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R MICHIGAN

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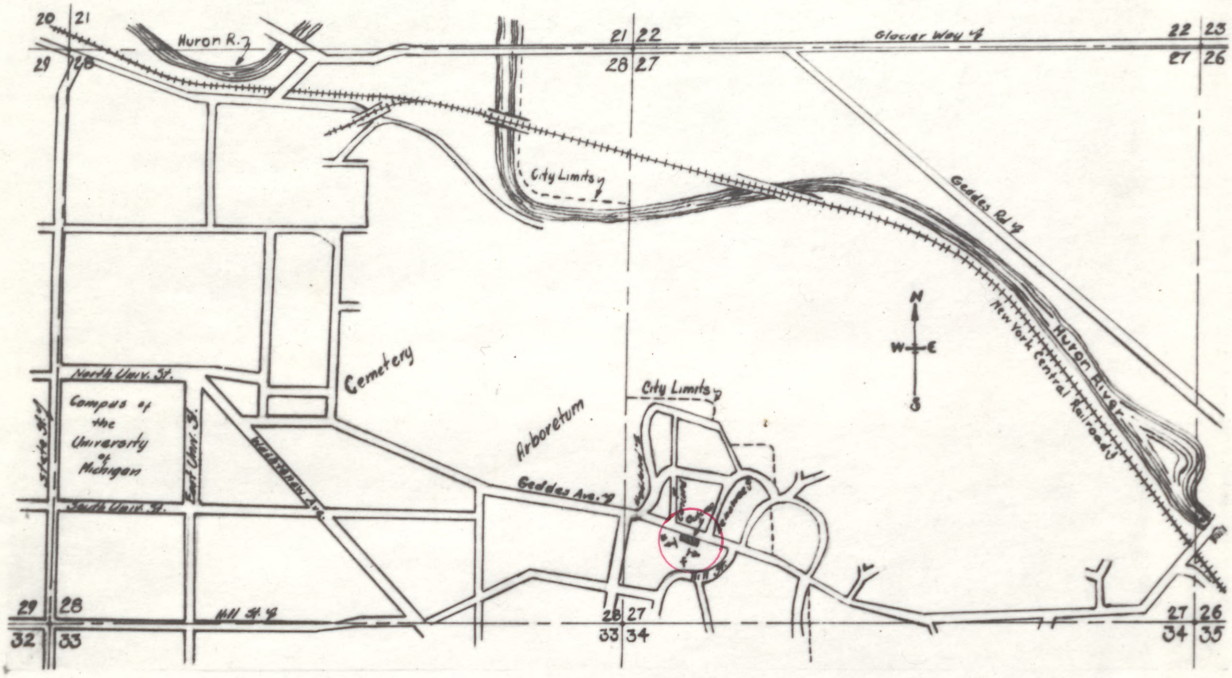

Part of Ann Arbor, Michigan, & Vicinity
(T2S R6E; Sects. 27 & 28)
Showing Location of Outcrop Studied
u = attitude of base of unit viii, strike N55°W, dip 31°SW
f = attitude of fault, strike N63°E, dip 40°SE
Scale: 3.4 inches = 1 mile

A LOESSLIKE SILT DEPOSIT IN ANN ARBOR, MICHIGAN

by

Louis Heyman

Submitted in partial fulfillment of
the requirements for the degree of
Master of Science in Geology

Horace H. Rackham School of Graduate Studies
University of Michigan
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CONTENTS

Illustrations

ABSTRACT

Field examination and sedimentary analyses of a silt exposed in Ann Arbor, Michigan, showed that it resembled a loess in gross physical properties, but was coarser than a "true loess" in grain size distribution. The silt is a cryoturbate glacial outwash of early Cary (Wisconsin) age, deposited in front of the Huron-Erie lobe of glaciation. The sedimentary analyses included mechanical analyses before and after treatment of the silt with hydrochloric acid, and roundness analyses of the dominant grade-size fractions of the untreated material.

ACKNOWLEDGMENTS

The writer wishes to express his thanks to the many people whose interest, aid and counsel greatly facilitated the completion of this work. Dr. H. B. Hungerford of the Department of Entomology, University of Kansas, very kindly identified the insect material, and Messrs. J. C. Ferm, Derwin Bell, and Paul R. May aided materially in the field and in the sedimentary investigations. Dr. G. V. Cohee of the U. S. Geological Survey gave the author much time and labor saving advice on laboratory procedure. The author is particularly grateful to Dr. M. W. Senstius of the Department of Geology, University of Michigan, for his suggestion of the subject and his advice and patient guidance in research and in the preparation of this paper.

INTRODUCTION

Purpose of Paper

An exposure of unconsolidated sediments in Ann Arbor, Michigan, resembles traditional loess in its light tan color, ability to stand in vertical walls, and calcification in places, but unlike loess shows bedding and cross-bedding in places. It has been found worthwhile investigating this sediment more thoroughly, in order to determine its origin and the physical bases for its peculiar properties.

Location

The exposure of a loesslike silt in a road cut on the south side of Geddes Avenue, between Lenawee and Concord Roads, Ann Arbor, Washtenaw County, Michigan, was investigated in the spring and fall of 1948. The exposure is quite close to the eastern city limits of Ann Arbor, and is located, on the U. S. Geological Survey _Ann Arbor_ topographic sheet, in the center of the SW¼ of the SW¼ of Section 27, T2S R6E (Ann Arbor Township) at an elevation of about 870 feet.

Description of Exposure

<u>Stratigraphy</u>: The exposure, about 50 feet long and 15 feet high at its highest point, shows small interlensing sedimentary bodies of sandy silts. These bodies are called "units" in this paper to avoid violating any of the rules of stratigraphic nomenclature, and are designated by Roman numerals from the lowest exposed upward. The entire exposure has been called the "Geddes loess" by Dr. M. W. Senstius, more as a convenience than as a formal stratigraphic designation.

The material is yellow-gray or tan in color. In first examination it appears to be uniform in texture, showing no conspicuous larger particles such as gravel, pebbles or boulders.

It is overlain by 2 to 6 feet of material that is undoubtedly glacial till. This till is reddish brown in color at the surface, below the darker colored humus top soil, and grades downward to a gray-brown podsolized horizon of eluviation. This in turn is followed by a reddish-brown horizon of illuviation, where it rests on the silts. The texture of the till is characteristic of most of the morainal deposits around Ann Arbor; that of a boulder clay. On the geological map of the Ann Arbor quadrangle of Russell and Leverett, it is designated as glacial till of Later Wisconsin age. This overburden is thus clearly distinguishable as to color and texture from the underlying loess-like material which is the subject of this investigation. The silts themselves rest on a blue boulder clay as stated by other observers. (See under Age and origin.)

The author measured the following section, as shown on plate 2, starting from the floor of the excavation shown on plate 3. The units showed great lateral variation in thickness in a short distance.

Measured section, Geddes Avenue:-

From bottom of pit upward:

Unit I. Fine sandy silt, very friable, light brown in color, showing no signs of lamination. 5 inches thick

Unit II. Silt, partly consolidated, dark brown when wet. Dries very hard and light tan in color. Contains small pebbles. Made up of finely crumpled fine and coarse silt laminae. Vertically jointed. 5-8 inches thick

Unit III. Fine sandy silt, friable, light brown in color. Contains some pebbles near the upper contact. No lamination, but exhibits very faint cross-bedding in places. May be continuous with unit I. 29.5 inches thick

Unit IV. Silt, partly consolidated and calcified. Light brown in color, thin bedded and vertically jointed. Contains some small pebbles. Pinches and swells along the exposure, but appears to be a more persistent unit. Dries hard and light tan in color. 6-8.5 inches thick

Unit V. Fine sandy silt, light brown in color, finely cross-bedded, cross-bedding west. Contains occasional pebbles up to 2 inches in greatest dimension. Four pebbles were collected, two of diorite porphyry with zoned plagioclase phenocrysts, one of gray narrow banded fine-grained crystalline limestone, and one of black massive fine-grained pyritiferous arenaceous slate. 29.5 inches thick

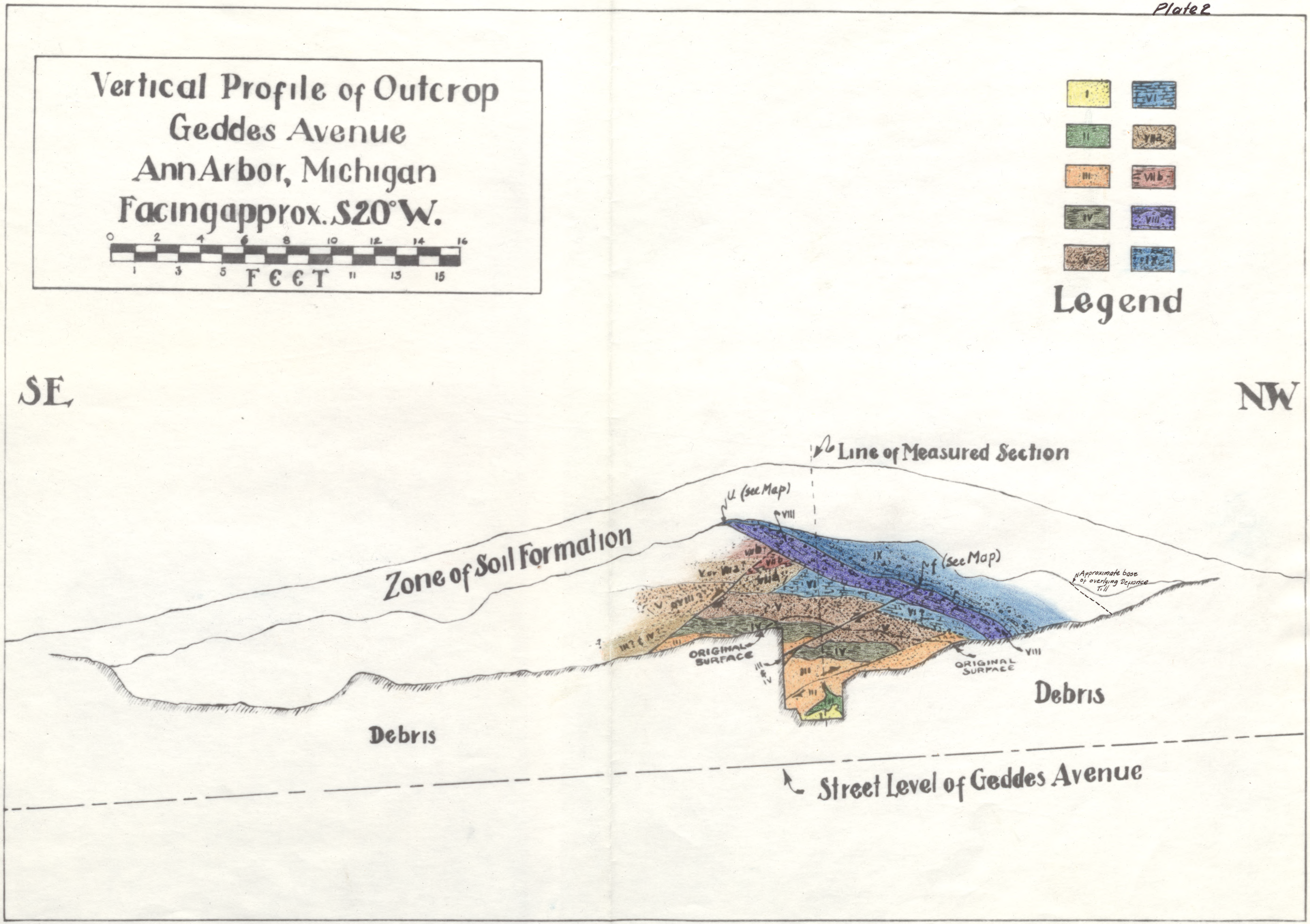
Unit VI. Silt, medium brown, drying to light tan. Thinly laminated, calcified and vertically jointed. Plant rootlets and some insect borings are present. 0-16 inches thick

Unit VIIa. Sandy silt, light brown, cross-bedded, with cross-bedding dipping approximately west. Contained numerous insect borings. (See Faunal Content.) Grades upward into unit VIIb.
0-12 inches thick

Unit VIIb. Fine sandy silt, dark brown, drying to light tan. Somewhat laminated and vertically jointed. 0-8 inches thick

-----Unconformity-----

Unit VIII. Silt, pebbly, light grayish tan in color. Calcified and contains some small limy concretions. Thinly laminated, with small lenses of fine sand. 12 inches thick


Vertical Profile of Outcrop
Geddes Avenue
Ann Arbor, Michigan
Facing approx. S20°W.
0 2 4 6 8 10 12 14 16
1 3 5 FEET 11 13 15
I
II
III
IV
V
VI
VIIa
VIIb
VIII
IX
Legend
SE
NW
Line of Measured Section
U (see Map)
VIII
IX
f (see Map)
Approximate base of overlying Defiance Till
Zone of Soil Formation
VIIb?
VIIb
V or VIIa?
VIIa
VI
V
V or VIII?
VI?
IV
III? & IV?
III
ORIGINAL SURFACE
III & IV
VIII
ORIGINAL SURFACE
Debris
Debris
Street Level of Geddes Avenue

Unit IX. Silt, light brown in color. Calcified and contains many limy concretions near the contact with unit VIII, but becomes progressively finer and less calcified upwards to the contact with the dark-brown "B" horizon of the overlying podsolized till.

14 inches thick

Total measured section	11.5 feet
Soil and till above unit IX	2.6 feet
Total height of exposure	14.1 feet

The presence of much more pebbly material in a thin zone above a fairly well marked unconformity indicates a change in depositional conditions and in the type of sediment deposited. This is discussed at length under <u>Age</u>.

<u>Structure</u>: The overall structure of the "Geddes loess" is a set of interfingering lenses. These lenses or "units" show structural deformation in varying degrees. The most prominent structure is a reverse fault (marked f on map and plate 2) which strikes N 63°E and dips 40°SE, with a displacement of about 12 inches measured normal to the fault plane. This fault seems to extend into, but die out in unit VIII, possibly indicating movement started during deposition of this unit. Two other faults of similar attitude are discernable (see plate 1), but neither is as clear as the first, nor was the extent of displacement as obvious. The more consolidated units, especially IV and VI, show an intricate vertical joint

pattern which could not be interpreted. These may be planes of shearing, formed by the compression which produced the faulting, or may be shrinkage joints due to post-depositional dessication.

Units III, IV, V, VIIa and the upper part of unit IX though unconsolidated on the whole plainly show the typical loessal property of breaking away from the exposure walls in slabs, and standing in vertical walls. This may be parting along the vertical joint planes.

The more friable and loosely coherent units V and VIIa appear to have been less competent; they also show numerous small nappes and what appear to be drag folds. These may be due to the compressional forces which formed the faults, but also may be due to slumping during deposition or movement under subsequent sedimentary loading. An examination of oriented hand specimens of unit VIIa disclosed nothing beyond a general inclination to the west of a few minor folds.

Unit II is stretched and warped in a manner which appears quite different from the distortions of the other units; it is pinched at one point, stretched into a long, almost vertical "neck" at another, somewhat resembling periglacial features in central Montana (Schafer, 1949, pp. 156-157 and pp. 160ff, also plate 1b). Shrock (1948, pp. 161-162), has called these features "head, trail, underplight, and warp", ascribing their origin to frost action. Schafer (1949, loc. cit.) also thinks the somewhat similar structures in central Montana are due to frost action, in this case in the seasonally thawed zone, overlying perennially frozen ground, of a periglacial area. In the European literature, these features are referred to as "cryoturbate" phenomena (Edelman et. al., 1936, pp. 301-336).

However, the main structural effects shown in the exposure are due to the compressional forces exerted by ice (ice shove) subsequent to the deposition of the silts. Similar phenomena have been described by Fuller (1914, pp. 92ff and p. 106ff) in pre-Wisconsin Pleistocene deposits of Long Island, New York. Most notable is the disturbed condition of the Jacob sand, of Sangamon age according to Flint (1947, table 8, p. 270). Fuller describes the Jacob sand as follows: "In its most characteristic form, the Jacob sand consists of exceedingly fine sands, mainly quartz flour, but with many grains of white mica and some of dark minerals. In color the sands commonly range from a very light gray to yellowish and buff tints, but where laminae of true clay are present, they may be stained reddish externally...What has already been said as to the structure of the Gardiners clay applies with equal force to the Jacob sand. Though classed as sand, its texture was so

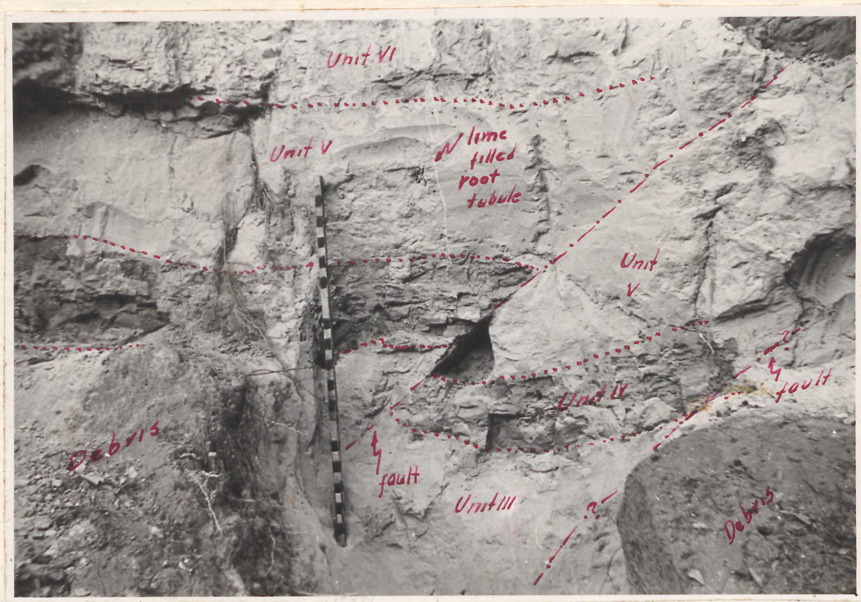


Plate 3 - Detailed Views of Geddes Ave. Exposure

fine and it contained so much silt that it behaved like clay under the action of the overriding ice, being bent, folded, crumpled and overturned, instead of crumbling and disintegrating as the coarser sands and gravels commonly did." (Fuller, 1914, pp. 107-108.) The analogy between the lithology and disturbed condition of the Jacob sand and the similar conditions in the Geddes silts is very close although the Jacob sand is late interglacial (Sangamon) in age and was deposited under marine conditions.

Faunal content: During sampling of the Geddes silts, many borings about 1/8 inch in diameter were noticed in the upper part of unit VI. A much greater number of similar holes were observed in unit VIIa. Excavation into unit VIIa revealed many more of these borings. The contents of these tunnels were separated from random samplings of unit VIIa, and found to be insects, insect parts, and cocoons. They were identified by Dr. H. B. Hungerford of the University of Kansas (Hungerford, 1948) as modern insects of the families Cercopidae and Cicadellidae of the Homoptera; the Cicadellidae are of the genera Clastoptera and Philaenus, and the Cercopidae are of genus Stroganla and others. They were gathered and stored in underground chambers by a small wasp, subfamily Nysoninae of the family Sphecidae. The cocoons were wasp cocoons one of which contained a live wasp larva.

Since these wasps, and probably other insects as well, are able to survive the winter in the Geddes exposure, frost action at this depth must be quite mild. Therefore, such phenomena as the warping and vertical stretching of unit II must have occurred in previous, more rigorous climatic periods. This is verified by Schafer, (1949, pp. 154, 162-163), who states that the undisturbed modern soil zones of central Montana show that modern climatic conditions are inadequate to form involutions of the type found in unit II (see Structure). This is obviously true in Ann Arbor also, where the winters are even less rigorous than in Montana.

Age: The approximate age of the Geddes silts may be determined by an examination of the evidence given above under Structure, Stratigraphy, and Faunal content, as well as by examination of the relationships of the silts to the sediments above and below them.

Dr. M. W. Senstius (personal communication) has noted a "blue till", which he tentatively calls Illinoian, underlying the Geddes silts at depth. The silts themselves are overlain unconformably by units VIII and IX which are pebbly silts of a different grain-size distribution than the units under them. Unit IX is in turn overlain by a coarse cobbly till. The latter is probably "Outer Defiance Moraine"

(Leverett, 1915, p. 6 and areal geologic map) of the Huron-Erie lobe of Later Wisconsin age.

Flint (1947, p. 210, pp. 212-213, pp. 249-251) gives the names Iowan, Tazewell, Cary and Mankato to the substages of the Wisconsin, from oldest to youngest. The Iowan and Mankato are not represented in this area; the Tazewell may be present and the Cary certainly is. The Tazewell perhaps corresponds to Leverett's Early Wisconsin, and the Cary to his Later Wisconsin (Flint, 1947, p. 268, fig. 57, and Leverett, 1915, p. 5, fig. 10). In all likelihood, part of what has been called the pre-Wisconsin or Iowan (?) in this area may be Tazewell in age. Thus the Geddes silts are not older than Illinoian nor younger than Cary substage of the Wisconsin.

A closer dating of the Geddes silts is possible by determining when an agent existed in pre-Mankato-post Illinoian time which could have deposited and deformed the silts. A source of sediment located to the east is indicated by the generally westward dip of the cross-bedding. (See Stratigraphy, page 2). The faults noted under Structure are all reverse and show a general dip to the southeast, and the axes of the small folds noted in hand specimens of unit VIIa are inclined to the west. This shows the presence of post-depositional compressive forces from the east or southeast. The peculiar deformation of unit II seemingly is due to local heavy frost action, thus a more rigorous climate than now prevails is indicated.

The only agent that seems to explain all these phenomena is the Huron-Erie lobe in its initial stages, moving from southeast to northwest in this general area. (Leverett, 1915, fig. 10, p. 5.) As the glacier advanced, a thin but probably continuous layer of outwash was deposited in its path. Ice rafting carried pebbles, cobbles, and perhaps boulders away from the glacier front and dropped them at random. (vide unit V). Either the advancing glacier plastered a layer of ground moraine on top of the silts, or an increase in the amount of meltwater due to the increasing proximity of the ice front caused channel cutting into, and deposition of coarser material on, the silts. The author is inclined to favor the latter explanation of the unconformity and units VIII and IX above it. When the glacier overrode the Geddes silts in order to ascend the hill of pre-Wisconsin(?) drift on which they are located, (Leverett, 1915, p. 6 "Pre-Wisconsin Drift" and p. 8 "Defiance Moraine of the Huron-Erie Lobe...") the compressive forces of the advancing ice deformed and faulted the silts. The periglacial climate may be responsible for the upheavals which deformed unit II.

The sequence of events is thus: 1. Outwash deposited on a very much less steep pre-Cary surface.

2. Heaving up and deformation of the outwash by frost action in the periglacial climate. 3. Glacial advance caused thrusting and overturned folding, also perhaps a steepening to the northwest of the plane of the unconformity. 4. The glacier retreated and deposited the Outer Defiance Moraine material on the earlier outwash deposits.

Unfortunately, the silts could not be traced to their lower contact, since the structural features seen at the exposure may only be the surface expression of ice shove effects of greater magnitude at depth.

A possibility that the silts represent outwash deposited during the retreat of the Tazewell ice and subsequent deformation by Cary glaciation cannot be overlooked. The evidence against this point of view is mostly negative, and may be summarized as follows: 1. Lack of any apparent weathered zone or other sign of an interglacial period between the silts and the Defiance till above them. 2. Deposition from the east presumes that the Tazewell ice came from that direction, as the Huron-Erie lobe did. There is no evidence to support this. 3. Absence of any data on the extent or lithology of the Tazewell deposits in this area, if they exist at all.

The burden of proof is thus on the proponent of a Tazewell age for the silts; the arguments against it are few, but the evidence for it is completely lacking.

Other Similar Deposits

Mr. Ward H. Austin, graduate student in geology, and Dr. J. T. Wilson of the Geology Department, University of Michigan, have brought two similar silt exposures in the vicinity of Ann Arbor to the author's attention.

The exposure noted by Mr. Austin was in a test pit at the site of the future Veteran's Hospital on Glacier Way. The location is estimated to be about 1000 feet east of the intersection of Geddes Road and Glacier Way, thus locating it just south of the section line between Sections 22 and 27. The elevation is about 800 feet, and the depth of the test pit is about 4 feet. Specimens of the spoil from the excavation were inspected in hand specimen. The material is a fine sandy silt, dark gray and somewhat plastic when wet, and drying to a friable but firm condition and light gray color. It has little apparent bedding. In most respects it resembles unit III of the Geddes silts. The gray color is apparently due to the reduced condition of the iron present, since many fragments show yellow and yellow-orange spots indicative of local oxidation.

A comparison of a sketch by Mr. Austin with the location on Leverett's 1915 areal geologic map of Ann Arbor, shows that the material is probably a fine unit in the river terrace deposits laid down when the Huron River was Tributary to the glacial Great Lakes. The reduced condition is explained by the fact that the pit is below the water table (Leverett, 1915, Artesian Water map) and was being pumped when visited by Mr. Austin.

The exposure noted by Dr. Wilson is in T4S R6E (York Township) in the W$\frac{1}{2}$ of the SW$\frac{1}{4}$ of Section 18, about 3 miles due south of Saline. As described by Dr. Wilson, the exposure is in a stream bank and is composed of very fine sandy silts which are brown or tan in color, cross-bedded, and generally resemble the samples of Geddes material he has seen. Dr. Wilson is of the opinion that the deposit is a delta formed by a stream emptying into Glacial Lake Maumee, and is thus later in age than the Geddes silts. Its importance, as also that of the material noted by Mr. Austin, is in demonstrating the variety of origins one lithologic type may have.

SEDIMENTOLOGY

Field Work

During measurement of the exposure at Geddes Avenue, samples were taken of all units exposed except the material in the "B" soil horizon. The face of the exposure was smoothed off before sampling, and then channel samples taken of each unit individually. The channels were located at the line of measurement, except where the unit was too thin to yield sufficient sample. In these cases, samples were taken where the unit was thicker, but as close as possible to the line of measurement. The channels were about 2 inches wide and extended from lower to upper contact of each unit. The sample was cut away with the sharp end of a geologists' hammer and caught in pint cardboard containers. At least 500 grams of sample per unit were collected. The few excessively large pebbles, mostly found in unit V, which were collected, were separated and saved. These pebbles were not noted in the mechanical analyses, since their great weight would exert an influence out of all proportion to their number. Oriented blocks of unit VIIa and an oriented block of unit II were also collected. Random samples of unit VIIa were taken to obtain insect material for identification.

Mechanical Analyses

Methods used: Two analyses of each unit were made, one of the material as collected, the other after treatment with hydrochloric acid, to determine what possible effects the removal of the carbonates would have on the grain-size distribution. The analytical procedure was the same for both treated and untreated material. Per cent size distribution by weight, using the Wentworth Scale was determined for the range greater than 2 mm. to less than 1/1024 mm. for each unit. The Wentworth scale is expressed on the graphs in this paper in terms of Ø numbers, where Ø equals $-\log_2 \xi$; ξ is the actual diameter in mm. (Krumbein and Pettijohn, 1938, pp. 84-85). Ø values are simple integers with Ø of 1 mm. equal to 0; Ø of numbers greater than 1 are negative and Ø of numbers less than 1 are positive. These values are thus directly expressible on arithmetic coordinate paper.

Before any analyses were made, the entire samples were disaggregated to a fairly uniform small particle size. All visible organic material and other extraneous matter were removed and the samples were allowed to air dry at room temperature for at least a week. The percentage moisture content of each sample was then determined on the basis of oven dry weight at 100 C. Similar determinations were made for some of the acid treated material, but little difference was found in the moisture content of the treated and the untreated material. Therefore all computations of the weights were made on a moisture free basis as determined for the untreated material.

The analyses were performed in two stages. The first stage was dry sieving to determine fractions larger than 1/16 mm.; the second stage was pipette analysis for fractions less than 1/16 mm. The sieves used in the first stage were U. S. Standard Series sieves, made by the W. S. Tyler Co., of the following sizes: 2 mm., 1 mm., ½ mm., ¼ mm., 1/8 mm., and 1/16 mm. The sieves were shaken for 20 minutes by a homemade electrically driven reciprocating shaker. Some inefficiency of the shaker was noted in that it failed to readily pass the smaller sizes through the finer sieves.

The procedure for pipette analysis was that described by Krumbein and Pettijohn (1938, p. 166ff) with the following modifications: A Lowy pipette, automatically delivering 25 cc. was used instead of the ordinary type. The graduates containing the dispersions were kept in room temperature water baths to minimize the fluctuation of the viscosity of the water due to temperature changes. The times of settling for the grades chosen; 1/16, 1/32, 1/64, 1/128, 1/256, 1/512, and 1/1024 mm., were computed from a table of settling velocities given by Krumbein and Pettijohn (1938, p. 111, table 13). This table was computed for spheres of specific gravity 2.65 at a temperature of 20 C., on the basis of Wadell's modification of Stokes' equation. This modification corrects for the non-spherical shape of most of the particles in a sediment (Krumbein and Pettijohn, 1938, p. 104ff). No correction was made for the peptizing agent, sodium silicate, used.

Sampling: After the percentage moisture content had been determined, each entire sample was roughly quartered. One quarter, composed of portions drawn from two opposite quarters, was prepared for analysis in the untreated state by further disaggregation in a stone-ware mortar with a rubber pestle. This material was again quartered and these quarters, ranging in weight from approximately 40 to 83 grams were the final untreated samples. For the analyses of the treated material, the remaining roughly disaggregated material was again quartered, one quarter of each of these samples further disaggregated with mortar and rubber-tipped pestle, and a quartering of this treated with acid. After treatment, which is described under Preparation and dispersion, the treated samples, ready for analysis, ranged in weight from 46 to 60 grams.

After the sieve analyses were completed, the fraction passing the 1/16 mm. sieve was prepared for pipette analysis. Since this "pan" fraction was in some cases as small as 13 grams, it was necessary to use at least a major portion of it for pipette analysis. This was done by quartering the sample and discarding a small part of each quarter. Thus the major portion of the pan fraction was retained for analysis. The samples ready for pipetting, untreated, varied in weight from 12.3 to 33.3 grams; the treated varied from 13.1 to 35.3 grams.

Preparation and dispersion: The acid used in preparing the treated material was commercial hydrochloric acid, diluted approximately in the ratio one part acid to three parts distilled water. About 50 ml. of the dilute acid was added to each sample, the suspension stirred, and reaction permitted to go to an end. More acid was added, and the suspension again allowed to react. This procedure was repeated until the addition of acid ceased to produce effervescence. Each sample was then first washed with about 7 liters of tap water and subsequently with 4 liters of distilled water until acid-free as shown by tests with litmus paper. The washing was done by pouring the suspension of acid and sample into a battery jar, adding water, stirring the suspension vigorously to break up lumps, and drawing off the water through a Pasteur-Chamberland filter connected to an aspirator. It was found expedient to allow the initially unwashed suspension to settle for about 24 hours, pour off the supernatant liquid, and then proceed with the washing. The 24-hour period was ample, since even the finest material flocculated in the acid medium in that period and left the acid solution clear. The addition and filtering off of the wash water was repeated until the amounts of water given above were used for each sample. The resulting "cake" was then dried at 100 C., carefully recrushed with mortar and rubber-tipped pestle and was then ready for mechanical analysis. All the samples reacted quite vigorously with the acid.

The untreated material, as has been noted above, was not subjected to any further treatment beyond pulverizing to prepare it for analysis.

The samples of material passing the 1/16 mm. sieve were prepared for pipette analysis by dispersion in about 700 ml. of distilled water to which 5 ml. of saturated sodium silicate solution of 36 on the Bouyoucos mechanical analysis hydrometer had been added as a peptizing agent. The dispersion was accomplished by agitating the suspension for about 10 minutes in an electric mixer, as used for the hydrometer method of mechanical analysis. After dispersion seemed complete, the suspensions were washed into liter graduates with enough distilled water to make exactly 1 liter of total suspension each. These filled graduates were then placed in a water bath and allowed to stand for about 14 hours. Before redispersing the sediment for analysis, each graduate was examined for signs of flocculation. (Krumbein and Pettijohn, 1938, p. 73.) The redispersion was accomplished by placing a hand over the mouth of the graduate, inverting and shaking vigorously. The same procedure was followed in preparing both treated and untreated materials.

Sources of Error: A table of sources of error occurring in mechanical analysis is given below, with their effects on observations and possible corrections. In connection with these errors, the following three types of effect may be noted: 1. An error which tends to increase the value of all observations (positive); 2. An error which tends to decrease the value of all observations (negative); and 3. An error which tends to increase the value of some observations at the expense of others (compensating).

The errors in the mechanical analyses due to dry sieving are uncorrected; the errors in the pipette analyses were handled as follows: Losses in dispersion and agitation were kept to a minimum, but some loss of suspension was encountered in the latter process.

TABLE I

A. Sieve Errors (affect all sizes of particles)

	Source of error	Effect on Observations	Possible Correction
1.	Loss of material into the air during sieving.	Negative	Wet sieving; note under sieve loss.
2.	Lodgement of particles in the sieve.	Negative	Wet sieving; more efficient shaker.
3.	Incomplete disaggregation.	Compensating; smaller particles cohere to form larger aggregates.	Wet sieving, care in preliminary disaggregation.
4.	Static electricity charging particles.	Effects probably similar to 3.	Wet sieving.

B. Errors in Pipette Analyses (affect only particles below 1/16 mm.)

5.	Losses during preparation for analysis and agitation.	Negative	Care in dispersion Better agitating method.
6.	Temperature fluctuation.	If temperature rises effect is negative. If temperature falls effect is positive.	Regulation of temperature of the suspension column.
7.	Peptizing agent.	Positive	Correction for weight of peptizer applied to sample weights.
8.	Variation in size of pipette sample.	Negative and/or positive.	Use device which delivers constant samples.

TABLE 1 (cont'd.)

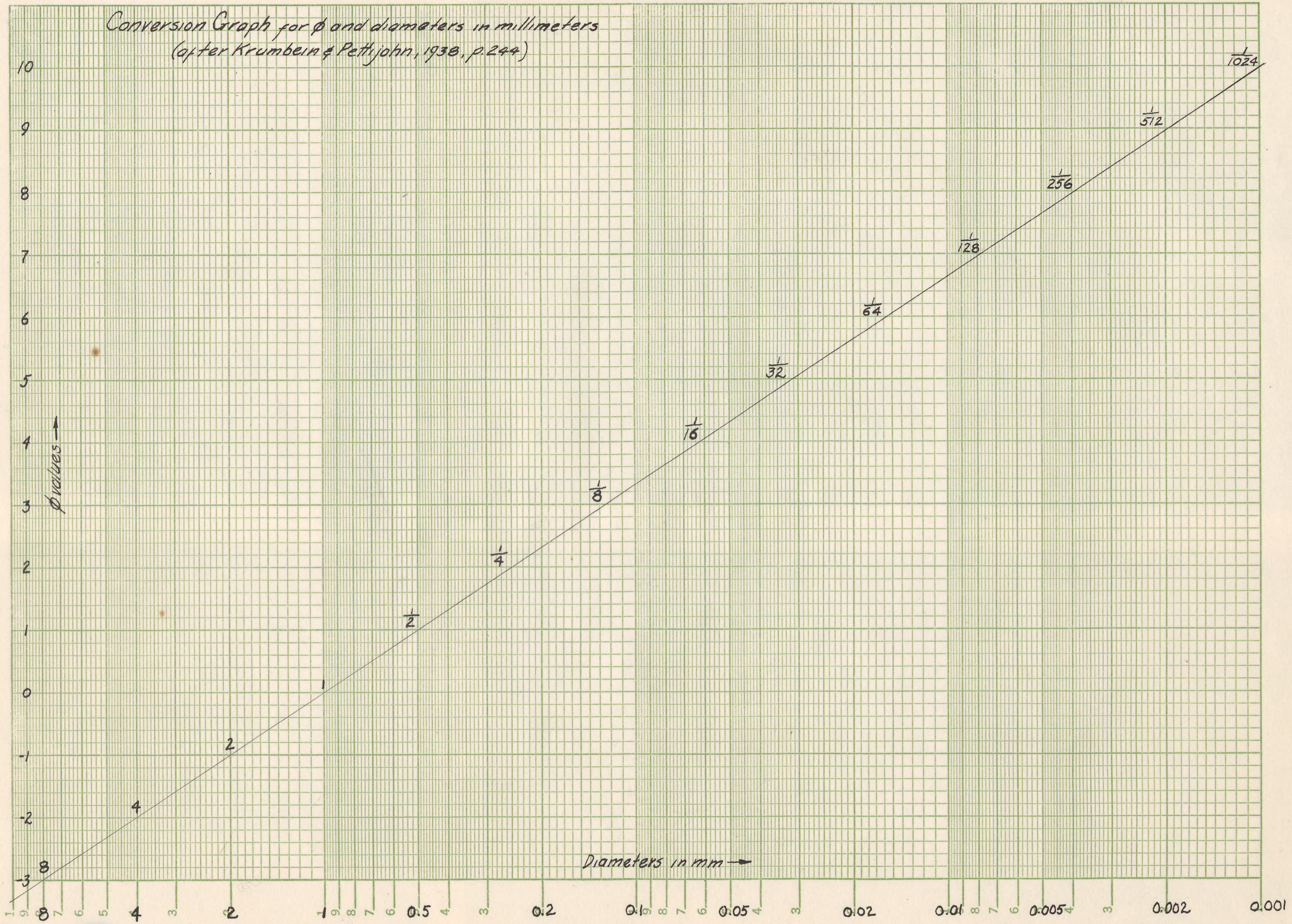
	Source of error	Effect on Observations	Possible Correction
9.	Disturbance of sediment by insertion and withdrawal of pipette.	Probably positive.	Proper precautions in sampling.
10.	Flocculation of suspension.	Complex, discussed by Krumbein and Pettijohn (1938, pp. 57-61, 73-74).	Proper use of peptizers; removal of electrolytes.
11.	Variation in the specific gravity and shape of particles.	Negative and/or positive according to properties of majority of particles.	Corrections applied to computations of settling velocity.

Temperature fluctuation was kept down by immersion of the graduates in a water bath at room temperature. The error due to the addition of a peptizer was uncorrected. Variations in the pipette sample size were minimized by the use of a Lowy pipette which delivered a constant sample automatically. Flocculation was minimized by thorough washing of the acid treated material and the addition of a peptizer to the suspensions. Variations in specific gravity were not corrected for; an assumed standard specific gravity of 2.65 was used. Variation in particle shape was corrected for by the use of Wadell's modification of Stokes' equation (Krumbein and Pettijohn, 1938, p. 106, equation 14).

Data from mechanical analyses: On the following pages, the data found by the mechanical analyses of the Geddes silts are given, and some statistical measures derived therefrom. The correlations and conclusions drawn from these data, as well as conclusions from the roundness analyses are given under Conclusions From Sedimentary Analyses.

The results of the mechanical analyses are arranged as follows: Weight percentages of both treated and untreated material, ranging from greater than 2 mm. to less than 1/1024 mm.; cumulative percentages for the same; and percentage differences between the weight percentage for the treated and untreated material.

Also given are the following statistical measures, in terms of ∅ values: The first quartile, the median, the third quartile, the quartile mean, the quartile deviation and the skewness. The quartile mean is equal to ½ the sum of the quartile, the quartile deviation to ½ the difference between the quartiles, and the skewness is equal to ½ (the sum of the quartiles minus twice the median). The latter two measures have geometrical significance in terms of the curves. The quartile deviation indicates ½ the difference between the quartiles in terms of Wentworth grades, and thus is a rough measure of the sorting, whereas the skewness expresses the difference in position of the median and the quartile mean in terms of Wentworth grades. A positive skewness implies that the mean is to the right of the median; for negative skewness the mean is to the left of the median.



Semi-Logarithmic 4 Cycles X 10 to the inch MADE IN U.S.A.
NO. 5784

TABLE 2

Unit I

Median untr: 4.05 tr: 3.90 Quartile Devn. untr: 0.68 tr: 0.73

1st Quartile untr: 3.40 tr: 3.30 Skewness untr: 0.03 tr: -0.03

3rd Quartile untr: 4.75 tr: 4.75 Quartile Mean untr: 4.08 tr: 4.03

∅ value	∅ size fr	% untr	% tr	diff	cum ∅ size fr	% untr	% tr
-2							
	over -1	0.958	0.226	-0.73	over -1	0.958	0.226
-1							
	-1 to 0	0.123	0.069	-0.05	over 0	1.081	0.295
0							
	0 to 1	0.229	0.127	-0.10	" 1	1.310	0.442
1							
	1 to 2	1.092	0.601	-0.49	" 2	2.402	1.023
2							
	2 to 3	8.400	10.724	+2.32	" 3	10.802	11.747
3							
	3 to 4	38.82	42.120	+3.30	" 4	49.622	53.867
4							
	4 to 5	29.820	25.523	-4.30	" 5	79.442	79.390
5							
	5 to 6	11.501	13.498	+2.00	" 6	90.943	92.888
6							
	6 to 7	3.906	1.998	-1.91	" 7	94.849	94.886
7							
	7 to 8	1.861	2.097	+0.24	" 8	96.710	96.983
8							
	8 to 9	0.895	0.970	+0.07	" 9	97.605	97.953
9							
	9 to 10	0.268	0.166	-0.10	" 10	97.873	98.118
10							
	less than 10	1.741	1.645	-0.09	SubTotal	99.614	99.763
11							
					Sieve loss	0.690	2.233
	% sieve loss	0.690	2.233		Total %	100.304	101.996
	% pipette error	0.304	1.997				

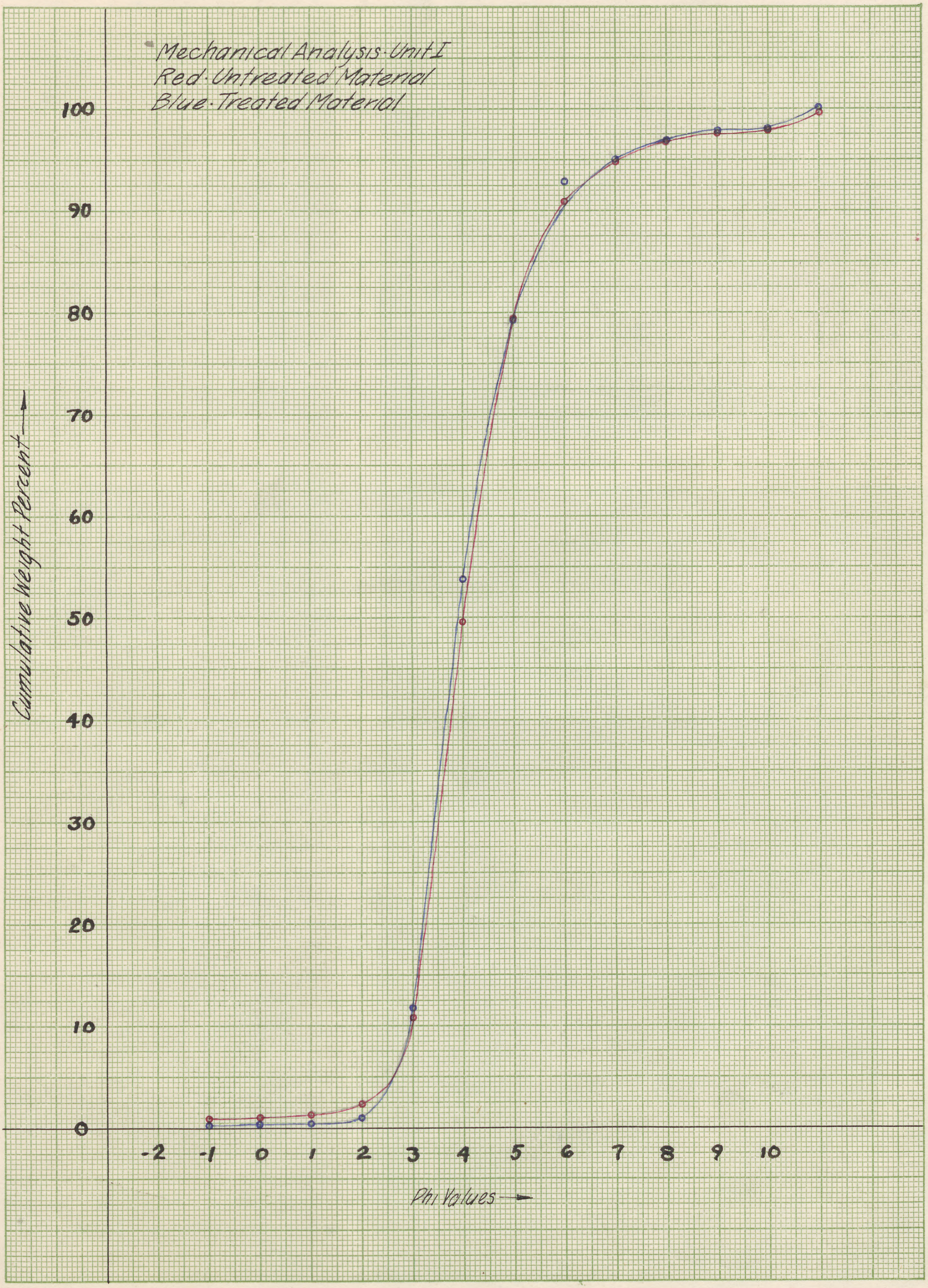

Mechanical Analysis · Unit I
Red · Untreated Material
Blue · Treated Material
Cumulative Weight Percent
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 3

Unit II

Median untr: 4.40 tr: 5.55 — Quartile Devn. untr: 2.18 tr: 2.03

1st Quartile untr: 2.40 tr: 3.40 — Skewness untr: 0.18 tr: -0.13

3rd Quartile untr: 6.75 tr: 7.45 — Quartile Mean untr: 4.58 tr: 5.43

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0	0	0	over -1	0	0
-1							
	-1 to 0	0.160	0.059	-0.10	" 0	0.160	0.059
0							
	0 to 1	3.093	0.159	-2.93	" 1	3.353	0.218
1							
	1 to 2	16.06	6.433	-9.63	" 2	19.31	6.651
2							
	2 to 3	15.72	11.630	-4.09	" 3	35.03	18.281
3							
	3 to 4	11.16	18.209	+7.05	" 4	46.19	36.490
4							
	4 to 5	10.16	8.863	-1.30	" 5	56.35	45.353
5							
	5 to 6	9.233	9.073	-0.16	" 6	65.58	54.426
6							
	6 to 7	13.61	13.815	+0.21	" 7	79.19	68.241
7							
	7 to 8	10.72	12.701	+1.98	" 8	89.91	80.942
8							
	8 to 9	4.258	7.743	+3.49	" 9	94.15	88.685
9							
	9 to 10	2.449	4.615	+2.17	" 10	96.60	93.300
10							
	less than 10	2.847	5.109	+2.26	SubTotal	99.45	98.409
11							
					Sieve loss	0.813	1.566
	% sieve loss	0.813	1.566		Total %	100.263	99.975
	% pipette error	0.263	0.025				

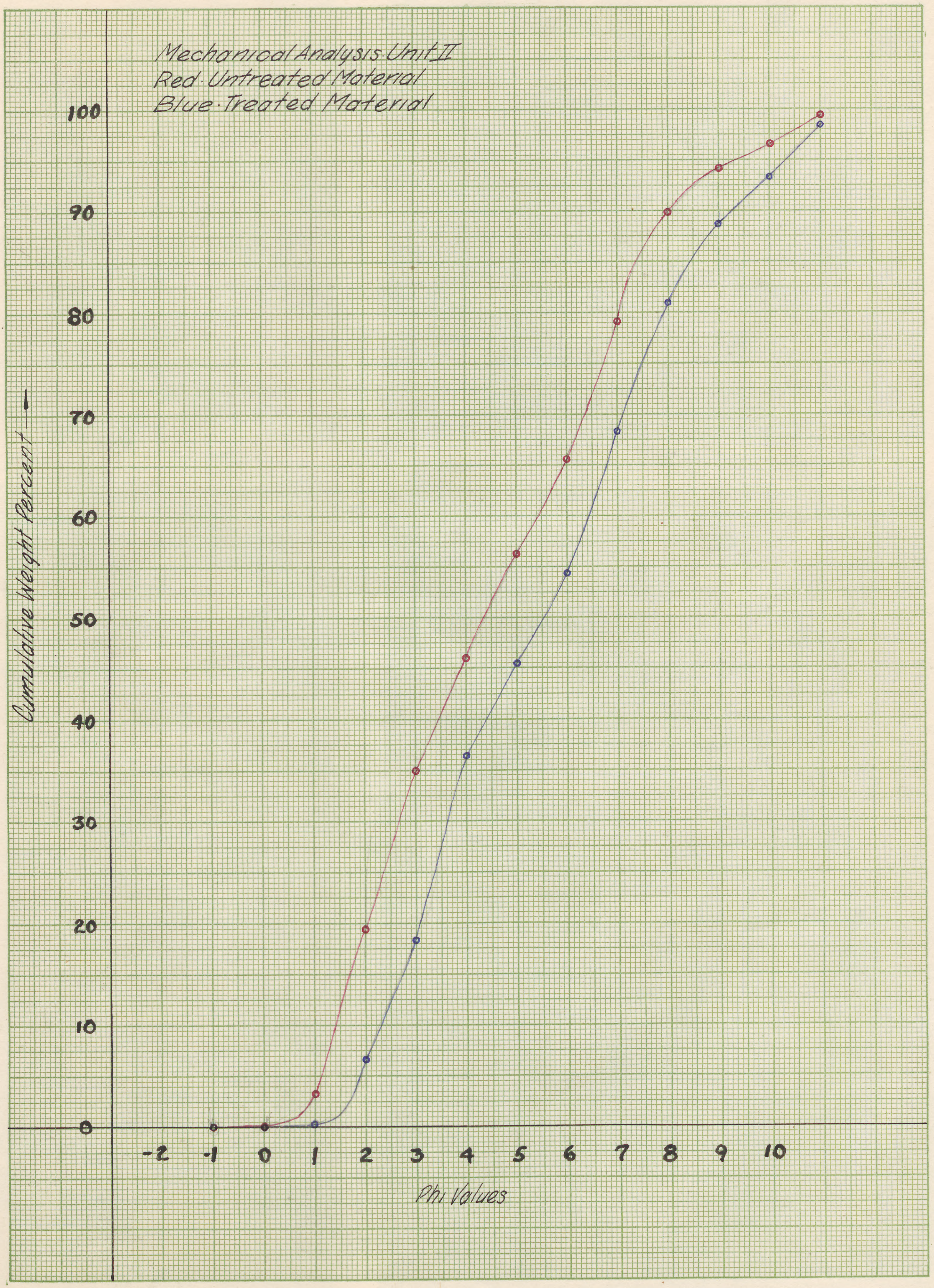

Mechanical Analysis Unit II
Red · Untreated Material
Blue · Treated Material
100
90
80
70
60
50
40
30
20
10
0
Cumulative Weight Percent
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 4

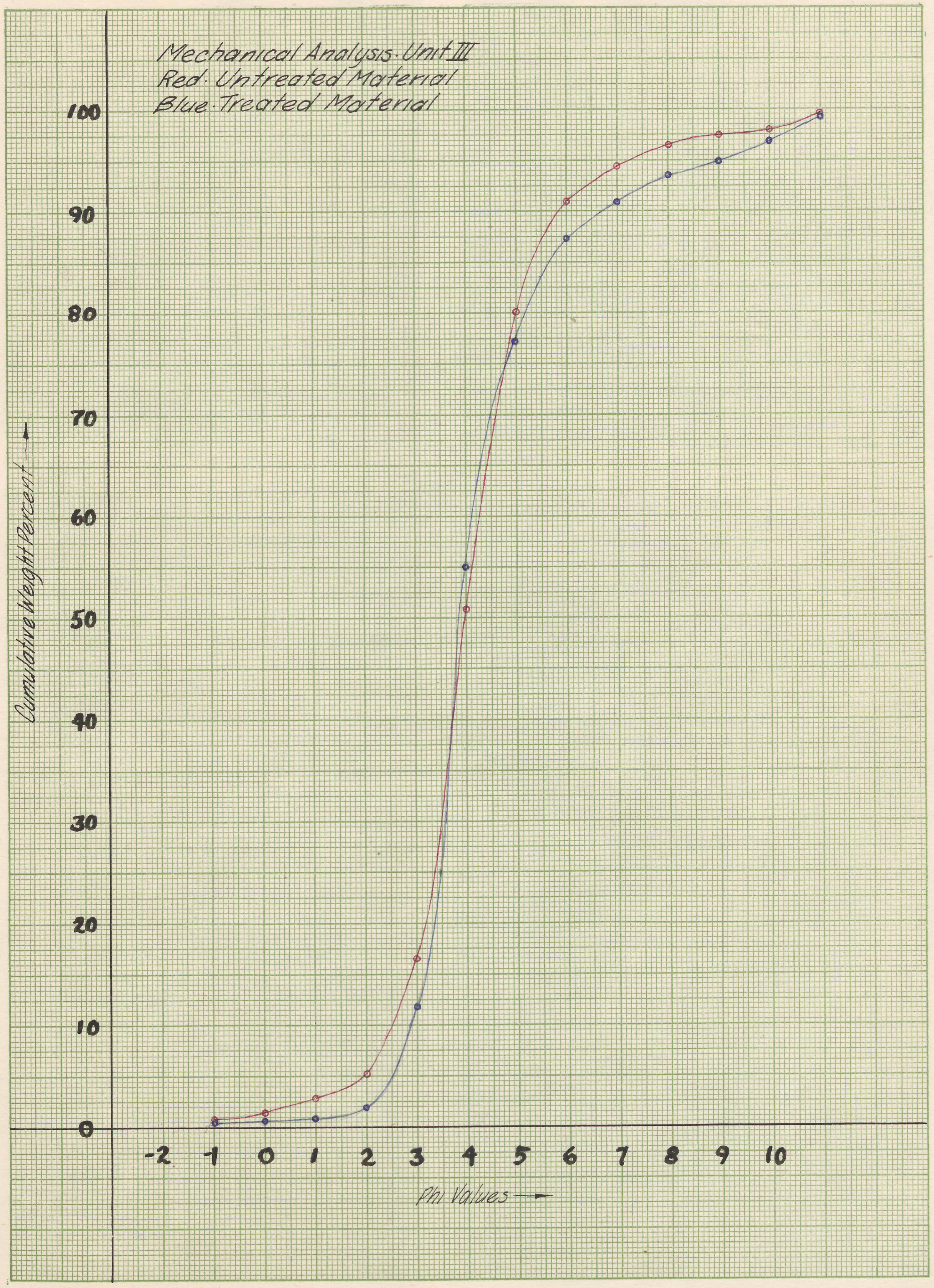
Unit III

Median untr: 4.00 tr: 3.90 Quartile Devn. untr: 0.73 tr: 0.63

1st Quartile untr: 3.35 tr: 3.45 Skewness untr: 0.07 tr: 0.23

3rd Quartile untr: 4.80 tr: 4.80 Quartile Mean untr: 4.08 tr: 4.13

∅ value	∅ size fr	% untr	% tr	diff	cum ∅ size fr	% untr	% tr
-2							
	over -1	0.873	0.513	-0.36	over -1	0.873	0.513
-1							
	-1 to 0	0.600	0.148	-0.45	over 0	1.473	0.661
0							
	0 to 1	1.361	0.283	-1.08	" 1	2.834	0.944
1							
	1 to 2	2.320	0.971	-1.35	" 2	5.154	1.915
2							
	2 to 3	11.35	9.927	-1.42	" 3	16.50	11.842
3							
	3 to 4	34.34	43.230	+8.89	" 4	50.84	55.072
4							
	4 to 5	29.18	22.133	-7.05	" 5	80.02	77.205
5							
	5 to 6	10.94	10.221	-0.72	" 6	90.96	87.426
6							
	6 to 7	3.479	3.525	+0.05	" 7	94.44	90.951
7							
	7 to 8	2.007	2.703	+0.69	" 8	96.45	93.654
8							
	8 to 9	0.972	1.305	+0.34	" 9	97.42	94.959
9							
	9 to 10	0.387	1.936	+1.55	" 10	97.81	96.895
10							
	less than 10	1.766	2.495	+0.73	SubTotal	99.58	99.390
11							
					Sieve loss	0.430	0.611
% sieve loss		0.430	0.611		Total %	100.01	100.001
% pipette error		0.012	0.001				



Mechanical Analysis · Unit III
Red · Untreated Material
Blue · Treated Material
Cumulative Weight Percent
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 5

Unit IV

Median untr: 3.90 tr: 4.25 Quartile Devn. untr: 1.48 tr: 1.25

1st Quartile untr: 2.45 tr: 3.55 Skewness untr: 0.03 tr: 0.55

3rd Quartile untr: 5.40 tr: 6.05 Quartile Mean untr: 3.93 tr: 4.80

Ø value	Ø size fr	% untr	% tr	diff	cum Ø size fr	% untr	% tr
-2							
	over -1	0.069	0.140	+0.07	over -1	0.069	0.140
-1							
	-1 to 0	0.032	0.002	-0.03	over 0	0.101	0.142
0							
	0 to 1	6.630	0.104	-6.53	" 1	7.639	0.246
1							
	1 to 2	6.353	0.173	-6.18	" 2	13.992	0.419
2							
	2 to 3	12.52	8.584	-3.94	" 3	25.512	9.003
3							
	3 to 4	25.94	34.382	+8.44	" 4	52.452	43.385
4							
	4 to 5	18.39	20.102	+1.71	" 5	70.838	63.487
5							
	5 to 6	9.777	10.963	+1.18	" 6	80.615	74.450
6							
	6 to 7	10.38	10.842	+0.46	" 7	90.997	85.292
7							
	7 to 8	3.587	5.822	+2.23	" 8	94.584	91.114
8							
	8 to 9	1.952	3.092	+1.14	" 9	96.536	94.206
9							
	9 to 10	1.225	2.268	+1.04	" 10	97.761	96.474
10							
	less than 10	2.441	2.862	+0.42	SubTotal	100.202	99.336
11							
					Sieve loss	0.710	0.642
% sieve loss		0.710	0.642		Total %	100.912	99.978
% pipette error		0.912	0.022				

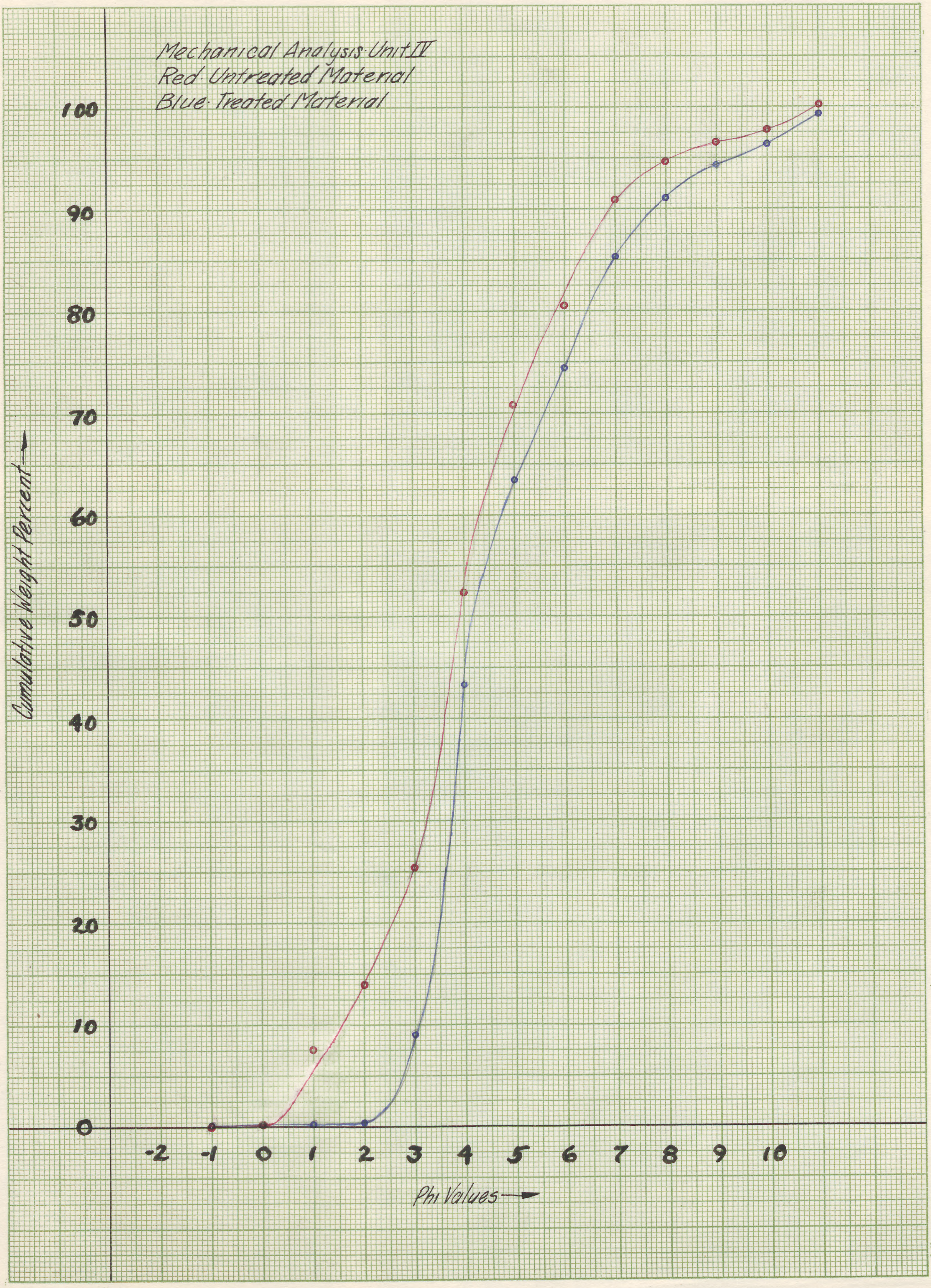

Mechanical Analysis Unit IV
Red Untreated Material
Blue Treated Material
Cumulative Weight Percent
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 6

Unit V

Median untr: 4.15 tr: 3.95 Quartile Devn. untr: 0.70 tr: 0.75

1st Quartile untr: 3.50 tr: 3.40 Skewness untr: 0.05 tr: 0.20

3rd Quartile untr: 4.90 tr: 4.90 Quartile Mean untr: 4.20 tr: 4.15

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0.046	0.525	+0.48	over -1	0.046	0.525
-1							
	-1 to 0	0.086	0.031	-0.06	over 0	0.133	0.556
0							
	0 to 1	0.089	0.068	-0.75	" 1	0.215	0.624
1							
	1 to 2	2.011	0.189	-1.82	" 2	2.225	0.813
2							
	2 to 3	7.764	6.615	-1.14	" 3	9.989	7.428
3							
	3 to 4	35.52	43.720	+8.20	" 4	45.50	51.15
4							
	4 to 5	32.89	25.438	-7.45	" 5	78.39	76.59
5							
	5 to 6	8.535	9.530	+1.99	" 6	86.94	86.12
6							
	6 to 7	5.282	4.917	-0.36	" 7	92.22	91.03
7							
	7 to 8	2.386	2.723	+0.33	" 8	94.61	93.76
8							
	8 to 9	0.981	1.877	+0.90	" 9	95.59	95.63
9							
	9 to 10	0.924	1.607	-0.69	" 10	96.51	97.24
10							
	less than 10	2.055	2.320	+0.26	SubTotal	98.57	99.56
11							

% sieve loss	0.680	0.438	Total %	99.25	99.99(8)
% pipette error	0.770	0.002			

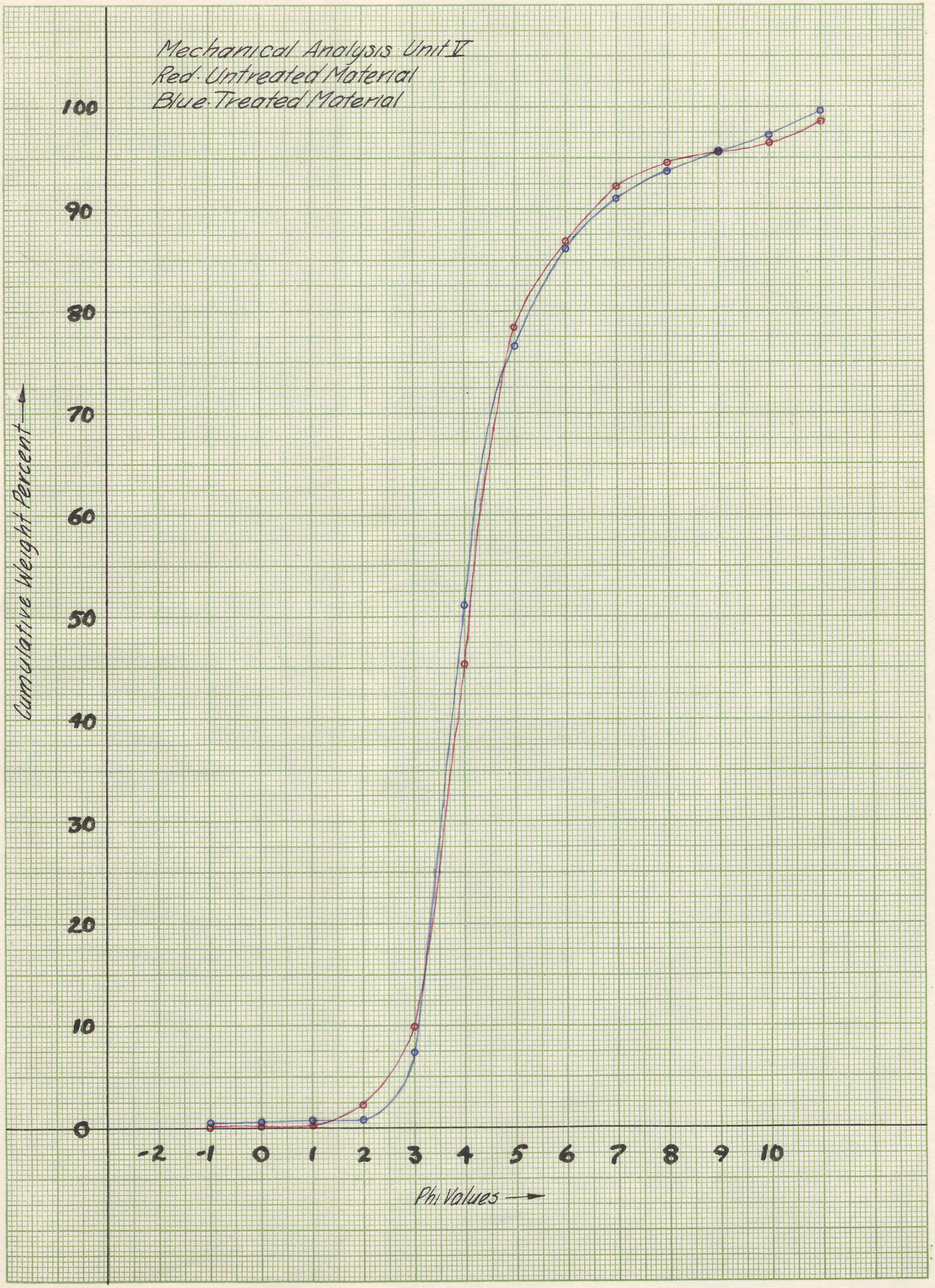

Mechanical Analysis Unit V
Red · Untreated Material
Blue · Treated Material
100
90
80
70
60
50
40
30
20
10
0
Cumulative Weight Percent
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 7

Unit VI

Median untr: 3.70 tr: 4.25

1st Quartile untr: 2.65 tr: 3.45

3rd Quartile untr: 5.35 tr: 5.90

Quartile Devn. untr: 1.35 tr: 1.23

Skewness untr: 0.30 tr: 0.43

Quartile Mean untr: 4.00 tr: 4.68

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0.016	0	-0.02	over -1	0.016	0
-1							
	-1 to 0	0.119	0.020	-0.10	over 0	0.135	0.020
0							
	0 to 1	6.756	0.049	-6.71	" 1	6.891	0.069
1							
	1 to 2	7.889	0.121	-7.77	" 2	14.78	0.190
2							
	2 to 3	16.58	10.97	-5.61	" 3	31.36	11.16
3							
	3 to 4	25.66	34.43	+8.77	" 4	57.02	45.59
4							
	4 to 5	13.72	15.18	+1.46	" 5	70.74	60.77
5							
	5 to 6	13.13	14.83	+1.70	" 6	83.87	75.60
6							
	6 to 7	8.394	2.771	-5.62	" 7	92.26	78.37
7							
	7 to 8	3.129	12.45	+9.32	" 8	95.39	90.82
8							
	8 to 9	1.552	2.609	+1.06	" 9	96.94	93.43
9							
	9 to 10	0.834	2.144	+1.31	" 10	97.77	95.58
10							
11	less than 10	1.928	3.103	+1.17	SubTotal	99.70	98.68
					Sieve loss	0.290	0.465
% sieve loss		0.290	0.465		Total %	99.99	99.14
% pipette error		0.002	0.86				

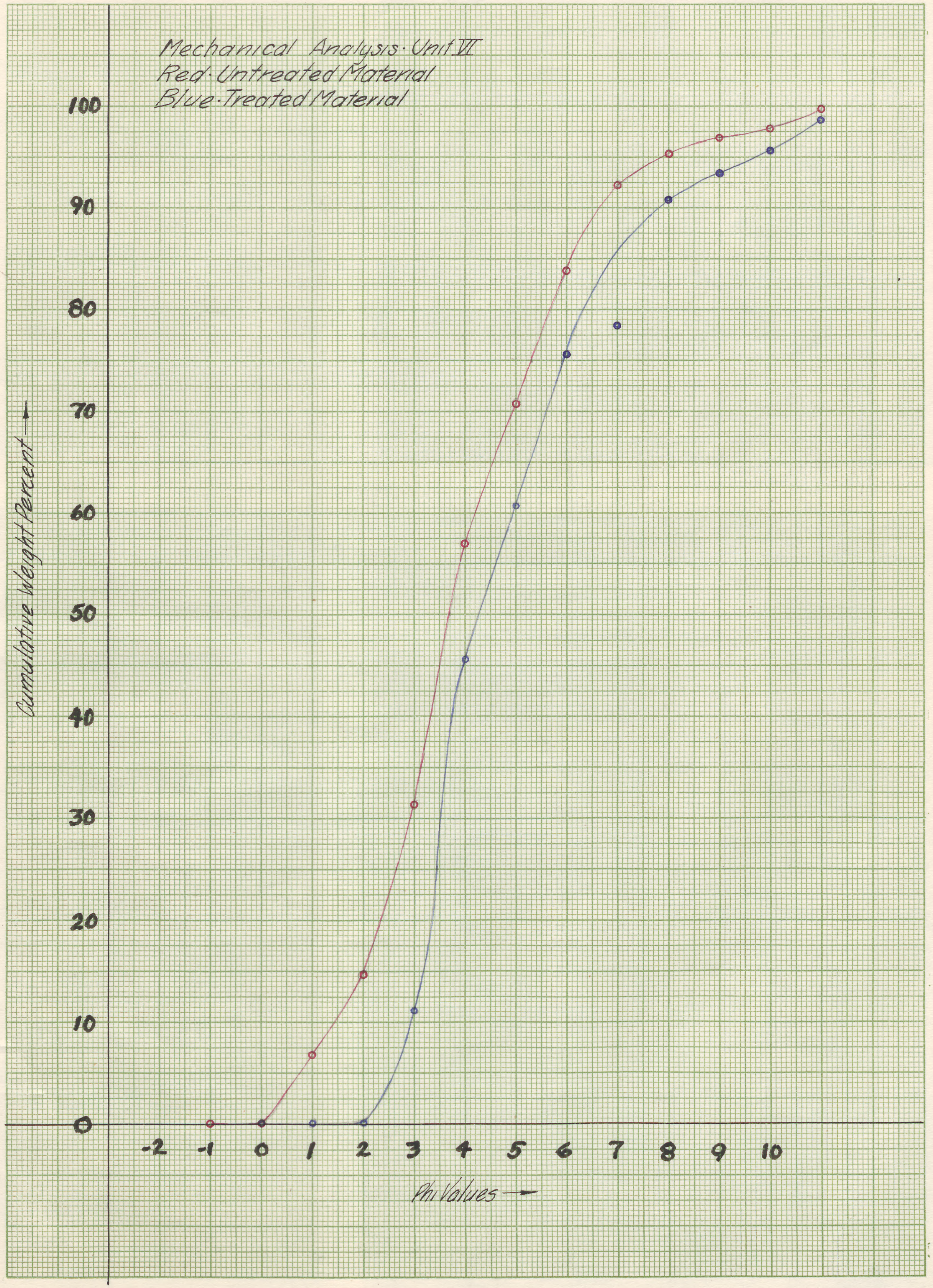

Mechanical Analysis · Unit VI
Red · Untreated Material
Blue · Treated Material
Cumulative Weight Percent
0
10
20
30
40
50
60
70
80
90
100
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values

TABLE 8

Unit VIIa

Median untr: 3.55 tr: 3.25 Quartile Devn. untr: 0.75 tr: 0.58

1st Quartile untr: 2.90 tr: 2.90 Skewness untr: 0.10 tr: 0.23

3rd Quartile untr: 4.40 tr: 4.05 Quartile Mean untr: 3.65 tr: 3.48

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0	0	0	over -1	0	0
-1							
	-1 to 0	0.016	0	-0.02	over 0	0.016	0
0							
	0 to 1	0.176	0.011	-0.17	" 1	0.192	0.011
1							
	1 to 2	2.572	0.869	-1.70	" 2	2.764	0.880
2							
	2 to 3	27.36	31.81	+4.45	" 3	30.12	32.69
3							
	3 to 4	35.57	41.46	+5.89	" 4	65.69	74.15
4							
	4 to 5	22.54	13.37	-9.17	" 5	88.23	87.52
5							
	5 to 6	8.324	5.158	-3.16	" 6	96.55	92.68
6							
	6 to 7	0.645	1.827	+1.19	" 7	97.20	94.51
7							
	7 to 8	4.599	1.652	-2.95	" 8	101.80	96.16
8							
	8 to 9	0.920	0.846	-0.07	" 9	102.72	97.01
9							
	9 to 10	0.285	0.677	+0.39	" 10	103.00	97.68
10							
11	less than 10	2.823	1.700	-1.12	SubTotal	105.83	99.38
					Sieve loss	0.291	0.613
% sieve loss		0.291	0.613		Total %	106.12	99.99(7)
% pipette error		6.118	0.003				

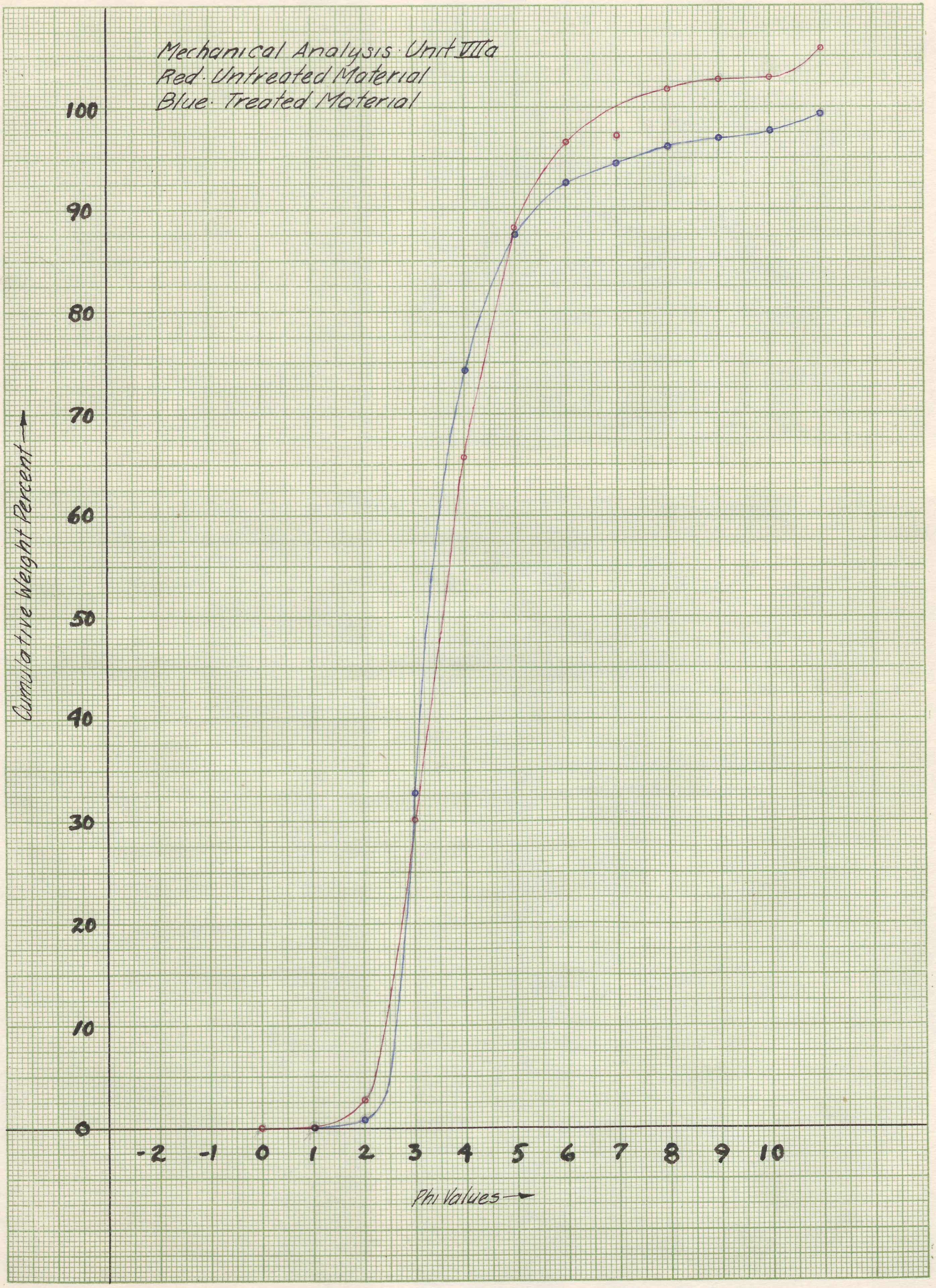

Mechanical Analysis · Unit VIIa
Red · Untreated Material
Blue · Treated Material
Cumulative Weight Percent →
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values →

TABLE 9

Unit VIIb

Median untr: 4.10 tr: 3.90

1st Quartile untr: 3.30 tr: 3.40

3rd Quartile untr: 5.00 tr: 5.00

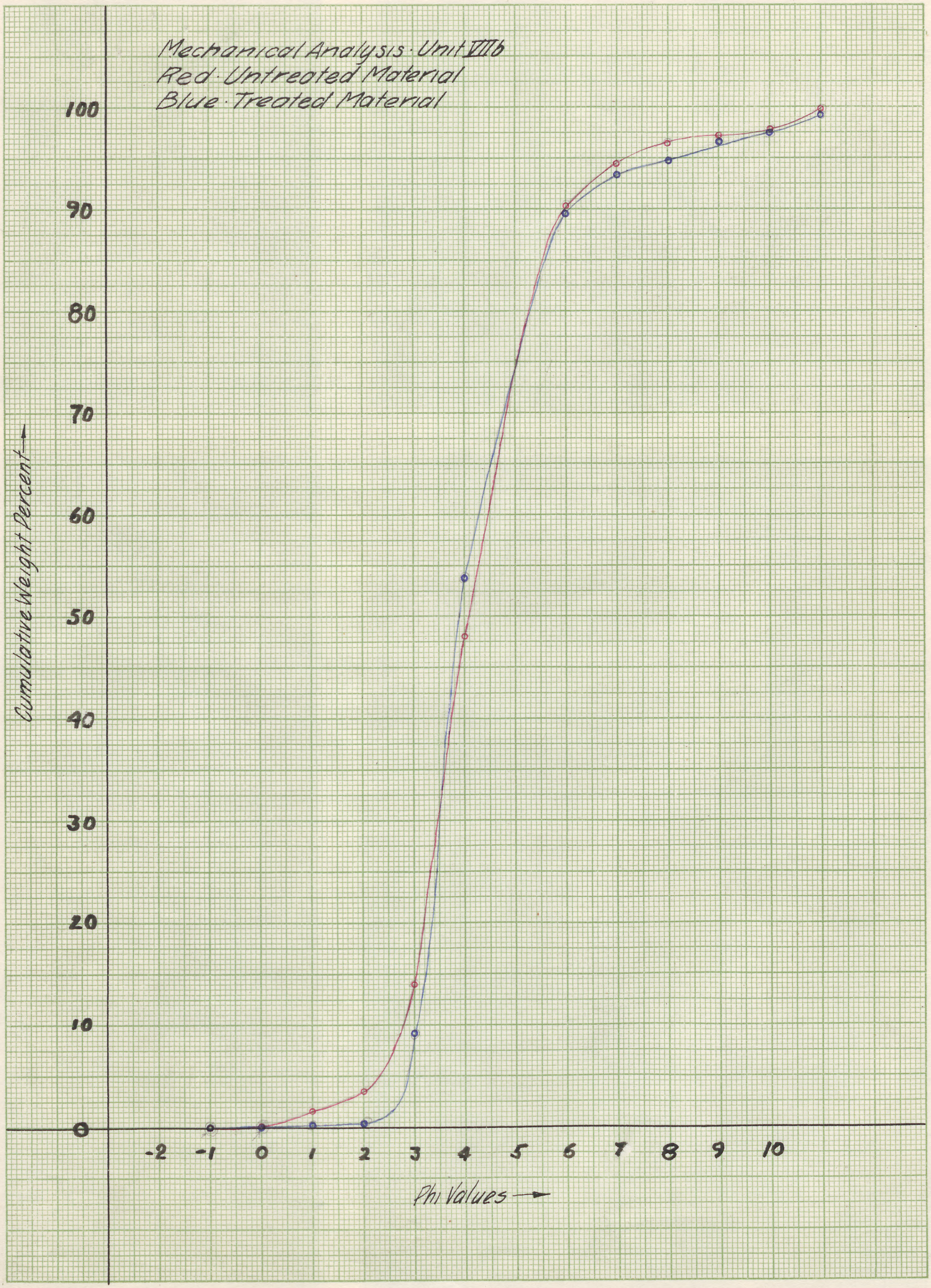
Quartile Devn. untr: 0.88 tr: 0.83

Skewness untr: 0.05 tr: 0.33

Quartile Mean untr: 4.15 tr: 4.23

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0.063	0.087	+0.03	over -1	0.063	0.087
-1							
	-1 to 0	0.127	0.12	-0.12	over 0	0.190	0.099
0							
	0 to 1	1.386	0.047	-1.34	" 1	1.576	0.146
1							
	1 to 2	1.944	0.303	-1.64	" 2	3.520	0.449
2							
	2 to 3	10.54	8.827	-1.71	" 3	14.06	9.276
3							
	3 to 4	33.94	44.51	+10.57	" 4	48.00	53.79
4							
	4 to 5				" 5		
5		42.29	35.88	-6.41		90.29	89.67
	5 to 6				" 6		
6							
	6 to 7	4.259	3.639	-0.62	" 7	94.55	93.31
7							
	7 to 8	1.970	1.552	-0.42	" 8	96.52	94.86
8							
	8 to 9	0.665	1.657	+1.00	" 9	97.18	96.52
9							
	9 to 10	0.524	0.963	+0.44	" 10	97.70	97.48
10							
	less than 10	2.12	1.631	-0.49	SubTotal	99.82	99.11
11							
					Sieve loss	0.177	0.809

% sieve loss	0.177	0.809	Total %	100.00	99.92
% pipette error	0.007	0.080			



10 Millimeters to the Centimeter
MADE IN U.S.A.
No. 5788

TABLE 10

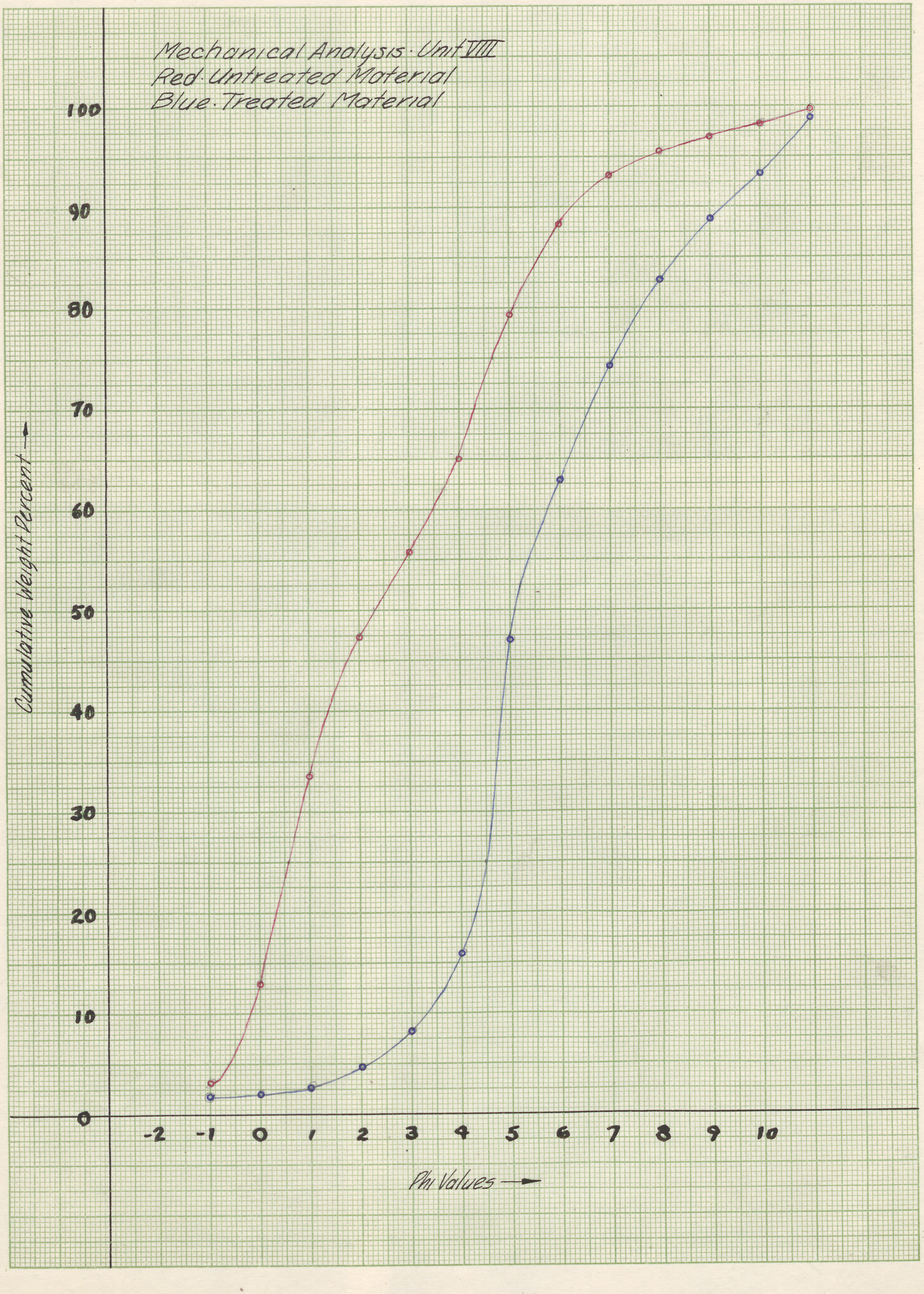
Unit VIII

Median untr: 2.30 tr: 5.10 Quartile Devn. untr: 2.08 tr: 1.30

1st Quartile untr: 0.55 tr: 4.50 Skewness untr: 0.33 tr: 0.70

3rd Quartile untr: 4.70 tr: 7.10 Quartile Mean untr: 2.63 tr: 5.80

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	3.313	1.773	-1.54	over -1	3.313	1.773
-1							
	-1 to 0	9.849	0.239	-9.61	over 0	13.16	2.012
0							
	0 to 1	20.41	0.680	-19.73	" 1	33.57	2.692
1							
	1 to 2	13.82	1.958	-11.86	" 2	47.39	4.650
2							
	2 to 3	8.572	3.450	-5.12	" 3	55.96	8.100
3							
	3 to 4	9.212	7.862	-1.35	" 4	65.18	15.96
4							
	4 to 5	14.18	31.16	+16.98	" 5	79.36	41.12
5							
	5 to 6	8.945	15.86	+6.91	" 6	88.31	62.97
6							
	6 to 7	4.855	11.28	+6.43	" 7	93.16	74.26
7							
	7 to 8	2.358	8.444	+6.08	" 8	95.52	82.70
8							
	8 to 9	1.541	6.091	+4.55	" 9	97.06	88.79
9							
	9 to 10	1.066	4.460	+3.39	" 10	98.13	93.25
10							
11	less than 10	1.657	5.723	+4.06	SubTotal	99.79	98.97
					Sieve loss	0.123	1.030
% sieve loss		0.123	1.030		Total %	99.91	100.00(5)
% pipette error		0.10	0.005				



Mechanical Analysis · Unit VIII
Red · Untreated Material
Blue · Treated Material
Cumulative Weight Percent →
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
Phi Values →

TABLE 11

Unit IX

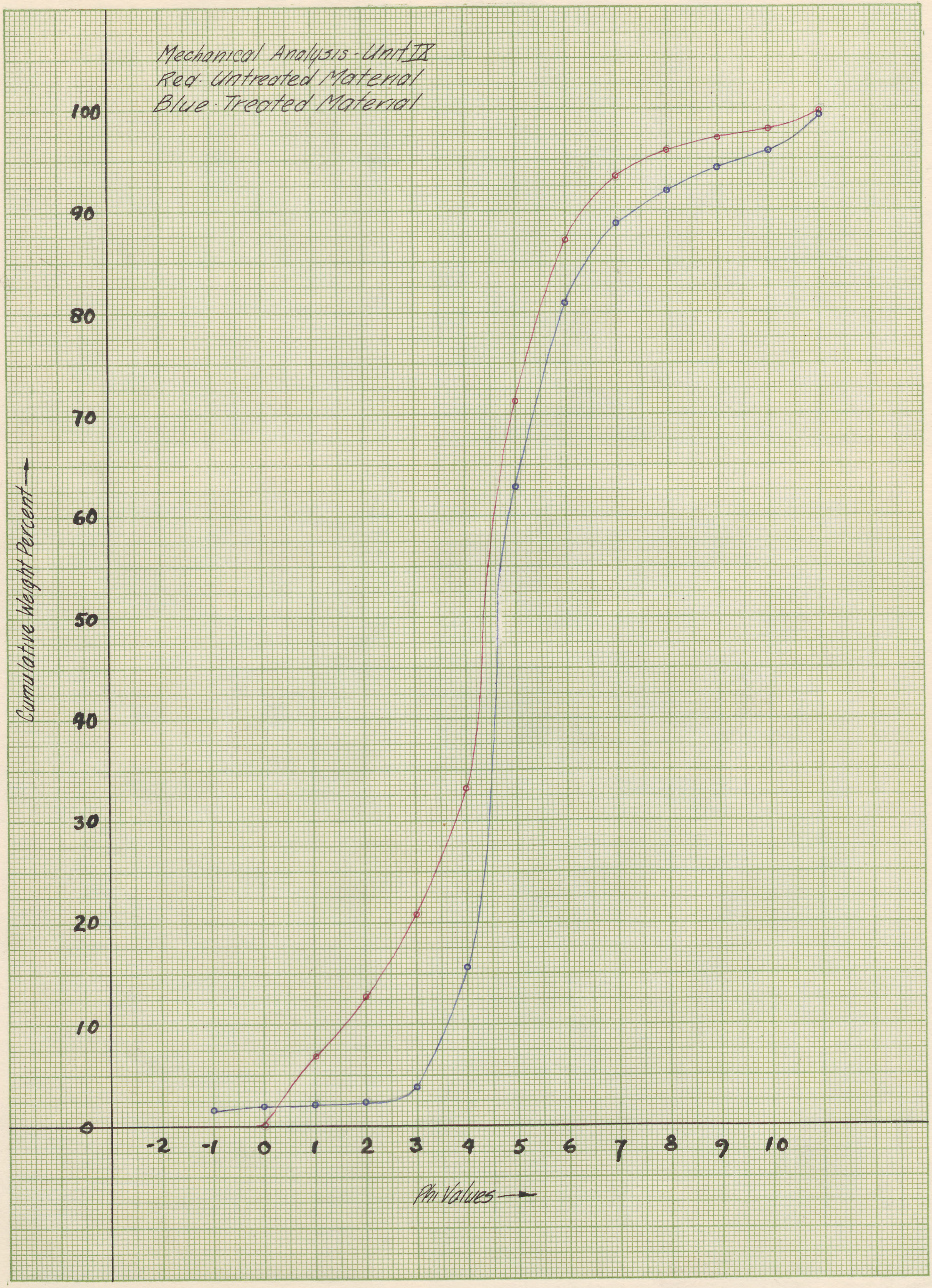
Median untr: 4.35 tr: 4.70 — Quartile Devn. untr: 0.93 tr: 0.65

1st Quartile untr: 3.35 tr: 4.35 — Skewness untr: -0.08 tr: 0.30

3rd Quartile untr: 5.20 tr: 5.65 — Quartile Mean untr: 4.28 tr: 5.00

ø value	ø size fr	% untr	% tr	diff	cum ø size fr	% untr	% tr
-2							
	over -1	0	1.63(?)	+1.63	over -1	0	1.630(?)
-1							
	-1 to 0	o.151	o.360	+o.21	over 0	o.151	1.990
0							
	0 to 1	6.734	o.116	-6.61	" 1	6.885	2.106
1							
	1 to 2	5.878	o.309	-5.57	" 2	12.76	2.415
2							
	2 to 3	8.001	1.497	-6.50	" 3	20.76	3.912
3							
	3 to 4	12.38	11.64	-o.64	" 4	33.14	15.55
4							
	4 to 5	39.21	47.34	+8.13	" 5	72.35	62.89
5							
	5 to 6	14.79	18.09	+3.30	" 6	87.14	80.97
6							
	6 to 7	6.189	7.744	+1.55	" 7	93.33	88.72
7							
	7 to 8	2.510	3.245	+o.74	" 8	95.84	91.96
8							
	8 to 9	1.284	2.221	+o.94	" 9	97.12	94.18
9							
	9 to 10	o.872	1.640	+o.77	" 10	97.99	95.82
10							
	less than 10	1.775	3.593	+1.81	SubTotal	99.77	99.42
11							
					Sieve loss	o.230	o.587

% sieve loss	o.230	o.587	Total %	100.00(1) 100.00(3)
% pipette error	o.001	o.003		



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Roundness Analyses

Method used: Theoretically, the measurement of the roundness of any individual particle involves the measurement of all the solid angles of the particle which cause its "corners" and "edges" to depart in roundness from that of a solid of perfect roundness, such as a sphere. Such measurement is manifestly impossible under practical conditions, except for objects such as fairly large pebbles, and even in those cases, measurement is extremely difficult. Thus, measurements of the roundness of individual small grains are undertaken mainly by measurement of either their projected areas or cross-sections.

The method of roundness determination given by Wadell (1935, pp. 250-280) is based on measurements on the projected area of a grain, and is discussed at some length by Krumbein and Pettijohn (1938, pp. 283-286; 295-302). According to them, Wadell's method, although time consuming is theoretically sound and sensitive to small changes in angularity. Therefore, with certain modifications, it was adopted for use in studying the Geddes silts.

Wadell defined the roundness of a plane corner as expressible by the ratio R/r, where R is the radius of the maximum inscribed circle in the projected area of the grain, and r is the radius of curvature of the corner. The total roundness is found by dividing the number of corners, N, by the sum of R/r to give the value ρ (rho), which varies between a maximum of 1.0 (perfect roundness) and a minimum of 0 (no roundness-complete angularity). The equation is thus (Wadell, 1935, p. 267)

$$\frac{N}{\Sigma(R/r)} = \rho \qquad (1)$$

This equation is preferred by Wadell to the more usual form which is given by Krumbein and Pettijohn (1938, p. 285) as

$$\frac{\Sigma(R/r)}{N} = \rho \qquad (2)$$

The reasons given by Wadell for preferring equation (1) are as follows: Equation (1) results in a slightly lower value than (2) for the roundness of particles having corners of greatly differing roundness values. Relatively well rounded particles, which by chipping or fracturing shortly before deposition have obtained a very low degree of roundness are placed in a lower roundness class by (1). The results are thus more influenced by recent events of transportation preceding deposition than when using (2). (Wadell, 1935, loc. cit.)

The preparation for measurement as outlined by Wadell are extremely complicated and tedious. Therefore, the following abridged procedure was adopted.

From an inspection of their mechanical analyses curves, units I, III, IV, and VI were chosen for examination, as being representative of the samples with the exception of units VIII and IX. The dominant grade-size fraction 1/8-1/16 mm., obtained by the previous mechanical analysis of the untreated material, was carefully wet sieved through a 1/16 mm. sieve, to insure that any remaining particles under 1/16 mm. would be removed. The fractions were then dried and three random samples taken of each of the four fractions. From each sample, a separate slide was made by mounting the grains in random orientation in Mowilith "H" a mounting medium of n approximately 1:50.

These slides were placed in a microprojector fitted with Polaroid "J" discs, one of which was placed in the light source as a polarizer and the other below the objective as an analyser. The images of the grains were projected onto sheets of drawing paper by means of a right angle prism.

The grains were magnified to give an average largest diameter for the projected images of approximately 7 cm., as an equivalent to Wadell's "standard size" of 7 cm. (Wadell, 1935, p. 257). Although the images varied in largest diameter from 5 to 10 cm., depending on the objective-ocular combination used, the majority fell in the range 6-8 cm., thus giving the desired approximate average of 7 cm.

The grains, when examined in plane polarized light, and under crossed Nicols, proved to be mainly quartz. Thus it was not difficult to select 20 random grains from each slide, and trace their outlines. An effort was made to avoid using grains showing secondary enlargement, and all grains of a suspicious nature were disregarded. Even so, some secondarily enlarged grains may have been used accidentally. The effect of this is discussed under <u>Sources of error</u>.

Wadell (1935, p. 256) advises that not less than 20 grains should be traced in any single grade size. Since three slides were made for each unit, a total of 60 grains was traced per unit, giving a "safety factor" of 3 in securing a representative sample for computation.

The actual roundness determinations were made by measurement of the tracings with a circle scale. This scale consisted of a series of concentric circles whose radii increased from 1 mm. to 70 mm., inscribed on a sheet of transparent plastic. The innermost 1 mm. circle is drawn in black, the following 2, 4, 6, 8, and 10 mm. circles in red, those from 12 to 20 in black and up to 70 mm. in even amounts, with alternating colors every 10 mm. Using this scale, the radius of the largest inscribable circle (R) and the radius of each corner (r) was found for all grains traced, by superimposing the scale on the traced grain and shifting the scale until the proper curve was located. Odd numbered values were found by interpolating between two adjacent circles.

The problem of what is, and what is not, a "corner" is partially solved by Wadell's definition of a corner as "a curve of the outline of reproduction having a radius equal to, or less than, the radius of the maximum inscribed circle." (Wadell, 1935, p. 268.) This problem is discussed at greater length under Sources of error.

After the values R and r_1, r_2, r_3, ...r_n had been found for each grain, and the number of corners counted, the value was computed by slide rule, using equation (1). The data resulting is given under Data from roundness analyses.

Sources of error: As in the section on Mechanical Analyses, a table of sources of error; their probable effect on observations and possible corrections is given below. The usages positive and negative are in the same sense as in that section. The errors discussed here are errors in the application of Wadell's method. Theoretical errors in the method itself are beyond the scope of this paper.

TABLE 12

	Source of Error	Effect on Observation	Possible Correction
1.	Non-standard image size.	If image is above 7 cm. small irregularities will be enlarged so that they can be measured, thus −. If image is below 7 cm., larger corners smoothed, and small corners suppressed, thus +.	Sufficient number of grains to even out inequalities of individual grains. Also magnification adjustable.
2.	Tracing of image.	If corners oversmoothed, give larger corner radii, thus +. If corners overly irregular, effect is opposite, thus −.	Care in tracing.
3.	Secondary enlargement.	Usually increases the number and angularity of corners, thus −.	Avoid using grains showing such growth, or if possible, treat grains before mounting to remove such material.

The problem mentioned above as the "size of corners," needs a more extended discussion than can be given in the tabular form. It is related to items (1) and (2) in table 12, above.

Wadell's definition of "corner" given above delimits the maximum radius a corner may have, and on the projected image, we may assume that 1 mm. is the minimum. But when the corner is considered as the arc of a circle, what are the limits to the size of the chord?--In other words, how "big" must a corner be, especially when considered in relation to other corners? It was found that many large or moderate-sized corners were actually made up of smaller corners, due to the superimposition of corner images not in the same plane on the grain. The problem is made more complex by Item (1) table 12, since a higher magnification used to bring a small grain up to standard size will also enlarge the size of the secondary corners, whereas if that particular image were over standard size, reduction would suppress the smaller secondary corners. The author finally was forced to a rule of thumb usage in dealing with this problem. All corners which appeared to be simple or independent, regardless of size, were measured, while large corners which seemed to be made of several small corners where measured as a whole, with no attention paid to their component parts. If the number of grains is large enough, the positive error introduced by this smoothing of large curves will be distributed quite evenly throughout the data and the results should be consistent within themselves.

Data from roundness analyses: On the following pages, the data found in the roundness analyses which are described above are given. Also given are some statistical measures derived from these data. The correlations and conclusions drawn from these data as well as from the mechanical analyses are given under Conclusions From Sedimentary Analyses.

The data resulting from the roundness analyses are given as a frequency table for each unit, and also as a general frequency table for the combined four units. The statistical measures given are: The arithmetic mean for each unit, the arithmetic mean for the combined four units and the median, first quartile, third quartile, quartile deviation, quartile mean and skewness are given for the combined four units. Accumulative frequency curve in terms of per cent roundness between 0 and o.499 is also given.

TABLE 13

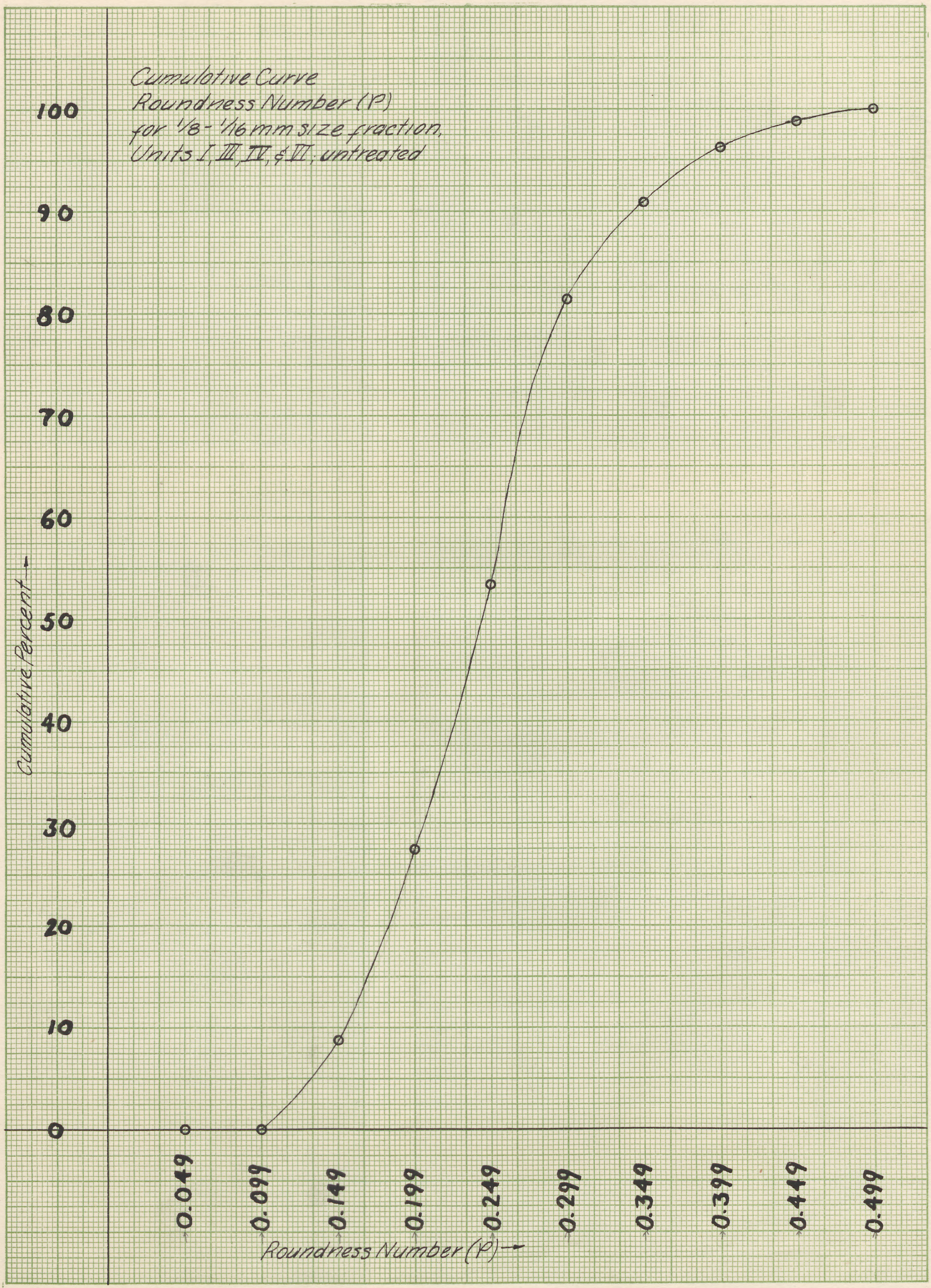
Frequency Tables for Roundness Values, 1/8-1/16 mm. Size Fraction, Units I, III, IV, & VI; Untreated

1st Quartile: o.195 3rd Quartile: o.288

Median: o.244 Quartile Devn.: o.047

Quartile Mean: o.242 Skewness: -o.003

Classes	I	III	IV	VI	Total	Cumul	Cum %	Cumul Classes
o.000-o.049	0	0	0	0	0	0	0	0-o.049
o.050-o.099	0	0	0	0	0	0	0	0-o.099
o.100-o.149	9	9	1	2	21	21	8.75	0-o.149
o.150-o.199	12	17	8	8	45	66	27.5	0-o.199
o.200-o.249	12	20	16	14	62	128	53.4	0-o.249
o.250-o.299	20	4	23	20	67	195	81.3	0-o.299
o.300-o.349	3	7	5	8	23	218	90.8	0-o.349
o.350-o.399	0	3	4	6	13	231	96.3	0-o.399
o.400-o.449	3	0	1	2	6	237	98.8	0-o.449
o.450-o.499	1	0	2	0	3	240	100.0	0-o.499
Arith. Mean	o.234	o.219	o.266	o.266	o.246			


Cumulative Curve
Roundness Number (P)
for 1/8 - 1/16 mm size fraction,
Units I, III, IV, & VI; untreated
100
90
80
70
60
50
40
30
20
10
0
Cumulative Percent
0.049
0.099
0.149
0.199
0.249
0.299
0.349
0.399
0.449
0.499
Roundness Number (P)

Conclusions From the Sedimentary Analyses

The sedimentary analyses of the Geddes silts and the statistical measures derived therefrom display several outstanding characteristics, which give a fairly good basis for the conclusions farther on in this section.

The statistical measures derived from the mechanical analyses are described in terms of ∅ intervals or ∅ values (boundaries of ∅ intervals). The statistical measures derived from the roundness analyses are given in terms of ρ, where ρ is Wadell's roundness number, varying between 0 and 1.0 as lower and upper limits. Thus o.50 would be the expression for a particle having half the theoretical maximum roundness value.

The characteristics derived from the mechanical analyses are: (1) A dominant grade-size fraction lies between 3 and 4 ∅ values (1/8-1/16) in all the mechanical analyses with the exception of II untreated and VIII and IX treated and untreated. In II, untreated, the dominant grade-size fraction is located between 2 and 3 ∅ values (1/4-1/8 mm.). In VIII and IX, the maximum grade-size fraction is located between 4 and 5 ∅ values (1/16-1/32 mm.). (2) The median varies from 2.50 ∅ value (VIII) to 4.40 ∅ value (II) for the untreated material, and from 3.25 ∅ value to 5.55 ∅

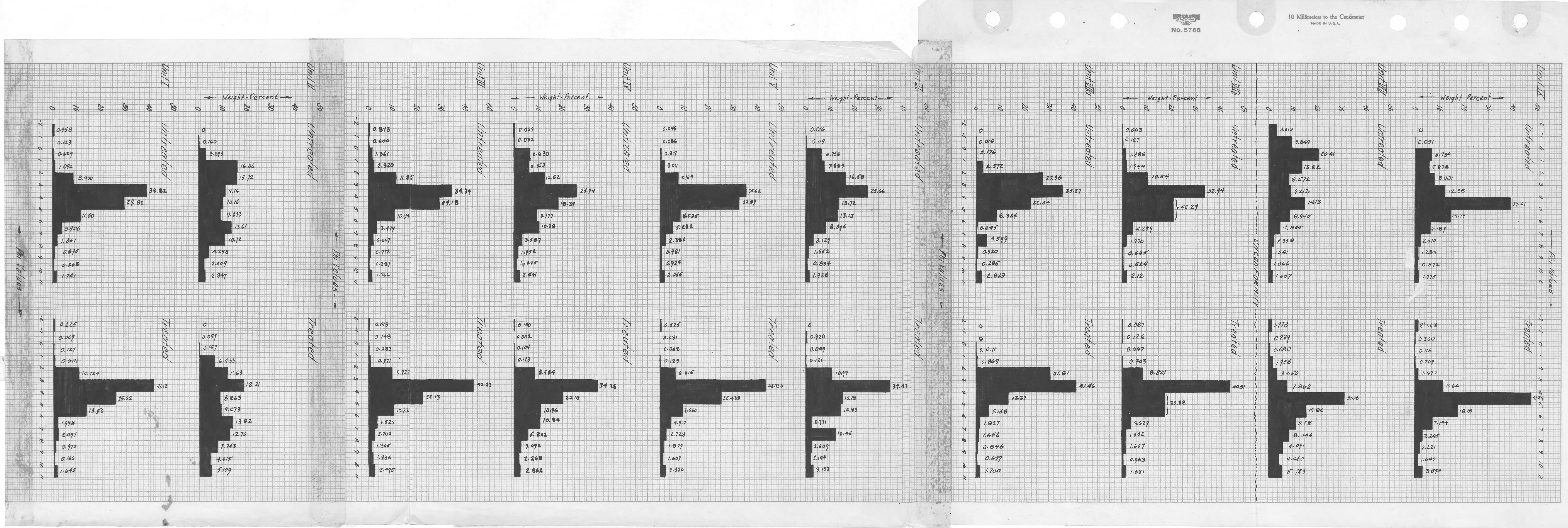
TABLE 14

Results of Acid Treatment of Geddes Silts

(+ means increase after treatment

(- means decrease after treatment

	Dominant Grade-size fract. Position	Dominant Grade-size fract. % change	Median Shift (Ø value)	Quartile Mean Shift (Ø value)	Quartile Devn. Change (Ø interval)	Quartile Skewness Position untr.	Quartile Skewness Position tr.	Quartile Skewness Change (Ø int)
Unit I	3Ø to 4Ø	+3.30	-0.15	-0.05	+0.05	0.03	-0.03	-0.06
Unit II	3Ø to 4Ø 2Ø to 3Ø	+7.05 -4.09	+1.15	+0.85	-0.15	0.18	-0.13	-0.31
Unit III	3Ø to 4Ø	+8.89	-0.10	+0.05	-0.10	0.07	0.23	+0.16
Unit IV	3Ø to 4Ø	+8.44	+0.35	+0.87	-0.23	0.03	0.55	+0.52
Unit V	3Ø to 4Ø	+8.20	-0.20	-0.05	+0.05	0.05	0.20	+0.15
Unit VI	3Ø to 4Ø	+1.46	+0.55	+0.68	-0.12	0.30	0.43	+0.13
Unit VIIa	3Ø to 4Ø	+5.89	-0.70	-0.17	-0.17	0.10	0.23	+0.13
Unit VIIb	3Ø to 4Ø	+10.57	-0.20	+0.08	-0.05	0.05	0.33	+0.28
Unit VIII	4Ø to 5Ø	+16.98	+2.80	+3.17	-0.78	0.33	0.70	+0.37
Unit IX	4Ø to 5Ø	+8.13	+0.35	+0.72	-0.28	-0.08	+0.30	+0.38



"Geddes Silt" Histograms in Stratigraphic Sequence value for the treated material, with 15 of the total 20 values falling between 3.51 and 4.50 ∅ values.

(3) The quartile mean varies from 2.63 ∅ value (VIII) to 4.58 ∅ value (II) for the untreated material, and from 3.48 ∅ value (VIIa) to 5.80 ∅ value (VIII) for the treated material, with 15 of the 20 values falling between 3.76 and 5.00 ∅ values.

(4) The quartile deviation varies between 2.18 ∅ intervals (II) and 0.68 ∅ interval (I) for the untreated material, and 2.03 ∅ intervals (II) and 0.58 ∅ intervals (VIIa) for the treated, with 12 of the 20 values falling between 0.51 ∅ interval and 1.00 ∅ interval.

(5) The quartile skewness varies from -o.08 ∅ interval (IX) to 0.33 ∅ interval (VIII) in the untreated material, and from -o.13 ∅ interval (I and II) to 0.70 ∅ interval (VIII) in the treated material, with 13 of the 20 values falling between 0.00 ∅ interval and 0.30 ∅ interval.

The following conclusions may be drawn as to the effect of acid treatment on the Geddes silts (see Table 14):

a. There is a general decrease in the percentages of the sizes above 3 ∅ value, with a large increase in the size 3 ∅ - 4 ∅, a decrease in the size 4 ∅ to 5 ∅, and variable small increases in the sizes below 5 ∅.

b. The dominant grade-size fraction showed no shift in position after treatment, but as noted above, showed an increase in percentage.

c. The median showed a curious alternation in position. It shifted in alternate units from large to smaller ∅ values and vice versa, until units VIIa and VIIb, where both medians shift to smaller values, and units VIII and IX, where both medians shift to larger values.

d. The quartile mean shifted irregularly, units I, V, and VIIa shifting to smaller ∅ values, while the rest shifted to larger ∅ values.

e. The quartile deviation showed a general decrease except for units I and V which showed small increases in ∅ interval.

f. The quartile skewness shows a shift to a greater ∅ interval in the positive sense, in all cases but I and II where the shift is not only negative in sense, but transfers the quartile mean to the negative side of the median.

Although the size range in all of the sediments is high, going from gravel in some cases, and coarse sand in others, to clay, the sorting is good, as is shown by the quartile deviation. The only units possessing "low" sortings are VIII untreated and II treated and untreated. This is on the basis of a quartile deviation of more than 2.00 ∅ intervals as a low sorting index.

The maximum grade-size fraction is coarse for a true loess, but the medians fall generally at less than 3.50 ϕ value (less than o.09 mm.) indicating that at least 50% of the sediments are below that size. The quartile mean shows a concentration closer to the value 4.30 ϕ value (0.04 mm.) indicating that the central 50% of the grade sizes are clustered about this value.

Because the measurements of roundness were done on a more restricted scale, interpretations are made with greater hesitancy than is the case with size analysis. The 240 grains which were measured are classified according to the table given by Pettijohn (1949, table 14, p. 51) as follows: 8.72% angular, 43.6% subangular, 44.0% subrounded and 2.68% rounded, with the arithmetic mean of the 240 grains (o.246) falling in the subangular size grade. Both the quartile deviation and the skewness are very small. The curve is thus narrow in spread and skewed slightly to the left of the median.

The classification given above according to the groupings by Pettijohn is used only because the limits of Pettijohn's table and Wadell's roundness number are the same; i.e. between 1 and 0. Whether Wadell's method really gives values that can be fitted with confidence to Pettijohn's classification is unknown.

However, the grains are certainly dominantly sub-angular. This, plus carbonate cementation may explain the ability of the silts to stand in straight upright walls.

COMPARISONS WITH SOME SIMILAR SEDIMENTS

The mean grade-size analysis of the units I to VIIb, untreated, inclusive, is compared in a table and on a graph with the following: A loess from the Neckar Valley, Heidelberg, Germany (Russell, 1934, p. 30); the mean of two loesses from the Sanborn formation of the High Plains of Northwestern Kansas (Swineford and Frye, 1945, p. 252); a dust collected in September 1939, on the third floor of a hotel in Ft. Meade, Kansas, (Swineford and Frye, op. cit. loc. cit.) and the mean of two dusts collected in 1919 and 1920 at Madison, Wisconsin. (Winchell and Miller, 1922, p. 362.) Cumulative curves for all five sets of data are also given.

An inspection of the cumulative curves of figure 12 shows two important differences between the Geddes silt and the other four sediments. These are the maximum grade-size fraction and the sorting.

The maximum grade-size fraction, and with it the median, lies between the 3 Ø - 4 Ø values. The median is just about at 4 Ø value, whereas the maximum grade-size fractions of the other materials are located between 4 Ø - 5 Ø in (3) and (4), between 5 Ø - 6 Ø in (2) and 6 Ø - 7 Ø values in (5). The medians are

TABLE 15

Grain Size Distribution in the "Geddes loess" as Compared with Known Loesses and Two Dust Falls

Ø value	Ø size fr	(1)	(2)[a]	(3)[a]	(4)[a]	(5)[a]
-2						
	over -1	0.254	n.d.	n.d.	n.d.	n.d.
-1						
	-1 to 0	0.154	n.d.	n.d.	0.04	0.54
0						
	0 to 1	2.47	1.0	0.11	0.19	0.16
1						
	1 to 2	5.04	0.5	0.29	0.38	0.32
2						
	2 to 3	13.83	0.5	0.31	1.64	0.48
3						
	3 to 4	30.21	4.5	2.96	8.45	2.00
4						
	4 to 5	19.35	27.5	46.42	41.45	7.00
5						
	5 to 6	11.60	40.5	26.11	24.41	28.00
6						
	6 to 7	6.24	14.0	9.49	5.63	33.00
7						
	7 to 8	3.79	4.0	5.20	3.89	8.00*
8						
	8 to 9	1.525	2.0	2.72	5.31	19.70**
9						
	9 to 10	0.863	1.0	1.39	2.67	
10						
	less than 10	2.219	(5.5)	5.02	5.55	
11						

a) Recomputed to the Ø scale by the author.
*--7.0 to 7.5 Ø
**--less than 7.5 Ø

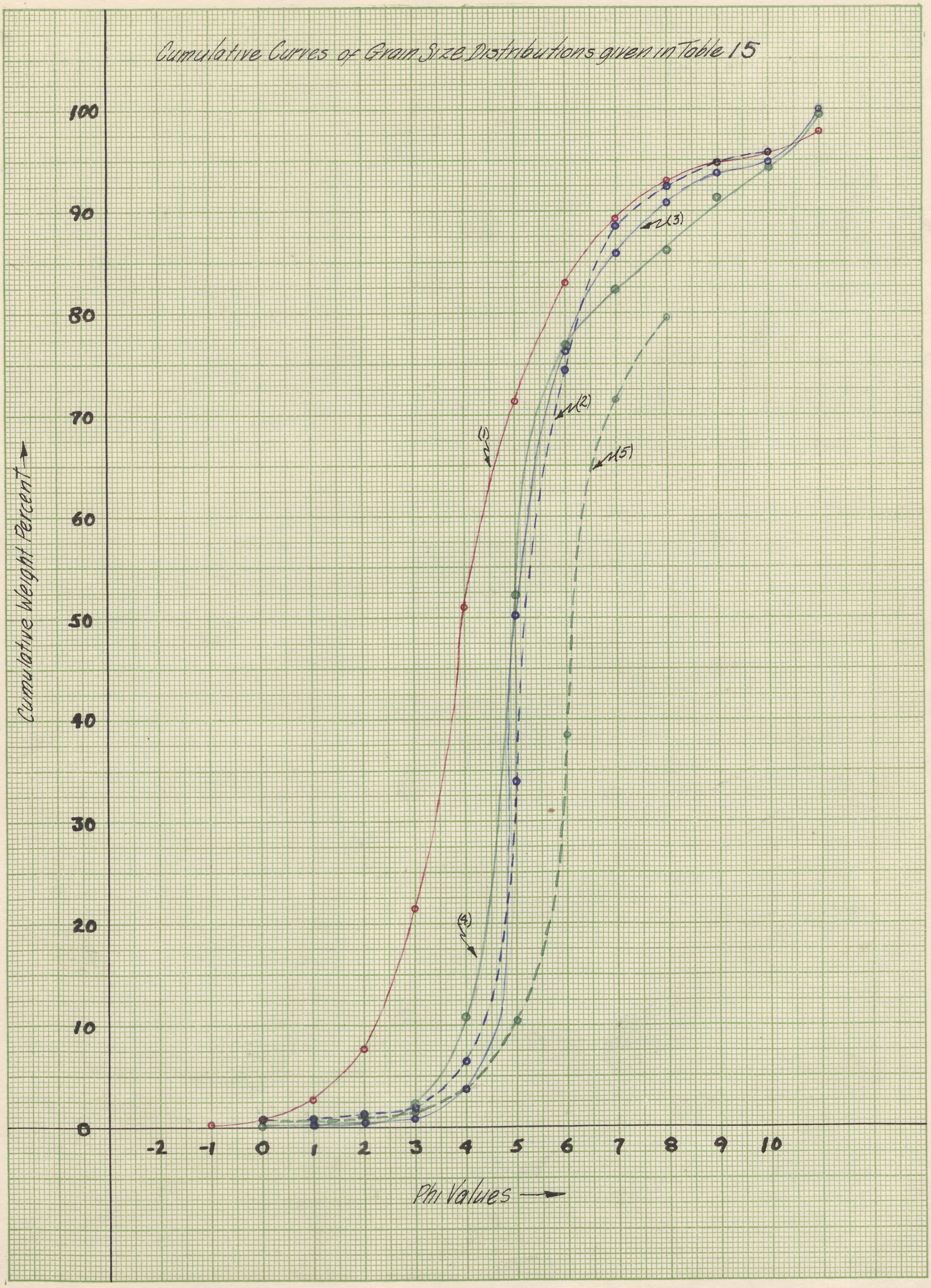
(1) Mean of Units I-VIIb, "Geddes loess," Ann Arbor, Michigan

(2) Loess from the Neckar Valley, Heidelberg, Germany (Russell, 1944)

(3) Mean of two loesses from the Sanborn formation, Northwest Kansas (Swineford and Frye, 1945)

(4) Dust collected in Fort Meade, Kansas, September, 1939 (Swineford and Frye, 1945)

(5) Mean of two dusts collected in Madison, Wisconsin, in 1918 and 1920 (Winchell and Miller, 1922)



Cumulative Curves of Grain Size Distributions given in Table 15
Cumulative Weight Percent →
100
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
(1)
(2)
(3)
(4)
(5)
Phi Values →

correspondingly shifted into the smaller grade sizes. The median of (2) is at 5.4 Ø value; of (3) at 5 Ø value; of (4) at 5 Ø value and of (5) at 6.3 Ø value. Thus all the medians are at least 1 Ø interval smaller than that of (1).

The sorting of (1), as indicated by a quartile deviation of 1.08 Ø interval, is fairly good. The quartile deviation of (2) is 0.63 Ø interval; that of (3) is 0.55 Ø interval; that of (4) is 0.73 Ø interval; and that of (5) is 0.75 Ø interval. The poorest sorted among these is (5), yet it is almost half again as well sorted as (1).

Thus the Geddes silts, although resembling true loess and dust deposits in grade-size composition is too coarse and too poorly sorted to be classified as a true loess on these grounds alone. Further inspection of the cumulative curves for table 14 discloses a grouping which is very interesting. Curves (2), (3), and (4) all fall quite close to each other, with (1) and (5) removed in opposite directions, but approximately equidistant from the central group. This may indicate that a sediment of type (1) and a sediment of type (5) form boundary curves to a general loessal group which falls in the area between the curves. Conclusions based on only 5 grade-size curves may be misleading, but if a great many curves of true loess and loesslike material were plotted, the existence of such an area might be precisely demonstrated. This "area" and its limiting curves could perhaps be used as the basis for a more precise definition of loess than any now current.

GENERAL CONCLUSIONS

The study made of the exposure on Geddes Avenue suggests the following general conclusions:

1. The "Geddes loess" is a series of loesslike sandy silts, deposited, probably by glacial melt-water in a periglacial pond, as outwash from the advancing Huron-Erie lobe of Cary glaciation.

2. The lack of bedding within many units of the exposure, a fairly high carbonate content, a light tan to brown color, the angularity of the component sedimentary grains, ability to stand in vertical walls and break away in slabs, all justify the adjective "Loesslike" for this material. However, it is not a true loess on the basis of grain-size distribution. Scheidig (1934, pp. 58-64) discusses loesslike sediments at length as "Loesslike sediments" and as "Related earth materials." Strictly according to Scheidig's ideas, the Geddes silts are related to his "Silte und Schluffe," on account of their common fluvial origin. On the other hand the Geddes silts are also related to Scheidig's "Sand loess, Loesssand, Feinsand" by reason of their grain-size distribution.

3. The origin of loesses or loesslike sediments is not to be found in any one particular mechanism.

With a moderate shift of grain-size distribution, the Geddes silts would be trueloess, without being of aeolian origin, as is so often made a requirement. Similarly a fine dune sand, although of aeolian origin, is not a loess. Thus, a definition of loess should not be made on purely genetic grounds. This is borne out by Scheidig's list (1934, p. 42) of twenty hypotheses of the origin of loess. The presence of so many hypotheses, several of which are well backed by proof, shows the futility of attempts to formulate a strictly genetic definition of what is essentially a special kind of silt.

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Exposure on Geddes Avenue