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SIGNIFICANCE OF COMPOSITIONAL AND TEXTURAL PROPERTIES OF SOUTH CANADIAN RIVER CHANNEL DEPOSITS, NEW MEXICO, TEXAS, AND OKLAHOMA

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SIGNIFICANCE OF COMPOSITIONAL AND TEXTURAL PROPERTIES

OF SOUTH CANADIAN RIVER CHANNEL DEPOSITS,

NEW MEXICO, TEXAS, AND OKLAHOMA

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CHAPTER I

INTRODUCTION

General Statement

This dissertation is based on a study of the mineralogical composition and the textural properties of channel sediment of the South Canadian River, New Mexico, Texas, and Oklahoma. Surficial samples of sediments from the low water channel of the river were collected over more or less regularly spaced intervals from near the headwaters in eastern New Mexico to near the mouth in eastern Oklahoma, a distance of about 650 miles. These samples were analyzed in order to determine their size distributions and mineralogical content. The roundness, sphericity, and shape factor of the common minerals present were ascertained in the various samples and in the various sizes of individual samples. These properties were treated statistically in order to determine the relationships between these properties and apparent distance of transportation and size, as well as the interrelationships among the properties themselves. Because, in the reach of the river under study, there were no sizes larger than sand, and because of the special equipment necessary to study sizes smaller than sand, the mineralogical composition, roundness, and shape analyses were limited to the sand sizes.

Data in this extremely pertinent facet of geology are far from complete and, in some instances, are contradictory. Pettijohn (1957) repeatedly emphasizes ambiguities which persist in experimental and field studies of transported sediment with respect both to the effects of transportation on the properties and the interrelationships of the properties. Though numerous studies of the effects of transportation on sediment composition and texture have been made, all but a few of these studies have dealt with a different environment, or, even when dealing with river transported material, have concerned themselves with large (i.e. pebble) particles. In addition, in many of these studies, the effect of composition and size on particle shape and roundness has been treated sketchily. The following quotation from Russell (1939, p. 32) still effectively summarizes the situation:

> Evidently only a few of the commonly accepted concepts regarding the effects of transportation on sedimentary particles can be considered as definitely proved. Some appear to be false; others, though possibly true, have not been firmly established by sufficient evidence. Further research is necessary on all phases of this problem before positive conclusions will be justified.

For the reasons stated, it was felt that this study might provide additional information in a phase of geology where it is sorely needed. Only by continuing study of recent sediments will sufficient data be gathered so that interpretations of ancient sediments become reliable. The difficulty in the interpretation of any sediment is a result of the multitude of environmental factors which act upon, and react with, each other. In rivers, some of these environmental factors such as source rocks, current direction and intensity, and area of deposition are either known or are limited. Because of this, rivers are, in the words of Sneed and Folk (1958, p. 114), a "natural laboratory."

To the writer's knowledge, this is the only study in which the roundness and shape of essentially all the individual minerals composing sediment of a river channel over such a long distance have been analyzed.

Previous Work

Size distribution parameters. The detrital elements of a clastic sediment differ from one another in size by infinitesimals (Pettijohn, 1957). In order to study the distribution it is necessary to place size elements into various classes or groups according to some grade scale. Numerous such grade scales exist but the one most commonly used in geology in the United States is the Wentworth scale (Wentworth, 1922) based on the work of Udden (1914) and further refined by the National Research Council (Lane and others, 1947). The Wentworth scale is based on the measurement of the size of the particles in millimeters. If mechanical analysis of particle size distribution is done by sieving, the size measured is the largest diameter of the smallest cross-section of the particle. Wentworth's classes are arranged in a geometric scale based on the power of two. Examples of the limits of his size classes would be 2 mm - 1 mm, 1 mm - 1/2 mm, 1/2 mm - 1/4 mm, etc. The handling of a geometric scale is frequently cumbersome. To avoid irrational class mid-points as well as to make statistical computations simpler, Krumbein (1934) introduced the phi (Ø) scale. In this scale phi is defined as minus the log of the diameter in millimeters to the base 2 ($\phi = -\log_2$ diameter in mm).

Conversion of the Wentworth scale to phi units causes limits in the Wentworth scale to be whole numbers in the phi scale, such that the larger the number in phi, the smaller the diameter in millimeters. Because the most common diameters encountered are less than 1 mm, the use of a minus logarithm makes these common diameters positive whole numbers. The notation is such that values of 0, 1, 2, 3, 4, etc. in the phi scale correspond to diameters in millimeters of 1, 1/2, 1/4, 1/8, 1/16, etc. Furthermore, the phi units may be graphed as equally spaced divisions rather than on a geometric scale and the arithmetic mid-point between two class limits corresponds to the geometric mid-point between the corresponding limits on the Wentworth scale.

The size frequency distribution is generally illustrated through the use of various graphical forms such as histograms, frequency curves, and cumulative curves. The cumulative curve is an especially useful means of illustration because certain pertinent elements (parameters) of the size distribution, such as the median diameter, can be read directly from the curve. This curve can be plotted (if Ø units are used) on arithmetic cross-section paper or, especially if the distribution approaches normality, on arithmetic probability paper. The advantages of the use of probability paper are discussed by Lohse (1955) and Tanner (1956).

In order to describe and study a given size distribution and to compare one distribution with another it becomes necessary to indicate quantitatively certain elements of the distribution. These descriptive elements are called parameters. Numerous parameters for size distributions of sedimentary particles have been devised. Those most commonly used have been defined by Trask (1930, 1932), Krumbein (1936), Inman (1952), Folk (1957), and Folk and Ward (1957). The parameters defined by Trask and Krumbein are based on quartile measurements, that is, based on the 25th, 50th, and 75th percentile of the size distribution. Inman's and Folk's parameters are based on these percentiles as well as on percentiles closer to the extremes of the distribution and, therefore, yield more discriminating results. Trask's parameters are based on the size measurements in millimeters, the other three on measurements in ϕ scale. Regardless of who has defined the parameters, five different ones are generally used. These are:

1. Median diameter: that size such that 50 percent of the particles are larger and 50 percent smaller. It is generally preferred to the mean diameter as a measure of

central tendency as it is less influenced by skewness and, therefore, serves as a better approximation of the modal diameter.

2. Mean diameter: the average size.

3. Sorting or dispersion: a measure of the spread of the distribution. It would correspond, more or less, with the standard deviation of standard statistical methods.

4. Skewness: a measure of symmetry of the distribution curve. In a normal distribution the mean and median coincide and the distribution curve is symmetrical, but if they depart from each other, the distribution is skewed. If the mean is greater (in Ø units) than the median, the curve has a positive skewness; if less, a negative skewness. In a normal distribution the skewness value equals zero.

5. Kurtosis: a measure of the peakedness of the curve. Curves more peaked than a normal distribution are called leptokurtic; those less peaked, platykurtic.

The parameters used in this paper are those which have been defined by Folk. These are, as mentioned previously, based on percentile measurements in Ø scale. These parameters and their formulae are as follows (in all the formulae p^n indicates the percentile value n, and may be read directly off the cumulative curve):

1. Median diameter:

$$Md = p^{50} \quad \text{(This is the 50th percentile)}$$

2. Mean diameter:

$$Mz = \frac{p^{16} + p^{50} + p^{84}}{3}$$

3. Sorting: Folk's term is Inclusive Graphic Standard Deviation:

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

Perfect sorting would give a value of zero with all other conditions giving higher results.

4. Skewness: Folk's term is Inclusive Graphic Skewness.

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

In normal distributions $Sk_I = 0.00$. The limits of this measure are from +1.00 to -1.00. The positive skewness indicates a "tailing" in the larger numbers of the distribution and since the measurement is in ϕ units this "tailing" would be toward the smaller diameters. The reverse would be true for a negative skewness.

5. Kurtosis: Folk's term is Graphic Kurtosis.

$$K_G = \frac{p^{95} - p^{5}}{2.44\ (p^{75} - p^{25})}$$

In normal distributions $K_G = 1.00$. Curves that are leptokurtic have values over 1.00 while those that are platykurtic have values less than 1.00. Theoretically the lower limit to this measure is 0.14 with no upper limit but Folk has indicated that most sediments have a K_G range between 0.60 and 5.00.

Shape measurements. The shape of a sedimentary particle refers to its geometric configuration. Until 1932, the shapes of particles were defined and described in various fashions and often such terms as shape, roundness, and sphericity were used indiscriminately and interchangeably. In spite of the fact that numerous workers developed methods of quantitatively measuring shape and roundness, the concept of a particle having more than one distinct and separate property of geometric configuration was not demonstrated until Wadell (1932; 1933; 1934; 1935) clearly defined shape (sphericity) and roundness. Additional configuration properties have been added by Zingg (1935) called shape factor and recently by Sneed and Folk (1958) called form. A discussion of the earlier methods of describing particle "shape" may be found in Krumbein and Pettijohn (1938, p. 278-291).

Roundness measurements. As mentioned above, roundness was first clearly defined quantitatively by Wadell (1935). This was expressed as

$$P\ (Rho) = \frac{\sum \frac{r}{R}}{N},$$

where P equals the roundness, r the radius of a single grain corner, R the radius of the maximum inscribed circle in a longitudinal section, and N the number of corners measured. These measurements were accomplished by projecting an image of the grain and making the necessary measurements on this image. By this formula a perfectly rounded grain would have a value of 1.00, all others would be less, with 0.00 being the theoretical lower limit. This formula captures the idea of roundness and gives extremely accurate results, but workers found it extremely tedious and time consuming to make the necessary measurements of a sufficient number of grains so that a study might be statistically valid. Because of this objection, numerous visual comparison charts have been devised with the models on the charts being made to conform with roundness values as defined by Wadell.

One of the earliest of the comparison charts was made by Russell and Taylor (1937) where photographs of grains were arranged in five descriptive roundness classes. Russell and Taylor referred their class limits to the Wadell system but the size range of their classes was arbitrary. Krumbein (1941), using Wadell's formula, prepared a chart showing silhouettes of grains for nine roundness values in arithmetic progression from 0.1 to 0.9. Krumbein made no attempt at division into descriptive classes. Pettijohn (1957, p. 58-59), modified Russell and Taylor's descriptive classes, re-arranging them into a geometric progression with larger class ranges in the higher roundness values. This change was felt to be necessary by Pettijohn because "it is difficult to distinguish slight differences in roundness if the roundness values are high but similar differences can be readily ascertained at the lower end of the scale." He also showed a comparison chart illustrating in silhouette approximate mid-point values of his classes. Powers (1953) agreed with Pettijohn's statement quoted above and further stated that "even this geometric scale does not provide small enough divisions in the lower roundness values." Therefore, he constructed a six class system, staying with a geometric progression to achieve greater distinction in the lower roundness values. He constructed clay models of grains of the mid-point values of his classes (testing the grains using the Wadell formula) and then photographed the models so the pictures might be used as a comparison chart. The models were constructed so that for the same roundness value, there were grains of both high and low sphericity.

Beal and Shepard (1956, p. 50-52) in a study of environmental effect on roundness made an analysis of the determination of roundness by the use of Powers' comparison photographs and Krumbein's silhouettes. They found the roundness results of both comparable, though Krumbein's method gave slightly higher values. In this comparison of methods, they found Krumbein's silhouettes difficult to use for direct comparison with actual grains and, therefore, since both gave approximately the same results regarding roundness, they chose Powers' scale for their complete study. However, after studying over 200 samples, they reported a fallacy in Pettijohn's and Powers' idea regarding an operator's ability to distinguish roundness differences. They stated that an operator could more easily distinguish differences in roundness when the roundness values were high rather than the reverse and, therefore, they recommended a scale giving fine divisions in the high roundness values.

It appears, then, on the basis of Beal and Shepard's work, that the use of Krumbein's silhouettes, which are arranged in an arithmetic progression, might give more accurate results than Pettijohn's or Powers' if an easy method of comparison with actual grains could be utilized. Such a method has been devised and is described later in this paper under "Methods of Study."

Sphericity measurements. Wadell (1932) defined true sphericity as the ratio of the surface area of sphere to the surface area of a particle of equal volume as expressed in the formula

$$\Psi = \frac{s}{S}$$

where Ψ is the sphericity, S the surface area of a particle, and s is the surface area of a sphere of equal volume. Because the determination of the surface area of an irregular particle would involve extremely difficult, if not impossible, integration, he devised an operational sphericity for sand grains that would closely approximate the true sphericity. This is

$$\Psi = \frac{d_c}{D_c}$$

where d_c is the diameter of a circle of equal area to the area of the projection of the grain when resting on its largest face, and D_c is the diameter of the smallest circle that can circumscribe this projection.

The operational sphericity of Wadell is also cumbersome to use and because of this Krumbein (1941) defined another operational sphericity by using the measurements of intercepts (axes) of the particle. He compared the particle to a triaxial ellipsoid rather than a sphere. His concept is defined by the formula

$$= \left(\frac{bc}{a^2} \right)^{1/3}$$

where a is the longest intercept, b the intermediate, and c the shortest. Since for most particles the intercept measurements can be more or less easily measured, Krumbein's method has gained wide usage.

Aschenbrenner (1956) has refined Krumbein's intercept sphericity to make it more closely approximate Wadell's original true sphericity by substituting a tetrakaidecahedron for the triaxial ellipsoid as the comparison solid. His sphericity is defined as

$$= \frac{12.8\ (p^2q)^{1/3}}{1 + p\ (1+q) + 6[1+p^2(1+q^2)]^{1/2}}$$

where $q = \frac{b}{a}$, $p = \frac{c}{b}$, and a, b, and c are still the long, intermediate, and short intercepts respectively. He presented a chart whereby the sphericity value may be readily ascertained from the values of the ratios p and q.

Sneed and Folk (1958) presented a variation of Krumbein's intercept sphericity called maximum projection sphericity which they feel takes into account the actual hydraulic behavior of particles. Their sphericity is defined as

$$\Psi = \left(\frac{S^2}{LI}\right)^{1/3}$$

where L is the long intercept, I the intermediate, and S the short.

<u>Shape factor and form measurements</u>. It has been recognized that though sphericity measurements give a quantitative approximation of the equidimensionality of a grain, particles of equal sphericity may not resemble each other in overall appearance; that is, both a disc-shaped and rod-shaped particle may yield exactly the same sphericity values. To describe this additional geometric property of particles, Zingg (1935) has defined <u>shape factor</u>, and Sneed and Folk (1958), <u>form</u>. Zingg's shape factor is determined by the formula $F = \frac{p}{q}$, where p and q are the same ratios as in the discussion above on sphericity. Zingg further provided four

descriptive shape classes based on the values p and q. In his system a single F value may transgress several of his shape classes.

Sneed and Folk defined form in ten classes based on certain areas of a triangle on which a coordinate system had been ruled using the ratios $\frac{S}{L}$ and $\frac{L-I}{L-S}$ as the coordinates. S, L, and I refer to the same intercepts as in the discussion above on sphericity. They also provided for a "form ratio" which is based on the number of specimens in a sample that fall into each of their descriptive classes.

In attempting to describe the appearance of a particle according to this property it seems that Sneed and Folk's classes are considerably more discriminating than Zingg's. However, in summarizing shapes of groups of particles, Zingg's shape factor, F, being dependent only on the intercept measurements and not on the number of particles in each class, may be a better quantitative measurement than the form ratio developed by Sneed and Folk.

River sediment investigation. Numerous studies have concerned themselves with the changes in clastic sediments with distance (see Pettijohn, 1957, p. 525-587; and Russell, 1939, for discussion and review of the literature on this phase), but only a few have been restricted to river transported sediment and still fewer to particles of sand size. The only studies which concerned themselves exclusively with sand size particles over an appreciable distance were those of Russell and Taylor (1937) and Russell (1936; 1937) which dealt with Mississippi River sands from Cairo, Illinois to the Gulf of Mexico. Other river studies have been concerned with particles larger than sand size, though Plumley (1948) in his study of river terraces in the Black Hills, South Dakota region did include some study of sand size particles.

Many of the results of these river studies are contradictory with regard to changes in textural properties with distance. Some differ with respect to their interpretations of interrelationships of properties. There is some variance of opinion as to changes in composition with distance. Little has been written regarding variance in composition and particle shape with change in size. Some studies have dealt with changes in a few particular minerals (Plumley, 1948, Sneed and Folk, 1958). None have been concerned with textural properties of all the minerals present in the sediment.

A reduction of pebble size with distance has been observed by Krumbein (1942) in Arroyo Seco, California, and Plumley (1948) in the Black Hills area. Krumbein reported the decrease to be exponential, while Plumley indicated size decrease is a linear function. In dealing with sand size particles, Russell and Taylor (1937) showed a decrease in the mid-points of modal sizes in Mississippi River sand.

Plumley (1948) reported no progressive change in sorting with distance in Black Hills terrace material, but indicated that size distributions show a marked decrease in skewness with distance. Pettijohn (1957, p. 542) stated that to his knowledge, regular change in sorting as a result of transportation has never been clearly demonstrated.

Krumbein (1940; 1942) working with pebbles in the San Gabriel Canyon, California, reported an increase in roundness over 5.5 miles and, in Arroyo Seco, California, an increase over about 10 miles. He reported that this roundness increases rapidly at first and then more slowly as it approaches a limit of rounding. Plumley (1948) indicated much the same condition in Black Hills terrace gravels. Sneed and Folk (1958) in a study of lower Colorado River, Texas, pebbles, reported that limestone rounds rapidly and reaches a limit of rounding in about 10 miles of transport, that chert rounds very slowly and requires several hundred miles of transportation, that quartz rounds rapidly over distance of about 10 miles to 150 miles, and that both limestone and quartz particles will approach a similar limiting value of roundness.

Russell and Taylor (1937), working with sands showed a decrease in roundness downstream in the Mississippi River over some 1,100 miles of distance. However, Plumley (1948) also working with sands (of a single size fraction, 1 mm to 1.414 mm) reported an increase in roundness of 71 percent over only 40 miles. Russell and Taylor attributed the decrease to progressive fracturing.

Krumbein (1940; 1942) indicated no significant increase in sphericity downstream in the pebble particles he studied, nor did Plumley (1948). For Colorado River pebbles, Sneed and Folk (1958) reported that the sphericity of quartz of one size remains constant while that of another size increases significantly. They also reported that chert of one size decreases in sphericity; of another size, increases. Limestone, they write, does not change systematically. Russell and Taylor (1937) reported a decrease in sphericity in the Mississippi River sands.

In 1940, Krumbein, working with the San Gabriel Canyon pebbles, formulated a relationship between roundness and sphericity. However, in his 1942 study of the Arroyo Seco pebbles he showed that a marked increase in roundness occurs with no similar increase in sphericity. Plumley (1948) also reported this increase in roundness but no significant increase in sphericity. Sneed and Folk (1958) indicated that roundness and sphericity may vary independently but that both are controlled primarily by mineralogy and secondarily, for a given mineral, by transport distance for roundness and by size for sphericity. In sands, Russell and Taylor (1937) found better rounded quartz grains to be more spherical.

For larger sized particles, Plumley (1948) and Sneed and Folk (1958) indicated some compositional modification downstream. For sands, Plumley reported only slight decrease in feldspar content in the Cheyenne River over 150 miles, as did Russell (1937) in the Mississippi River over 1,100 miles. On some rivers, however, Plumley found a marked downstream decrease in feldspar content in the sands. Russell (1937) stated that the heavy mineral proportions remain constant in the Mississippi River.

CHAPTER II

DESCRIPTION OF PRESENT INVESTIGATION

Description of River

The South Canadian River (or simply, the Canadian River) and its tributaries drain an area of about 47,500 square miles in New Mexico, Texas, and Oklahoma. The drainage basin, which makes up about 30 percent of the drainage area of the Arkansas River, to which the South Canadian is tributary, is about 600 miles long in an east-west direction and approximately 85 miles in average width. The basin extends from eastern New Mexico to eastern Oklahoma.

The principal headwater tributaries of the South Canadian River rise in the Cimarron and Sangre de Cristo Mountains in the northeastern part of New Mexico. The main stem rises near Raton, New Mexico and flows in a general southerly direction to its confluence with the Conchas River, at the site of Conchas Reservoir, thence it flows easterly across the Texas Panhandle and through central Oklahoma where it finally enters the Arkansas River near the Arkansas state line (fig. 1). Because Conchas Dam prevents the head-water system from contributing to the main stem below, this study has concerned itself only with that portion of the river below the dam. The length of the river from Conchas Dam to the mouth is 740 miles. The fall of the river varies from about 5 feet per mile below the dam to about 3 feet per mile near the mouth. The average fall over this distance is approximately 4 feet per mile.

Conchas Dam is built in a canyon about 150 feet deep which gradually disappears below the dam. For the remaining distance to the Texas state line the river intermittently flows in small canyons between high mesas, and the valley continues to deepen until it is some 330 feet below the level of the divides. In the western part of the Texas Panhandle the South Canadian River is entrenched in a relatively narrow canyon that reaches a maximum depth of close to 1,000 feet a little west of Amarillo. This canyon effect largely disappears in the eastern part of the Panhandle. In Oklahoma the valley is relatively wide, averaging about one mile, and the low water channel is meandering and very shallow. The stream often exhibits braiding. There are very few tributaries of any significant size to the South Canadian, the major ones being Ute Creek which enters the main stream at Logan, New Mexico; Little River which enters above Calvin in eastern Oklahoma; and the North Canadian River which flows into the main stream near Eufaula, Oklahoma, just 38 miles above the South Canadian's conjunction with the Arkansas River.

The headwater streams in New Mexico rise in Cretaceous and Jurassic sediments, part of which are capped by Quaternary lava flows. The lower portions of the headwater tributaries and the main stem above Amarillo are in poorly consolidated Triassic sediments. Throughout the Texas Panhandle and extending into extreme western Oklahoma the South Canadian has cut through the Ogallala formation of Pliocene age which forms the High Plains, and from Amarillo eastward to central Oklahoma the valley is cut in Permian red beds. In eastern Oklahoma the bedrock is Pennsylvanian in age.

The river, in the portion under study, is generally an aggrading stream and is flowing on recent alluvium. It is felt that the material examined in this study has originated, at least during its present erosional cycle, from this fill material.

There is comparatively wide variation in climatic conditions over the length of the river. In the western portion the winters are frequently severe and the summers mild, while in the eastern portion the winters are less severe and the summers are characterized by higher temperatures. The average annual rainfall in the river basin varies from about 15 inches in New Mexico to 42 inches in eastern Oklahoma. It is characteristic of the basin, particularly in the western portion, that temperatures and precipitation vary over fairly wide extremes.

Methods of Study

Sampling. Samples were collected from twenty locations on the South Canadian River channel and from five different tributaries. The sample numbers indicated on figure 1 and throughout the report refer to the river-mile distance of the sample location from the mouth of the river. (This method of sample numbering was chosen so that one might, at a glance, tell the location from which the sample was collected and the distance between any two samples). The locations of the samples were determined by accessibility to the river and are approximately 70 to 20 miles apart. The most upstream sample was collected at Logan, in eastern New Mexico, and the most downstream from near the mouth of the South Canadian close to the town of Stigler in eastern

Oklahoma. The tributaries were sampled a little upstream from their confluence with the main stem.

The samples were collected with a "dredge-like" sampler from the center of the low water channel. This sampler scraped approximately the upper inch of bed load material. Two samples were taken at each location and mixed to form a single sample representing that particular location.

The sampling device was constructed from a steel cylinder which was open at one end. The cylinder was flattened on one side and a beveled lip was riveted at the open end on this side. The flattened side was weighted down by bolting lead weights on the interior of the cylinder. Large eye-screws were fastened on the exterior of each side of the cylinder through which ropes were attached so the sampler could be pulled along the bottom. The holes, through which the bolts and screws went, were soldered so the cylinder was water-tight. By using about ten feet of rope attached to the eye-screws, it was possible to throw the sampler out so the bottom sediment was not stirred by walking in the stream bed at the place the sample was taken. After pulling the sampler a short distance, the device was upturned and withdrawn from the stream with its contained water and sediment. The sample and water were poured into a standard large cloth sample sack and the water allowed to filter through the sack. (An experiment showed that a sample sack makes an excellent filter with essentially no loss of sediment if the water is allowed to drain slowly by itself). The sampling device proved quite effective and, though there may have been some loss in the "upturning" operation, it is believed that this loss was negligible.

Mechanical analysis. The samples were dried, split, and weighed for size analysis. At first, an analysis was attempted through the use of the Emery settling tube (Emery, 1938) but, after comparison with sieving methods, it was found that the results from the two methods were inconsistent. Therefore, size analysis by sieving alone was used. The sieving was accomplished by mechanically shaking the sample through a standard set of sieves in a Wentworth scale progression. By weighing prior to sieving and then weighing each of the size fractions subsequent to sieving, the percentage of sample by weight in each size fraction and, therefore, the size distribution was ascertained. The size distribution for each sample was plotted on both arithmetic cross-section and arithmetic probability paper so that the proper percentiles could be read and the size parameters computed. The parameters were found as previously mentioned, using the formulae developed by Folk (1957) and Folk and Ward (1957). These parameters are the median, mean, sorting (dispersion), skewness, and kurtosis. Though Folk has qualified the names of these parameters by special terms (for example, his skewness is called Inclusive Graphic Skewness) for the purpose of this paper the general parameter terms alone are used.

Mineral separation. After sieving, the samples were further split for mineral analysis. It was hoped that the separation could be accomplished by making use of the magnetic properties of the minerals (Krumbein and Pettijohn, 1938, p. 344-348) through the use of the Frantz Isodynamic Separator (Gaudin and Speddin, 1943), but it was found after running numerous samples that much of the quartz had minute amounts of hematite stain which caused these grains to respond magnetically and be collected together with various magnetic fractions. It was felt that the amount of work necessary to separate this quartz from the magnetic minerals did not justify the use of the separator in spite of speed in which the samples could be run through the machine. For this reason, separations were finally made by conventional heavy mineral separation methods based on the specific gravity of the minerals and the use of a heavy liquid, in this instance tetrabromoethane (Krumbein and Pettijohn, 1938, p.

320-343). These separations were made of the 0.062 mm and 0.125 mm size fraction of each sample. It was found that the amount of heavy minerals present in larger sizes was not sufficient to warrant mineral separation. Since the study of roundness and shape was to be limited to sand size particles, no separations were made of sizes smaller than 0.062 mm.

Mineral, roundness, and shape determinations. Splits of the light and heavy mineral assemblage of the 0.062 mm and 0.125 mm size fractions and total content of the larger sizes were mounted on glass micro-slides for microscopic examination. Approximately 1,000 grains were mounted on each slide. Both Canada Balsam and Lakeside 70 were used as mounting agents.

The minerals present in each slide were identified and counted by making a traverse of the slide using a mechanical stage mounted on a petrographic microscope. The traverse consisted of examining the entire field at the intersection of grid lines which were arbitrarily spaced for a given size fraction examined. The same grid spacing was used for all slides of the same size grade, but larger spacing was used for smaller sizes and smaller spacing for larger sizes. The entire grid was covered in each slide. This resulted in the identification and counting of between 300 and 500 grains on each slide. It is felt that this method of examination allows a statistically representative portion of the sample to be identified.

As each mineral grain was identified, its roundness was ascertained and its intercepts measured for the determination of its sphericity and shape factor.

Roundness values were determined by direct comparison with Krumbein's silhouettes (Krumbein, 1941). As mentioned previously, on the basis of Beal and Shepard's work (1956), there appears to be some advantage to Krumbein's arithmetic scale. It was felt that having a progression of nine roundness values for comparison would yield more accurate results than having to compare with six classes as in the Powers' (1953) scale, particularly as there might be significant variations within the classes. Beal and Shepard's main objection to the Krumbein silhouettes was the difficulty in making direct comparisons. It is believed that this problem has been solved. A camera lucida was mounted on the petrographic microscope and a reproduction of Krumbein's chart (one with black background and white grain outline and one with the conventional white background and black silhouettes) was placed on the desk next to the microscope. With the camera lucida prism placed over the ocular of the microscope, an image of the grain being examined could be seen simultaneously with the Krumbein chart. By moving the chart, the image could be superimposed directly upon the proper silhouette and the correct roundness value quickly and accurately determined.

Intercept measurements were also made at the time a grain was identified. Two intercepts parallel to the slide were measured using a micrometer ocular in the microscope. A third intercept, perpendicular to the slide, was measured by focusing the microscope on the bottom and top of the grain with the fine adjustment knob of the microscope and reading the difference on a calibrated vernier scale which is geared to the knob. In all instances an objective lens was used with a very short focal length so that extremely minor changes in the adjustment of the microscope brought different portions of the grain into sharp focus. It is recognized that the lower-most portion of the grain as viewed through the microscope does not necessarily coincide with the bottom of the grain as it rests on the slide. However, it was felt that most grains would come to rest on the slide with their flattest side downward so that this discrepancy would be at a minimum. Also, though a discrepancy might exist, it would affect only the absolute values of sphericity and shape factor, and because this paper is primarily concerned with relative values as variations in these properties, and each grain was measured in the same manner, such discrepancies were considered insignificant.

From the intercept measurements, the values of p and q as defined by Zingg (1935) were calculated. The sphericity was determined from the chart given by Aschenbrenner (1956) using the values of p and q. The shape factor was calculated from p and q. The formulae for p, q, and shape factor are given in the preceding chapter.

As a corollary of the mineral determination, the quartz-feldspar ratio was computed for each sample run.

It became apparent after a preliminary examination of the slides that there were few differences in the character of the sediment regardless of where the samples were collected, and therefore, it was unnecessary to make detailed measurements for all the samples. Of the twenty samples collected on the main stem, ten were selected for the determinations described above. These samples were more or less evenly spaced and ranged from 50 to 84 miles apart. No determinations were made on the tributary samples.

It should be emphasized that the determinations of roundness, sphericity, and shape factor were made for each mineral in each size in each of the ten samples run.

Statistical treatment. After determining the roundness, sphericity, and shape factor for each grain of each mineral counted, the mean value of each of these properties for an individual mineral in each size at the various locations was computed. Three kinds of data analyses were conducted:

1. Mean roundness, mean sphericity, mean shape factor, and mean size for each mineral, and mean quartz-feldspar ratio were plotted against river distance. Because it is logical to examine the linear relationship between mineral characteristic and river distance, a regression line ("best-fitting" line in the least-square sense) was determined for each plot (Dixon and Massey, 1951, p. 153-160). The slope of each of these lines was tested against the statistical hypothesis that the "true" slope equals zero. As a consequence of this test, the slope is considered to be equal to zero or different from zero. A slope that equals zero means no linear trend in these properties over river distance.

2. For each mineral, the existence of a relationship between size and each of the other mineral characteristics (roundness, sphericity, and shape factor) was evaluated;

in addition, the relationship between the quartz-feldspar ratio and size was also examined. Each sample was divided into "small" and "large" groups on the basis of size (the 0.062 mm and 0.125 mm size grades in the case of the heavy minerals). For the other characteristic, an overall median (i.e. a median for the combined "small" and "large" groups) was determined. Each of the "small" and "large" samples was placed into a "low" or "high" characteristic group, "low" or "high" determined by a split at (or near) the overall median of the characteristic. Thus, a double dichotomy which generates four classes was established. If size and any other characteristic are independent (i.e., there is no relationship between them), there should be as many "small" samples with "low" characteristic values as there are "large" samples with such values (Dixon and Massey, 1951, p. 187-190). Under the hypothesis of independence, a set of theoretical frequencies for the four classes may be determined. If the obtained frequencies in the four classes are similar to the theoretical frequencies, there is no basis for rejecting the hypothesis of independence; i.e., the premise that there is no relationship between the property and size is accepted. If the obtained frequencies are different from the theoretical frequencies, the hypothesis of independence is rejected and the premise that a relationship does exist between the property and size is accepted. Chi-square (Dixon and Massey, 1951, p. 187-190) was used to evaluate the discrepancies between theoretical and obtained frequencies; therefore, Chi-square was used to evaluate the existence of a relationship between size and the other characteristic. As a result of this test, a relationship between size and another characteristic is considered to exist or is considered not to exist.

3. For each mineral, the interrelationships among sphericity, roundness, and shape were evaluated. First, the relationship between each property and size was examined. If the property and size were related, the evaluation of the relationship between that property and any other was made separately for each of the size groups. If there was no relationship between size and either of the properties being considered, the "small" and "large" samples were combined, and one test was conducted. Such a procedure succeeds in removing most of the effects of size upon the relationship between the two properties studied. Each of the two characteristics was dichotomized at (or near) its median, and four classes are formed from the double dichotomy. A Chi-square test of independence between the two variables is conducted in the same manner as in (2) above.

Each kind of analysis described above demands a criterion for rejecting an hypothesis of no relationship ("slope equals zero" is equivalent to "no linear relationship"). A level of significance of 0.05 was used in this study as such a criterion. This level of significance may be interpreted in the following ways: even when the statistical hypothesis of no relationship is correct, sample slope and Chi-square values will depart from zero because of sampling fluctuations. Great departures from zero will occur with low probability, but they will occur; hence a cut-off point which defines "too improbable" must be established. In this study, a slope or Chi-square value which departs from zero by such a large amount that its occurrence under the hypothesis of no relationship is 0.05 or less is regarded as "too improbable" for the hypothesis to be correct. Given such a statistic-value, the hypothesis of no relationship is rejected and the relationship is said to be "significant." "Non-significant" results merely state that the no-relationship hypothesis is consistent with the data obtained.

CHAPTER III

RESULTS OF INVESTIGATION

Size Analysis

As mentioned previously, the size parameters discussed here are those developed by Folk (1957) and Folk and Ward (1957). The formulae on which they are based are given in the section on "Previous Investigation." Though there are special names for these particular parameters, for the purpose of this paper, the more general terms of median, mean, sorting, skewness, and kurtosis are used.

Table I, in the appendix, shows the size parameters for each of the samples collected. The median diameter ranges from 1.80 Ø for sample 547 to 3.60 Ø for sample 45; the mean diameter from 1.85 Ø for sample 547 to 3.61 Ø for sample 45. It should be noted that the mean and the median diameters are essentially identical in each of the samples. The mean of all the samples is 2.57 Ø for the median diameter and 2.58 Ø for the mean diameter.

The sorting ranges from 0.48 Ø for sample 238 to 0.99 Ø for sample 356. The mean sorting for all the samples is 0.65 Ø. Folk and Ward (1957) reported that the "best" sorted sands on a Brazos River, Texas, bar have a sorting value ranging from 0.40 Ø to 0.60 Ø. However, mean sorting for all their bar samples was 1.2 Ø with one method of sampling and 1.8 Ø with another. It should be noted, however, that Folk and Ward's samples were bimodally distributed. Plumley (1948) working with three different river terrace gravels in the Black Hills reported sorting values (though computed by a different but comparable formula from that used by Folk and Ward or in this paper) that range from 2.24 Ø to 2.83 Ø. On the basis of these studies it appears that the sorting values for the South Canadian are of an expected magnitude and indicate that the sands are well-sorted.

The skewness values range from +0.08 for sample 670 to -0.04 for sample 238. The mean skewness for all samples is +0.02. Considering that normal distribution gives a skewness of 0.00 and that the limits of skewness are +1.00 and -1.00, the range of skewness values is small. Folk and Ward (1957) reported a skewness range in the Brazos River bar of +0.53 to -0.68 with a mean skewness value of +0.09.

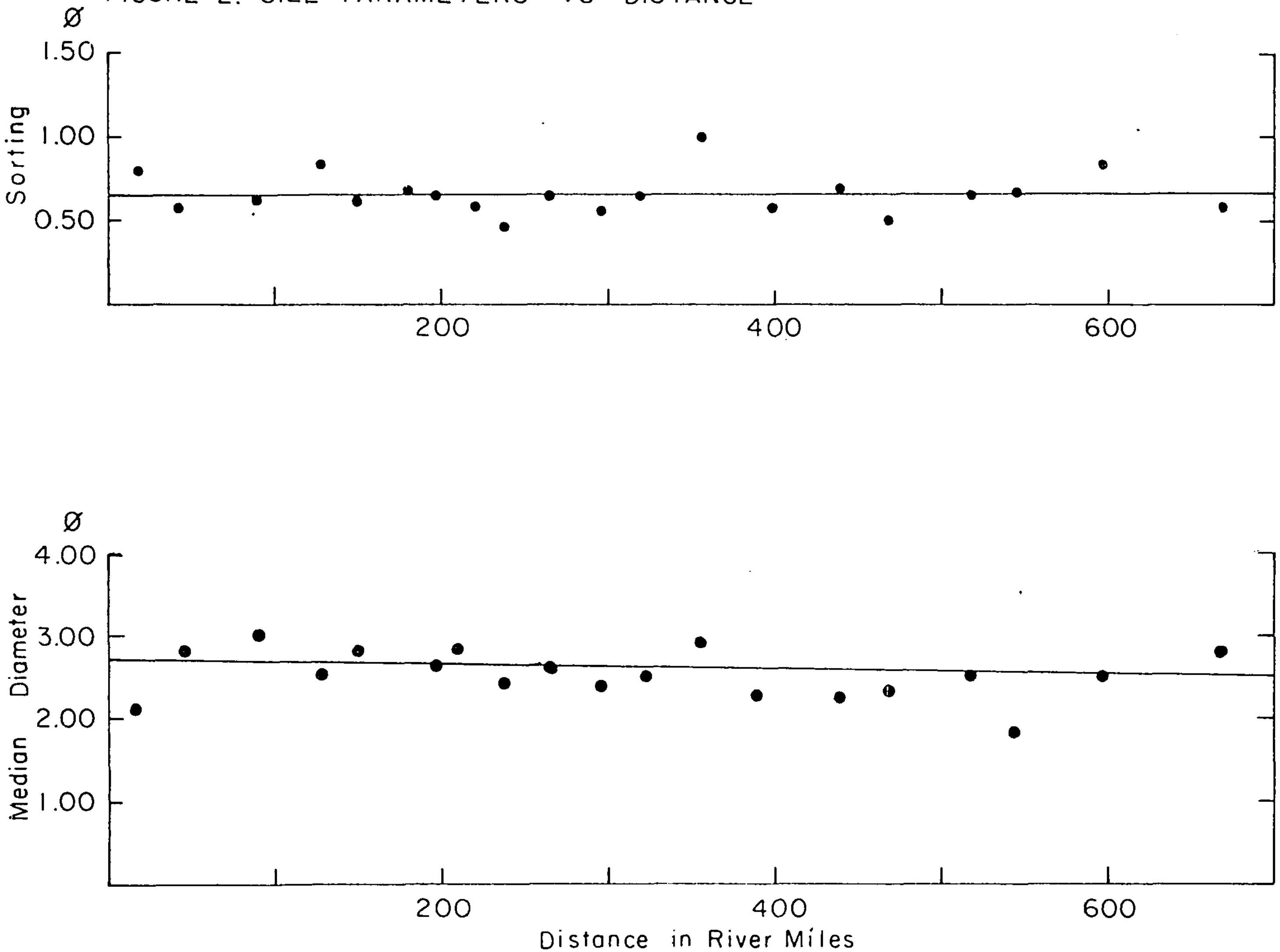
The kurtosis value range is low, varying from 0.86

for sample 670 to 1.13 for sample 213. The mean kurtosis value for all samples is 1.00. Compared to the Brazos River bar study of Folk and Ward (1957), this variance is very low, as they reported a kurtosis range of 0.54 to 2.85 and a mean kurtosis of 0.96. The theoretical lower limit of kurtosis is 0.41 with no theoretical maximum. A normal distribution has a kurtosis value of 1.00.

From inspection of Table I, it can be seen that in each of the samples the mean and median diameters closely correspond, the skewness approximates 0.00, and the kurtosis is close to 1.00. Or in other words, in each of the samples the distribution is essentially normal.

The five size parameters were plotted against river distance as shown on figures 2 and 3. With the exception of kurtosis, there is no significant linear trend in the size parameters over about 650 miles of river distance. The kurtosis, though the range of values is low, does show a significant increase downstream; that is, the distribution curves tend to become slightly more peaked. This is probably caused by an increase in the grain population of the modal class, but interestingly enough this trend is not accompanied by any significant decrease in the sorting values which would indicate better sorted sands. The formulae for the

FIGURE 2. SIZE PARAMETERS VS DISTANCE



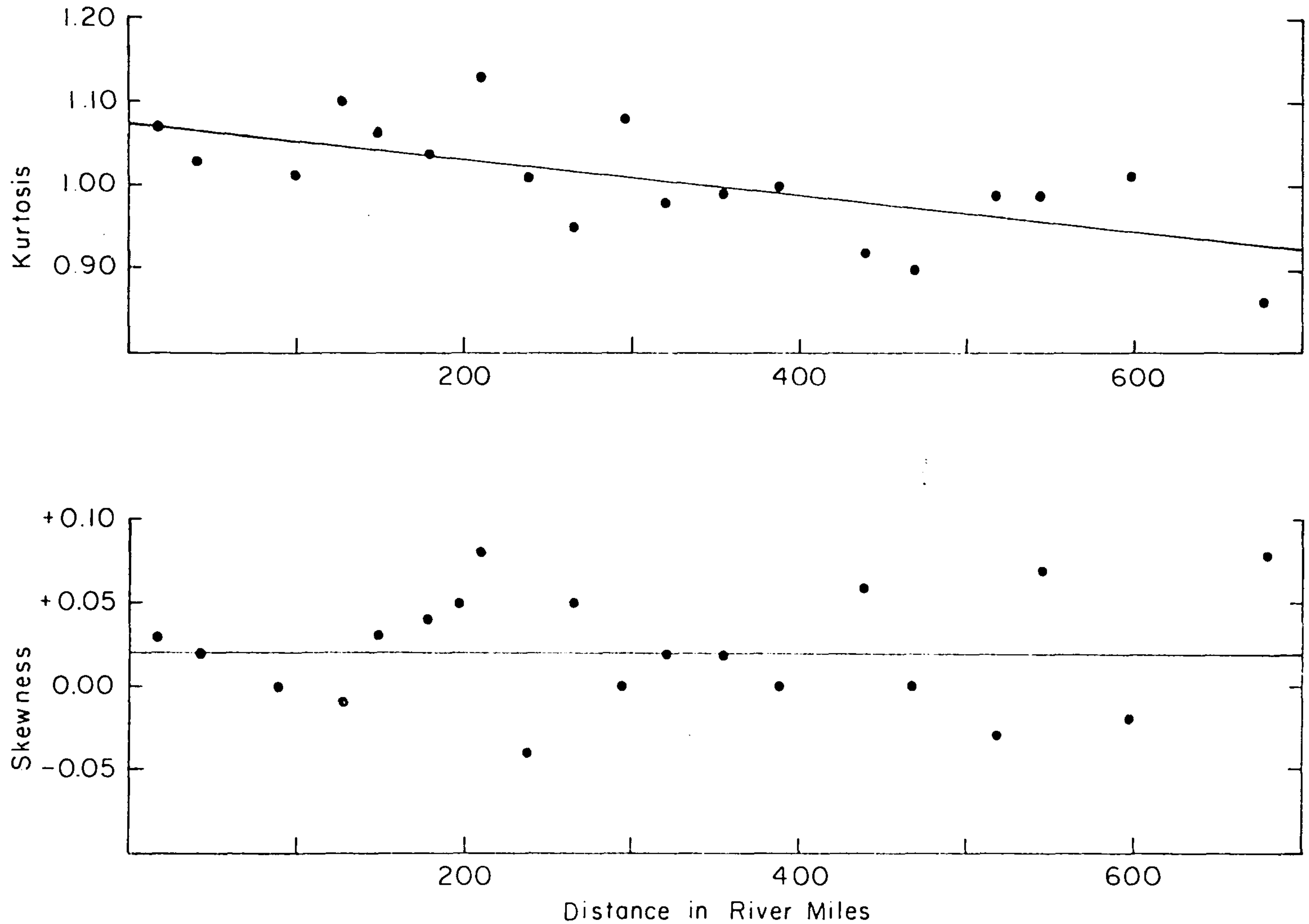


FIGURE 3. SIZE PARAMETERS VS DISTANCE

regression lines of all the size parameters on distance are given in Table VI.

Pettijohn (1957, p. 532-533) stated:

> in general the size of the clastic elements carried in a current progressively decreases in the direction of transport . . . although the rate of size decline varies widely in different situations, theoretically the direction of current flow and perhaps distance of transport of a clastic sediment could be estimated by mapping the maximum or mean size of the clastic elements and by drawing isopleths through equal size values and sketching normals thereto.

Certainly, if the sands of the South Canadian River constituted some unknown channel deposit this could not be done.

The constancy of the parameters might at first seem odd, but considering that the gradient of the stream is fairly uniform (5 feet per mile to 3 feet per mile) over the distance studied and that each of the samples was obtained from essentially the same position in the channel, it is believed that each sample represents deposits of a similar hydraulic environment, and therefore, should have very similar size distributions.

Statistical tests were run to examine the interrelationship of the size parameters and no relationships were found to be significant. This is contrary to the results reported by Folk and Ward (1957) for the Brazos River bar, but they were dealing with bimodal distributions over a relatively large size range with large variance in the parameters, as compared to the unimodal, small parameter variation condition present in the South Canadian. The South Canadian River size parameters behave according to the theoretic premise that the parameter measures are geometrically independent.

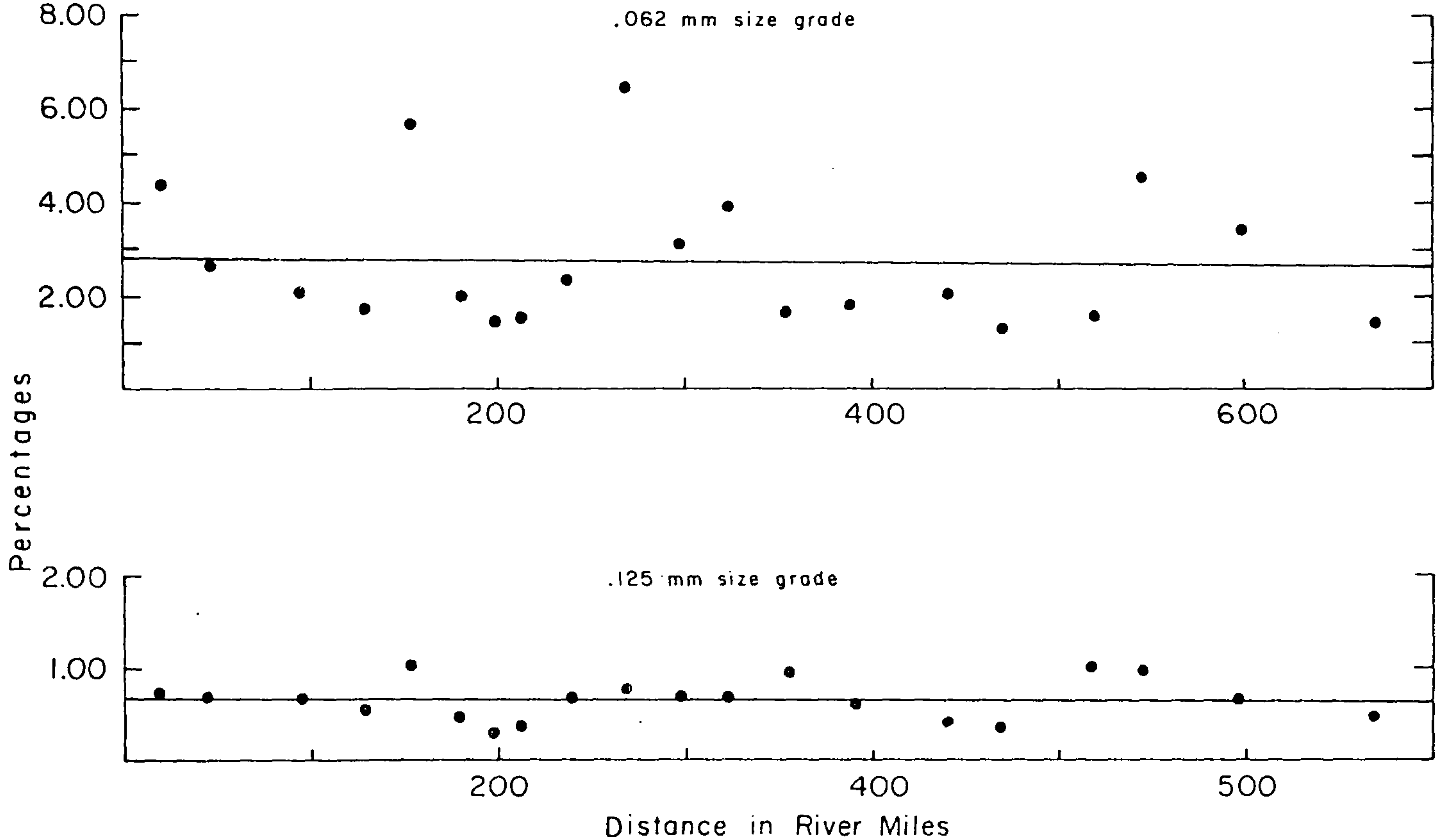
Mineralogical Composition

Heavy minerals. The heavy minerals of each sample in the 0.062 mm and 0.125 mm size grades were separated by the use of a heavy liquid. No separation was made of the 0.250 mm and 0.50 mm size grades because of lack of heavy minerals in these sizes. The percentage by weight of heavy minerals present for each sample in the two size grades for which the separation was made is given in Table II. These percentages range from 6.69 percent in sample 267 to 1.31 percent in sample 469 in the 0.062 mm size grade and from 1.04 percent in sample 152 to 0.27 percent in sample 198 in the 0.125 mm size grade. As would be expected, the smaller size consistently has higher percentages of heavy minerals. No significant change in the percentage of heavy minerals present in either size occurs in the South Canadian River over the distance studied (fig. 4). This agrees with the results reported by Russell (1937) for the Mississippi River.

The heavy minerals present in the 0.062 mm and 0.125 mm size grades were studied in ten samples spaced between 56 and 84 miles apart. Most common of the minerals present are magnetite, zircon, hematite, sphene, spinel-garnet (not differentiated), leucoxene-ilmenite (not differentiated), amphibole-pyroxene (not differentiated), and tourmaline. The several varieties of these minerals were not distinguished for this study. These eight minerals constitute over 95 percent of the heavy minerals present in each slide studied. No other mineral is present in percentages greater than 1 percent. Table III shows the percentage by count of these common minerals in the heavy mineral suite (considering the total suite 100 percent) in the two sizes for the samples studied. It can be seen that each of the minerals is present in about the same relative abundance in each size of each sample. That is, there is no significant change in the percentages of the common minerals downstream, and though magnetite tends to occur with a slightly higher percentage in the smaller size for most samples, there is essentially little difference in the relative abundance between the two sizes.

The fact that each of the minerals present remains

FIGURE 4. PERCENTAGE OF HEAVY MINERALS VS DISTANCE



in about the same relative abundance leads one to assume that in the South Canadian River:

1. Selective abrasion is not an important factor in the destruction of either physically or chemically less resistant minerals, as illustrated by the persistence of pyroxene-amphibole.

2. Because the various minerals present have, in many cases, markedly different shapes and roundness (see below), selective sorting on the basis of these factors is also not important.

In analyzing the progressive changes in mineralogical composition the possibility of tributary dilution should be considered. In the South Canadian, this effect is unimportant. Because the relative abundance of the minerals remains essentially constant, the tributaries are either contributing minerals in the same proportions as are present in the main stream, or, if they are contributing minerals of a different order of abundance, this effect is lost within a short distance when mixing of the bed load occurs. Russell (1937, p. 1333) reported that in the Mississippi River the effects of influx by tributaries are lost within a very short distance. He stated:

> Immediately below the mouth of each of these tributaries [of the Mississippi River], the effect of the

entrance of tributary bed load can be detected in bed-material samples from the Mississippi, but in 5 or 10 miles this effect becomes indistinguishable, and the Mississippi bed material appears to be the same as that above the mouth of the tributary.

Light minerals. Quartz and feldspar compose over 99 percent of the light mineral fractions of the 0.062 mm and 0.125 mm size grades. Feldspar, here, is used in the broadest sense, and no attempt was made to identify the individual minerals in this group, nor, since other "light" occurred only in fractions of a percent, were any other minerals counted. Though the 0.250 mm and 0.50 mm size grades were not separated into weight fractions, quartz and feldspar also constituted over 99 percent of these size grades and, therefore, the other minerals, in these sizes as well were not counted.

The relative abundance of quartz and feldspar in each size grade, as well as for all sizes combined, was ascertained on the basis of a quartz-feldspar ratio. This ratio was computed as the amount of quartz present as determined by count divided by the amount of feldspar present as determined by count. These ratios are given in Table IV and are illustrated in figures 5 and 6. The downstream trend of these ratios and the differences in these ratios between sizes was statistically tested. The behavior of the ratios

FIGURE 5. QUARTZ-FELDSPAR RATIO VS DISTANCE

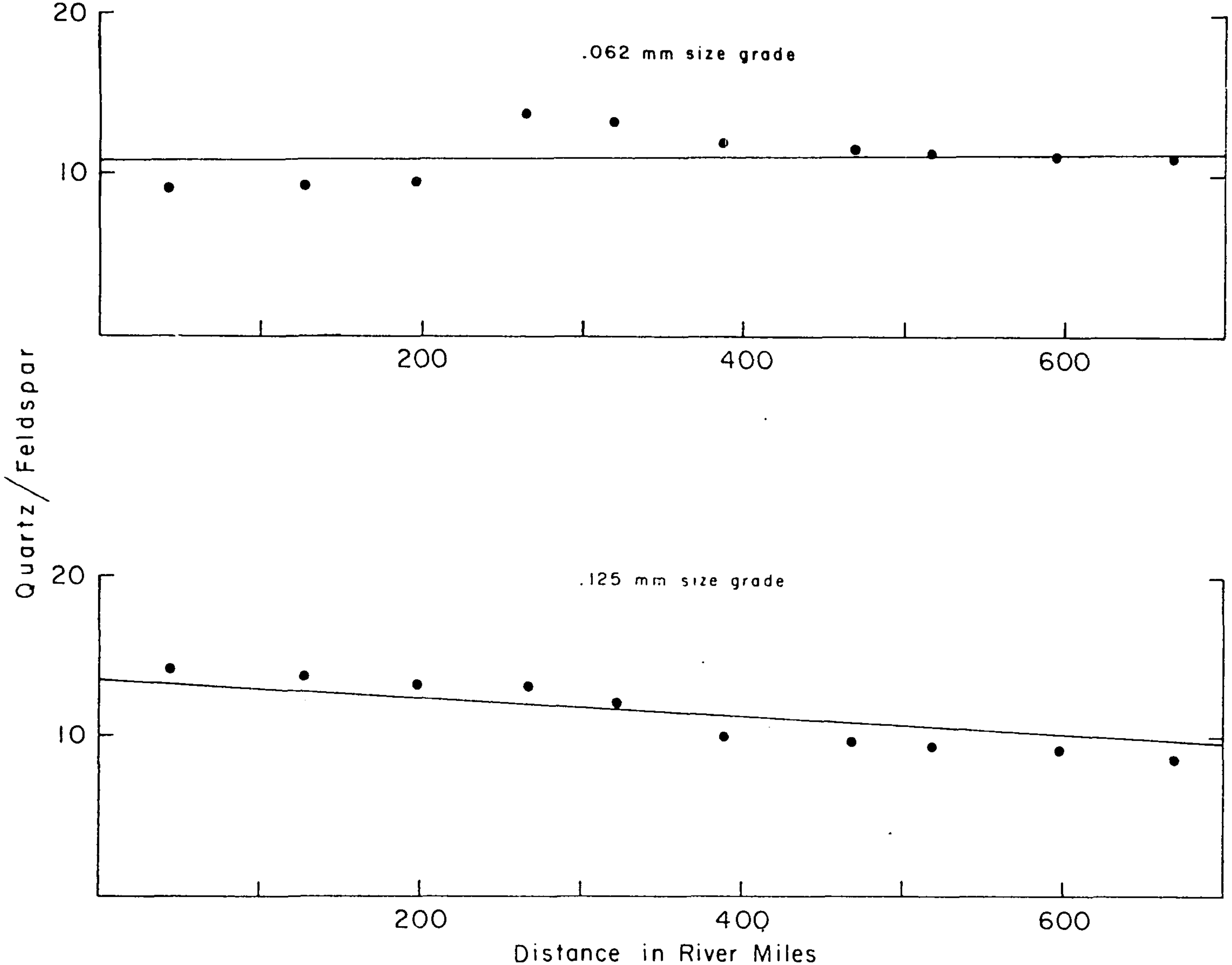
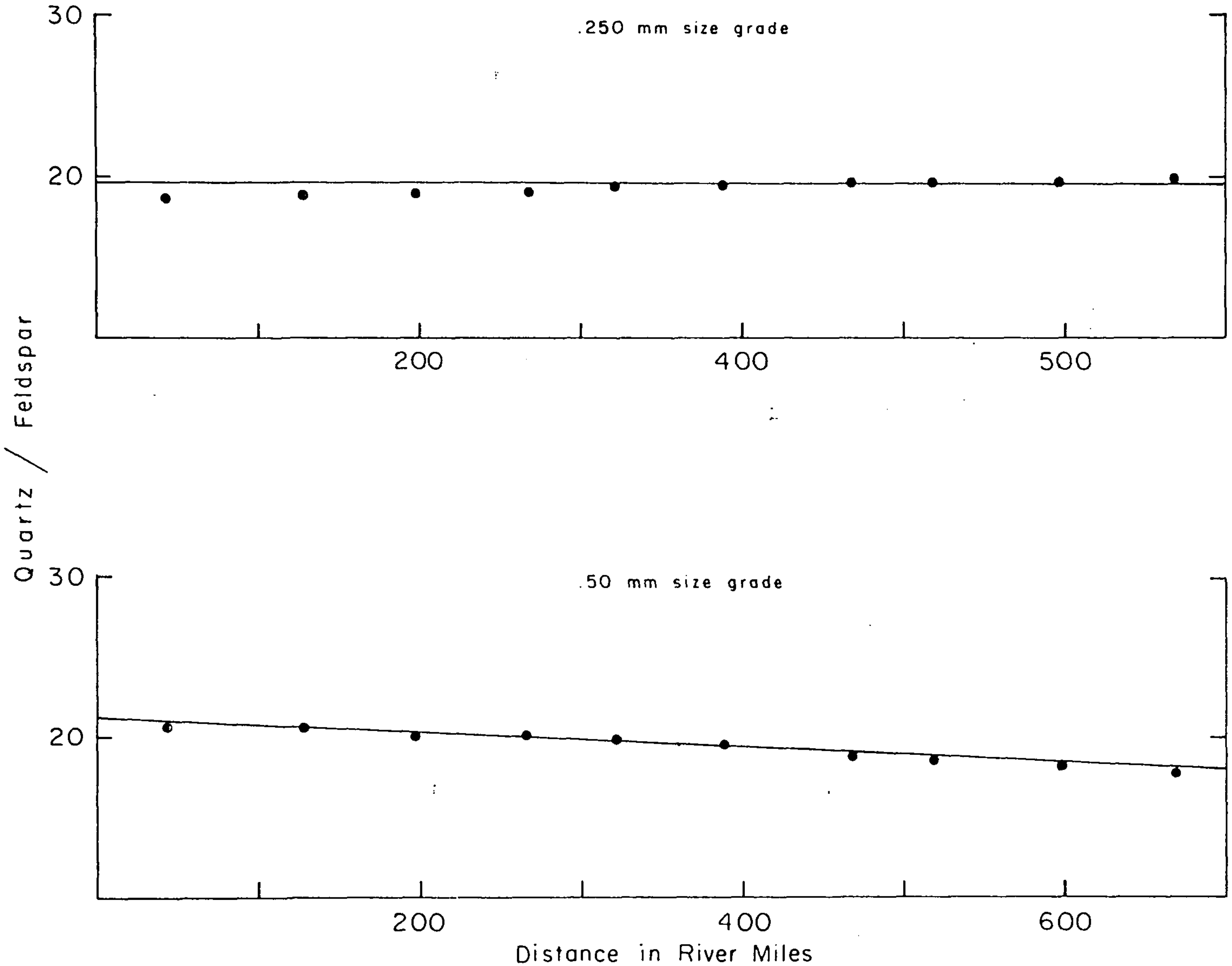


FIGURE 6. QUARTZ-FELDSPAR RATIO VS DISTANCE



can be summarized as follows:

1. Considering the total samples not broken into size grades, there is no significant change in the quartz-feldspar ratio with river distance. This is somewhat contrary to the results reported by Russell (1937) who, also dealing with a mixture of all size grades present in Mississippi River sands, reports small but significant increase in the ratio from Cairo, Illinois to the Gulf of Mexico.

2. On the basis of the actual values of the ratios, there are two size groups: a small one (0.062 mm and 0.125 mm size grades), within which there is no significant difference in the values between sizes, and a large one (0.250 mm and 0.50 mm size grades), within which there is also no significant difference in the values between sizes. The larger size group has higher quartz-feldspar ratios than the smaller.

3. Within each of these two major groups, the larger size grade shows a small but significant increase in the ratio downstream while the smaller size grade does not. It should be noted, however, that in the 0.062 mm size grade, though the regression line for the entire distance tested as a zero slope and, therefore, indicates no trend, if shorter distances are considered, there is a slight downstream increase and then a decrease. This reversal is not present in

the other size grades.

It appears, then, that the amounts and the downstream variations in the amounts of feldspar in comparison with quartz are dependent upon size. The absence of a trend in the smaller size grades of the two groups may be due to an "artificial influx" of feldspar in the small size caused by cleavage of particles of the larger size. Also, as indicated by the low range of values even in those sizes where there is a significant trend, the removal of feldspar by abrasion or weathering is a slow, if operative process. Russell (1937) drew similar conclusions about the removal of feldspar from the Mississippi River.

Roundness

The roundness values of all the grains counted were determined by comparison with the silhouette chart prepared by Krumbein (1941) and the mean roundness for each mineral in each size (0.062 mm and 0.125 mm size grades for the heavy minerals and 0.062 mm, 0.125 mm, 0.250 mm, and 0.50 mm size grades for the light minerals) of the ten samples analyzed was computed. These mean roundness values by mineral and size are given in Table V. It can be seen from this chart that, though different minerals may have similar roundness values, many have greatly dissimilar values, and furthermore, changes in these values are dependent on the particular mineral. Sneed and Folk (1958) reported similar conditions for chert, limestone, and quartz pebbles from the Colorado River. In the South Canadian River it is also noted that, for some minerals the roundness values for one size differ from those for another size. This difference was tested and the following are found to be significantly different:

Zircon: higher roundness in the larger (0.125 mm) size grade.

Sphene: higher roundness in the larger (0.125 mm) size grade.

Pyroxene-amphibole: higher roundness in the larger (0.125 mm) size grade.

Feldspar: higher roundness in two larger sizes (0.250 mm and 0.50 mm) as compared to the two smaller sizes (0.062 mm and 0.125 mm), but the two smallest sizes when compared to each other and the two largest when compared to each other show no significant difference.

It can be said, then, that if there is a significant difference in roundness of a mineral according to size the larger size is consistently rounder. This agrees with most previous work (Pettijohn, 1957, p. 63-64).

Roundness values were also plotted against river distance to see if there is any significant change in roundness downstream. The following show a trend:

Sphene: roundness increases downstream in the larger (0.125 mm) size grade.

Leucoxene-ilmenite: roundness increases downstream in both the 0.062 mm and 0.125 mm size grades.

Hematite: roundness increases downstream in both the 0.062 mm and 0.125 mm size grades.

Pyroxene-amphibole: roundness increases downstream in only the larger (0.125 mm) size grade.

Tourmaline: roundness increases downstream in only the larger (0.125 mm) size grade.

Quartz: roundness decreases downstream in only the largest (0.50 mm) size grade.

Feldspar: roundness increases downstream in the 0.062 mm size grade but decreases in the largest (0.250 mm and 0.50 mm) size grades.

Plots of roundness values against distance for those minerals which exhibit a significant change in this property are illustrated in figures 8, 9, 10, and 11, and the formulae of all the regression lines are given in Table VI.

With the exception of tourmaline, all the heavy minerals which increase in roundness downstream have a hardness generally less than 6 while all those which show no significant change are greater than 6. Magnetite, which does not exhibit a downstream trend may be an exception to this but its hardness spans this critical value, being from 5.5 to 6.5. Also, of the heavy minerals which do become rounder downstream, all but two exhibit this trend only in the larger size, and these two in both size grades. The light minerals, quartz and feldspar, decrease in roundness downstream in the largest sizes.

Possible reasons to explain why some of the minerals show a significant downstream increase in roundness and some a downstream decrease, while many did not show any change are:

1. If abrasion causes an increase in the roundness of particles, the rigor of abrasion in the South Canadian was not sufficient to produce this change except in the softer heavy minerals.

2. Abrasion may cause a decrease in roundness because of chipping or cleaving of grains. The roundness decrease in the larger quartz and feldspar size grades may be a function of this. Russell and Taylor (1937), reporting a decrease in roundness in Mississippi River sands, attributed it to chipping and fracturing in samples which were essentially all quartz and feldspar.

3. Some of the minerals might be close to a critical lower limit of rounding whereby additional abrasion would produce no significant changes. Sneed and Folk (1958) report a lower limit of rounding for quartz pebbles of 0.65 on the

Colorado River. The highest mean roundness value for any sample of quartz sand in any size on the South Canadian River is 0.47, considerably below the figure for pebbles given by Sneed and Folk.

4. The size of some minerals might be below some critical point whereby rounding processes are no longer effective. This may be why in most cases only the 0.125 mm size showed a trend while the 0.062 mm size did not.

Any, or all, of the above factors may be involved in the South Canadian, and the rate of change, or lack of change, in these values is dependent on the mineralogy and, for a particular mineral, on the size.

Sphericity

The sphericity was determined by the measurement of intercepts and extrapolation, using these measurements, from a chart given by Aschenbrenner (1956, p. 21). A discussion of the reference solid used by Aschenbrenner has been given in the section, "Previous Investigations." As was done for roundness, the sphericity values were determined for each grain counted and the mean sphericity for a particular mineral in various size grades in each sample was determined. These are given in Table V. Also, the relationship of these mean sphericity values to both size and river distance was examined. The following relationships exist:

1. Though many of the minerals have the same sphericity values, the size and river distance variations, when they exist, are dependent on the particular mineral.

2. Pyroxene-amphibole, tourmaline, quartz, and feldspar show significant differences in sphericity in different size grades. For pyroxene-amphibole, the smaller size grade (0.062 mm) is more spherical; for tourmaline, the larger size grade (0.125 mm) is more spherical; and for both quartz and feldspar, each of the smaller size grades is more spherical than the next larger with the exception of the two largest size grades (0.250 mm and 0.50 mm) which have no significant difference in their sphericity values.

3. Only magnetite (a downstream sphericity decrease in the 0.125 mm size grade), hematite (a downstream sphericity decrease in the 0.125 mm size grade), quartz (a downstream sphericity decrease in the 0.50 mm size grade), and feldspar (a downstream increase in both the 0.125 mm and 0.50 mm size grades) show significant variation over the course of the river.

The formulae for the regression lines of sphericity versus distance are given in Table VI, and the plots of those with significant slopes are shown on figures 12 and 13.

The lower values of sphericity in the larger sizes for all the minerals in which there was a significant difference, except tourmaline, are contrary to values reported by some workers (Pettijohn, 1957, p. 64-65). Though Russell and Taylor (1937, p. 250) stated that "there appears to be a tendency for the larger grains [of the Mississippi River] to possess . . . higher sphericity values . . .," they further indicated that "this relationship . . . is not uniformly applicable. . . ."

The fact that most of the minerals do not vary significantly in their sphericity along the course of the river is probably due partly to the same reasons given for the lack of change in many roundness values, namely the lack of abrasional rigor, the possibility of a lower limit of value change, and the possibility of a lower size limit below which the abrasional forces are non-operative. In addition, it has been demonstrated that sphericity is partly a function of the original particle character (Pettijohn, 1957, p. 66 ff.). While there is no apparent system to the changes that are significant, it is interesting to note that Russell and Taylor (1937) reported a decrease in sphericity downstream in Mississippi River sands that are predominantly quartz in composition, and that in the South Canadian River, in the 0.50 mm size grade, quartz also shows a downstream decrease in sphericity. Sneed and Folk (1958) pointed out that, for Colorado River pebbles, quartz of one size increased in sphericity, one size decreased, while another size remained constant in a downstream direction. They also reported similar variations in the behavior of chert and no systematic changes in limestone pebbles. They stated (p. 149) that sphericity is a "complex function of rock type, pebble size, and distance." The South Canadian River sands bear this out.

Shape Factor

The mean shape factor (F) for each mineral by size and sample was determined from the intercept measurements according to the formulae given by Zingg whereby

$$F = \frac{p}{q}, \qquad p = \frac{c}{b}, \qquad q = \frac{b}{a},$$

where a is the long intercept; b, the intermediate; and c the short intercept. This means that

$$F = \frac{\frac{c}{b}}{\frac{b}{a}} \quad \text{or} \quad F = \frac{ac}{b^2}$$

It can be seen that for a given value of the smallest intercept, c, if the values of a and b diverge from each other the F value would get larger and the shape of the grain would tend to become more elongate. Conversely, if the values of a and b approach each other the F values would get smaller and the shape of the grain would tend to become less elongate. These relationships, as well as actual shape classes that Zingg has constructed, are illustrated in figure 7.

The mean F values computed for the minerals in the various sizes in each sample of the South Canadian River are given in Table V. The following minerals show a significant difference in the mean F between sizes:

Hematite: larger F in the smaller (0.062 mm) size grade.

Pyroxene-amphibole: larger F in the larger (0.125 mm) size grade.

Tourmaline: larger F in the larger (0.125 mm) size grade.

Quartz and feldspar: larger F in each successive smaller size grade except the two largest size grades (0.250 mm and 0.50 mm) which have no significant difference.

The mean F value for each mineral in each size was plotted against river distance. The formulae for these regression lines are given in Table VI. A few showed a

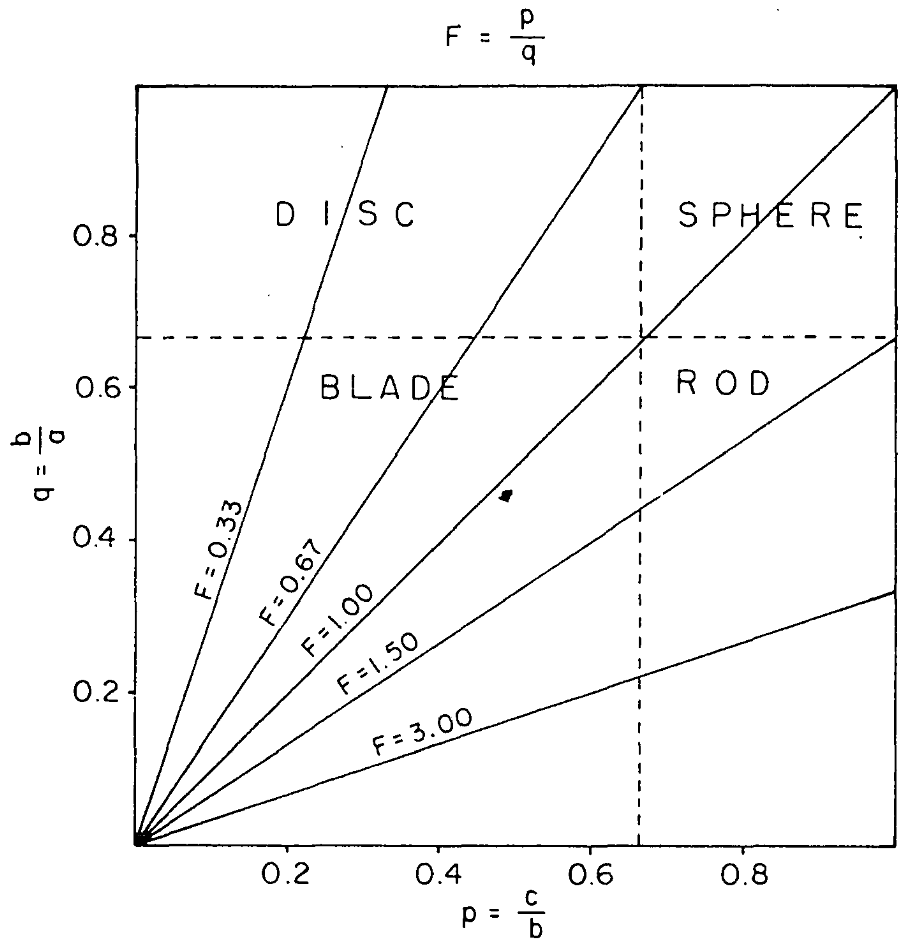


FIGURE 7
SHAPE FACTOR AND ZINGG SHAPE CLASSES
(in part after Aschenbrenner, 1956)

significant change downstream and their plots are illustrated on figures 14 and 15. They are:

Pyroxene-Amphibole: decreases in F only the larger (0.125 mm) size grade.

Quartz: increases in F the two largest (0.250 and 0.50 mm) size grades.

Feldspar: decreases in F the two largest (0.250 and 0.50 mm) size grades.

It can be seen that, though most of the minerals do not show a significant change with distance, in those that do only the larger sizes are affected.

That most minerals do not exhibit a change in shape factor is probably the result of the same causes as set forth for roundness and sphericity. It is interesting to look, however, at the behavior of quartz. Quartz tends to be more elongate in the smaller sizes and also tends to be more elongate downstream in the larger sizes. (Note that the use of the words "more elongate" depends on the interpretation of the Zingg relationships holding the small intercept, c, constant and increasing the F value.) This suggests that quartz may become reduced in size by rolling, though the actual abrasional process might be one of chipping as suggested above in the section on "Roundness." Feldspar and pyroxene-amphibole which are also more elongate in the smaller classes, however, become less elongate downstream in the larger classes. These minerals may become reduced in size by cleavage which might produce more elongate small "slivers" from larger particles and at the same time produce less elongate "parent" particles. This method of size reduction seems borne out by the fact that feldspar also increased in sphericity downstream in the larger sizes. It seems significant that all the minerals that show a change downstream also exhibit a significant difference in their shape factor between sizes.

Certainly, the shape factor, like roundness and sphericity, is mainly dependent upon the mineral.

Interrelationship of Roundness, Sphericity and Shape Factor

Pettijohn (1957, p. 60) stated:

> Theoretically sphericity and roundness are geometrically distinct and independent properties. Theoretically both are independent to size - another geometrical property of clastic particles. Actually in natural sediments not only are sphericity and roundness closely correlated with each other but each in turn is a function of size.

As has been shown previously, for a given mineral the roundness, sphericity, and shape factor values and the variations in these values over distance are, in some instance, related to the size of a particle. However, the relationship of the mean roundness, mean sphericity, and mean shape factor to each other was found to be not significant for the minerals in South Canadian River sands.

The interrelationships were examined by the method described in the section on "Statistical Treatment." When a property was related to size then comparisons between properties were made for each individual size grade. When the properties were not related to size then the properties were compared regardless of size. These comparisons were made for each mineral.

None of the ten minerals studied show any significant relationship between these properties.

For Mississippi River sand, Russell and Taylor (1937, p. 248-249) indicated that their data "suggest a relationship" between sphericity and roundness. However, they pointed out that "the data scarcely justify positive conclusions." Sneed (1955, p. 72) working with Colorado River pebbles found that "there is only slight correlation between particle roundness and particle sphericity" and attributes this slight relationship to a third variable, distance.

It seems that in the study of the interrelationships of these particle properties great care should be taken to eliminate erroneous results due to the effect of other variables, particularly composition, size and distance of transport.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The composition and textural properties of the channel sediment of the South Canadian River remain essentially constant over some 650 miles of river distance. When changes in the properties of particles do take place they are dependent on the particular mineral involved and, for a given mineral, on the size of the particle.

Specifically, the following conditions were noted:

1. The size distribution of all the samples is essentially normally distributed. There are no downstream trends in any of the size parameters except kurtosis, which, though the trend is of a low order, indicates slightly more peaked distributions in a downstream direction. The constancy of the size parameters is attributable to similarity in the hydraulic conditions in the river over the distance studied.

2. The percentages of heavy minerals in the sediment and the relative abundance of these minerals in the

heavy mineral suite show no downstream trend. The 0.062 mm size grade consistently has a greater abundance of heavy minerals than the 0.125 mm size grade but the minerals remain in the same relative abundance between sizes. It is felt that neither selective abrasion nor tributary dilution is an important factor in the South Canadian River.

3. The quartz-feldspar ratio is higher in the larger size grades (0.250 mm and 0.50 mm) than in the smaller size grades (0.062 mm and 0.125 mm) but within these two groups the values are similar. In the larger size grade of each of these groups (0.125 mm and 0.50 mm) there is a significant increase downstream in the ratio, but in the smaller size grade there is not. It is felt that the reduction of feldspar in the larger size grades to produce the downstream increase in the ratio in these sizes, and at the same time the absence of a trend in the smaller sizes, may be because of an "influx" of feldspar from the large to the small sizes as the particles cleave.

4. Many minerals show no change in roundness downstream nor significant differences between sizes. Of those that do show a significant difference between sizes, the larger size is consistently rounder. All the heavy minerals that exhibit a trend become rounder downstream, and, though

some of these become rounder in more than one size grade, the larger size is always involved. Those heavy minerals that increase in roundness downstream have hardnesses generally less than 6 and it is believed that the abrasional rigor of the South Canadian River was not sufficient to produce an increase in roundness by attrition for minerals harder than this value. Quartz and feldspar show a decrease in roundness downstream in the larger size grades. This decrease is believed to be a result of chipping and fracturing in the case of quartz and cleaving in the case of feldspar.

5. Most minerals show no significant downstream trend in sphericity nor significant variation between sizes. Of those that do show variation, some are more spherical in the smaller sizes, some less; and all except feldspar decrease in sphericity downstream.

6. The shape factor remains essentially constant both in a downstream direction and between sizes for most minerals. The smaller sizes of quartz tend to be more elongate than the larger, and the larger sizes tend to become more elongate downstream. It is believed that quartz particles may roll as they are transported which would make smaller, more elongate grains from larger ones, though the actual reduction of size may be the result of chipping.

Feldspar, however, is more elongate in the smaller sizes but becomes less elongate downstream in the larger sizes. The size reduction of feldspar is probably due to cleaving which could produce small elongate particles while the "parent" particles become less elongate. The minerals that show a downstream trend in shape factor also have a significant difference in their shape factor between sizes.

7. The lack of downstream change of roundness, sphericity, and shape factor for most minerals is attributed to a lack of abrasional rigor of the river, the possibility that the values of these properties might be below a critical value whereby no further significant changes may take place, the possibility that size of the particles might be below a critical value whereby the forces to produce the changes are no longer operative, and the effect of the original particle character. Any, or all, of these factors may be involved.

8. Roundness, sphericity, and shape factor of a particle are dependent on the particular mineral and the size of the particle.

9. Because the composition of the South Canadian River sands is essentially uniform and the various textural properties remain essentially constant over the course of the river, selective sorting on the basis of roundness and shape

is not an important process over the river distance studied.

10. Many of the commonly used indices for determining direction of sediment transportation, such as a reduction in size of the median diameter, a decrease in the abundance of heavy minerals, a decrease in the abundance of unstable minerals, or an increase in particle roundness and sphericity, do not apply to the channel deposits of the South Canadian River. Therefore, these indices may not always be applicable to other recent or ancient channel deposits.

The above facts agree in part with the results of work reported in other studies of river transported material. Where they do differ, it may be for the following reasons:

1. Dependency of the properties on size and mineralogy was not fully considered in most other studies.

2. Since most previous studies dealt with particles larger than sand size, generalities regarding the behavior of particles cannot necessarily be extended to include all sizes of sedimentary particles.

3. The changes which take place in sedimentary particles are so complex and the interaction of factors in a sedimentary environment so complicated, that even when comparing sediment from similar environments, such as from river to river, the characteristics of the sediment may

differ. Thus, broad generalizations mask the true nature of sedimentary particles when applying these generalizations to the sediment of a particular environment. Dogmatic statements regarding the nature of sediments are certainly not defendable.

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APPENDIX

TABLE I

SIZE DISTRIBUTION PARAMETER VALUES

Sample	Median Ø	Mean Ø	Sorting Ø	Skewness	Kurtosis
670	2.80	2.85	0.57	+0.08	0.86
598	2.50	2.48	.83	- .02	1.01
547	1.80	1.85	.68	+ .07	0.99
519	2.55	2.53	.64	- .03	0.99
469	2.32	2.32	.50	.00	0.90
441	2.25	2.29	.69	+ .06	0.92
389	2.25	2.25	.59	.00	1.00
356	2.90	2.92	.99	+ .02	0.99
323	2.50	2.51	.64	+ .02	0.98
296	2.38	2.38	.53	.00	1.08
267	2.59	2.67	.64	+ .05	0.95
238	2.40	2.38	.48	- .04	1.01
213	2.80	2.85	.59	+ .08	1.13
198	2.61	2.64	.62	+ .05	1.04
180	2.80	2.83	.67	+ .04	1.10
152	2.50	2.52	.61	+ .03	1.01
129	3.00	2.99	.83	- .01	0.97
94	2.80	2.80	.61	.00	1.03
45	3.60	3.61	.57	+ .02	1.05
19	2.05	2.07	.70	+ .03	1.07

TABLE II

PERCENTAGE OF HEAVY MINERALS BY WEIGHT

Sample	Size Grade (mm) .062	.125
670	1.56	0.42
598	3.51	0.61
547	4.63	0.93
519	1.52	1.00
469	1.31	0.35
441	2.00	0.40
389	1.76	0.60
356	1.62	0.96
323	4.07	0.63
296	3.14	0.66
267	6.69	0.78
238	2.35	0.64
213	1.68	0.37
198	1.53	0.27
180	2.00	0.43
152	5.73	1.04
129	1.76	0.53
94	2.07	0.63
45	2.63	0.68
19	4.31	0.72

TABLE III

PERCENTAGE OF COMMON HEAVY MINERALS IN HEAVY MINERAL SUITE
(Total Heavy Mineral Suite - 100 Percent)

<u>Key</u>

M - Magnetite
Z - Zircon
H - Hematite
S - Sphene
S-G - Spinel-Garnet
L-I - Leucoxene-Ilmenite
A-P - Pyroxene-Amphibole
T - Tourmaline

Sample	Size Grade (mm)	M	Z	H	S	S-G	L-I	A-P	T
670	0.062	37	17	15	5	5	6	5	5
	.125	33	10	16	7	8	11	11	4
598	.062	42	14	13	6	7	5	5	3
	.125	38	12	12	8	9	7	6	3
519	.062	40	14	13	8	8	6	6	3
	.125	37	14	11	9	9	7	7	3
469	.062	40	15	15	8	8	5	4	3
	.125	37	13	14	9	10	6	6	3
389	.062	38	14	16	9	11	6	3	3
	.125	36	14	15	11	9	6	3	3

TABLE III--Continued

Sample	Size Grade (mm)	M	Z	H	S	S-G	L-I	A-P	T
323	0.062	47	14	11	10	9	3	5	1
	.125	37	17	8	10	10	4	8	4
267	.062	42	17	14	8	8	4	5	2
	.125	32	12	13	9	9	9	10	5
198	.062	34	10	15	14	5	6	7	6
	.125	34	15	12	14	3	8	10	2
129	.062	38	16	16	11	9	3	2	2
	.125	31	15	12	9	8	12	5	5
45	.062	33	15	10	12	8	9	2	7
	.125	38	17	13	8	11	6	5	2

TABLE IV

QUARTZ-FELDSPAR RATIO

(Ratio determined by dividing amount of feldspar by count into amount of quartz by count)

Sample	Size Grade				
	.062 mm	.125 mm	.250 mm	.50 mm	All sizes
670	11.20	8.84	20.00	17.84	10.74
598	11.26	9.12	19.85	18.00	11.28
519	11.43	9.34	19.83	18.46	10.73
469	11.85	9.61	19.80	18.75	12.62
389	12.06	10.00	19.66	19.44	11.93
323	13.46	12.21	19.37	19.62	12.38
267	13.93	13.07	19.00	20.00	10.21
198	9.33	13.11	19.00	20.01	11.21
129	9.24	13.77	18.97	20.50	11.31
45	9.15	14.08	18.96	20.60	10.25

TABLE V

MEAN ROUNDNESS, MEAN SPHERICITY, AND MEAN SHAPE FACTOR VALUES

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Magnetite		
670	0.062	0.58	0.88	0.85
598		.62	.85	.94
519		.59	.83	.87
469		.58	.81	.83
389		.54	.77	.69
323		.56	.73	.66
267		.62	.81	.73
198		.57	.84	1.05
129		.57	.83	.86
45		.58	.85	.93
670	.125	.62	.88	.87
598		.62	.88	.89
519		.62	.88	.88
469		.62	.87	.86
389		.59	.88	.84
323		.65	.83	.78
267		.64	.86	.84
198		.62	.85	.87
129		.61	.83	.92
45		.61	.78	.73

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Zircon		
670	0.062	0.50	0.92	1.05
598		.61	.88	1.22
519		.57	.87	1.18
469		.59	.86	1.15
389		.56	.85	1.00
323		.54	.82	1.02
267		.52	.89	1.16
198		.60	.87	1.06
129		.55	.88	1.24
45		.61	.91	1.29
670	.125	.62	.88	.95
598		.64	.90	.98
519		.64	.90	1.00
469		.64	.91	1.01
389		.63	.89	1.09
323		.63	.88	.95
267		.64	.91	.90
198		.60	.86	.95
129		.66	.92	.94
45		.65	.87	.89

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Hematite		
670	0.062	0.54	0.91	1.07
598		.56	.85	.94
519		.55	.85	.96
469		.54	.84	.96
389		.52	.83	.98
323		.55	.86	.96
267		.57	.82	.96
198		.58	.81	.94
129		.59	.84	.93
45		.63	.91	1.10
670	.125	.55	.88	.89
598		.54	.86	.84
519		.55	.86	.86
469		.56	.87	.86
389		.56	.88	.90
323		.58	.83	.96
267		.60	.87	.83
198		.65	.85	.93
129		.65	.82	.89
45		.66	.80	.82

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Sphene		
670	0.062	0.52	0.88	1.04
598		.53	.87	1.05
519		.54	.87	1.01
469		.56	.87	.96
389		.58	.86	.91
323		.58	.82	.93
267		.54	.88	.91
198		.60	.88	.89
129		.51	.89	1.02
45		.56	.89	1.15
670	.125	.58	.88	.95
598		.60	.89	.95
519		.60	.88	.93
469		.61	.88	.90
389		.61	.90	.85
323		.66	.89	1.02
267		.66	.88	.94
198		.61	.85	.90
129		.67	.90	.98
45		.62	.85	.95

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Spinel-Garnet		
670	0.062	0.35	0.82	0.91
598		.42	.86	1.21
519		.41	.86	.98
469		.41	.87	.97
389		.41	.82	.97
323		.45	.78	.87
267		.50	.90	1.00
198		.47	.88	1.16
129		.40	.83	.88
45		.39	.88	1.14
670	.125	.40	.82	.91
598		.42	.84	1.00
519		.43	.85	.98
469		.43	.86	.96
389		.43	.86	.95
323		.46	.86	.80
267		.47	.84	.87
198		.47	.84	.92
129		.45	.88	1.02
45		.44	.84	.80

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Ilmenite-Leucoxene		
670	0.062	0.57	0.87	0.93
598		.60	.86	.96
519		.55	.87	.92
469		.55	.87	.93
389		.55	.88	.92
323		.56	.85	.92
267		.60	.82	.92
198		.63	.86	.90
129		.66	.87	.93
45		.69	.89	1.10
670	.125	.47	.86	.88
598		.46	.85	1.05
519		.46	.85	.93
469		.46	.84	.80
389		.48	.82	.75
323		.50	.89	1.30
267		.52	.90	.89
198		.57	.80	.78
129		.61	.87	.96
45		.72	.80	.55

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Pyroxene-Amphibole		
670	0.062	0.43	0.71	0.64
598		.45	.66	.64
519		.43	.67	.63
469		.43	.67	.64
389		.42	.69	.62
323		.40	.64	.60
267		.47	.70	.64
198		.40	.71	.65
129		.43	.70	.64
45		.45	.73	.65
670	.125	.46	.75	.85
598		.47	.74	.86
519		.46	.75	.86
469		.46	.75	.85
389		.50	.76	.88
323		.50	.76	.82
267		.50	.78	.75
198		.49	.73	.69
129		.53	.72	.64
45		.53	.74	.64

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Tourmaline		
670	0.062	0.68	0.88	1.10
598		.68	.84	.89
519		.70	.85	.88
469		.70	.86	.88
389		.70	.84	.87
323		.72	.84	.87
267		.72	.88	.81
198		.70	.84	.79
129		.68	.86	1.21
45		.68	.87	1.15
670	.125	.62	.91	1.01
598		.63	.90	1.05
519		.63	.92	1.11
469		.63	.92	1.10
389		.63	.92	1.14
323		.67	.89	1.05
267		.70	.93	1.25
198		.70	.92	1.03
129		.68	.91	.98
45		.68	.92	1.00

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Quartz		
670	0.062	0.44	0.88	1.08
598		.44	.89	1.14
519		.44	.88	1.03
469		.44	.88	.99
389		.44	.85	.98
323		.44	.85	.90
267		.44	.89	.90
198		.44	.89	1.00
129		.45	.89	1.06
45		.46	.89	1.14
670	.125	.45	.83	.80
598		.45	.82	.78
519		.45	.83	.77
469		.45	.83	.76
389		.45	.82	.75
323		.45	.84	.72
267		.46	.82	.70
198		.46	.82	.78
129		.46	.85	.80
45		.46	.86	.83

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Quartz (Continued)		
670	0.250	0.44	0.77	0.51
598		.44	.77	.50
519		.44	.77	.54
469		.45	.77	.55
389		.45	.80	.58
323		.45	.78	.59
267		.47	.81	.60
198		.47	.77	.60
129		.45	.79	.65
45		.45	.80	.65
670	.50	.46	.78	.58
598		.46	.79	.58
519		.46	.78	.58
469		.47	.78	.58
389		.45	.78	.58
323		.45	.79	.60
267		.42	.78	.61
198		.42	.80	.64
129		.42	.81	.65
45		.42	.81	.65

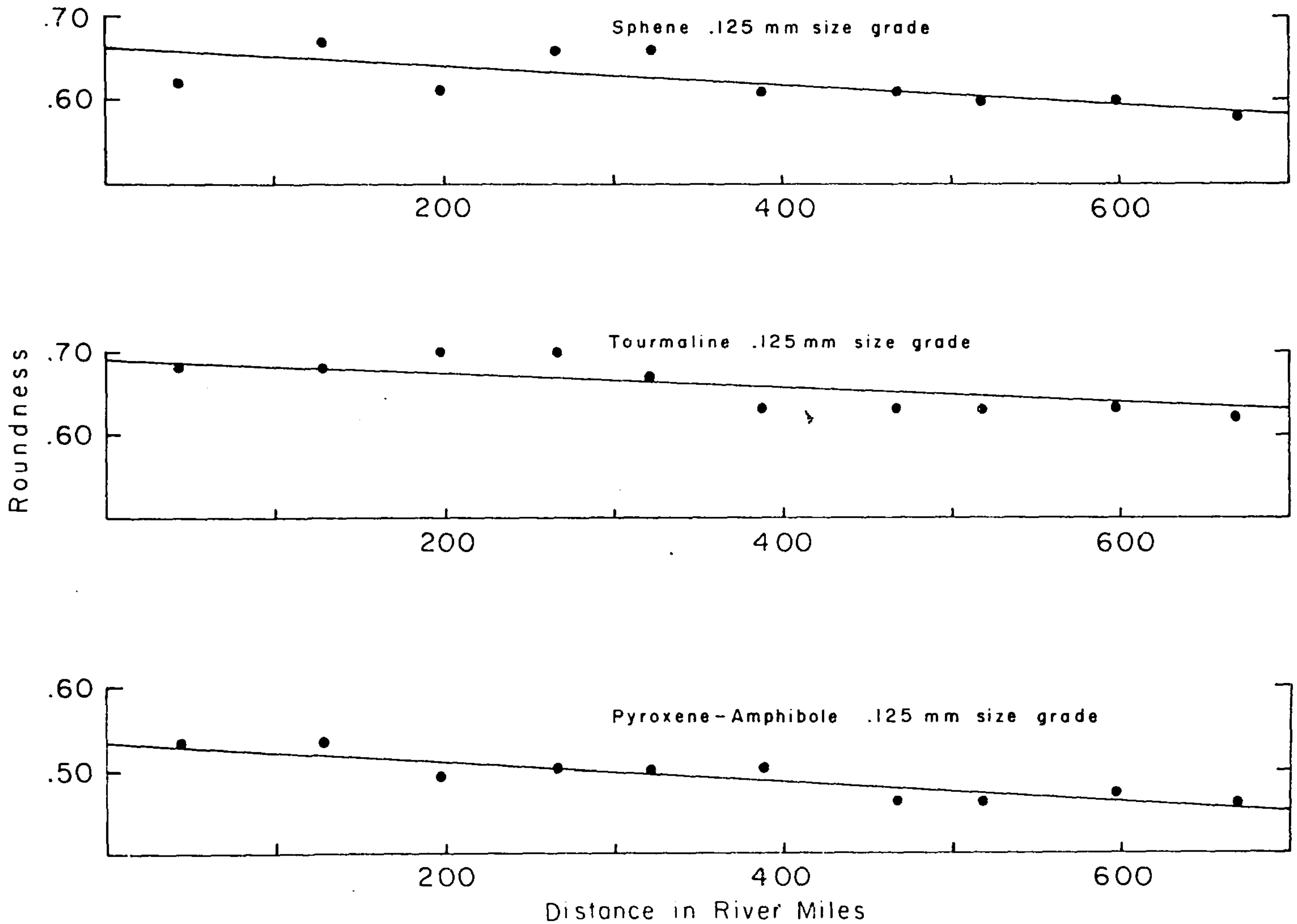
TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Feldspar		
670	0.062	0.40	0.89	1.00
598		.40	.88	1.04
519		.40	.88	1.05
469		.40	.87	1.09
389		.40	.86	1.11
323		.42	.86	1.23
267		.42	.89	1.27
198		.42	.89	1.08
129		.45	.88	1.04
45		.45	.88	1.02
670	.125	.43	.80	.84
598		.43	.82	.85
519		.43	.84	.85
469		.43	.84	.87
389		.43	.84	.87
323		.45	.84	.86
267		.45	.85	.86
198		.45	.84	.84
129		.45	.86	.91
45		.45	.90	.94

TABLE V--Continued

Sample	Size Grade (mm)	Mean Roundness	Mean Sphericity	Mean Shape Factor
		Feldspar (Continued)		
670	0.250	0.58	0.78	0.52
598		.58	.76	.52
519		.54	.78	.54
469		.53	.81	.54
389		.48	.74	.62
323		.48	.81	.65
267		.48	.79	.58
198		.48	.82	.63
129		.46	.76	.62
45		.45	.78	.60
670	.50	.53	.75	.60
598		.53	.74	.61
519		.53	.75	.59
469		.53	.76	.57
389		.51	.78	.63
323		.45	.80	.61
267		.43	.78	.59
198		.43	.81	.63
129		.40	.82	.64
45		.40	.82	.64

FIGURE 8. ROUNDNESS VS DISTANCE



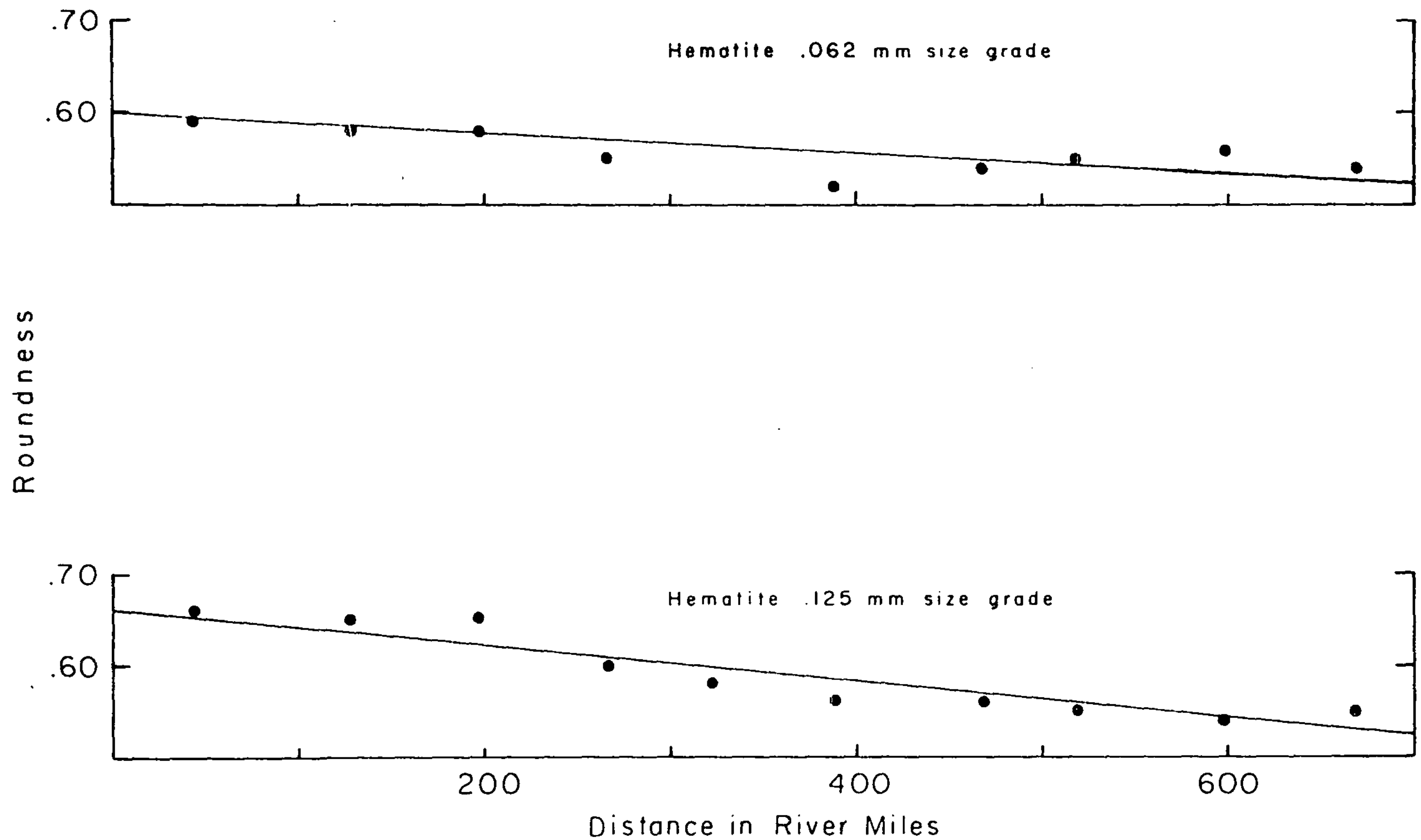


FIGURE 9. ROUNDNESS VS DISTANCES

FIGURE 10. ROUNDNESS VS DISTANCE

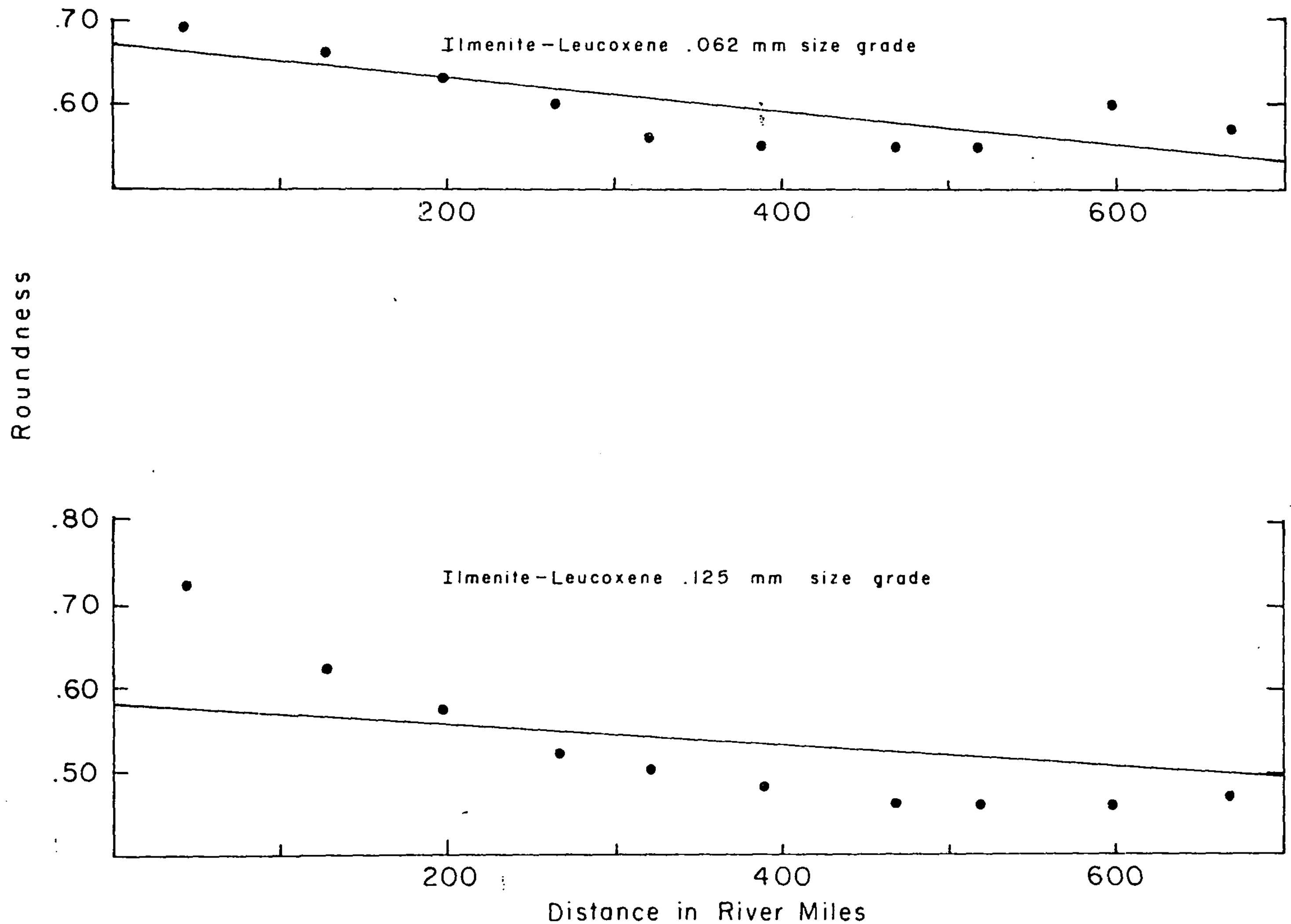


FIGURE II. ROUNDNESS VS DISTANCE

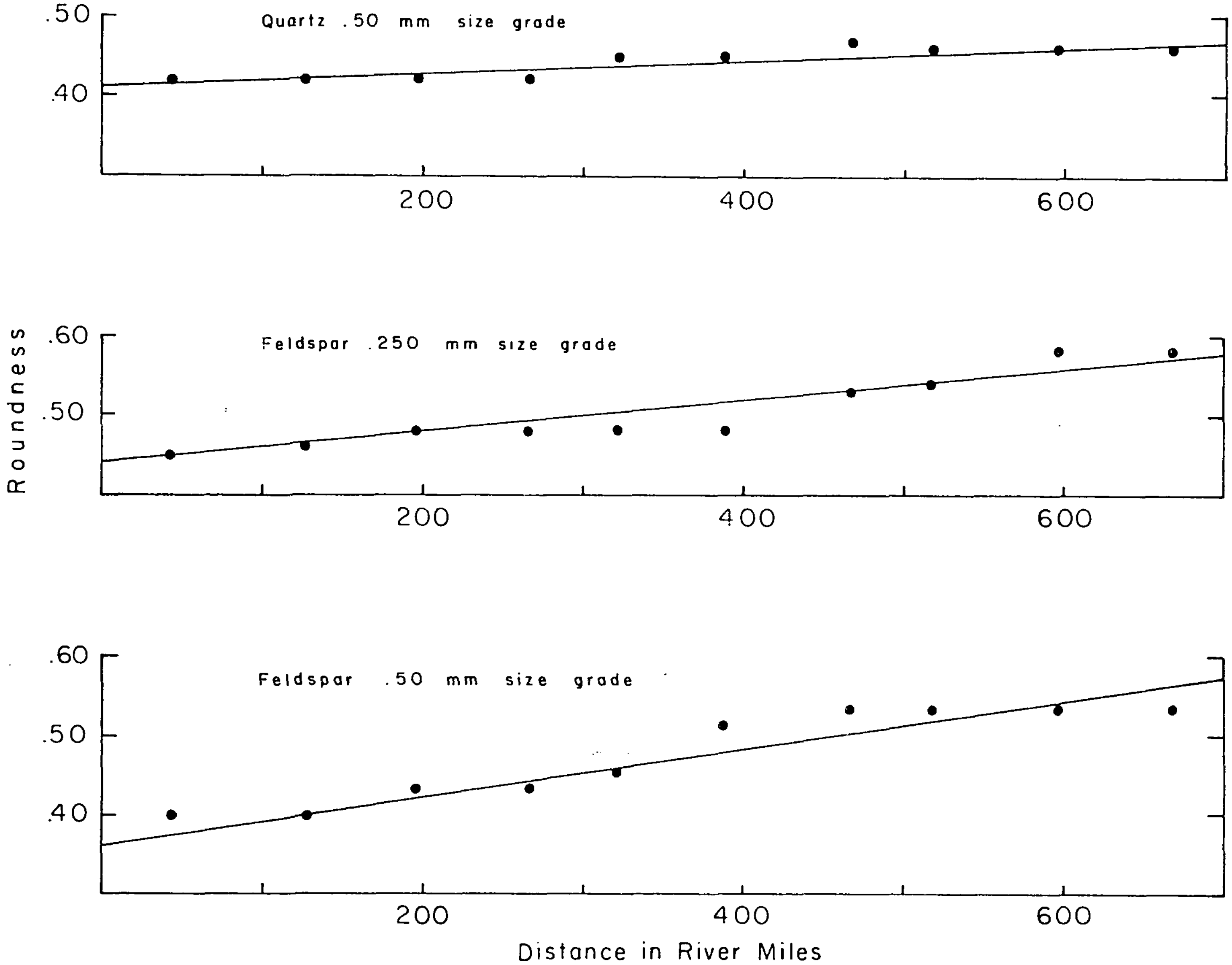
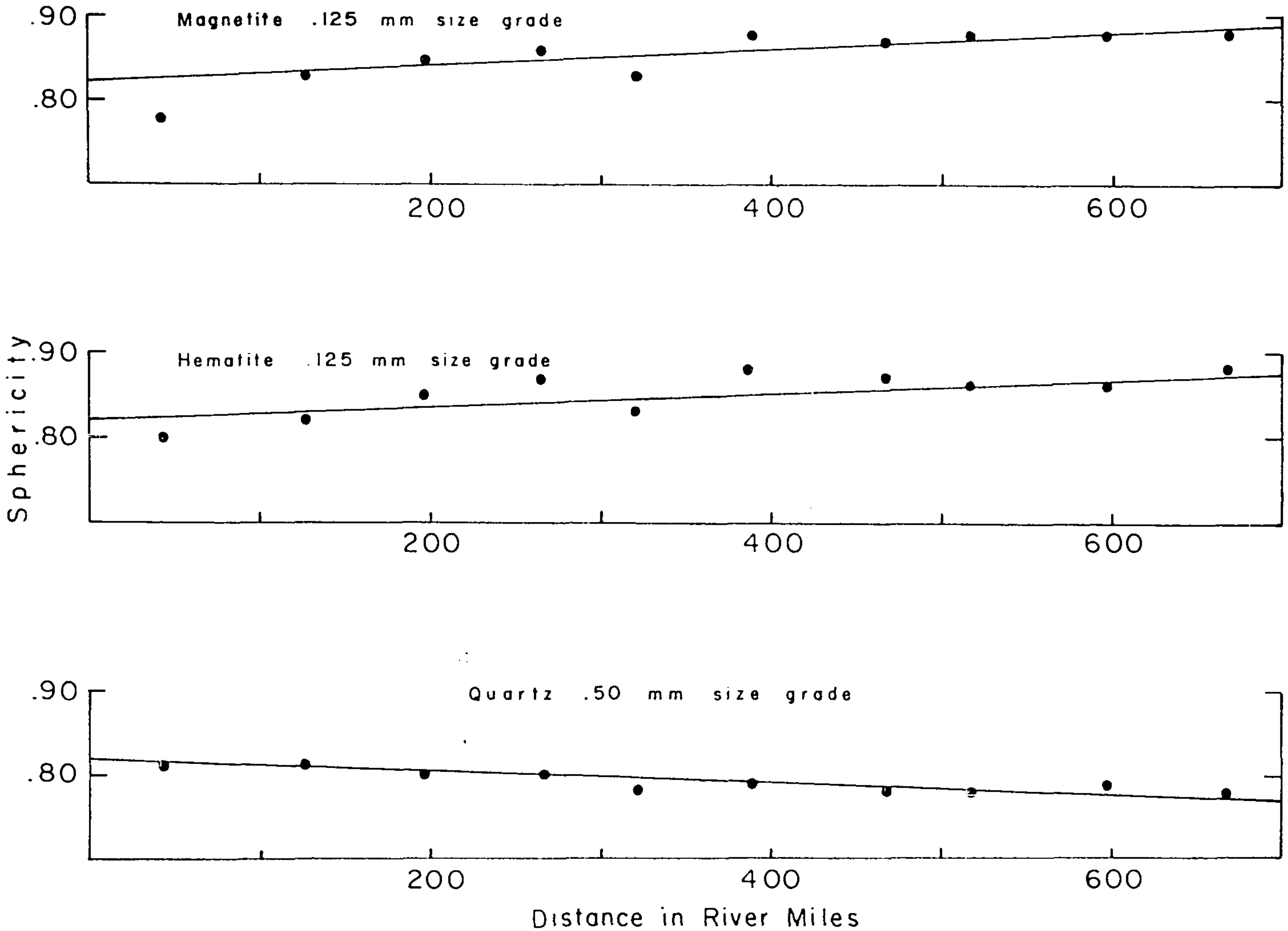


FIGURE 12. SPHERICITY VS DISTANCE



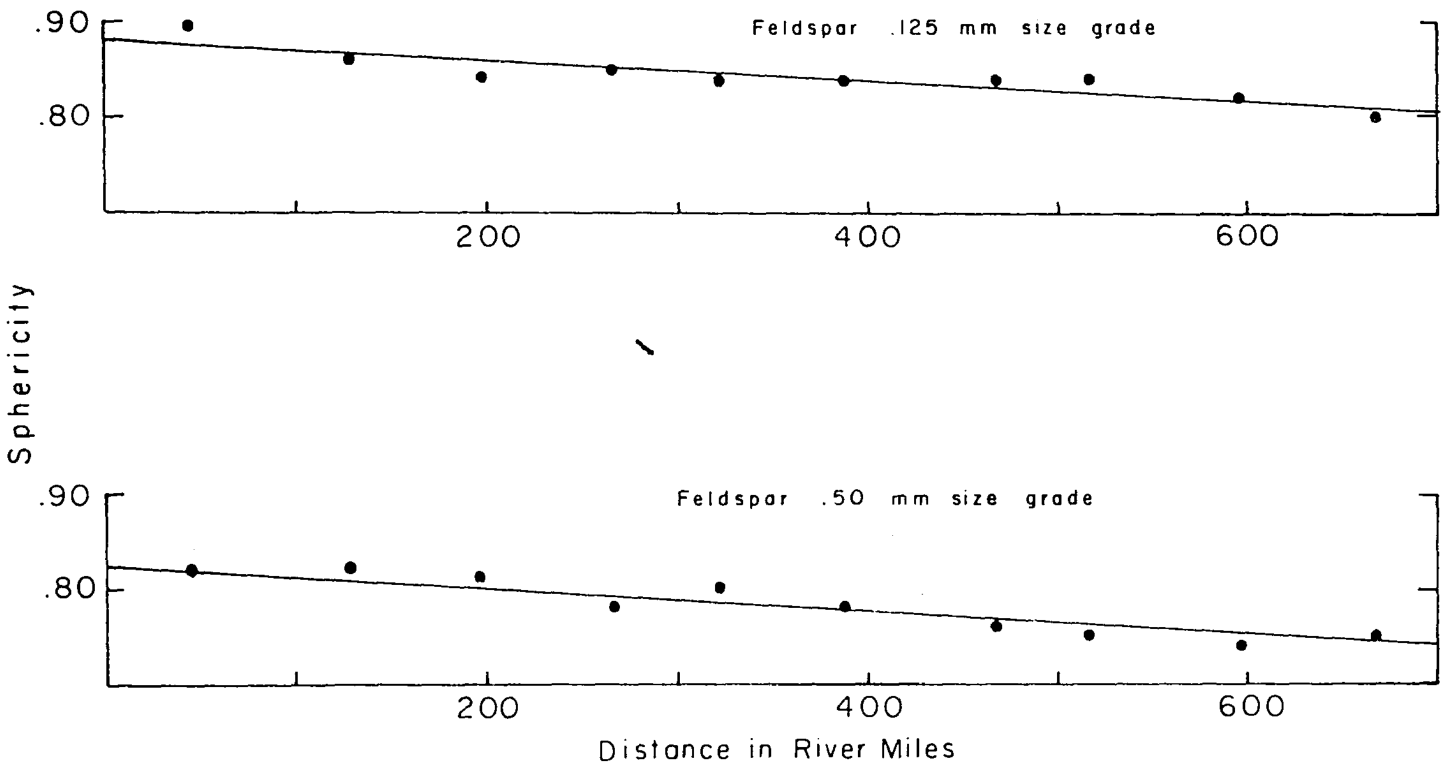


FIGURE 13. SPHERICITY VS DISTANCE

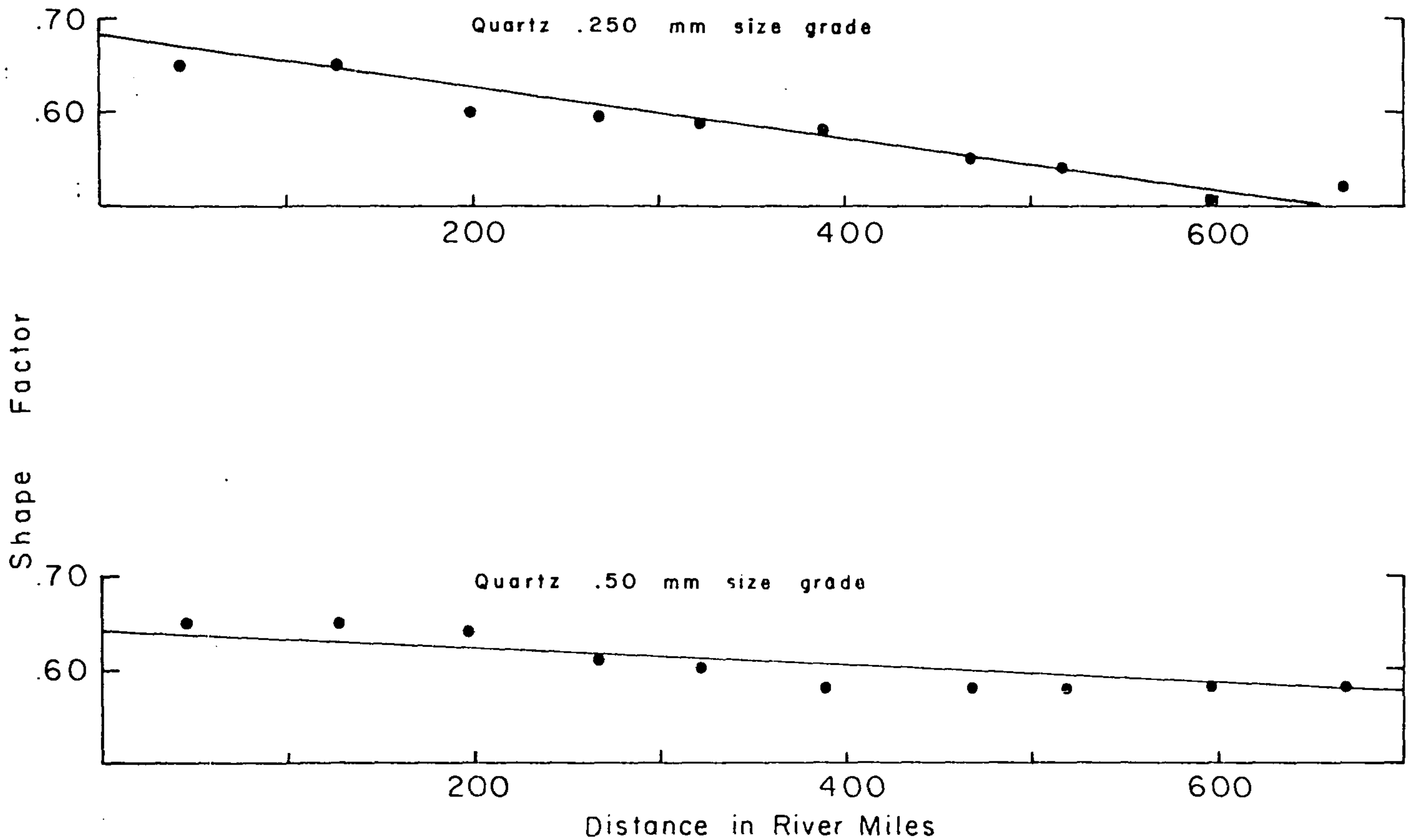


FIGURE 14. SHAPE FACTOR VS DISTANCE

FIGURE 15. SHAPE FACTOR VS DISTANCE

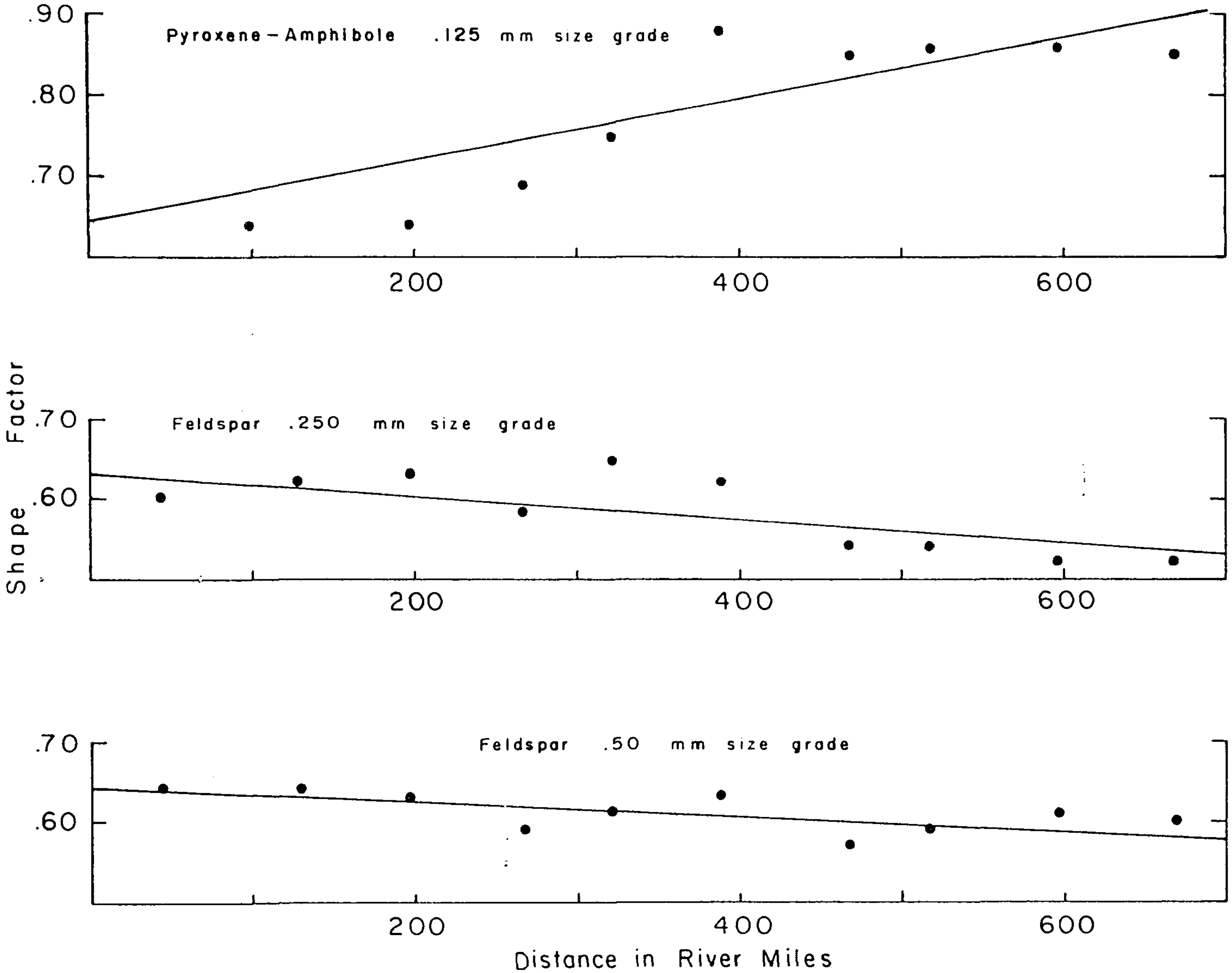


TABLE VI

REGRESSION LINE FORMULAE OF SEDIMENT CHARACTERISTICS PLOTTED AGAINST DISTANCE

These formulae are in the general form, y = a + bx, where y is the particular characteristic being plotted, x is the distance, and a and b are constants. The value of b determines the slope of the line. In the following formulae, those that have a significant slope (at a .05 level of confidence) are starred with an asterisk.

SIZE DISTRIBUTION PARAMETERS	
Median size Ø	2.77 - .0007 distance
Mean size Ø	2.78 - .0007 distance
Sorting Ø	.63 + .00005 distance
Skewness	.02 + .00001 distance
Kurtosis	1.07 - .0002 distance*
QUARTZ-FELDSPAR RATIO	
Size Grade (mm)	
0.062	10.34 + .003 distance
.125	13.31 - .01 distance*
.250	19.47 + .0009 distance
.50	21.12 - .005 distance*

TABLE VI--Continued

PERCENTAGE OF HEAVY MINERALS	
Size Grade (mm)	
0.062	2.82 - .0001 distance
.125	.63 + .000007 distance

MEAN ROUNDNESS

Mineral	Size Grade (mm)	
Zircon	0.062	0.56 - .00001 distance
	.125	.65 - .00002 distance
Spinel-Garnet	.062	.44 - .00007 distance
	.125	.47 - .00008 distance
Magnetite	.062	.57 + .00003 distance
	.125	.62 + .000002 distance
Sphene	.062	.59 - .00004 distance
	.125	.66 - .0001 distance*
Leucoxene-Ilmenite	.062	.67 - .0002 distance*
	.125	.57 - .0001 distance*
Hematite	.062	.60 - .0001 distance*
	.125	.66 - .0002 distance*
Pyroxene-Amphibole	.062	.43 - .000007 distance
	.125	.53 - .0001 distance*

TABLE VI--Continued

MEAN ROUNDNESS (Continued)		
Mineral	Size Grade (mm)	
Tourmaline	0.062	0.66 - .00001 distance
	.125	.69 - .0001 distance*
Quartz	.062	.45 - .00003 distance
	.125	.46 - .00002 distance
	.250	.46 - .00004 distance
	.50	.41 + .00008 distance*
Feldspar	.062	.45 - .00009 distance*
	.125	.46 - .00005 distance
	.250	.44 + .0002 distance*
	.50	.36 + .0003 distance*

MEAN SPHERICITY		
Mineral	Size Grade (mm)	
Zircon	0.062	0.86 + .00006 distance
	.125	.89 + .000007 distance
Spinel-Garnet	.062	.87 - .00005 distance
	.125	.86 - .00004 distance
Magnetite	.062	.81 + .00003 distance
	.125	.82 + .0001 distance*

TABLE VI--Continued

MEAN SPHERICITY (Continued)

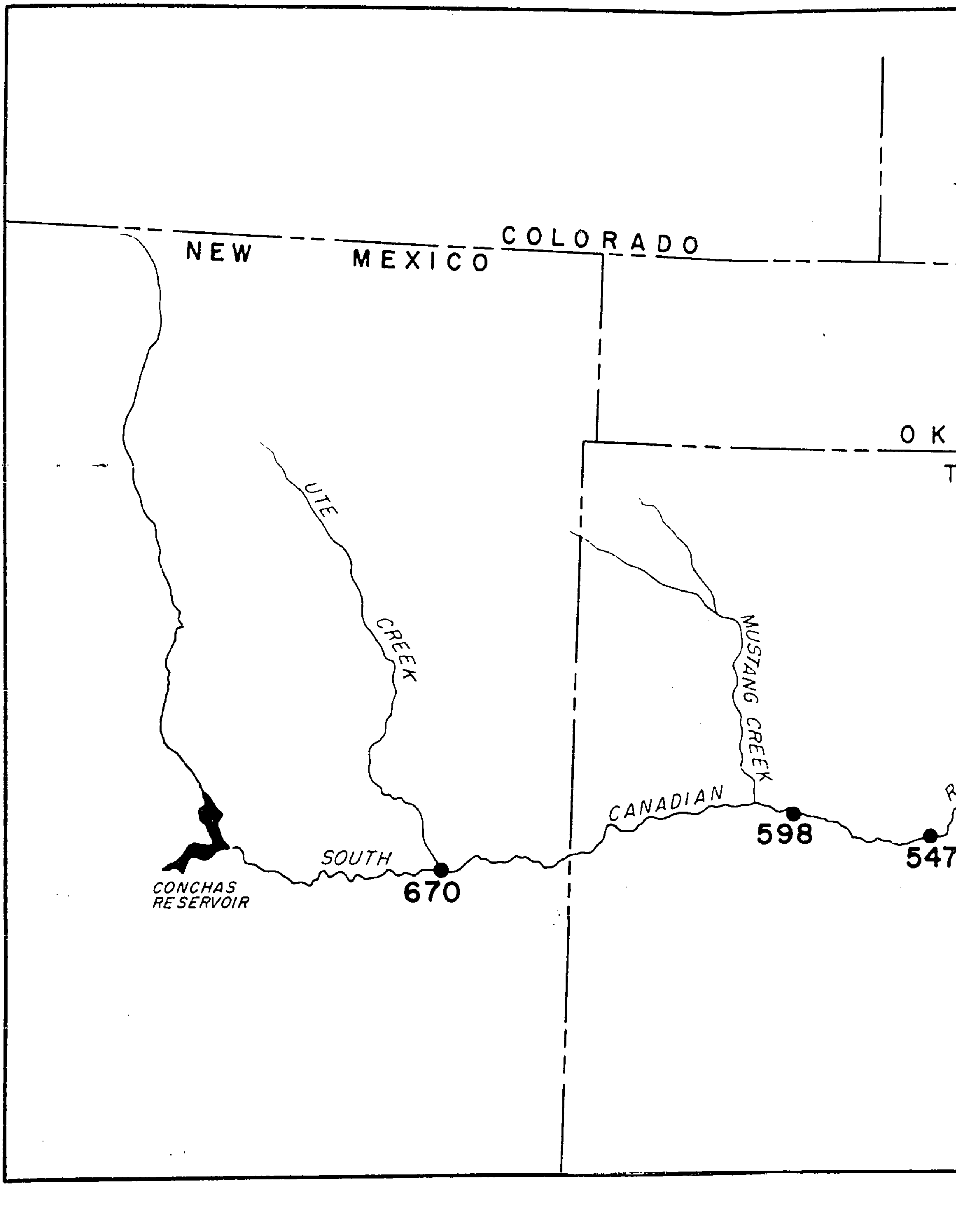
Mineral	Size Grade (mm)	
Sphene	0.062	0.88 - .00002 distance
	.125	.88 + .00001 distance
Leucoxene-Ilmenite	.062	.86 - .00001 distance
	.125	.84 + .00003 distance
Hematite	.062	.84 + .00002 distance
	.125	.82 + .00009 distance*
Pyroxene-Amphibole	.062	.72 - .00007 distance
	.125	.76 + .00002 distance
Tourmaline	.062	.87 - .00003 distance
	.125	.92 - .00003 distance
Quartz	.062	.88 - .00001 distance
	.125	.85 - .00005 distance
	.250	.79 - .00005 distance
	.50	.81 - .00004 distance*
Feldspar	.062	.78 - .000002 distance
	.125	.88 - .0001 distance*
	.250	.79 - .00002 distance
	.50	.82 - .0001 distance*

TABLE VI--Continued

MEAN SHAPE FACTOR		
Mineral	Size Grade (mm)	
Zircon	0.062	0.88 (zero slope)
	.125	.94 + .0001 distance
Spinel-Garnet	.062	1.03 - .00006 distance
	.125	.89 + .0001 distance
Magnetite	.062	.86 - .00006 distance
	.125	.81 + .0001 distance
Sphene	.062	.99 - .000005 distance
	.125	.89 + .00004 distance
Leucoxene-Ilmenite	.062	.98 - .0001 distance
	.125	.87 + .00006 distance
Hematite	.062	.99 - .00002 distance
	.125	.87 - .000002 distance
Pyroxene-Amphibole	.062	.64 - .00002 distance
	.125	.64 + .0004 distance*
Tourmaline	.062	1.02 - .0002 distance
	.125	1.05 + .00005 distance
Quartz	.062	1.01 + .00003 distance
	.125	.78 - .00003 distance
	.250	.69 - .0003 distance
	.50	.64 - .0001 distance*

TABLE VI--Continued

MEAN SHAPE FACTOR (Continued)		
Mineral	Size Grade (mm)	
Feldspar	0.062	1.13 - .0001 distance
	.125	.88 - .0004 distance
	.250	.63 - .0002 distance*
	.50	.64 - .00007 distance*


COLORADO
NEW MEXICO
OK
T
UTE CREEK
MUSTANG CREEK
CANADIAN
SOUTH
CONCHAS RESERVOIR
670
598
547

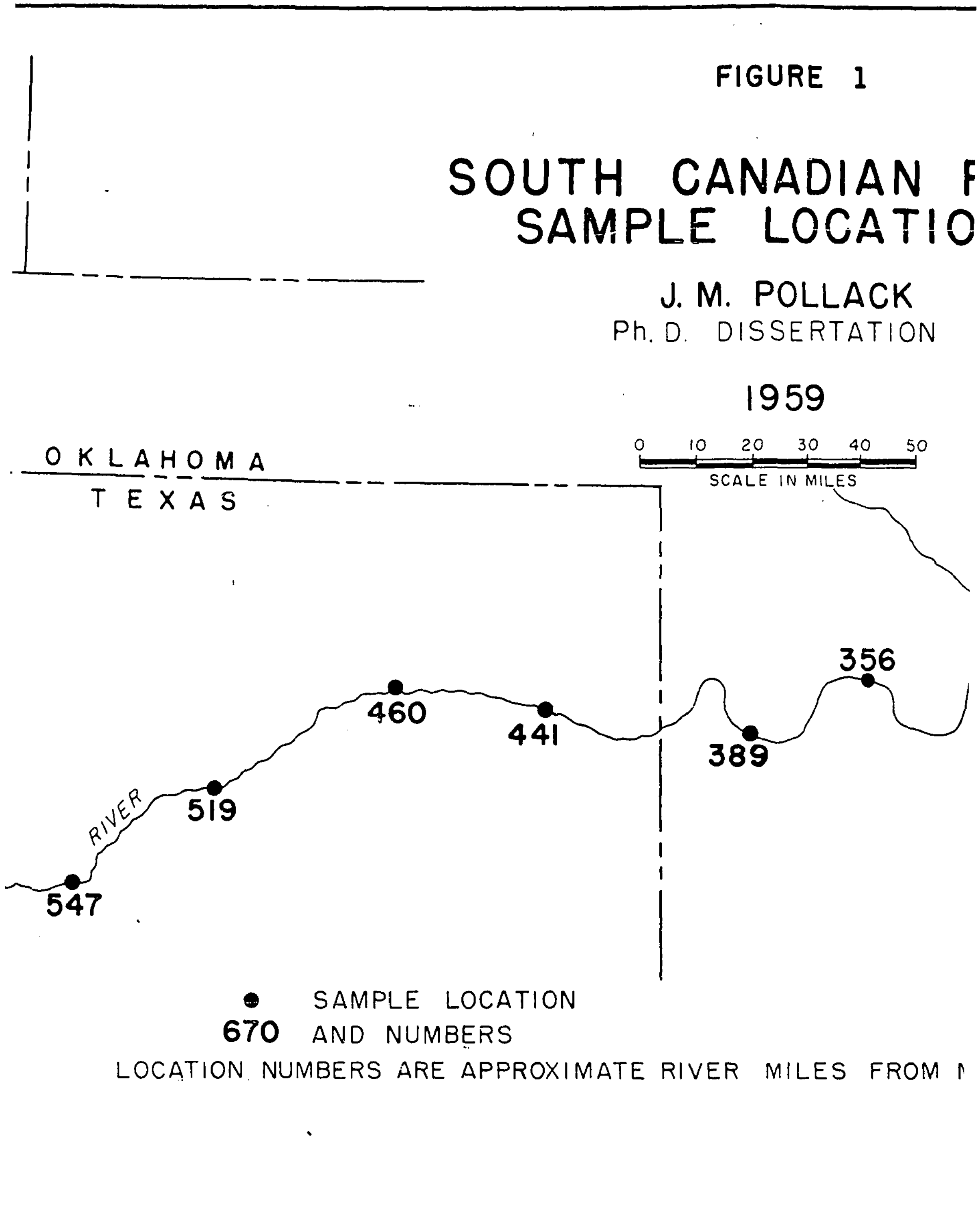


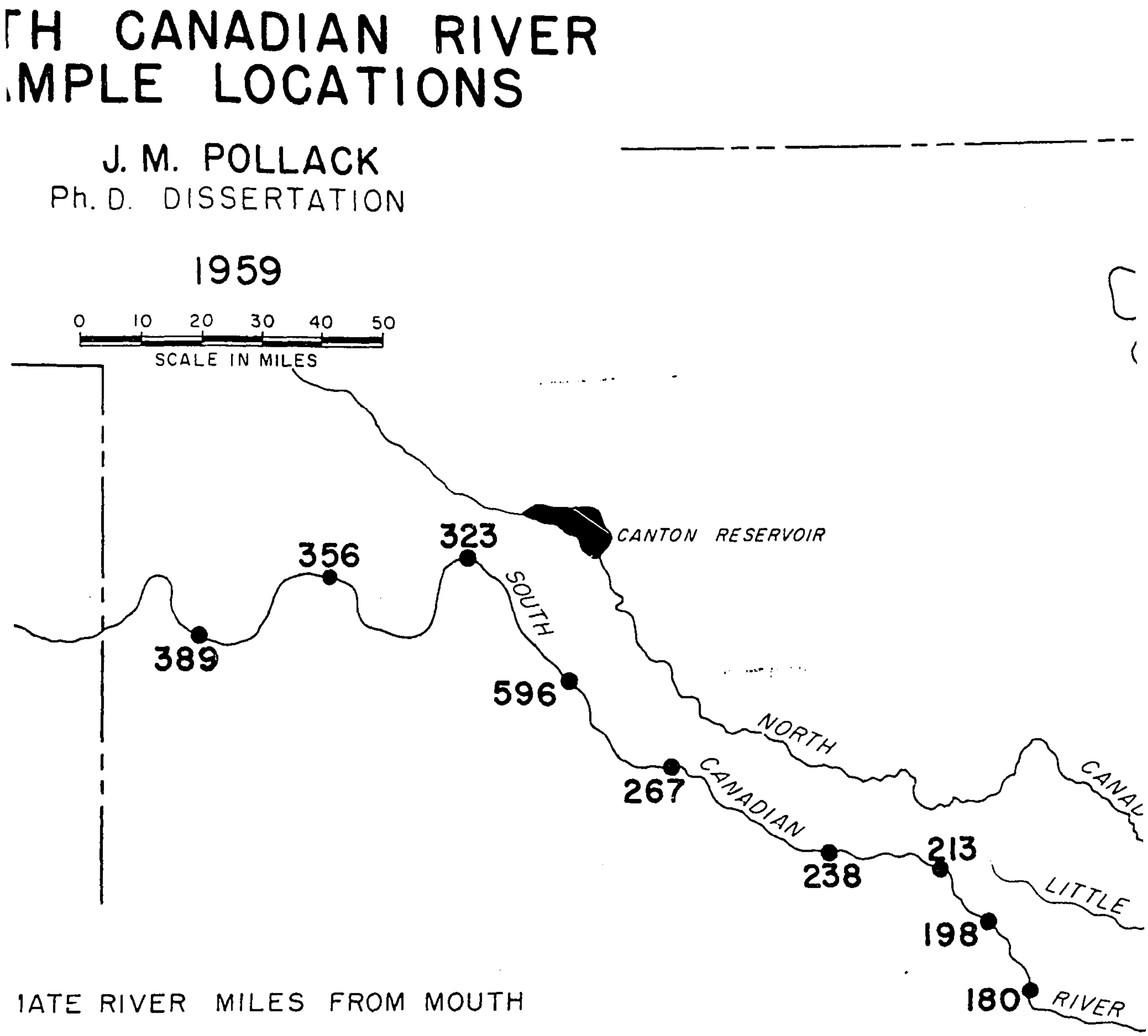
FIGURE 1

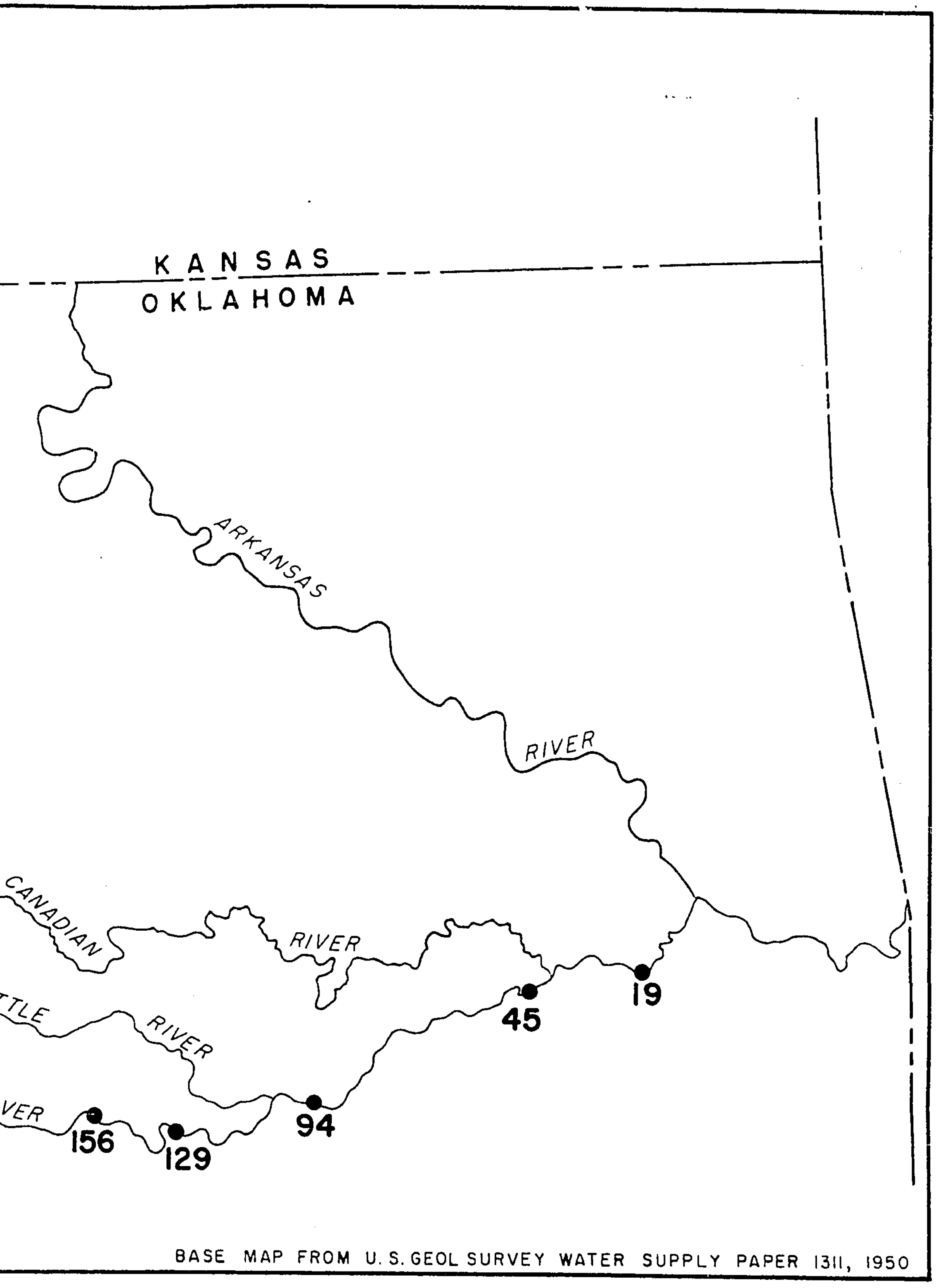
SOUTH CANADIAN R
SAMPLE LOCATIO

J. M. POLLACK
Ph. D. DISSERTATION

1959

FIGURE 1


TH CANADIAN RIVER
MPLE LOCATIONS
J. M. POLLACK
Ph. D. DISSERTATION
1959
0 10 20 30 40 50
SCALE IN MILES
CANTON RESERVOIR
323
356
389
596
267
238
213
198
180
SOUTH
NORTH
CANADIAN
CANAL
LITTLE
RIVER
IATE RIVER MILES FROM MOUTH



KANSAS
OKLAHOMA
ARKANSAS
RIVER
CANADIAN
RIVER
TLE
RIVER
VER
19
45
94
156
129
BASE MAP FROM U. S. GEOL SURVEY WATER SUPPLY PAPER 1311, 1950