0.63	-0.11	4.18	0.12
GLF 149	-1.41	-1.27	0.43	3.21	0.22
GLF 150	-1.35	-0.57	-0.05	2.88	0.08
GLF 151	-1.29	-0.86	0.79	1.79	0.29
GLF 152	-1.85	-0.87	0.93	2.18	0.31
GLF 153	-0.40	-0.36	0.99	0.72	0.40
GLF 154	0.30	0.07	1.13	0.26	0.45
GLF 155	0.42	0.28	1.11	0.26	0.46
GLF 156	0.29	0.26	1.20	-0.06	1.51
GLF 157	0.66	0.69	1.31	-0.03	0.93
GLF 158	-0.71	-0.61	0.95	1.00	0.29
GLF 159	-0.58	-0.14	1.09	0.96	0.49
GLF 160	0.69	0.43	1.39	0.14	0.37
GLF 161	-1.17	-0.40	0.30	-56.91	0.83
GLF 162	-0.96	-0.73	0.83	1.30	0.43
GLF 163	-1.51	-0.63	-0.06	2.72	-0.15
GLF 164	0.43	0.33	1.28	0.30	0.48
GLF 165	0.43	0.31	1.46	0.31	0.53
GLF 166	-1.10	-0.90	0.56	1.94	0.29
GLF 167	0.81	0.76	1.12	-0.20	1.81
GLF 168	-0.45	-0.15	1.08	0.30	0.87

TABLE ONE (Cont'd)

Explanation to sample identification

FA-	Foreshore samples from Site A
MA-	Shallow agitated samples from Site A
NA-	Dune samples from Site A
SA-	Backshore samples from Site A
MB-	Shallow agitated samples from Site B
FB-	Foreshore samples from Site B
SB-	Backshore samples from Site B
MC-	Shallow agitated samples from Site C
FC-	Foreshore samples from Site C
SC-	Backshore samples from Site C
NC-	Dune samples from Site C
MD-	Shallow agitated samples from Site D
FD-	Foreshore samples from Site D
SD-	Backshore samples from Site D
ME-	Shallow marine samples from Site E
FE-	Foreshore samples from Site E
GLF-	Glacial samples from Site F

5B) , and in a plot of inclusive graphic standard deviation against mean size for the samples as "unknowns" (Figure 6A), and for the samples as "knowns" (Figure 6B).

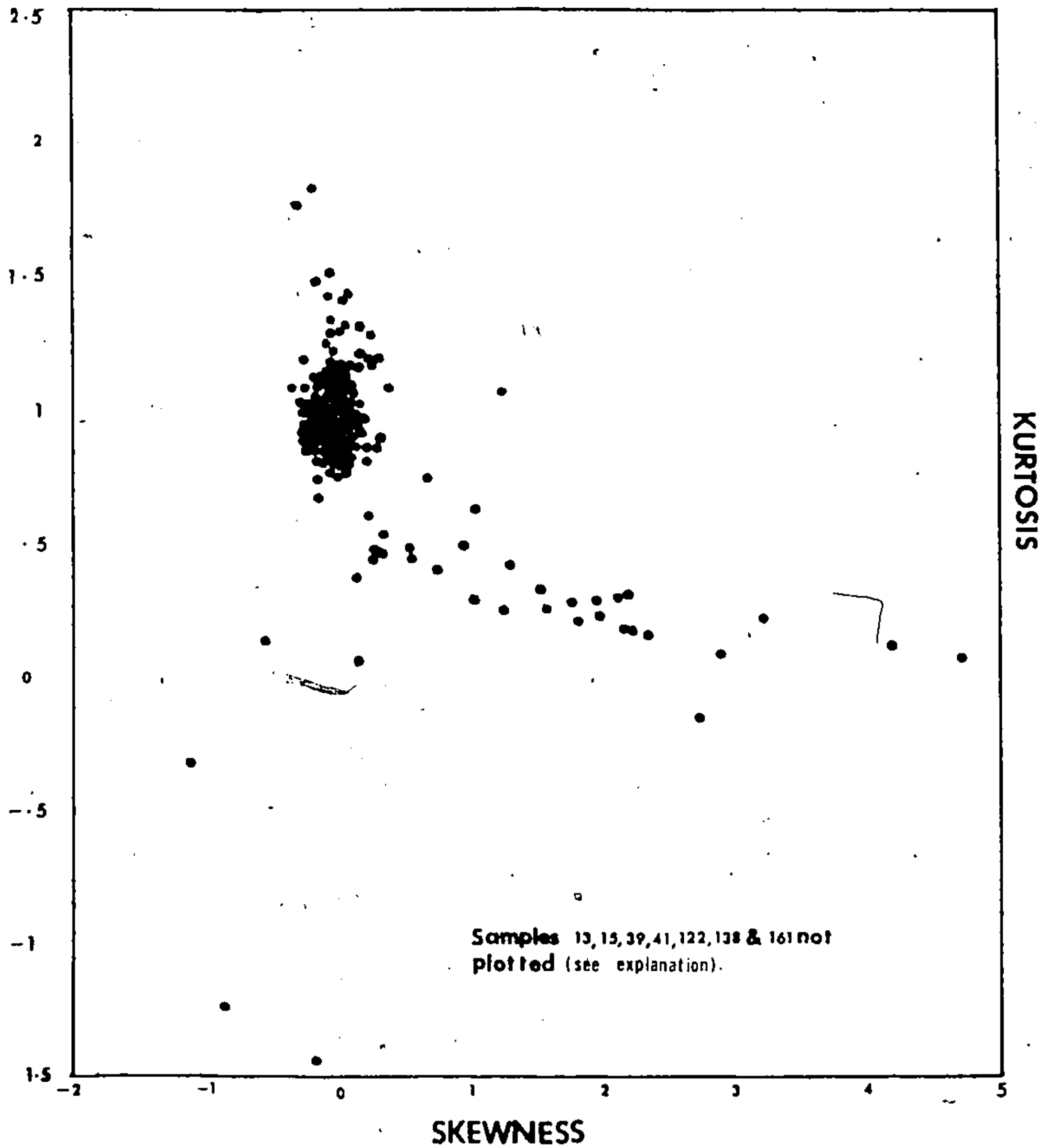
In the plot of skewness against kurtosis (Figures 5A and 5B), seven samples (Nos. I3, I5, 39, 4I, I22, I38, and I6I) have not been plotted. Samples I3, I5, 39, 4I, and I22 are from the shallow agitated environment with skewness values of 65.6I, 43.49, -02.87, 04.95, and 07.63 respectively, and samples I38 and I6I are from the glacial environment with respective skewness values of -05.52 and -56.9I. The skewness values of these samples when plotted against the kurtosis distort the appearance of the graph, and were therefore omitted from the scatter plot. The plot of skewness against kurtosis (Figure 5A) for the samples as "unknowns" show an extremely clustered pattern for approximately 80 % of the samples. Plot of the samples as "knowns" (Figure 5B) indicate a complete mixture of samples from the shallow agitated , foreshore, backshore and dune environments. Only samples from the glacial environment are partially separated. It can be clearly seen that the plot of skewness against kurtosis has failed to differentiate samples from all of the environments.

The plot of the inclusive graphic standard deviation against the mean size for the samples as "unknowns" (Figure 6A) show a widely distributed pattern with three small clustered groups. With the sample environments identified (Figure 6B) three environments (shallow agitated, foreshore and glacial) are partially separated. Samples from all of the environments are intermixed especially those from the backshore and dune environments. From these results it can be claimed that graphic measures cannot reliably separate environments of deposition even if the samples are identified as "knowns".

Although Mason and Folk (I958) claim that skewness and kurtosis offer the best means of identifying the environments and considered standard deviation to be helpful , but the mean size to be worthless it is evident that their results are not

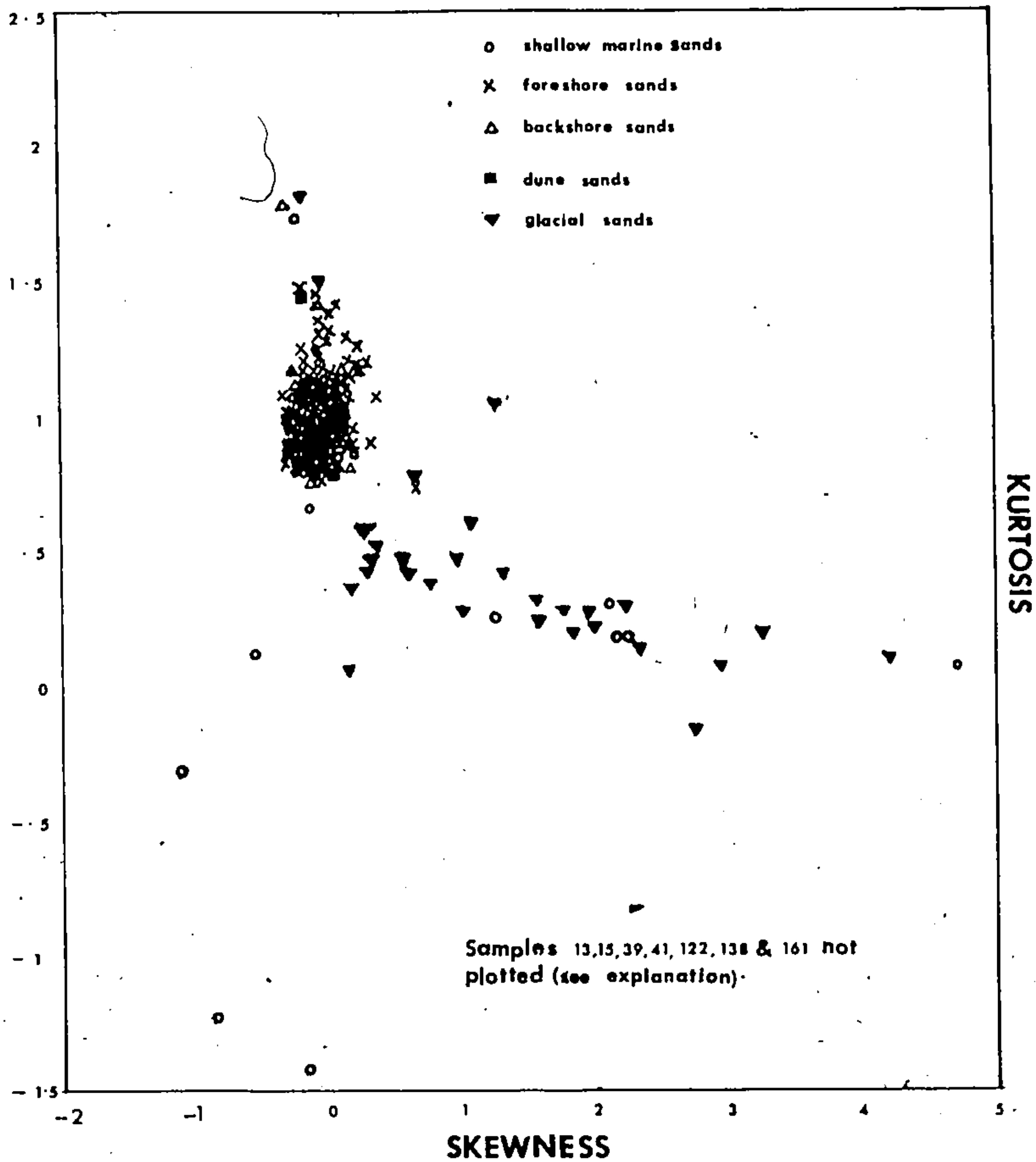
FIG·5A

PLOT OF GRAPHICAL PARAMETERS AFTER MASON AND FOLK. SAMPLES PLOTTED AS "UNKNOWNS."



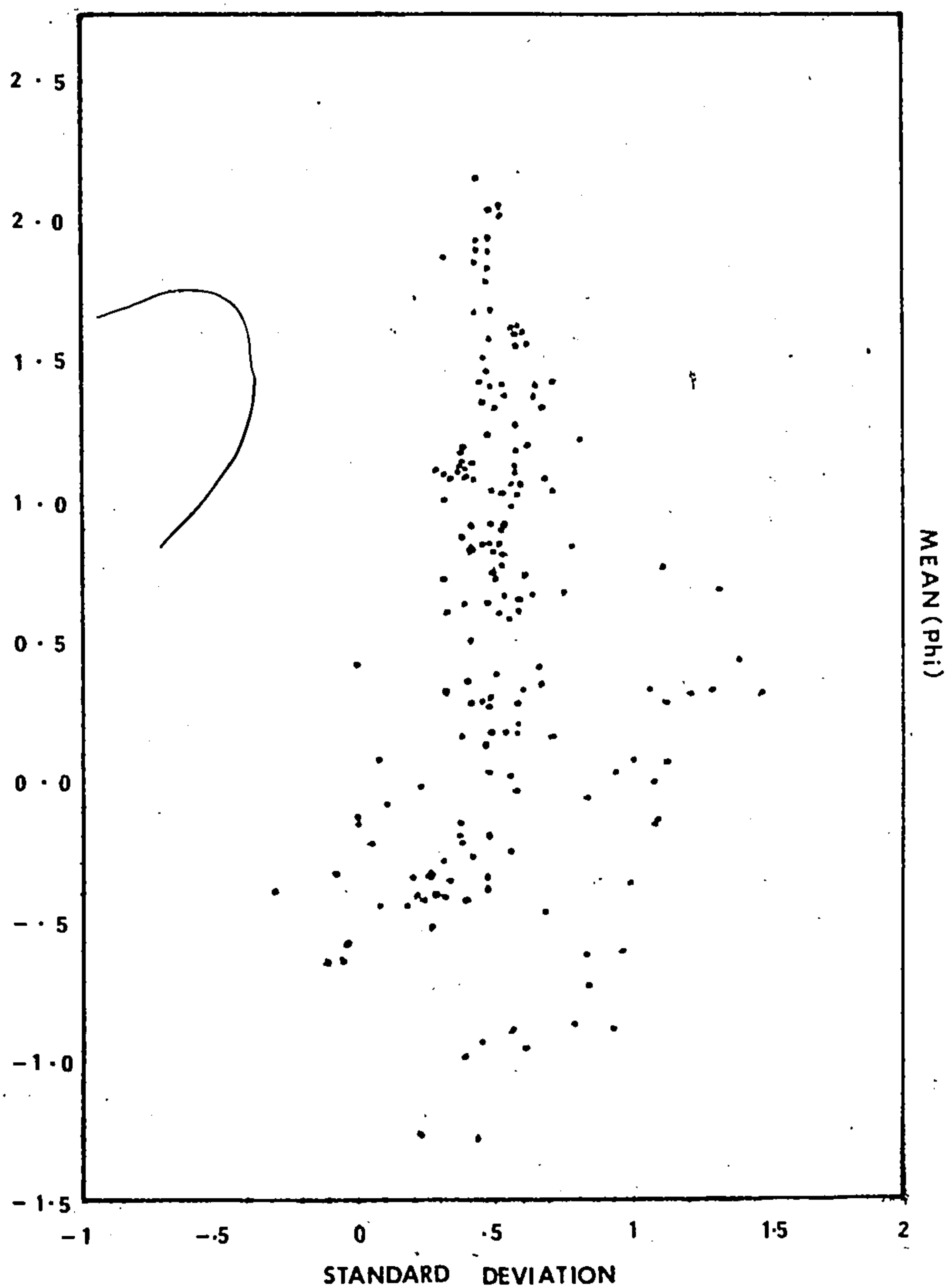
FIG·5B

PLOT OF GRAPHICAL PARAMETERS AFTER MASON AND FOLK· SAMPLES PLOTTED AS "KNOWNS."



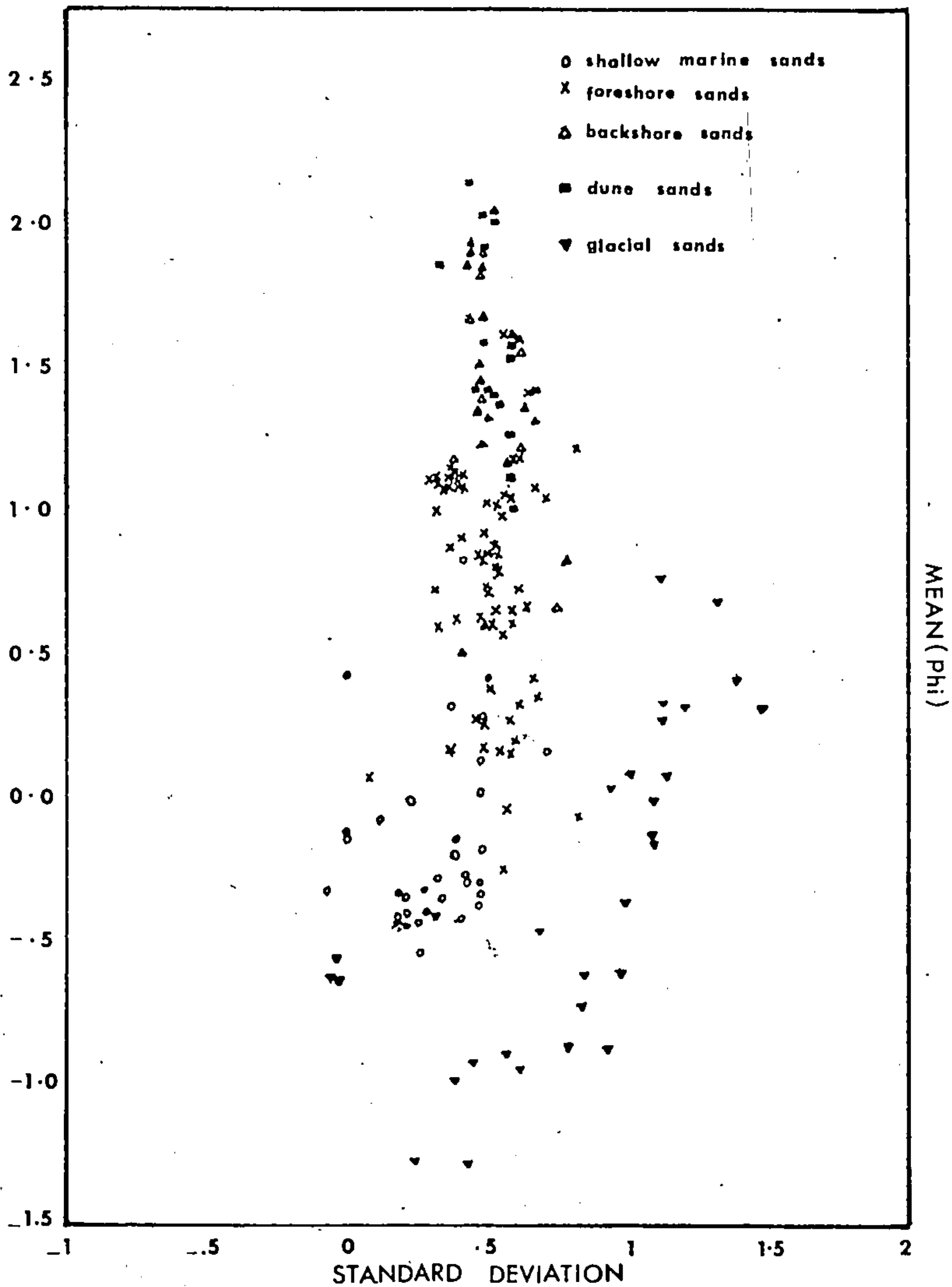
FIG·6A

PLOT OF GRAPHICAL PARAMETERS AFTER MASON AND FOLK. SAMPLES PLOTTED AS "UNKNOWNS."



FIG·6B

PLOT OF GRAPHICAL PARAMETERS AFTER MASON AND FOLK SAMPLES PLOTTED AS "KNOWNS."



supported by this study. The plot of standard deviation against mean size yields better results than the plot of skewness against kurtosis. This directly indicates that there are differences in the average size of the sediment from the various environments. Mason and Folk (I958) observed a remarkable similarity between all samples in average grain- size and indicated that a set of peculiar conditions may have influenced this. They claimed that the source supplying sand to their study area apparently contribute only limited range of sizes and that the environmental processes acting on the deposits effected an extreme degree of homogenization. In Essex County, however, it can be argued that marked differences in the size of the sediment are due to different physical and environmental processes at each of the environments studied.

Moment Mbasures

Use of percentiles read from the cumulative curve is not the only way to obtain statistics that summarise the properties of an observed distribution. Another method is moment measures described in Chapter One. This technique proposed by Van Orstand (I925), uses the entire frequency distribution, and is now widely used in sedimentological studies. Friedman (I96I) is one of the early workers who have shown the effectiveness of these measures. He has demonstrated that by plotting the skewness against the the mean for 267 samples derived from dunes, oceans, lake beaches, and rivers, that it is possible to distinguish between the dune and beach sands in terms of these two characteristics. The dune sands tend to have a positive skewness, which implies a tail of finer particles, while the beach sands mostly had a very small or negative skewness , indicating a tail of coarser particles.

Further Friedman (I96I) claimed that within certain limitations , river sands can be distinguished from beach sands on the basis of plots of the third moment (skewness) against standard deviation (sorting) , because beach sands tend to be better sorted than river sands, and thus tend to have lower numerical standard deviation values. In plots involving other moment parameters, Friedman stated that kurtosis is not environmentally sensitive, and as such plots of kurtosis against any of the other moment parameters have not been reproduced in this study. His results when interpreted from the various plots have environmental significance in that different size particles are controlled by varying energy conditions and different processes.

The moment measures of the I68 samples have been computed using a computer program (Appendix 6), and the results presented in Table Two. Scatter plots of the results are presented as "unknowns" (Figure 7A) and as "knowns" (Figure 7B) for the measures of mean against skewness and as "unknowns" (Figure 8A)and "knowns" (Figure 8B) for the measures of standard deviation against skewness.

According to Friedman (I96I), if the moment technique is an effective indicator of environments of deposition, then the scatter plots should show specific groupings. Further, by inspection of the scatter plots it should be illustrated that sands from different environments fall above or below the dashed line on the scatter plots. The plot of mean against skewness (Figure 7B) classified only I2.5 % of the dune samples correctly. Further, 58.06 % of the samples from the glacial environment have been classified with the samples from the shallow agitated and foreshore environments.

The plot of standard deviation against skewness (Figure 8A) for the samples (Nos. I-I37) as coming from "unknown" environments show a widely distributed pattern, with no apparent meaning. With the samples environmentally identified (Figure 8B), 42 samples (7 shallow agitated, I8 foreshore, I3 backshore, and 4 dune) have been classified as coming from a river environment when in fact, samples were not taken from a river environment. Further, samples from known environments are scattered and intermixed. The distribution of the samples on the scatter plots when plotted as "knowns" indicate that the application of moment measures to differentiate depositional environments is not particula-

TABLE TWO

MOMENT MEASURES

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FA 1	1.01	0.49	-0.15	3.78
MA 2	-0.39	0.40	-0.14	2.66
MA 3	-0.32	0.41	-0.21	2.50
FA 4	0.68	0.63	0.02	3.22
FA 5	0.87	0.51	-0.08	3.49
FA 6	0.61	0.60	-0.28	2.94
MA 7	-0.34	0.27	-0.27	3.74
FA 8	0.37	0.53	-0.13	2.85
MA 9	-0.45	0.39	-0.55	3.18
NA 10	1.15	0.58	-0.06	2.65
FA 11	0.56	0.58	-0.24	2.83
SA 12	1.55	0.61	-0.01	2.82
MA 13	-0.65	0.41	0.22	2.53
FA 14	1.05	0.70	-0.90	3.59
MA 15	-0.38	0.31	0.19	2.80
SA 16	0.69	0.81	-0.22	2.20
NA 17	1.27	0.59	-0.28	2.50
SA 18	0.42	0.55	-0.10	3.09
FA 19	0.16	0.41	0.09	3.57
NA 20	2.04	0.56	-1.33	6.26
NA 21	1.42	0.60	-0.28	3.40
NA 22	1.56	0.60	-0.47	2.68
MA 23	-0.31	0.32	0.83	5.11
NA 24	1.55	0.59	-0.35	3.06

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
MA 25	-0.42	0.28	0.19	3.01
NA 26	1.45	0.74	-0.25	2.07
SA 27	0.82	0.76	-0.07	2.24
NA 28	1.00	0.60	0.01	2.67
SA 29	1.31	0.53	-0.32	3.51
MA 30	-0.34	0.30	0.19	3.09
FA 31	0.31	0.67	-0.50	2.80
FA 32	0.31	0.56	-0.51	2.96
FA 33	0.67	0.55	-0.28	2.83
SA 34	1.22	0.49	-0.26	3.23
MA 35	-0.34	0.37	-0.54	3.86
NA 36	1.42	0.48	-0.07	2.69
SA 37	0.59	0.52	0.02	2.87
NA 38	1.14	0.60	1.03	2.13
MB 39	-0.53	0.52	0.40	2.85
MB 40	-0.29	0.49	0.83	4.87
MB 41	-0.27	0.44	1.36	5.68
MB 42	-0.20	0.47	0.25	3.16
MB 43	-0.20	0.43	0.18	2.78
MB 44	-0.21	0.43	0.29	2.60
MB 45	-0.00	0.28	0.27	2.56
FB 46	0.30	0.48	0.11	2.48
FB 47	0.19	0.58	-0.39	2.54
FB 48	0.23	0.58	-0.30	2.58

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FB 49	0.44	0.67	0.07	2.89
FB 50	0.20	0.59	0.11	2.26
FB 51	0.34	0.60	0.03	2.76
FB 52	0.76	0.56	-0.61	2.83
FB 53	0.75	0.50	-0.38	2.65
FB 54	1.04	0.62	-0.10	3.53
FB 55	1.06	0.60	-0.13	2.78
FB 56	1.05	0.63	0.06	2.95
FB 57	1.24	0.78	-0.26	2.55
SB 58	1.60	0.60	-0.42	2.95
SB 59	1.33	0.68	-0.27	2.60
SB 60	1.17	0.59	-0.42	3.43
SB 61	1.18	0.63	-0.08	3.07
SB 62	1.38	0.68	-0.34	2.52
SB 63	1.68	0.50	-0.23	4.00
SB 64	1.56	0.51	0.04	3.52
SB 65	1.77	0.50	-0.41	4.53
SB 66	1.36	0.48	-0.02	2.92
MC 67	-0.39	0.46	-0.08	3.08
MC 68	-0.41	0.41	-0.01	2.97
MC 69	-0.33	0.45	-0.13	4.42
MC 70	-0.51	0.48	1.31	5.90
MC 71	-0.22	0.42	-0.11	3.31
FC 72	0.28	0.62	0.85	4.13
FC 73	0.19	0.50	-0.19	2.24

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
FC 74	1.08	0.72	0.15	2.45
FC 75	0.83	0.51	-0.13	2.51
SC 76	1.64	0.51	-0.47	3.23
SC 77	1.01	0.63	0.01	2.83
SC 78	1.42	0.68	-0.47	2.82
SC 79	1.67	0.51	-1.41	6.03
SC 80	1.24	0.45	-0.52	3.21
SC 81	1.42	0.51	-0.31	3.54
NC 82	1.42	0.50	0.09	2.80
NC 83	1.58	0.53	-0.59	3.12
NC 84	2.17	0.47	-0.58	3.43
NC 85	1.90	0.37	-0.48	3.72
NC 86	1.99	0.55	-0.69	3.58
NC 87	1.86	0.52	-0.07	3.56
FC 88	0.64	0.60	-0.24	2.22
FC 89	0.72	0.54	-0.55	2.69
SC 90	0.87	0.57	0.47	3.83
MD 91	-0.41	0.43	-0.06	2.60
MD 92	-0.32	0.49	-0.16	2.84
MD 93	0.84	0.44	-0.47	3.99
MD 94	0.34	0.48	-0.77	3.00
MD 95	0.14	0.48	-0.29	2.54
FD 96	0.89	0.46	0.04	4.44
FD 97	0.74	0.37	-0.01	3.83
FD 98	0.87	0.40	0.85	5.77

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNWSS	KURTOSIS
FD 99	1.16	0.42	-0.32	4.59
FD 100	1.09	0.44	-0.85	5.71
FD 101	1.14	0.48	-0.10	4.86
FD 102	1.11	0.42	-0.92	5.48
FD 103	1.01	0.36	-0.75	4.67
FD 104	1.18	0.43	-0.28	4.40
FD 105	1.18	0.41	0.10	4.65
FD 106	1.10	0.41	0.12	3.47
FD 107	1.14	0.43	0.24	3.52
FD 108	1.14	0.43	0.20	3.23
FD 109	0.85	0.50	-0.52	3.17
FD 110	1.14	0.33	-1.00	6.48
FD 111	1.13	0.39	0.44	6.48
FD 112	1.15	0.40	0.05	3.48
SD 113	1.63	0.58	0.06	2.83
SD 114	1.83	0.52	-0.57	3.90
SD 115	2.02	0.53	0.06	2.94
SD 116	1.85	0.48	0.53	4.48
SD 117	1.93	0.51	0.51	3.38
SD 118	1.94	0.47	-0.58	3.63
SD 119	1.89	0.44	0.06	3.14
ME 120	0.25	0.54	-1.04	4.34
ME 121	0.17	0.72	-0.40	2.45
ME 122	-0.16	0.72	-0.09	1.91
ME 123	-0.27	0.45	-0.11	2.79

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
ME 124	-0.36	0.48	-0.26	2.62
ME 125	0.03	0.51	-0.21	3.69
FE 126	-0.24	0.65	-0.19	2.06
FE 127	-0.12	0.82	0.51	2.27
FE 128	-0.25	0.58	-0.38	3.09
FE 129	0.03	0.58	0.18	3.40
FE 130	-0.03	0.59	-0.04	3.21
FE 131	0.29	0.48	0.06	2.92
FE 132	0.60	0.38	0.69	2.74
FE 133	0.81	0.55	-0.07	2.76
FE 134	0.86	0.53	-0.09	3.12
FE 135	0.67	0.48	-0.21	2.99
FE 136	1.07	0.55	0.40	3.19
FE 137	1.18	0.64	0.70	3.25
GLF 138	-1.19	0.59	0.85	5.96
GLF 139	-0.93	0.74	0.82	4.99
GLF 140	-0.08	1.33	0.23	2.29
GLF 141	0.02	1.23	0.52	3.18
GLF 142	-0.92	0.95	0.65	3.34
GLF 143	-0.44	1.01	-0.07	2.75
GLF 144	0.12	1.29	-0.02	2.25
GLF 145	0.38	1.39	-0.16	2.53
GLF 146	-0.88	0.79	0.59	4.32
GLF 147	-0.59	1.12	0.98	3.49
GLF 148	-1.23	0.76	0.95	4.36

TABLE TWO (Cont'd)

SAMPLE IDN. AND NO.	MEAN DIAMETER	STANDARD DEVIATION	SKEWNESS	KURTOSIS
GLF 149	-1.18	0.81	0.81	3.07
GLF 150	-1.22	0.83	0.46	2.23
GLF 151	-0.85	1.12	0.79	2.49
GLF 152	-0.47	1.27	0.33	1.80
GLF 153	-0.33	1.29	0.37	2.30
GLF 154	0.07	1.42	-0.10	2.09
GLF 155	0.28	1.39	-0.11	2.16
GLF 156	0.27	1.15	-0.16	3.07
GLF 157	0.67	1.28	-0.30	2.56
GLF 158	-0.51	1.26	0.29	2.05
GLF 159	-0.13	1.43	0.46	2.24
GLF 160	0.52	1.66	-0.27	1.74
GLF 161	-0.93	1.19	1.41	4.83
GLF 162	-0.73	1.14	0.83	3.31
GLF 163	-1.32	0.88	1.00	3.92
GLF 164	0.40	1.53	-0.21	2.12
GLF 165	0.35	1.54	-0.33	2.07
GLF 166	-0.84	0.93	0.81	3.88
GLF 167	0.66	1.08	-0.95	4.01
GLF 168	-0.26	1.06	0.43	2.42

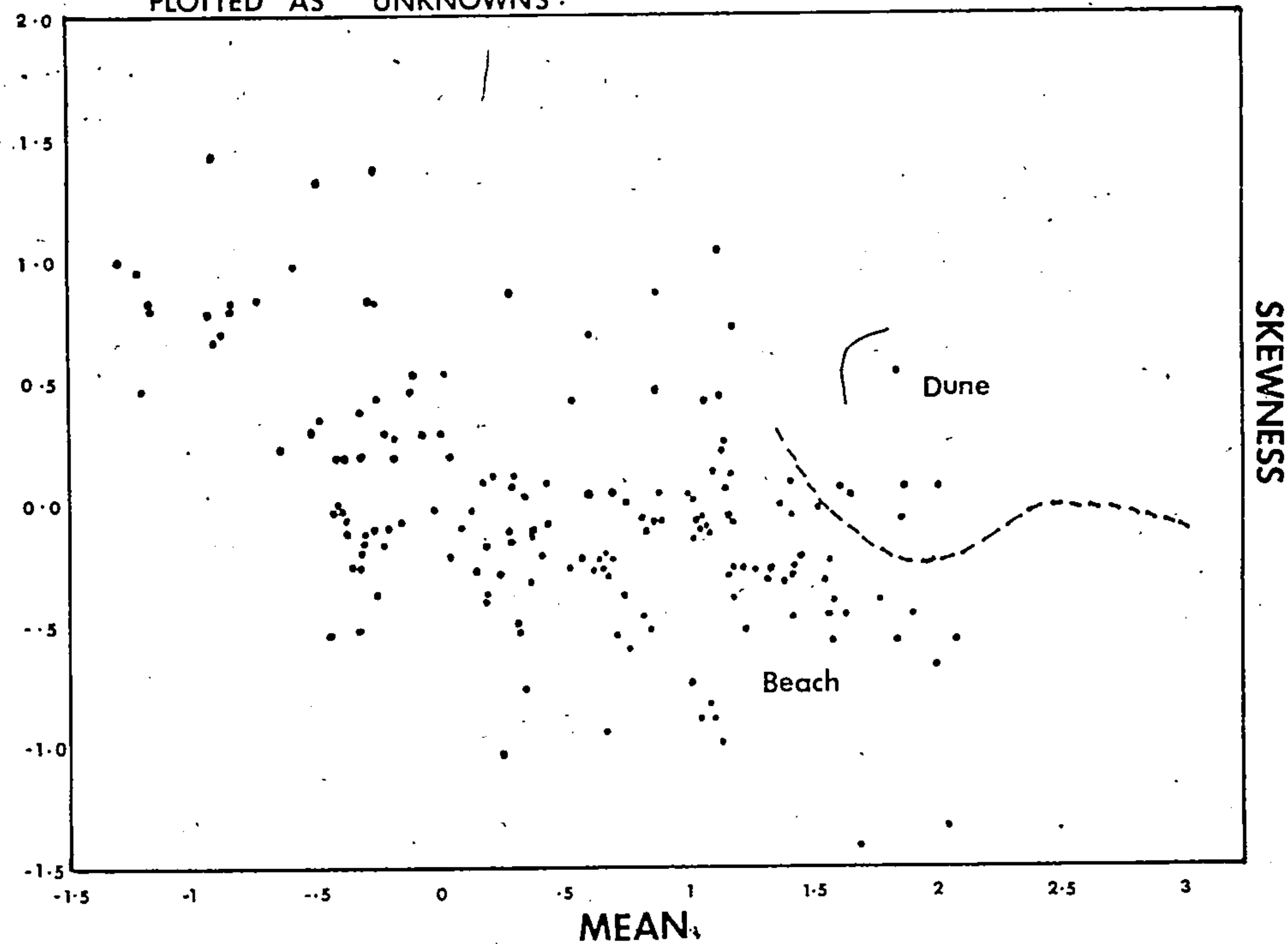
TABLE TWO (Cont'd)

Explanation to sample identification

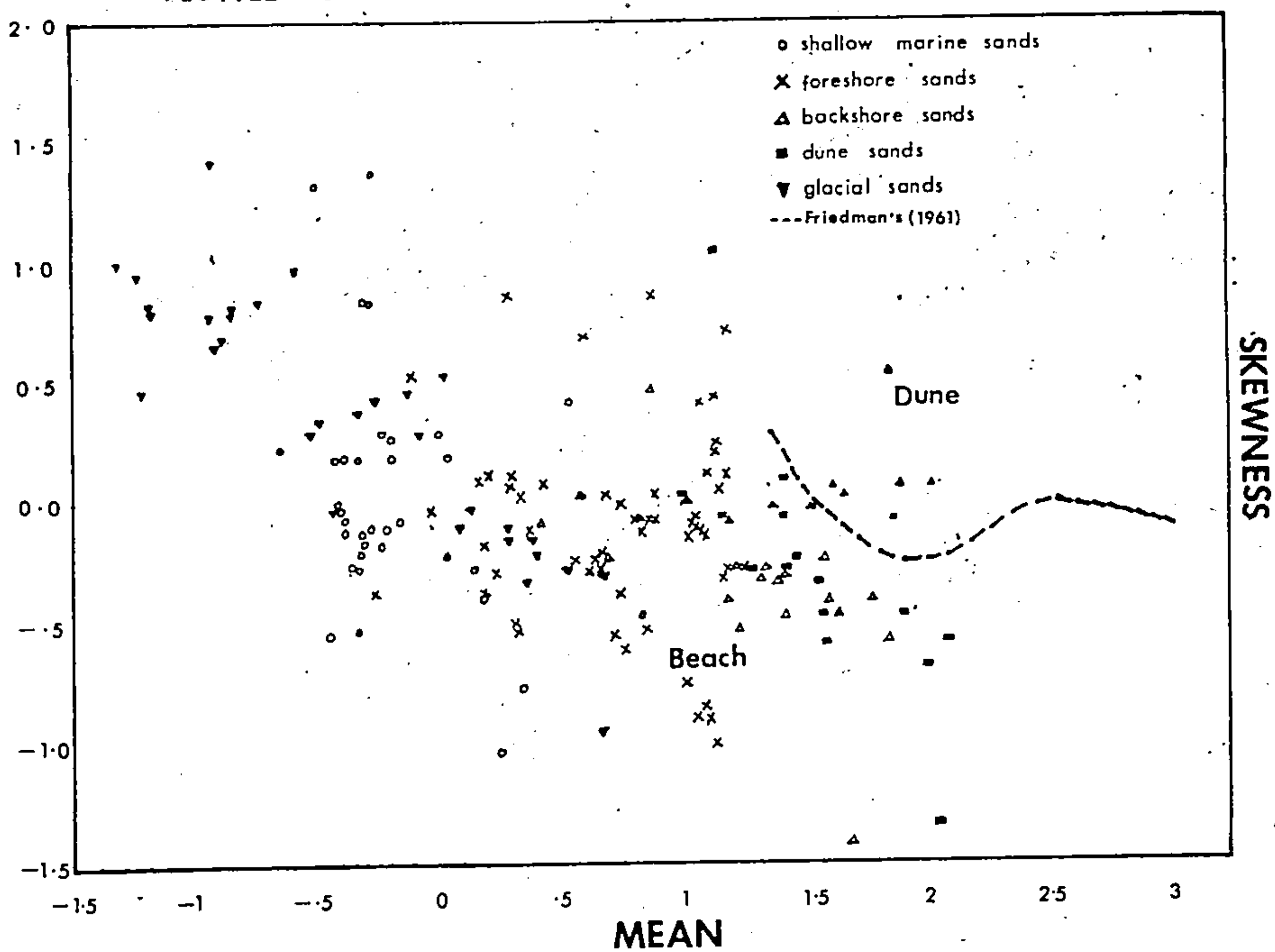
FA-	Foreshore samples from Site A
MA-	Shallow agitated samples from Site A
NA-	Dune samples from Site A
SA-	Backshore samples from Site A
MB-	Shallow agitated samples from Site B
FB-	Foreshore samples from Site B
SB-	Backshore samples from Site B
MC-	Shallow agitated samples from Site C
FC-	Foreshore samples from Site C
SC-	Backshore samples from Site C
NC-	Dune samples from Site C
MD-	Shallow agitated samples from Site D
FD-	Foreshore samples from Site D
SD-	Backshore samples from Site D
ME-	Shallow agitated samples from Site E
FE-	Foreshore samples from Site E
GLF-	Glacial samples from Site F

FIG·7A

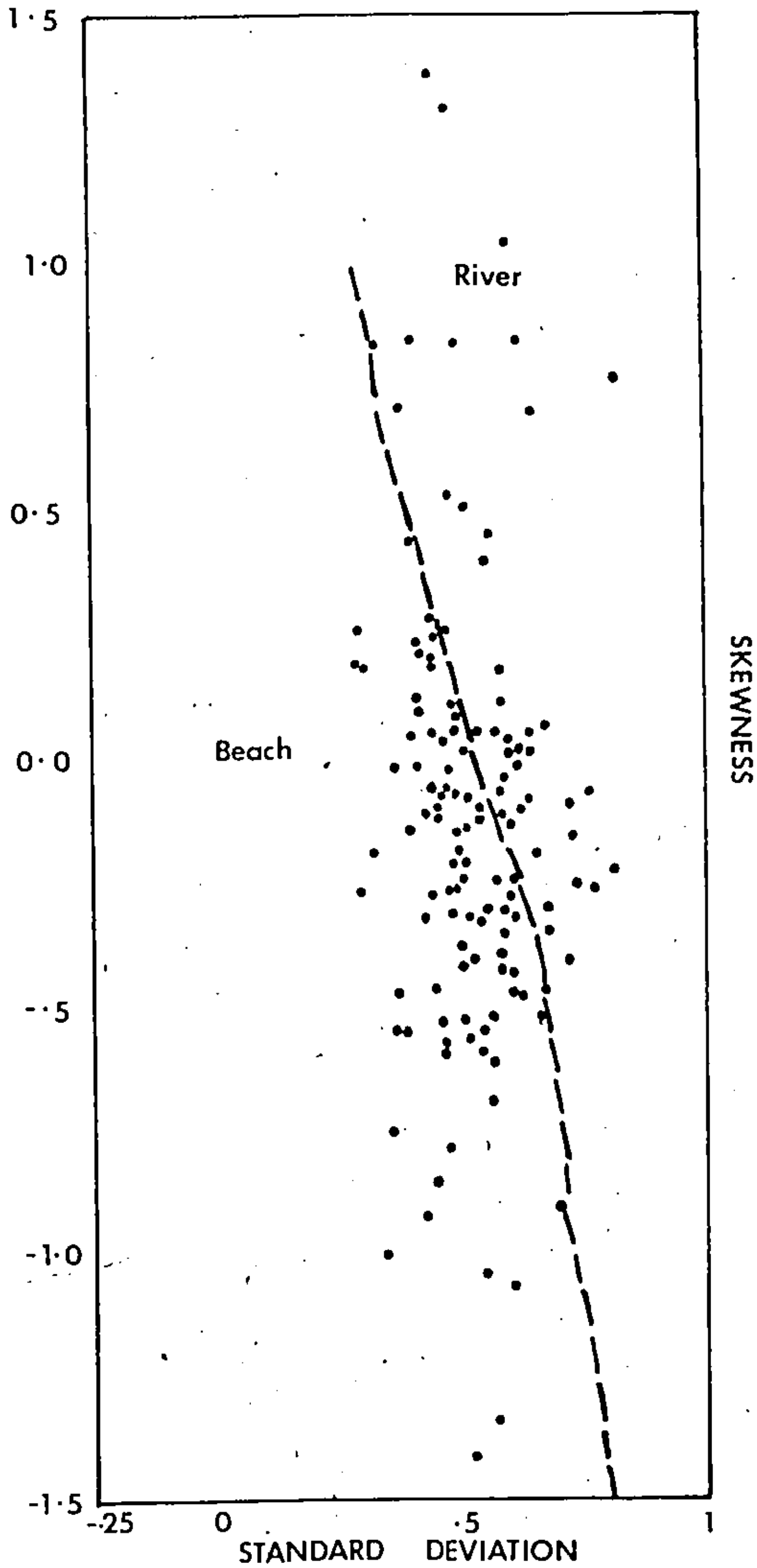
PLOT OF MOMENT PARAMETERS AFTER FRIEDMAN· SAMPLES PLOTTED AS "UNKNOWNS."



FIG·7B
PLOT OF MOMENT PARAMETERS AFTER FRIEDMAN· SAMPLES PLOTTED AS "KNOWNS·"

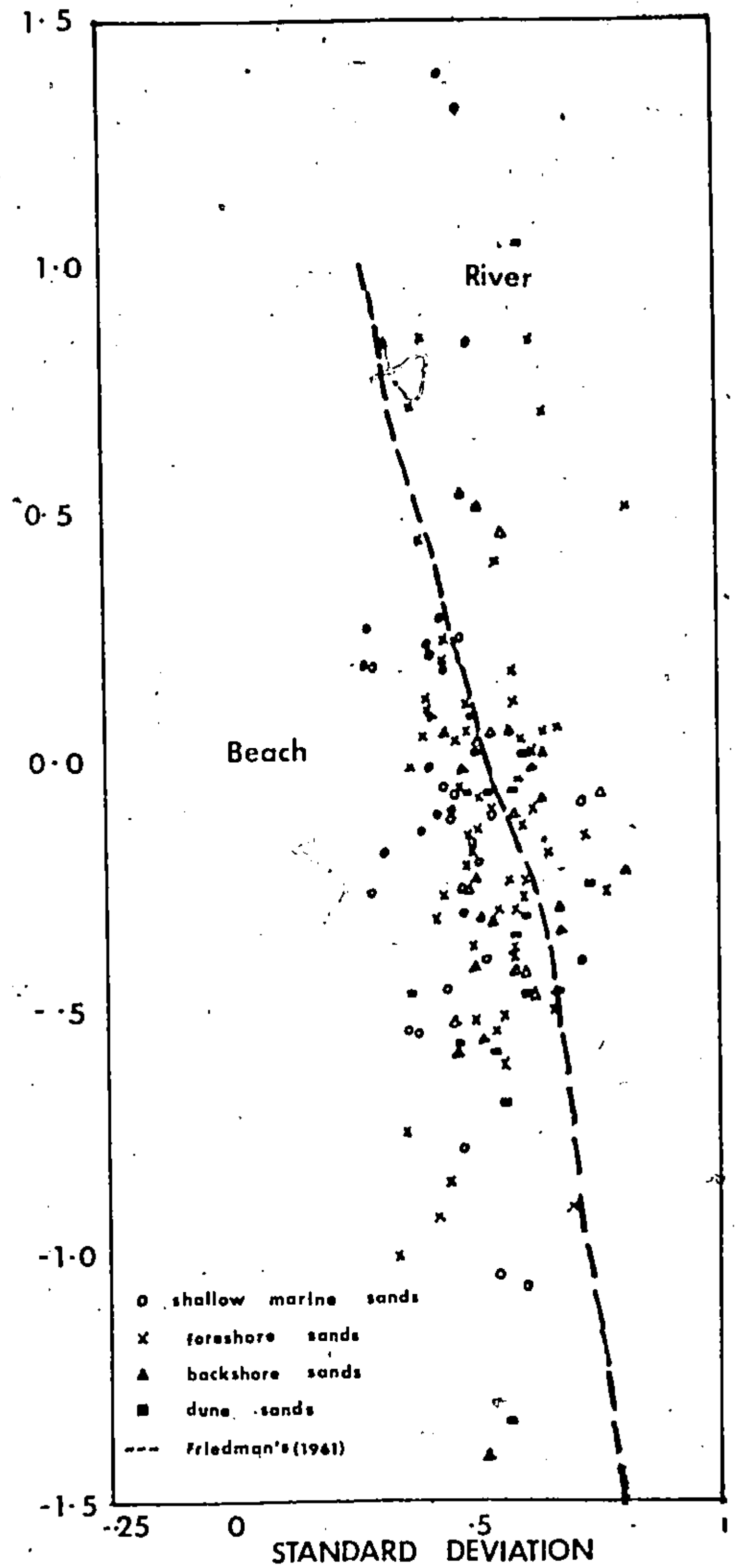


FIG·8A
PLOT OF MOMENT PARAMETERS AFTER FRIEDMAN· SAMPLES PLOTTED AS "UNKNOWNS·"



FIG·8B

PLOT OF MOMENT PARAMETERS AFTER FRIEDMAN· SAMPLES PLOTTED AS "KNOWNS·"



rly reliable.

Discriminant Analysis

Discriminant Analysis is now widely used by earth scientists. A mathematical discussion of how the discriminant coefficients are given is explained by Krumbein and Graybill (I965) and Davis (I973). The mathematical objective of discriminant analysis is to weigh and linearly combine the discriminating variables in some fashion so that the variables are made to be as statistically distinct as possible. The technique does this by one or more linear combinations of the discriminating variables , where the discriminating functions are selected. The functions are computed by:-

$$D_i = d_{iI} W_I + d_{i2} W_2 + \ldots + d_{ip} W_p$$

where D_i is the score on discriminant i,
the d's are weigting coefficients, and
the W's are the standarized values of the p discriminating variables used in the analysis.

Following the computation of the functions, analysis and classifaction follows. Previous studies, (for example, Middleton I962; Sahu I964; Greenwood I969; and Greenwood and Davidson- Arnott I972) have achieved satisfactory results in sedimentological studies by using linear discriminant analysis. This study however, uses the stepwise procedure because it allows elimination of certain variables in order to allow satisfactory discrimination. The stepwise procedure begins by selecting the best discriminating variable according to a user-determined criterion. A second discriminating variable is selected as the variable best able to improve the value of the discrimination criterion in combination with the first variable. The third and subsequent variables are similarly selected(in order of importance) until the stepwise procedure halts and further analysis is performed using only the selected variables(Klecka, I975).

The discriminant functions have been developed by first classifying sediment samples into groups on the basis of their known depositional environments. Five groups (shallow agitated-coded MARI; foreshore- coded FORE; backshore- coded BACK; dune-coded DUNE; and glacial- coded GLACIL) were selected. Knowing that the statistical package programs in the computer are more efficiently run when raw-data is used as input*, the weight percent within each size (phi) class of 168 samples were used as input data for the BMDO7M Statistical Package Program (Dixon 1972) for stepwise discriminant analysis. The technique correctly classified 78.571 % of all the samples into their correct environments. The classification matrix (Table Three) shows that the greatest number of misclassified samples are from the backshore region. The interpretation of the possible causes of this

Table Three: <u>BMDO7M output results showing the number of samples classified into groups</u>.

Table Three:

GROUP	MARI	FORE	BACK	DUNE	GLACIL
MARI	28	5	0	0	0
FORE	6	49	3	0	0
BACK	0	6	17	7	0
DUNE	0	1	4	11	0
GLACIL	1	3	0	0	27

misclassification will be discussed in the next chapter. Further evidence about the groups similarities and differences is shown in a plot of the first canonical variable X, against the second canonical variable Y (FIG. 9). It can be clearly seen that the groups are well separated . Although it can be claimed that their is a slight degree of overlap among the groups the summary statistics (Table Four) however, indicate that the discrimination

* personal communication with Prof. H.D.Baillargion, Statistician, Department of Computer Science, University of Windsor.

FIG·9 PLOT OF FIRST AND SECOND CANONICAL VARIABLES

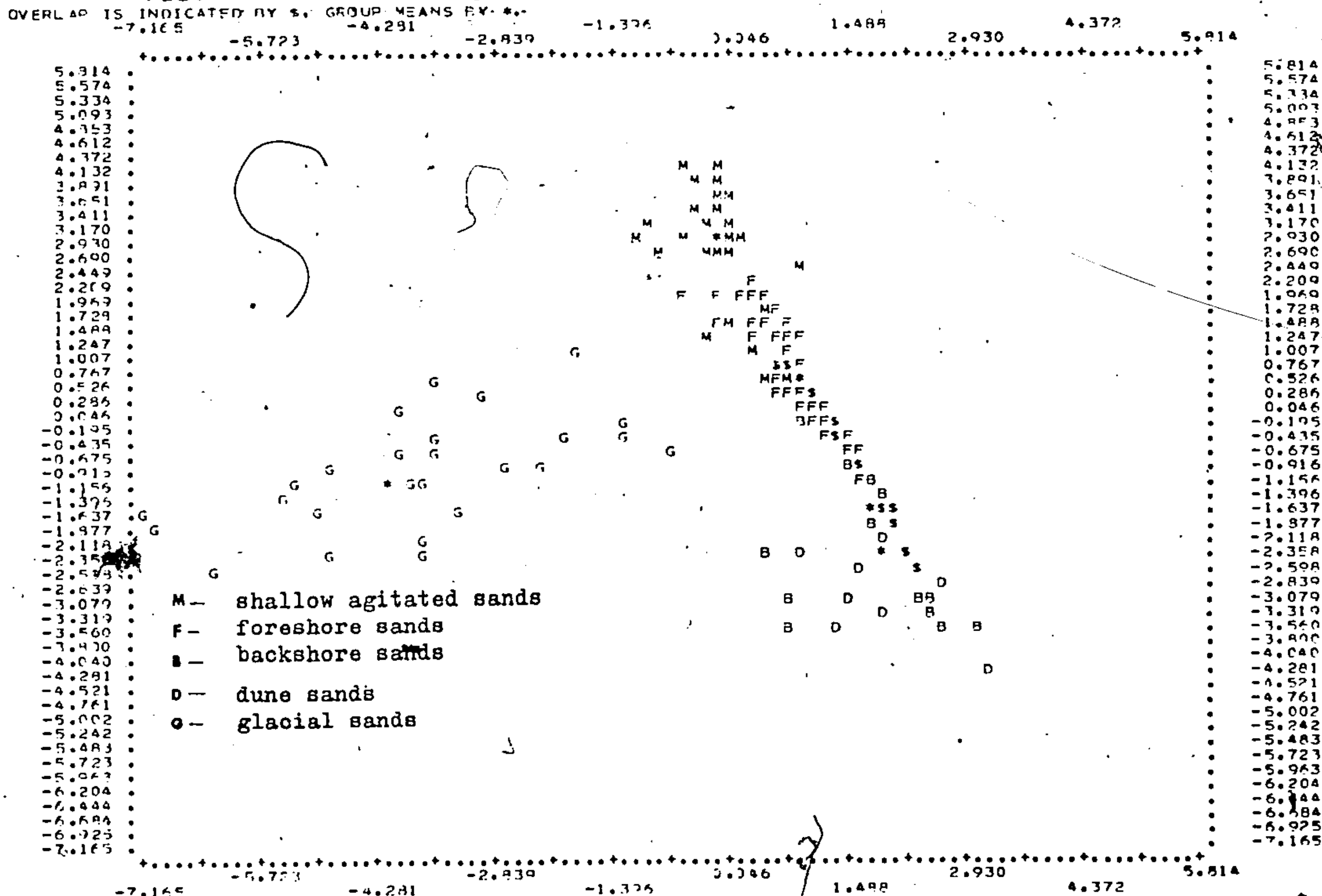


Table Four Summary Statistics from BMD07M output on Stepwise Discriminant Analysis

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED REMOVED	F VALUE TO ENTER OR REMOVE	NUMBER OF VARIABLES INCLUDED	U-STATISTIC
1	1	126.7934	1	0.7404
2	3	77.4336	2	0.0925
3	7	41.1732	3	0.0408
4	13	11.9701	4	0.0315
5	4	9.1935	5	0.0256
6	12	3.6140	6	0.0234
7	2	3.2633	7	0.0214
8	11	1.4704	8	0.0208
9	10	1.0674	9	0.0203
10	5	1.0393	10	0.0139
11	6	0.5145	11	0.0134
12	9	0.4267	12	0.0132
13	7	3.0537	11	0.0178

EIGENVALUES

4.67457	1.91877	1.01501	0.26220	0.00006	0.00000	0.00000	0.00000	0.00000
-0.00000	-0.00000	-0.00000	-0.00001					

CUMULATIVE PROPORTION OF TOTAL DISPERSION

0.55595	0.77155	0.96923	0.99999	1.00000	1.00000	1.00000	1.00000	1.00000
1.00000	1.00000	1.00000	1.00000					

CANONICAL CORRELATIONS

0.95355	0.84453	0.72074	0.46101	0.00778	0.00209	0.00149	0.00076	0.00037
0.00052	0.00107	0.00132	0.00256					

COEFFICIENTS FOR CANONICAL VARIABLE -

ORIGINAL VARIABLE	1	2	3	4	5	6	7	8	9
1	0.12667	0.10406	-0.03734	-0.25686	0.33497	-0.27303	-0.10529	-0.01407	-0.12975
2	0.16712	0.07112	0.01390	-0.29555	0.36590	0.16817	0.14215	0.00714	0.16653
3	0.06094	0.01345	-0.02171	-0.29071	0.37534	0.09413	0.08909	0.06816	-0.03640
4	0.16103	-0.01824	-0.04713	-0.27171	0.39519	-0.10628	0.00562	0.07899	0.07667
5	0.09477	-0.03575	-0.03326	-0.24747	0.37530	0.06544	-0.00669	0.02004	0.00743
6	0.02512	0.01710	-0.01303	-0.27567	0.37336	-0.05562	0.10240	0.01497	0.00730
7	0.04694	0.01417	0.01026	-0.29542	0.18643	0.04718	-0.05102	0.03266	0.01011
8	0.06712	0.01045	0.20043	-0.10276	0.16691	-0.02742	0.05611	0.06514	0.04990
9	0.20111	0.00574	-0.05377	-0.18718	0.40677	0.00114	0.01741	0.00278	0.00796
10	0.07315	0.17607	-0.00365	-0.61242	0.31990	-0.00570	0.02250	0.02713	-0.00455
11	0.06135	-0.03731	0.35213	-0.27264	0.32984	0.04073	-0.02549	0.10075	0.09047
12	0.27513	0.02417	0.17717	0.43514	1.18442	0.23664	0.38547	1.22260	0.11128
13	2.41762	1.12241	-0.15957	-3.23362	-1.72976	1.52127	-1.19956	-10.46576	8.19577

GROUP	CANONICAL VARIABLES EVALUATED AT GROUP MEANS								
1	0.10955	-2.61448	-1.16616	0.01126	-0.00001	0.00003	0.00002	0.00001	-0.00001
2	-3.85541	-0.52442	1.29150	-0.10332	0.00001	-0.00002	-0.00003	-0.00001	0.00001
3	-1.73786	1.72637	-0.35734	0.02132	0.00014	0.00001	0.00001	0.00001	0.00000
4	-1.20134	2.32533	-1.12973	-1.20198	-0.00024	0.00002	0.00003	-0.00000	-0.00002
5	4.15414	1.11227	0.02301	0.00717	0.00000	-0.00000	0.00000	-0.00000	0.00000

COEFFICIENTS FOR CANONICAL VARIABLE -

ORIGINAL VARIABLE	10	11	12	13
1	-0.12334	-0.01384	-0.06396	-0.15371
2	0.18323	0.04214	-0.12308	-0.15030
3	-0.09661	-0.05277	0.03120	-0.09456
4	0.03601	-0.03531	0.04101	-0.07391
5	-0.06353	-0.02267	-0.04459	-0.13980
6	-0.01319	-0.00571	-0.02201	-0.14428
7	0.02262	-0.05242	0.01739	-0.08751
8	-0.06174	0.00283	-0.03545	-0.13551
9	-0.06461	-0.01313	0.01356	-0.12050
10	0.00049	-1.03053	-0.03497	-0.04543
11	0.01171	-0.05534	0.12034	-0.32325
12	-0.75623	-1.27233	-2.00472	1.63558
13	-7.01151	-1.16776	5.30107	-1.07784

GROUP	CANONICAL VARIABLES EVALUATED AT GROUP MEANS			
1	-0.00001	-0.00001	0.00002	0.00002
2	-0.00002	0.00001	-0.00007	-0.00001
3	-0.00001	-0.00001	0.00001	-0.00001
4	-0.00007	-0.00001	0.00004	0.00000
5	0.00000	0.00000	-0.00001	0.00000

CHECK ON FINAL U-STATISTIC 0.01774

is statistically significant. The eigenvalues and their associated canonical correlations show the relative ability of each function to separate the groups. The gradual decrease in the U-statistic values to the final value of 0.01778 illustrate quite clearly the significance of the discriminating functions after each is derived.

Since samples from each of the environments have been misclassified the technique was further tested on the samples collected from sites A, B, C, D and E. The results were as follows:

a/ In area A, 6 samples (15.78 %) were misclassified.
b/ In area B, none of the samples were misclassified.
c/ In area C, 3 samples (12.49%) were misclassified.
d/ In area D, 1 sample (3.44 %) was misclassified.
e/ In area E, 1 sample (5.55 %) was misclassified.

The results for stepwise discriminant analysis indicate that this technique is very effective in classifying sediments in their known depositional environments. The extremely low misclassification of the sediment samples from the individual environments illustrate that each environment can be considered to be a distinct depositional unit. Similar results as to the efficiency of discriminant analysis have been achieved by Sahu (1964), Greenwood (1969), Miola and Weiser (1969) and Greenwood and Davidson - Arnott (1972).

R- Mode Factor Analysis

Factor analysis is a multivariate statistical technique which can be used in determining the depositional environment of sediments from their grain-size distributions. This technique relies on a set of assumptions about the nature of the parent population from which the samples are drawn. Given the basic postulate that factor analysis involves the calculation of appropriate measures for a set of relevant variables then it can be quickly realised that R-Mode factor analysis can be used to group the measured attributes of a series of samples into associations or factors. Kim (I975), expresses the basic model as :

$$z_j = a_{jI} F_I + a_{j2} F_2 + \ldots\ldots a_{jm} F_m + d_j U_j \quad j = I, 2, \ldots, n$$

where z_j = variable j in standardized form

F_i = hypothetical factors

U_j = unique factor for variable j

a_{ji} = standardized multiple-regression coefficient of variable j on factor i (factor loading)

d_j = standardized regression coefficient of variable j on unique factor j

The unique factor U_j is assumed to be orthogonal to all the common factors associated with other variables. This means that the unique portion of a variable is not related to any other variable or to that part of itself which is due to the common factor Kim (I975).

Using the R- Mode factor analysis technique (based on correlation between variables) this study has grouped the measured attributes of the samples collected into associations (i.e. factors). Input variables (weight percentage in each of the I3 phi size classes) for the I68 samples were used in a Statistical Package for the Social Sciences (I975) program on factor analysis. Deciding on the principal factor matrix, a varimax rotation was performed on the four factors which have an eigenvalue greater than I (Table Five). These eigenvalues which accounted for 80.I % of the proportion of variance demonstrate the influence of four influencing factors. The rotated factor matrix (Table Six) shows that the four factors exert their influence on different grain-size (phi grade scale). The loading profile for each factor (FIG. IO, A, B, C and D) indicates that these distinct size ranges probably represent the sampled sediment population of Essex County and hence reflect differing environmental processes

Table Five

Statistical Package For The Social Sciences (SPSS) output showing estimated communalities , eigenvalues and proportion of variance.

EST COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
1.00000	1	4.17958	32.2	32.2
1.00000	2	3.13343	24.1	56.3
1.00000	3	1.80915	14.5	70.8
1.00000	4	1.21306	9.3	80.1
1.00000	5	0.79537	6.1	86.3
1.00000	6	0.41770	3.2	89.5
1.00000	7	0.32328	2.5	92.0
1.00000	8	0.30203	2.3	94.3
1.00000	9	0.23578	1.9	96.1
1.00000	10	0.18937	1.5	97.6
1.00000	11	0.17501	1.4	98.9
1.00000	12	0.13831	1.1	100.0
1.00000	13	0.00291	0.0	100.0

Factor I is associated with grain size 2.0 phi, 2.5 phi and 3.0 phi in terms of positive loadings. These grain-size values (phi) are directly related to the fine sand range (Nat. Res. Council Report Comm. Sedimentation, I94I). The negative aspect of the loading profile can be considered to be only relative to the other phi grade sizes; for instance, if factor I is assumed to have the highest loading between 0.0 phi to I.0 phi (negative) on the profile then it will be inversely related to 2.0 phi to 3.0 phi (positive). In order to directly decide on which cases Factor I influences the factor scores output for the I68 samples (cases) can be consulted. These factor scores together with the examination of the cumulative probability curves indicate that this factor has the greatest influence on samples from the backshore and dune environments.

Factor 2 is associated with sands which are in the coarse

Table Six

VARIMAX ROTATED FACTOR MATRIX
(SPSS Program on Factor Analysis)

PHI	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
-2.0	-0.01974	0.04830	0.91529	0.13326
-1.5	-0.00538	0.08399	0.92489	-0.01018
-1.0	-0.06226	0.31805	0.82120	-0.06503
- .5	-0.21699	0.83109	0.26282	-0.15460
0.0	-0.35024	0.84824	-0.17962	-0.14112
0.5	-0.78632	0.12406	-0.26840	0.11204
1.0	-0.45330	-0.76685	-0.26190	-0.10020
1.5	0.17313	-0.80328	-0.22843	-0.21304
2.0	0.80323	-0.31778	-0.23127	0.14538
2.5	0.81460	-0.08905	-0.17591	0.31773
3.0	0.64924	0.03086	-0.07701	0.54694
3.5	0.33730	0.01690	0.03103	0.81577
4.0	-0.01925	-0.02028	0.055250	0.82891

range . According to the factor scores, the influence is partly on samples from both the shallow agitated and foreshore environments.

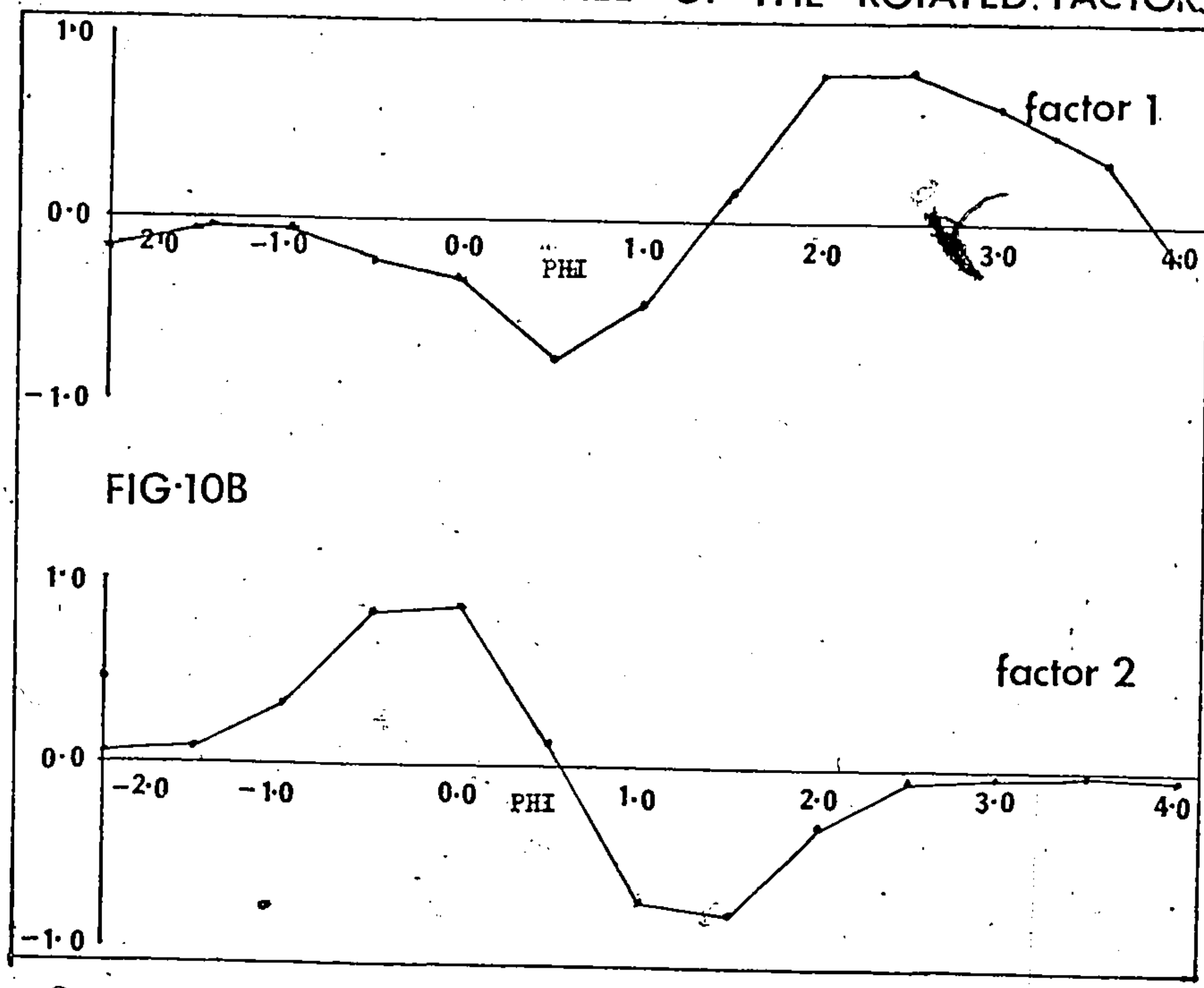
Factor 3 is controlled by positive loadings on -2.0 phi, - I.5 phi and -I.0 phi. These sands are typical of granule and very coarse material. Looking at the factor scores and the cumulative probability curves it is indicated that this factor has influence on samples from the glacial and nearshore environments.

Factor 4 is representative of very fine sediments, namely the suspension population indicated by the cumulative probability curves. The size classes (3.0 phi to 4.0 phi) which influences this factor are typical of dune sediments.

On a generalised basis the four factors have accounted for ten different grain size (phi units) classes. These grain- size

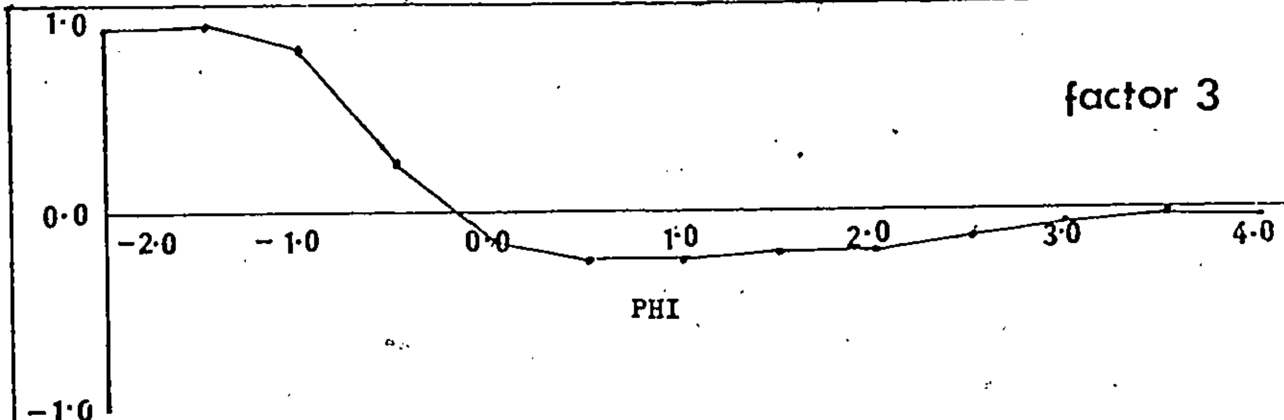
FIG·10A

LOADING PROFILE OF THE ROTATED FACTORS

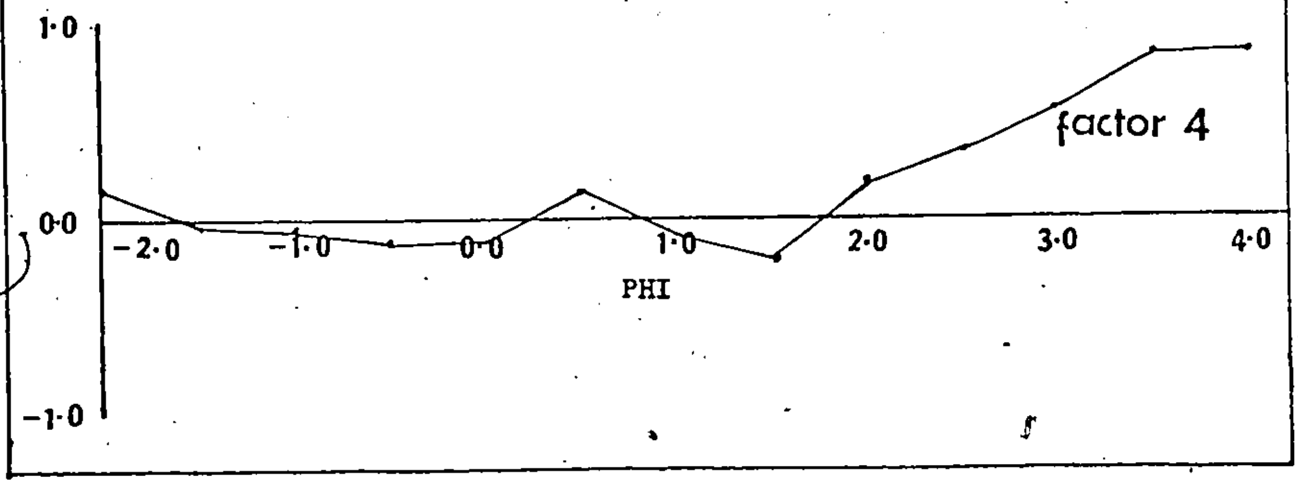


FIG·10C

LOADING PROFILE OF THE ROTATED FACTORS



FIG·10D



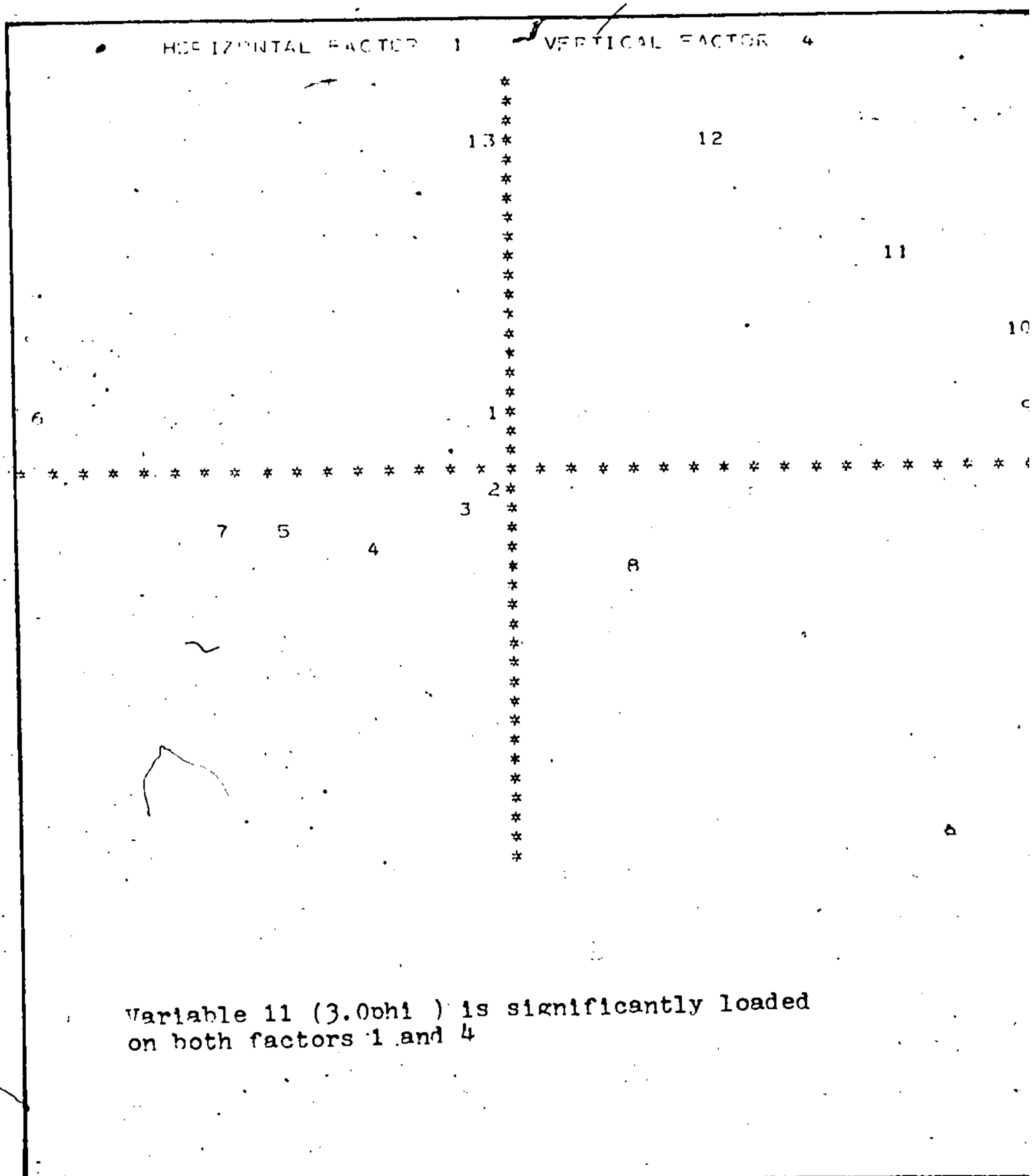
classes can be claimed to represent the various environments of sand deposition in Essex County. The environments have different populations of sand which are:

Population I – fine sands (3.0 phi to 2.0 phi)
Population 2 – coarse sands (0.0 phi to 0.5 phi)
Population 3 – granule and very coarse sands (– I.0 phi to -2.0 phi)
Population 4 – very fine sands (4.0 phi to 3.0 phi)

From the findings of Bagnold (I966), Visher (I969) and Allen et al (I972), it can be claimed that these four sand size populations reflect differences in the energy level at the sites of deposition, with each population representing sands from a particular environment. The technique has clearly distinguished the population of coarsest material (namely sediments from the glacial environment), and the population of finest material (namely sediments from the dune environment). Further, the loading of one sediment size (3.0 phi) in factors I and 4 indicate that there is an apparent mixture of sands from one population in two environments(FIG. II). This is likely for sands from the backshore and dune environments. However no clear-cut distinction is shown for sands from the foreshore and shallow agitated environments. The coarse fraction in Factor 3 might probably represent sands from the shallow agitated environment; likewise the coarse fraction in Factor 2. If this is considered to be true then it can be argued that sands from the shallow agitated environments are of different size ranges.An examination of the mean grain-size from the five sampled shallow agitated environments (Site A, -0.394 phi; Site B, -0.242 phi; Site C, -0.372 phi; Site D, +0.II8 phi and Site E, -0.056 phi) partly supports this. As such it can be claimed that the technique illustrates that sands from the shallow agitated environemnts fall in either the glacial or foreshore environments.

FIG. II

SPSS R-Mode Factor Analysis Graphic out-put on Rotated Orthogonal Factors



Variable 11 (3.0phi) is significantly loaded on both factors 1 and 4

CHAPTER FIVE

VERIFICATION OF HYPOTHESES AND DISCUSSION

Hypothesis One

This study has attempted to discover if there is any relationship between sand texture (specifically grain-size) and depositional environments in Essex County. The results of the analysed samples from the delienated environments illustrate the fact that over 85% of the samples have different mean, sorting, skewness and kurtosis values. Studies (for example by Friedman 1961; Sahu 1964; and Greenwood 1969) found that the mean size of the sediment gives an indication of the average kinetic energy (velocity) of the depositing agent, and the size distribution of the source materials. The standard deviation measures the sorting of a sediment and indicates the fluctuations in the kinetic energy (velocity) conditions of the depositing agent about its average velocity. The skewness according to Greenwood (1969) reflects the relative frequency of occurrence of energy fluctuations above or below the average, while the kurtosis relates directly to the energy level and energy time relationship within any given environment.

The sands in the shallow agitated and foreshore zones of the various environments which are negatively skewed , indicate that the high energy (Bagnold, 1963; Shepard, 1963; Ingle, 1966) present in the swash and breaker zones do not allow the deposition of the finer particles. Mothersill who worked on the longshore bars and troughs of Lake Superior in 1969 claimed that waves breaking in the trough set finer particles in motion which eventually return seaward after the wave has broken. Taking this into consideration, it can be claimed that the tail of coarser particles shown in the cumulative curves (5^{th} percentile) gives the negative skewness of the sediments found in these environments. The positive skewness of approximately 42% of the samples collected from the shallow agitated and foreshore environments of Site A indicate strong environmental mixing. As will be discussed , Site A experiences rapid variations in energy levels.

The decrease in the mean diameter of sands away from the shallow agitated zone shows the lessening effects of wave energy. The mean diameter calculated by both the Graphic and Moment measures demonstrate this (Table Seven).

Table Seven.Mean Size of sediment for various Environments

Environments	Mean (Graphic Formula)	Mean (Moment Formula)
Shallow agitated	-0.I44 phi	-0.2I9 phi
Foreshore	+0.709 phi	+0.700 phi
Backshore	+I.432 phi	+I.399 phi
Dune	+I.566 phi	+I.557 phi

From the findings of field investigations (for example Clifton I969; Greenwood I969; King I972; and Williams I974)wave energy is dissipated as the waves move shoreward ; hence the ability of the waves to transport material up the foreshore slope is decreased. As a result a marked decrease in material size is found away from the foreshore zone. This is also true when material away from the nearshore zone is considered. Various workers (for example, Damiani and Thomas, I974; Dickas, I970; Fox,<u>et al</u> I966; Lewis and McNeely, I967; Mothersill, I970; Rukavina, I969; I970; Rukavina and St. Jacques, I97I; Thomas, <u>et al</u> I972; I973; and Upchurch, I970) have analysed sediments from different environments, especially off shore and basin deposits, within the Great Lakes System, and reported a far smaller size range of materials away from the nearshore zone (lake-ward extending). These results not only prove that the foreshore and nearshore environments are the most dynamic within the shoreline system but also supports the contention that the mean size of the sediment can be used to some extent in differentiating depositional sedimentary environments.

The range of sorting values(0.44 phi) for sediments collected from the sub-environments making up the beach indicate the relative inefficiency of this parameter in differentiating the first four defined depositional environments. However the sample statistics indicate that the samples from the shallow agitated environments are poorly sorted while the sediments from the dune environments are well sorted. Both the graphic and moment measures indicate that skewness is sensitive enough in differentiating the various environments of deposition.

The dune sands, especially those collected at Site A, have displayed characteristics of a dominant fine population and a subordinate coarse population which gave some of the samples low values of negative skewness. It is not abnormal to find a coarse sub-population of material in a dune environment for it has been pointed out by Bagnold (1954) that no dune creation can take place unless more than one particle size is present. The dominance of the finer particles is due principally to the fact that once these particles have been transported by wind, and which once deposited require a higher velocity to be eroded.

The sands are made up of a wide range of different-sizes in the glacial environment. Distinct bi-modality , and in some cases trimodality are displayed by the cumulative probability curves. The main factors controlling the nature of sediments in this environment are (Kukal;1970):

1. Character of bedrock on which the glacier moves.
2. Morphological characteristics and velocity of flow of the glacier
3. Position of the transported material in relation to the glacier

4. Mode of deposition
5. Subsequent reworking by meltwater.

The sample statistics calculated by both the graphic and moment measures reflect the heterogeneous nature of the glacial samples. An average mean size of -0.364 phi for the glacial samples does not truly reflect the considerable differences between the sample means. The high sorting values (ranging from 0.59 phi to I.66 phi) indicate the non-uniform nature of the material present within the glacial environment. At this stage it is not possible to make any firm statements as to whether the glacial sediments have undergone any significant weathering or erosion.

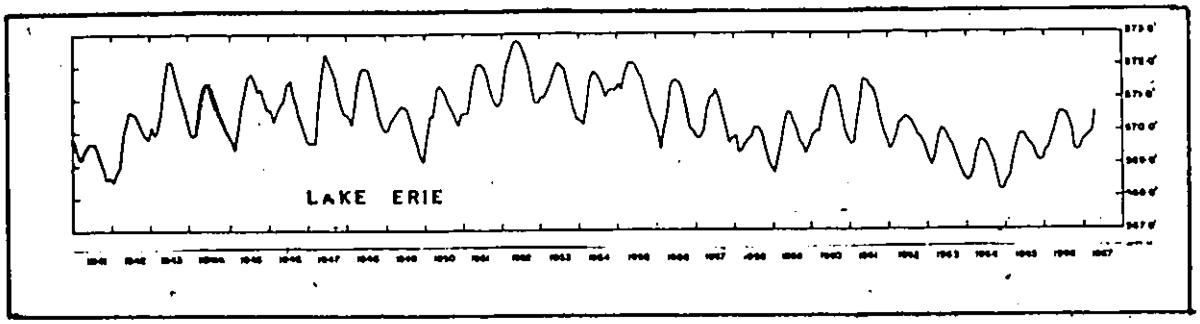
From the sample statistics , especially the mean diameter, it is noted that the various environments of deposition show marked differences in their grain-size distributions, hence supporting the hypothesis that there is a relationship between sand texture (grain-size) and depositional environments. Further each of the environments defined can be considered to be a distinct depositional unit. However, the multivariate technique of discriminant analysis demonstrated that 2I.43% of the samples have not been classified in their true depositional environments. The reasons for this misclassification can be the result of several interacting variables. Although Greenwood and Davidson-Arnott (I972) rightly claim that surface sediment patterns react very quickly to changing morphodynamic controls it should be pointed out that the nature of morphodynamic controls are not fully known. Many of the processes which affect a depositional sedimentary environment have been discussed only to a very limited extent. This paper attempts to discuss some of the possible factors (short term and long term) which can affect the sampled depositional environments of Essex County. These are:

Changing Lake Levels

Richards (I969) reported that major variations in lake levels are due to a rather delicate balance or perhaps more precisely an inbalance between precipitation and evaporation. The net increase in lake levels (FIG. I2) have been recorded since I963 with the trend reaching its peak in I973. Brazel and Phillips (I972) found that precipitation in the Great Lakes basin between I967 and I972 was I2 inches greater than the normal amounts for that time period. It is obvious that the hydrograph for Lake Erie (FIG. I3)

FIG. I3

Hydrograph of Lake Erie, I940 - I967



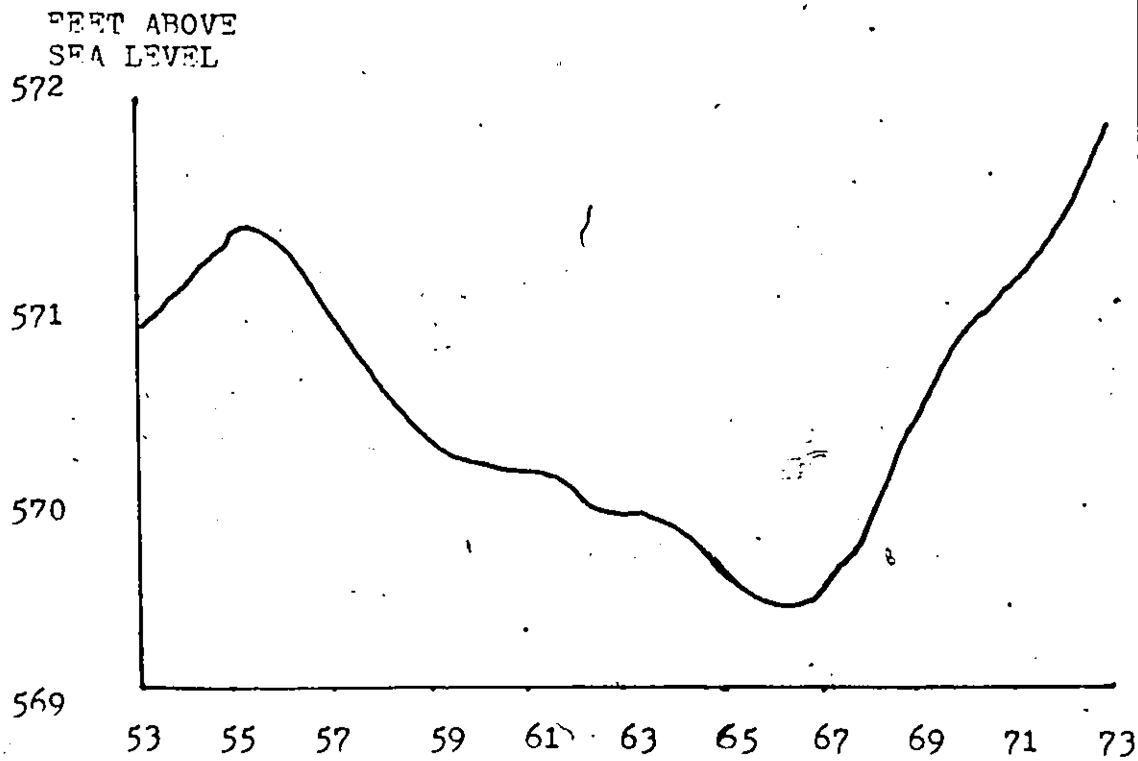
Source: Richards (I969)

shows annual variations superimposed on variations of a much longer term. The average annual rise and fall of Lake Erie in particular can be attributed to interacting meteorological factors. As illustrated in FIG. I4 rising lake levels occur in spring when precipitation is the highest and falling levels occur in fall and winter when evaporation losses are greatest.

The effects of Lake levels have been noted by Davis <u>et al</u> (I973) who studied Lake Michigan and noted that lake levels play a passive role in that they allow erosion to take place at a rapid rate , but that they do not cause it to do so. This fluctuation in lake levels can be one of the factors which have caused the mixture of shallow agitated sands with the foreshore sands and vice versa . Five shallow agitated samples have been classified with sands of the foreshore environment. It should be noted that the effect of a change in water levels is similar to

FIG. 12

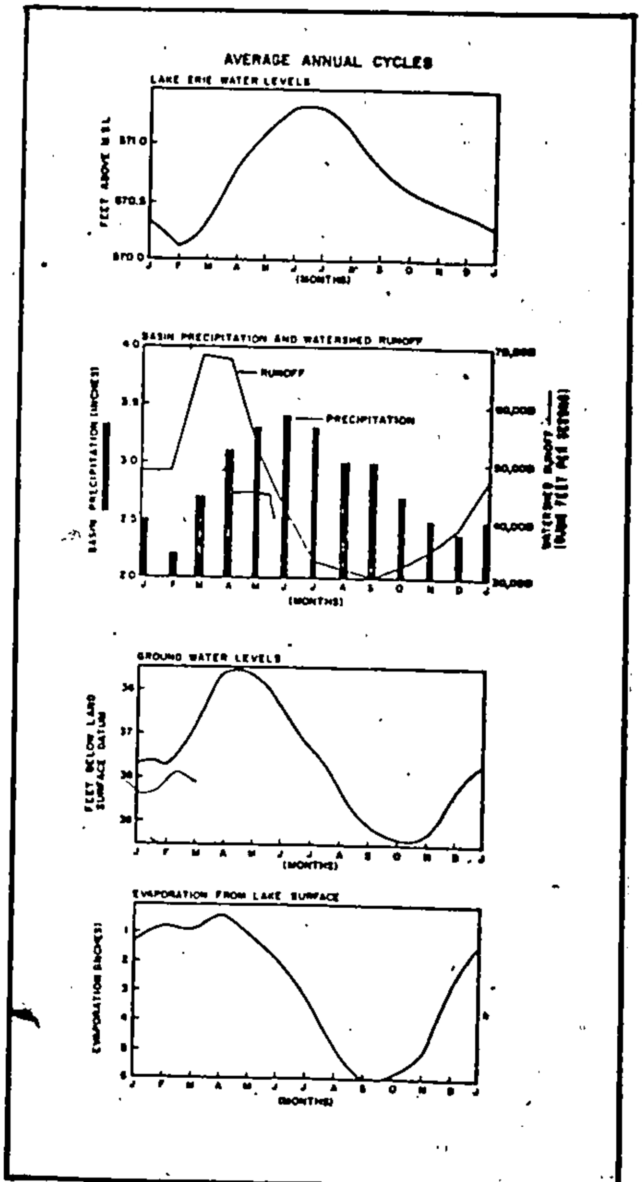
MEAN ANNUAL LAKE LEVELS AT CLEAVELAND, OHIO (GRAPH OF 5-YEAR MOVING MEANS).



Source:
Hydrograph of Monthly Mean Levels of the Great Lakes, 1953–1973

FIG. I4

Average Annual Cycle of Lake Erie water levels related to meteorological factors



Source: Taken from Richards (I969), Fig. 8

that of varying wave dimensions because the breaker zone is changed as the water rises , thus creating a new shallow agitated zone which previously had been part of the shallow nearshore zone . As the lake level fall in winter (Bruce and Rodgers, I962;

Phillips, 1969; Richards, 1969), the position of the shallow agitated and foreshore zones again changes. Although data has not been presented it is known that very short period changes (in terms of a day or less) occur in lake levels. When this change in profile occurs, Zenkovich (1967) claims that there may be some mixture of materials in the various beach zones until a new equilibrium is reached.

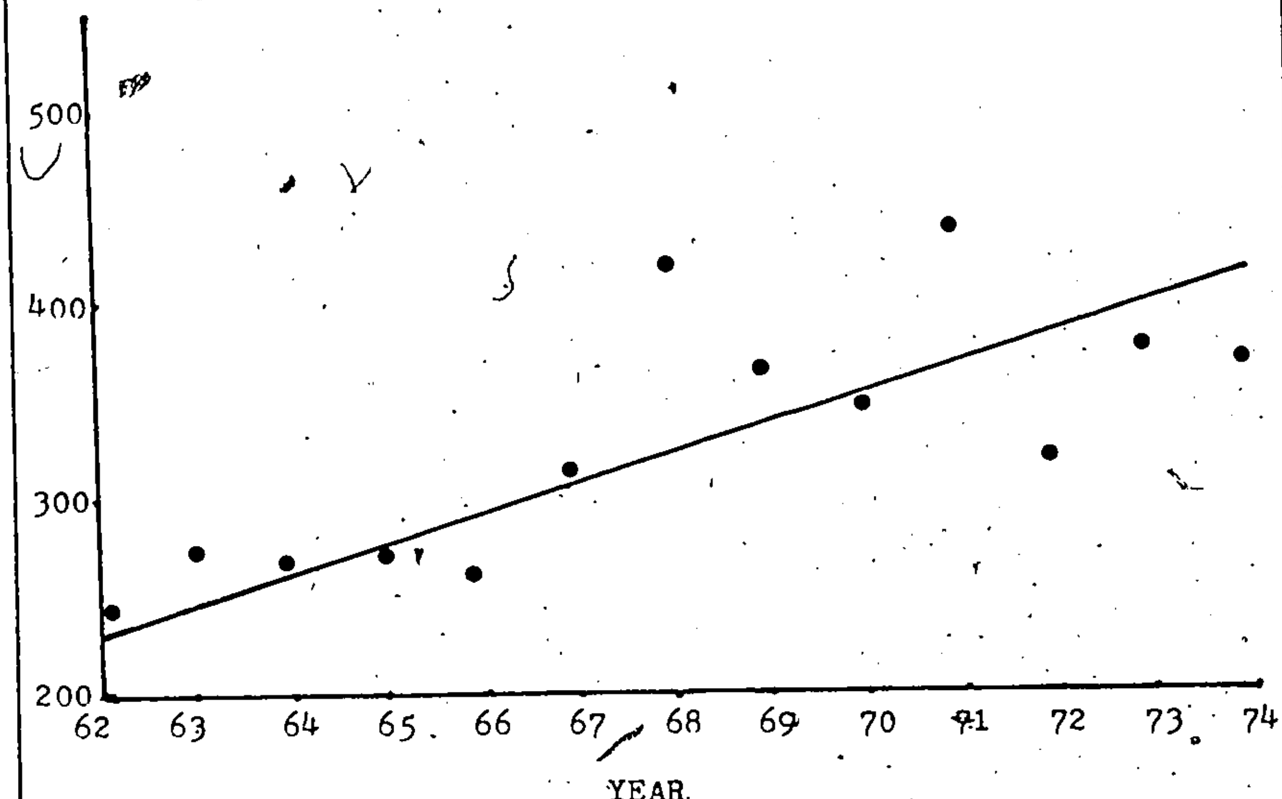
Storm Activity

During the spring through to the fall months the Great Lakes Region and Lake St.Clair area experience low pressure systems at 4 to 6 day intervals (Environment Canada, 1962-1974). These low pressure systems have recently been increasing in frequency through the April to November ice free period (FIG. 15). Davis and Fox (1972), making observations along the lake shore of Michigan found that storms associated with barometric pressure less than 29.7 inches (1003 mb) possessed the highest wind velocities, resulting in the highest breaker point, and the greatest longshore current velocity. This regular change in wave dimensions, and longshore current velocity effect changes in the morphological and sedimentary characteristics of the beaches along the shores of Lake Erie (Wood,1969; Coakley and Cho, 1972). This has been confirmed by other workers (for example Inman,1953; Darling 1964; Miller and Zeigler, 1964; Henrik, 1967; Sonu and Van Beck, 1971; Walton and Goodell, 1972; and Williams, 1974) studying other areas and reported that beach sedimentation patterns change in evident response to the fluctuating nature of the physical forces which act on them. These authors regard nearly all beaches to be in a constant state of flux. Sedimentary characteristics change during the seasons of high waves (King, 1953; Darling, 1964; Dolan and Fern, 1966), while the profile changes in height and width during the stormy seasons (Zeigler et al 1959; Thompson and Harlett, 1968). It is thus evident that sediments from one

FIG·15

INDEX OF STORM INTENSITY; 1962 — 1974

INDEX (The product of the frequency of intense low pressure systems and the associated maximum wind velocity).



Source: ENVIRONMENT CANADA, 1962-1974
DAILY SYNOPTIC WEATHER RECORDS, WINDSOR

environment can be mixed in another environment due to variations of wave energy and wind velocity velocity which act on the beaches in Essex County.

It is also significant to point out that the intermixture of backshore and dune material (7 samples from the backshore environment classified in the dune environemnt and 4 samples from the dune environment classified in the backshore environemnt) can be the result of storm winds. Bagnold (1954) clearly pointed out that one of the chief role of storm winds is to add new material to dunes, and that storms must occur occasionally for the dune process to continue.

Also associated with strong winds in the fall and winter are wind set-ups. Wind set-ups are particularly evident on Lake Erie where they have been responsible for an increase of more than eight feet in the lake level at the eastern end of the Lake (Richards, 1969). Whenever a set-up occurs the water mass oscillates (oscillation of the water mass is known as a seiche), and affects the foreshore region . Material characteristics in both the nearshore and foreshore zones can be changed until that time it takes the lake to return to its equilibrium.

Longshore Currents

Workers agree on at least two unifying and fundamental ideas on the longshore transportation of sediments . Wave energy or power provides the principal means by which sediment movement is initiated, and the angle of wave incidence creates the alongshore component of wave power which transports sand along a shore (Saville, 1950; Johnson, 1953; Caldwell, 1956; Inman, 1963; Inman and Bagnold, 1963; Johnson and Eagleson, 1966; Zenkovich, 1967; Komar, 1970, 1971). Although no meaningful study has been done on the longshore transport of sand along the shore of Western Lake Erie and Lake St. Clair it has been generally found that lake currents are weak in comparison with the ocean. Over most of the area of the Great Lakes , currents are less than one mile per hour and average speeds near the surface are only about two-tenths of a mile per hour (Rodgers, 1969). Since shore currents are dependent on winds it should be remembered that greater wind velocity generate currents of greater speeds.

Field observations by Chrysler and Latham (1974) report that Point Pelee is experiencing erosion because of the reduction in the amount of longshore drift material on the updrift side of the Point. Under normal conditions , sands are transported south along the eastern side of Point Pelee. Some of this sediment is then washed over the tip of the Point, and redistributed on the western beaches. However, Chrysler and Latham (1974) found that this redistribution of material has been affected by the construction of artifical barriers (chiefly long,low, narrow groynes). This redistribution of material which has been affected by these artifical constructions has partially resulted in the absence of finer sediments on the western beaches. Only in times of high longshore current velocity (stormy weather) finer sediments are transported to the western beaches. It should also be pointed out that owing to the smaller fetch distance on the western side of the Point energy level will not vary as much as on the eastern side of the Point. King (1972) studied the relationship between fetch distance and particle size and noted that larger particles are found in areas with short fetch distances. Given these conditions the sorting characteristics of the material on the western beaches remain poor; hence the possible misclassification of 15.78% of the samples at Site A.

The above discussion of the factors which could have caused possible modification of the depositional environments of Essex County are in no way complete. It should be remembered that the process-response relationships existing between sediment texture and the hydrodynamics of depositional environments are incompletely understood (Greenwood and Davidson-Arnott, 1972).However, it does appear reasonable to accept the hypothesis that there is a relationship between sand texture and depositional environments; although 2I.43% of the samples have been misclassified. In sedimentological studies this margin of error is to be expected ,as a result of the energy producing forces varying in intensity over space and time.

Hypotheses Two and Three

Graphic and Moment Measures

Both Graphic and Moment measures provide alternative ways of describing the distribution of grain-size data, and determining depositional environments. This study has pointed out the strengths and weaknesses of both these measures. The component population analysis using cumulative curves provide an effective means of determining whether two or more populations are present by the sharp angular discontinuities of the curves. They further provide useful information regarding the normality of the population, and reveal errors in the analytical (sieving, weighing) method. One of the major limitations of component population analysis is the subjectivity that is introduced in the interpretation of the various truncation points. Moreover, Visher(I969) points out that although the cumulative curves indicate certain general hypotheses concerning the cause and effect relationships between sedimentary processes and textural responses, a precautionary note must be taken in that they are not based upon quantitative hydraulic studies.

The easy computation of the graphic statistics is one of the chief advantages of this method. However, it has limitations as to its reliability in differentiating depositional environments , as shown by this study , and those of other workers (for example Chappell, I967; Miola and Weiser, I968).The plot of Graphic skewness against Graphic kurtosis (FIGS. 5A and 5B) as suggested by Mason and Folk (1958) to differentiate depositional environments has failed to show any significant differences in the various environments although the environments have been identified. Only the plot of Inclusive Graphic standard deviation against mean size (FIGS. 6A and 6B) shows partial environmental separation when the samples have been identified in their true environments of deposition.

It can also be claimed that although the moment measures use all the items in the distribution they are not more reliable than the graphic measures for environmental discrimination. In the plot of mean against skewness (FIGS. 7A and 7B) only 12.5% of the dune samples were correctly classified. In the plot of the standard deviation against skewness (FIGS. 8A and 8B) Friedman (1961) proposed that samples should fall into two respective areas (beach and river). On inspection of the scatter plot, 42 samples have been determined as belonging to a river environment when in fact samples were not taken from any rivers. This study thus supports the results of other workers (for example Gees, 1961; Solohub and Klovan, 1970) that moment measures are not reliable enough to differentiate depositional environments.

The applicability of graphic and moment measures to differentiate depositional environments may well be questioned. Their effectiveness is restricted to only certain environments . Interestingly enough, Solohub and Klovan (1970) who also studied sediments from a lacustrine setting noted inherent weaknesses in the use of bivariate plots. These are:

a/ environmental discrimination may not be possible using two parameters because process-response relationships are multi-dimensional

b/ in order to test the accuracy of the bivariate plots, one needs 'a priori' knowledge of the origin of the samples.

Given these major limitations, it can be claimed that graphic and moment measures are not universally applicable in differentiating environments of sand deposition.

Discriminant Analysis

Stepwise discriminant analysis has served the function of discriminating between size distributions of sand samples collected from several different environments. The technique when applied to the entire collection of samples showed only 21.43% of the samples to be misclassified. Using samples from each of the five sites sampled (A,B,C,D,E), the technique demonstrated that each environment is distinct and statistically defined. It has been clearly shown that area A (Point Pelee) is the most variable of the sites in that it had the highest percentage (15.78%) of its samples misclassified. Further, it can be claimed that this technique provides information on the variations of energy levels in each of the sampled environments. Although it seems that stepwise discriminat yields good results, it must be remembered that one major limitation of this technique is that it assumes samples were not misclassified and requires classification on 'a priori' basis.

R-Mode Factor Analysis

The advantage of R-Mode factor analysis is that it allows for no 'a priori' reasoning. The four factors which accounted for 36.4%; 22.5%; 14.1% and 8.0% of the total grain-size variation respectively represent the fine sand, coarse sand, granule, and very fine sand in the various environments of Essex County. These populations of sand can be related directly to the energy characteristics of the area. The sub-group in factor three indicates that very coarse sand representative of the shallow agitated are loaded with sediments of glacial origin. This is some what misleading for glacial sediments and shallow agitated sediments are influenced by different types of energy and transportation mechanisms. It may well be true that sediments from the shallow agitated environments and the glacial environment are similar in characteristics but the problem of determining the exact differentiation between the sediment characteristics of these two environments on the basis of grain-size data restricts the applicability of this technique to an extent. However it should be further tested before any definite conclusions can be made as to its general utility.

REVIEW, LIMITATIONS, AND CONCLUSION

Review

Sediments are laid down in a wide variety of environments by different depositing agents. Identifying specific environments of sand deposition on the basis of geomorphological and sedimentologic criteria, 168 samples were randomly collected from six areas which represented shallow agitated, foreshore, backshore, dune and glacial sediments. Using statistical techniques which have been proposed for differentiating depositional environments, it was found that each technique has its strengths and weaknesses.

The scatter plots of the graphic and moment measures indicate that these measures are not reliable enough to differentiate depositional environments. The chief limitation lies in the fact that they fail to account for the multi-dimensional nature of process-response relationships. Both these measures however, show that skewness is environmentally sensitive. Strongly skewed samples were obtained from zones of environmental mixing. The negative skewness reflects the high energy environments in the shallow agitated and foreshore zones, while the the positive skewness is a reflection of lower energy levels, where only smaller particles can be transported and then deposited. Further both the graphic and moment statistics reflect the importance of mean size. Each of the environment of deposition is associated with a different mean sediment size; with the mean size of the shallow agitated samples being the largest while the dune sands had the smallest mean size.

The multivariate techniques , stepwise discriminant analysis and R-Mode factor analysis have been more effective in discriminating the various environments. Similar results have been achieved by workers using discriminant analysis (Sahu, 1964; Greenwood, 1969) and workers using factor analysis (Klovan, 1966; Allen et al 1972). Discriminant analysis distinguished the various environments of deposition, and showed that a mixture of sediments are found in the backshore and dune areas, and that the shallow agitated and foreshore areas are subject to varying energy conditions. The technique lends support to the concept that sand texture is related to environments of deposition, but suffers the limitation in that a 'a priori' assumption is made as to the original environment of the samples.

R-Mode factor analysis demonstrated that four distinct sand populations are representative of the six sampled sites. The relative environmental importance of each population is reflected in the factor groupings. These groupings can be related to different energy conditions, but the problem arises when energy is related to environment of deposition on 'a priori' basis. As such it can be claimed that one of the major limitations of this technique is the interpretation of the factor groupings. The results obtained from this technique illustrate that no clear distinction is made between the sediments of the shallow agitated, foreshore and glacial environments.

Limitations

Despite the conclusions reached by a number of workers (for example Folk and Ward, 1957; Mason and Folk, 1958) using the graphical methods; workers (for example Friedman, 1961; 1967; Hails, 1967; Anan, 1969) using moment measures; workers (for example Sahu, 1964; Miola and Weiser, 1969; Greenwood and Davidson- Arnott, 1972) using discriminant analysis; workers (for example Klovan, 1966; Solohub and Klovan, 1970; and Allen et al 1972) using factor analysis, it is clear that none of the methods can completely discriminate between depositional sedimentary environments. In sedimentology this is not unique, because the grain-size distribution of a sediment is a result of the interaction of numerous factors. Possible modification in a depositional environment can be caused by variation in the energy levels of the environment and the availability and the type of sediment. Reineck and Singh (I973) further claim that many other parameters can influence the state of a depositional environment . These might be the effects of tectonics and tides, influence of transgressive, and regressive tendencies, effect of chemical factors, influence of abnormal weather conditions, etc.

Possible reasons why the results of this study have not achieved close correlation with the results of other studies can be:

I/ differences in sampling procedures;
2/ differences in laboratory techniques (mechanical analysis);
3/ differences in scales employed;
4/ differences in the delineation of the environments;
5/ environments sampled are related to a marine setting rather than a lacustrine setting, and
6/ mutually exclusive and exhaustive populations have not been sampled.

It will now be interesting to employ different methods to determine whether grain size is related to environment of deposition. For example,facies identification through grain size (Glaister and Nelson, I974) could prove useful in determining whether an environment was stable or not. Further the greater use of the electron microscope can aid in the study of grain-size as related to environments of deposition. It is also believed that statistical and simulation models should be employed to simulate the grain-size of any environment given defined conditions.

Whatever the limitations of grain-size studies , it has been shown that there is some correlation between size frequency distribution, and the environment of deposition.

Conclusion

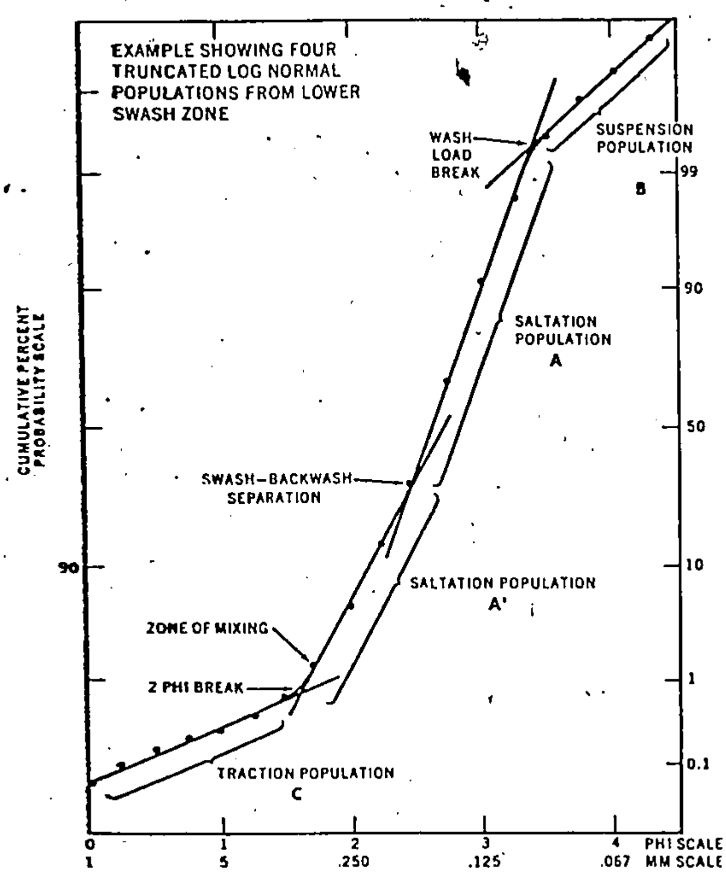
The use of grain-size distribution in the identification of depositional environemnts is discussed frequently in the literature, with differing conclusions on the value of the method. This study of grain-size distributions from different environments in Essex County has shown that grain-size distributions can be used as environmental indicators. Principal among the reasons as to why the use of proposed statistical have been only partially successful is that the grain-size distribution is a product of the energy of the environment. The variation of energy in sedimentary environments over space and time are believed to be only partly understood. Occasionally similar energy levels may be active in a number of different environments, and thus similar grain-size distribution may result in rather different environments. Further availability and type of sediments , plus inconsistencies in the energy levels, will result in various environments having a mixture of sediments.

Although it is believed that the proposed statistical techniques for treating grain-size data can be used for environmental discrimination in particular settings, no reliability can be placed on any of the techniques to show complete environmental separation.

APPENDIX I

The sample material is heaped up into a cone. The cone is cut into quarters with a knife or with a tin cross. The first and third (or second and fourth) quarters are again heaped into a cone, and once more divided into quarters. This division into quarters is repeated until the desired sample size is reached.

APPENDIX 2



Relation of sediment transport dynamics to populations and truncation points in a grain size distribution.

After Visher (1969)

APPENDIX 3A

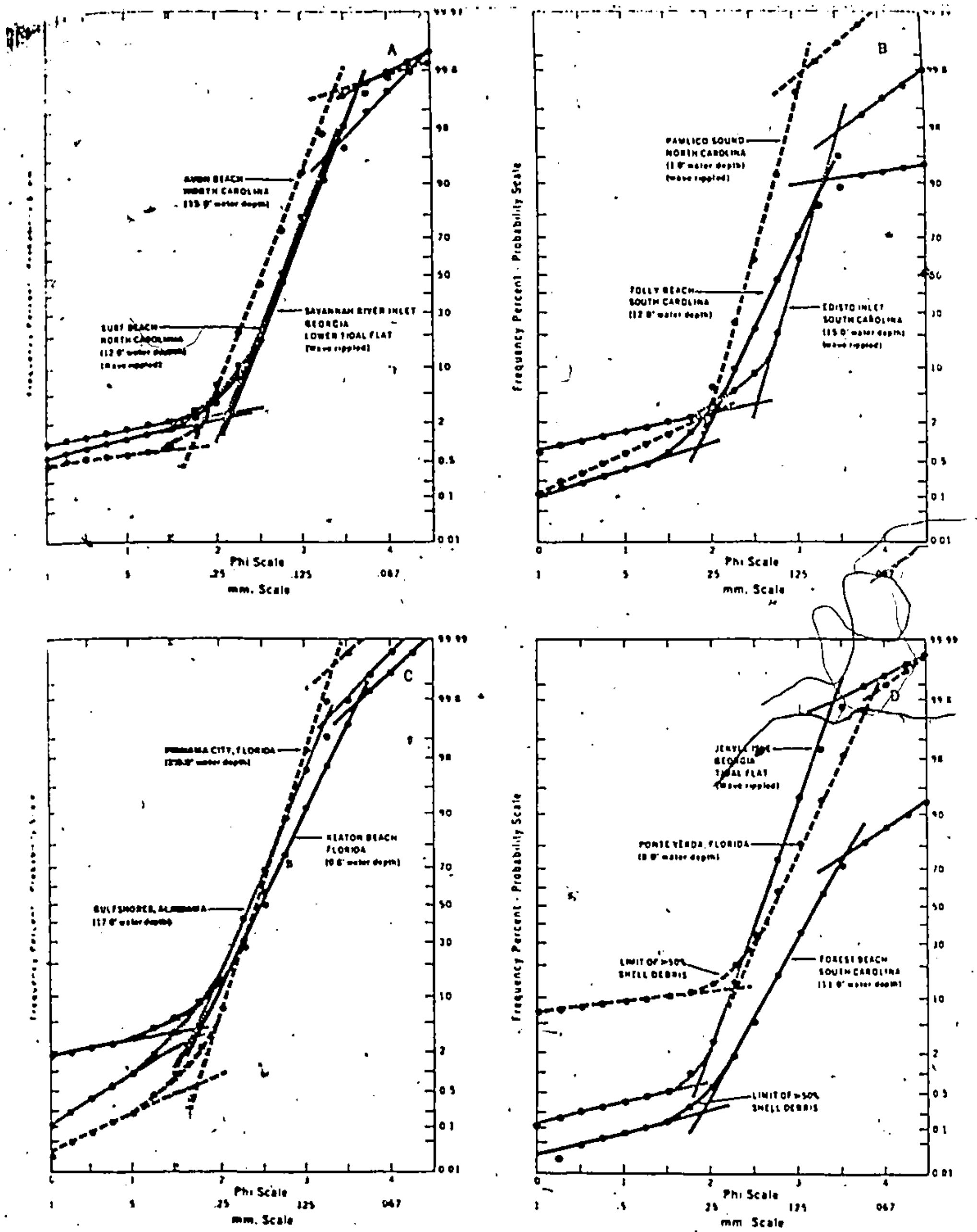
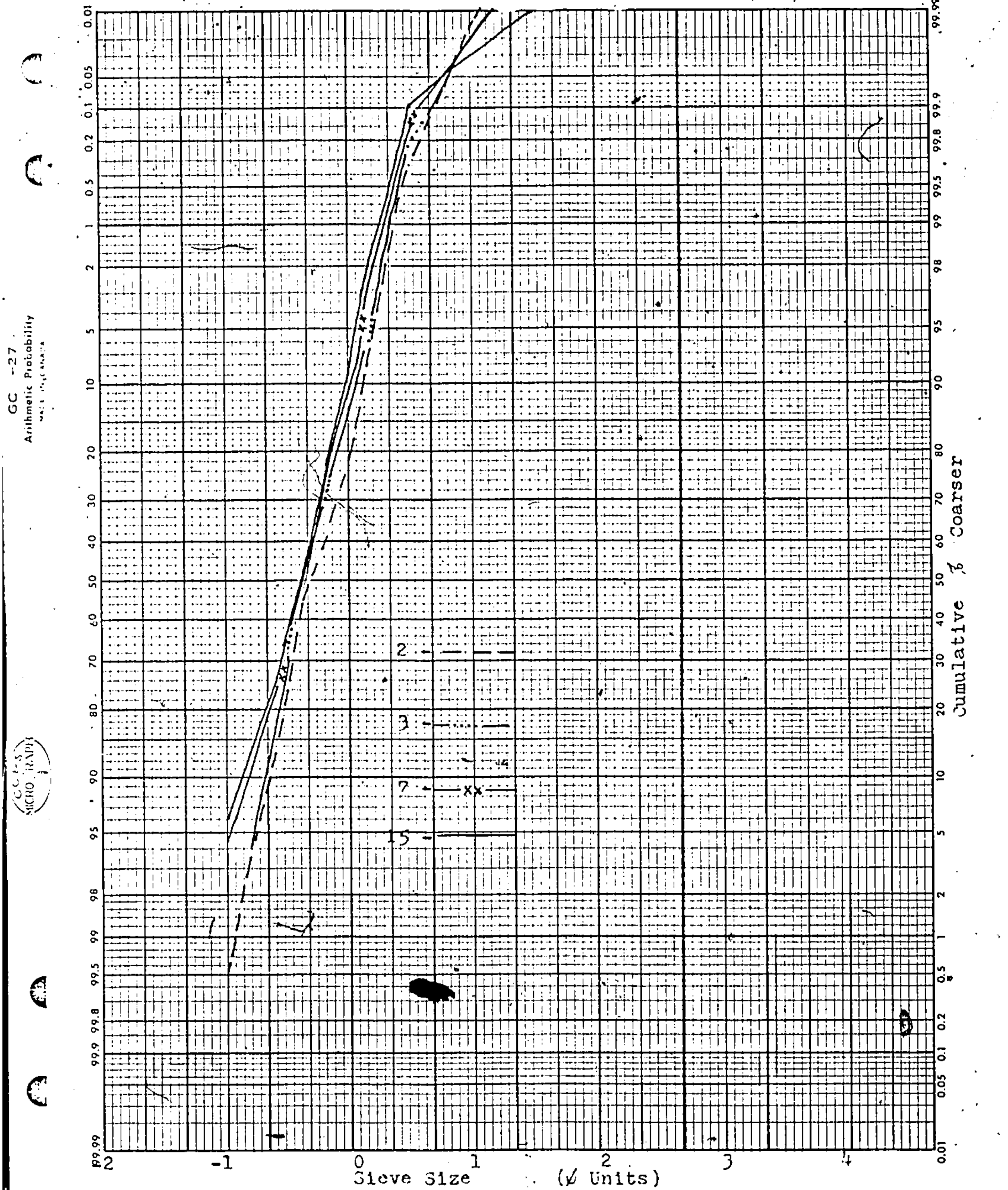


FIG. 9.—Wave zone sand distributions. Similarity in the general form of these distributions can be seen. The variation in water depth does not appear to affect the grain size curve shape.

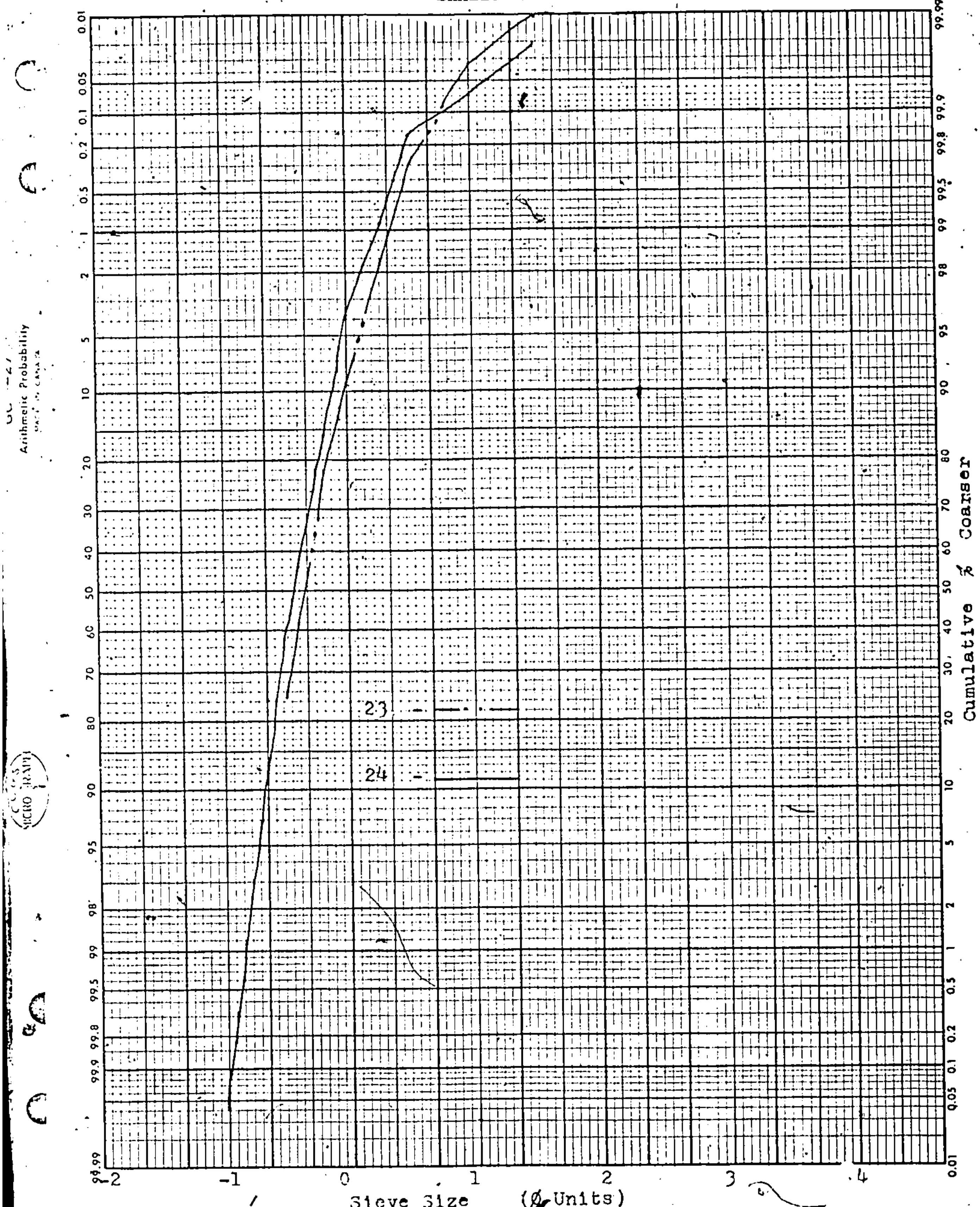
After Visher (1969)

APPENDIX 4

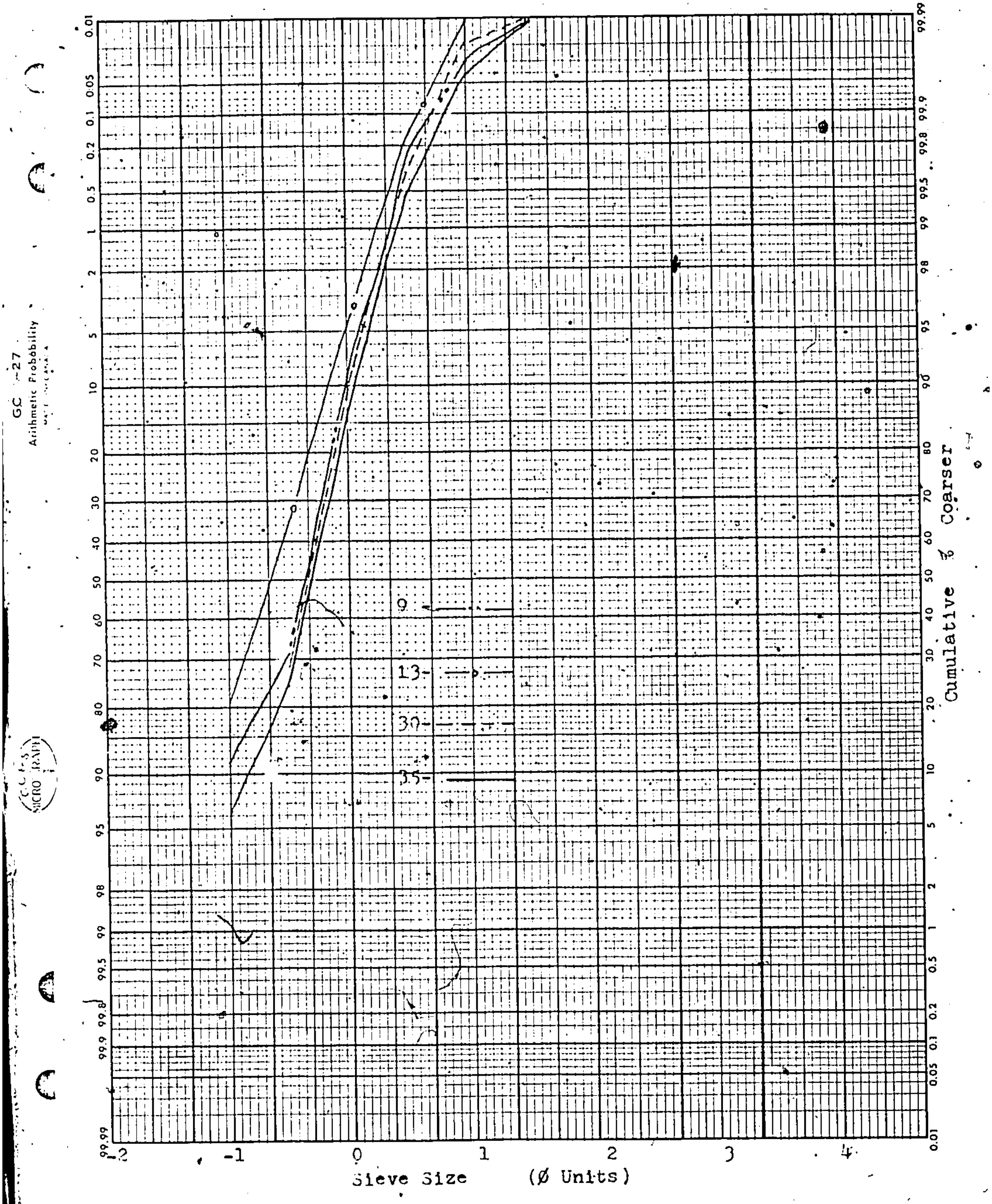
SHALLOW AGITATED SAMPLES



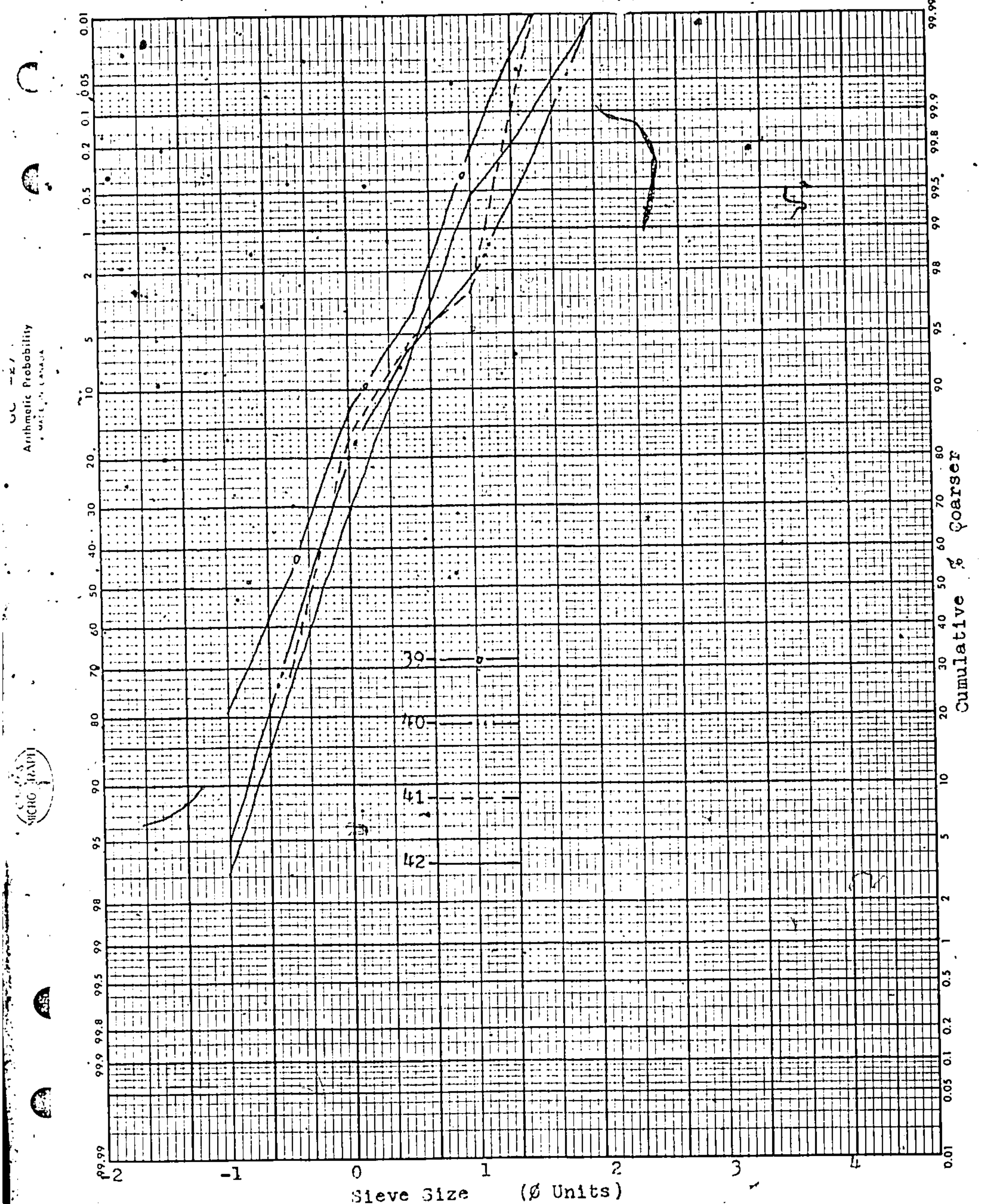
SHALLOW AGITATED SAMPLES

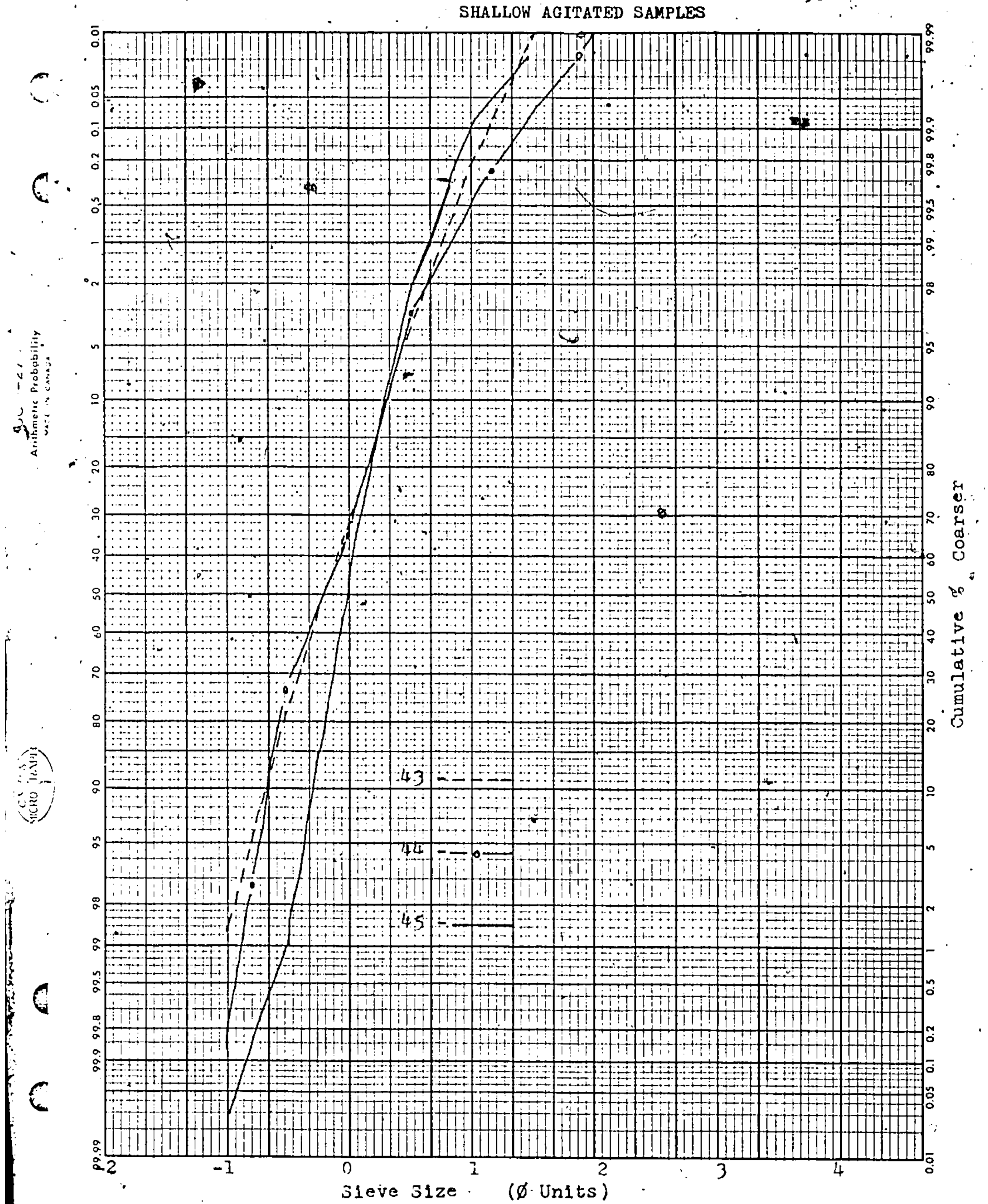


SHALLOW AGITATED SAMPLES

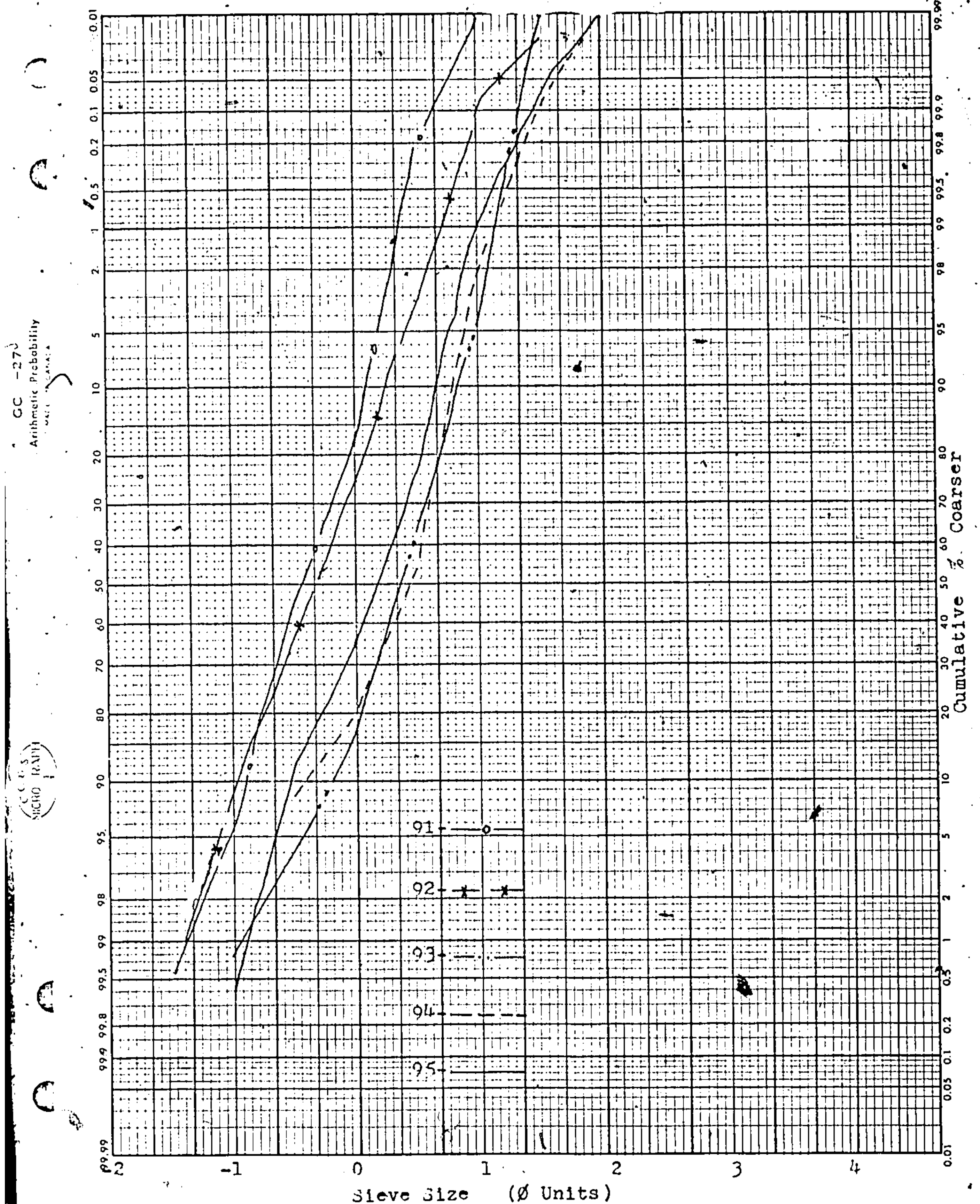


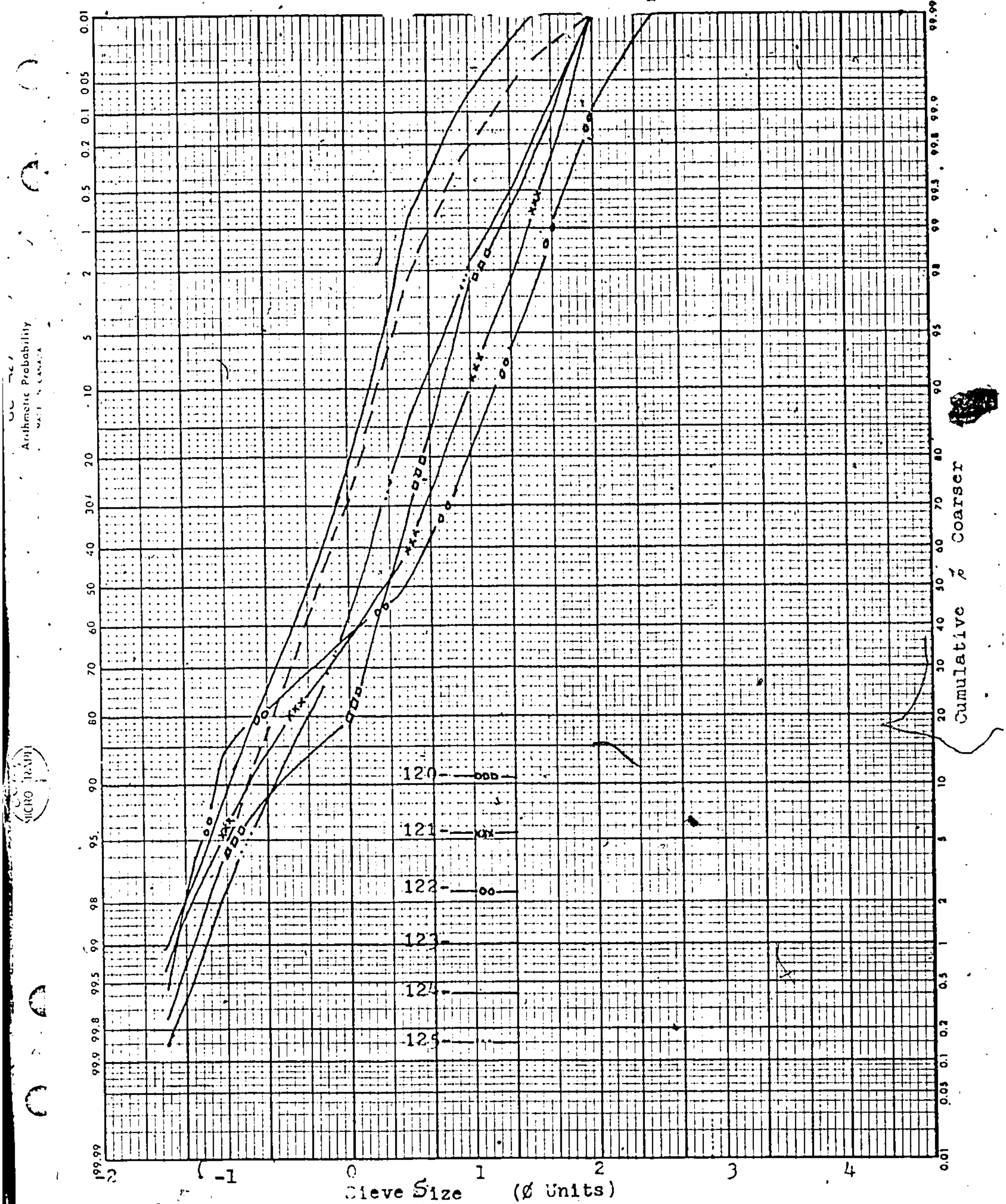
SHALLOW AGITATED SAMPLES



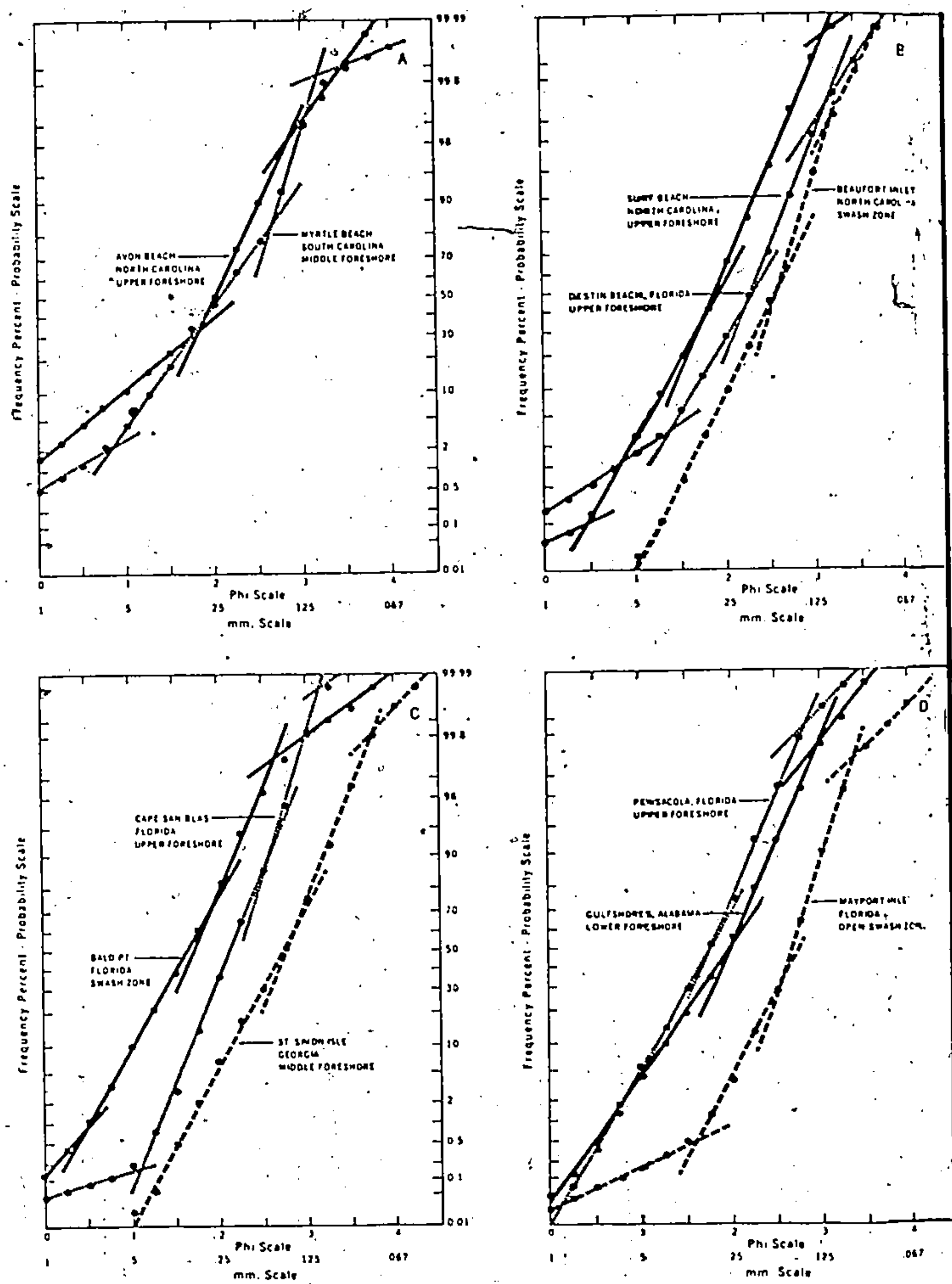

SHALLOW AGITATED SAMPLES
43
44
45
Sieve Size (Ø Units)
Cumulative % Coarser
Arithmetic Probability
-2
-1
0
1
2
3
4

SHALLOW-AGITATED SAMPLES




120- ooo
121- xxx
122- oo
123-
124-
125-
Sieve Size (Ø Units)
Cumulative % Coarser
Arithmetic Probability

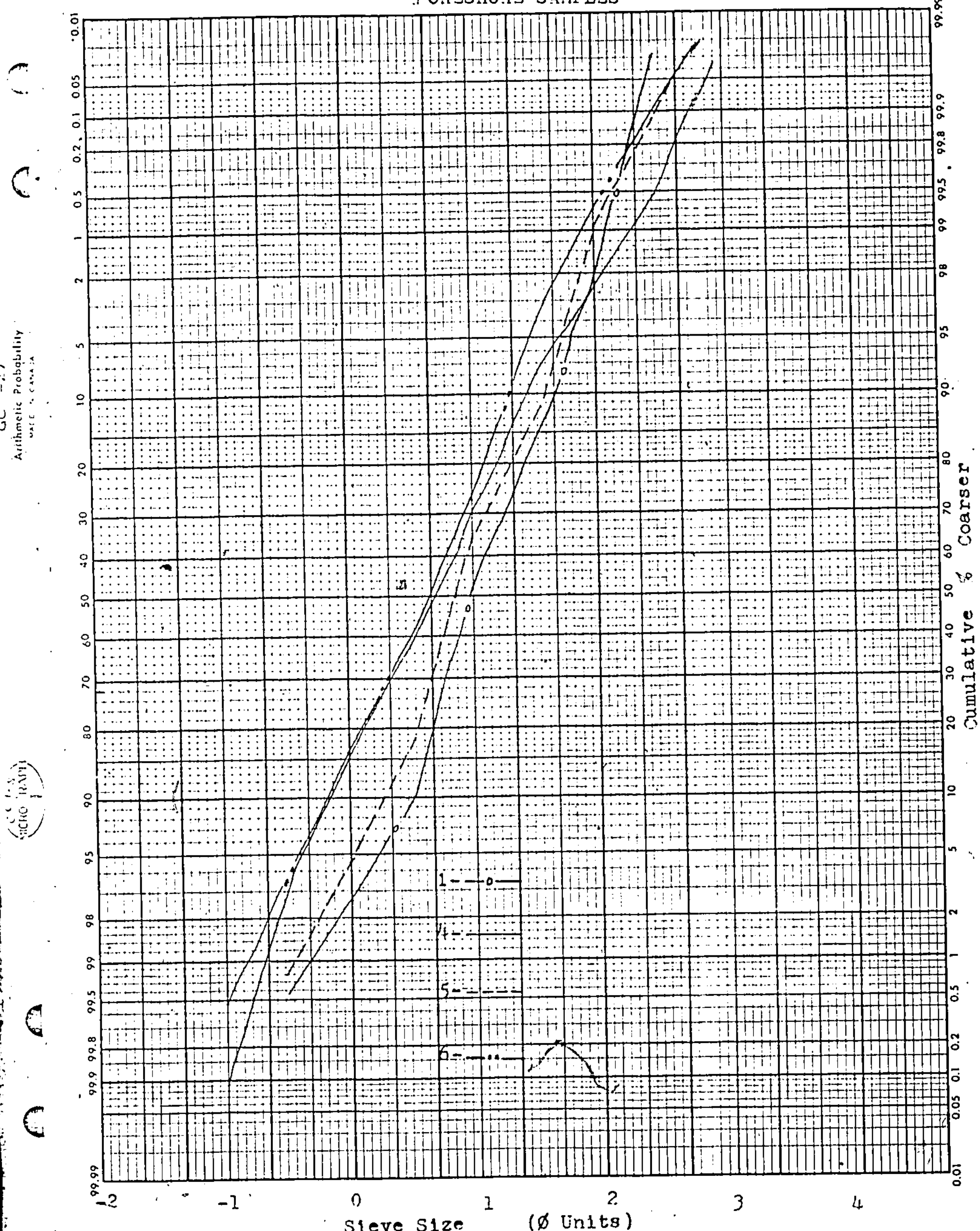
APPENDIX 3B



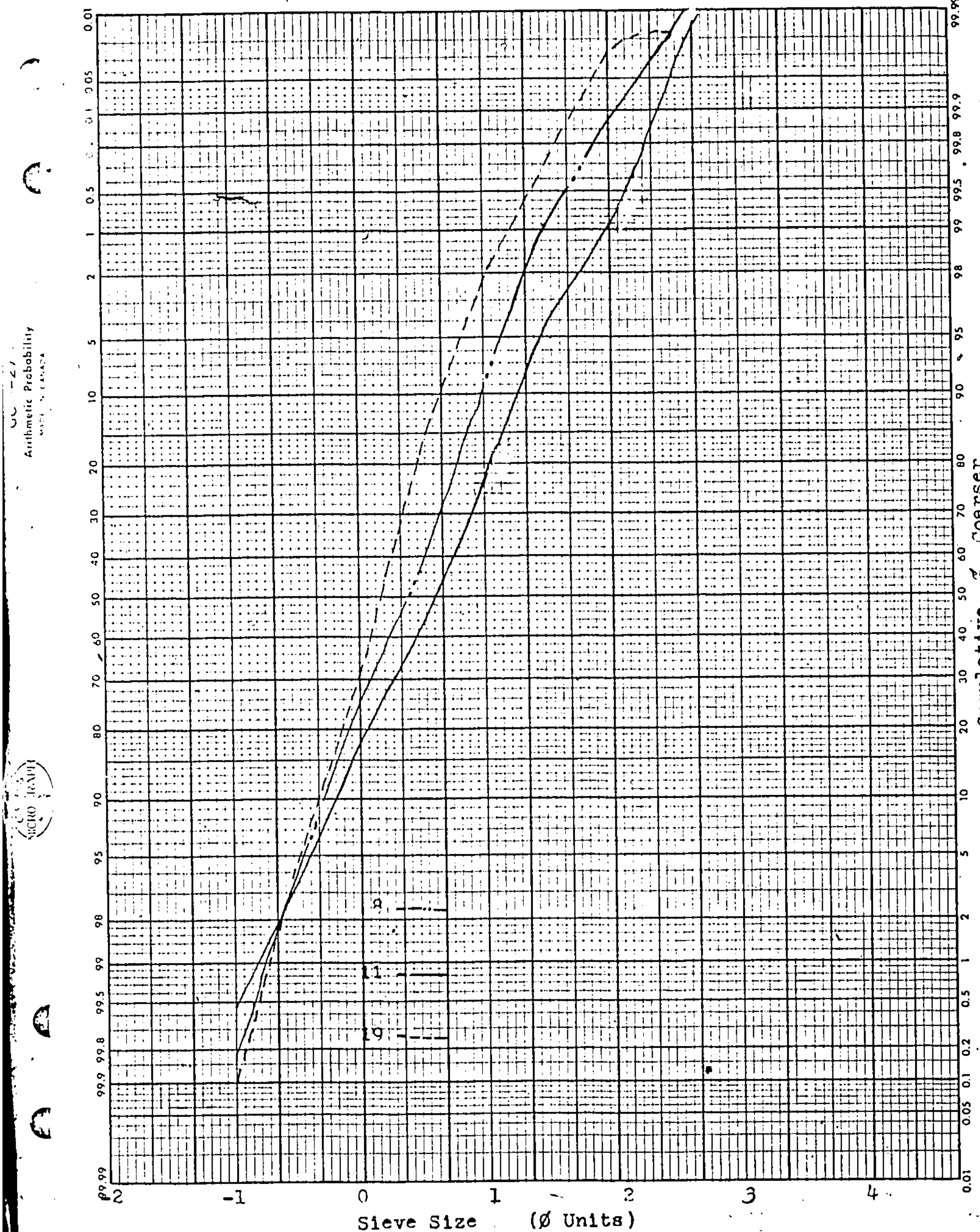
Examples of beach foreshore sands. Sands formed by differing wave and provenance conditions included. All curves have a similar shape.

After Visher (1969)

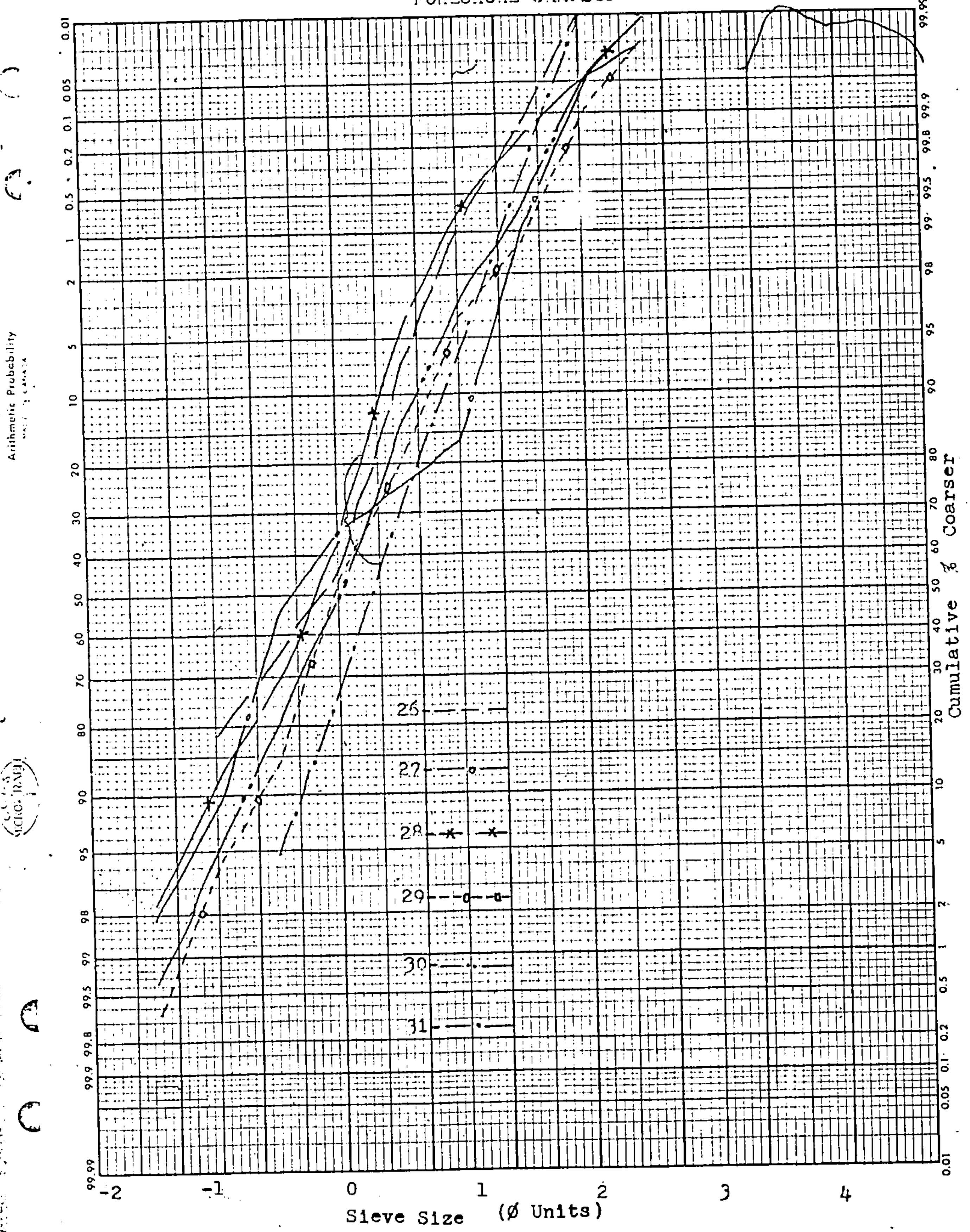
FORESHORE SAMPLES



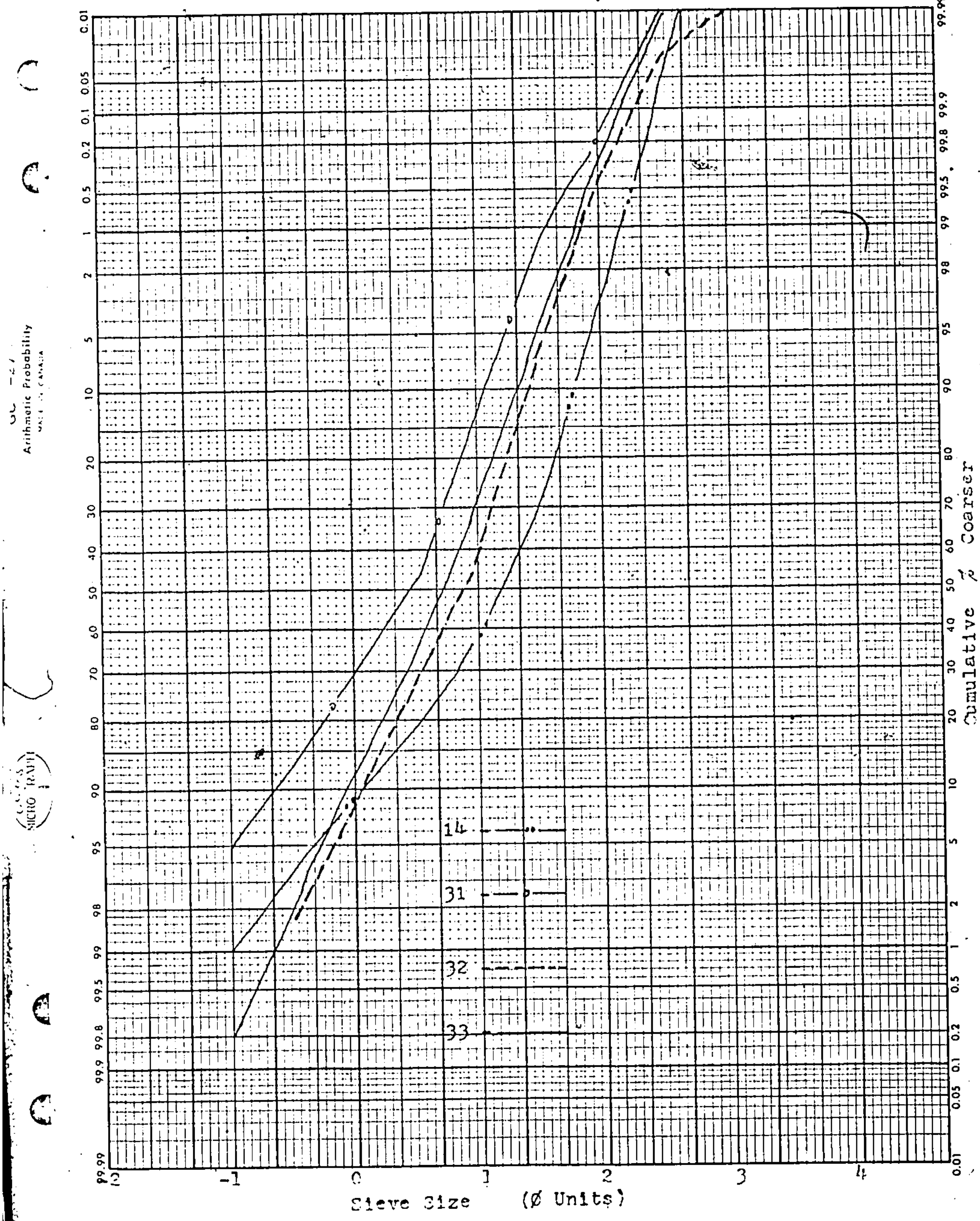
FORESHORE SAMPLES



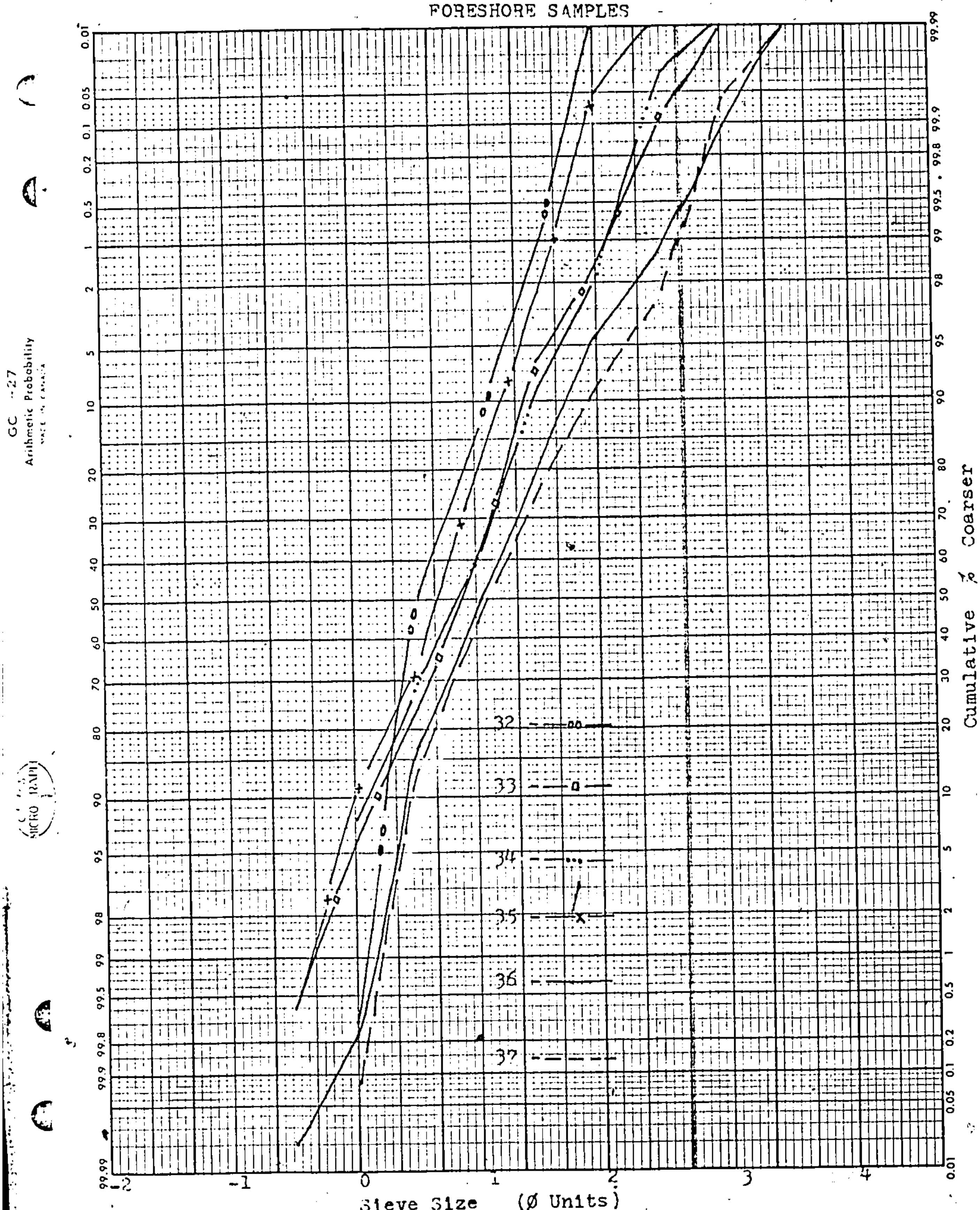
FORESHORE SAMPLES



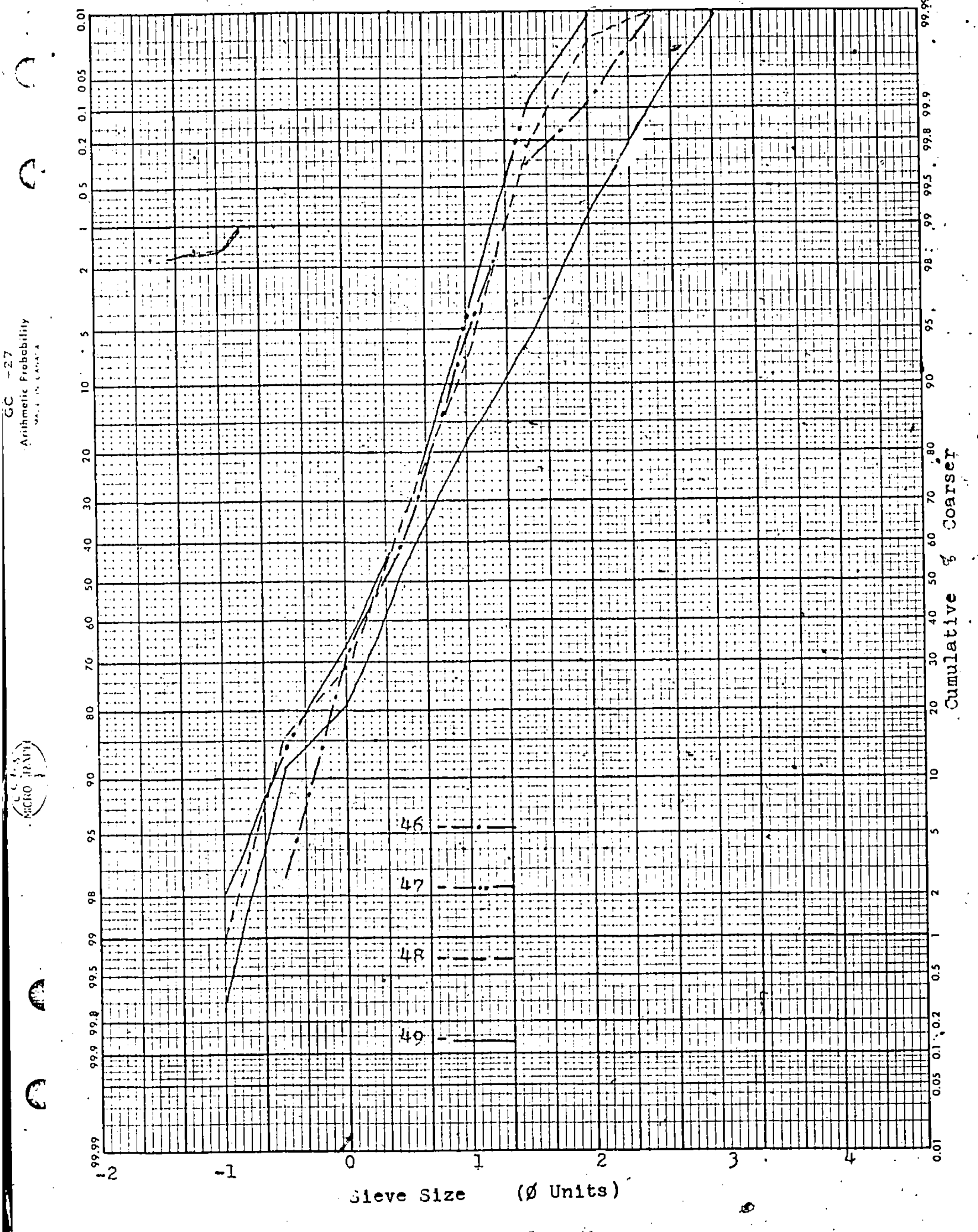
FORESHORE SAMPLES



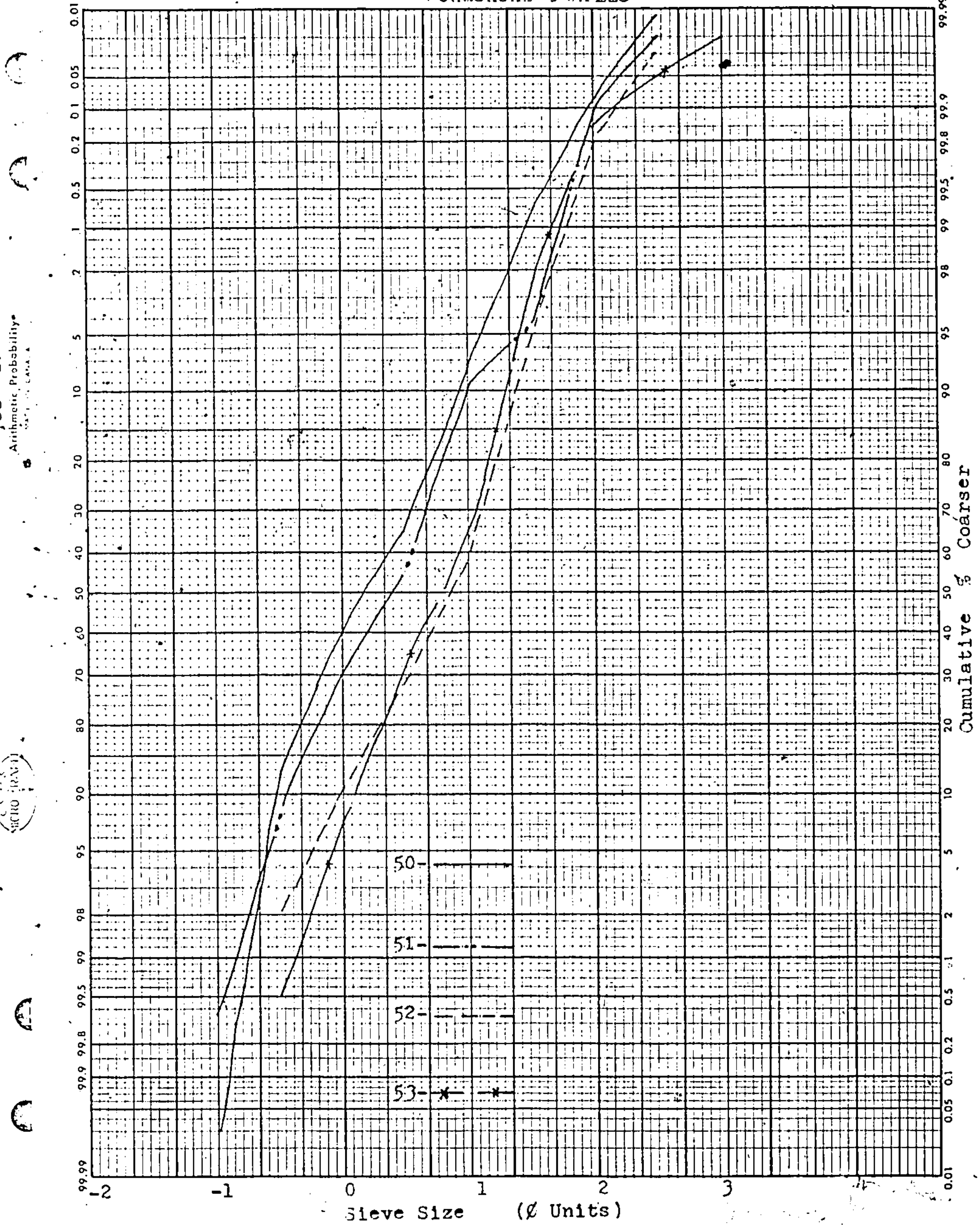
FORESHORE SAMPLES



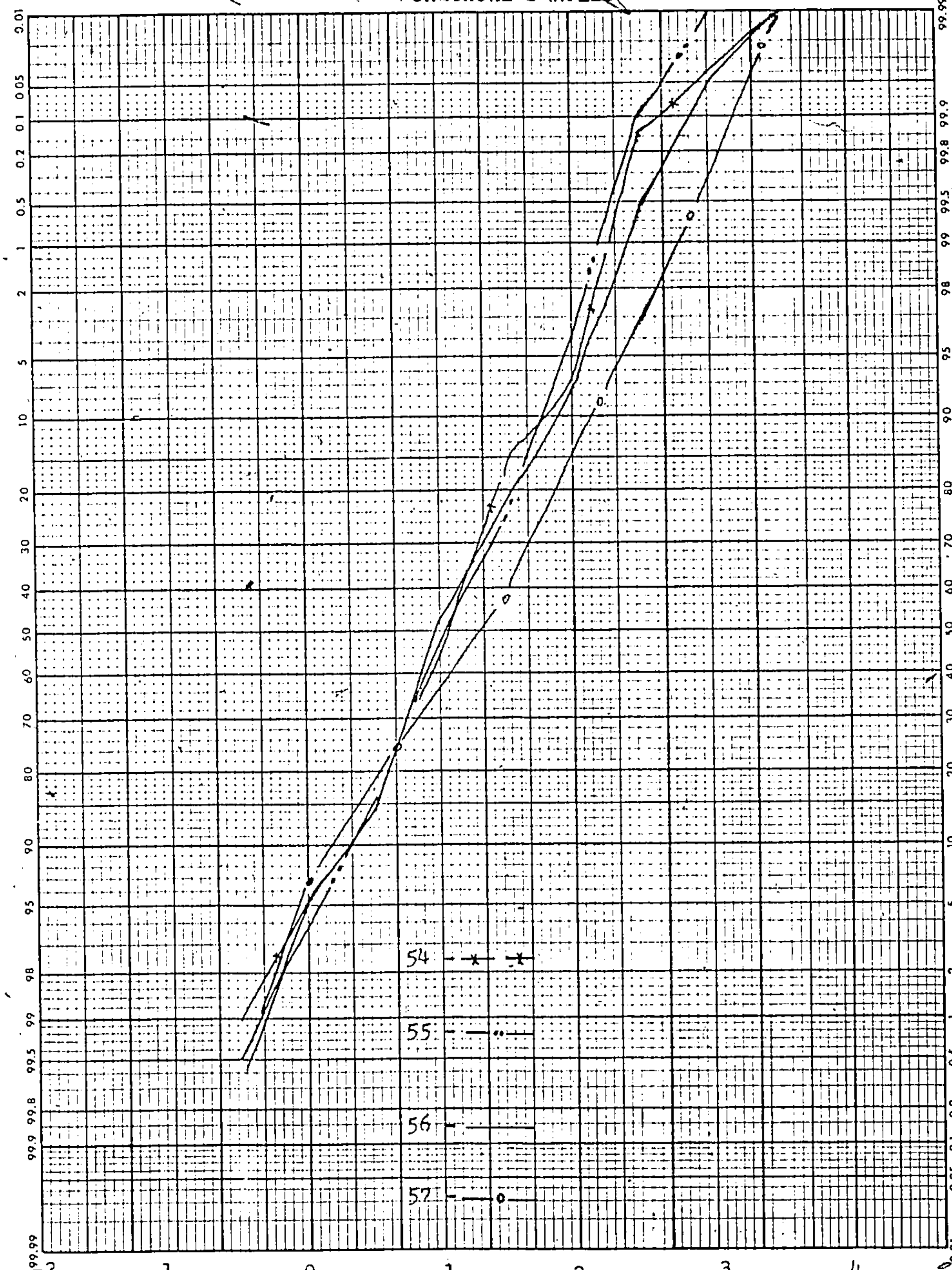
FORESHORE SAMPLES



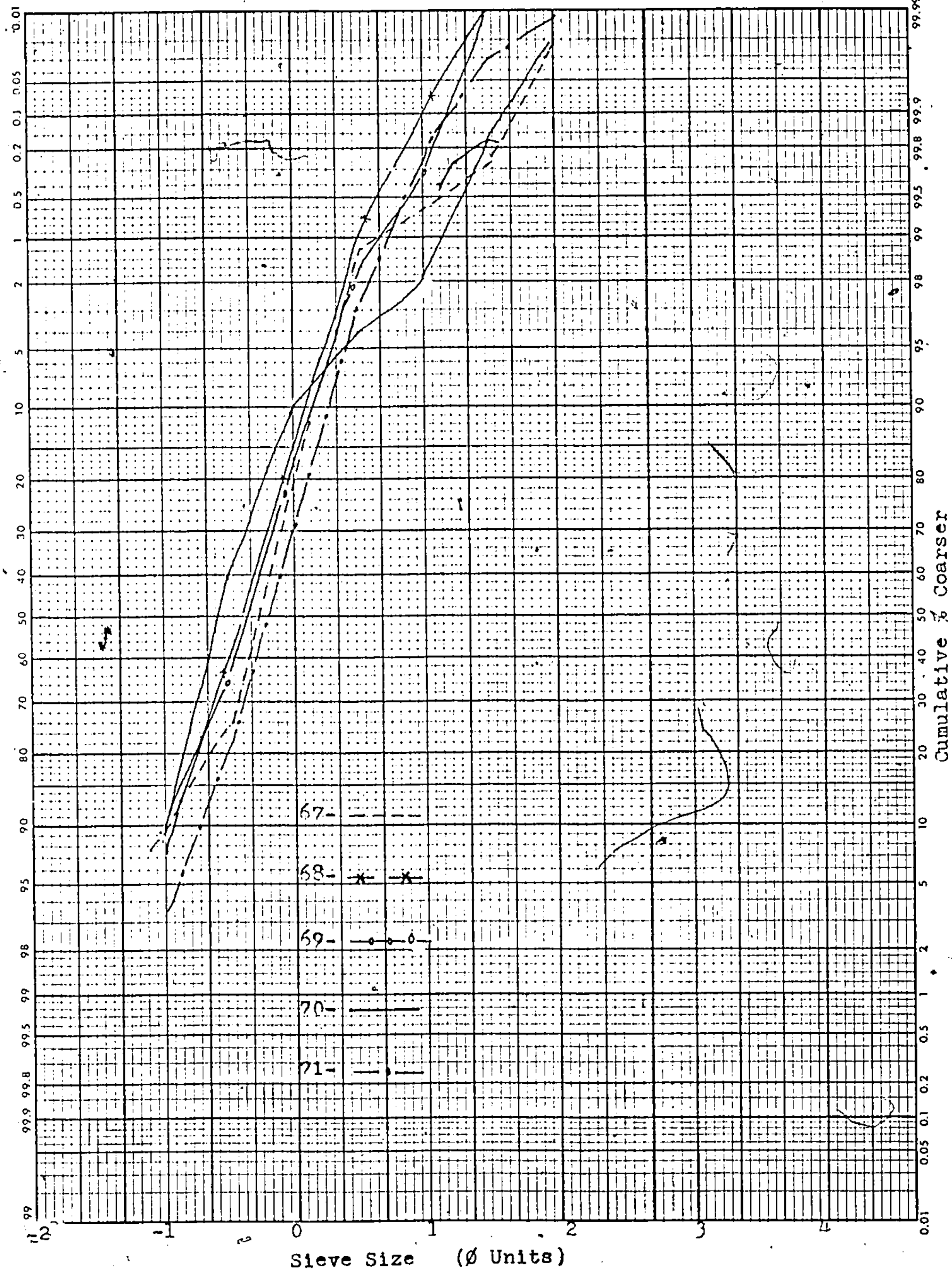
FORESHORE SAMPLES

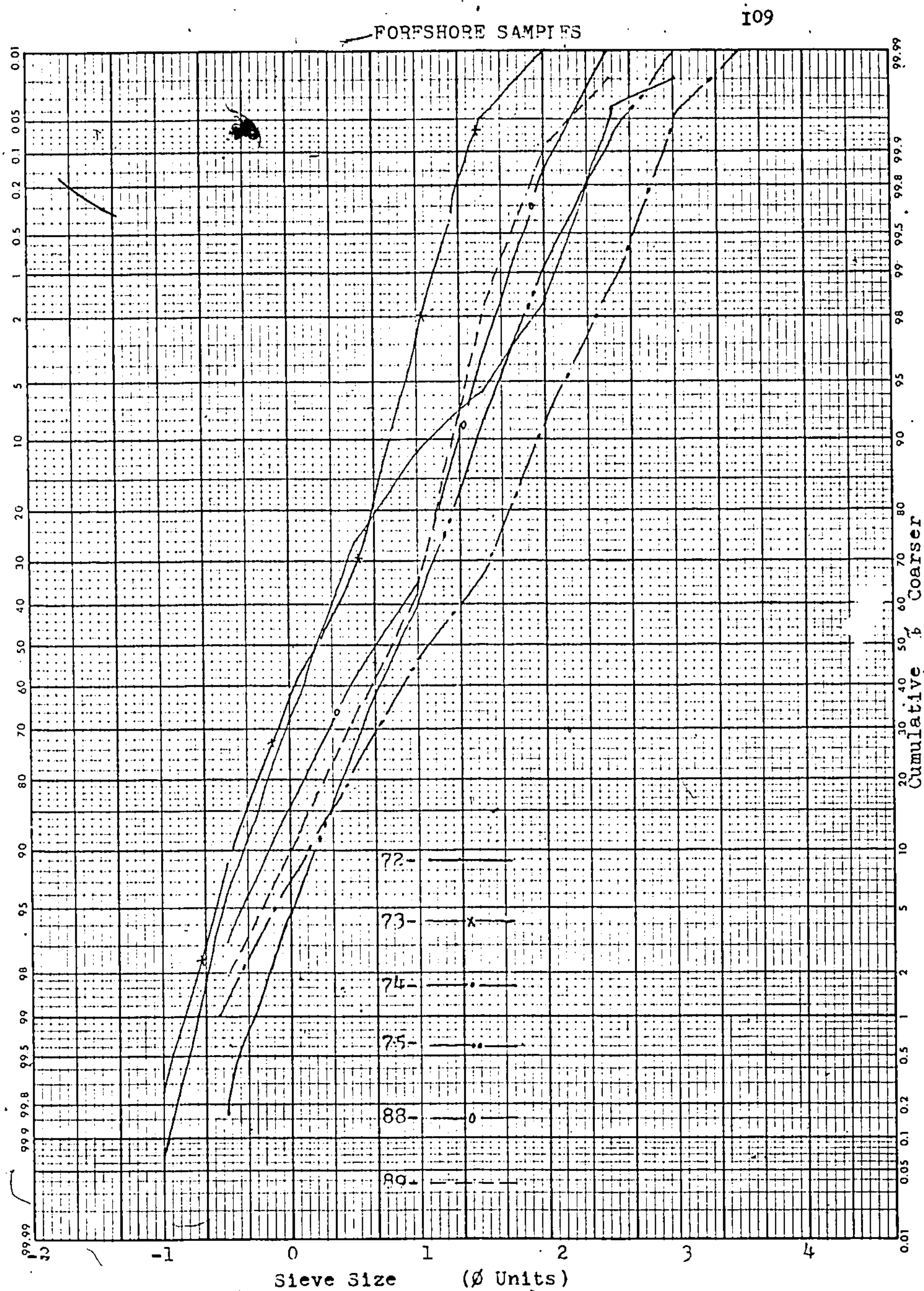


FORESHORE SAMPLES

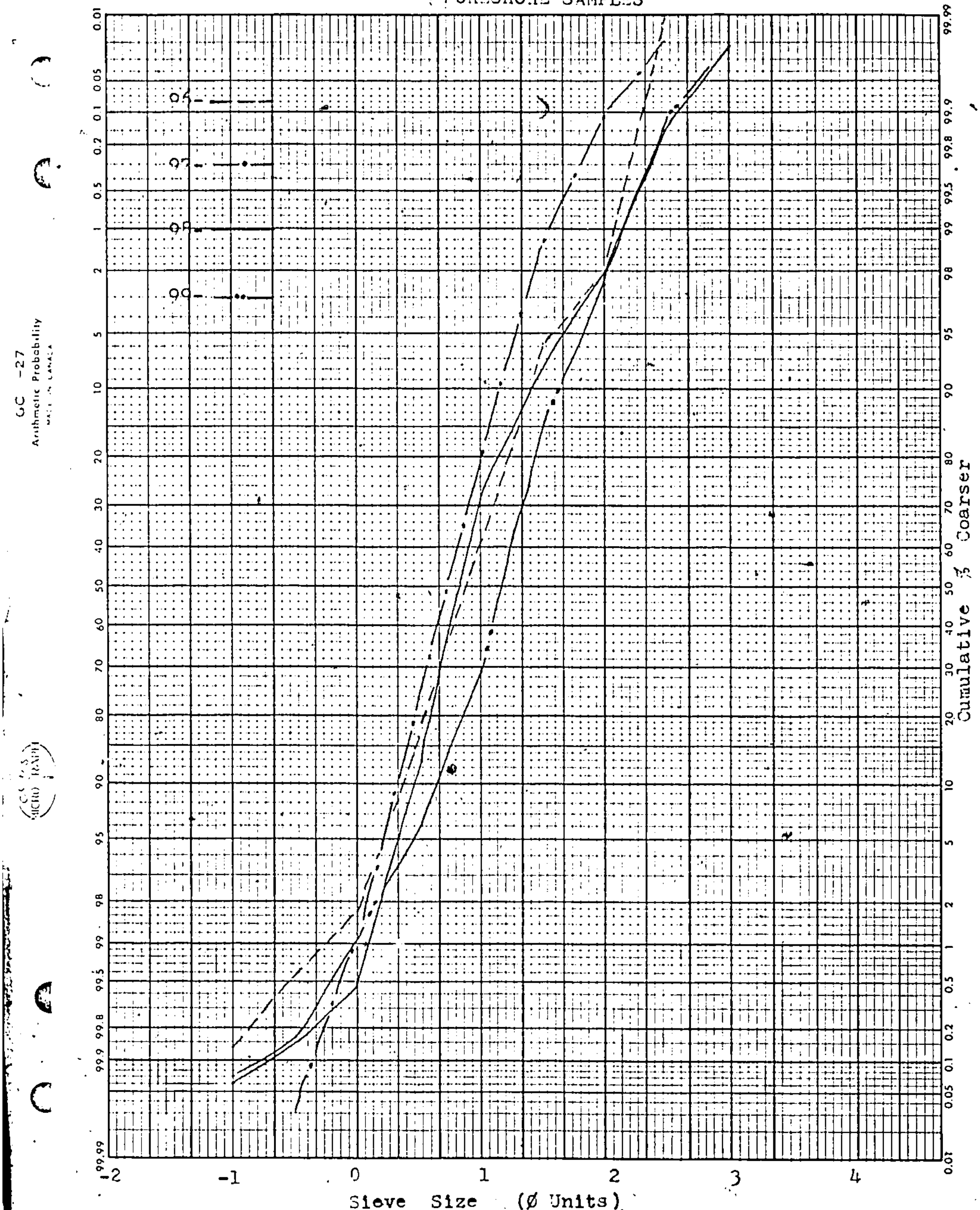


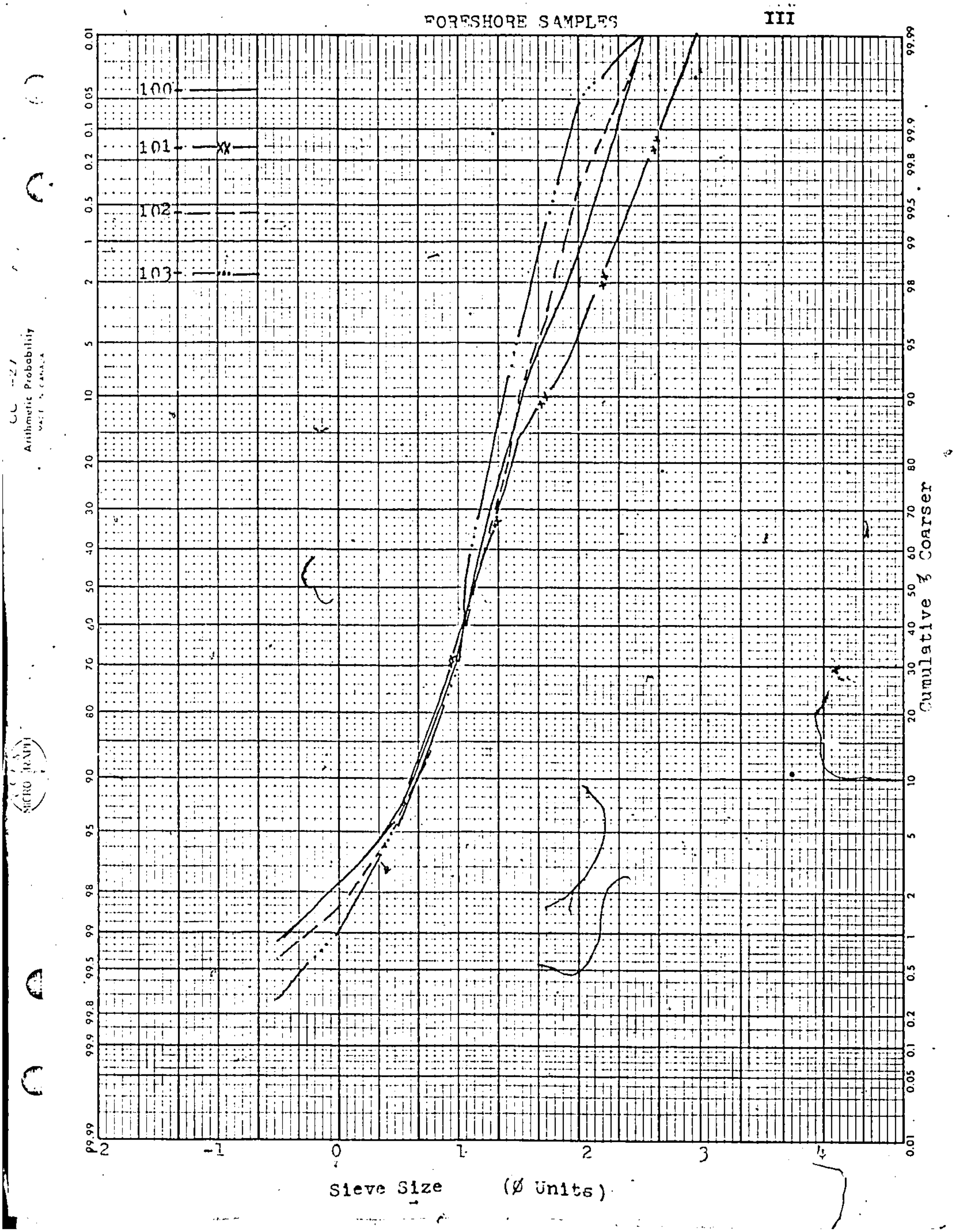
FORESHORE SAMPLES



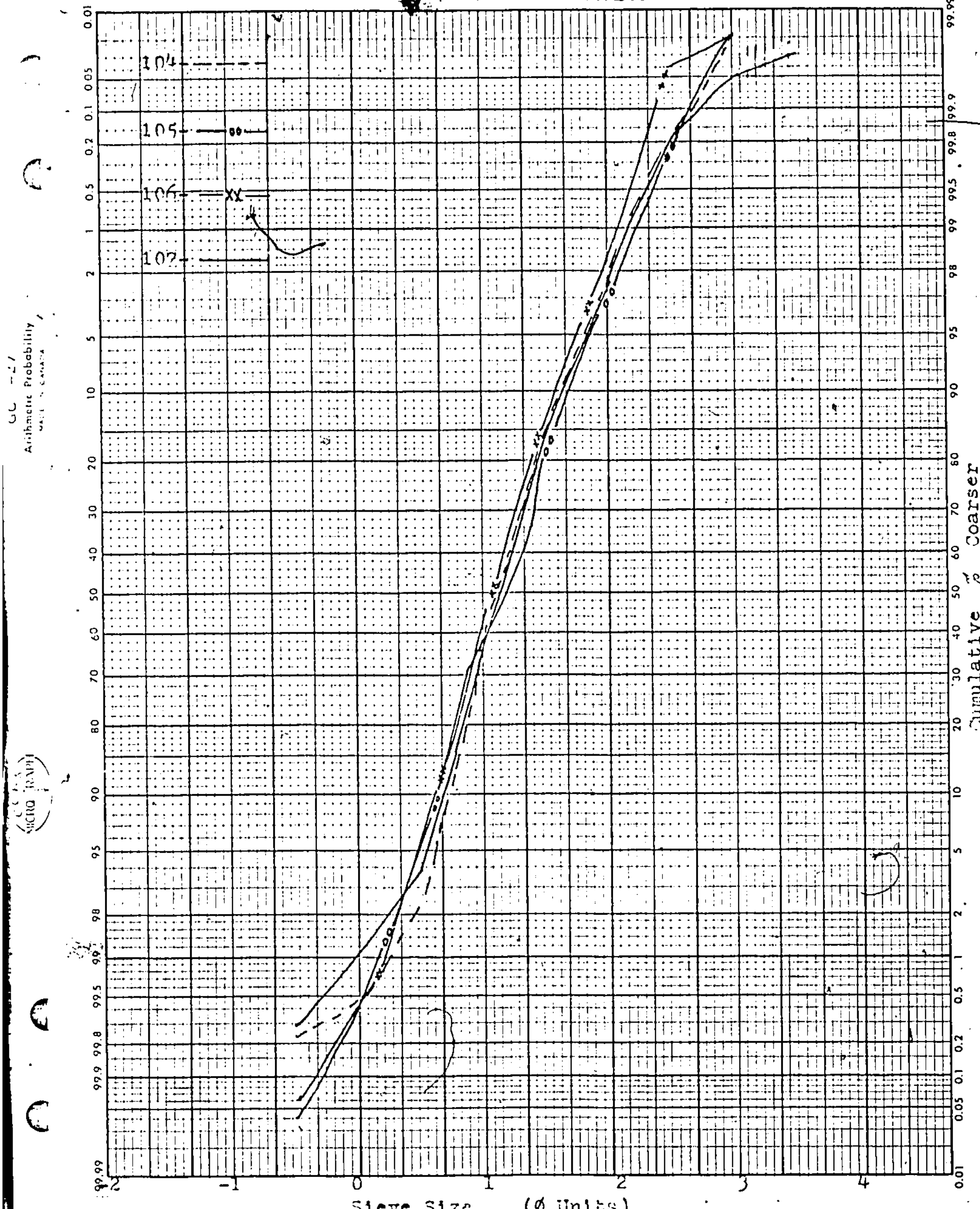

FORESHORE SAMPLES
72-
73-
74-
75-
88-
89-
Sieve Size (Ø Units)
Cumulative % Coarser
-2
-1
0
1
2
3
4

FORESHORE SAMPLES

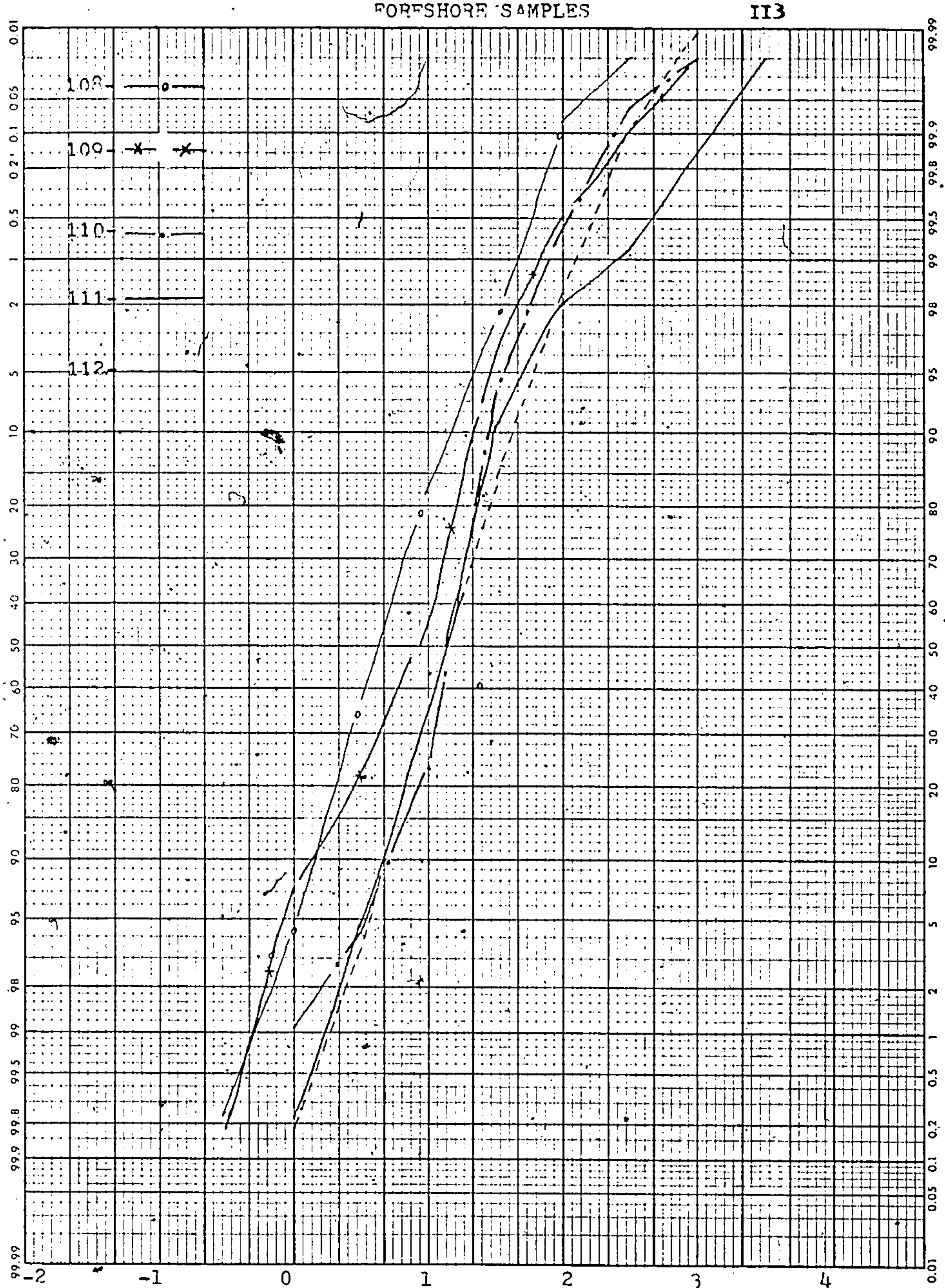


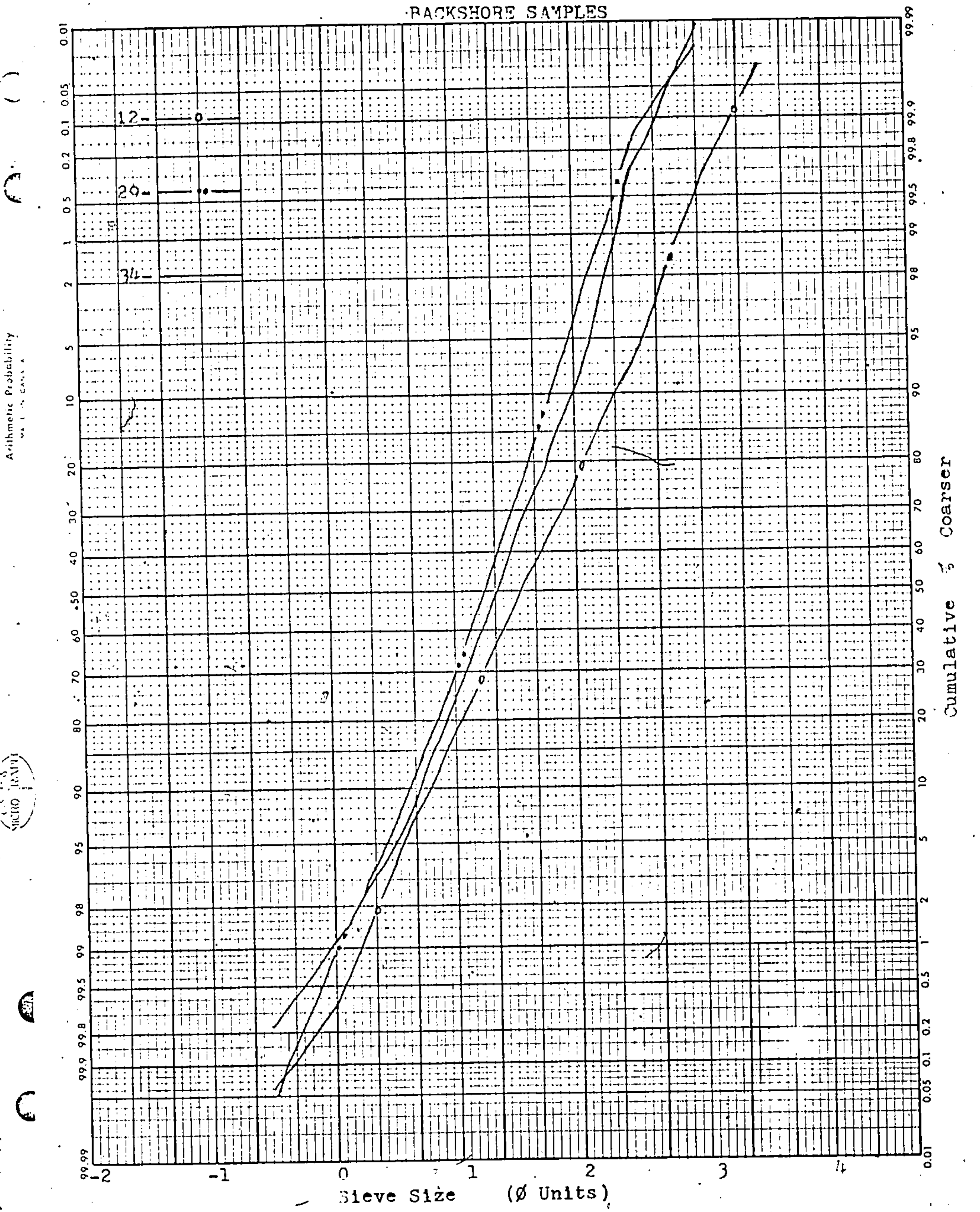

FORESHORE SAMPLES
III
100
101
102
103
Cumulative % Coarser
Sieve Size (Ø Units)
Arithmetic Probability

FORESHORE SAMPLES

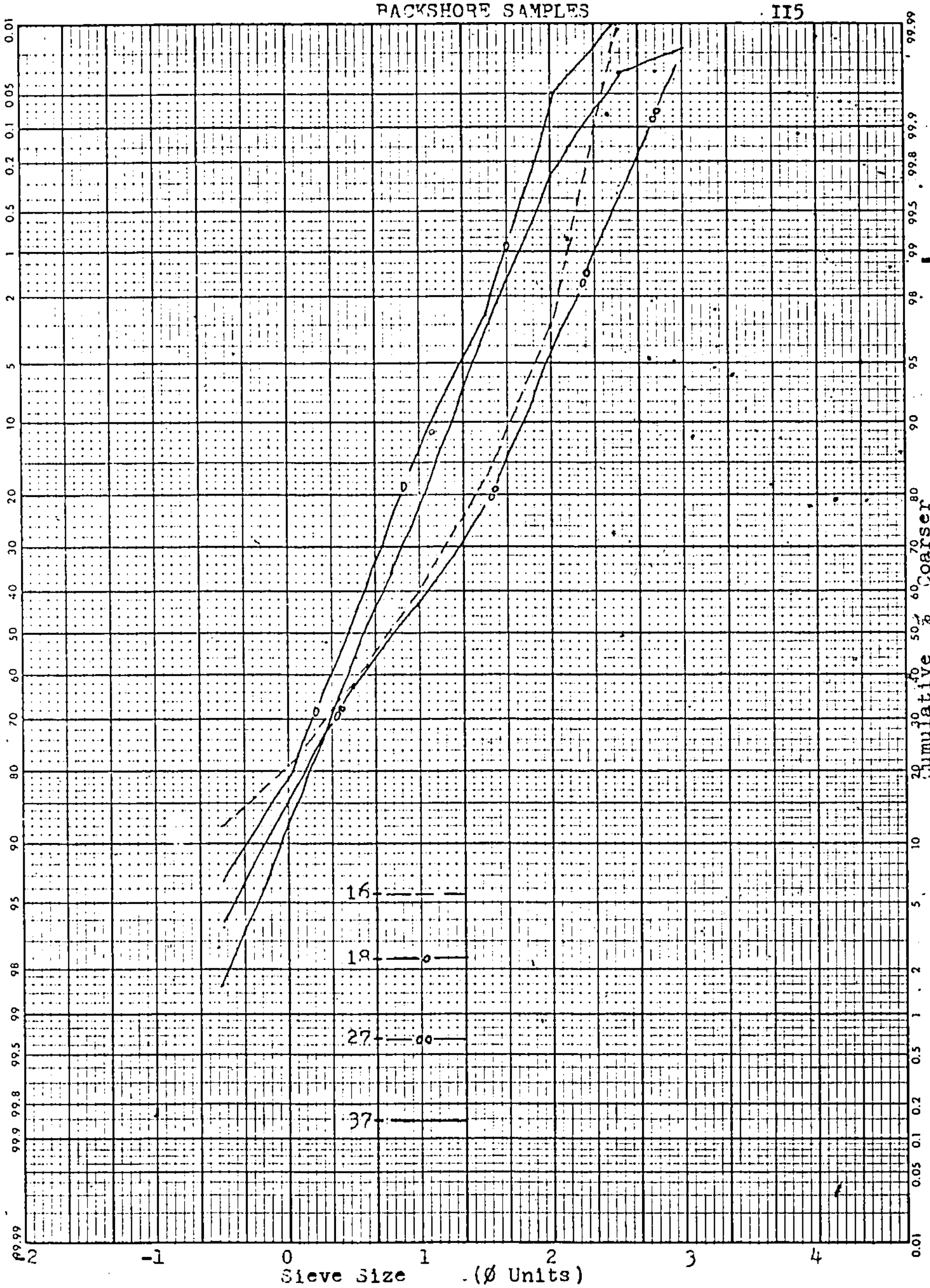


FORESHORE SAMPLES

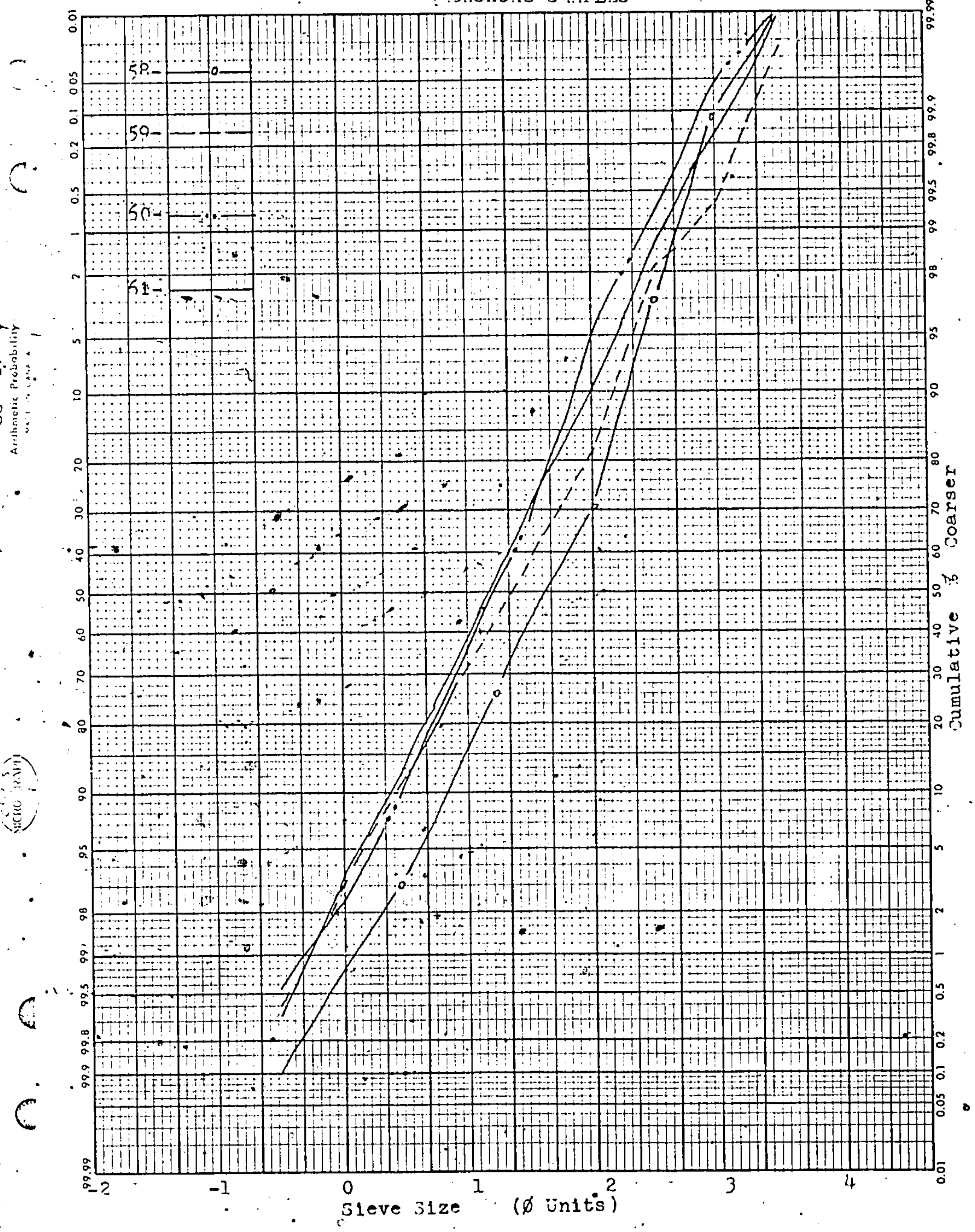



BACKSHORE SAMPLES
12-
20-
34-
Cumulative % Coarser
Sieve Size (Ø Units)
-2
-1
0
1
2
3
4
Arithmetic Probability

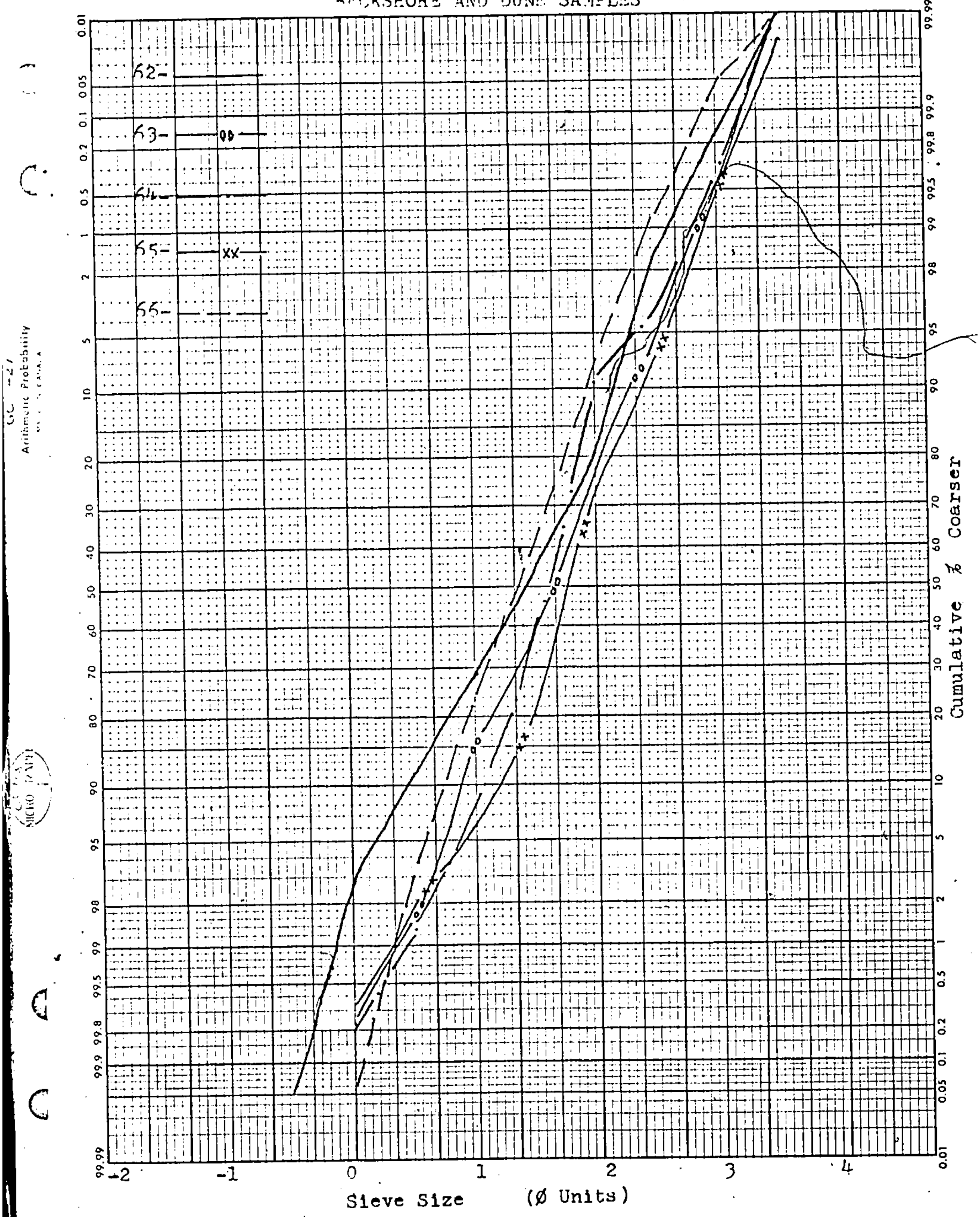
BACKSHORE SAMPLES



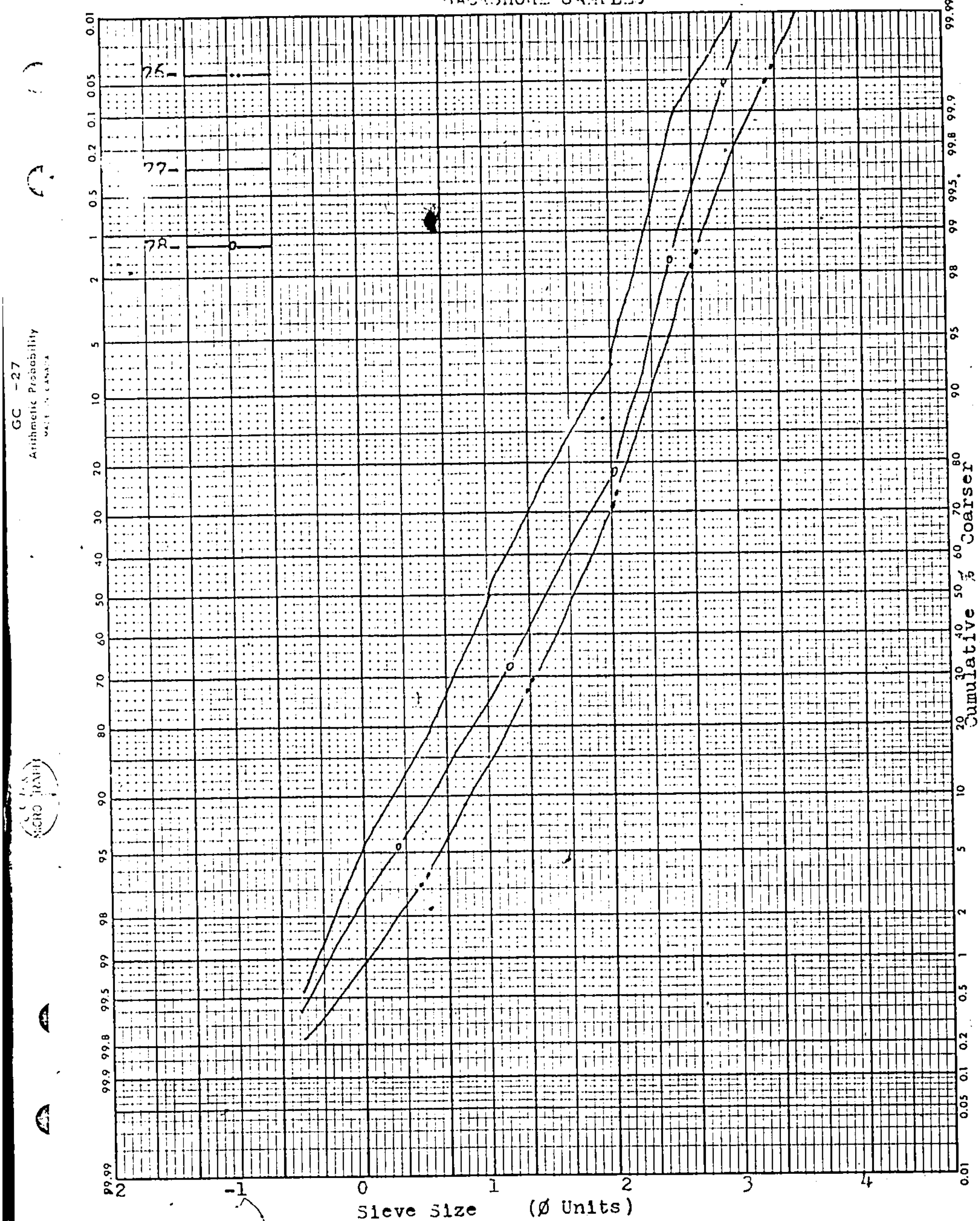
BACKSHORE SAMPLES

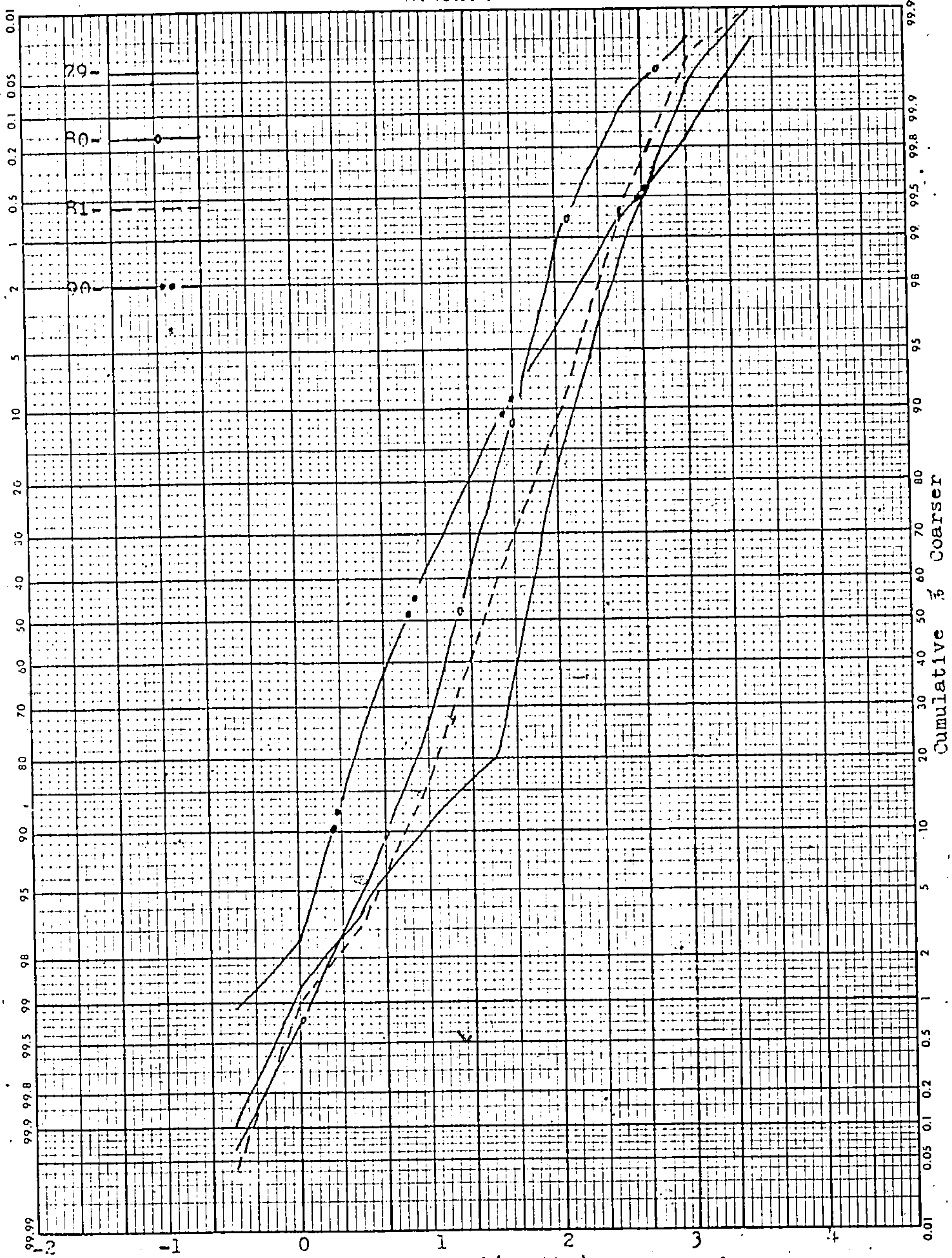


BACKSHORE AND DUNE SAMPLES

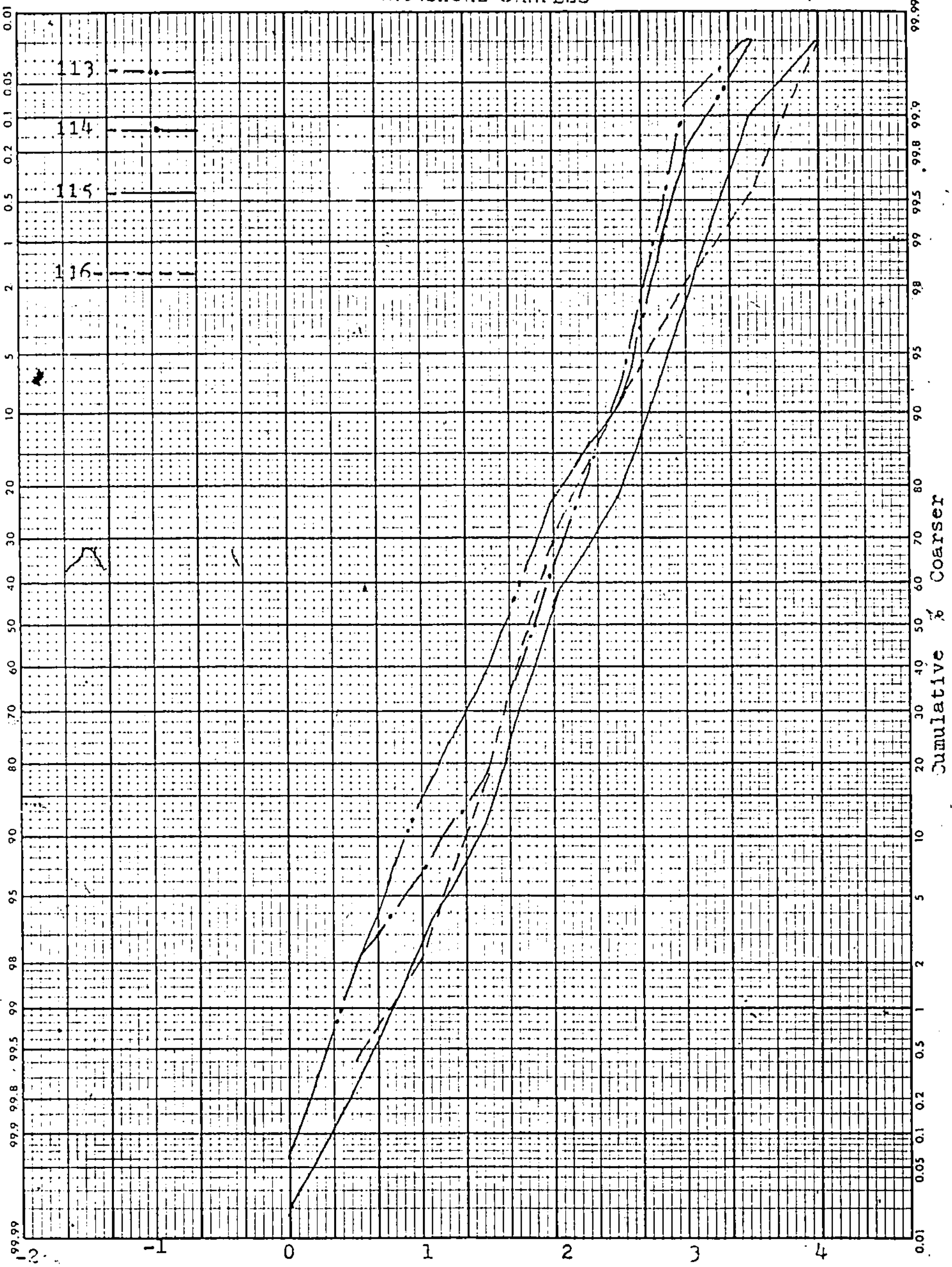


BACKSHORE SAMPLES

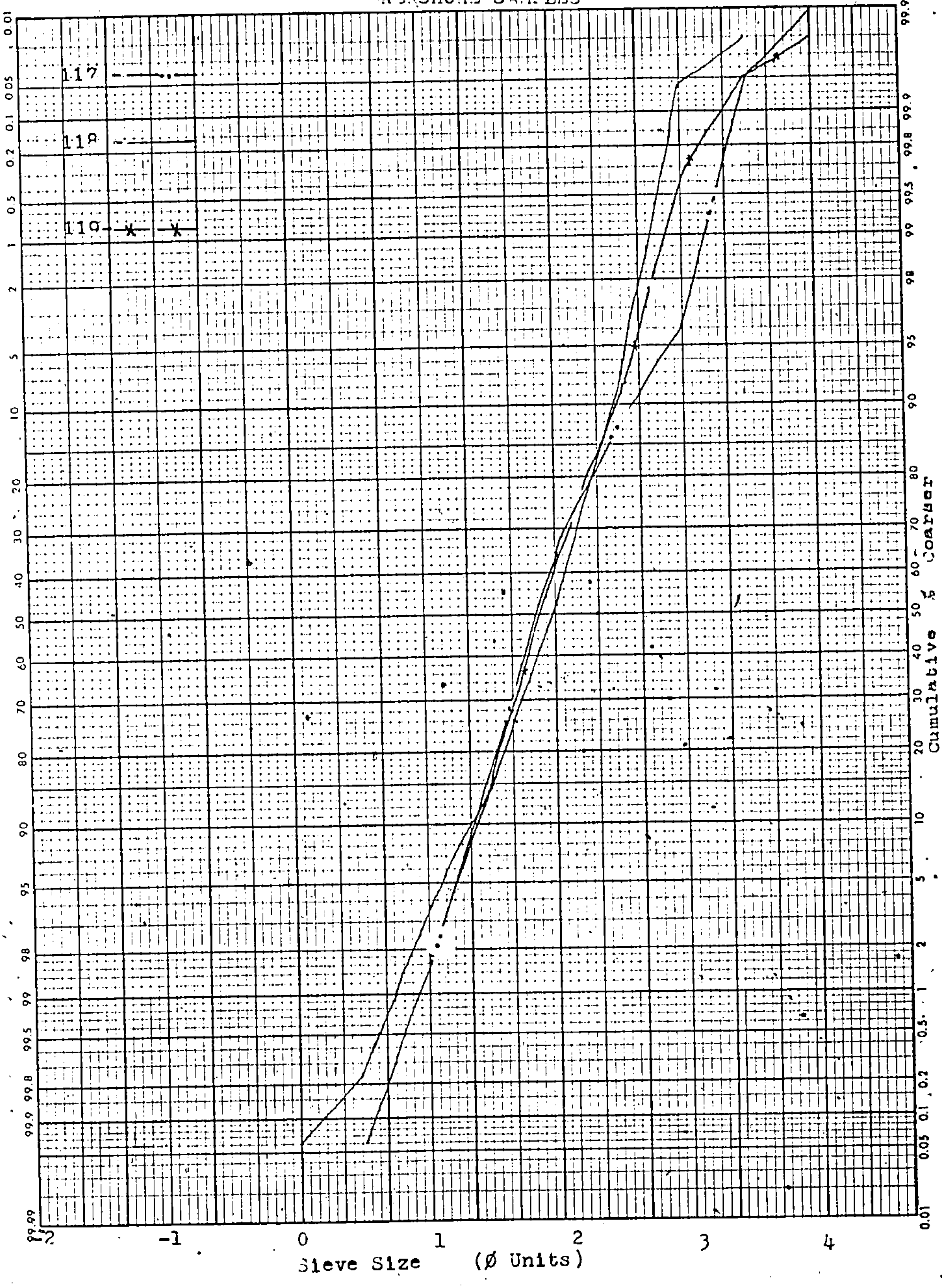



79-
80-
81-
90-
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.99
99.99 99.9 99.8 99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
Cumulative % Coarser
-2 -1 0 1 2 3 4
Sieve Size (Ø Units)

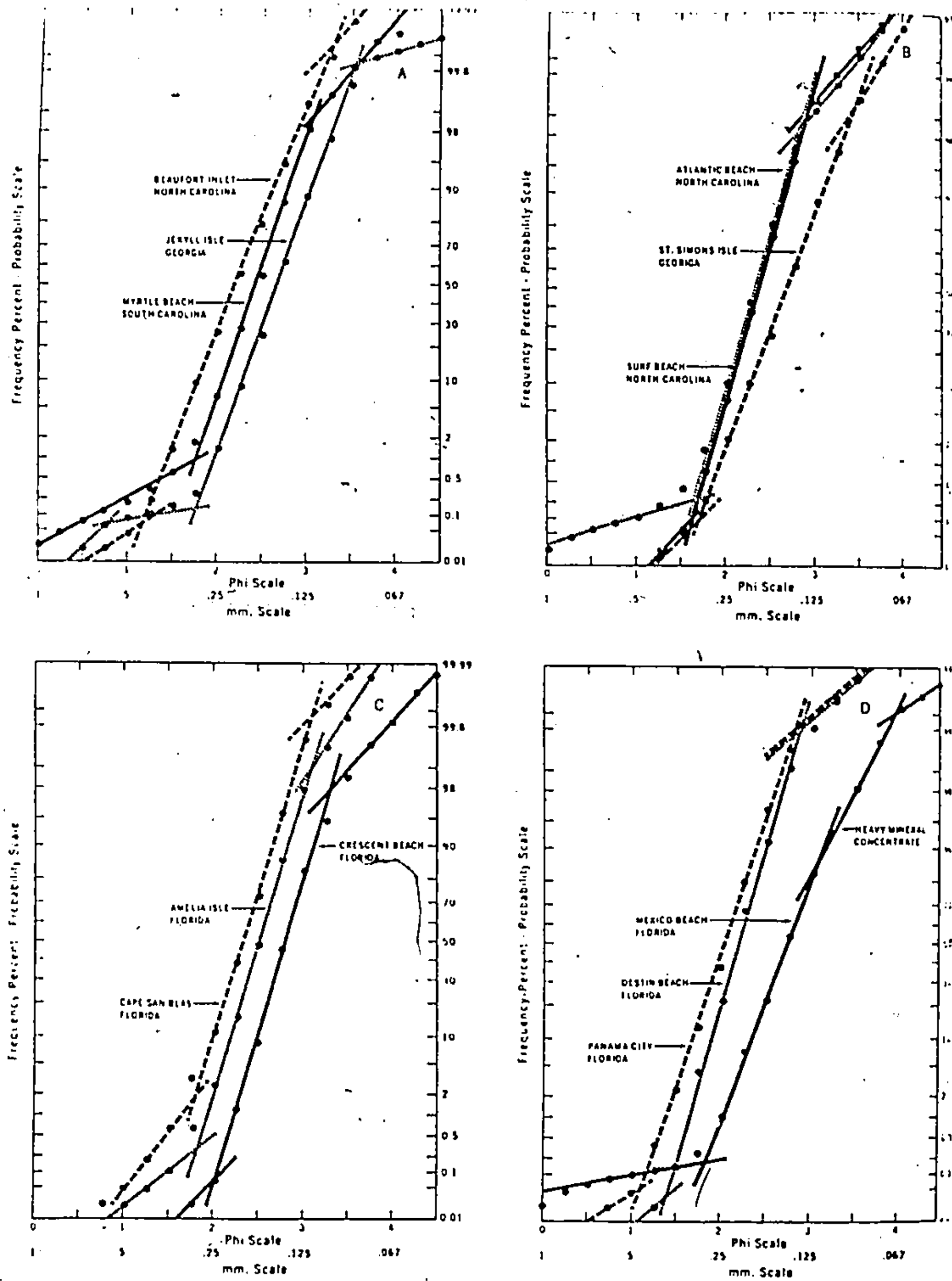
BACKSHORE SAMPLES



BACKSHORE SAMPLES



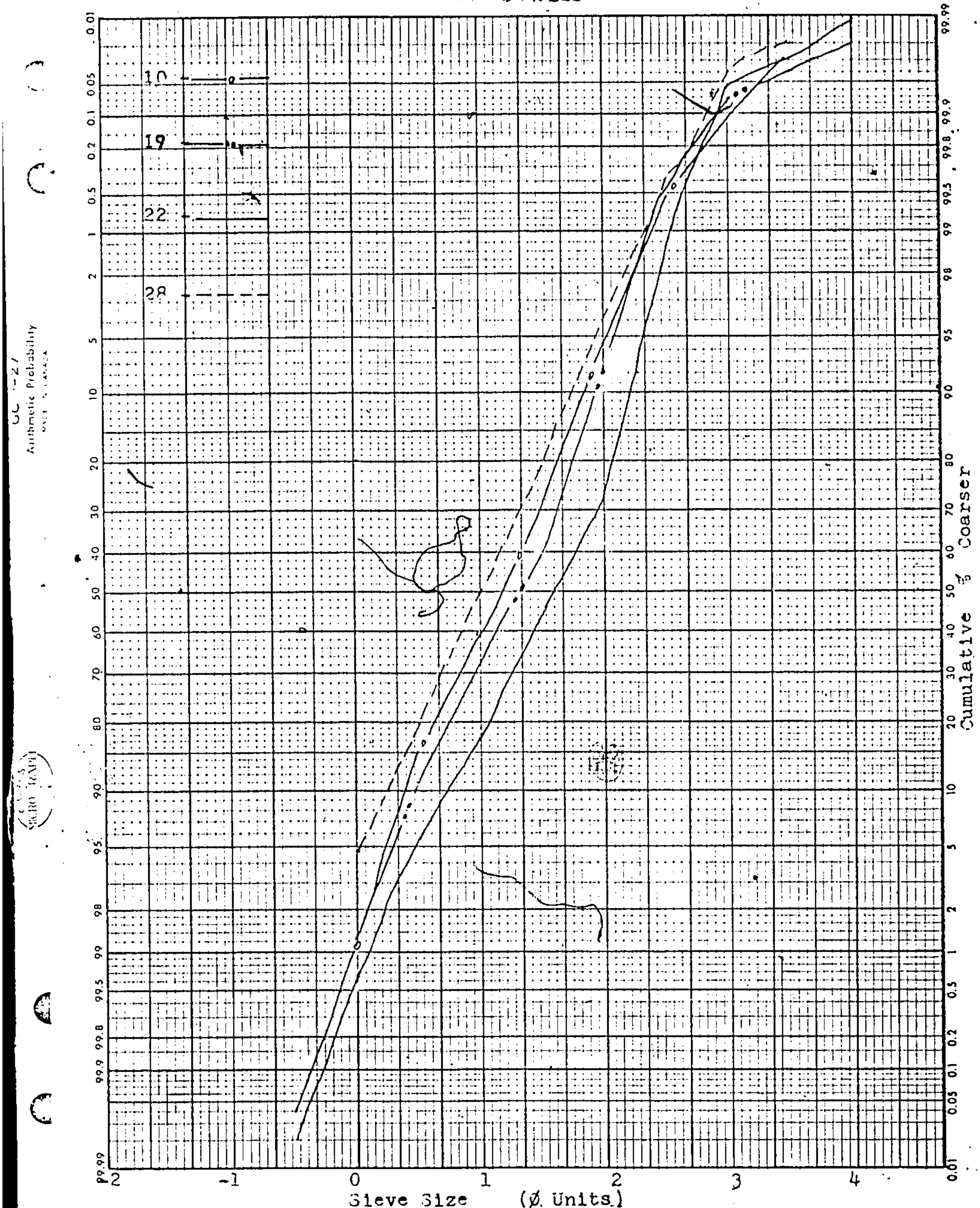
APPENDIX 3C



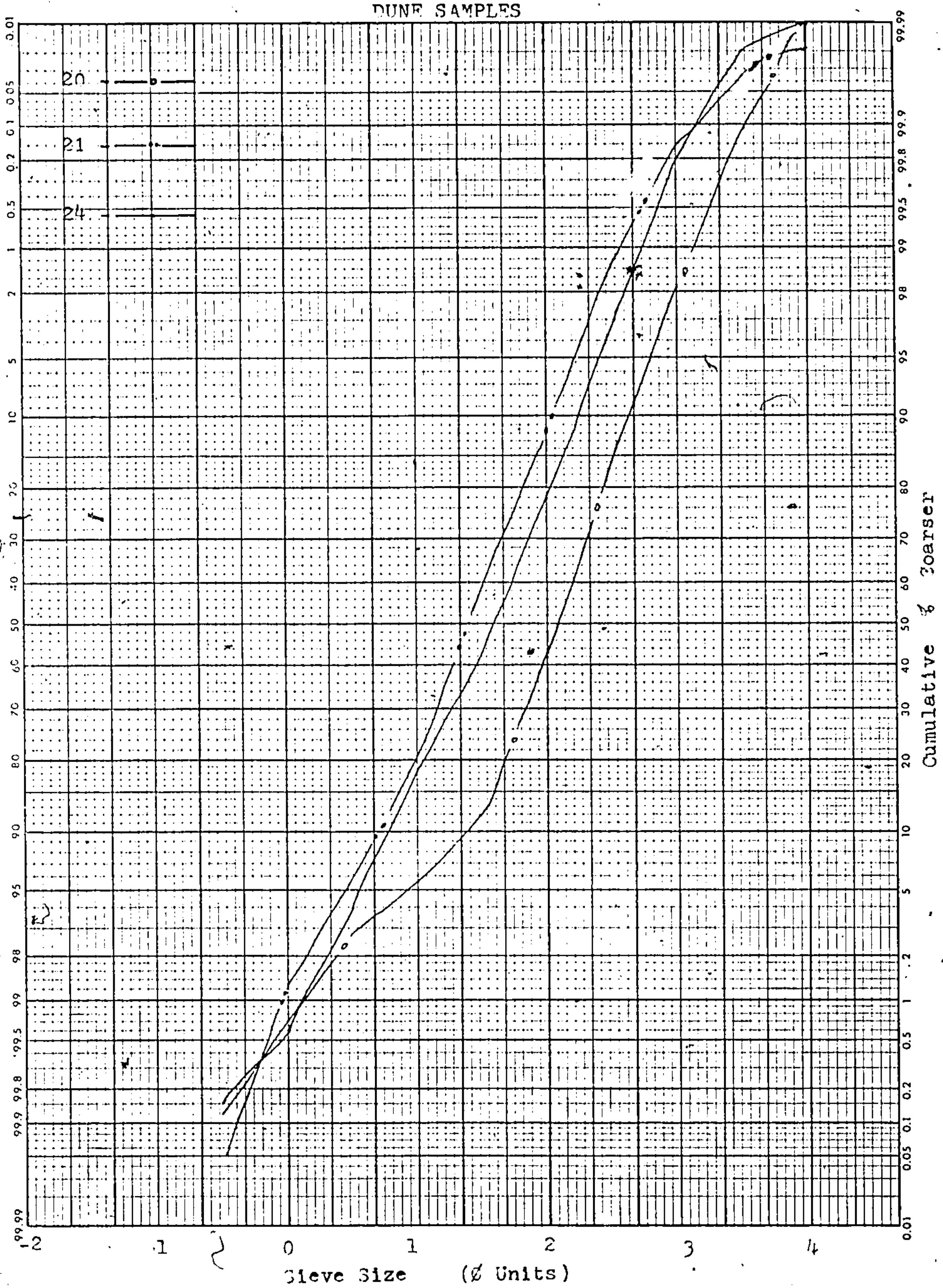
Examples from beach dune ridges. The similarity of curve shapes is evident, but variation in mean and maximum grain sizes and amounts of individual populations are illustrated.

After Visher (1969)

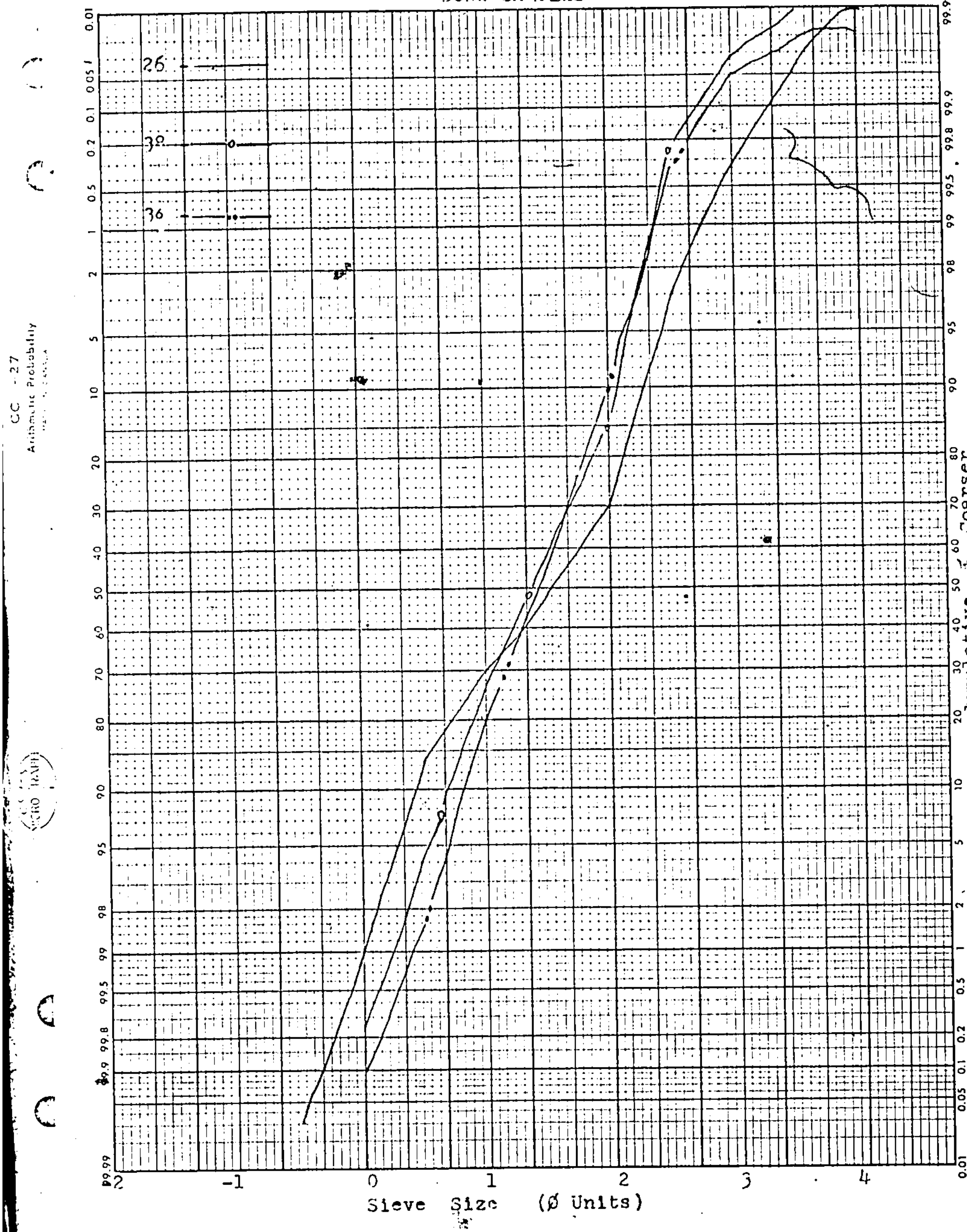
DUNE SAMPLES



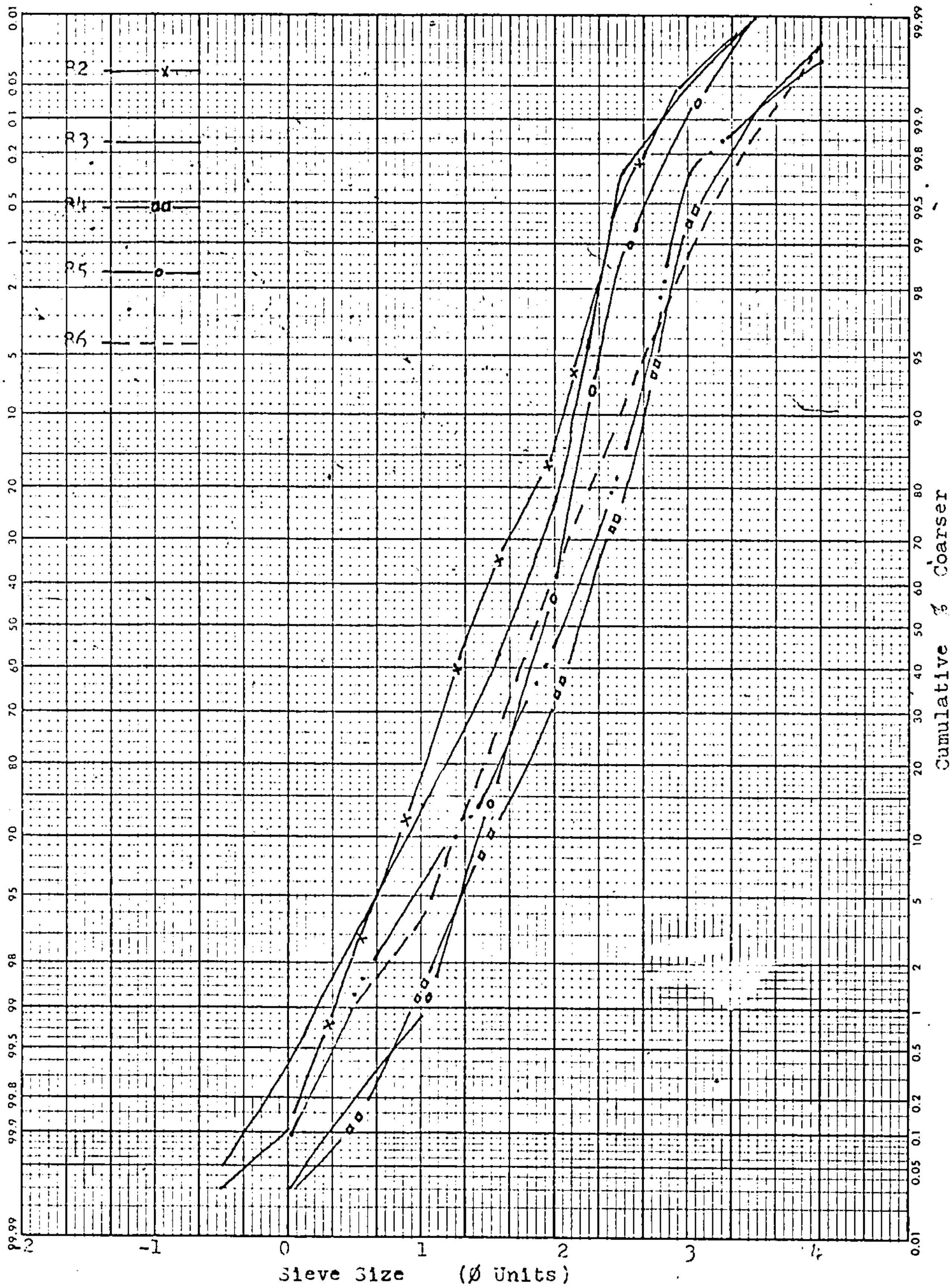
DUNE SAMPLES



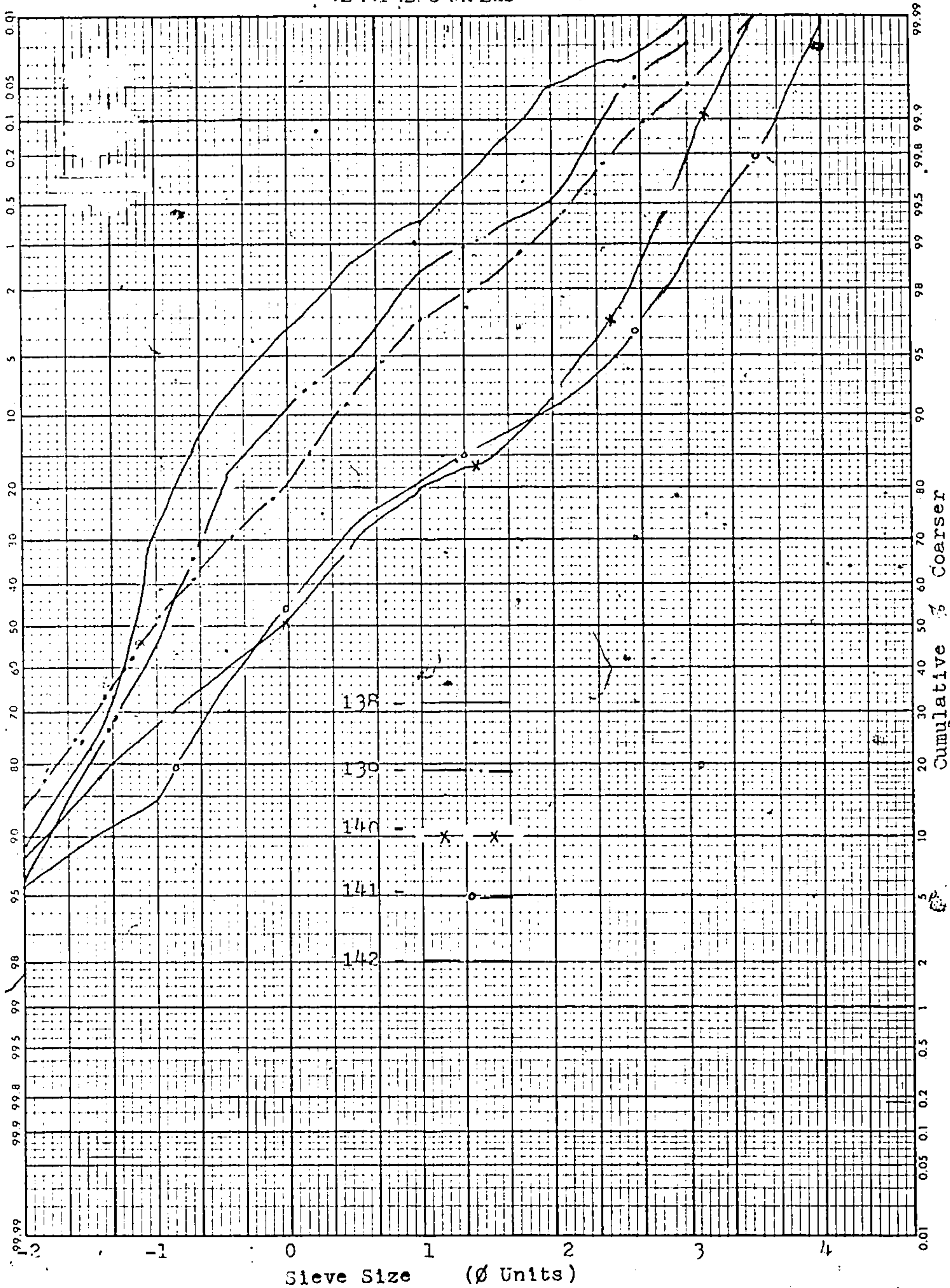
DUNE SAMPLES



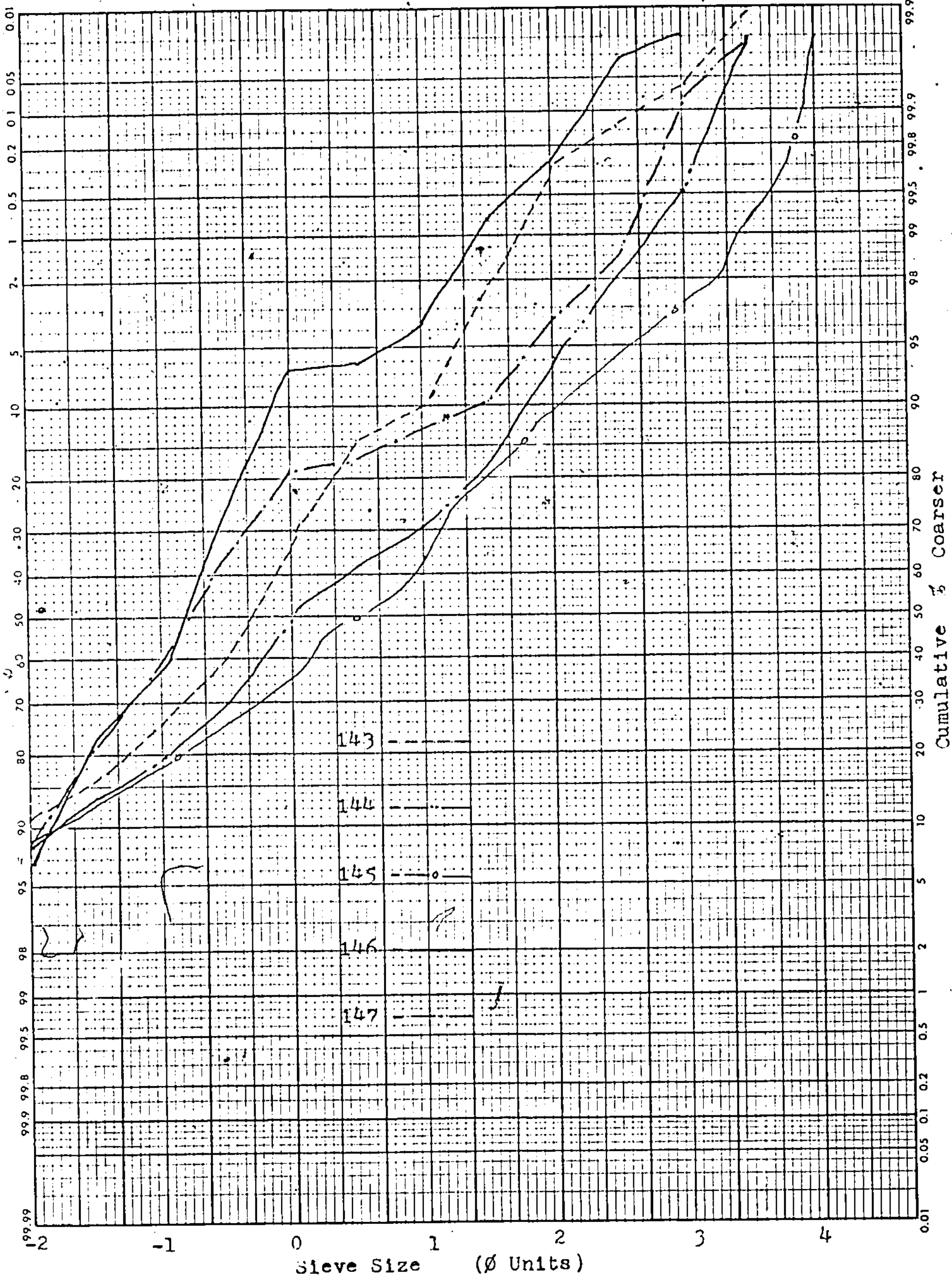
DUNE SAMPLES



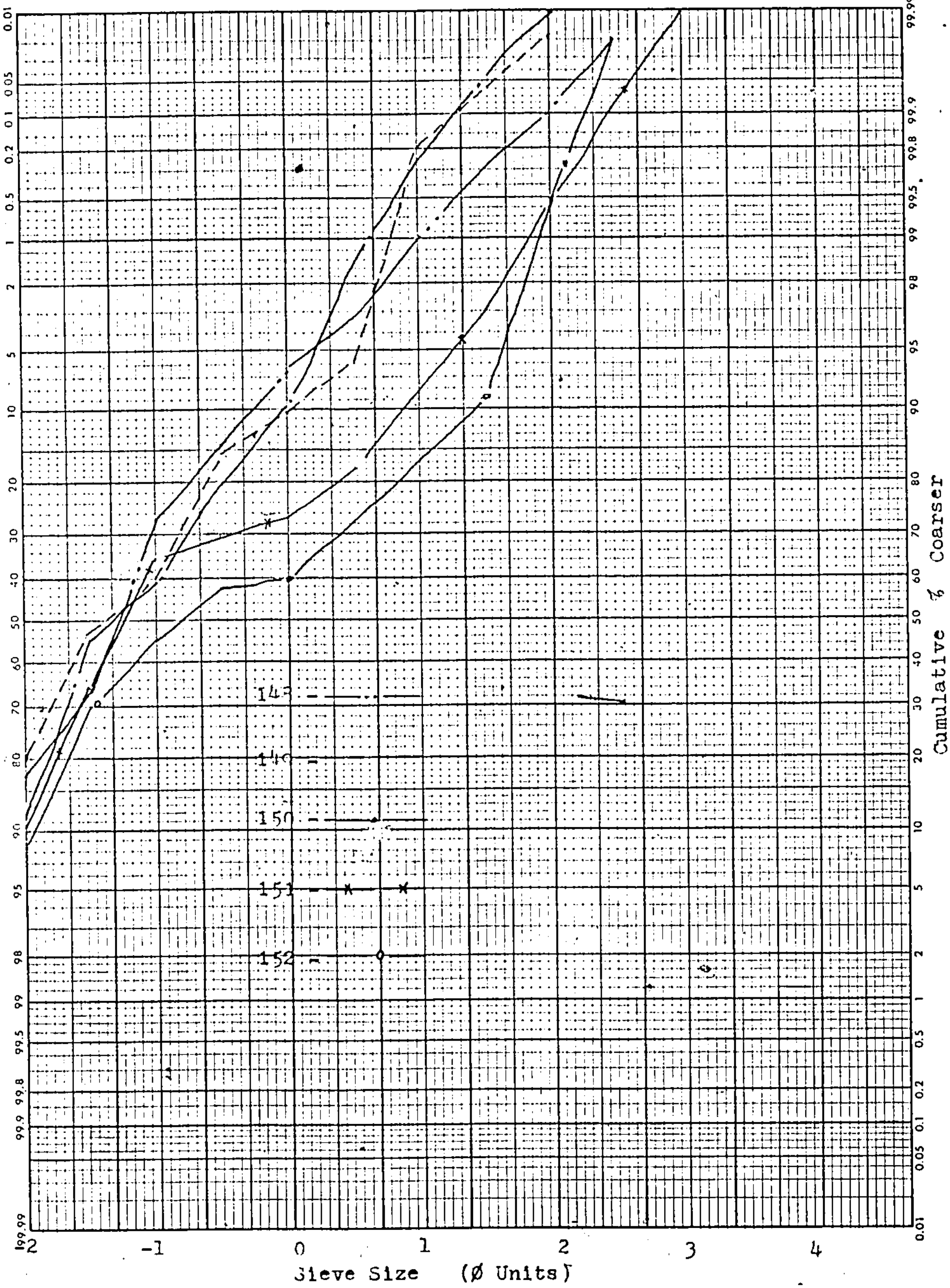
GLACIAL SAMPLES

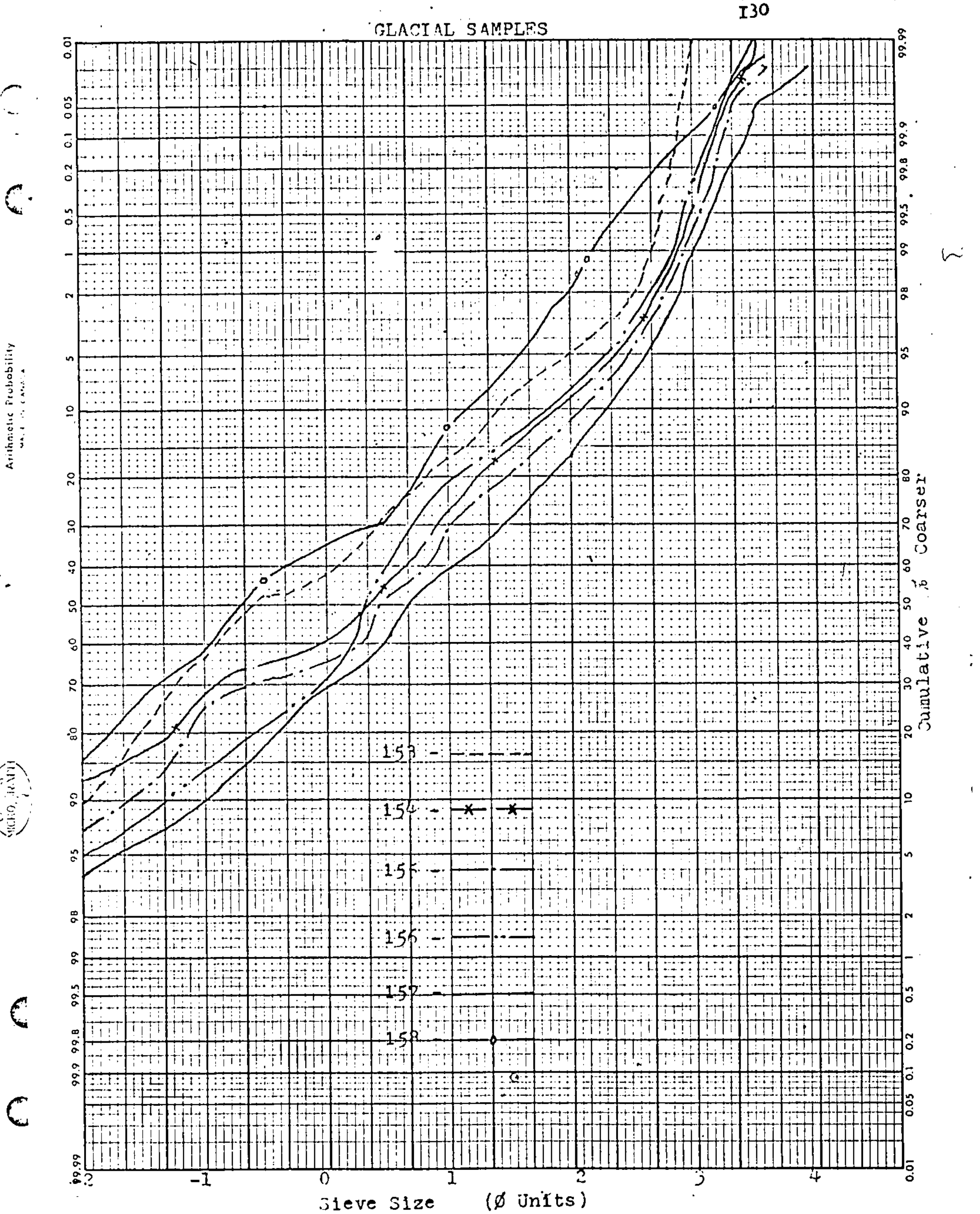


GLACIAL SAMPLES

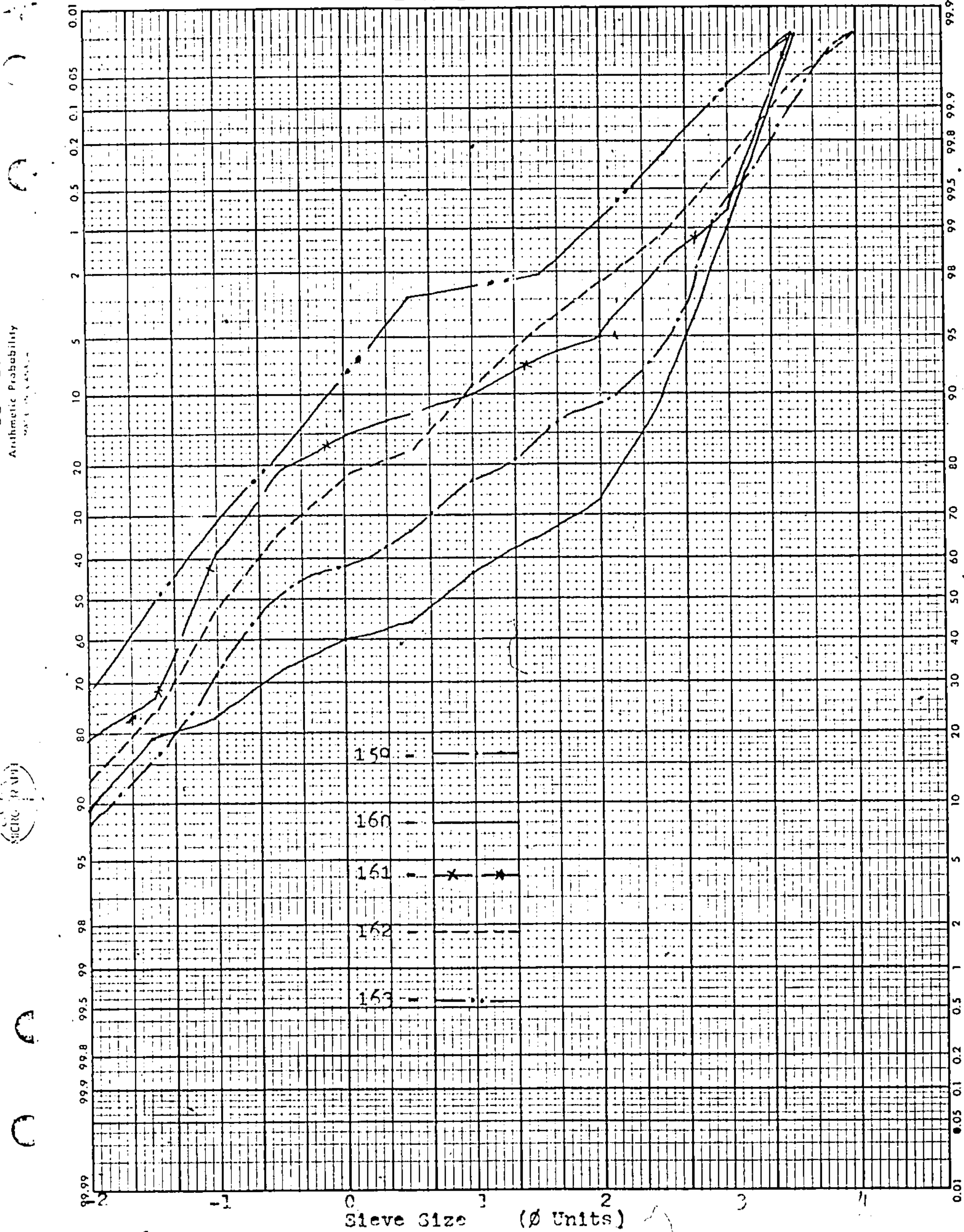


GLACIAL SAMPLES

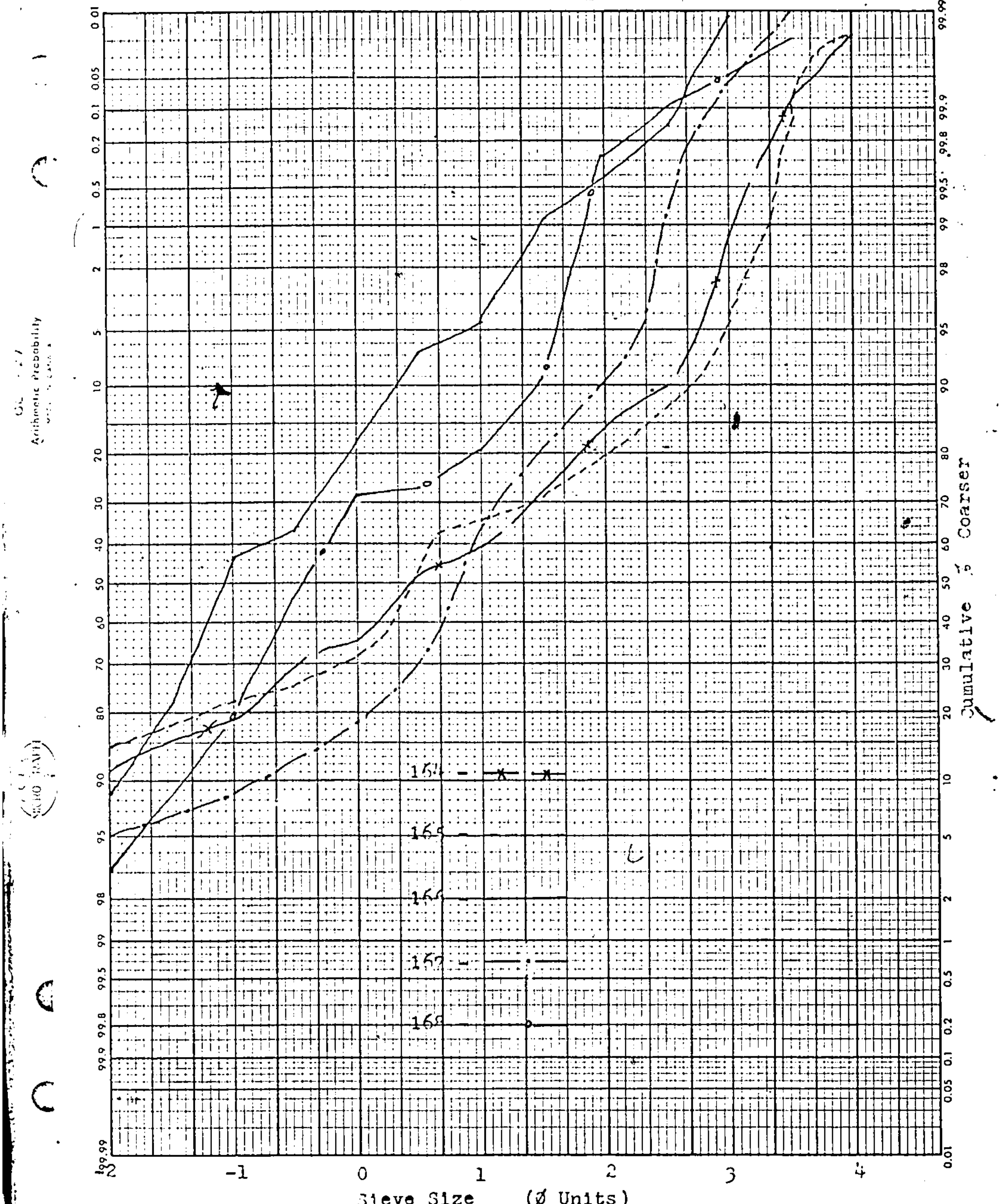



GLACIAL SAMPLES
153
154
155
156
157
158
Sieve Size (Ø Units)
Cumulative % Coarser
-2
-1
0
1
2
3
4
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99

GLACIAL SAMPLES



GLACIAL SAMPLES



APPENDIX 5


```
$JOB              XXXXXXXXXX
CTHIS PROGRAM CALCULATES GRAPHICAL MEASURES
C FORMULAE ARE THOSE PROPOSED BY FOLK AND WARD(1957)
C PROGRAM USED BY J.T.SOLOHUB., UNIV. MANITOBA
C PROGRAM MODIFIED FOR UNIV. WINDSOR I.B.M. 0360
      DIMENSION XB(7)
      N=0
110   N=N+1
      READ(5,10) (XB(J),J=1,7),M
10    FORMAT(7F6.2,32X,I1)
      WRITE(6,14) N
14    FORMAT(21X,15HCASE NUMBER     ,I3)
      WRITE(6,116)
116   FORMAT(1H0,20X,28HPHI DIAMETERS AT PERCENTILES)
      WRITE(6,118)
118   FORMAT(1H0,25X,15H PERCENTILE PHI)
      WRITE(6,119) XB(1)
119   FORMAT(31X,1H5,7X,F6.2)
      WRITE(6,120)XB(2)
120   FORMAT(30X,2H16,7X,F6.2)
      WRITE(6,121)XB(3)
121   FORMAT(30X,2H25,7X,F6.2)
      WRITE(6,122) XB(4)
122   FORMAT(30X,2H50,7X,F6.2)
      WRITE(6,123)XB(5)
123   FORMAT(30X,2H75,7X,F6.2)
      WRITE(6,124)XB(6)
124   FORMAT(30X,2H84,7X,F6.2)
      WRITE(6,125)XB(7)
125.  FORMAT(30X,2H95,7X,F6.2)
C CALCULATION OF PHIQUARTILE PARAMETERS(FOLK)
      PMED=XB(4)
      PMEAN=(XB(2)+XB(4)+XB(6))/3.0
      PDEV=((XB(6)-XB(2))/4.0)+((XB(7)-XB(1))/6.6)
      PSK=00.5*(((XB(6)+XB(2)-(2.0*XB(4))))/(XB(6)-XB(2)))+
     1((XB(7)+XB(1)-2.0*XB(4)))/(XB(7)-XB(1)))
      PKG=(XB(7)-XB(1))/(2.44*(XB(5)-XB(3)))
      WRITE(6,21)
21    FORMAT(1H0,20X,23HPHI QUARTILE PARAMETERS)
      WRITE(6,22)PMED
22    FORMAT(1H0,25X,15HMEDIAN DIAMETER,5X,F6.2)
      WRITE(6,23)PMEAN
23    FORMAT(26X,13HMEAN DIAMETER,7X,F6.2)
      WRITE(6,24)PDEV
24    FORMAT(26X,20H STANDARD DEVIATION ,F6.2)
      WRITE(6,25)PSK
25    FORMAT(26X,8HSKEWNESS,12X,F6.2)
      WRITE(6,26)PKG
26    FORMAT(26X,8HKURTOSIS,12X,F6.2)
      IF(M-9)110,200,110
200   CONTINUE
      STOP
      END

$ENTRY
```

```
$JOB              XXXXXXXXXX
C THIS PROGRAM CALCULATES MOMENT MEASURES
C FORMULAE ARE THOSE USED BY FRIEDMAN(1961)
C PROGRAM USED BY J.T.SOLOHUB,UNIV. MANITOBA
C PROGRAM MODIFIED BY V.LAKHAN FOR THIS STUDY
          DIMENSION PHI(13),CUM(13),W(13),PCT(13),PM(24)
          PHI(1)=-2.0
          PHI(2)=-1.5
          PHI(3)=-1.0
          PHI(4)=-0.5
          PHI(5)=0.0
          PHI(6)=0.5
          PHI(7)=1.0
          PHI(8)=1.5
          PHI(9)=2.0
          PHI(10)=2.5
          PHI(11)=3.00
          PHI(12)=3.5
          PHI(13)=4.0
          N=0
    110   N=N+1
          READ(5,14,END=200)(W(I),I=1,13),M
    14    FORMAT(13F5.2,14X,I1)
          WRITE(6,88) N
    88    FORMAT(21X,15HCASE NUMBER     ,I3)
          SUM=0.0
          SMF=0.0
          DO 16 I=1,13
          SUM=SUM+W(I)
    16    CONTINUE
          DO 15 I=1,13
          PM(I)=PHI(I)-0.25
    15    CONTINUE
          DO 17 I=1,13
          PCT(I)=(W(I)/SUM)*100.0
          SMF=SMF+PM(I)*PCT(I)
    17    CONTINUE
          SMEAN=SMF/SUM
          WRITE (6,22)(PHI(I),W(I),PCT(I),I=1,13)
    22    FORMAT(21X,F6.2,1X,F7.2,3X,F7.2)
          WRITE(6,23)SUM
    23    FORMAT(1H0,27X,F7.2)
          SUB 2=0.0
          SUB 3=0.0
          SUB 4=0.0
          DO 30 I=1,13
          SUB 2=SUB2+(PCT(I)*((PM(I)-SMEAN)**2))
          SUB 3=SUB3+(PCT(I)*((PM(I)-SMEAN)**3))
          SUB 4=SUB4+(PCT(I)*((PM(I)-SMEAN)**4))
    30    CONTINUE
          DEV=SQRT(SUB2/100.0)
          SK=SUB3/(DEV*DEV*DEV*100.0)
          ALPHA=SUB4/(DEV*DEV*DEV*DEV*100.0)
          WRITE(6,40)
    40    FORMAT(1H0,20X,17H MOMENT PARAMETER)
          WRITE(6,41)SMEAN
    41    FORMAT(26X,13HMEAN DIAMETER,7X,F10.2)
          WRITE(6,42)DEV
    42    FORMAT(26X,20HSTANDARD DEVIATION   ,F10.2)
          WRITE(6,43)SK
    43    FORMAT(26X,8HSKEWNESS,12X,F10.2)
          WRITE(6,44)ALPHA
    44    FORMAT(26X,8HKURTOSIS,12X,F10.2)
          WRITE(6,100)
    100   FORMAT(1H1)
    76    IF (M-9)110,200,110
    200   CONTINUE
          CALL EXIT
          STOP
          END

$ENTRY
```

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