UNCONSOLIDATED SEDIMENTS IN THE OFFSHORE ZONE NEAR PLUM ISLAND, MASSACHUSETTS

by

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Submitted in Partial Fulfillment
of the Requirements for the
Degree of Master of Science
at the
Massachusetts Institute of Technology
June, 1966

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ABSTRACT

A detailed study of the textural and mineral properties of sediments in the offshore zone east of Plum Island, Massachusetts suggests that the samples may conveniently be classified as one of two types: (1) Samples from shallow water, of depth less than about 65 feet, are very fine to medium sands, and generally become finer in a seaward direction. (2) Samples from water of depth greater than about 65 feet are coarse sands and fine gravels.

The shallow water samples generally become finer and better sorted in the direction of longshore transport (southward), and there are several significant variations in the mineralogy and particle morphology in this direction. The deep water samples show no significant variations in a longshore direction.

The strikingly different texture, morphology, and coloration of samples from these two zones suggests that the material from these two zones may be of different origin. Comparison of the deep water samples with those taken in the Merrimack River and with the glacial outwash from farther inland suggests a common origin for all of these samples.

Sizeable differences between "duplicate" samples taken at the same locality suggest that a considerable sampling error may have been present.

I. INTRODUCTION

A. Purpose of Study

This study was undertaken with the intent of sampling the unconsolidated sediment in an offshore zone and analyzing the material texturally and mineralogically in order to answer the following questions:

1. Can variations in the textural parameters (mean diameter, sorting, skewness) of present-day sediments be used as a reliable indication of the direction of longshore transport in the offshore zone?

2. Can studies of other sediment parameters, such as coarse fraction analysis, heavy mineral analysis, and morphology studies, be used more satisfactorily for this purpose than textural parameters?

B. Area of Study

Selection of area.

For carrying out this study an area in the vicinity of Boston was sought in which (1) the direction of longshore transport can be clearly determined, and (2) complicating effects, both geological and man-made, are at a minimum. The area chosen was the offshore zone east of Plum Island and Salisbury Beach on the northeastern coast of Massachusetts, about 35 miles north of Boston (see Figure 1).

FIGURE 1a Area of Study: Northeastern Coast of Massachusetts

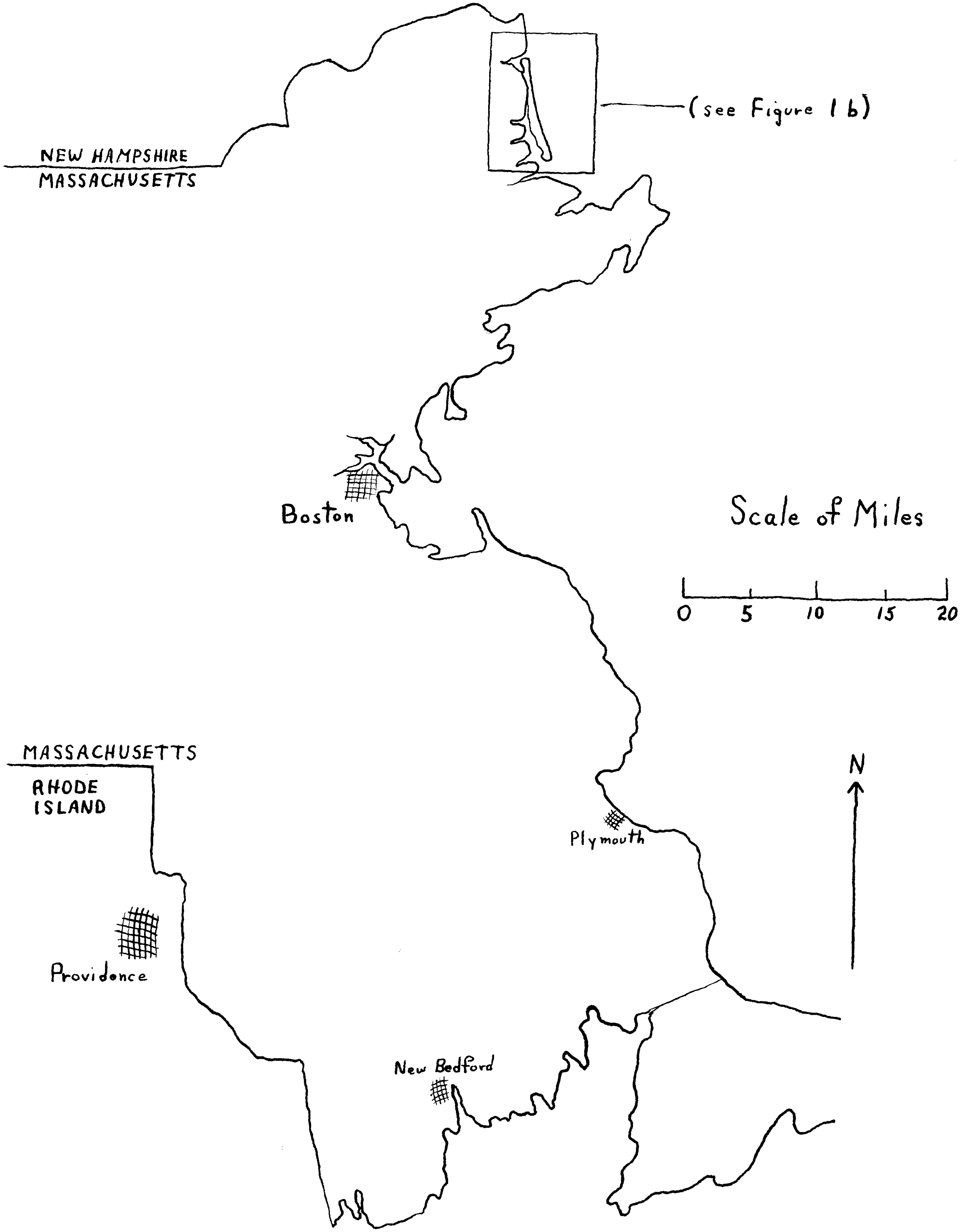
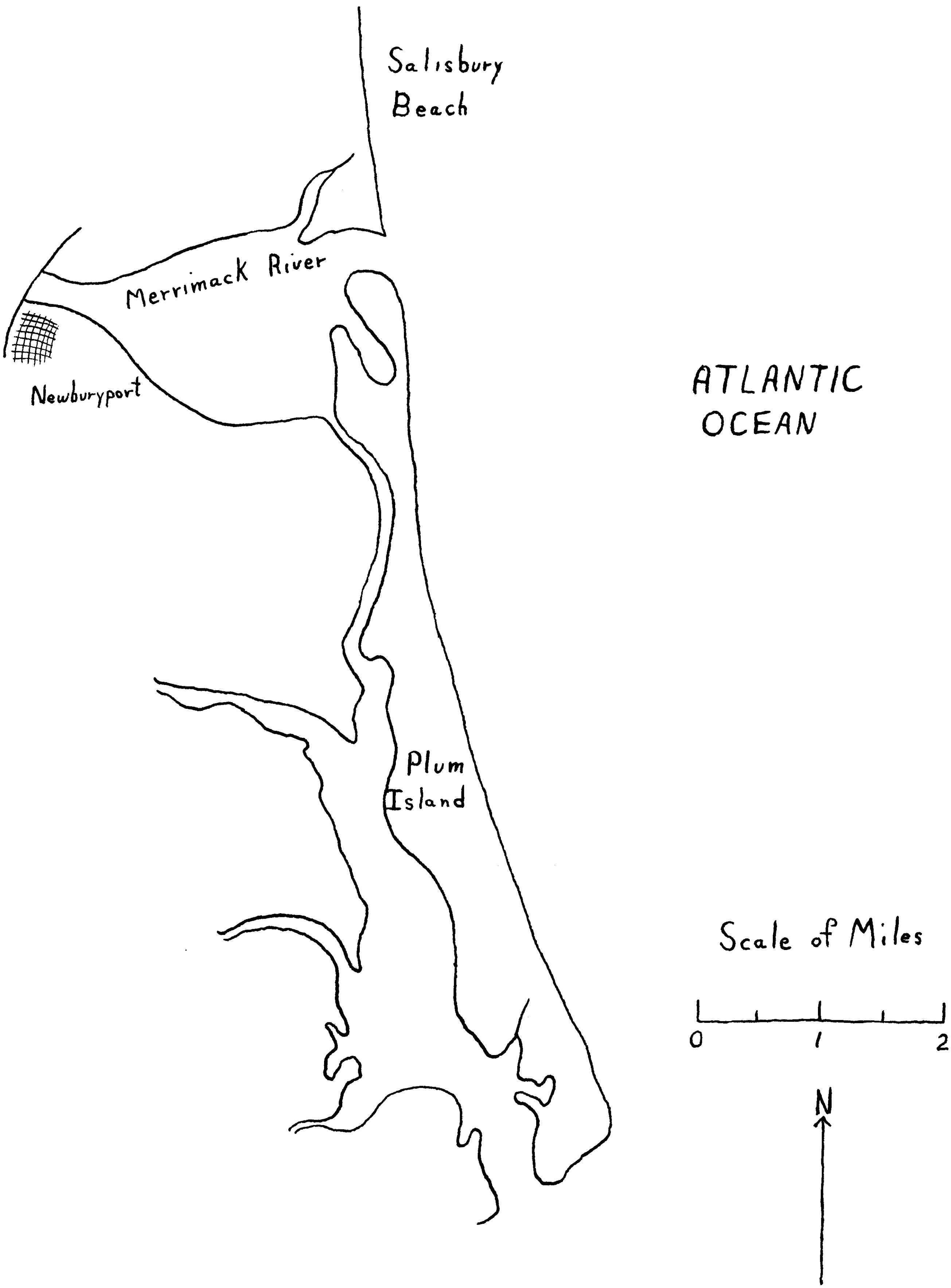


FIGURE 1b Area of Study: Northeastern Coast of Massachusetts



Regional geology and geomorphology.

Most of the bedrock in the coastal area of Massachusetts and New Hampshire is of Paleozoic age. It consists of metamorphosed sediments and large igneous bodies that are hard and compact, and resistant to wave erosion. The bedrock is blanketed by five general types of glacial and post-glacial deposits in most of the area: till, glacial outwash, marine clays, marsh deposits, and beach sands. Each of these will be considered in terms of its composition, regional distribution, and possible contribution to the offshore deposits.

The till is the oldest of the non-consolidated materials, and has the form of drumlins and ground moraine. Each drumlin is an oval-shaped hill, consisting of poorly sorted glacial debris formed by local concentration. The drumlins are generally 60 to 200 feet high, and $\frac{1}{2}$ mile in length, the long dimension oriented parallel to that of the ice movement. The ground moraine is an irregular blanket of till that was laid down by the ice as it moved and melted. It has a highly variable thickness, but is seldom more than about 50 feet thick (Chute and Nichols, 1941). The upper few feet are heavily stained by limonite, but beneath the weathered zone the material is grey (Chute and Nichols, 1941).

The glacial outwash is glacial debris later acted upon by melt waters, and sorted and stratified to varying degrees. It is distributed as small sand and gravel hills (kames), sand and gravel terraces on hillsides and drumlins (kame terraces), and level deposits of sand and gravel that cover an extensive area (outwash plains). The outwash is commonly present in a belt about one to three miles in width, just inland from the tidal marsh deposits.

The marine clays are irregularly scattered along the coast in a belt that increases in width to the north. These were deposited in marine waters in post-glacial time when the sea level stood even higher than today. They are non-varved, and are up to 12 feet in thickness (Chute and Nichols, 1941).

Extending northward from Cape Ann is a nearly continuous salt water marsh that separates the beaches from the mainland. This area is composed of sandy and silty marine peat, and is covered with marsh grass except in the tidal channels. The accumulation of peat is as much as 9 feet. Since the marsh grass can survive only a 2 foot tidal range, the land has evidently been subsiding as the peat has accumulated.

The barrier beaches in the area of study are Plum Island and Salisbury Beach. Large dunes are commonly present on the landward side of these beaches, some of which on Plum Island rise to 40 or 50 feet above sea level.

Of the ten miles of coastline in the area under study, only the northern portion (Salisbury Beach and the northern tip of Plum Island) is inhabited. The remainder is part of the Plum Island Wildlife Sanctuary. Most of the offshore area east of Plum Island is relatively free of man-made complications to the sediment properties and distribution.

C. Method of Sampling

All the samples taken in the offshore zone (see Plate I, showing station localities) were obtained with a pipe dredge, using the 40-foot fishing vessel "Sea Legs" of Marblehead, Massachusetts. The dredge was an open-ended aluminum pipe, one end of which was covered with canvas for retaining the sediment. The pipe had an external diameter of eight inches, a length of 24 inches, and weighed about 25 pounds; no additional weights were attached.

At each station the dredge was allowed to fall freely to the bottom. The ship's position was noted, either visually, by sextant bearings, or by dead reckoning. Then a fair scope of cable was paid out, and the dredge was towed slowly over the bottom for about half a minute. Upon recovery of the dredge, sediment samples were removed and stored in two-quart ice cream cartons and sealed.

The reliability of this sampling method might be questioned. Inman (1957), reporting on observations made by divers, states that ripples were always present on sandy sea floors where the significant orbital velocity was somewhere between 1/3 and 3 feet per second. Furthermore, he found the material locally segregated with the coarser grains present on the crests of the ripples while the finer and denser grains were in the troughs. It is likely that ripples of considerable size were present on the bottom at the time of the sampling off Plum Island. Ten to twelve foot waves were present in the offshore area on the first day of sampling, and these undoubtedly resulted in ripple formation and perhaps other means for redistributing the bottom sediment. It was assumed that this sampling difficulty could be overcome by towing the dredge over the bottom for several seconds, so that both crests and troughs of the ripples were likely to be sampled. As a further check on the reliability of the sampling method, two of the profiles (samples 11-16 and 61-65) were sampled in duplicate. On each of these stations the dredge was lowered again after the first recovery before the ship proceeded on to the next station.

The beach and dune samples came from within one inch of the surface. The samples of glacial outwash were taken at least a foot beneath the overlying soil cover. These samples were likewise stored in ice cream cartons and sealed.

D. Method of Laboratory Analysis

Preparation of samples.

All samples were split with a mechanical splitter and dried. A few of the samples, including the samples of glacial outwash and those taken in the Merrimack River, contained a noticeable amount of silty material. These were washed through a 230 mesh screen (mesh diameter = 4 ϕ, or .062 mm.) to remove the silt and clay fraction. For the textural studies, approximately 100 grams of material were required for the sieve analysis, and 5 grams for the settling tube.

Textural analysis.

All offshore samples were analyzed texturally using the settling tube belonging to the Woods Hole Oceanographic Institution. The settling tube yields a frequency distribution of the settling velocities of the grains that make up the sample. This distribution is equivalent to a frequency distribution of grain sizes, to a very good approximation. Points were read at quarter-phi intervals from the graph printed out by the settling tube recorder, and replotted on probability paper as a cumulative frequency distribution of grain sizes (see Appendix E). Desired statistical parameters were then computed by reading the values of the grain sizes at selected percentiles on the cumulative curve.

The graphic method was used for computing the statistical parameters desired. The parameters listed below were selected as representing the average size, uniformity, and skewness of the material. The formulae used for computing these parameters (after Folk, 1965) are listed on the right. The notation "ϕ_X" stands for the ϕ diameter such that X per cent of the sample has a diameter coarser than this value.

Statistical Parameters	Method of Computation
Graphic Mean	$\dfrac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$
Inclusive Graphic Standard Deviation	$\dfrac{\phi_{84} - \phi_{16}}{4} + \dfrac{\phi_{95} - \phi_{5}}{6.6}$
Inclusive Graphic Skewness	$\dfrac{\phi_{16} + \phi_{84} - 2\,\phi_{50}}{2\,(\phi_{84} - \phi_{16})} + \dfrac{\phi_{5} + \phi_{95} - 2\,\phi_{50}}{2\,(\phi_{95} - \phi_{5})}$

To serve as a check on the resluts obtained with the settling tube, one profile of six samples (samples 11B, 12B, 13A, 14B, 15B, 16B) was analyzed by sieving, using sieves of 1/4 ∅ intervals. Each sample was sieved in duplicate. Points were plotted on probability paper, as in the settling tube analysis, and appropriate percentiles were chosen for computing the desired statistical parameters,

Sieved fraction analysis.

There was insufficient time for a detailed mineral study of all samples. It was necessary to select for study a small number of samples which would be representative of all the types of material present in the area, and which would represent all parts of the area geographically. Nineteen samples were selected; each was sieved, and the following size fractions were kept for study:

Coarse fraction	∅ = 0.25 to ∅ = 0.50
Intermediate fraction	∅ = 1.25 to ∅ = 1.50
Fine fraction	∅ = 2.25 to ∅ = 2.50

A fourth fraction, of size ∅ = 3.25 to ∅ = 3.50, was not studied because of the abundance of heavy minerals in this fraction. The heavy mineral fraction was analyzed separately.

A study of the mineralogy, roundness, and staining of the grains was made for each of the three size fractions of the 19 samples selected. Estimates of the mineralogy of each fraction were made by examination of the sample under a binocular microscope and under a petrographic microscope using oil mounts of grains for refractive index comparison. An estimate of the roundness of some mineral grains was made, using the visual comparison charts of Powers (1953). The degree of staining on the grains was noted.

Heavy mineral analysis.

The heavy minerals of each of the 19 samples studied were separated using bromoform, and the weight per cent of heavy minerals was noted. Then an estimate was made of the mineralogy of the heavy fraction, again using a binocular microscope and a petrographic microscope with oil mounts of the grains.

II. DETERMINATION OF DIRECTION OF TRANSPORT

The following evidence supports the conclusion that the longshore component of sediment transport in the offshore zone is in a southerly direction:

1. During the winter season when severe storms are more common, the principal wind direction is from the northwest or northeast.

2. The underwater contours (see Plate I in pocket) become increasingly farther seaward toward the south.

3. There is a significant accumulation of sand on the north side of the jetties constructed near the mouth of the Merrimack River.

4. The channel followed by the Merrimack River at its mouth turns sharply (about 30°) toward the south in passing through the offshore zone.

5. The samples taken in the Merrimack River possess a considerable amount of organic material, including living Mollusca, and the sand has a noticeable organic odor. This same odor was distinctly present in the samples taken in the profile immediately to the south of the river mouth (samples 41-45), but was not present in the samples just to the north of the river mouth (samples B, 51-56).

6. The offshore samples to the south of the river mouth are similar in texture (possessing considerable fine sand and silt) and appearance (frosted, cloudy, dirty appearance of grains) to the river samples, whereas those from north

of the river mouth are considerably coarser and have a "cleaner" appearance (see discussion of results in next section).

III. PRESENTATION AND DISCUSSION OF RESULTS

A. Textural Analysis

Sizing of material.

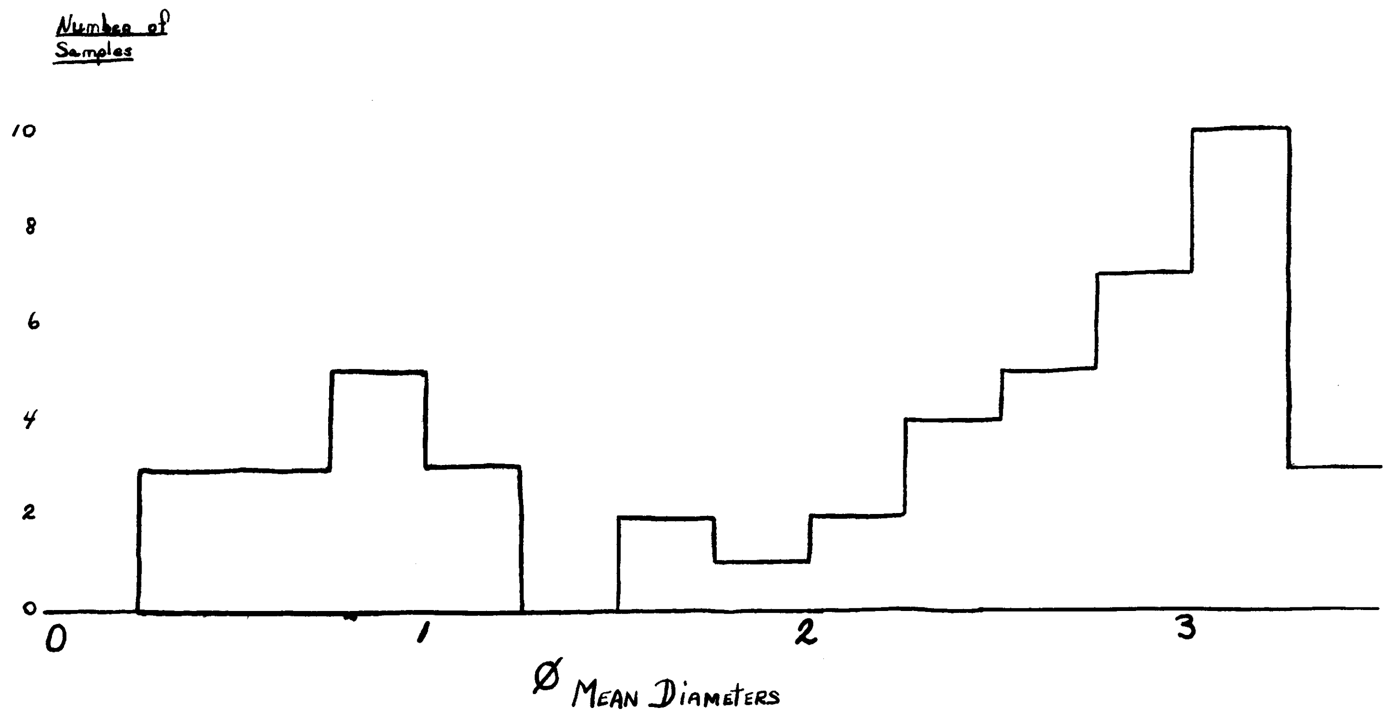
Folk (1965, p. 45) has suggested that the graphic mean is the best graphic measure for describing the overall size of a sample. The graphic means of the samples were computed, and the results are tabulated in Appendix B.

A frequency distribution of the graphic means was plotted in order to determine whether certain mean diameters are more common than others (see Figure 2). This distribution of means does not immediately suggest any criteria for classifying the samples according to average size. Consequently the modal diameters were selected from the histograms of the grain size distributions (see Appendix F), and a frequency distribution of the modal diameters was plotted (Figure 2). From this distribution a more clearly defined division of the samples according to average size emerges. The distribution suggests that there are four distinct ranges of modal diameters present:

1) A coarse sand, of diameter ϕ = 0.25 to ϕ = 0.75;
2) A medium sand, of diameter ϕ = 1.50 to ϕ = 2.00;
3) A fine sand, of diameter ϕ = 2.25 to ϕ = 2.75;
4) A very fine sand, of diameter ϕ = 3.00 to ϕ = 3.50.

Figure 3 illustrates the distribution of these modal sand sizes over the area sampled.

Figure 2 Distribution of Mean and Modal Diameters



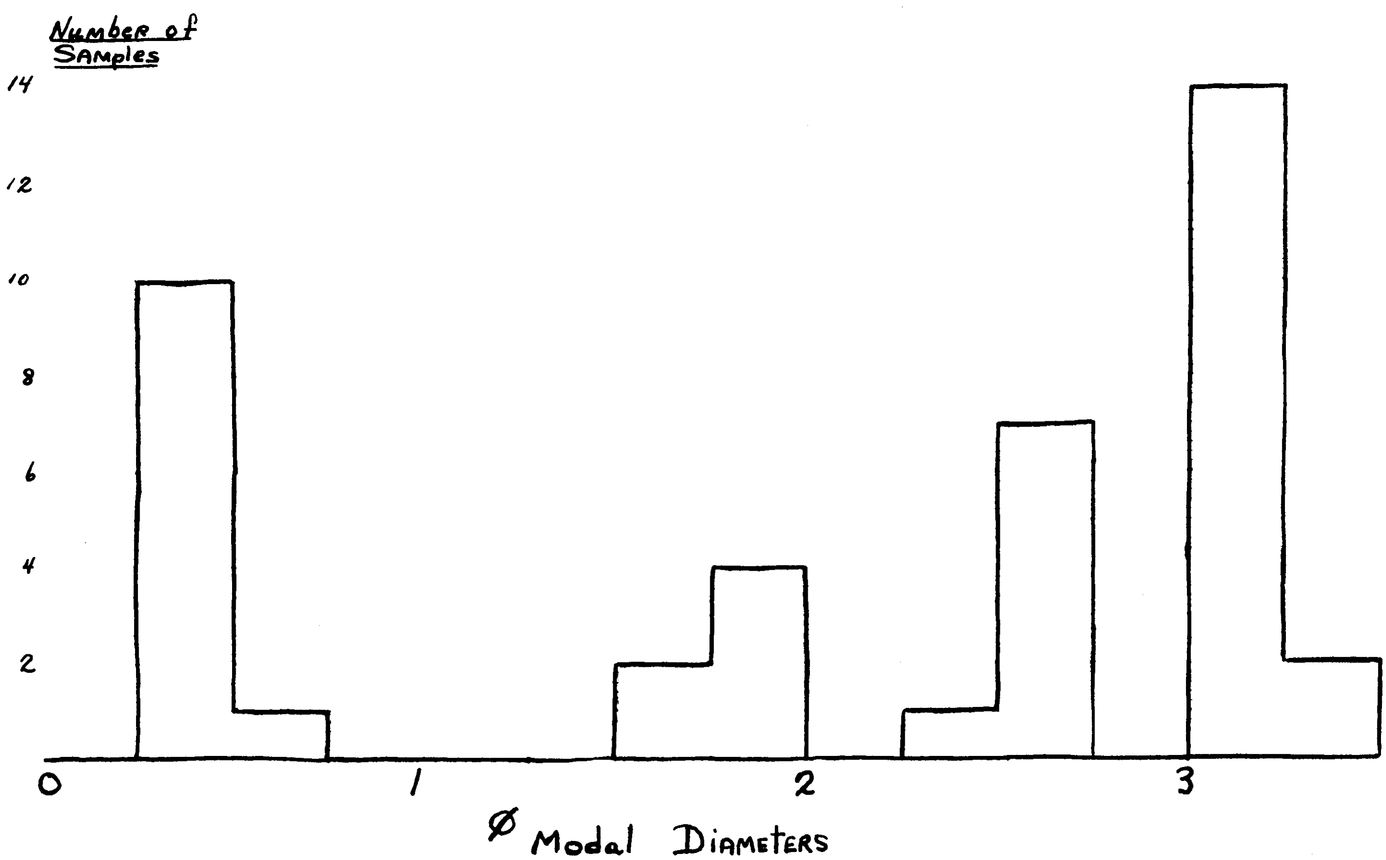
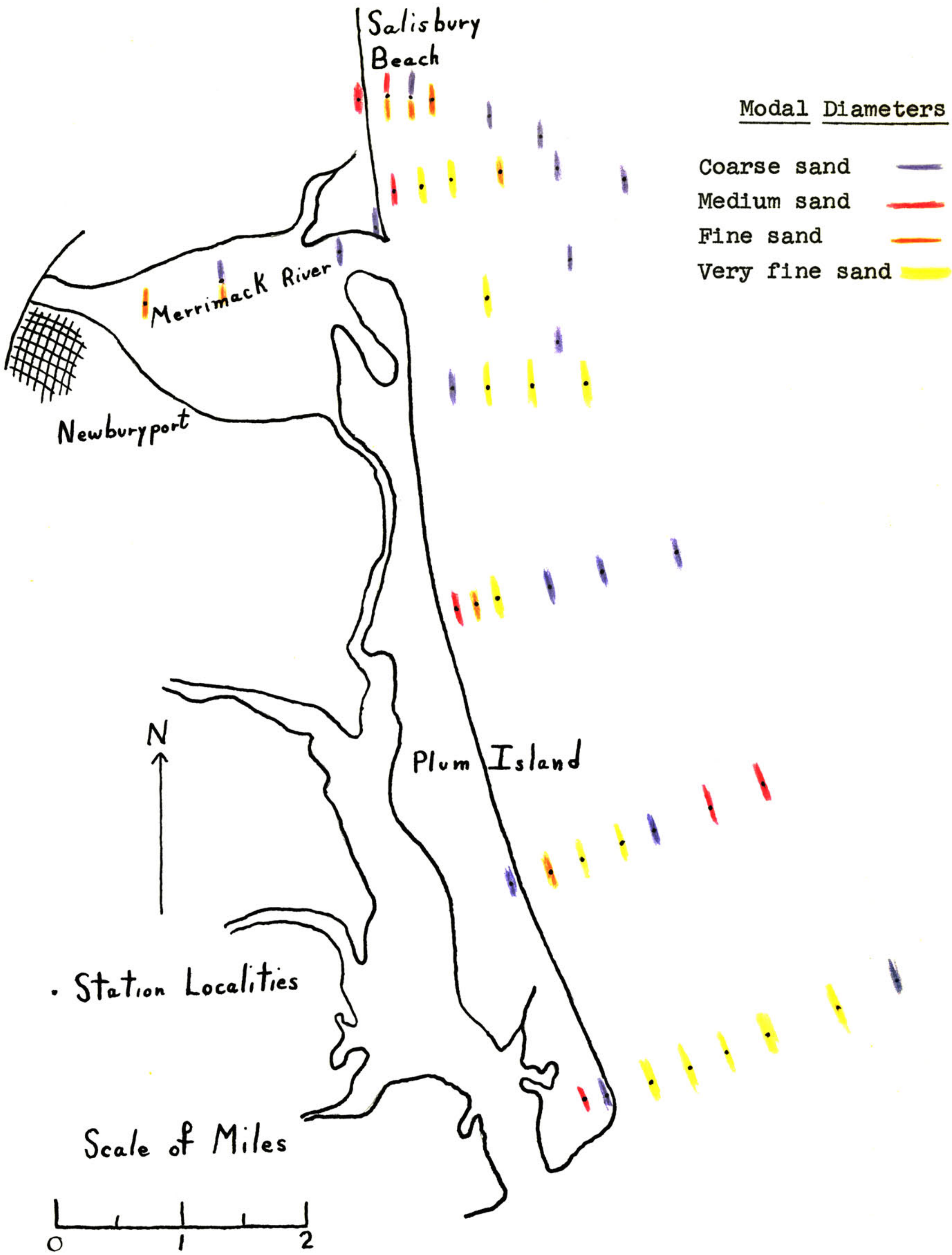


FIGURE 3 Areal Distribution of Modal Diameter of Samples



Referring to Figure 3, several trends in sediment sizing in a direction normal to the shore may be noted. On all profiles in the offshore zone the modal diameter of the samples appears to decrease in a seaward direction over a limited distance. The beach samples (taken in the swash zone) and the samples from shallow water are generally coarse to medium sands; these grade into fine and very fine sands to a depth of 40-60 feet. Seaward of this point (generally at a depth of about 60 feet) there is on all profiles a coarse sand to fine gravel mixture, strikingly different in texture and in general appearance (see sieved fraction analysis) from the material in shallower water. There is no apparent gradation on any of the profiles between this coarse material and the finer material to landward. It is therefore likely that the coarse material in deep water is of different origin from the material in shallower water and on the barrier islands.

Disregarding for the moment this coarser material in deep water, the samples from shallow water confirm the predictions that have been made regarding sorting normal to the shore. Theoretical and experimental work on this subject has been done recently by Ippen and Eagleson (1955). They found that if a beach is initially composed of a uniformly graded sand, the different hydrodynamic properties of grains of different sizes will cause the material to be redistributed. As an oscillatory wave gradually enters shallow water, a depth will eventually be reached where the finer grains will be put into "incipient motion" (oscillatory motion) and then "established motion" (shoreward or seaward). Outside the breaker zone this established motion is almost entirely in a shoreward direction, according to Ippen and Eagleson. Once the established motion of the particle has set in, it will travel along the bottom all the way to the breaker zone, at increasingly faster rates. As the water becomes shallower, larger particles will be capable of movement and will move onshore. As a result, a greater proportion of coarser particles would be expected on the bottom as the bottom becomes shallower.

Several observations have been made in the offshore zone which seem to confirm this prediction. Trask (1955) has taken 175 bottom samples from depths of 80 feet and less in the area around Point Conception, California. He found that the median diameter of samples in the offshore zone decreased consistently with depth, at a rate of .02 mm. - .05 mm. per ten feet of depth increase. A summary of his results is shown in Figure 4.

For comparison with Trask's results, the mean diameters of the samples from the five southernmost profiles off Plum Island are plotted in Figure 5. On all profiles except profile 4 (the profile just south of the mouth of the Merrimack River) a depth was eventually reached where the offshore coarse sand appeared. For the samples shoreward of this depth

Figure 4 Variation of Median Diameter with Depth, off Point Conception, California (after Trask)

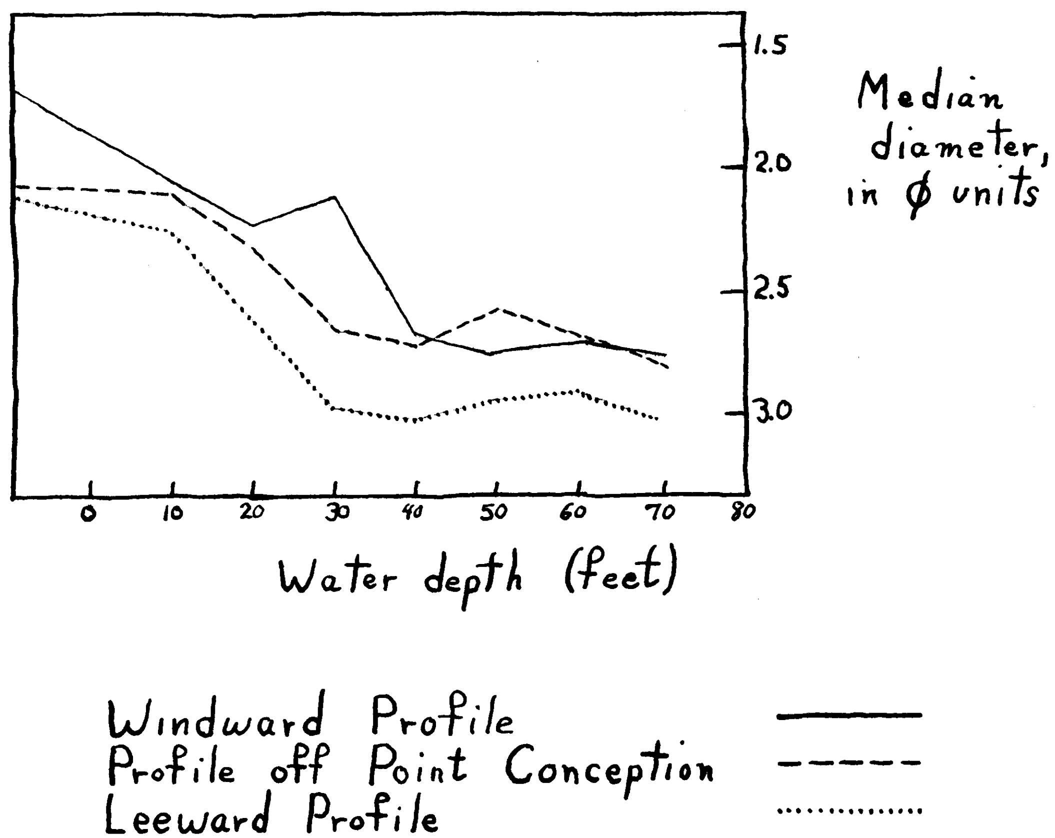
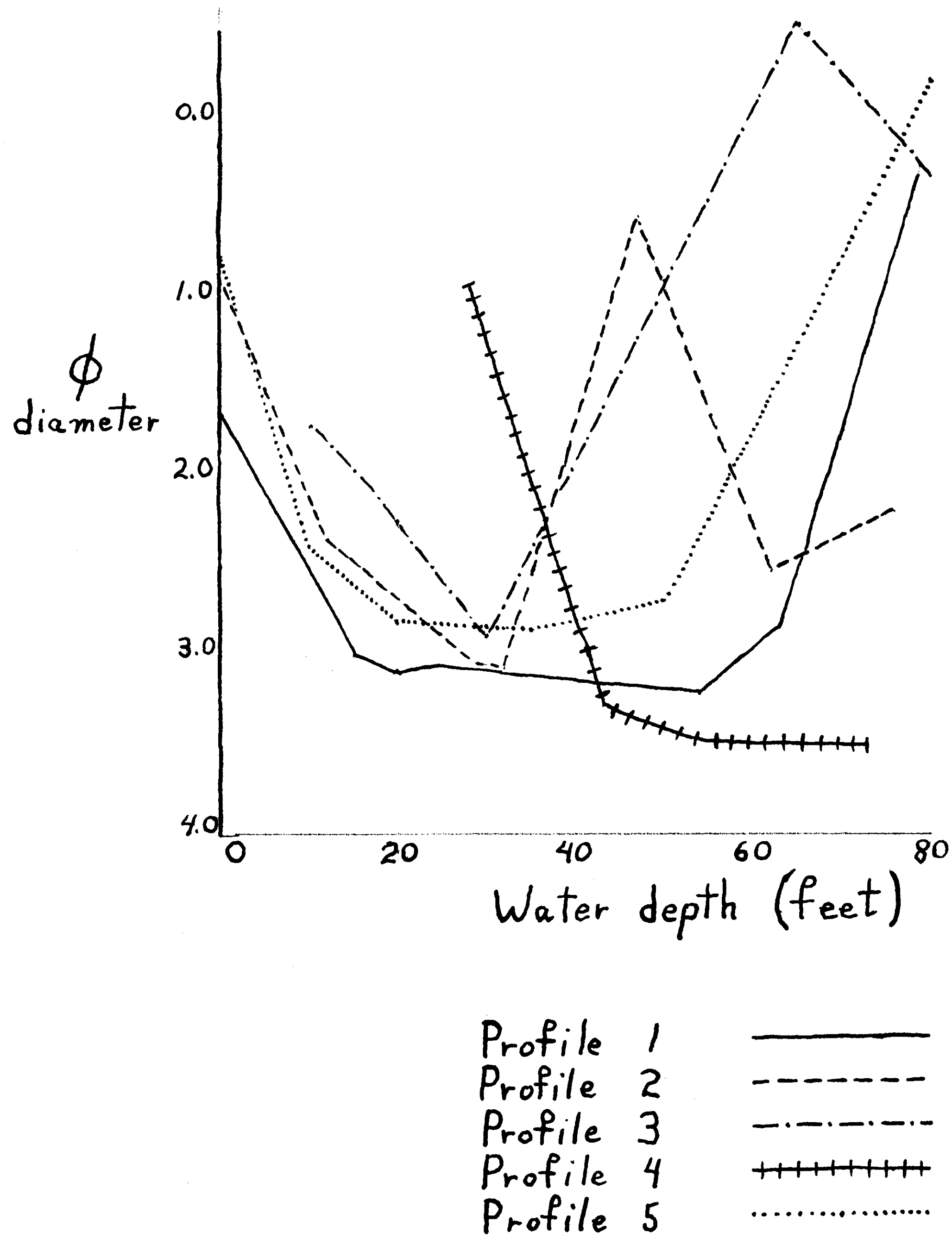


Figure 5 Variation of Mean Diameter with Depth, off Plum Island, Massachusetts



on all profiles the mean diameter decreases regularly in a seaward direction.

Referring back to Figure 3, the trends in material sizing in a direction parallel to the shore should be noted, considering first the beach samples. Since the purpose of the present study was to investigate the offshore sediments, only a limited number of beach samples was taken (samples 10, 20, 50, 60). The mean diameter of the sample from the beach at the mouth of the Merrimack River was 0.76 ∅; five miles to the south along Plum Island beach the mean diameter decreased to 0.85 ∅, and a mean of 1.64 ∅ was found on the beach at the southern tip of Plum Island. For these three samples the trend is a decreasing mean diameter toward the south. In contrast, the sample taken one and one-quarter miles to the north of the river mouth has a mean of 1.28 ∅, and therefore does not coincide with this trend.

Schalk (1936) sampled the beach sand at 15 localities along Plum Island and noted "a definite decrease in median diameter" in a southerly direction. His northernmost sample, from the beach near the mouth of the Merrimack River, had a median of .690 mm. (0.54 ∅). For the next four stations to the south the values varied between .705 mm. (0.51 ∅) and .530 mm. (0.92 ∅). Beyond this point the medians decreased regularly to the last station (on the southern tip of the island), which had a mean of .208 mm. (2.27 ∅). Although the trends present along Plum Island are the same in Schalk's study as in the present study, the values found at corresponding localities differ considerably. No explanation is here offered for this difference.

The longshore trends present in the offshore samples should now be considered. Disregarding the coarse sand and fine gravel found in deep water, there is a significant decrease in mean grain size in a southerly direction. The fine and very fine sand, commonly found in the samples taken in shallow water, extends farthest seaward on the southernmost profile, and its areal extent generally decreases toward the north.

In Schalk's discussion of the beach samples from Plum Island, three possible explanations were presented to account for the decrease in median diameter toward the south along the beach, and his arguments are probably applicable to the offshore zone as well. His suggested hypotheses include (1) size reduction by abrasion, (2) variations in exposure to waves and currents, and (3) selective transportation of the fine sand grains.

Reduction in size proceeds at much too slow a rate to have any demonstrable effect on an eleven mile stretch of beach, and this explanation may therefore be ruled out. However, there _is_ a significant difference in exposure along Plum Island. The southern part of the Island is more in the lee of Cape Ann, which affords protection from easterly storms. Furthermore the seaward slope of the bottom is more gradual toward the south, such that incoming waves dissipate more of their energy in deeper water. This difference in exposure might therefore be partly or entirely responsible for the variations in sediment size along the beach.

The third possibility is that of selective transportation of the finer grains. Longshore transport has been shown to take place principally by two processes: (1) beach drifting in the swash zone, and (2) transport of suspended material by longshore currents in the vicinity of the breaker zone (King, 1959, p. 144). The type of transport present in any given area varies with the wave characteristics. When steep storm waves are present, up to 60% of the material may be carried in suspension, but for low flat waves most of the transport is in the swash zone. Regardless of the mode of transport, however, the finer grains will be transported more easily. In the swash zone the uprush of the waves is strong enough to carry both coarse and fine grains along the beach, but the backwash is much weaker, so that only the finer grains are carried along during this part of the wave cycle on the beach face. In the breaker zone the finer grains remain in suspension longer than the coarser grains, and are likely to be carried greater distances by the longshore currents present. An accumulation of the finer grains would then be expected in the direction of longshore drift.

Numerous observational studies of the sizing of beach and nearshore material in a direction parallel to the shore generally confirm this prediction of Schalk and others. If the shore line is irregular in shape, such that wave refraction takes place in the offshore zone, it is generally found that the degree of exposure is the principal factor in determining the relative sizing of the material. Referring back to the results of Trask's study in the offshore zone around Point Conception, California (Figure 4), the coarser material was found on those profiles that were most exposed to wave attack. Similarly, Emery (1960, pp. 188-189) describes the effect of irregular submarine contours on the grain size of beach material. Wave refraction away from the deep water at the head of Newport Canyon in southern California yields a fine-grained sand on the beach at the head of the canyon. In contrast, sand at both sides of this point where the waves are higher is coarser. Similar results were obtained at this point in summer and winter.

If, on the contrary, the beach is relatively long and straight, and subject to relatively the same amount of wave attack at all points, then the direction of longshore drift will probably be the critical factor in sizing the material along the beach. In studying the sizing of the beach material on Castle Neck (near Ipswich, Massachusetts), which is just south of the area under study in this paper, Horodyski (1965) found that "the mean diameter tends to decrease and the material tends to be better sorted in the direction of material transport," which in this case is toward the southeast.

Model studies of littoral transport, however, have sometimes yielded conflicting results. Saville (1950) made model studies, in a tank of dimensions of about 60' x 120', of littoral sediment transport by wave action on an "infinitely long" straight beach. Uniformly graded sand, with a mean diameter of .30 mm., was set out on the beach slope and subjected to wave attack until an equilibrium profile was established and the longshore transport had been established. Then material was continuously introduced from the "upwind" end of the model to replenish the sand that was removed. Collection traps were placed at various points along the beach to sample the material transported. Two of Saville's observations are worthy of note:

1. The material transported along the model beach and deposited in the trap at the downcoast end of the beach showed <u>no appreciable change</u> in grading from the original sand sample initially supplied to the beach. Whether the transport was by littoral current or by beach drifting, and regardless of the character of the incident waves, there was no significant grading of the sand longitudinally along the beach.

2. Considerable grading of the material <u>was</u> found to be established in a direction perpendicular to the beach contours, with the heavier material being carried along the foreshore, and the lighter material more at sea.

The first of these observations by Saville is in conflict with the results of the present study, for significant trends in sediment properties were noted in a longshore direction east of Plum Island. The second of his observations, though, does correspond with the results of the present study.

Sorting of material.

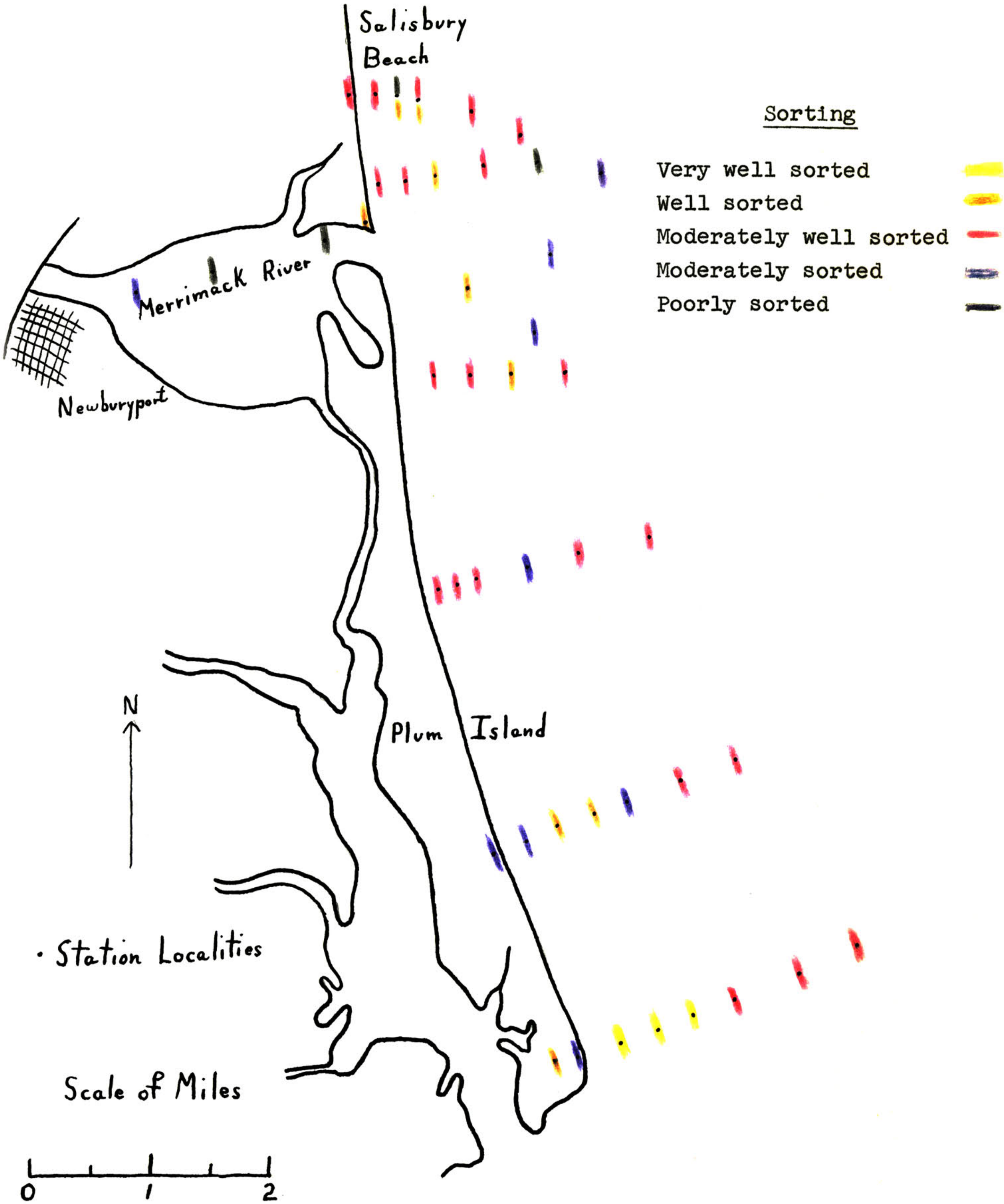
The inclusive graphic standard deviation (Folk, 1965, pp. 45-46) was used to indicate the uniformity or degree of sorting of the samples. Folk's verbal classification for the sorting of sands, tabulated below, will be used in the discussion that follows:

Values of Inclusive Graphic Standard Deviation	Description of Sorting
.35 ∅	very well sorted
.35 ∅ to .50 ∅	well sorted
.50 ∅ to .71 ∅	moderately well sorted
.71 ∅ to 1.0 ∅	moderately sorted
1.0 ∅ to 2.0 ∅	poorly sorted

The degree of sorting present in the samples is illustrated in Figure 6. The following trends may be noted:

1. On the southern profile, the samples taken in water of depth less than about 35 feet are very well sorted, whereas those from deeper water on this profile are only moderately well sorted. It should be noted that on this profile a depth of 35 feet separates the material into two groups on the

FIGURE 6 Areal Distribution of Sorting of Samples



basis of sorting, whereas a depth of about 65 feet was used to separate the material on the basis of grain size.

2. This moderately well sorted material continues northward at the same depth, becoming less well sorted toward the north.

3. The very well sorted material is present only in the southernmost profile. This material becomes progressively less well sorted in the two profiles immediately to the north.

4. In the three profiles taken near the mouth of the Merrimack River the sorting of the bottom material is irregular in all parts of the offshore zone. No significant trends in sorting are present, either in a seaward direction or in a direction parallel to the coast.

5. The samples taken in the Merrimack River show the poorest sorting of all samples taken. Material of silt to gravel size is generally present in the river bottom.

Folk (1965, p. 4) believes that the following five factors are important in determining the sorting properties of sediments:

1. Size range of the material supplied to the environment. If the primary source material is glacial till, and this is probably true in the area under study, the beach and offshore sediments will not be relatively well sorted.

2. Type of deposition. Deposition in which sediments are dumped down the front of an advancing series of cross beds

and then buried rapidly by more sediment will give poor sorting compared to the "spreading" type of deposition on a beach such that thin sheets of grains are continuously being reworked by the swash of waves.

3. Current characteristics. For best sorting of material beneath unidirectional flow, the currents must be of an intermediate strength and also be of constant strength. In the area of study the poorest sorting is generally found in the river bottom, where strong reversing tidal currents are present. Poorly to moderately well sorted material is present in deeper water (depth $>$ 65 feet) in the offshore zone, but this poor sorting is probably more correlated to grain size than to the current characteristics of the environment (see statement 5 below). The best sorting is generally found in shallow water beyond the breaker zone, where slow but relatively uniform longshore drift is probably present.

4. Rate of supply compared to rate of reworking. Schalk (1936, p. 50) believes that it is doubtful if the Merrimack River is now transporting much sand or gravel to the offshore zone or beaches, because the numerous power dams constructed along the river have created effective settling basins for the deposition of the coarser material. Results of the present study, however, will show that there are several significant trends in sediment mineralogy in a longshore direction away from the mouth of the Merrimack River. These trends suggest that considerable material is at present being supplied to the offshore zone by the Merrimack River.

5. Grain size. Folk (1965, p. 4) states that it is probable that "in every environment, sorting is strongly dependent on grain size. This can be evaluated by making a scatter plot of mean size versus sorting. In making many of these plots, a master trend seems to be revealed: the best sorted sediments are usually those with mean sizes of about 2 ∅ to 3 ∅ (fine sand). As one measures coarser sediments, sorting worsens until those sediments with a mean size of 0 to -1 ∅ show the poorest sorting values." In the area of study, the deep water samples and river samples generally have modal diameters in the coarse sand range, and are generally poorly sorted. The finer samples (from shallow water in the offshore zone) are generally well sorted.

Skewness of material.

The inclusive graphic skewness of each sample was computed, and the values are summarized in Appendix B. The skewness of each sample was then classified according to the following system, as suggested by Folk (1965, pp. 46-47):

Values of Inclusive Graphic Skewness	Classification of Skewness
+ 1.00 ∅ to + 0.30 ∅	Strongly fine-skewed
+ 0.30 ∅ to + 0.10 ∅	Fine-skewed
+ 0.10 ∅ to - 0.10 ∅	Near symmetrical
- 0.10 ∅ to - 0.30 ∅	Coarse-skewed
- 0.30 ∅ to - 1.00 ∅	Strongly coarse-skewed

The degree of skewness present in the samples taken is illustrated in Figure 7. The following observations may be made:

1. Most of the samples taken in water of depth less than about 65 feet show a nearly symmetrical grain size distribution, with no pronounced skewness.

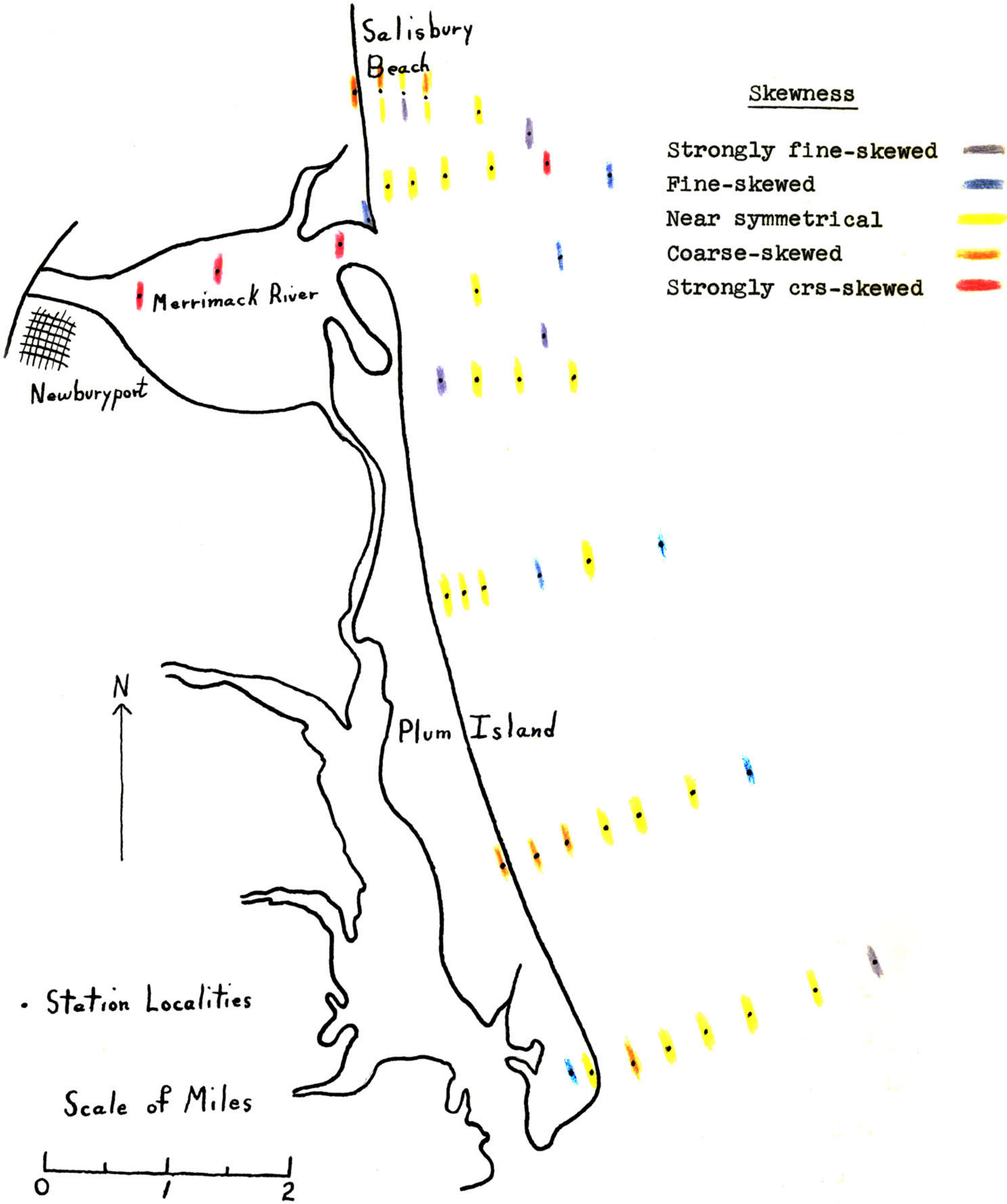
2. All samples taken in water of depth greater than about 65 feet (except sample 56) are fine-skewed to strongly fine-skewed.

3. For the three southernmost profiles, the skewness is increasingly more positive (finer skewed) in a seaward direction. For the remaining three profiles, there is no uniform trend in skewness in a seaward direction.

4. There is a fair correlation of skewness with modal grain size. The near-symmetrical material is generally fine to very fine sand. The skewed material (whether positively or negatively skewed) is generally coarser.

The mode and energy of the transporting medium are influential on the textural parameters of a sediment, particularly on the skewness. Several investigators (Friedman, 1961; Martins, 1965) have found that the skewness can sometimes be a useful indication of environment of deposition of a sediment. When the material is moved by a river or wind, such that the transportation is generally unidirectional, there is a maximum size of grains that can be carried in suspension or by saltation, which varies with the competency of the

FIGURE 7 Areal Distribution of Skewness of Samples



transporting medium. As a result many dune and river samples lack a "tail" at the coarse end of the grain size distribution curve, and are commonly fine-skewed (positively skewed). In contrast, beach samples are commonly coarse-skewed, due to the winnowing of the finer grains by wind and by the backwash of waves in the swash zone.

Samples in the area of study generally conform to these predictions. Of the four beach samples taken, two are coarse-skewed, one is nearly symmetrical, and the other is fine-skewed. The river samples, however, are not representative of the type discussed by Friedman because of the non-unidirectional nature of the flow in that part of the river bottom that was sampled. It is likely that the strongly coarse-skewed nature of the samples from the Merrimack River may be explained by the winnowing of the finer material by strong tidal currents.

No explanation is offered for the more positive skewness in increasingly deeper water on some of the profiles. Because of the probable difference in origin of the shallow water and deep water samples, any explanation for this trend in skewness would probably be misleading.

Comparison of sieve and settling tube.

There was generally very good agreement between the results obtained in the sieve analysis and those obtained using the settling tube. Differences between the two methods were small and somewhat consistent. Values of the mean are generally about 0.10 ∅ units coarser by the sieve method. A comparison of the methods in the determination of sorting indicates that for the three very well sorted samples, the sieve analysis indicated a slightly better sorting than did the settling tube, but for the moderately well sorted samples the sieve analysis indicated a slightly poorer sorting. In the skewness determinations the same trends were found present in the sieve analysis as in the settling tube analysis, but the agreement between corresponding values of skewness was not good.

B. Sieved Fraction Analysis

Each of the 19 samples selected for this study was sieved, and three size fractions (coarse sand, medium sand, fine sand) were studied. The results of this study are tabulated in Appendix C, and may be summarized as follows:

Mineralogy.

1. There is no general relationship between quartz content and the grain size of the sample. For a significant number of the samples, however, the presence of rock fragments and micas in the coarse fraction commonly lowers the relative quartz content, whereas heavy minerals and feldspar in the finer fractions may lower the relative quartz content. No general relationship can be observed between the quartz content and the environment.

2. The micas are found only in shallow water. They are not present in the swash zone, and are not present in water of depth greater than about 40 feet. The micas are present only in the coarse fractions of the samples in which they are found.

3. Orthoclase, microcline, and plagioclase feldspars were observed in most samples. Generally the feldspar content is low in the intermediate fraction and high in the coarse fraction and fine fraction. Geographically the feldspar content is highest in the river sample and lowest at those stations that are farthest from the river mouth.

4. Rock fragments are most abundant in the samples of glacial outwash, the sample from the Merrimack River, and the deep water samples. They are present in all size fractions, but are generally more abundant in the coarse fraction.

Particle morphology.

1. The roundness of the grains is closely related to mineralogy in all samples and in all fractions. Quartz is always the most angular, with feldspar intermediate and rock fragments showing the best rounding.

2. The roundness of the quartz is dependent upon grain size; roundness generally increases with increasing grain size within each sample. For other minerals there is no significant variation in roundness with grain size.

3. The quartz is generally more rounded in the southern part of the area. This seems to be true for all size fractions

studied, and for both deep water and shallow water environments. For the feldspar and rock fragments there is no significant variation in roundness with environment; they are generally subrounded to rounded in all environments and in all size fractions.

"Staining"

During the sampling program it was noted that the samples taken in deep water (depth greater than about 65 feet) had a markedly different appearance from those taken closer to shore. The deep water samples were generally coarse-grained, and the grains appeared "stained with a red to orange color. This coloration was found present to an even greater extent on grains from samples of glacial outwash (samples K2, K3) taken well inland from the coast. Closer examination of these grains indicated the following:

1. The coloration is present primarily on feldspar grains, and is occasionally present on quartz.

2. The coloration is not surficial; when the "stained" grains are fractured, the coloration may still be seen on the smaller fragments.

3. The coloration is not simply the natural color of feldspar, but is due to an orange to black opaque material.

Samples taken in shallow water, by contrast, have only minor amounts of the highly colored grains; clear, glassy, angular quartz grains generally make up greater than 80% of these samples. Noticeable coloration was present on samples taken in the swash zone, and was also present on many of the grains that comprise the dunes farther inland.

In addition to this red-orange coloration on the feldspars, the deep water samples were characterized by a frosted, cloudy appearance on the quartz grains. This is in sharp contrast to the glassy, angular quartz found in shallow water. These frosted quartz grains are commonly present in the samples of glacial outwash and in the sample taken in the Merrimack River.

These striking similarities between the coarse sand-fine gravel in deep water and the glacial deposits inland suggest a common origin. Schlee (1964) describes an offshore gravel deposit off the coast of New Jersey, and the origin that Schlee proposes for the New Jersey deposit may be applicable to the coarse sand-fine gravel east of Plum Island. The gravel studied by Schlee forms a fan-shaped deposit roughly between the 66- and 132-foot contours, and covers an area of approximately 560 square miles. The sand and gravel in this zone were found to have a distinctive yellowish brown color, in marked contrast to the grayish-white sand adjacent to the deposit. Most of the pebbles in the "gravel" region were grey quartzite and vein quartz, stained by limonite.

From considerations of the shape, location, texture, color, and composition of this deposit, Schlee concluded that these sediments were derived from erosion of crystalline rocks and Paleozoic sedimentary rocks, probably to the northwest, and were deposited as an alluvial apron by the Hudson River on the continental shelf during a lower stand of the sea. Several features of the deposit support this interpretation of its origin. The deposit is next to the submerged extension of the Hudson River. It is fan-shaped in plan view, and the main axis of gravel concentration is parallel to the trend of the Hudson channel.

Deposits similar to this have been described on land. The upland gravels of southern Maryland (Schlee, 1957) form an erosionally persistent capping on the southern Maryland upland. The fabric, grain size, and composition of these gravels suggest that they were deposited by the ancestral Potomac River during the Pliocene or Pleistocene. These gravel deposits show the same limonite stain of pebbles as the offshore gravel described by Schlee (1964). This color may have resulted from the weathering of soils during the late Pleistocene.

Schalk (1936, p. 50) believed that the Merrimack River was formerly an important source of supply of material to the offshore zone under study, particularly during the glacial periods when sea level was lower and consequently the coast line farther to the east. "During the glacial period," he suggests, "the augmented volume of water, plus the ready supply of glacial debris, must have enabled the Merrimack

River to deliver a great deal of material to the shore. In addition there may have been a gently sloping sand plain; with the submergence of the coast line . . . some of the material would have been thrown forward and a barrier beach built. . . . As the sand was distributed along the shore, some was blown inland and dunes formed."

Schalk's suggestion concerning the origin of the barrier beaches in the area can neither be verified nor disproven by the results of the present study.

C. Heavy Mineral Analysis

The heavy fraction of each of the 19 samples studied was separated using bromoform, and the weight per cent of heavy minerals was determined. These results are tabulated in AppendixD, in the first two columns. A graphical illustration of the longshore variation in heavy mineral abundance is shown at the bottom of Figure 8. The following observations on the geographical distribution of heavy mineral abundance may be made:

1. The lowest values of heavy mineral content are for samples taken in the swash zone, where the heavy mineral content is generally less than 1% by weight. The value of 2.2% for sample 10 may perhaps be explained by the proximity of this sample to a source area (the till deposit on the south end of Plum Island).

2. The overall abundance of heavy minerals is generally greater for the deep water samples than for the shallow water samples.

3. The overall abundance of heavy minerals appears to increase in a longshore direction away from the mouth of the Merrimack River (see graph at bottom of Figure 8).

4. The dune sample (sample 10X) contains the highest percentage of heavy minerals of all samples analyzed. This is in accordance with the predictions of Bradley (1957) and others.

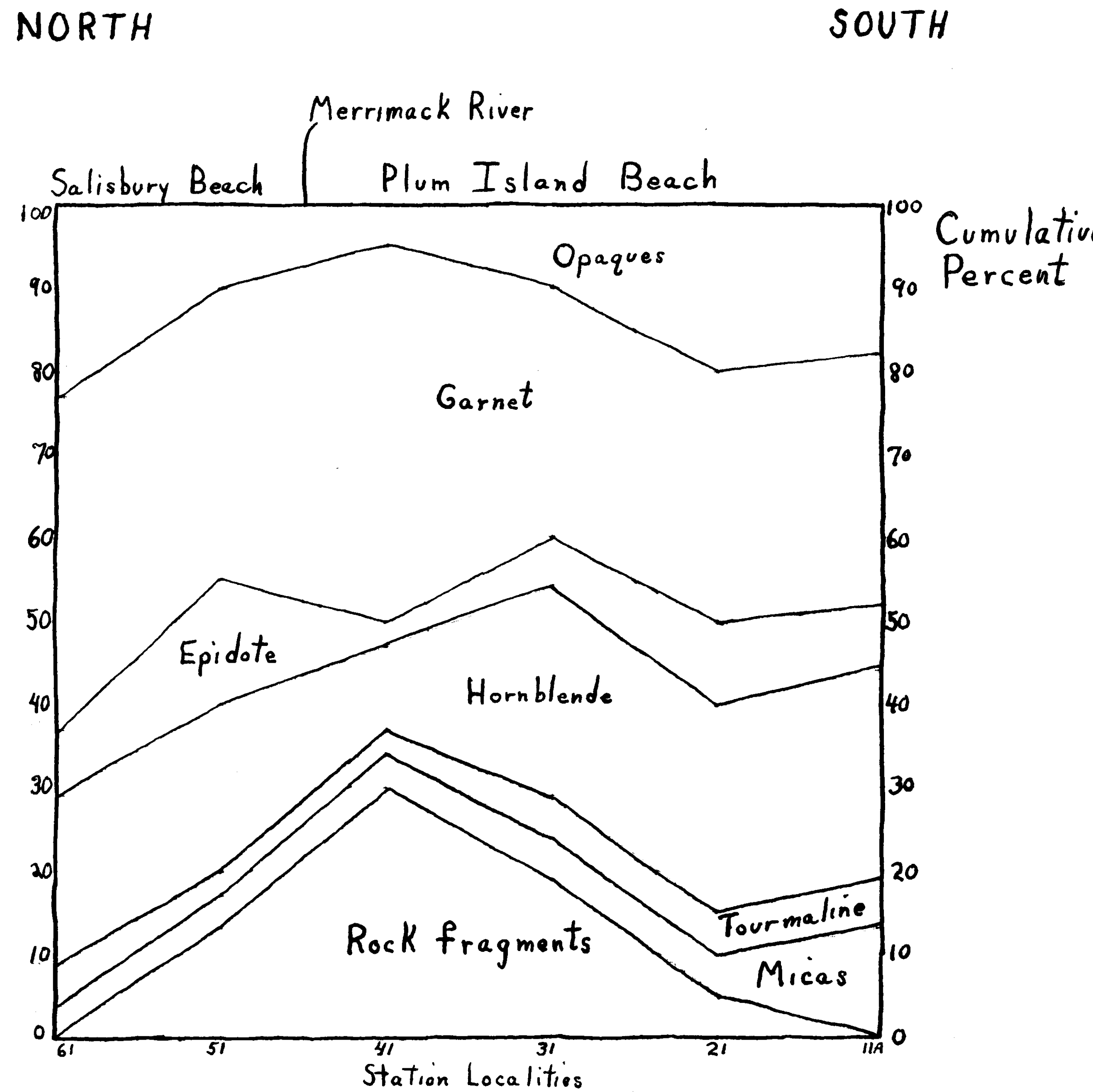
The mineralogy of the heavy fraction was then estimated. Results of this study are tabulated in Appendix D. Figure 8 graphically illustrates the longshore variation in the mineralogy of the heavy fraction of the shallow water samples. The following statements summarize the results of this study:

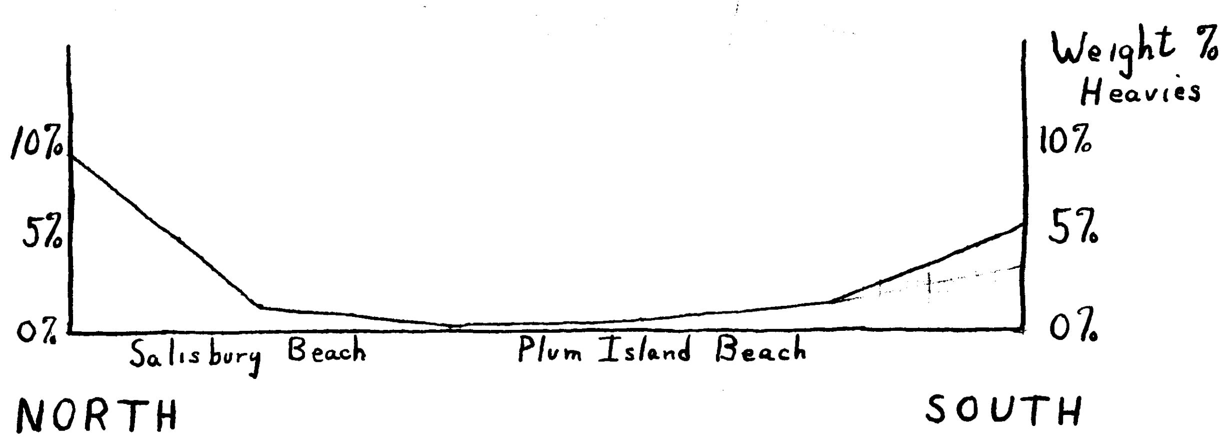
1. As noted previously, the shallow water samples contain a considerable amount of mica, commonly 4% - 12% of the heavy minerals. The mica is rarely present in significant amounts in other environments.

2. Garnet is the chief heavy mineral constituent of the deep water samples. It is least abundant in the samples taken in the swash zone, and its relative abundance appears to increase uniformly in a seaward direction.

3. For ilmenite, hornblende, and tourmaline there appears to be no correlation between the relative abundance of each of these minerals and the environment in which the

Figure 8 Longshore Variation of Heavy Mineral Abundance in Shallow Water





sample was taken.

4. The rock fragments in the shallow water samples are relatively more abundant near the mouth of the Merrimack River, and decrease in abundance toward the north and toward the south.

5. Many of the samples seem to conform to the following summary of the relative abundance of the heavy minerals (see Appendix D):

> Most abundant--garnet or rock fragments (about 50%)
> Next in abundance--ilmenite and hornblende (about 20% each); epidote and tourmaline (about 5% each)

D. <u>Sediment Properties Related to Longshore Transport</u>

Having established that the primary direction of longshore sediment transport is toward the south (see Section II), the significant trends in mineralogy, texture, and grain morphology of the samples in a longshore direction should be noted. For the present we are excluding from consideration the deep water samples, which are strikingly different in appearance (and perhaps also in origin) from those samples taken in more shallow water:

1. The material is generally finer and increasingly better sorted toward the south.

2. The roundness of the quartz grains is somewhat greater for the southernmost stations than for those farther north.

3. There are only a few significant variations in mineralogy in a longshore direction:

a. The abundance of both feldspar and rock fragments is highest near the mouth of the Merrimack River and lowest at those stations that are farthest from the river mouth.

b. The overall percentage of heavy minerals is highest near the river mouth and decreases in a longshore direction, both toward the north and toward the south.

In general, however, there appear to be mineral "zones" in a direction parallel to the shore, and longshore variations within each zone are probably insignificant.

4. Although considerable longshore transport may take place in the offshore area studied, the clearest and most uniform trends and variations in sediment properties are found in a direction normal to the shore rather than along the shore.

E. Error in Sampling

In order to determine the reliability and reproducibility of the results of this study, two profiles of stations (the northernmost and southernmost profiles) were sampled in duplicate. On each station in these profiles the dredge was re-lowered immediately after the first sample was brought aboard, while attempting to keep the ship from drifting.

Results of this study indicate that the sampling error in this type of study may be quite large (see Appendix B). For the southern profile (samples 11-16) the sampling was fairly reproducible in the near-shore stations, but a significant variation was found in the outermost station (samples 16A, 16B). This is probably due to the ship's drifting seaward over a distance of probably 300-400 feet during the time required to recover and re-lower the dredge. For the northern profile (samples 61-65), and particularly for sample 62 which was taken very near shore (water depth about 20 feet), the "duplicate" sample was often quite different in texture from the "original". A comparison of the histograms of samples 62A and 62B (see Appendix F) will illustrate the marked differences obtained. The sampling error for this station, and perhaps for other stations as well, is large enough to warrant a reconsideration of the reliability of this type of approach in studying present-day sediments in the offshore environment.

IV. CONCLUSIONS

1. The predicted variation in textural parameters in the direction of longshore transport (decreasing grain size, increasing sorting) is found to be present in the nearshore stations (water depth less than about 65 feet) south of the Merrimack River.

2. Variations in the relative abundances and in the morphology of minerals which constitute the samples are probably not sufficiently well developed to be considered as reliable indications of the direction of longshore transport, with the possible exception of the increase in the roundness of the quartz grains in the direction of transport.

3. There are, however, several trends in sediment properties (grain size; relative abundance of feldspar, rock fragments, heavy minerals) which seem to be developed in a direction away from the mouth of the Merrimack River. This suggests that the Merrimack River may at present be supplying a considerable amount of material of sand size to the offshore zone.

4. In spite of the presence of longshore transport, the significant variations in textural and mineralogical properties of the sediments are in a direction normal to the shore.

5. The similarity in appearance of the deep water samples with the samples of glacial outwash and with those

samples from the Merrimack River suggests a common origin for all these samples.

6. The sampling error in studies of unconsolidated sediments in offshore areas is likely to be very sizeable.

V. SUGGESTIONS FOR FURTHER WORK

At least two more problems deserve further investigation in the offshore area in which the present study was undertaken:

1. A detailed study should be made of the nature of the coarse sand - fine gravel which is generally present in deep water. In particular, the nature of the red-orange coloration present on many of the grains should be determined. Detailed comparisons between this coarse material from offshore and the glacial outwash from inland may conclusively prove that these two "deposits" have a common origin.

2. More extensive sampling is necessary in the offshore zone north of the Merrimack River, in order to determine whether the longshore variations in sediment properties are primarily in a southerly direction over the entire area, or primarily away from the mouth of the Merrimack River. The answer to this question will be critical in evaluating the relative effects of southerly transport by longshore currents compared with the present rate of supply of material to the offshore zone by the Merrimack River.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the following individuals for their willingness to go to sea under trying conditions to help in obtaining the offshore samples: Mr. Lloyd Hendrick, Robert Berntson, Alan Kraning, Steve Bemis, David Pack, Robert Horodyski, Richard Warner, Gary Laux, and Cliff Lawrence. Thanks are due to Professors Ely Mencher and Frank Press of M.I.T. for their willingness to finance the cost of the ship through NSF Grant No. GP 2628 and the thesis fund of the M.I.T. geology and geophysics department.

I wish to express my thanks to Professor Ely Mencher for the time spent in critical evaluation of the progress of the work throughout the study, and for the suggestions made during the preparation of the final copies of the manuscript.

Thanks are due to John Schlee and K. O. Emery of the Woods Hole Oceanographic Institution for the use of the settling tube for the textural analyses.

Finally I owe my great appreciation to Miss Diann Dunn for her encouragement throughout the course of this study, and for her help in preparing the final copy of the manuscript.

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APPENDICES

APPENDIX A: FIELD DATA

Station	Profile	Water Depth (at mean low water)	Position	Precision and Method of Positioning (D=dead reckoning S=sextant V=visual)
11A	1	14 feet	42°42.7' N 70°45.9' W	± 100 yds. (V)
11B	1	15 feet	42°42.7' N 70°45.9' W	± 100 yds. (v)
12A	1	20 feet	42°42.8' N 70°45.6' W	± 100 yds. (D)
12B	1	20 feet	42°42.8' N 70°45.6' W	± 100 yds. (D)
13A	1	26 feet	42°42.9' N 70°45.2' W	± 100 yds. (D)
13B	1	25 feet	42°42.9' N 70°45.2' W	± 100 yds. (D)
14A	1	48 feet	42°43.1' N 70°44.7' W	± 200 yds. (D)
14B	1	54 feet	42°43.1' N 70°44.7' W	± 200 yds. (D)
15A	1	63 feet	42°43.3' N 70°44.2' W	± 300 yds. (D)
15B	1	63 feet	42°43.3' N 70°44.2' W	± 300 yds. (D)
16A	1	78 feet	42°43.5' N 70°43.5' W	± 400 yds. (D)
16B	1	78 feet	42°43.5' N 70°43.5' W	± 400 yds. (D)
21	2	12 feet	42°44.3' N 70°47.0' W	± 50 yds. (V)
22	2	29 feet	42°44.4' N 70°46.7' W	± 100 yds. (D)
23	2	32 feet	42°44.5' N 70°46.3' W	± 200 yds. (D)
24	2	47 feet	42°44.6' N 70°45.9' W	± 200 yds. (D)

Station	Profile	Water Depth (at mean low water)	Position	Precision and Method of Positioning (D=dead reckoning S=sextant V=visual)
25	2	62 feet	42°44.7' N 70°45.4' W	± 300 yds. (D)
26	2	76 feet	42°44.8' N 70°44.9' W	± 400 yds. (D)
31	3	10 feet	42°46.3' N 70°47.8' W	± 200 yds. (D)
32	3	20 feet	42°46.3' N 70°47.7' W	± 200 yds. (D)
33	3	30 feet	42°46.3' N 70°47.5' W	± 200 yds. (D)
34	3	50 feet	42°46.4' N 70°47.0' W	± 300 yds. (D)
35	3	65 feet	42°46.5' N 70°46.4' W	± 300 yds. (D)
36	3	80 feet	42°46.5' N 70°45.5' W	± 400 yds. (D)
41	4	28 feet	42°48.2' N 70°48.0' W	± 100 yds. (V)
43	4	43 feet	42°48.2' N 70°47.6' W	± 200 yds. (D)
44	4	53 feet	42°48.2' N 70°47.2' W	± 200 yds. (D)
45	4	73 feet	42°48.2' N 70°46.7' W	± 200 yds. (D)
51	5	10 feet	42°49.7' N 70°48.7' W	± 50 ft. (S)
52	5	20 feet	42°49.7' N 70°48.3' W	± 50 ft. (S)
53	5	35 feet	42°49.7' N 70°48.0' W	± 50 ft. (S)
54	5	50 feet	42°49.8' N 70°47.7' W	± 75 ft. (S)
55	5	80 feet	42°49.9' N 70°47.1' W	± 75 ft. (S)
61A	6	10 feet	42°50.5' N 70°48.7' W	± 50ft. (S)

Station	Profile	Water Depth (at mean low water)	Position	Precision and Method of Positioning (D=dead reckoning S=sextant V=visual)
61B	6	10 feet	42°50.5' N 70°48.7'W	± 50 ft. (S)
62A	6	20 feet	42°50.5' N 70°48.4' W	± 100 ft. (S)
62B	6	20 feet	42°50.5' N 70°48.4' W	± 100 ft. (S)
63A	6	30 feet	42°50.5' N 70°48.2' W	± 100 ft. (S)
63B	6	30 feet	42°50.5' N 70°48.2' W	± 100 ft. (S)
65A	6	60 feet	42°50.4' N 70°47.7' W	± 100 ft. (S)
65B	6	63 feet	42°50.4' N 70°47.7' W	± 100 ft. (S)
66	6	78 feet	42°50.2' N 70°47.2' W	± 150 ft. (S)
67	6	85 feet	42°49.8' N 70°46.5' W	± 150 ft. (S)
M1	River	19 feet	42°48.8' N 70°51.3' W	± 25 ft. (V)
M2	River	15 feet	42°49.0' N 70°50.3' W	± 25 ft. (V)
M3	River	20 feet	42°49.1' N 70°49.3' W	± 25 ft. (V)
B	River	72 feet	42°48.9' N 70°46.8' W	± 150 ft. (D)
C	River	34 feet	42°48.8' N 70°47.6' W	± 50 ft. (V)
D	River	70 feet	42°48.5' N 70°47.0' W	± 50 ft. (V)
K2	Glacial Outwash		42°50.0' N 70°50.2' W	
K3	Glacial Outwash		42°54.6' N 70°52.8' W	

Station	Profile	Water Depth (at mean low water)	Position	Precision and Method of Positioning (D=dead reckoning S=sextant V=visual)
10	1	swash zone	42°42.3' N 70°46.3' W	± 50 ft. (V)
10X	1	dune	42°42.3' N 70°46.3' W	± 50 ft. (V)
20	2	swash zone	42°44.3' N 70°47.3' W	± 50 ft. (V)
50	5	swash zone	42°49.4' N 70°48.8' W	± 50 ft. (V)
60	6	swash zone	42°50.5' N 70°49.0' W	± 50 ft. (V)

APPENDIX B: RESULTS OF TEXTURAL ANALYSES

Part I: Settling Tube Analyses

Sample Number	Mean (Ø)	Standard Deviation (Ø)	Ø Skewness
11A	3.04	0.28	-.13
11B	3.01	0.34	-.22
12A	3.14	0.28	+.02
12B	3.08	0.32	+.02
13A	3.10	0.33	-.04
13B	3.05	0.34	-.03
14A	3.25	0.51	-.07
14B	3.22	0.51	-.07
15A	2.92	0.55	+.08
15B	2.85	0.63	+.05
16A	0.84	0.54	+.35
16B	0.25	0.51	+.23
21	2.34	0.72	-.17
22	3.04	0.36	-.11
23	3.07	0.36	-.05
24	0.54	0.73	+.05
25	2.52	0.67	+.03
26	2.19	0.60	+.34
31	1.72	0.57	-.05
32	2.25	0.58	-.09
33	2.89	0.51	-.06
34	0.90	0.98	+.25
35	-0.54	0.59	.00
36	0.33	0.64	+.11
41	0.92	0.55	+.32
43	3.28	0.51	+.04
44	3.48	0.44	+.08
45	3.51	0.59	+.05
51	2.39	0.52	+.04
52	2.82	0.51	+.09
53	2.86	0.41	-.09
54	2.70	0.60	.00
56	-0.22	1.32	-.34
61A	2.51	0.53	+.07
61B	2.40	0.64	-.17
62A	2.60	0.41	+.04
62B	1.01	1.20	+.41
63A	2.24	0.79	-.25
63B	2.70	0.44	-.01
65A	0.93	0.78	+.08
65B	0.74	1.22	+.08

Settling Tube Analyses (cont'd)

Sample Number	Mean (Ø)	Standard Deviation (Ø)	Ø Skewness
66	0.93	0.55	+.43
67	1.00	0.81	+.18
B	0.50	0.95	+.21
C	2.80	0.40	-.05
D	1.20	0.90	+.33
M1	1.94	0.93	-.29
M2	1.66	1.68	-.40
M3	0.29	1.08	-.32

Part II: Sieve Analyses

Sample Number	Analysis Number	Mean (∅)	Standard Deviation (∅)	∅ Skewness
11B	1	2.91	0.25	-.04
11B	2	2.93	0.25	+.01
12B	1	2.99	0.30	-.15
12B	2	3.00	0.29	-.08
13A	1	3.02	0.29	-.04
13A	2	3.02	0.30	+.07
14B	1	3.04	0.63	-.28
14B	2	3.04	0.61	-.25
15B	1	2.62	0.74	-.07
15B	2	2.53	0.74	+.03
16B	1	0.26	0.76	+.33
16B	2	0.31	0.87	+.38
10	1	1.64	0.73	+.01
10X	1	1.76	0.50	+.13
20	1	0.85	0.77	-.18
50	1	0.76	0.44	+.18
60	1	1.28	0.64	-.23

APPENDIX C: SIEVED FRACTION ANALYSIS

Part I: Coarse Fraction ∅ = 0.25 to ∅ = 0.50

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
10	Quartz	55%	2.4	minor
	Feldspar	30%	3.0	heavy
	Rock frags.	15%	3.8	
10X	Quartz	80%	2.0	moderate
	Feldspar	5%	3.0	heavy
	Rock frags.	15%	3.6	
11A	Muscovite	80%	4.0	none
	Quartz	8%	3.6	minor
	Biotite	5%	4.0	---
	Shells	2%	4.0	
	Rock frags.	5%	3.8	
16B	Quartz	90%	3.8	heavy
	Feldspar	2%	3.8	moderate
	Rock frags.	8%	4.0	
20	Quartz	97%	3.8	minor
	Rock frags.	3%	4.5	moderate
	Feldspar	T		
21	Quartz	80%	2.6	minor
	Feldspar	15%	3.8	very heavy
	Rock frags.	5%	4.2	
	Micas	T		
31	Quartz	70%	3.5	moderate
	Feldspar	25%	3.8	heavy
	Rock frags.	5%	4.2	
	Muscovite	T		
35	Quartz	40%	3.5	mod.-heavy
	Feldspar	30%	4.0	heavy
	Rock frags.	30%	4.2	
M1	Quartz	60%	2.7	fr
	Feldspar	15%	3.0	heavy
	Rock frags.	25%	3.5	

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
41	Quartz	50%	2.5	rare
	Feldspar	40%	3.8	very heavy
	Rock frags.	10%	4.1	
45	(not present in this size fraction)			
B	Quartz	50%	2.7	fr
	Feldspar	35%	3.3	very heavy
	Rock frags.	15%	4.1	
50	Quartz	70%	3.0	fr
	Feldspar	25%	3.7	heavy
	Rock frags.	5%	4.0	
51	Quartz	50%	2.2	fr
	Feldspar	40%	3.7	very heavy
	Muscovite	2%	4.0	
	Rock frags.	5%	4.0	
56	Quartz	50%	2.2	fr
	Feldspar	15%	3.5	heavy
	Rock frags.	35%	4.0	
60	Quartz	45%	2.6	fr
	Feldspar	45%	4.0	heavy
	Rock frags.	10%	4.0	
61	Quartz	50%	3.2	fr
	Feldspar	35%	4.2	very heavy
	Muscovite	5%		
	Biotite	1%		
	Rock frags.	9%	4.2	
K2	Quartz	90%	4.0	heavy fr
	Feldspar	5%	4.0	heavy fr
	Rock frags.	5%	4.0	
K3	Quartz	70%	3.5	heavy fr
	Rock frags.	30%	3.8	moderate

Part II: Intermediate Fraction $\phi = 1.25$ to $\phi = 1.50$

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
10	Quartz	90%	2.2	rare
	Feldspar	9%	4.0	common
	Rock frags.	1%	4.0	
10X	Quartz	85%	2.0	rare
	Feldspar	10%	3.5	common
	Rock frags.	1%		
	Micas	2%		
	Heavies	2%		
11A	Muscovite	45%	4.4	none
	Quartz	30%	2.5	rare
	Biotite	15%	4.4	
	Feldspar	10%	3.0	moderate
	Rock frags.	T		
16B	Quartz	90%	2.5	fr
	Feldspar	7%	3.0	moderate
	Rock frags.	3%	4.2	
20	Quartz	80%	2.5	minor
	Feldspar	15%	3.5	heavy
	Rock frags.	5%	4.0	
21	Quartz	65%	1.9	none
	Feldspar	30%	3.0	minor to heavy
	Rock frags.	5%	3.8	
	Mica	T		
31	Quartz	80%	1.5	none
	Feldspar	17%	3.0	moderate
	Rock frags.	3%	3.8	
35	Quartz	20%	1.7	none
	Garnet	70%	1.7	
	Rock frags.	10%		
M1	Quartz	80%	3.2	heavy fr
	Feldspar	10%	3.5	heavy fr
	Rock frags.	9%		
	Micas	1%		

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
41	Quartz	70%	1.9	none
	Feldspar	30%	3.6	moderate
	Rock frags.	T		
	Micas	T		
45	Quartz	40%	3.5	none
	Muscovite	40%	4.2	
	Biotite	20%	4.2	
B	Quartz	65%	1.8	fr
	Feldspar	17%	3.2	moderate
	Rock frags.	10%	3.8	
	Garnet	8%		
50	Quartz	85%	1.7	rare
	Feldspar	10%	3.6	moderate
	Rock frags.	5%	3.8	
51	Quartz	80%	2.0	minor
	Feldspar	15%	3.5	moderate
	Rock frags.	5%	3.8	
	Micas	T		
56	Quartz	70%	3.0	heavy fr
	Feldspar	10%	3.5	moderate
	Rock frags.	10%		
	Garnet	10%		
60	Quartz	65%	2.0	rare
	Feldspar	30%	3.4	minor to heavy
	Rock frags.	5%	4.0	
	Micas	T		
61	Quartz	40%	1.5	minor
	Feldspar	50%	3.0	minor to heavy
	Rock frags.	6%	3.5	
	Micas	4%	4.0	
K2	Quartz	70%	2.6	moderate
	Feldspar	25%	3.6	heavy
	Rock frags.	5%	4.0	
K3	Quartz	50%	1.5-4.0	fr
	Feldspar	15%	2.7	moderate
	Rock frags.	35%	4.0	heavy

Part III: Fine Fraction $\emptyset = 2.25$ to $\emptyset = 2.50$

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
10	Quartz	75%	1.2	none
	Feldspar	20%	3.5	
	Rock frags.	2%		
	Heavies	3%		
10X	Quartz	60%	2.5	none
	Feldspar	20%	3.0	moderate
	Micas	15%		
	Rock frags.	T		
	Heavies	2%		
11A	Quartz	60%	2.2	none
	Feldspar	15%	3.2	minor to mod.
	Micas	2%		
	Rock frags.	3%		
	Heavies	15%		
16B	Quartz	80%	1.5	none
	Feldspar	15%	2.7	mod. to heavy
	Micas	T		
	Heavies	5%		
	Rock frags.	T		
20	Quartz	90%	1.5	none
	Feldspar	8%	2.8	moderate
	Heavies	2%		
21	Quartz	60%	1.5	fr
	Feldspar	30%	2.5	fr
	Heavies	5%		
	Rock frags.	5%		
31	Quartz	85%	1.5	none
	Feldspar	10%	2.5	moderate
	Heavies	5%		
35	Quartz	85%	1.3	none
	Feldspar	15%	2.5	moderate
	Micas	T		
	Heavies	T		
	Rock frags.	T		
M1	Quartz	40%	3.2	heavy fr
	Feldspar	55%	3.8	heavy fr
	Heavies	2%		
	Rock frags.	3%		

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosted)
41	Quartz	50%	var.	moderate
	Feldspar	30%	var.	moderate
	Rock frags.	20%		
	Heavies	T		
45	Quartz	80%	0.8	none
	Feldspar	20%	3.0	minor
	Rock frags.	T		
B	Quartz	70%	1.0	none
	Feldspar	10%	3.2	minor
	Rock frags.	T		
	Heavies	20%		
50	Quartz	68%	1.0	none
	Feldspar	15%	3.0	rare
	Micas	2%	4.0	
	Rock frags.	T		
	Heavies	15%		
51	Quartz	35%	2.0	none
	Feldspar	25%	3.0	fr
	Rock frags.	T		
	Heavies	40%		
56	Quartz	40%	1.3	none
	Feldspar	30%	3.0	minor to mod.
	Rock frags.	5%		
	Heavies	25%		
60	Quartz	40%	1.0	none
	Feldspar	35%	2.5	moderate
	Rock frags.	1%		
	Heavies	25%		
61	Quartz	60%	2.0	none
	Feldspar	30%	2.8	minor to mod.
	Rock frags.	1%		
	Heavies	9%		
K2	Quartz	75%	2.2	none
	Feldspar	13%	3.2	fr
	Micas	T		
	Rock frags.	2%		
	Heavies	10%		

Sample Number	Mineralogy		Roundness (Powers)	Staining (fr=frosting)
	Quartz	60%	2.8	heavy fr
K3	Feldspar	30%	3.4	heavy fr
	Rock frags.	2%		
	Heavies	8%		

APPENDIX D: HEAVY MINERAL ANALYSIS

SAMPLE NUMBER	Weight % heavies in sample (uncorrected)	Weight % heavies in sample (corrected)*	Ilmenite	Magnetite	Garnet	Epidote	Hornblende	Tourmaline	Biotite	Muscovite	Rock frags.
10	2.8%	2.2%	15%	T	25%	2%	25%	3%	5%	T	25%
10X	16.3%	16.2%	25%	T	60%	2%	8%	1%	-	-	1%
11A	6.4%	6.4%	18%	-	30%	8%	25%	6%	6%	6%	-
16B	6.3%	5.3%	10%	1%	65%	2%	5%	1%	-	-	15%
20	2.3%	1.0%	15%	-	10%	2%	10%	1%	T	-	60%
21	3.1%	3.0%	20%	T	30%	10%	25%	5%	4%	1%	5%
31	1.5%	1.1%	10%	T	30%	6%	25%	5%	5%	-	20%
35	17.0%	11.4%	3%	T	65%	-	T	1%	-	-	30%
M1	5.0%	4.9%	25%	T	35%	5%	25%	5%	2%	-	3%
41	0.9%	0.6%	5%	T	45%	3%	10%	3%	3%	1%	30%
45	3.6%	3.6%	25%	T	20%	10%	30%	10%	5%	T	-
B	4.1%	1.7%	5%	-	25%	T	-	10%	-	-	60%
50	1.0%	0.5%	8%	-	30%	T	3%	5%	5%	1%	50%
51	2.7%	2.7%	10%	-	35%	15%	20%	3%	3%	1%	15%
56	7.3%	4.4%	8%	1%	50%	-	T	-	-	-	40%
60	0.7%	0.5%	10%	-	30%	3%	25%	5%	3%	-	25%
61	8.5%	8.5%	25%	T	40%	8%	20%	5%	3%	1%	-
K2	3.5%	3.4%	25%	1%	50%	3%	10%	6%	-	-	5%
K3	2.4%	1.9%	20%	T	25%	1%	30%	5%	-	-	20%

Mineralogy of heavy fraction: columns Ilmenite through Rock frags.

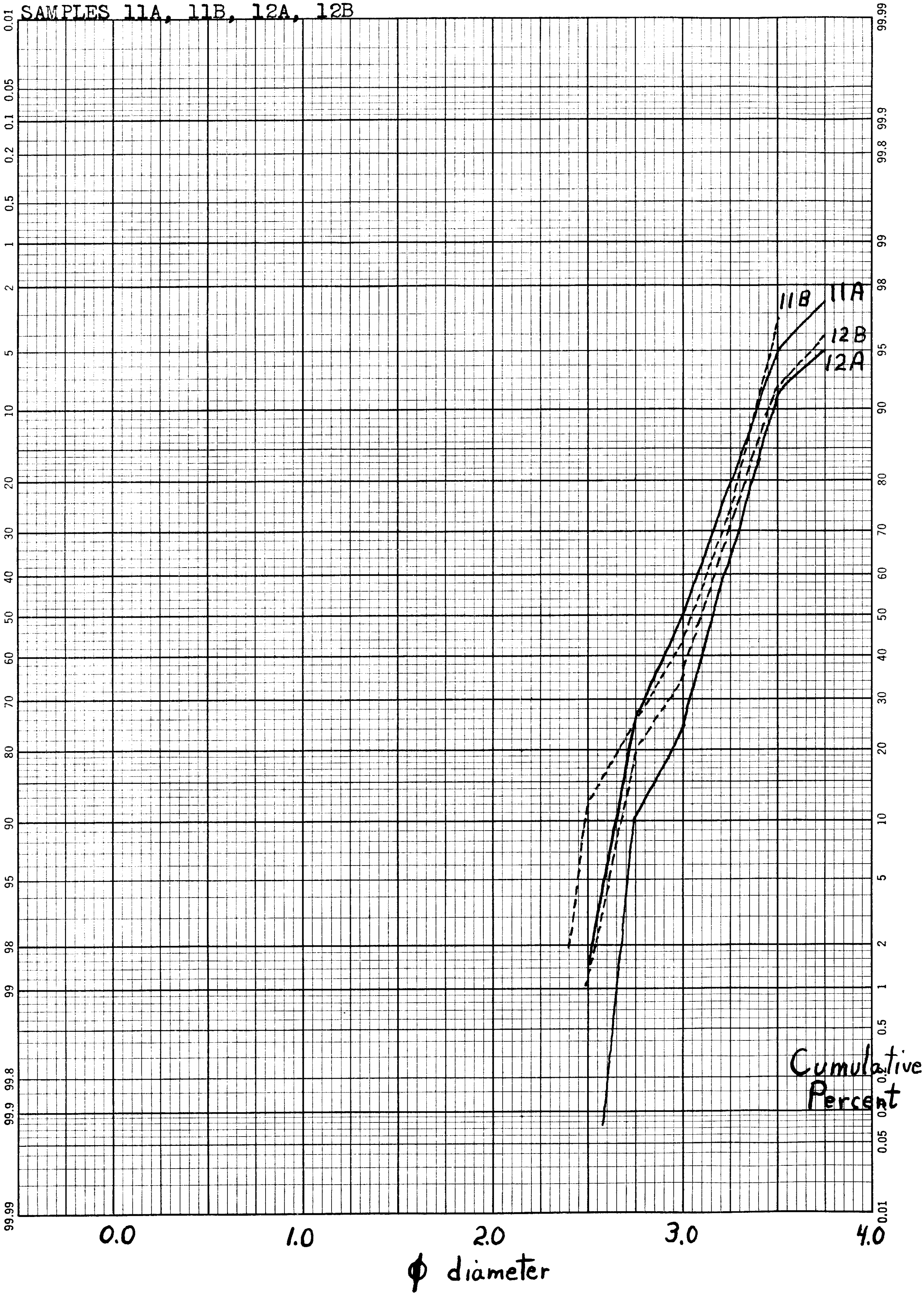
* Exclusive of rock fragments

A P P E N D I X   E :

C U M U L A T I V E   C U R V E S

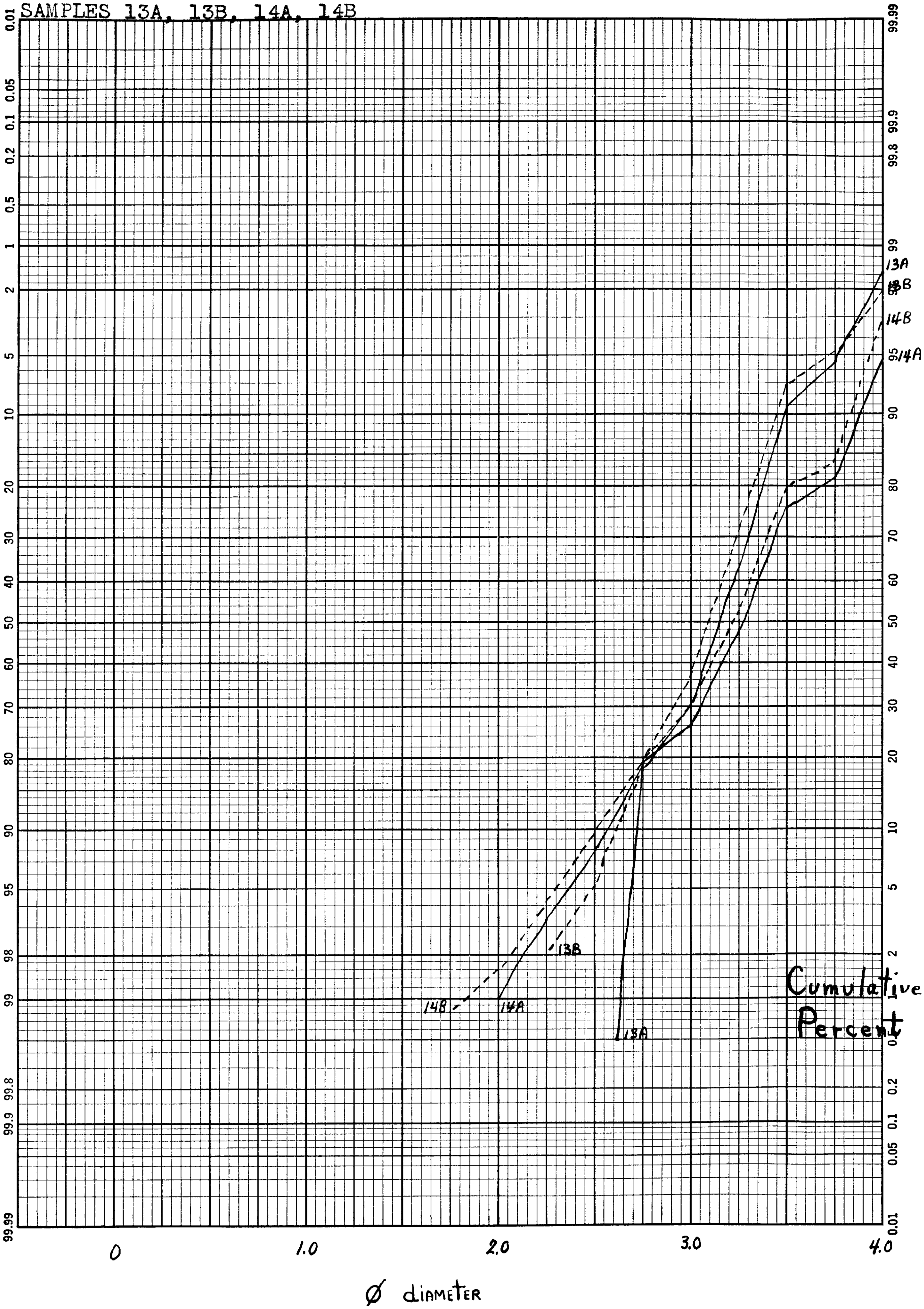
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 11A, 11B, 12A, 12B



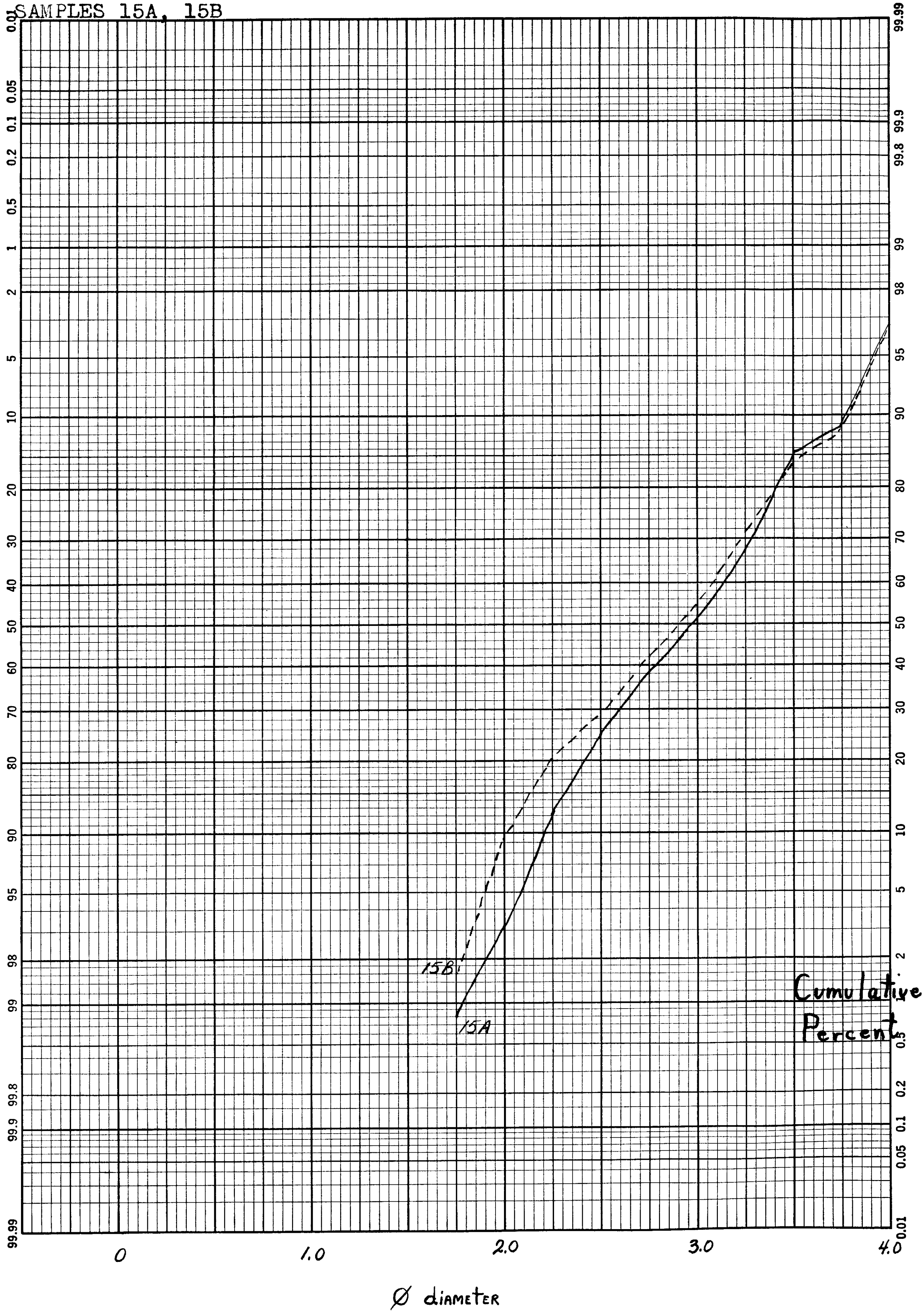
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 13A, 13B, 14A, 14B



CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 15A, 15B



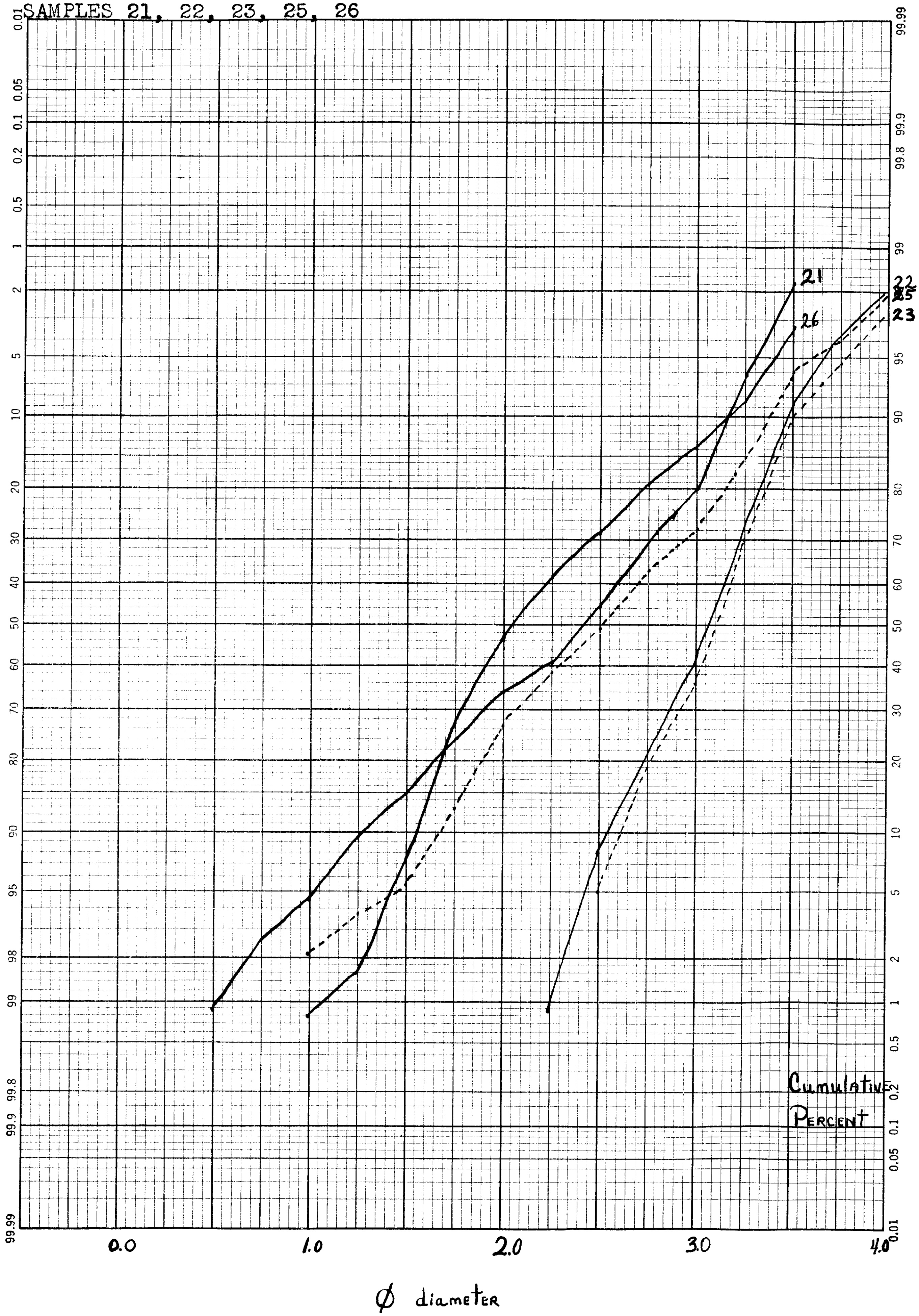
CUMULATIVE CURVES

SETTLING TUBE ANALYSES

SAMPLES 16A, 16B

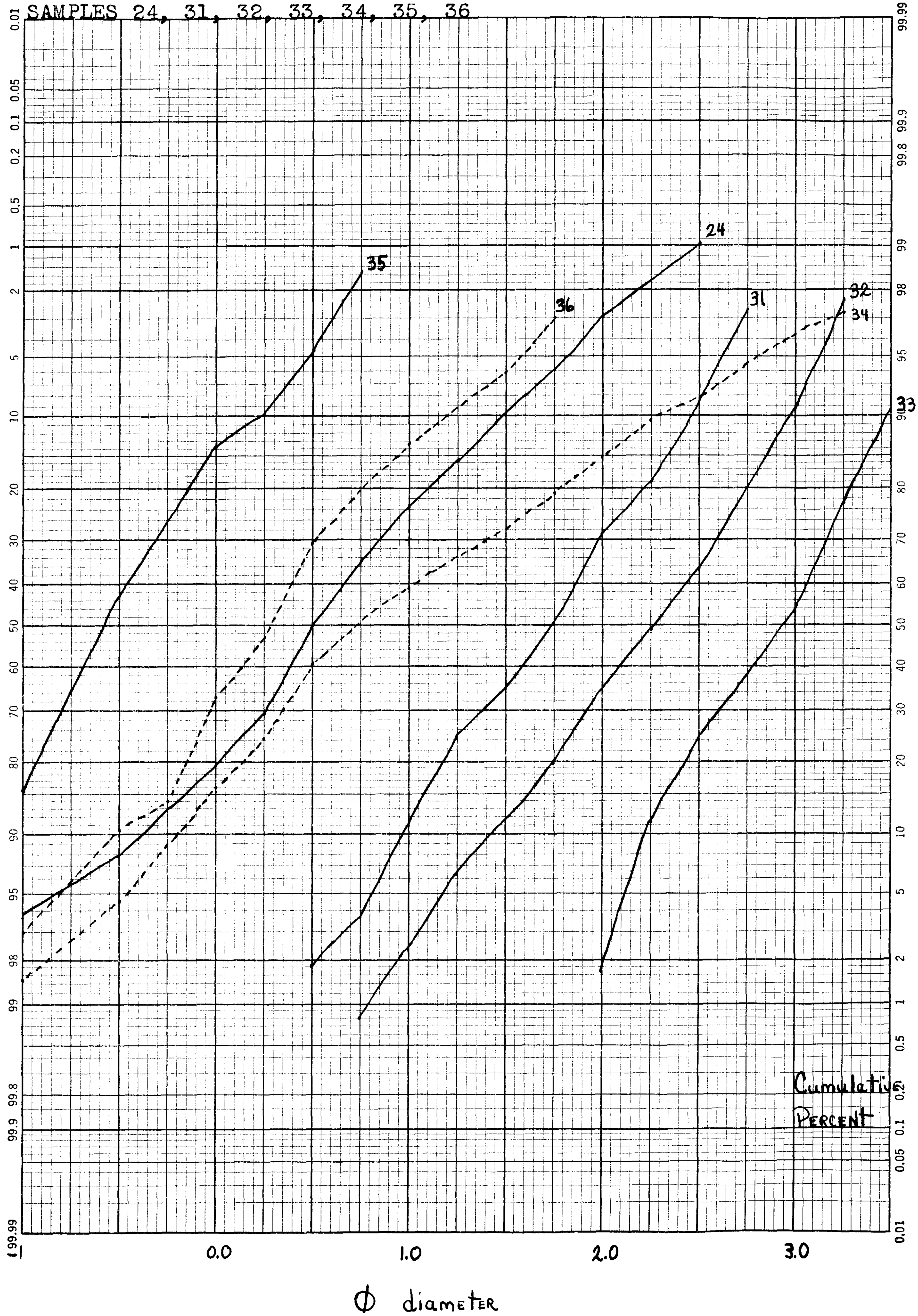
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 21, 22, 23, 25, 26



CUMULATIVE CURVES SETTLING TUBE ANALYSES

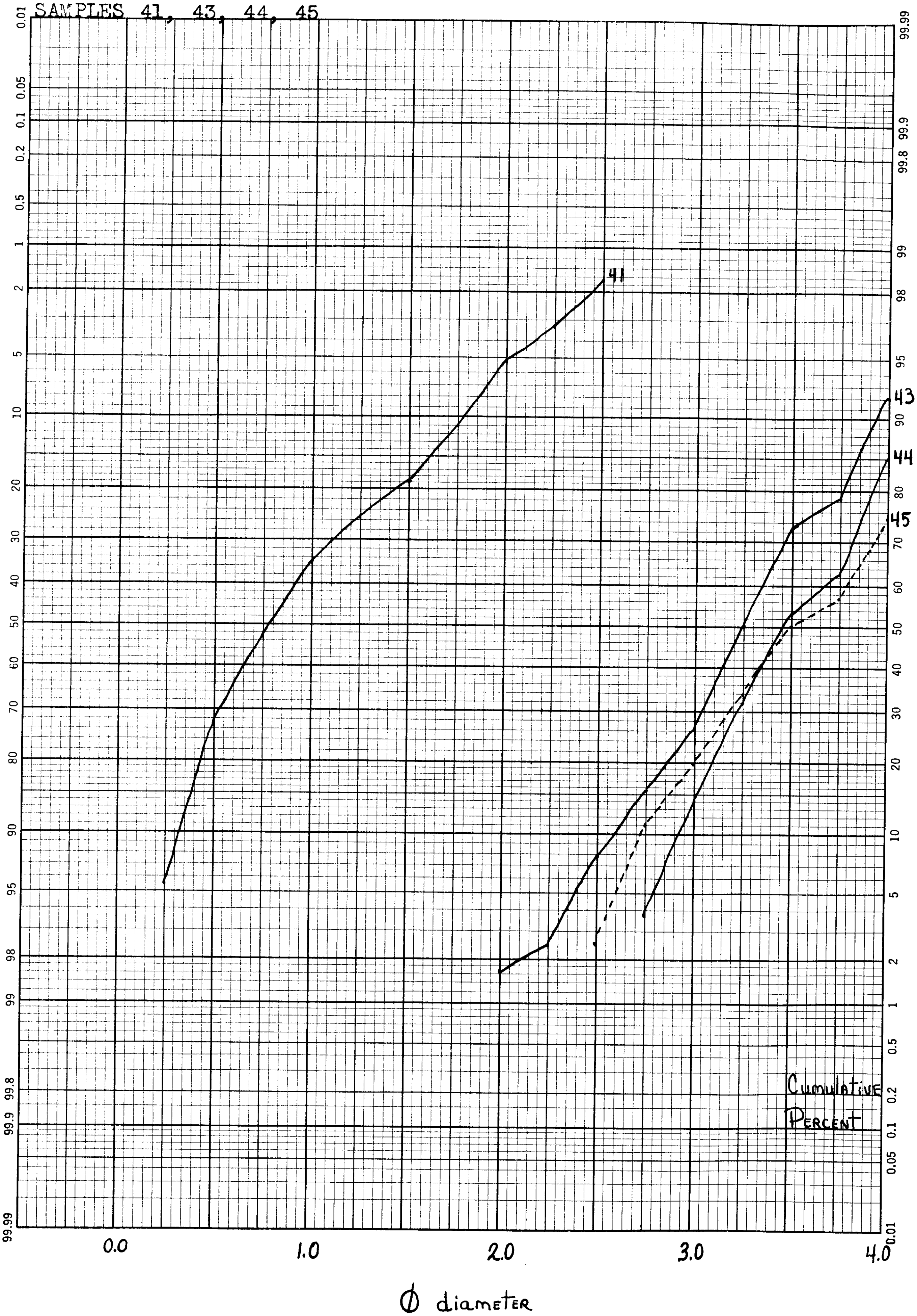
SAMPLES 24, 31, 32, 33, 34, 35, 36



CUMULATIVE CURVES

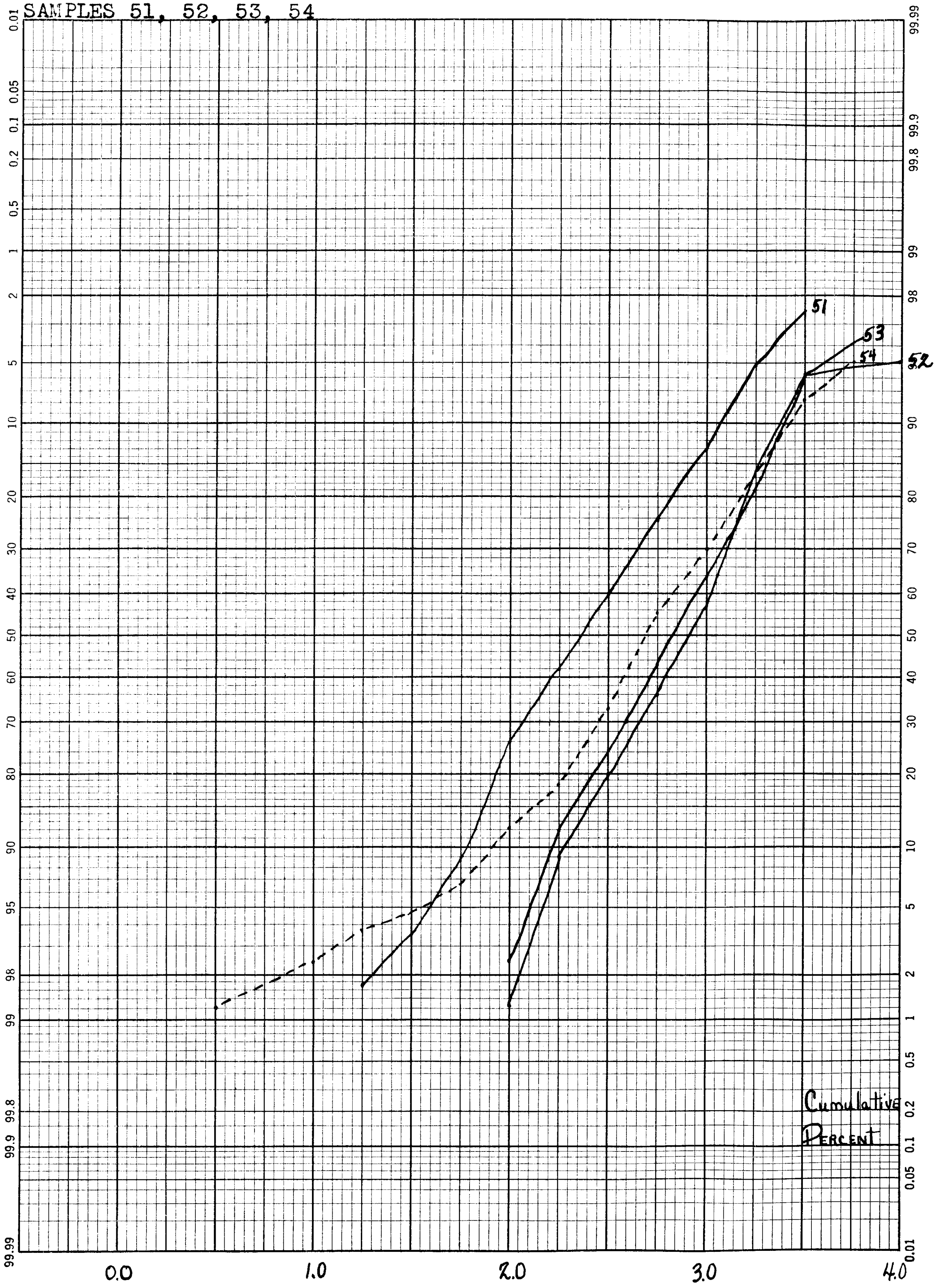
SETTLING TUBE ANALYSES

SAMPLES 41, 43, 44, 45



CUMULATIVE CURVES SETTLING TUBE ANALYSES

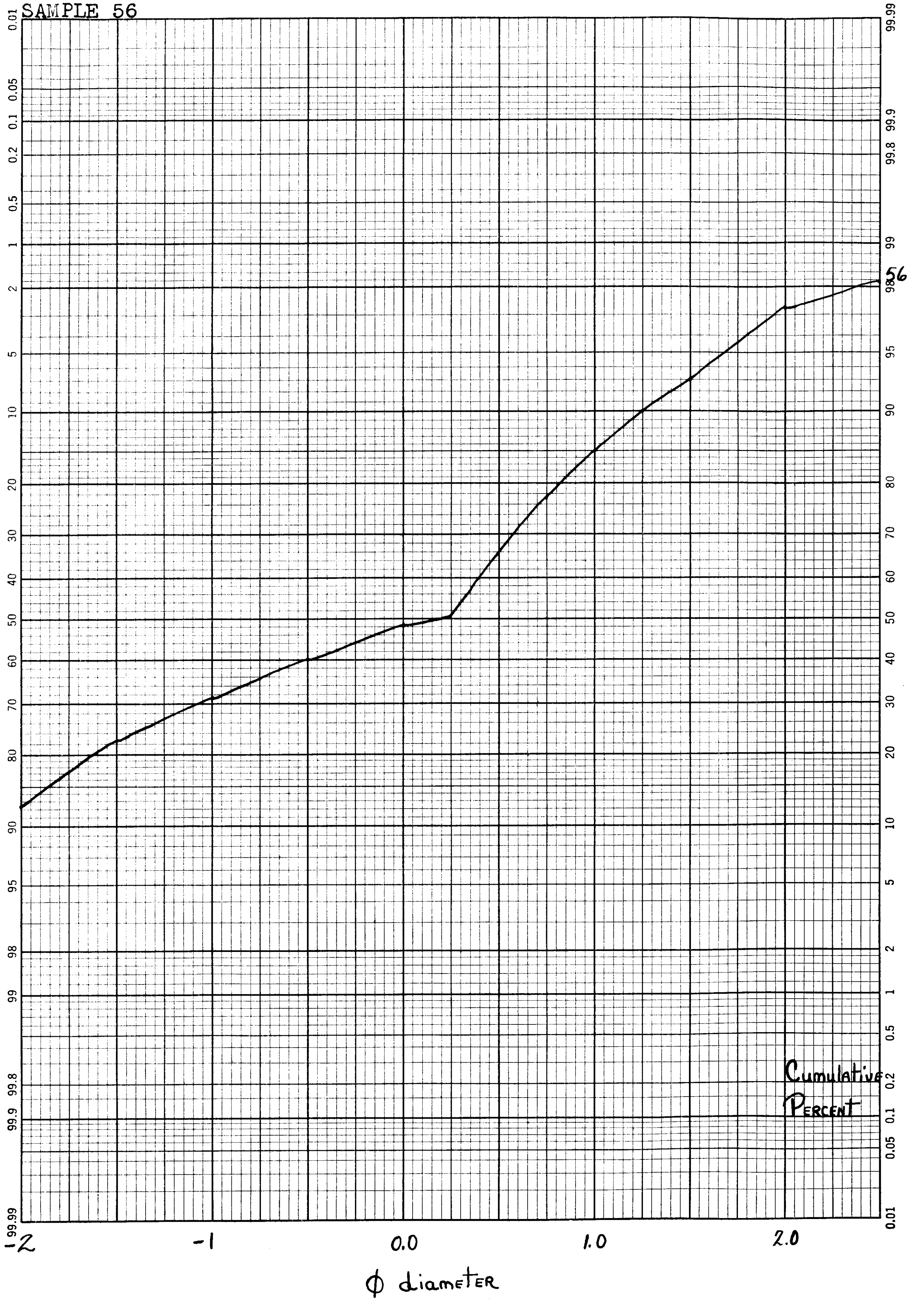
SAMPLES 51, 52, 53, 54



ϕ diameter

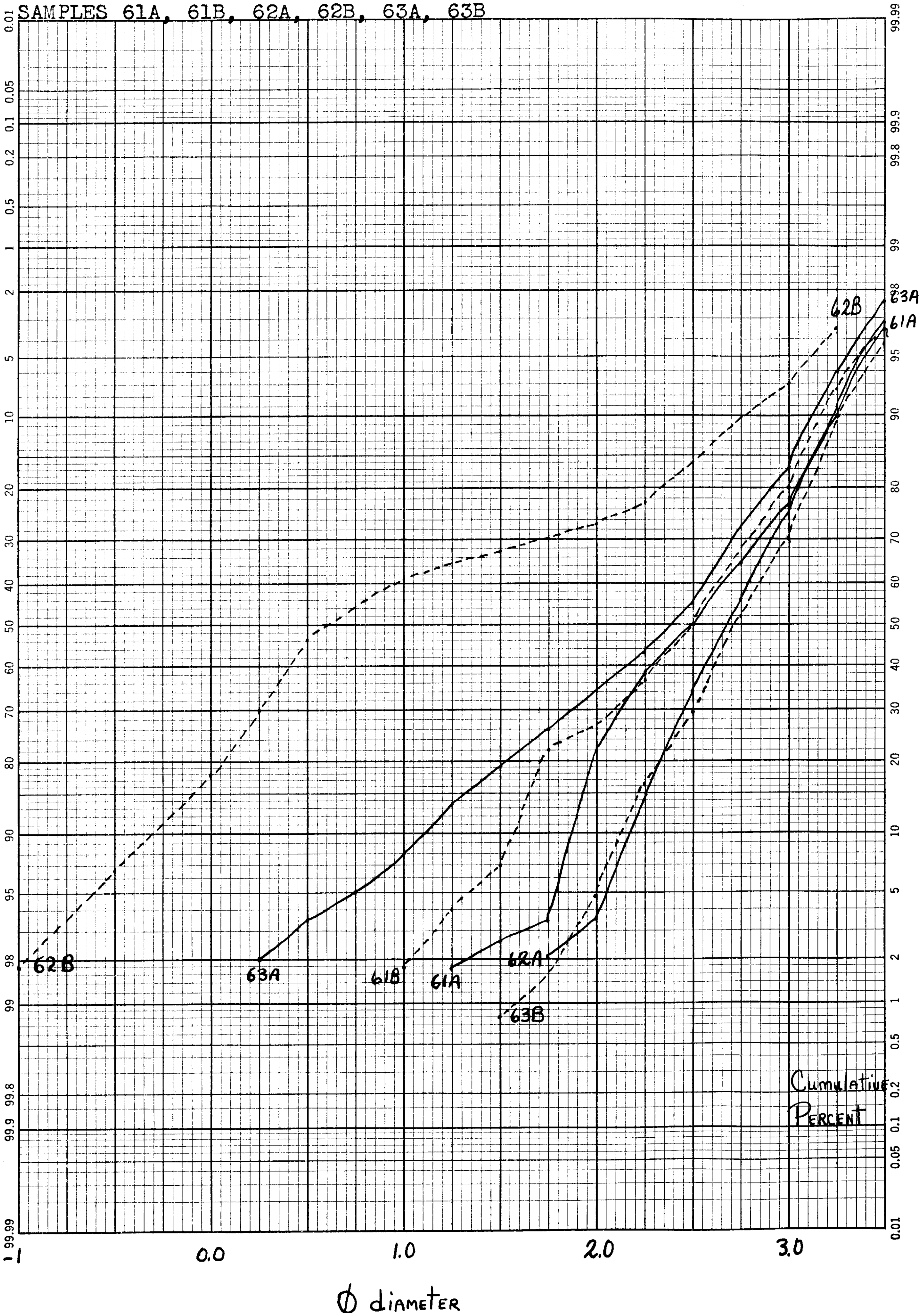
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLE 56



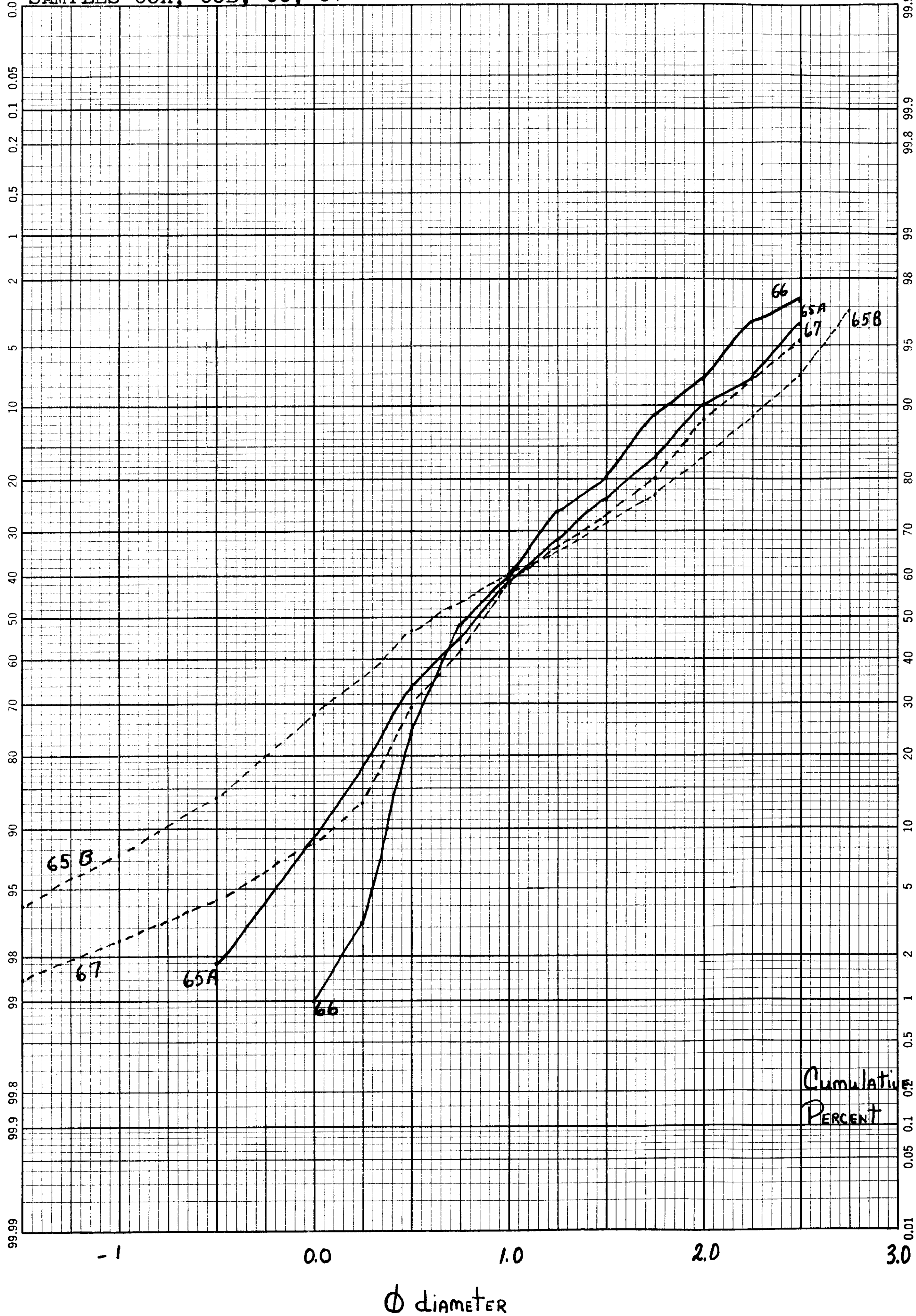
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 61A, 61B, 62A, 62B, 63A, 63B



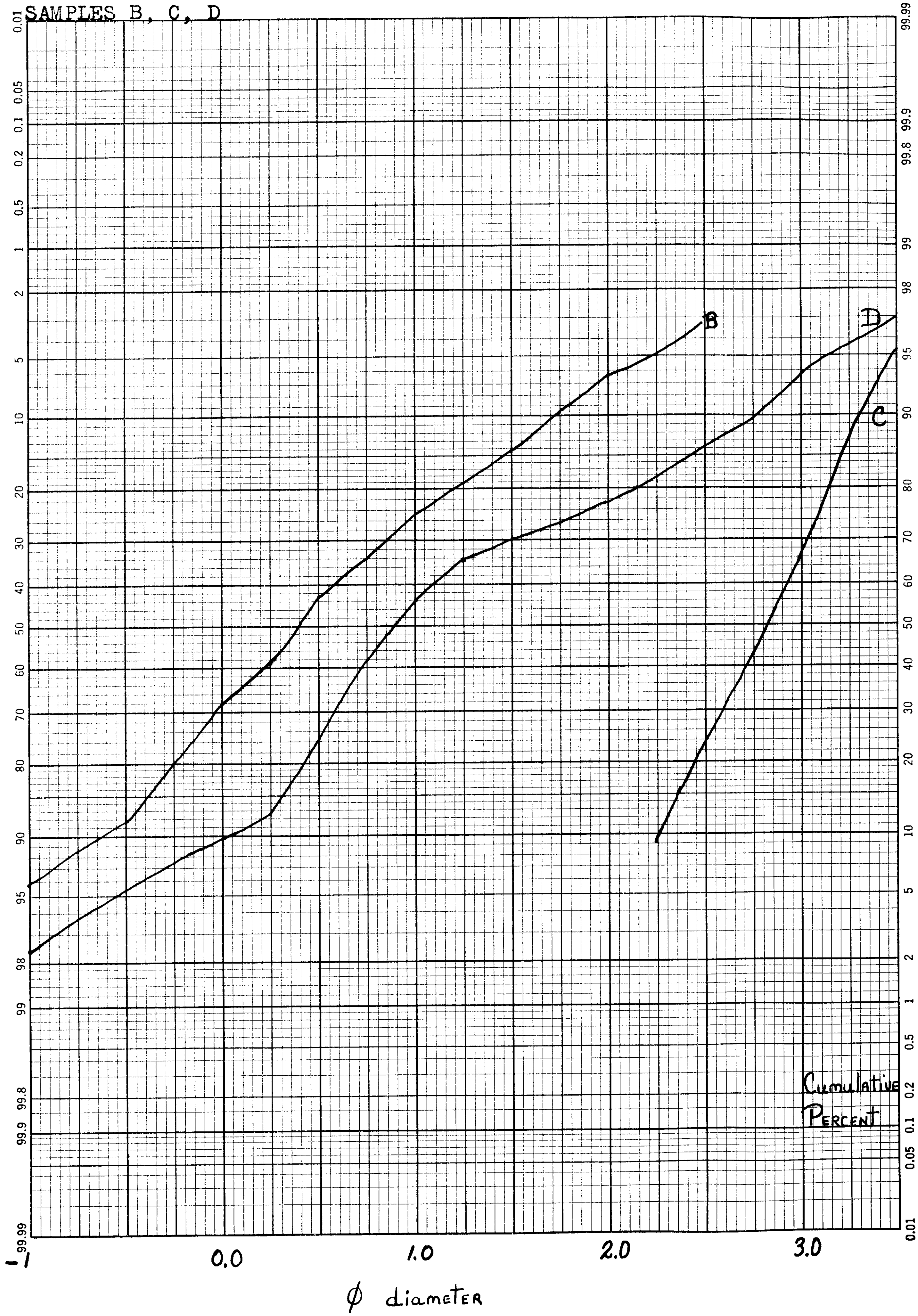
CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES 65A, 65B, 66, 67

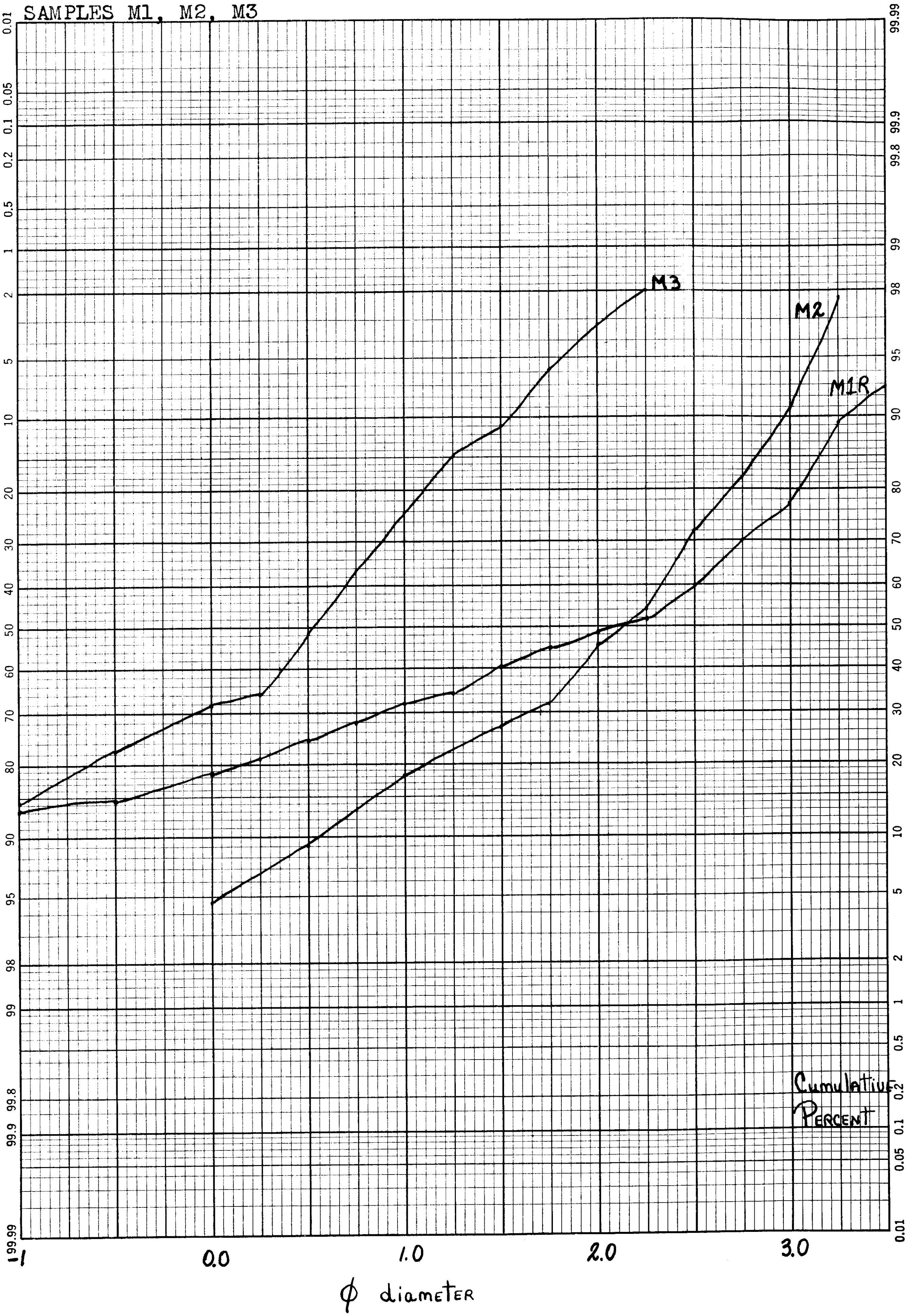


CUMULATIVE CURVES SETTLING TUBE ANALYSES

SAMPLES B, C, D

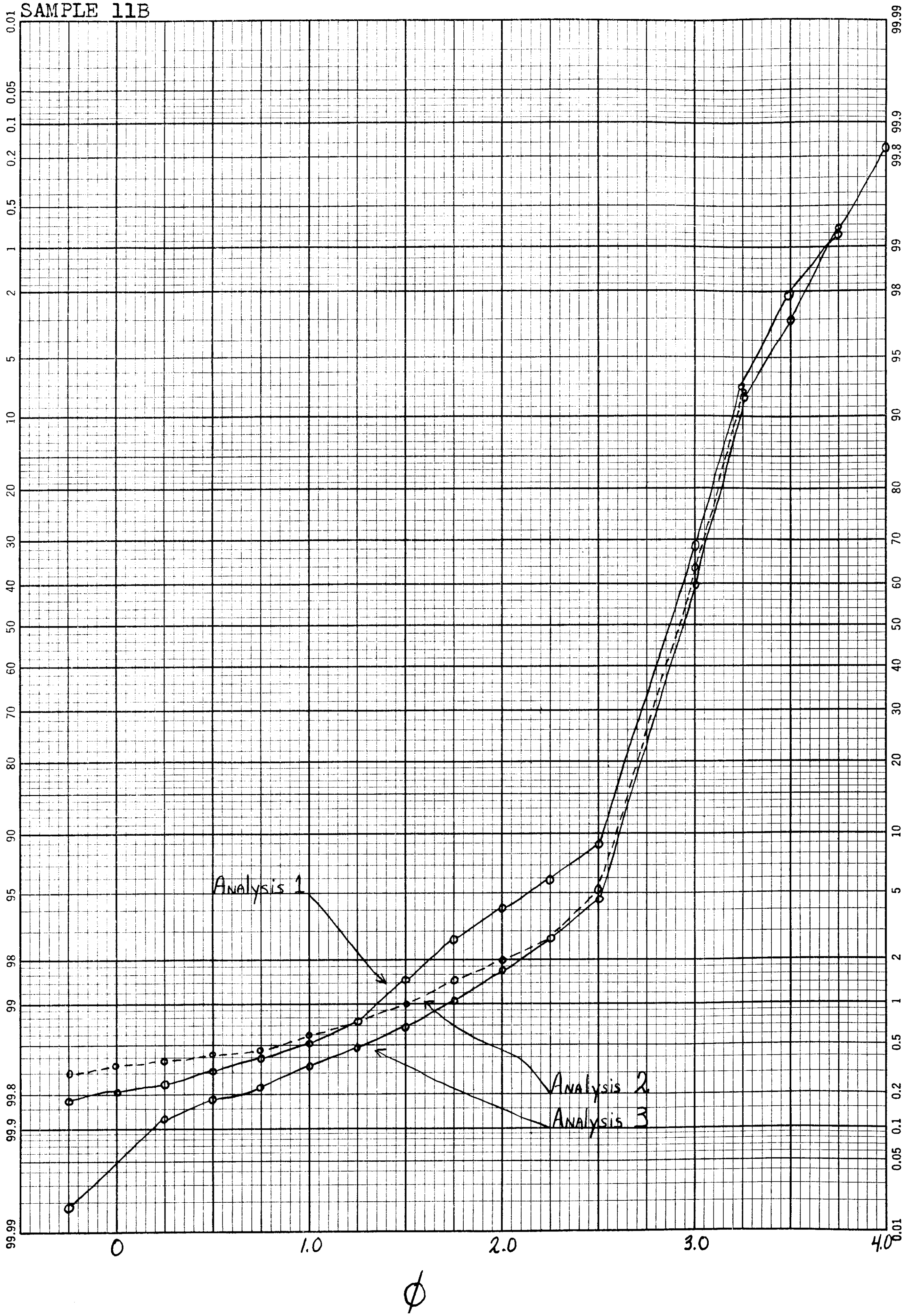


CUMULATIVE CURVES SETTLING TUBE ANALYSES



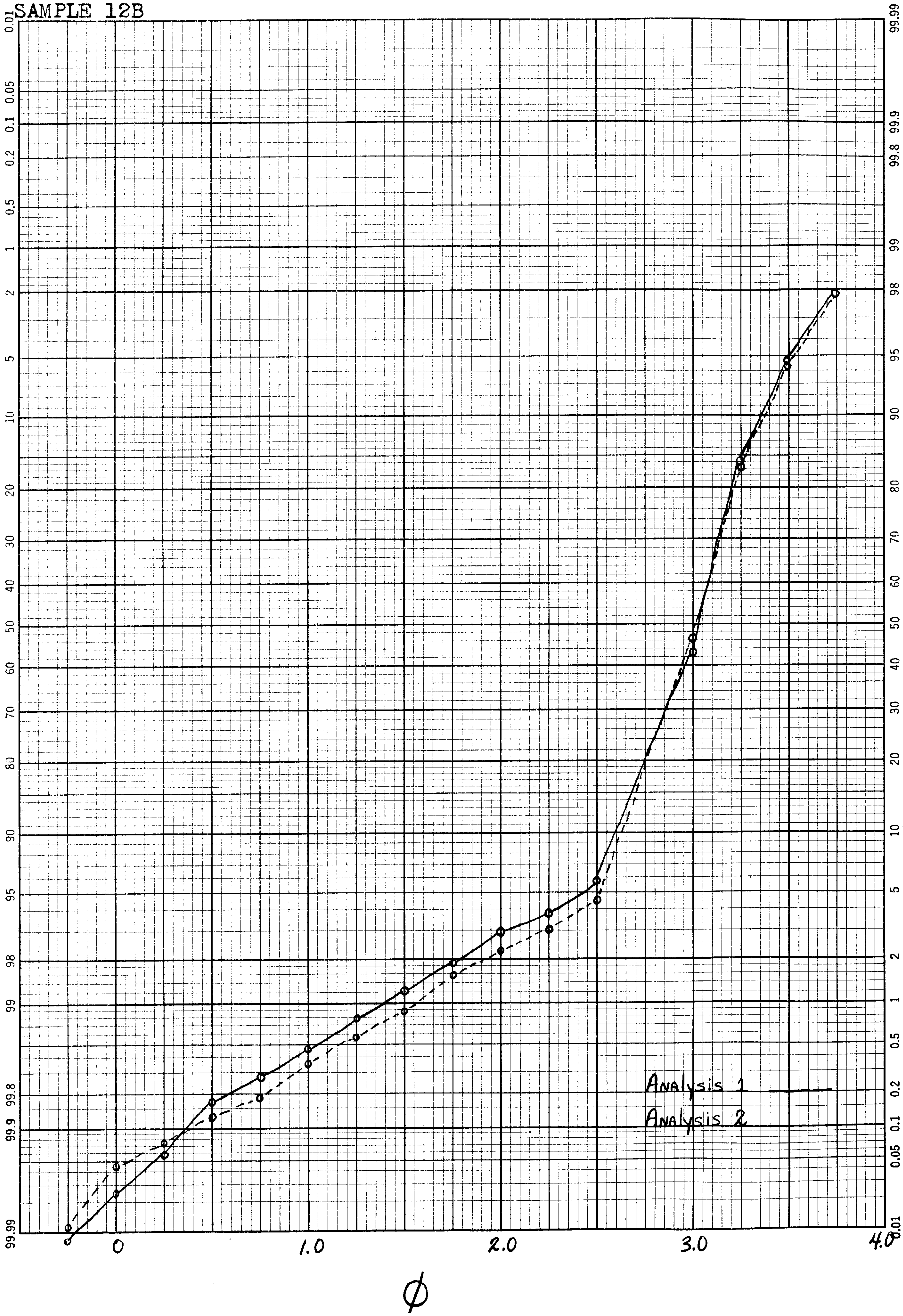
CUMULATIVE CURVES SIEVE ANALYSES

SAMPLE 11B



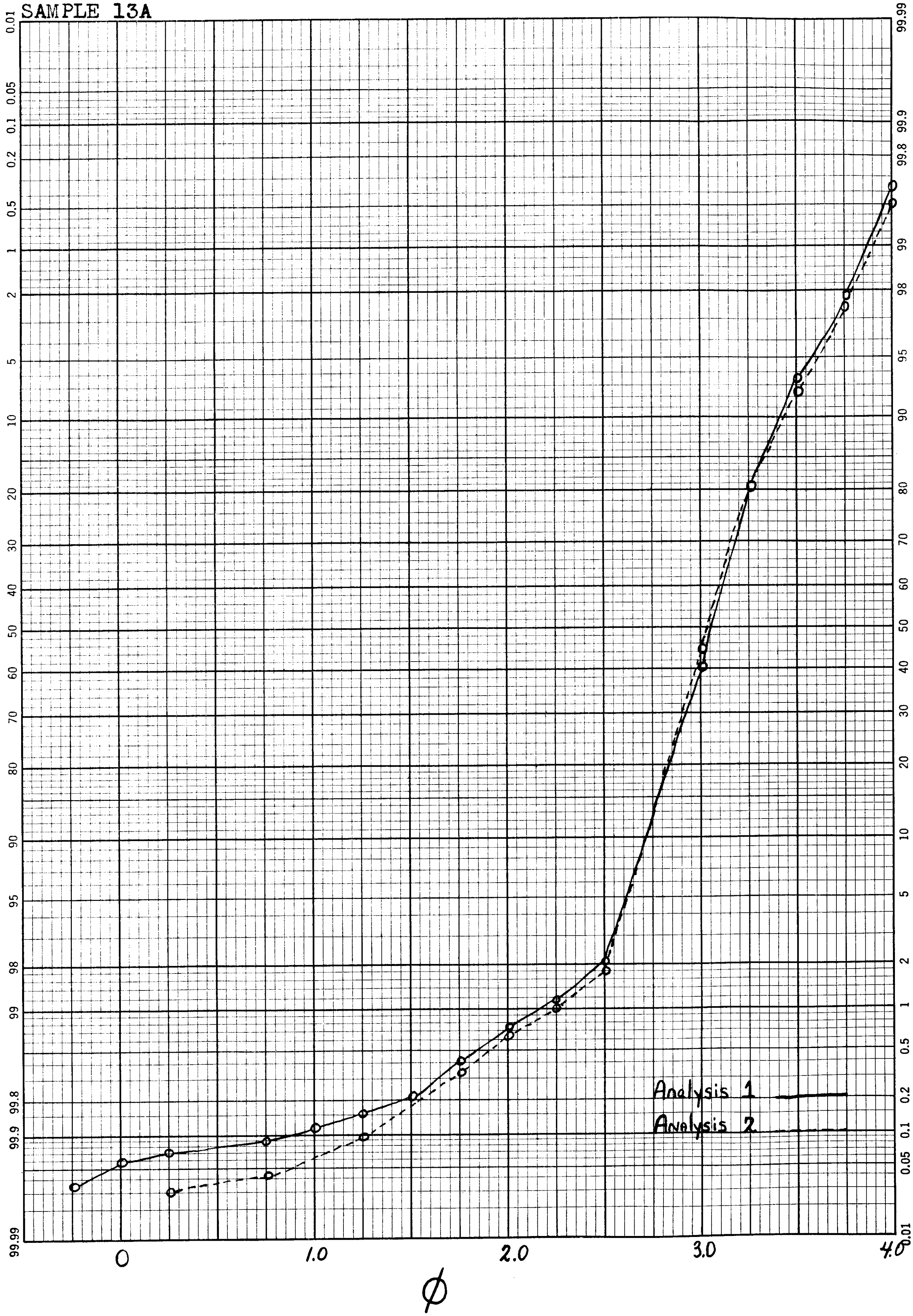
CUMULATIVE CURVES SIEVE ANALYSES

SAMPLE 12B



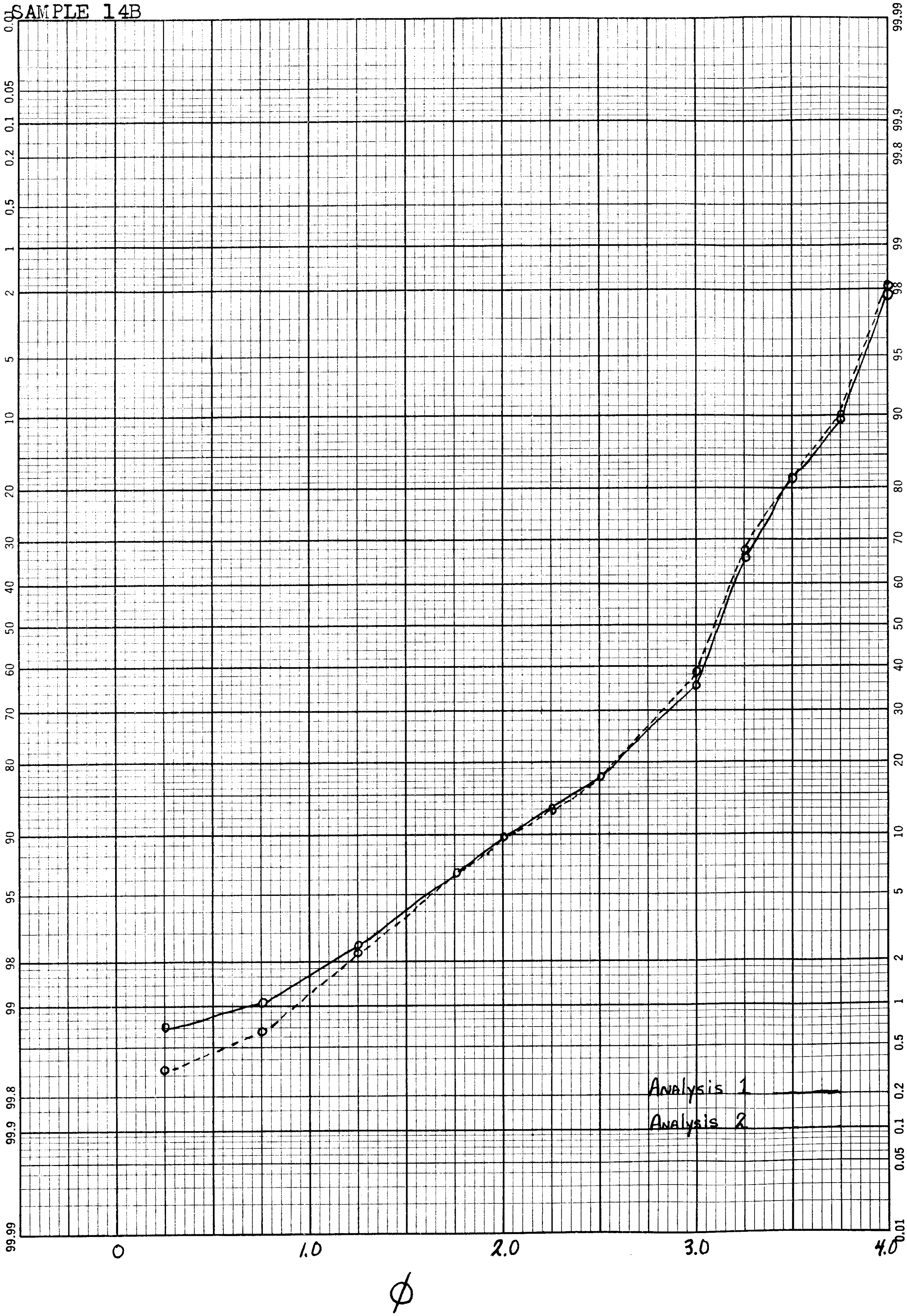
CUMULATIVE CURVES SIEVE ANALYSES

SAMPLE 13A

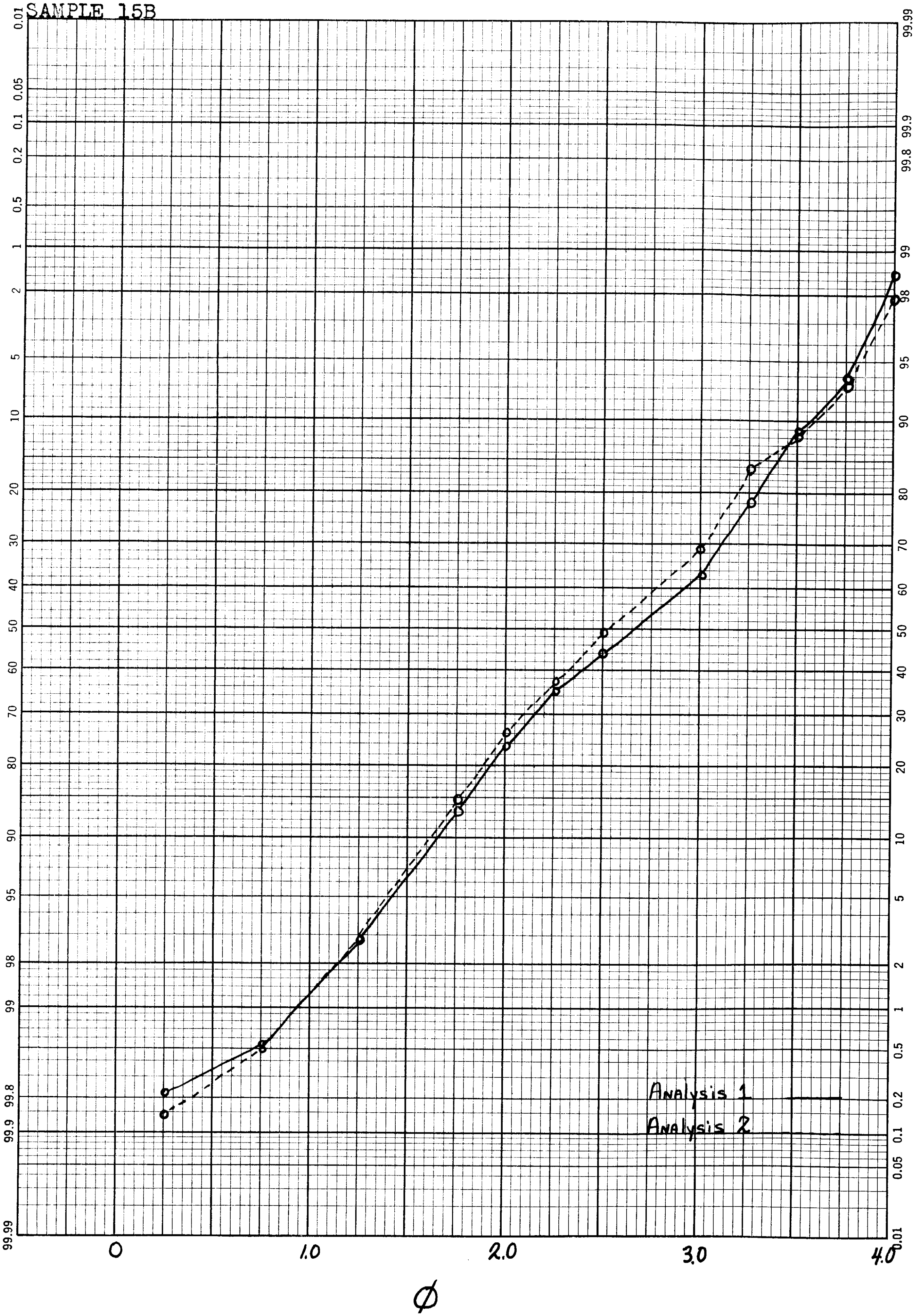


CUMULATIVE CURVES SIEVE ANALYSES

SAMPLE 14B

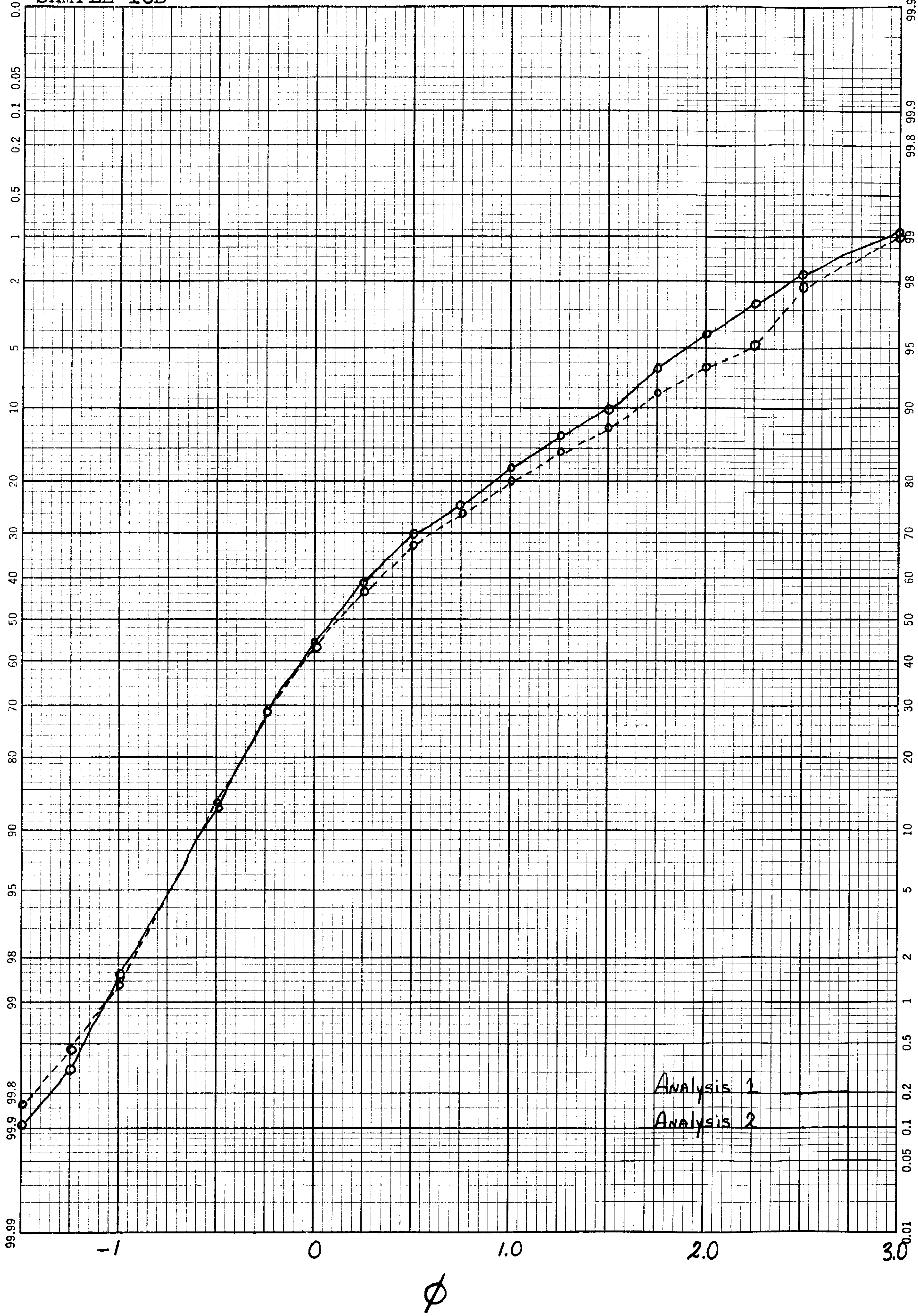


CUMULATIVE CURVES SIEVE ANALYSES



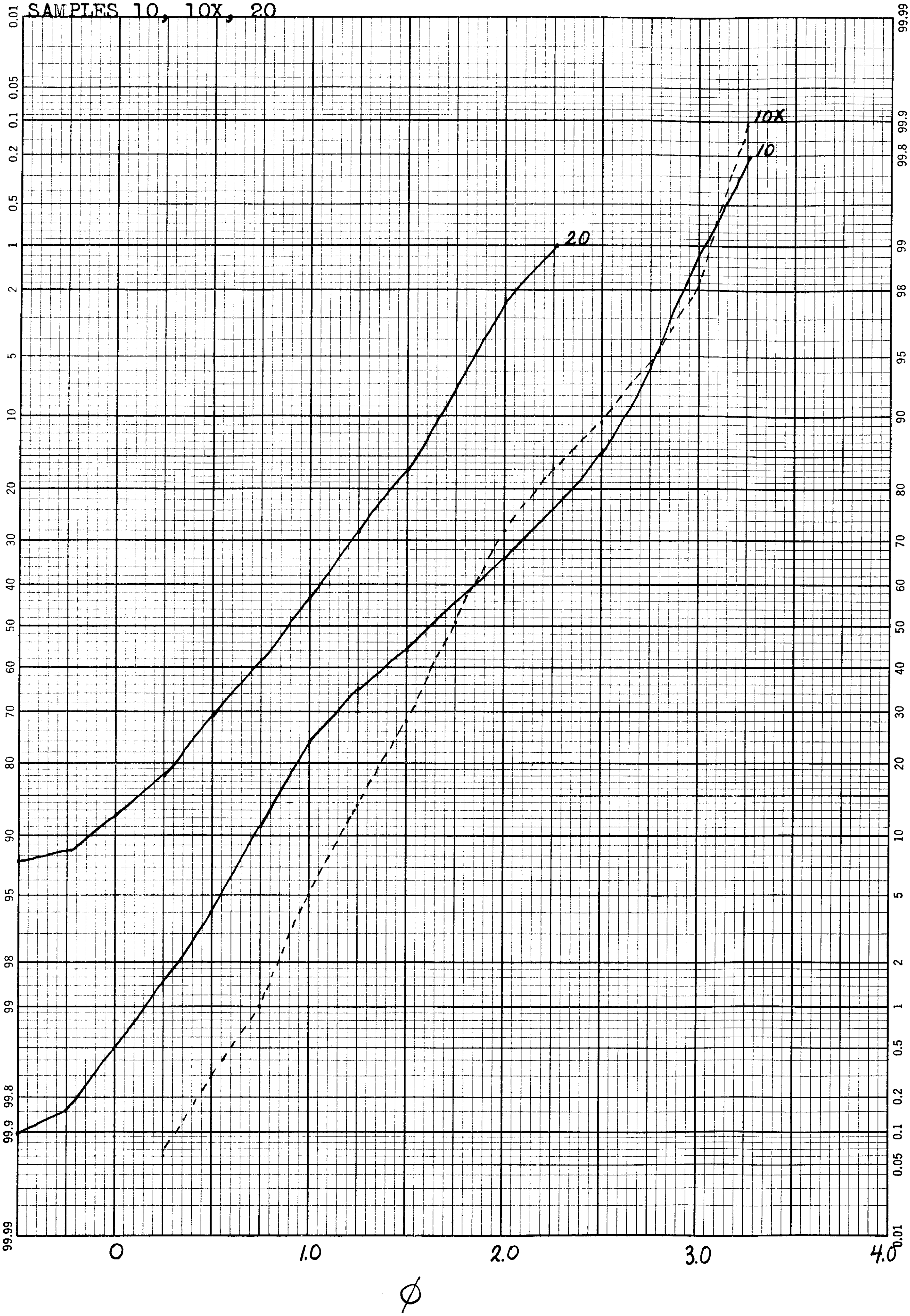
CUMULATIVE CURVES SIEVE ANALYSES

SAMPLE 16B



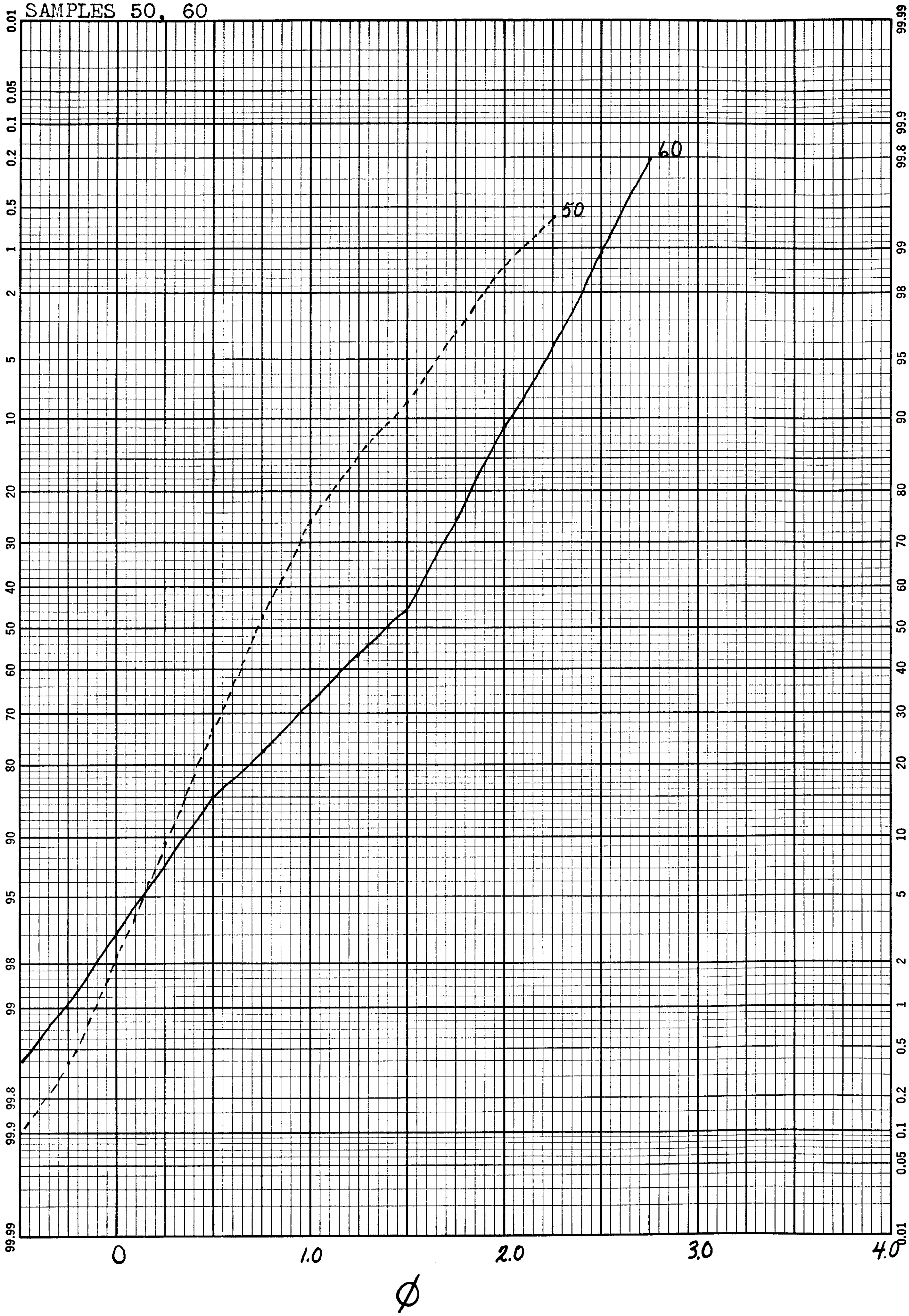
CUMULATIVE CURVES SIEVE ANALYSES

SAMPLES 10, 10X, 20



CUMULATIVE CURVES SIEVE ANALYSES

SAMPLES 50, 60

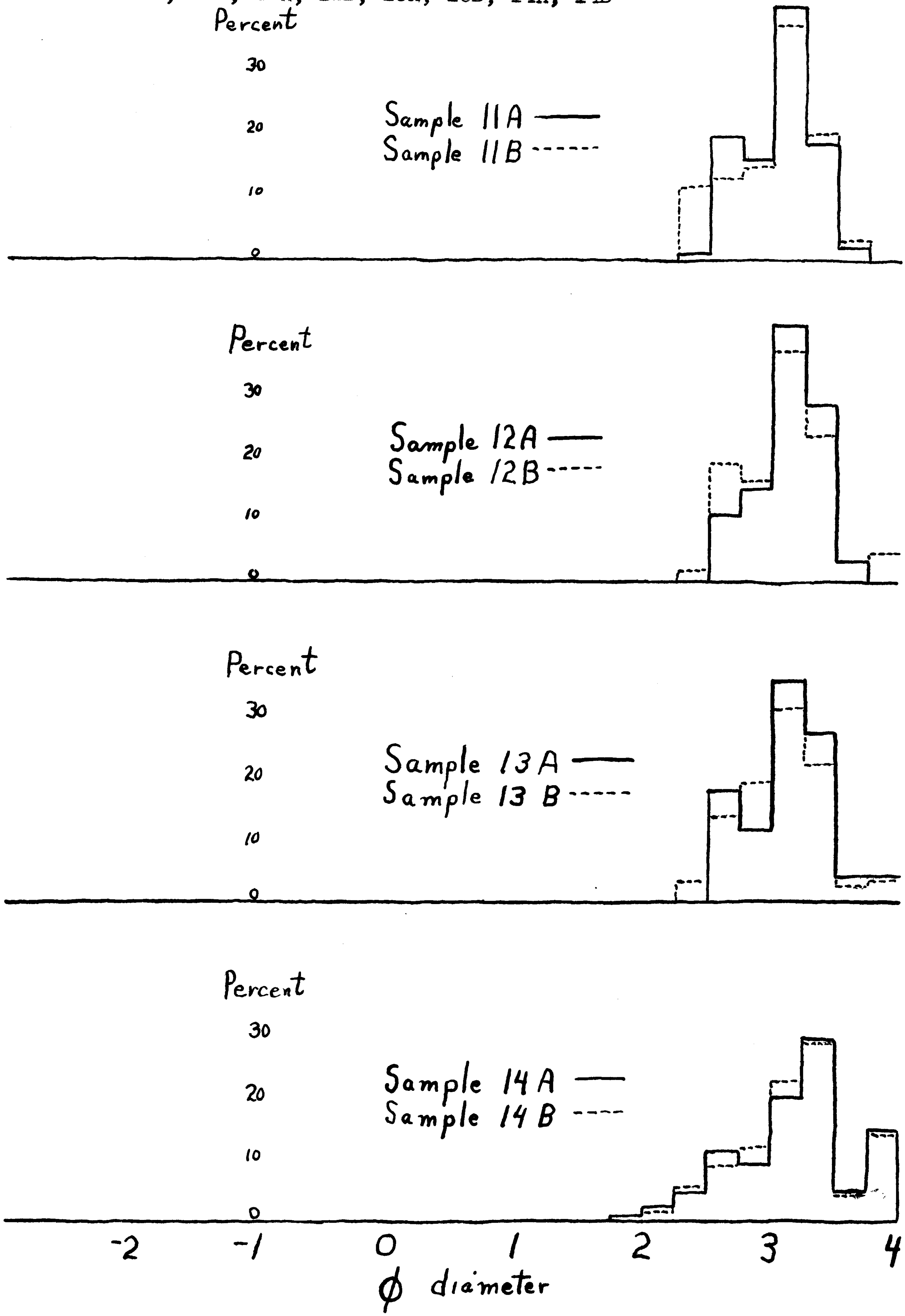


A P P E N D I X   F :

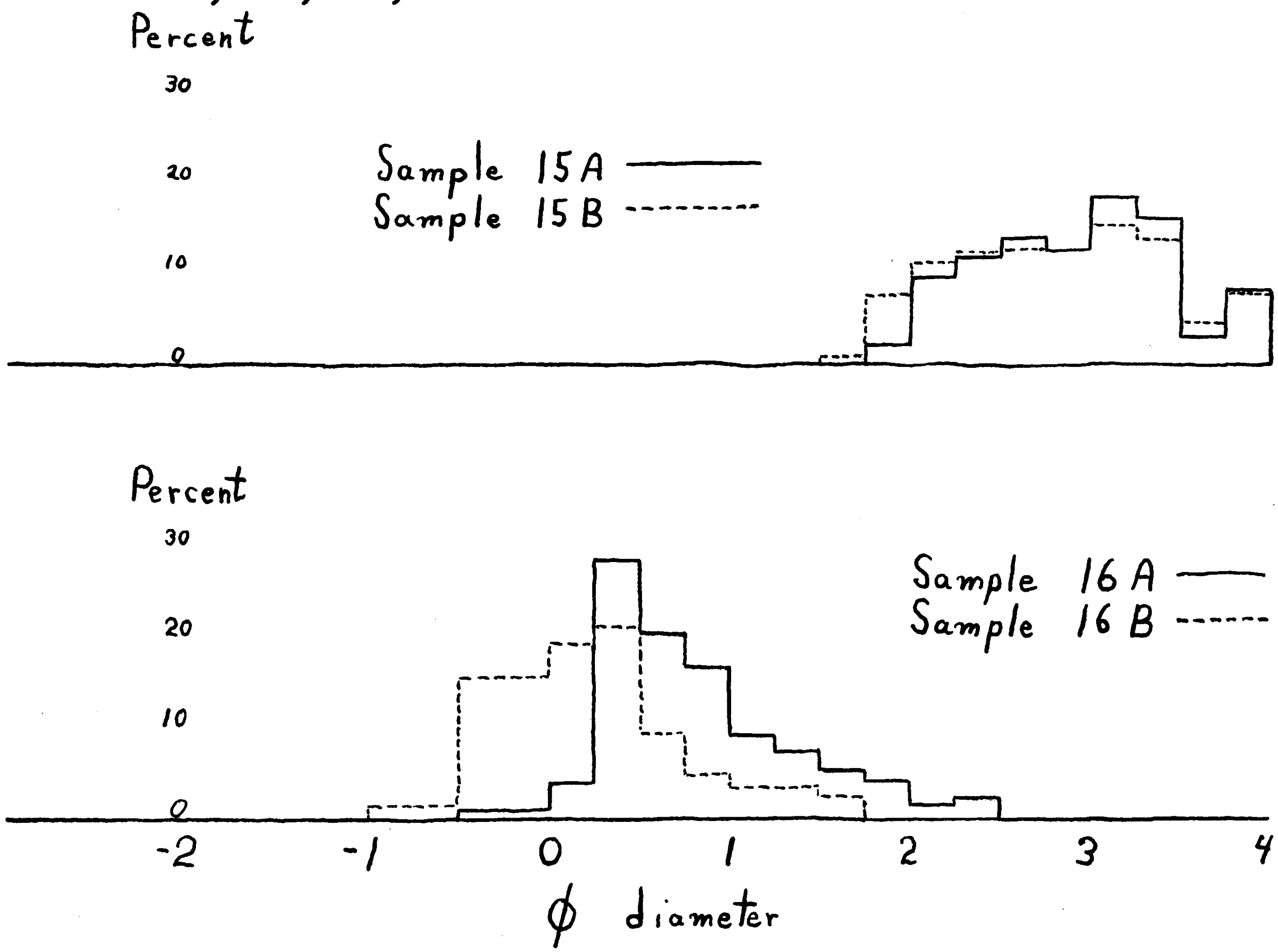
H I S T O G R A M S

HISTOGRAMS SETTLING TUBE ANALYSES

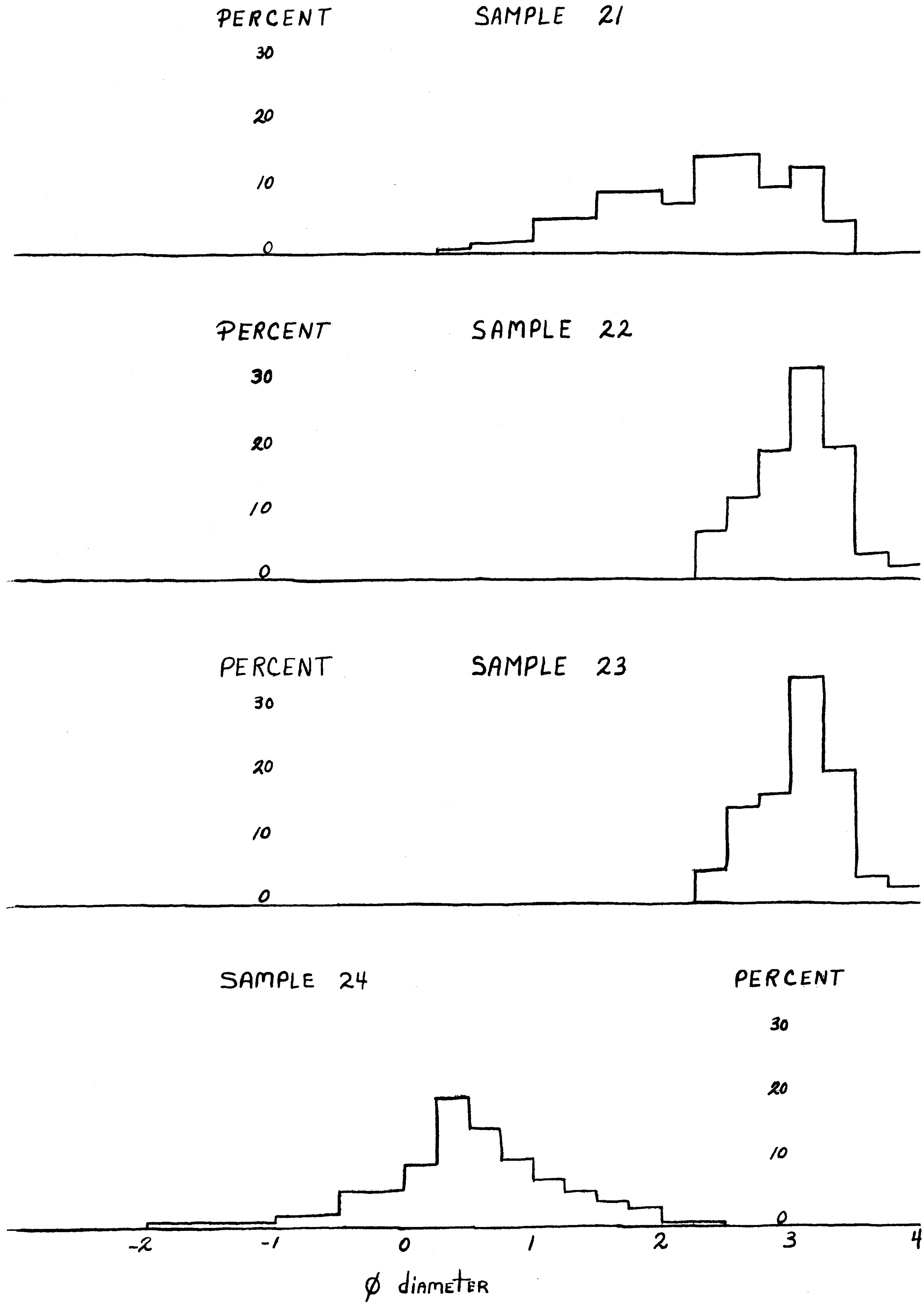
SAMPLES 11A, 11B, 12A, 12B, 13A, 13B, 14A, 14B

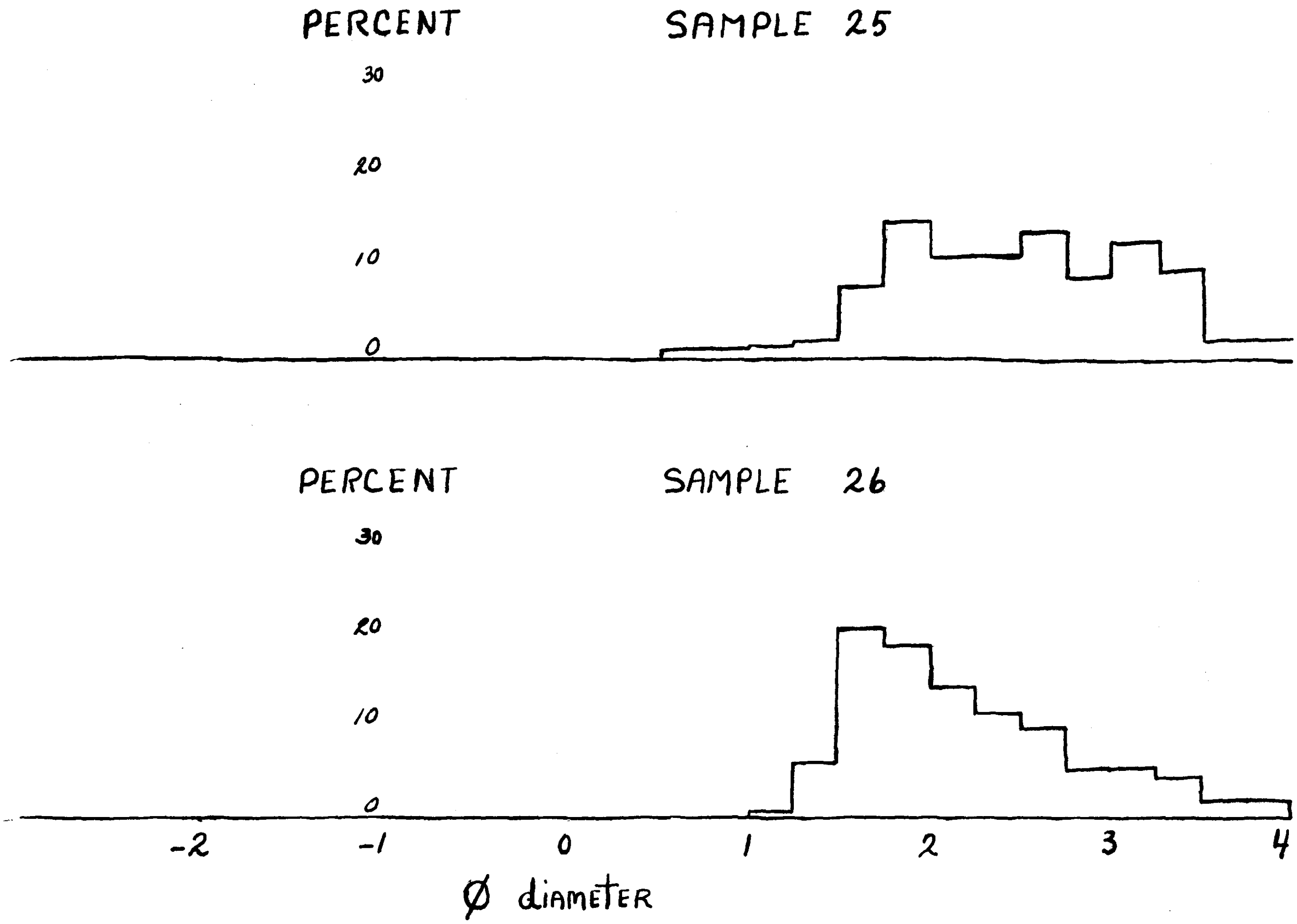


SAMPLES 15A, 15B, 16A, 16B

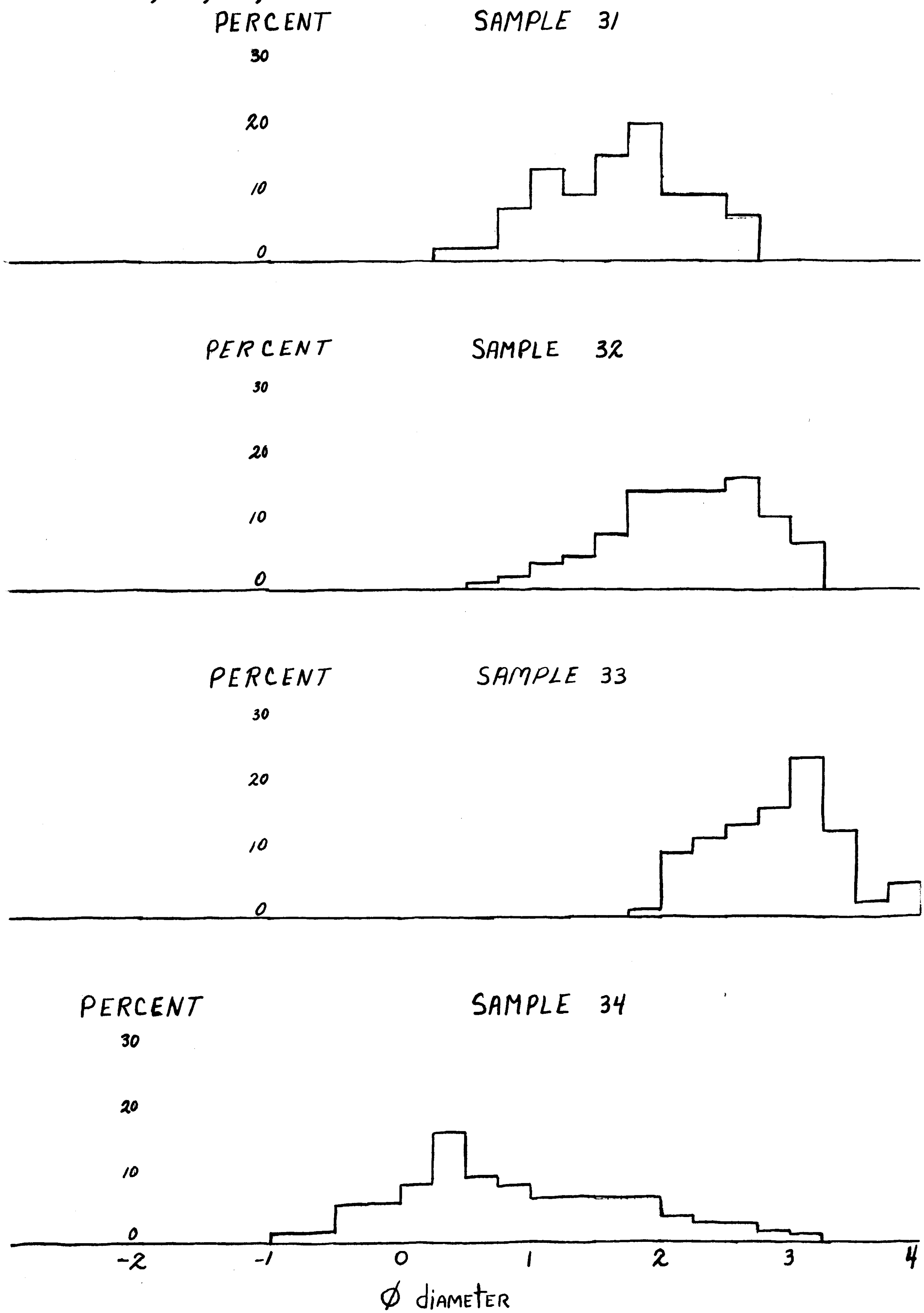


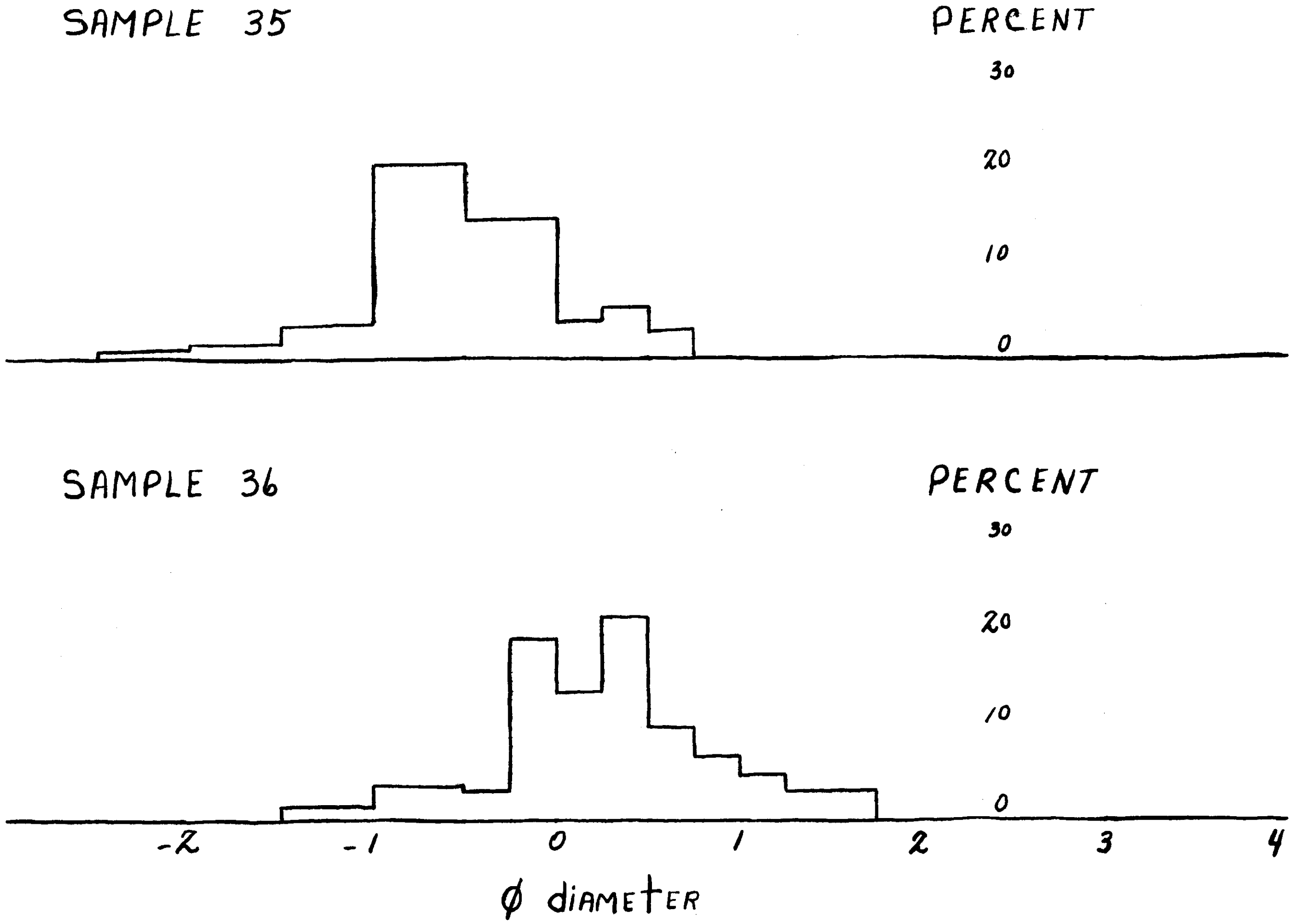
SAMPLES 21, 22, 23, 24



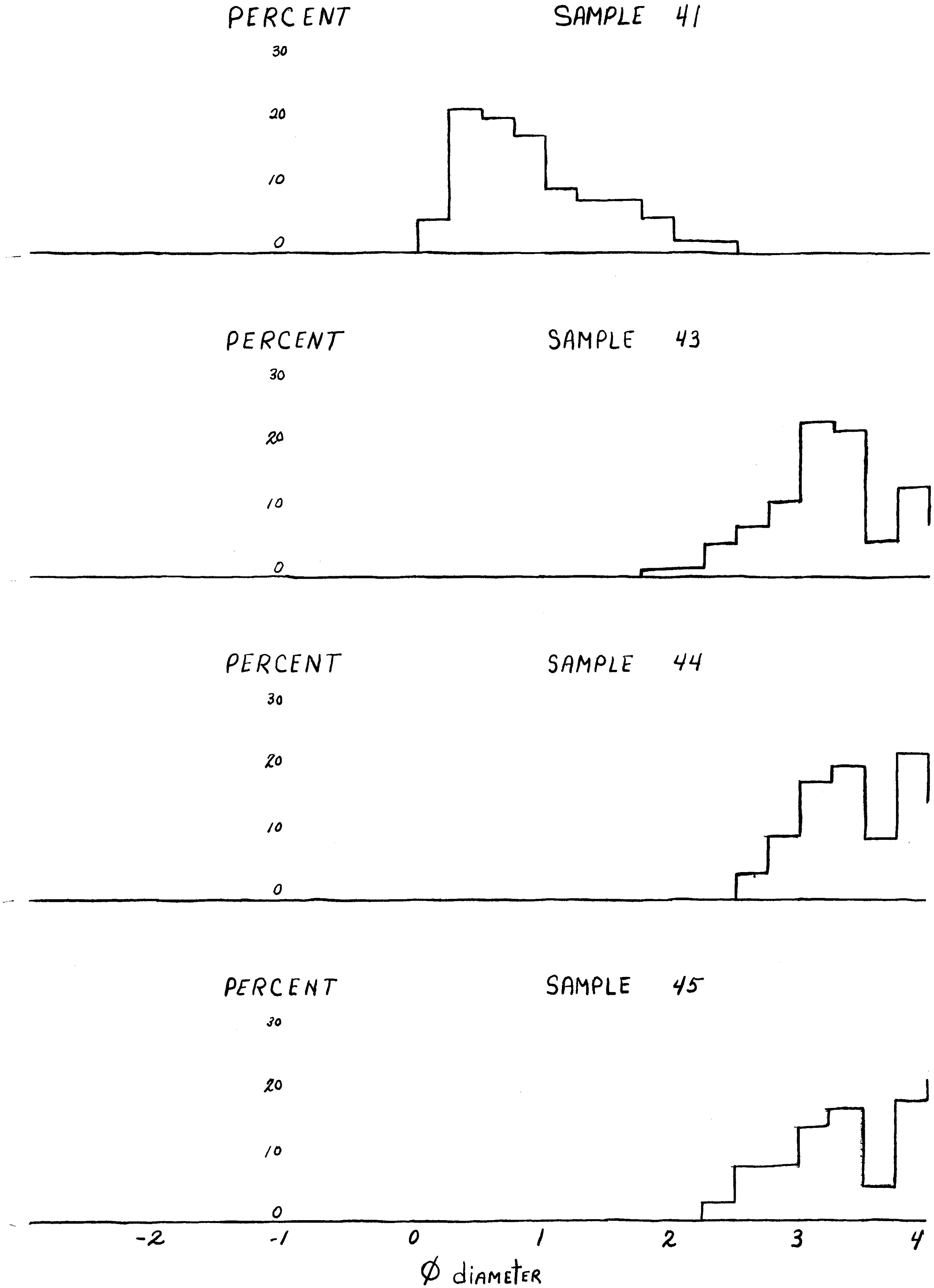

PERCENT
SAMPLE 25
30
20
10
0
PERCENT
SAMPLE 26
30
20
10
0
-2
-1
0
1
2
3
4
Ø diameter

SAMPLES 31, 32, 33, 34

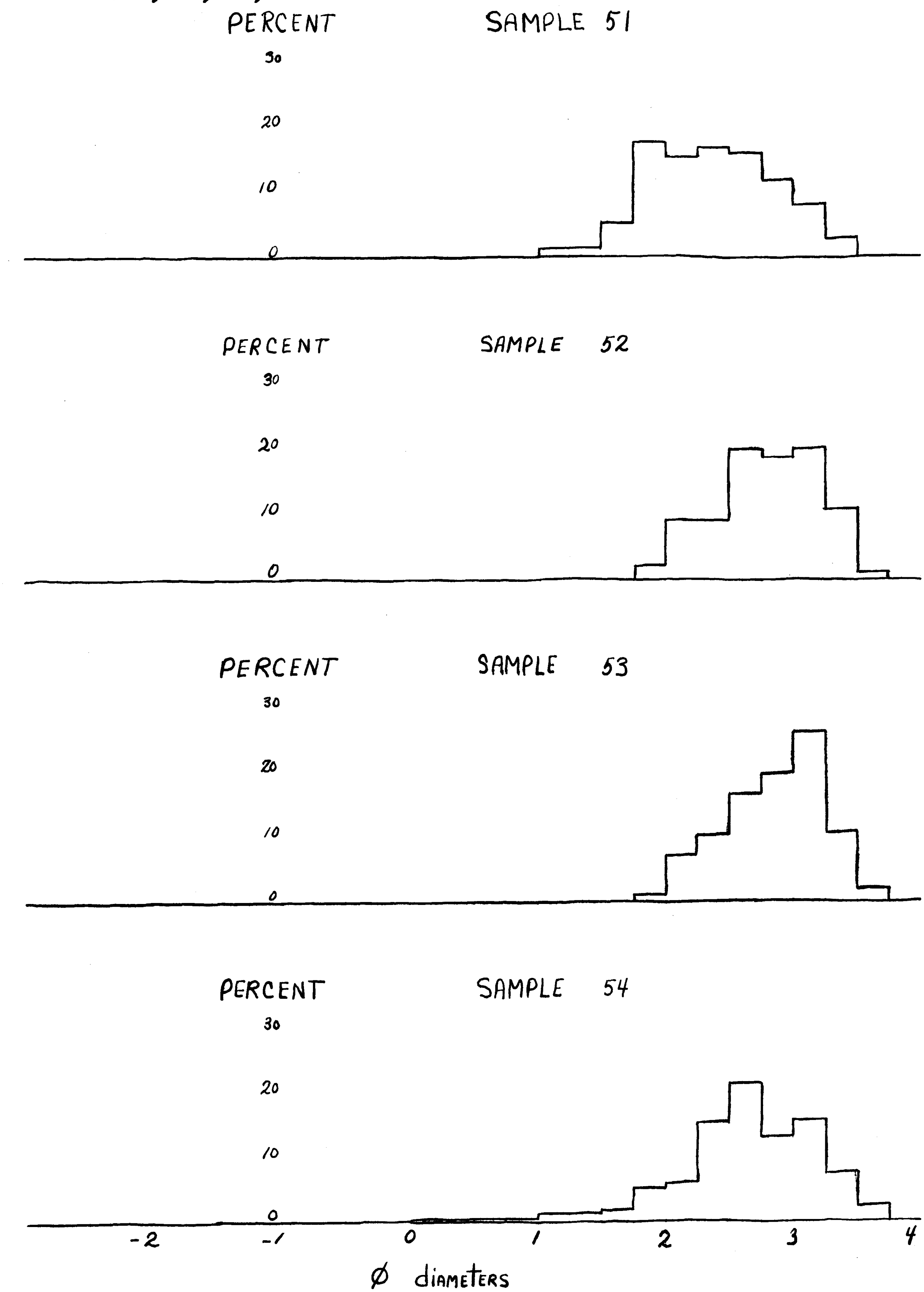



SAMPLE 35
PERCENT
30
20
10
0
SAMPLE 36
PERCENT
30
20
10
0
-2
-1
0
1
2
3
4
ϕ diameter

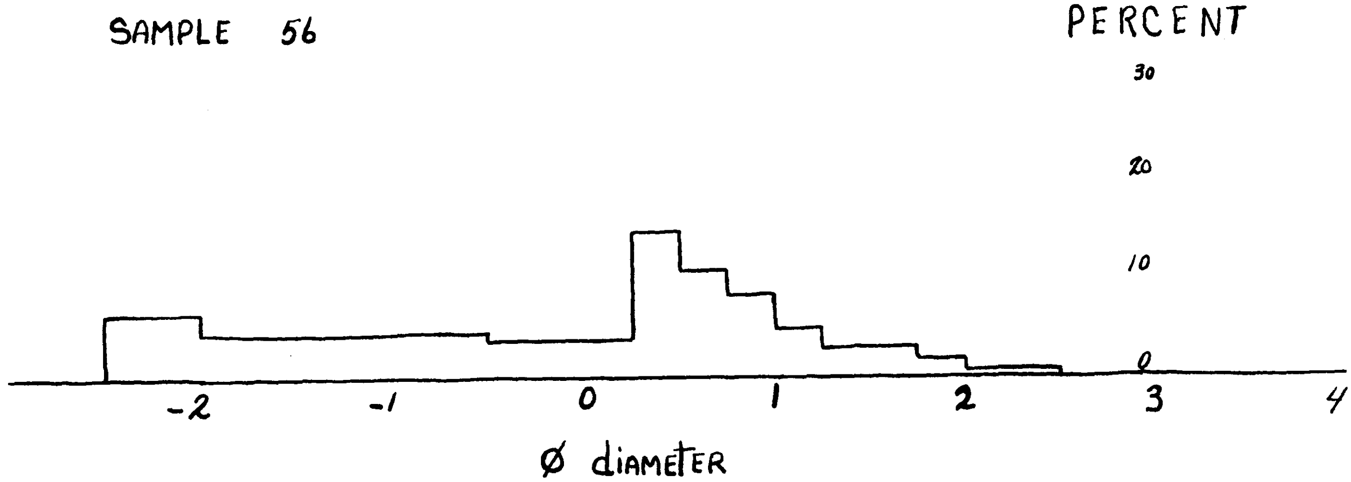
SAMPLES 41, 43, 44, 45



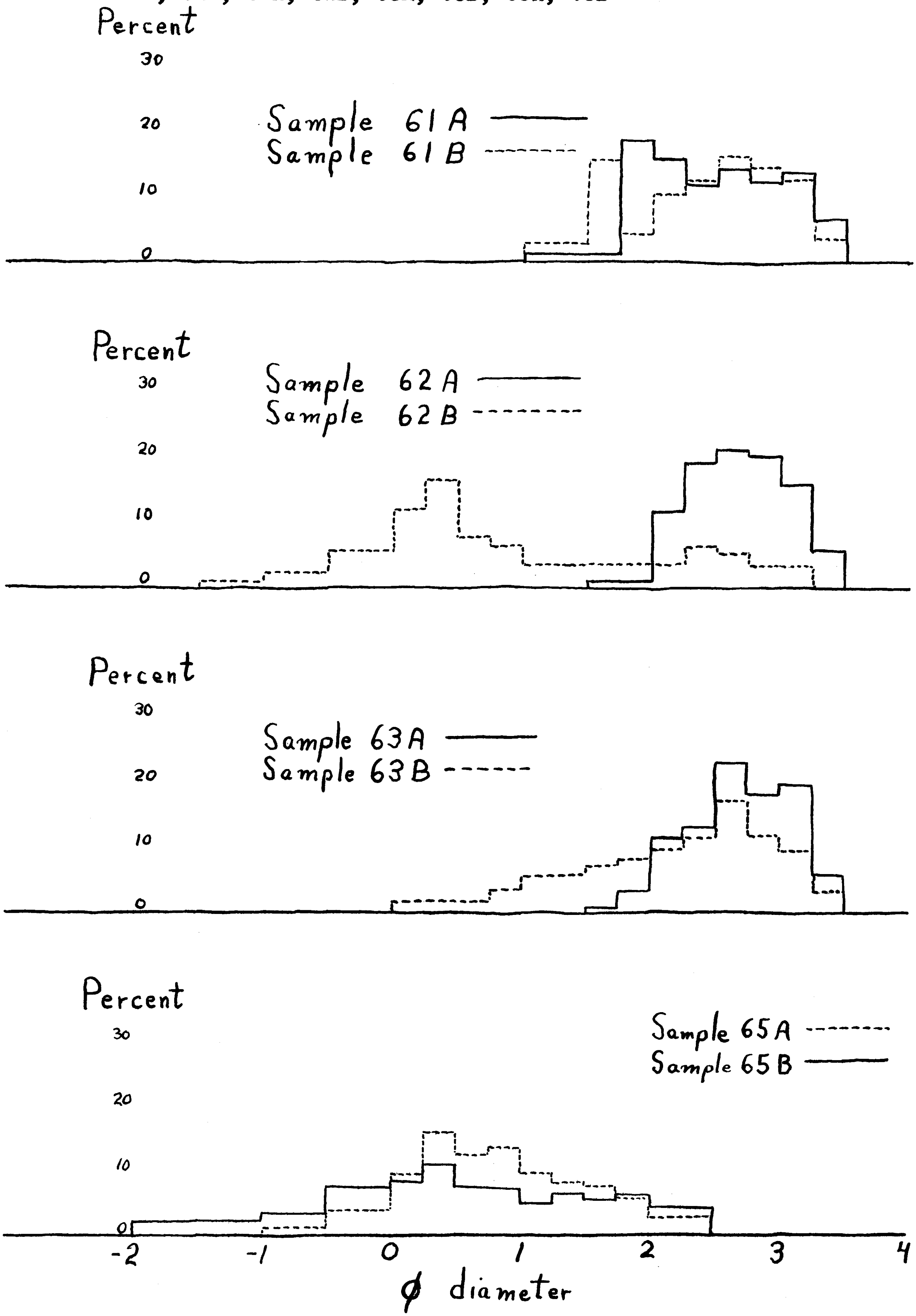
SAMPLES 51, 52, 53, 54



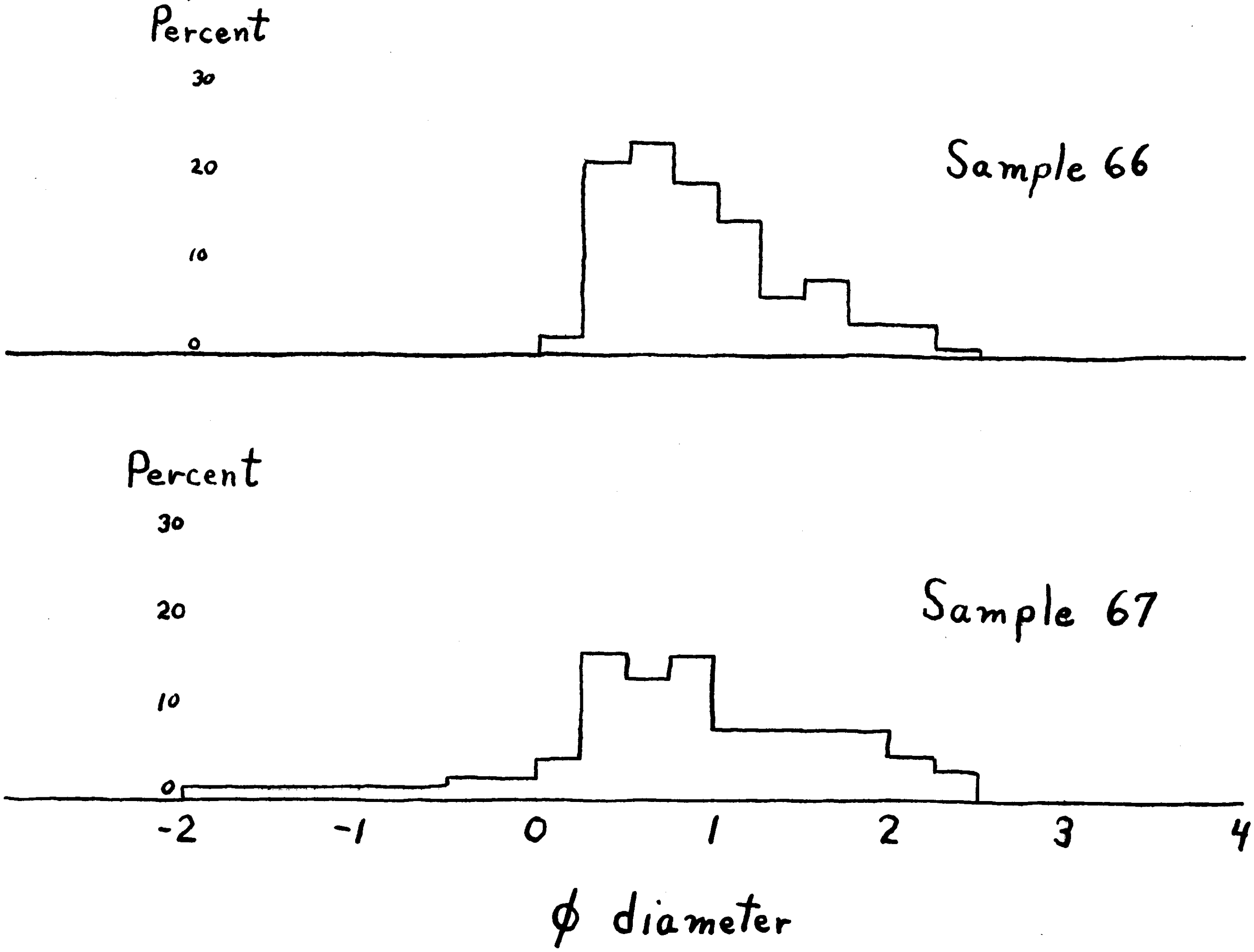
SAMPLE 56

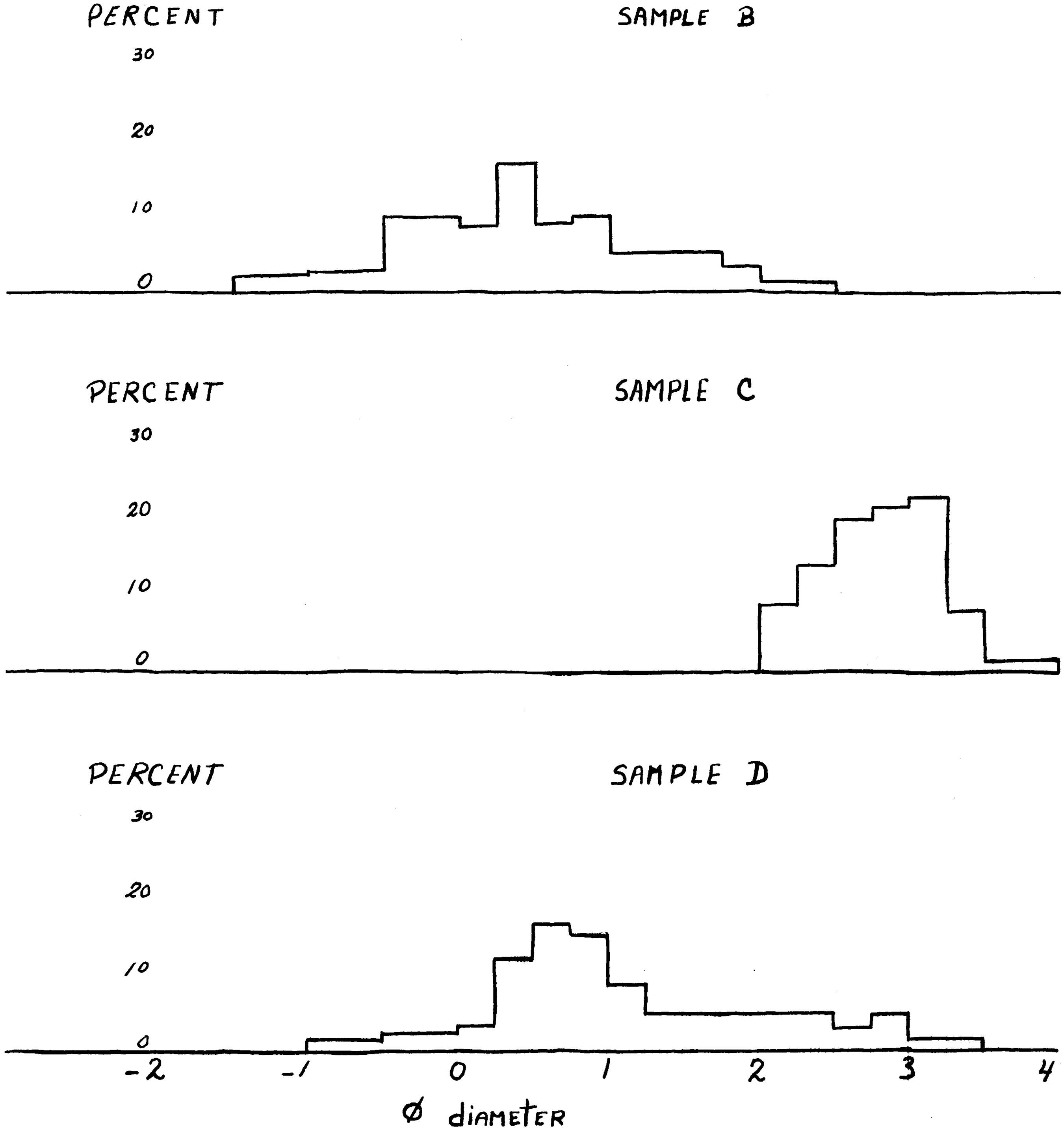


SAMPLES 61A, 61B, 62A, 62B, 63A, 63B, 65A, 65B

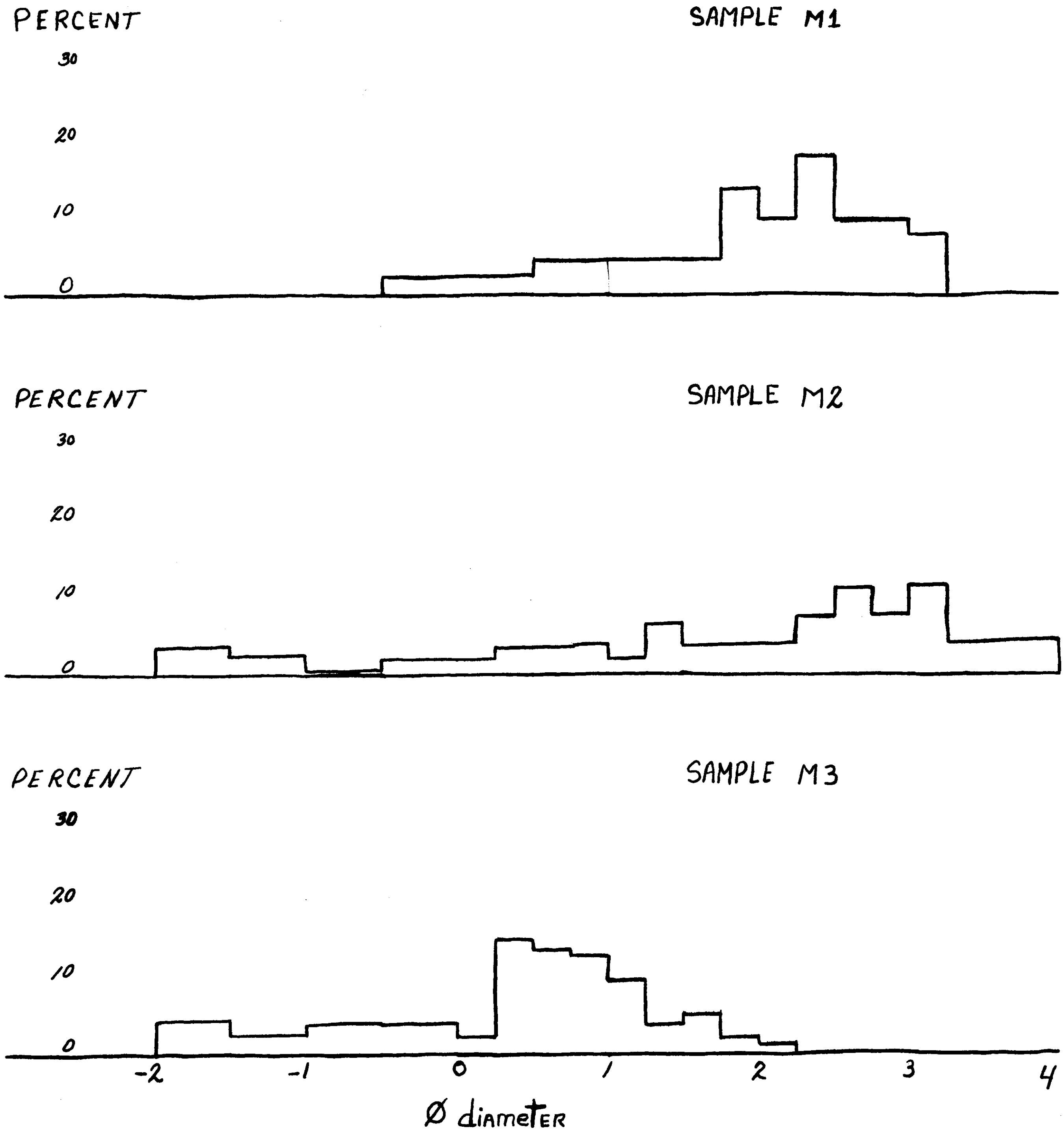


SAMPLES 66, 67

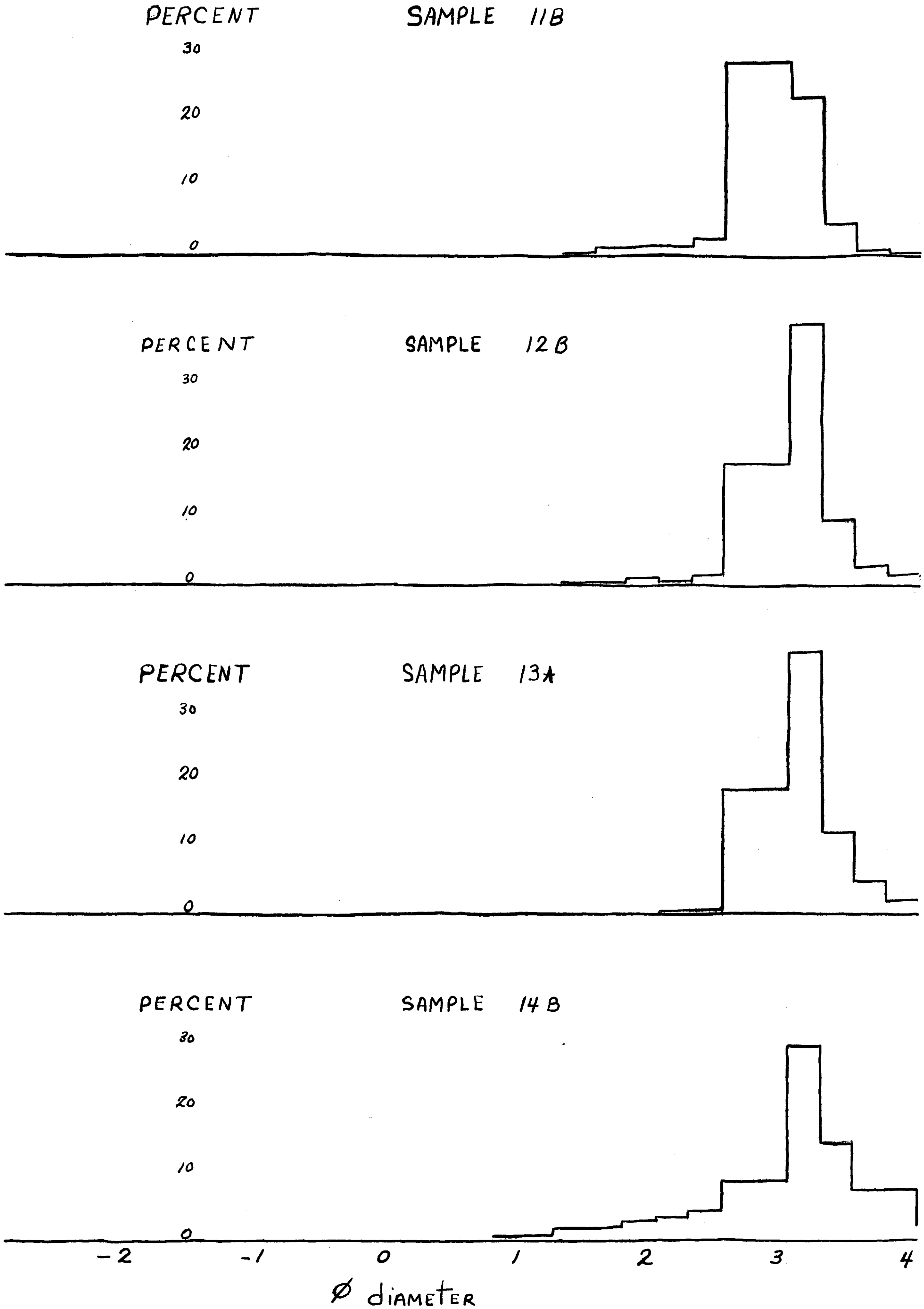



PERCENT
SAMPLE B
30
20
10
0
PERCENT
SAMPLE C
30
20
10
0
PERCENT
SAMPLE D
30
20
10
0
-2
-1
0
1
2
3
4
ø diameter

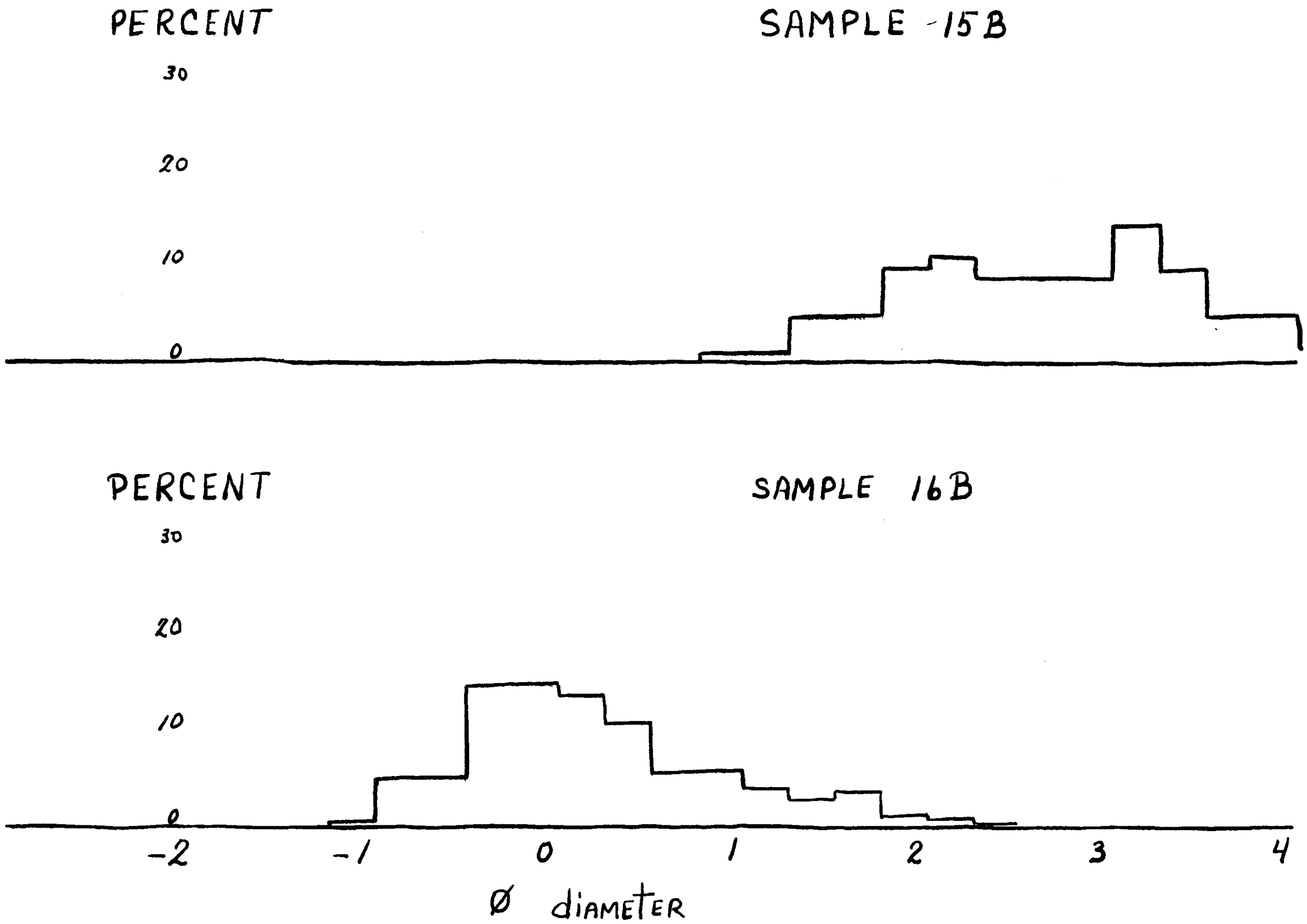
SAMPLES M1, M2, M3



SAMPLES 11B, 12B, 13A, 14B

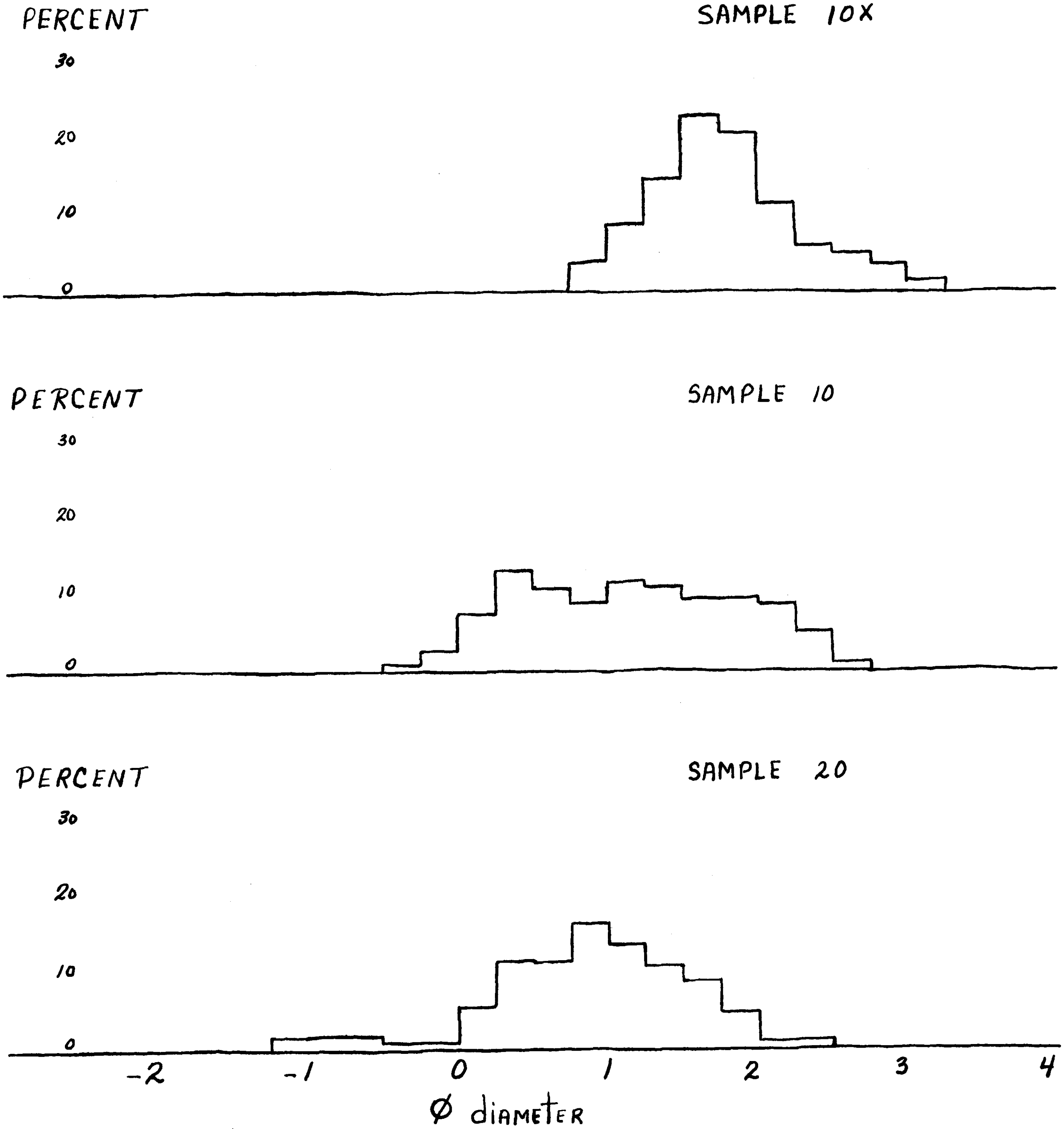


SAMPLES 15B, 16B

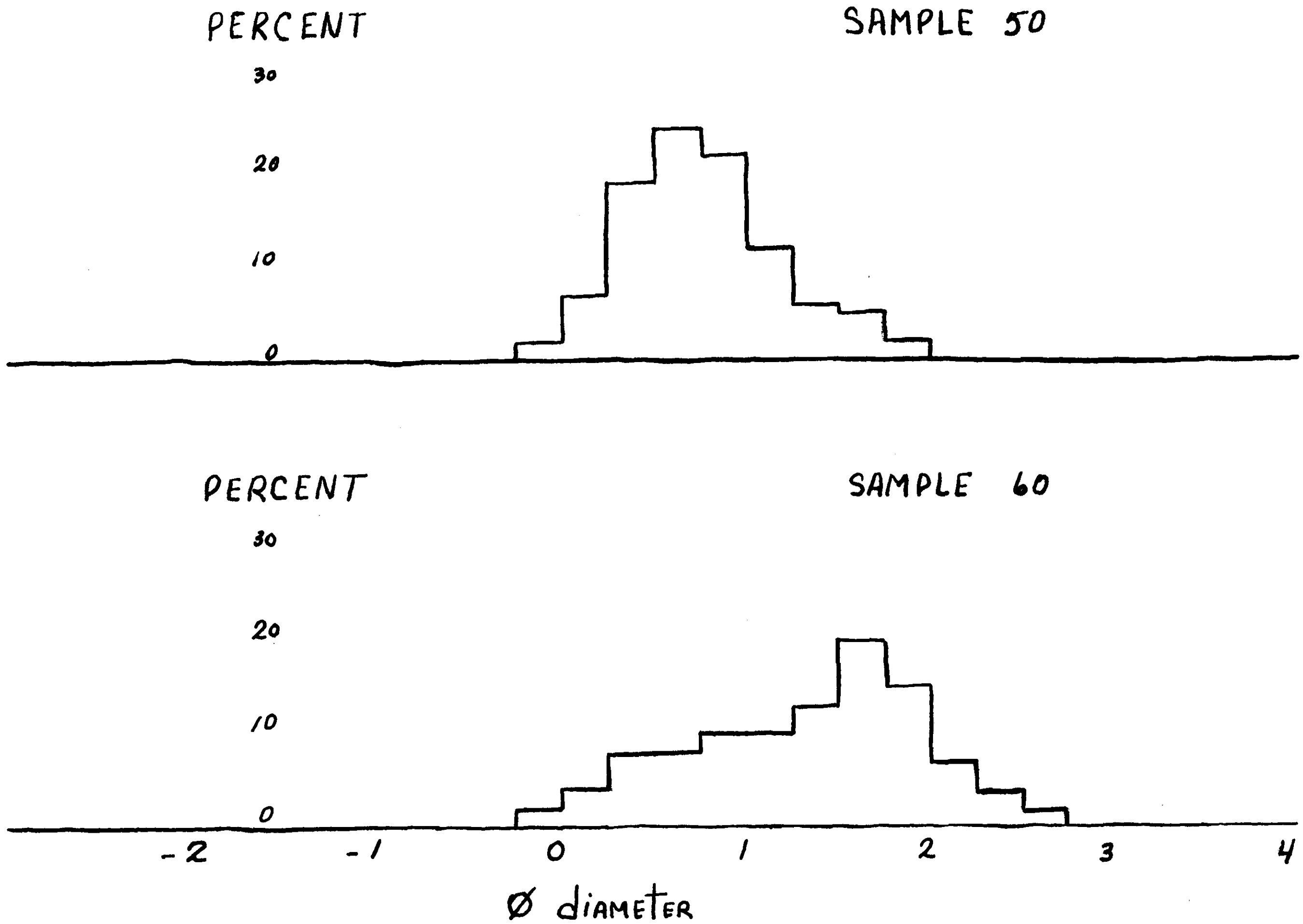


HISTOGRAMS
SAMPLES 10X, 10, 20

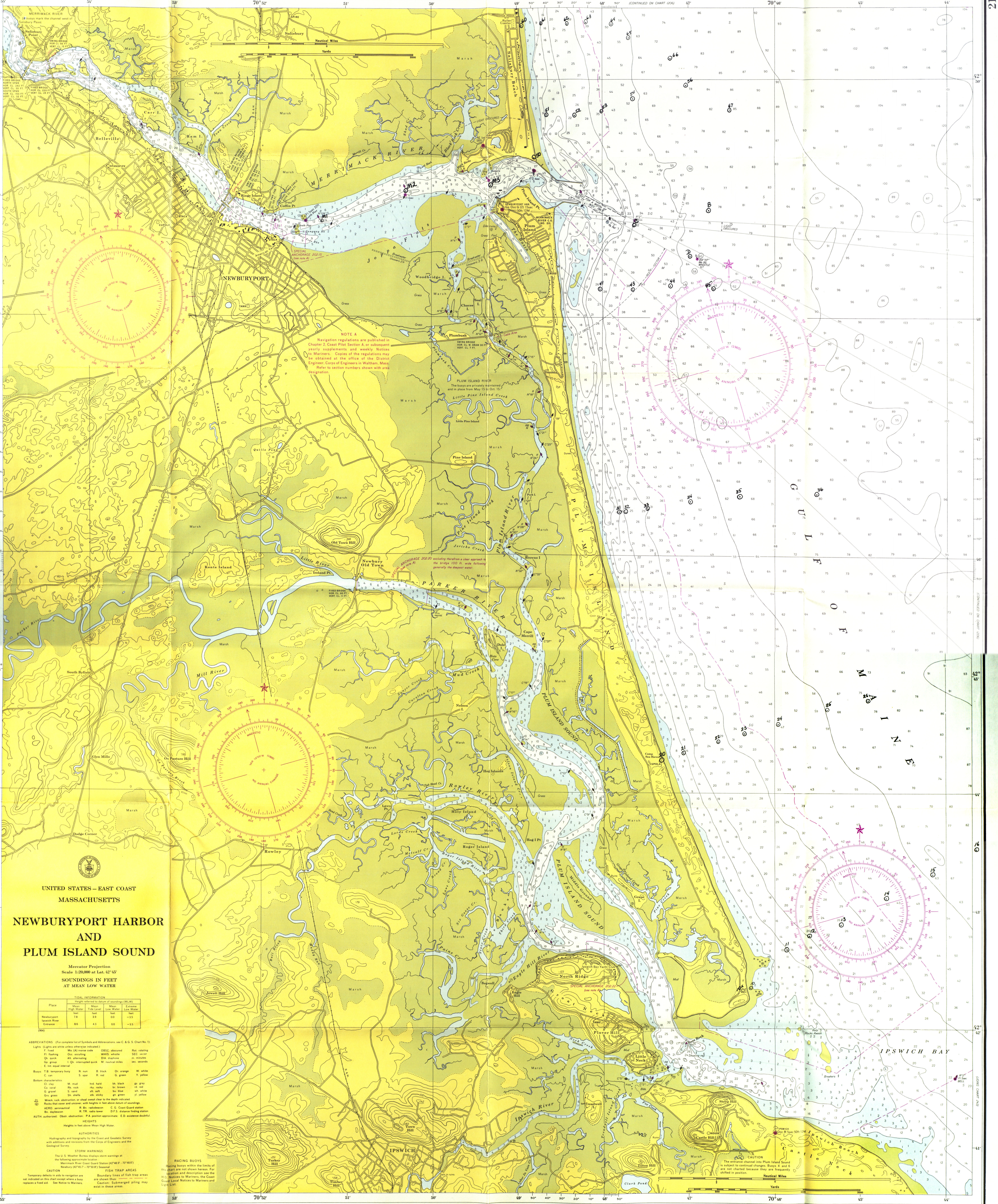
SIEVE ANALYSES



SAMPLES 50, 60



1st Ed., May 1957



2nd Ed., Mar. 6/61; Revised 1/11/65

LOGARITHMIC SPEED SCALE

1 2 3 4 5 6 7 8 9 10 15 20 25 30 40 50 60

To find SPEED, place one point of dividers on nautical miles run and the other on minutes run. Without changing divider spread, place right point on 60 and left point will then indicate speed in knots. Example: with 4.0 miles run in 15 minutes, the speed is 16.0 knots.

Compiled and printed at Washington, D. C. by
U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, Secretary
COAST AND GEODETIC SURVEY
H. Arnold Karo, Director

(Newburyport Harbor and Plum Island Sound)
SOUNDINGS IN FEET - SCALE 1:20,000