

PETROLOGY OF REPUBLICAN, SMOKY HILL, AND
KANSAS RIVER SANDS NEAR JUNCTION CITY, KANSAS

by

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INTRODUCTION

PURPOSE OF INVESTIGATION

In recent years, studies of modern depositional environments, in areas of known climate, relief, and source rock, have revealed important textural and mineralogical associations which are helpful in reconstructing ancient depositional environments. This study, of three modern river sands near Junction City, Kansas, was undertaken to describe the texture and mineralogy of each deposit in relation to its respective drainage basin and depositional environment. Both channel-lag and point-bar deposits of the Republican, Smoky Hill, and Kansas Rivers were included in the investigation.

Textural study included grain-size analysis, roundness determinations, and interpretations of Scanning Electron Microscope (SEM) photomicrographs of quartz grain surface features. Grain-size parameters, roundness values, and surface features were compared among rivers, and with those of other depositional environments. Grain-size parameters were also compared with water depth and surface velocity of each river.

Mineralogical study was concerned with identification of suites of heavy and light minerals from each river and comparison of these mineral suites with known source rocks of the Smoky Hill and Republican drainage basins.

LOCATION

The Republican and Smoky Hill Rivers merge at Junction City, Kansas, to form the Kansas River (Fig. 1). Channel lag and point bar deposits were sampled at 10-meter intervals along a cross-sectional traverse of each river. The cross-sectional traverse of the Republican River was made on Fort Riley Military Reservation approximately one-half kilometer below the Republican

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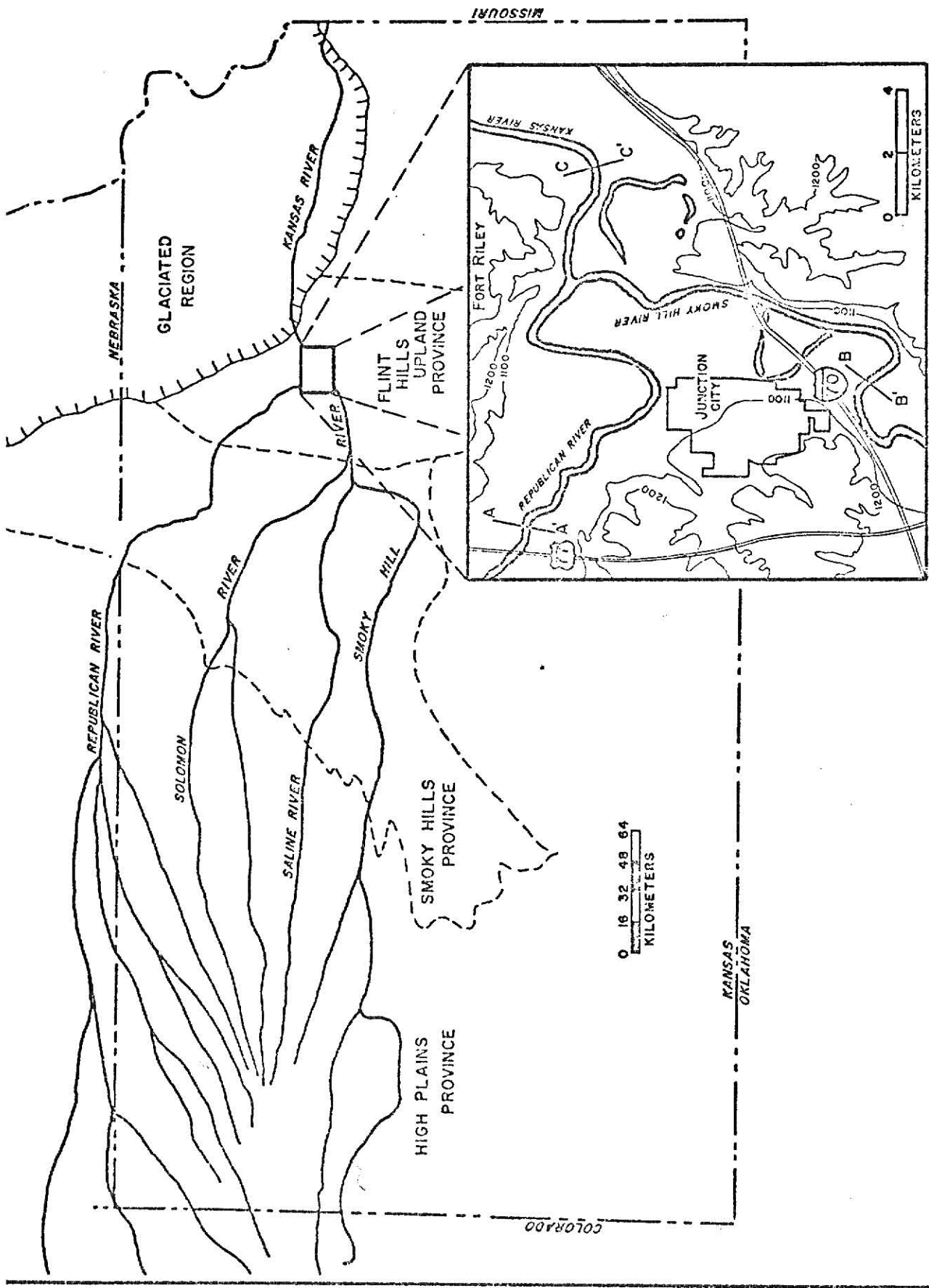


Figure 1. Location and physiographic provinces of the Republican and Smoky Hill River drainage basins.

River bridge on U. S. Highway 77. This location is at $39^{\circ}04'00''$ north latitude and $96^{\circ}51'36''$ west longitude or 14SPU85202643 on the Universal Transverse Mercator Grid (Fort Riley is not subdivided by the township-range grid system). The Smoky Hill cross-sectional traverse was made 250 meters below the abandoned Missouri Railroad trestle south of Junction City and is at $39^{\circ}00'20''$ north latitude and $96^{\circ}49'36''$ west longitude or NE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 13, T. 12 S., R. 5 E. The cross-sectional traverse of the Kansas River was made approximately 250 meters below the Marshall Airfield bridge on Fort Riley Military Reservation and is at $39^{\circ}03'30''$ north latitude and $96^{\circ}46'36''$ west longitude or 14SPU92452490 on the Universal Transverse Mercator Grid.

PREVIOUS INVESTIGATIONS OF MODERN ENVIRONMENTS

Many attempts have been made to uniquely identify modern sand deposits with their corresponding depositional environments. Probably the most persistent efforts have been made in grain-size analyses and attempting to relate several grain-size parameters in unique ways to particular environments. A second method, SEM analysis of quartz surface textures, has only recently been put to use and promises to be a valuable tool in differentiating depositional environments.

In an attempt to relate grain-size parameters to a bimodal river bar, Folk and Ward (1957, p. 26) discovered that skewness and kurtosis values were important in distinguishing unimodal from bimodal sediments. Skewness and kurtosis values of unimodal sediments are nearly normal whereas bimodal sediments are non-normal. They concluded that non-normal kurtosis values reflected a mixing of sediments, each with its size characteristics unmodified from a previous higher-energy environment.

Friedman (1967, p. 352) attempted to differentiate between river and

beach sands by choosing statistical grain-size parameters of size-frequency curves which described the depositional environments. Sediments deposited in river and beach environments include three grain-size populations which are transported by suspension, saltation, and traction (rolling or sliding). Grain-size parameters which were effective in characterizing these populations included the less than 62 μ fraction, which identifies the sediment deposited from suspension; the first percentile, which identifies the maximum grain size of the sliding or rolling population; inclusive graphic standard deviation, which describes the spread of the distribution; and inclusive graphic skewness, which describes the direction of skew of the tails. Scatter plots of these parameters showed good separation of the two environments because of differences in water flow between beach and river environments. Rivers have unidirectional flow with the suspension load traveling with the saltation load whereas the oscillatory motion of water along beaches tends to separate the suspension population from the coarser grained particles thus forming beach lag deposits. Size-frequency curves of beach deposits are consequently truncated in the tail of the fines whereas rivers are usually positively skewed.

Passega and Byramjee (1969, p. 241) showed that distinctive patterns are formed on C-M diagrams when C, the coarsest one percentile, is plotted against M, the median diameter of the sediment. These patterns reflect hydraulic conditions under which a deposit is formed and correspond to five general areas of clastic sediment transportation in water: pelagic suspension, uniform suspension, graded suspension, rolling and suspension, and rolling or sliding. In his study of Mississippi River sediments, Passega (1957, p. 1957) showed that sediment was being transported in uniform suspension, graded suspension, and by rolling or sliding. Each transport mechanism was well represented by the different parts of the C-M diagram. Other bottom currents which are

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capable of transporting their load by rolling and suspension are marine currents and waves touching bottom; their C-M patterns fall in the same area as those of river currents.

A somewhat different approach to textural analysis was proposed by Visher (1969, p. 1078). He studied many different marine and fresh water geological environments and, with the aid of log-probability plots of grain-size frequency distributions, was able to divide each of these environments into three modes of transport: saltation, suspension, and surface creep and rolling. Each mode is represented by a straight line segment of the log-probability curve; the slope of this line defines the sorting of the population whereas truncation points between segments reflect physical conditions at the time of deposition and availability of sediment. Each sand type has a unique log-probability curve. The fluvial environment contains a saltation population, a suspension population, and a surface creep population. The saltation population, which comprises 65 to 98 percent of the sediment, is fairly well sorted, has a coarse truncation point between 1.0 and 1.5 phi, and has a fine truncation point between 2.75 and 3.5 phi. The suspension population, which makes up 2 to 35 percent of the sediment, is poorly sorted and has a fine truncation point at 4.5 phi. The surface creep population, which makes up a variable portion of the sediment, is poorly sorted and has an unlimited coarse truncation point.

With the scanning electron microscope, Krinsley and Doornkamp (1973, p. 8) studied quartz surface features of sand grains from eight different geological environments. They were able to identify combinations of surface features which uniquely characterized these environments. Surface features which made up the different combinations included conchoidal breakage patterns, flat cleavage plates, and upturned plates on cleavage or crystal faces; the degree and type of alteration of these features was also considered in making the unique combination.

PREVIOUS INVESTIGATIONS NEAR MANHATTAN, KANSAS

Harned (1940, p. 1) studied the grain size and mineralogy of mantle rock in the Manhattan, Kansas, area in an attempt to better define the source and agents of transportation and deposition. Samples of till, stratified drift, upland non-residual mantle, Kansas valley terrace mantle, Kansas River alluvium, and mantle residual on shale were characterized and then compared with alluvium from other river valleys. Glacial sediments contained abundant magnetite, epidote, and hornblende whereas tributary alluvium and residual mantle deposits were characterized by abundant muscovite and biotite and lesser amounts of epidote.

In a similar study, Seiler (1951, p. 103) studied the mineralogy of alluvial deposits of the Kansas River floodplain between Topeka and Ogden, Kansas. He found a large percentage of relatively unstable heavy minerals (amphiboles, pyroxenes, garnet, and epidote) which indicated the parent sediment was of Recent age. In comparing these deposits with those of tributary floodplains of the Kansas River he found that the alluvium of the Solomon, Saline, and Salt Creek Rivers contained larger percentages of more resistant minerals (zircon, tourmaline, rutile, corundum, and topaz) which indicates a different source.

Holcombe (1957, p. 71) studied the 1951 Kaw (Kansas) River flood deposits between Ogden and Manhattan, Kansas, in an attempt to determine their origin. He found large percentages of amphibole, pyroxene, epidote, and garnet which correlated well with the mineral composition of nearby till, drift, and upland non-residual mantle deposits as reported by Harned. In comparing the flood deposits with those of tributary floodplains, he found differences of particle size, mineral percentages, and types of secondary minerals, indicating that the tributaries contributed very little to the flood deposits. A very close correlation was found between Kansas floodplain deposits and those of the 1951

flood which indicated that much of the sediment was derived locally.

Husain (1964, p. 97) used grain-size statistical parameters to differentiate river and dune sands of Hunters Island and vicinity, Riley County, Kansas. He found a significant difference between the mean grain size of the river sand and the mean grain size of the dune sand; grain-size skewness between the two environments was also significantly different. Good separation of the two environments was achieved when mean grain size and grain-size skewness were plotted against each other and when either mean grain size or grain-size skewness was plotted against grain-size standard deviation or grain-size kurtosis. A hornblende-epidote assemblage with 36 percent hornblende and 11 percent epidote in the heavy mineral fraction, sorting which ranged from ± 0.32 phi to ± 1.09 phi, and frosted grains led him to conclude that the Kansas River sand was probably derived from eolian deposits of northcentral Kansas. The suite of heavy minerals of the Kansas River contained 36 percent hornblende, 3 percent lamprobolite, 12 percent garnet, 7 percent tourmaline, 11 percent epidote, 3 percent muscovite, 3 percent apatite, 5 percent zircon, 15 percent magnetite (ilmenite), and 5 percent staurolite.

Ardell (1965, p. 37), in his study of the "Little Gobi Desert" in Pottawatomie County in northeastern Kansas, found a pronounced enrichment of opaques (magnetite and ilmenite) and garnet in the assemblage of heavy minerals. The average percentage of heavy minerals in four samples of this Pleistocene dune deposit was 29.5 percent hornblende, 2.0 percent basaltic hornblende, 12.5 percent garnet, 3.3 percent tourmaline, 9.5 percent epidote, 0.3 percent muscovite, 1.0 percent biotite, 0.8 apatite, 7.8 percent zircon, 30.5 percent magnetite (ilmenite), 1.0 percent staurolite, 1.5 percent enstatite, and 0.3 percent sphene. The dominance of hornblende, garnet, epidote, and ore minerals was constant for all four samples. The light mineral assemblage was characterized by a low concentration of chert. He noted that the enrichment of opaques and

garnet and deficiency of chert are characteristic of known glacially derived sediments in the area. He concluded that the source of the "Little Gobi Desert", an eolian deposit, was derived from the outwash plain of the Big Blue River.

G E O L O G I C S E T T I N G

SITE OF DEPOSITION

Channel-lag and point-bar deposits near Junction City, Kansas, have been deposited by a low energy fluvial environment. The mature Republican, Smoky Hill, and Kansas Rivers have meandering courses, adjacent oxbow lakes and swamps, and valley floor widths which are only slightly wider than their corresponding meander belts.

Baehr (1954, p. 18), in studying the relationships between rock structure and drainage near Junction City, reported stream gradients of 2.4 ft/mi for the Republican River, 2.1 ft/mi for the Smoky Hill River, and 1.9 ft/mi for the Kansas River. Floodplain gradients of the three rivers measured 2.8 ft/mi, 4.8 ft/mi, and 2.9 ft/mi respectively. Other measurements by Baehr included average meander widths, average floodplain widths, and average stream widths (Table 1).

TABLE 1. GENERAL RIVER MEASUREMENTS (MODIFIED FROM BAEHR, 1954, P. 18)

	Stream gradient	Floodplain gradient	Meander belt width (ave.)	Floodplain width (av.)	Stream width (av.)
Kansas	1.9 ft/mi	2.9 ft/mi	7125 ft	9697 ft	375 ft
Smoky Hill	2.1	4.8	6000	7250	150
Republican	2.4	2.8	5000	7514	250

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The U.S.G.S. Water Resources Division (1968, p. 32 and 74) reported that the average discharge for the Republican River near Junction City, between 1963 and 1968, was 675 cfs. A maximum discharge of 17,200 cfs occurred on June 22, 1964. Average Smoky Hill River discharge, over a 34 year period from 1934 to 1968, was 1,632 cfs with a maximum discharge of 233,000 cfs occurring on July 14, 1951. The 1969 report of the U.S.G.S. Water Resources Division (p. 74) showed average and maximum discharge rates for the Kansas River at the Marshall Field bridge were 2,184 cfs and 29,900 cfs respectively for the period between 1963 and 1968.

TOPOGRAPHY

The area drained by the Republican and Smoky Hill Rivers belongs to three physiographic provinces. The High Plains Province (Frye and Leonard, 1952, p. 201) occupies western Kansas, western Nebraska, and eastern Colorado (Fig. 1) and includes more than half the area drained by the Republican and Smoky Hill Rivers. The High Plains contain broad interfluves that slope gently to the east and are bounded by distinct scarps on their eastern and western boundaries.

The Smoky Hills Province, east of the High Plains, consists of low hills and plains which have developed on Cretaceous rocks. Indistinct terraces, dissected escarpments, and broad river valleys are typical features of the mature topography of this province (Schoewe, 1949, p. 309).

The Flint Hills Upland Province (Schoewe, 1949, p. 286) is an area defined by outcrops of Permian cherty limestones and is east of the Smoky Hills Province. The topography is characterized by narrow, steep sided stream channels, gently dipping cuestas, and narrowing of the Republican and Smoky Hill River Valleys as the rivers encounter the more resistant lithology of the area.

The relief of the area which is drained by the Republican and Smoky Hill Rivers and their tributaries is about 3000 feet. In eastern Colorado, where both the Republican and Smoky Hill Rivers begin, the elevation is more than 4000 feet above sea level. At Junction City the two rivers merge to form the Kansas River at an elevation of 1060 feet.

CLIMATE

The climate of the Republican and Smoky Hill River drainage basins is Humid Continental with the exception of extreme western edges of both basins which is classified as sub-humid or semi-arid. Data compiled by Flora of the U. S. Weather Bureau (1948, p. 148) show that the average annual temperature of the area drained by the Smoky Hill River and its tributaries is about 56°F. Average length of the frost-free period is 170 days with frost penetration reaching a depth of 15 inches during the winter. The average annual temperature of the Republican drainage basin is about 52°F. A 160-day frost-free period, with a winter frost penetration of about 20 inches, is normal for this area.

In both the Republican and Smoky Hill drainage basins, the average annual precipitation ranges from between 15 and 20 inches in the High Plains Province to 30 inches in the Flint Hills (Flora, 1948, p. 9). The greater proportion of rainfall in each basin occurs during the spring and summer months of May, June, and August.

SOURCE ROCKS

Two general sources of sediment being deposited by the Republican, Smoky Hill, and Kansas Rivers near Junction City are unconsolidated Quaternary sediments and rocks of the Permian, Cretaceous, and Tertiary Systems. Descriptions of these rocks are taken from Merriam (1963, p. 22-94).

Permian source rocks are restricted to the Flint Hills Upland Province and are primarily limestones and shales. Limestones of the Lower Permian Series are cherty and the shales are red and green or varicolored. Upper Permian rocks consist mainly of redbeds and evaporites and include units of silty shale, limestone, dolomite, anhydrite, gypsum, and salt.

Cretaceous sedimentary rocks of the Smoky Hills Province consist of limestones, sandstones, shales, and chalk beds. Sandstones of the Lower Cretaceous Series (including the Dakota Formation) are light colored and consist of fine- to medium-grained, subrounded quartz fragments and traces of mica, glauconite, and pyrite. The Kiowa Shale of this series is gray, micaceous, and silty, with interbedded limestone, sandstone, and siltstone. Fossiliferous limestones and chalky shales characterize the sediments of the Upper Cretaceous Colorado Group.

Possible source rocks of the High Plains Province include the Cretaceous Niobrara Chalk, Pierre Shale, and the Pliocene Ogallala Formation. The Niobrara Chalk consists of the Smoky Hill Chalk, a gray to white chalky shale which contains locally massive chalk beds, and the Fort Hays Limestone which consists of chalk and chalky limestone. The Pierre Shale includes six members which are slightly micaceous, fissile, and fossiliferous. Unconsolidated, calcareous sands and gravels, locally cemented by opal compose the Ogallala Formation.

Quaternary sediments are in all three physiographic provinces of the source area and lie unconformably on the Permian, Cretaceous, and Tertiary indurated rocks discussed above. Deposits of Wisconsinan and Recent loess blanket much of the upland areas whereas sand dunes occur along some stream channels. Alluvial terraces and floodplains of Wisconsinan and Recent age occur along present river systems and consist of unconsolidated gravel, sand, and silt. Kansan and Illinoian Stage alluvial terraces are in many stream

valleys above the Wisconsin deposits and have contributed sediment to the present floodplain.

METHODS OF INVESTIGATION

FIELD PROCEDURE

Selection of Study Site

Topographic maps of the Junction City area aided in the selection of river traverse locations. Profile sections across the Republican, Smoky Hill, and Kansas Rivers were made in narrow parts of their respective valleys with adjacent valley walls rising abruptly from the floodplain and having more than 100 feet of local relief. The sections of the Republican and Smoky Hill Rivers were made approximately 10 miles upstream from their confluence and the Kansas section was made two miles below this point.

Collection of Samples

A boat was used to collect channel-lag deposits and was kept from drifting downstream by a rope tied across the river. Ten-meter intervals marked sampling stations where water depth and surface velocity were measured and corresponding bottom samples collected (Fig. 2 and 3). A drag sampler was constructed by welding a 46 oz. tomato juice can to a four-meter steel rod at an angle of 45° . Point bar samples were also collected at ten-meter intervals with sampling station elevations determined with a hand level and stadia rod. Soundings at water sampling stations were made with a steel rod graduated in one-tenth meter intervals.

Measurement of Surface Velocity

The surface velocity at water-sampling stations was calculated from the length of time it took the current to carry floating cottonwood leaves a distance

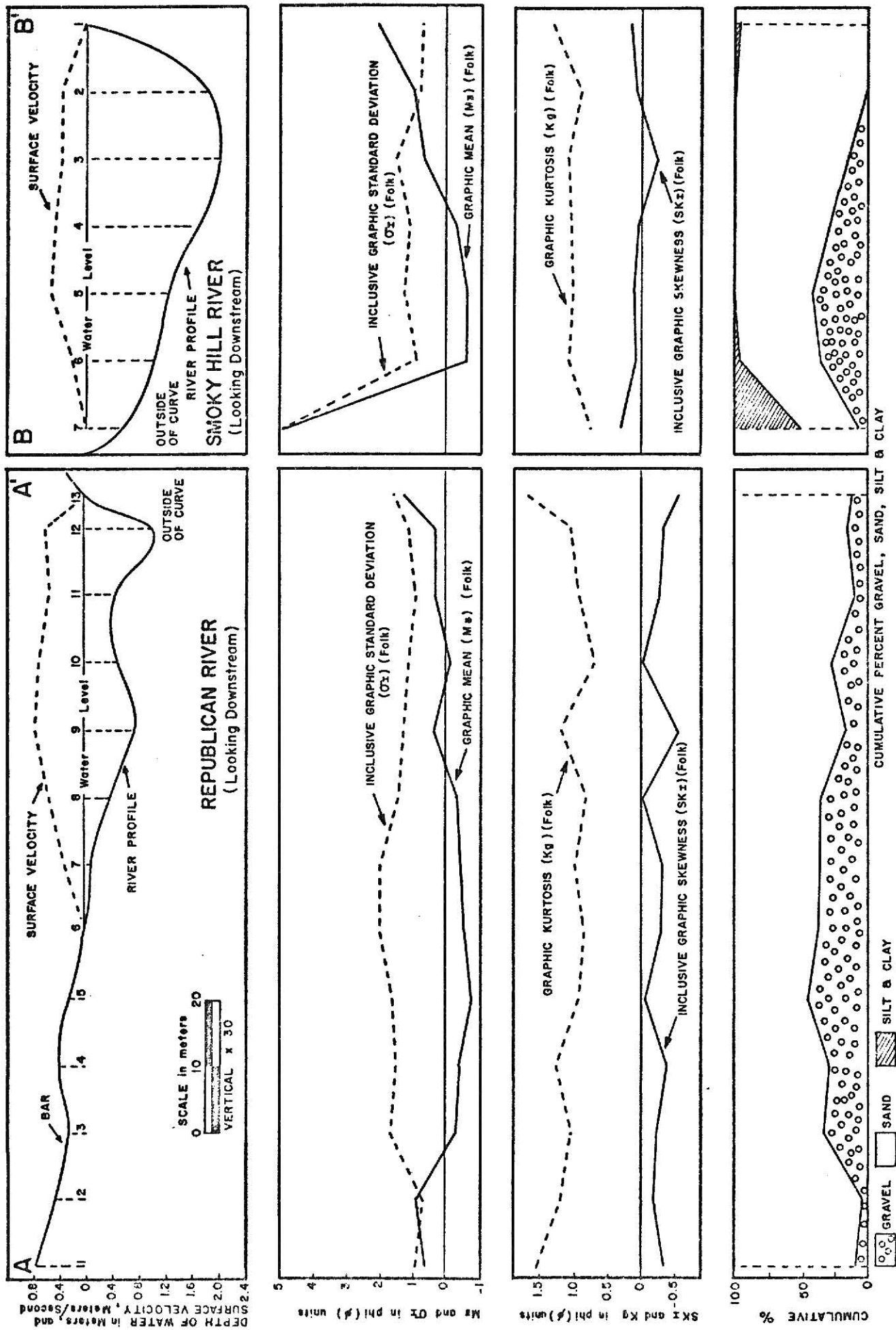


Figure 2. Republican and Smoky Hill Rivers profiles with surface velocity, textural parameters and gravel-sand-silt-clay ratios.

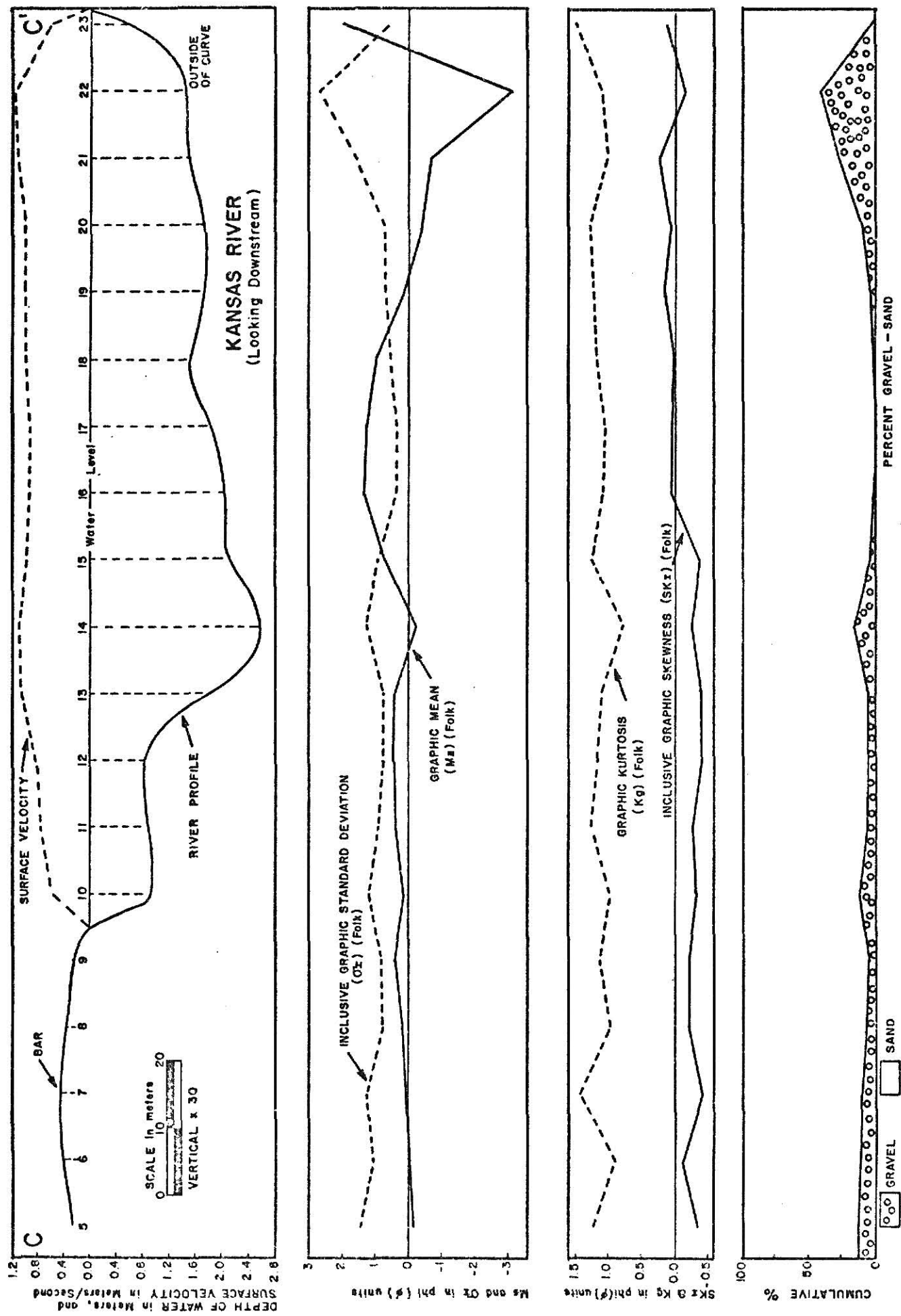


Figure 3. Kansas River profile with surface velocity, textural parameters and sand-gravel ratio.

of ten meters. This distance was marked by a buoy floating ten meters downstream from the boat. Leaves dropped at the zero mark of the rope holding the buoy were timed as they were carried by the current through the ten-meter distance. The average time of three trials was used in the velocity calculation.

TEXTURAL ANALYSIS

Preparation of Samples for Size Analysis

Samples which contained only small percentages of silt and clay were oven dried at 90°C for 24 hours, disaggregated, and weighed to the nearest 0.01 gram on a top loading balance. One exception to this procedure was a sample which contained approximately 40 percent silt and clay; sand and gravel separated from the silt and clay by wet sieving was oven dried, disaggregated, and weighed as above while the silt and clay were placed in a jar and prepared for pipette analysis. Gravel of each sample was separated from sand, silt, and clay by hand-sieving with a 2-mm sieve; sieve analyses were run on the gravel fraction as well as a split sample of the remaining sand, silt, and clay.

Particle-size Scales

Phi-notation of the geometric Wentworth Scale was used in the size analyses of this study. The relationship of the phi-unit to the Wentworth millimeter scale is given in Table 2 and expressed by the equation

$$\phi = -\log_2 \text{diameter (mm)}.$$

Sieve Analyses

The sand, silt, and clay fraction of each sample was split with a sample splitter to approximately 150 g. This sample was weighed and placed in a $\frac{1}{2}\phi$

TABLE 2. GRAIN-SIZE SCALES FOR SEDIMENTS (AFTER FOLK, 1974)

U. S. Standard Sieve Mesh #	Millimeters	Phi	Wentworth Size Class
	4096	-12	
	1024	-10	Boulder
	256	- 8	
	64	- 6	Cobble
	16	- 4	Pebble
5	4	- 2	
6	3.36	- 1.75	
7	2.83	- 1.5	Granule
8	2.38	- 1.25	
10	2.00	- 1.0	
12	1.68	- 0.75	
14	1.41	- 0.5	Very coarse sand
16	1.19	- 0.25	
18	1.00	0.0	
20	0.84	0.25	
25	0.71	0.5	Coarse sand
30	0.59	0.75	
35	0.50	1.0	
40	0.42	1.25	
45	0.35	1.5	Medium sand
50	0.30	1.75	
60	0.25	2.0	
70	0.210	2.25	
80	0.177	2.5	Fine sand
100	0.149	2.75	
120	0.125	3.0	
140	0.105	3.25	
170	0.088	3.5	Very fine sand
200	0.074	3.75	
230	0.0625	4.0	
270	0.053	4.25	
325	0.044	4.5	Coarse silt
	0.037	4.75	
	0.031	5.0	
	0.0156	6.0	Medium silt
	0.0078	7.0	Fine silt
	0.0039	8.0	Very fine silt
	0.0020	9.0	
	0.00098	10.0	
	0.00049	11.0	
	0.00024	12.0	Clay
	0.00012	13.0	
	0.00006	14.0	

interval nest of sieves and agitated in a Ro-tap for 15 minutes. The same procedure was followed for gravel fractions except that the total amount of gravel was used and the agitating time in the Ro-tap was reduced to ten minutes. The individual fractions were then weighed on an analytical balance to the nearest 0.01 g and placed in envelopes for further analyses.

Pipette Analysis

Laboratory procedure for pipette analysis as outlined by Jeppesen (1972, p. 13) was followed.

SEM Examination of Quartz Surface Textures

Representative quartz grains of one sample from each river were chosen to be examined under the Scanning Electron Microscope. A few grams of the 1 ϕ size fraction of each sample were boiled in 6N hydrochloric acid for 30 minutes and washed with distilled water to remove iron-oxide coatings from the quartz grains. The samples were then examined under the binocular microscope and five representative grains picked from each sample. These grains were mounted, in double rows of two and three, on metal plugs which had been covered with "double sticky" masking tape. The plugs were then taken to the Kansas State University SEM laboratory where they were placed in a vacuum chamber and sprayed with gold metal paint. The grains were then ready for viewing with the SEM. Photomicrographs recorded interesting surface features which were later described and classified according to environments which characteristically produce such features.

Microscopic Examination of Roundness

A comparison chart of Power's roundness images (1953, p. 118) was used in estimating the roundness of quartz and heavy mineral grains in samples from each river. Logarithmic (ρ) class limits (Folk, 1955, p. 297) applied to Power's

images were very angular 0.0-1.0, angular 1.0-2.0, subangular 2.0-3.0, sub-round 3.0-4.0, round 4.0-5.0, and very round 5.0-6.0.

Roundness of heavy mineral grains were estimated while making point counts of heavy minerals with the petrographic microscope. Corresponding grains were measured to discover whether a relationship existed between size and roundness in a particular species. Quartz roundness values were estimated with a binocular microscope; 100 grains of the 1 ϕ size class of two samples from each river were examined.

Statistical Analysis of Data

Graphic statistical parameters.--Data from grain-size analyses were plotted on log normal probability curves. Statistical parameters of coarsest one-percentile, mode, median, graphic mean, inclusive graphic standard deviation, inclusive graphic skewness, and graphic kurtosis were then calculated by plugging grain-size data, read directly from the cumulative curve, into graphic formulas defining these parameters. These formulas and verbal limits for sorting, skewness, and kurtosis are described by Folk (1974, p. 45-48) and are in Table 3.

The coarsest one-percentile is the diameter corresponding to the coarsest one-percent of sediment and is an indication of maximum amount of energy in an environment.

The average size of the sediment is represented by the mode, median, and graphic mean. The mode is the most abundant particle diameter and is found by locating the point of inflection on a cumulative curve (arithmetic ordinate) of the sediment. The median is the diameter corresponding to the 50th percentile on the cumulative curve and the graphic mean is based on three points of the curve, the 16th, 50th, and 84th percentiles, and better represents the overall size of the sediment.

TABLE 3. GRAPHIC STATISTICAL FORMULAS FOR GRAIN-SIZE PARAMETERS AND VERBAL LIMITS FOR INCLUSIVE GRAPHIC STANDARD DEVIATION, INCLUSIVE GRAPHIC SKEWNESS AND GRAPHIC KURTOSIS (AFTER FOLK, 1974)

<u>Coarsest One Percentile</u>	<u>Inclusive Graphic Standard Deviation</u>	
$C = \phi 1$	$\sigma I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$	
<u>Median</u>	<u>Verbal Limits</u>	
$Md_\phi = \phi 50$	0.00-0.35	Very Well Sorted
<u>Graphic Mean</u>	0.35-0.50	Well Sorted
$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3}$	0.50-0.71	Moderately Well Sorted
	0.71-1.00	Moderately Sorted
	1.00-2.00	Poorly Sorted
	2.00-4.00	Very Poorly Sorted
	Over 4.00	Extremely Poorly Sorted
<u>Inclusive Graphic Skewness</u>		
$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$		
<u>Verbal Limits</u>		
+1.00 to +0.30	Strongly Fine-Skewed	
+0.30 to +0.10	Fine-Skewed	
+0.10 to -0.10	Near-Symmetrical	
-0.10 to -0.30	Coarse-Skewed	
-0.30 to -1.00	Strongly Coarse-Skewed	
<u>Graphic Kurtosis</u>		
$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$		
<u>Verbal Limits</u>		
Less Than 0.67	Very Platykurtic	
0.67-0.90	Platykurtic	
0.90-1.11	Mesokurtic	
1.11-1.50	Leptokurtic	
1.50-3.00	Very Leptokurtic	
Greater Than 3.00	Extremely Leptokurtic	

Inclusive graphic standard deviation is a measure of the sorting of a sediment whereas inclusive graphic skewness and graphic kurtosis are measures of symmetry and peakedness of the grain-size distribution, respectively. Each parameter includes 90 percent of the cumulative curve and therefore is sensitive to the "tails" of the sediment.

Scatter plots.--Scatter plots of different grain-size parameters of the Republican, Smoky Hill, and Kansas River sands were prepared in an attempt to better define the river environments near Junction City. Mean, standard deviation, skewness, and kurtosis values were plotted against each other in an attempt to differentiate local river environments and also for comparison with depositional studies of Folk and Ward (1957) and Friedman (1967). The coarsest one-percentile was plotted against the median and then compared with Passega's tractive current C-M patterns (1964, p. 831).

One-way analysis of variance.--Average means, standard deviations, skewness values, and kurtosis values from samples of each river were compared using a computer program entitled KSU Stat. Lab Program Description 2: One-Way Analysis Of Variance. This program printed out a one-way analysis of variance table along with subclass means, frequency counts, variances, and standard deviations (i.e., number of samples from each river; the average of each river's means, standard deviations, skewness values, and kurtosis values; and the variances and standard deviations of each river's means, standard deviations, skewness values, and kurtosis values about their mean). Because the one-way analysis of variance test requires homogeneous variances of means between sampling sites, a Bartlett's test for homogeneity of variance was automatically computed by the program. If the variances were homogeneous and a significant difference existed between the means of a parameter being tested (mean, standard deviation, skewness, or kurtosis), least significant difference tests (LSD) were computed which showed which rivers differed significantly at the 5.0 percent level. If the

variances were not homogeneous an ordinary "t" test was run, with "t" calculated from the formula for unequal sample sizes and unequal variances.

The one-way analysis of variance program was run with three different sets of data. The first set included all samples along the traverses of the Republican, Smoky Hill, and Kansas Rivers near Junction City, and Husain's (1964, p. 65-68) Kansas River samples of his study near Manhattan, Kansas. These samples included channel lag, point bar, and bank sediments. The second set of data included all samples collected in each river and the third set included all samples collected in each river excluding bank samples.

Linear regression.--In order to determine whether grain-size parameters of the Republican, Smoky Hill, and Kansas Rivers were dependent upon each river's surface velocity or water depth, a linear regression involving these variables was calculated for each river. Independent variables of surface velocity and water depth, respectively, were regressed upon dependent variables of mean grain size, standard deviation, skewness, and kurtosis. Correlation coefficients of each regression described how dependent the grain-size parameters were upon the surface velocity or water depth.

MINERAL ANALYSIS

Heavy Mineral Separation

Two samples from each river sand were selected for heavy and light mineral analysis. Each sample contained very fine sand and had been collected from within the river channel; point bar and bank sediments were not analysed.

Heavy and light minerals were separated using standard separation procedure described by Milner (1962, v. 1, p. 101). Bromoform, the "heavy" liquid used in the separations, had a specific gravity of 2.8, and was recovered from the separated fractions by washing with ethanol. Different size fractions of samples

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from each river were analysed. In one sample, the weight percentage of heavy and light minerals was found for the 1-2 ϕ , 2-3 ϕ , and 3-4 ϕ size classes; in the other, the weight percentage of the heavy and light minerals in the whole sand fraction was found. Heavy minerals were mounted on petrographic slides in an epoxy medium ($n = 1.55$) whereas the lights were mounted in Canada balsam ($n = 1.54$).

X-Ray Identification of Heavy Minerals

The six most abundant minerals in heavy mineral fractions of the Republican River sand were hand-picked for identification by X-ray diffraction; these minerals included magnetite, garnet, hornblende, sillimanite, epidote, and titanite. A Norelco Wide Range Diffractometer with Ni-filtered Cu K-alpha radiation and conventional settings for X-ray diffraction was used in the analysis.

Microscopic Identification and Point Count of Heavy and Light Minerals

The petrographic microscope was used to identify suites of heavy and light minerals from each river and to establish percentages of minerals in each suite. Point counts of 100 grains per slide were made of the different size fractions of each sample. Included in the point-counting procedure was an estimation of roundness and measurement of length and width of each mineral grain. Quartz grains were classified according to the empirical classification of Folk (1974, p. 74). Six extinction types recognized were (1) straight, (2) slightly undulose, (3) strongly undulose, (4) semi-composite, (5) composite, and (6) composite metamorphic. Each type of grain was further subdivided into the type of inclusion: (a) abundant vacuoles, (b) rutile needles, (c) microlites, and (d) few vacuoles, no microlites.

Statistical Analysis of Data

A Chi-square test was used to determine whether mineralogical differences existed among sediments of the three rivers. A "2xn" table was constructed in which n was equal to nine; the number of common diagnostic mineral groups in each sample. Minerals in each group were (1) garnet, titanite, sillimanite, epidote, and epidosite, (2) zircon and tourmaline, (3) hornblende and IRF's, (4) ore minerals, (5) orthoclase, (6) microcline, (7) type 1a quartz, (8) type 1b and 1c quartz, and (9) type 6 quartz. These mineral groups were compared within as well as among the three rivers.

ENVIRONMENT OF DEPOSITION AND TRANSPORT

RELATIONSHIP OF GRAIN-SIZE PARAMETERS TO DEPOSITIONAL ENVIRONMENTS

Many attempts have been made to differentiate modern depositional environments by comparison of their respective grain-size parameters. Udden (1914, p. 659) made mechanical analyses of glacial till, aqueous deposits, and wind deposits, in an attempt to formulate "laws" which govern the mechanical composition of clastic sediments. Wentworth (1931, p. 4) published many mechanical analyses of different sediments "...to offer a somewhat comprehensive guide for the interpretation of origin of sediments in which the mechanical composition appears to be distinctive." Similarities or differences between "grading curves" of sediments from different environments are due to similarities or differences in hydro- or aerodynamic conditions of the transporting media. Current velocity, turbulence, density, and viscosity of the transporting medium are largely responsible for the different types of size-frequency curves (Pettijohn, 1957, p. 38).

Size and sorting are the grain-size parameters which have been used most in the description of modern sediments. Grain size is dependent upon the energy

of the transporting medium at the depositional site and the size of available particles (Folk, 1974, p. 3). High energy environments transport larger-sized particles than low energy environments, but only if the larger particles are available for transport. Sorting, or dispersion of a sediment about its mean, is dependent upon (1) size range of the sediment supplied to the environment (2) energy of the environment and (3) length of time a sediment is in the environment. Folk, in review of the geologic significance of grain-size parameters (1974, p. 5), pointed out that poor sorting usually occurs when a sediment is composed of a mixture of the three populations of grains found in nature: (1) pebbles (2) sand-coarse silt and (3) clay. If a sediment is composed of only one of these populations it will tend to be well-sorted; if it is composed of two or three, it will be poorly sorted. When considering sediments of a single source, however, better sorting is usually produced by higher energy environments whereas poorly sorted sediments are the result of low energy environments. Sediment skewness and kurtosis values give an indication of the normality of the grain-size distribution. Most single-source sediments have fairly normal curves and sediments from multiple sources tend to have extreme skewness and kurtosis values.

Plotting different grain-size parameters against one another on scatter plots has been moderately successful in the separation of different depositional environments, because modes of transport in these environments are inherently different. Some environments, however, although they are generally different, have one or more common modes of transport; for example, rivers and marine currents can both have suspension as well as saltation loads (Visher, 1969, p. 1076). Deposition in these environments would therefore be expected to reflect these common characteristics and somewhat similar grain-size curves might result. To interpret the depositional environment properly, therefore, grain-size analysis must be supplemented by analysis of sedimentary structures, bedding facies, and

the sediments position within the sand body (Pettijohn, Potter, and Siever, 1972, p. 87).

DESCRIPTION AND DISCUSSION OF GRAIN-SIZE PARAMETERS OF EACH RIVER

Introduction

Grain-size cumulative curves of the Republican, Smoky Hill, and Kansas Rivers are in Fig. 52 with grain size ranges summarized in Fig. 4. Republican River sediment ranges in size from pebbly medium sand to sandy pebble gravel, is poorly to moderately sorted, is strongly coarse-skewed to nearly symmetrical, and is very leptokurtic to platykurtic (Fig. 4 and 52, Table 26). Smoky Hill River sediment ranges in size from pebbly silt to sandy granule gravel, is poorly to moderately sorted, is fine to coarse-skewed, and is leptokurtic to platykurtic. Kansas River sediment ranges in size from pebble gravel to slightly granular medium sand, is poorly to well sorted, is fine to strongly coarse-skewed, and is leptokurtic to platykurtic. Sediment from each river is mostly unimodal (Fig. 52, Tables 24 and 25).

The relationship among surface velocity, water depth, mean grain size, sorting, skewness, kurtosis, and gravel-sand-silt-clay ratio of each sample of the three rivers is in Fig. 2 and 3; phi-statistical parameters in these graphs are in Tables 24 and 25. Correlations are shown between surface velocity and amount of gravel, sorting and amount of gravel, and mean grain size and sorting. The highest surface velocity corresponds with the largest amount of gravel in the Smoky Hill and Kansas Rivers and is on the outside curve of each river; higher sorting values of the Kansas River also correspond with the larger amounts of gravel. Inspection of the relationship between mean grain size and sorting of the Republican and Kansas Rivers reveals a decrease in sorting with an increase in size.

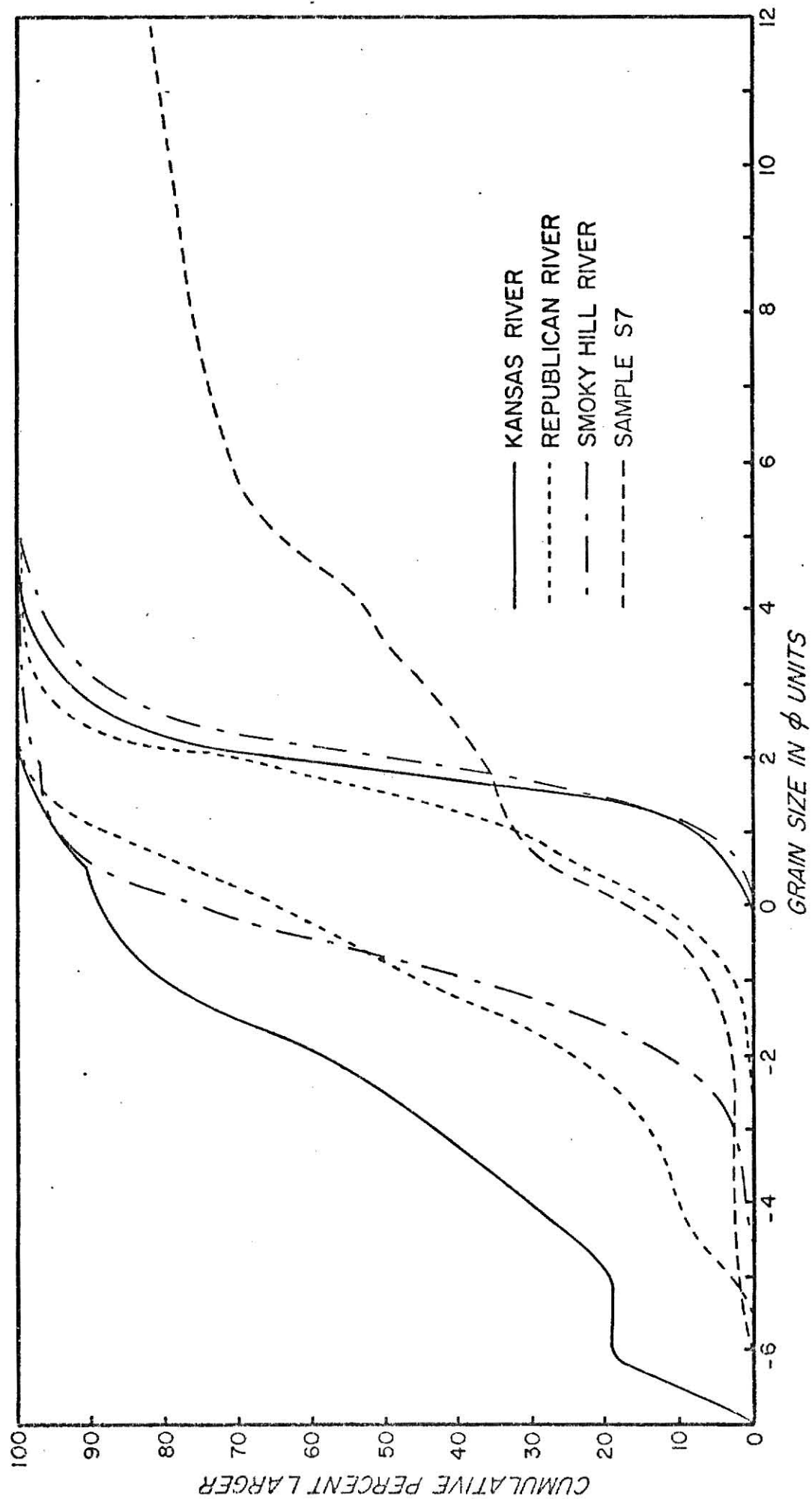


Figure 4. Total spread of cumulative grain-size frequency curves of the Republican, Smoky Hill, and Kansas River sands. 26

The samples on the outside and inside curves of the Smoky Hill River contain significant quantities of silt and clay, whereas no sediment finer than 4ϕ was found in samples of the Republican and Kansas Rivers. Positive skewness values of the Smoky Hill River are associated with those samples that contain some silt and clay and as the amount of silt and clay increases the positive skewness values increase.

Comparison of Grain-Size Parameters to Each River's Depth and Surface Velocity

Dependence of mean grain size, sorting, skewness, and kurtosis upon either surface velocity or depth was checked by running linear regressions on each of these dependent and independent variables, respectively, and are in Fig. 5-12. Correlation coefficients for each relationship, which show how well the dependent and independent variables are correlated, are in Table 4. Correlation coefficients range from +1.0 for perfect positive correlation to -1.0 for perfect negative correlation; zero values indicate no correlation exists between variables. Folk (1974, p. 61) has stated that "... coefficients beyond ± 0.50 are considered 'good' for most geological work." Bank samples R13, S1, S7, and K23 were not included in the analyses.

TABLE 4. CORRELATION COEFFICIENTS OF GRAIN-SIZE PARAMETERS (DEPENDENT VARIABLES) AND SURFACE VELOCITY AND WATER DEPTH (INDEPENDENT VARIABLES)

	Water Depth			Surface Velocity		
	Republican	Smoky Hill	Kansas	Republican	Smoky Hill	Kansas
Mean	+0.80	+0.86	+0.12	+0.64	-0.01	-0.46
Sorting	-0.58	+0.32	-0.14	-0.71	+0.41	+0.37
Skewness	-0.33	-0.75	+0.21	-0.06	+0.07	+0.38
Kurtosis	+0.45	-0.19	-0.37	+0.14	-0.14	-0.15

In both the Republican and Smoky Hill Rivers there is strong positive correlation between water depth and mean grain size which indicates a decrease in

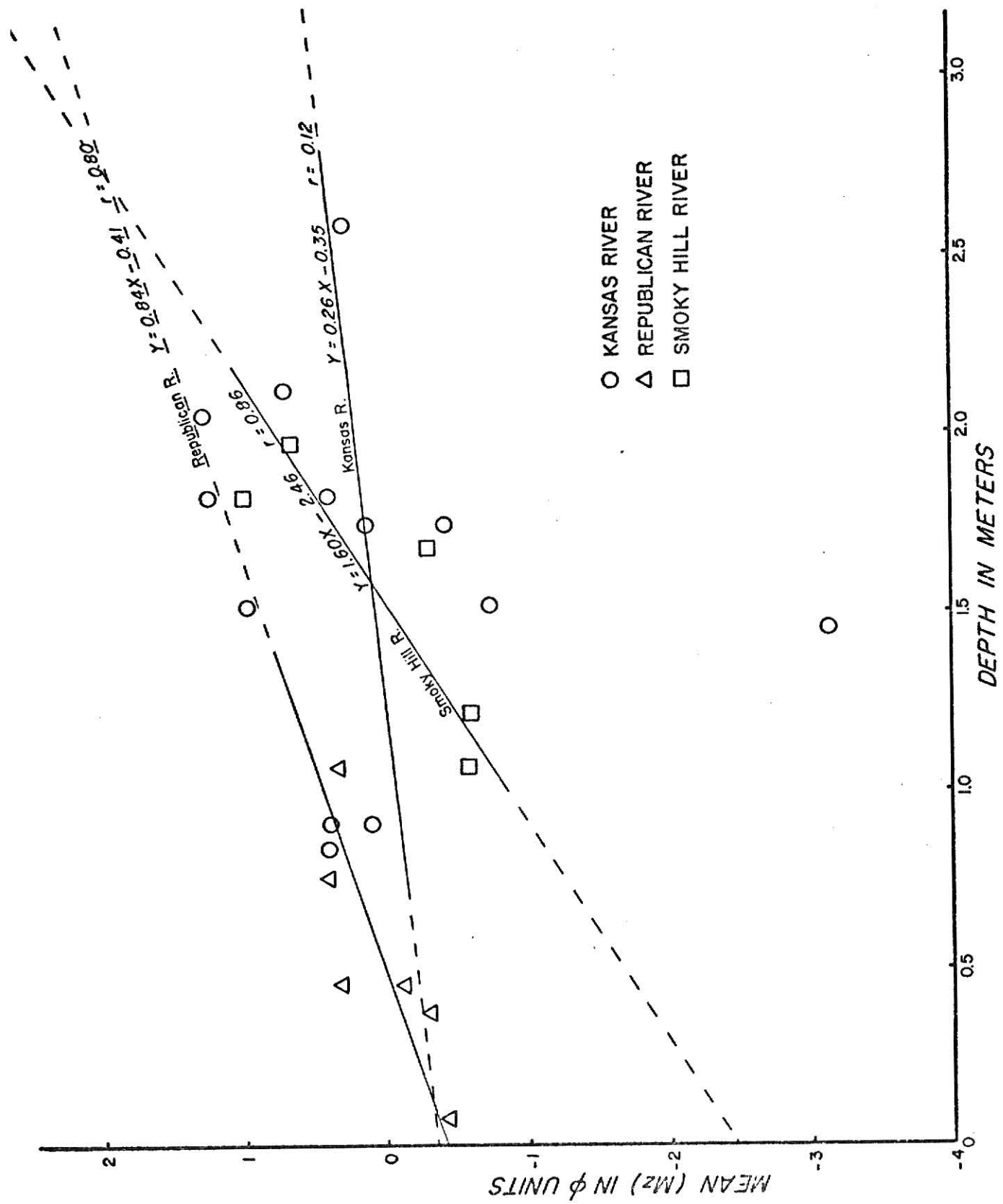


Figure 5. Mean grain size vs. water depth (linear regression).

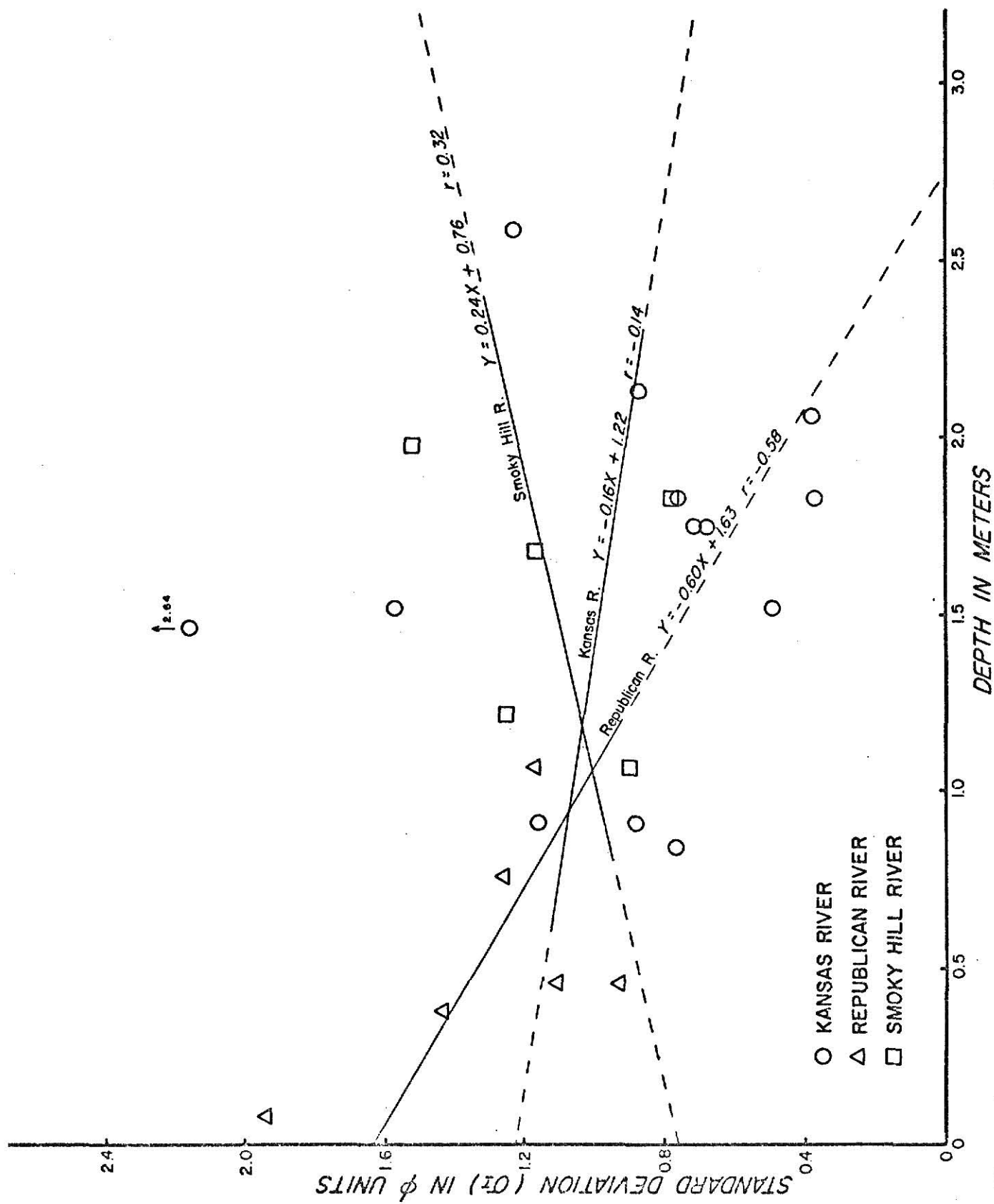


Figure 6. Grain-size standard deviation vs. water depth (linear regression).

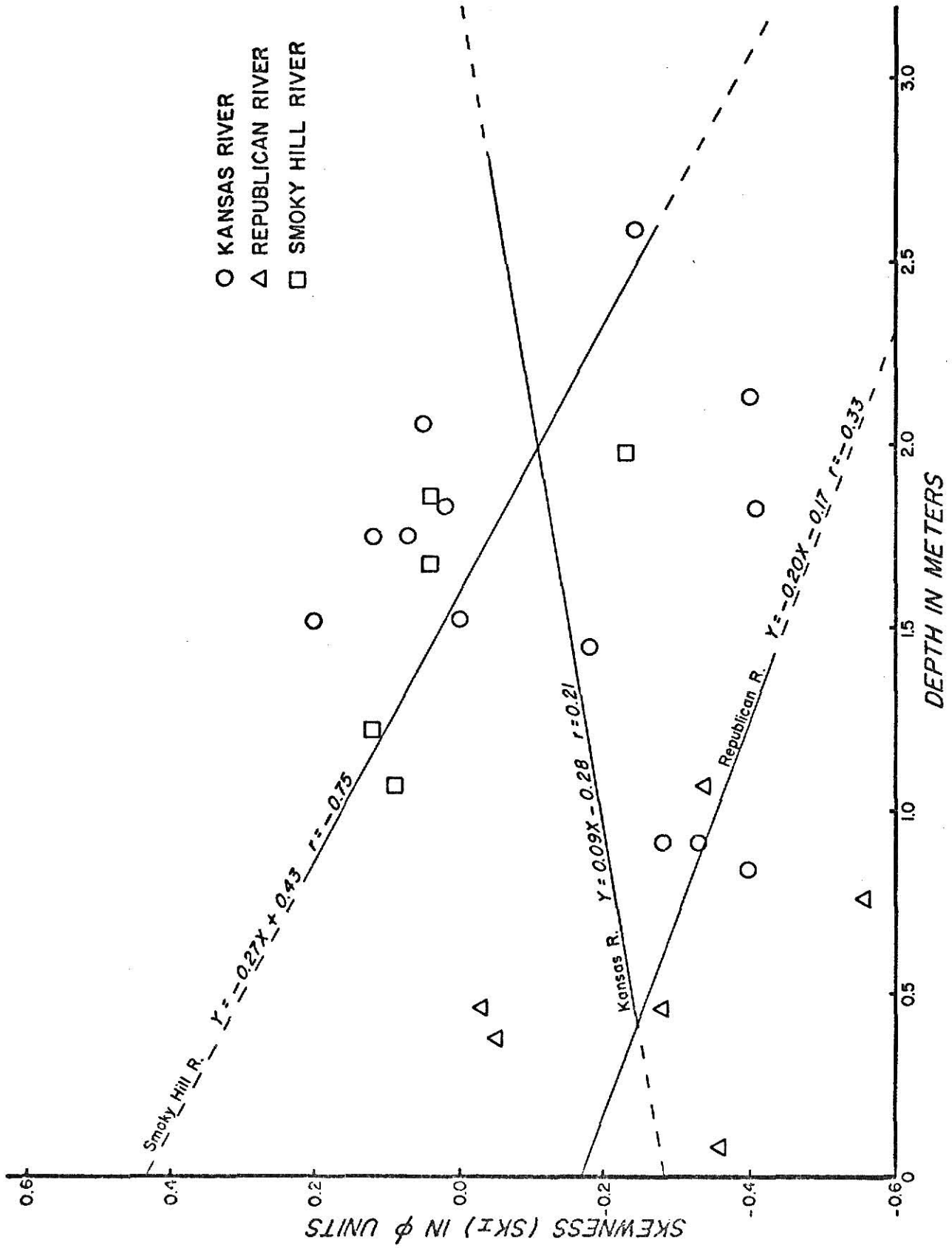


Figure 7. Grain-size skewness vs. water depth (linear regression).

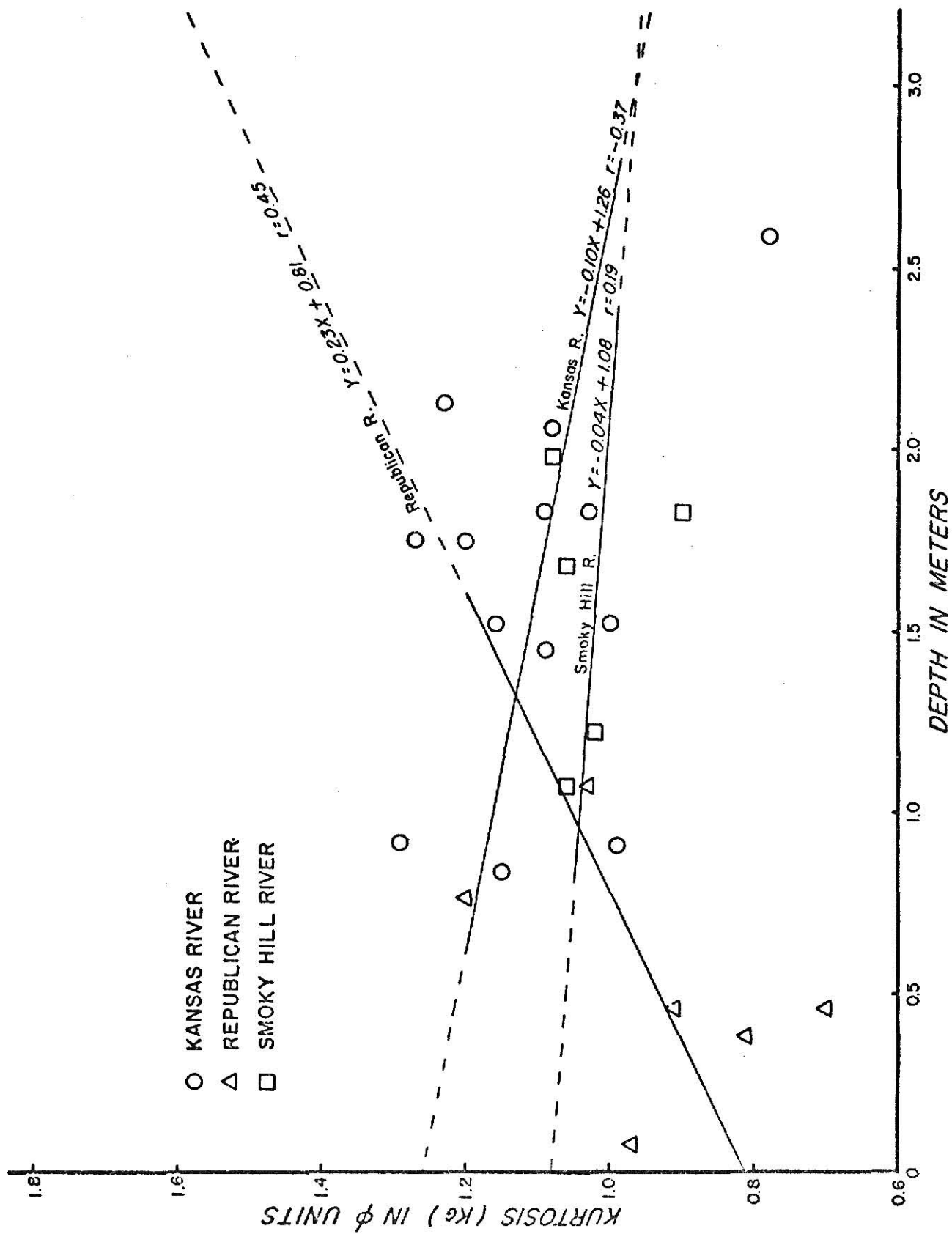


Figure 8. Grain-size kurtosis vs. water depth (linear regression).

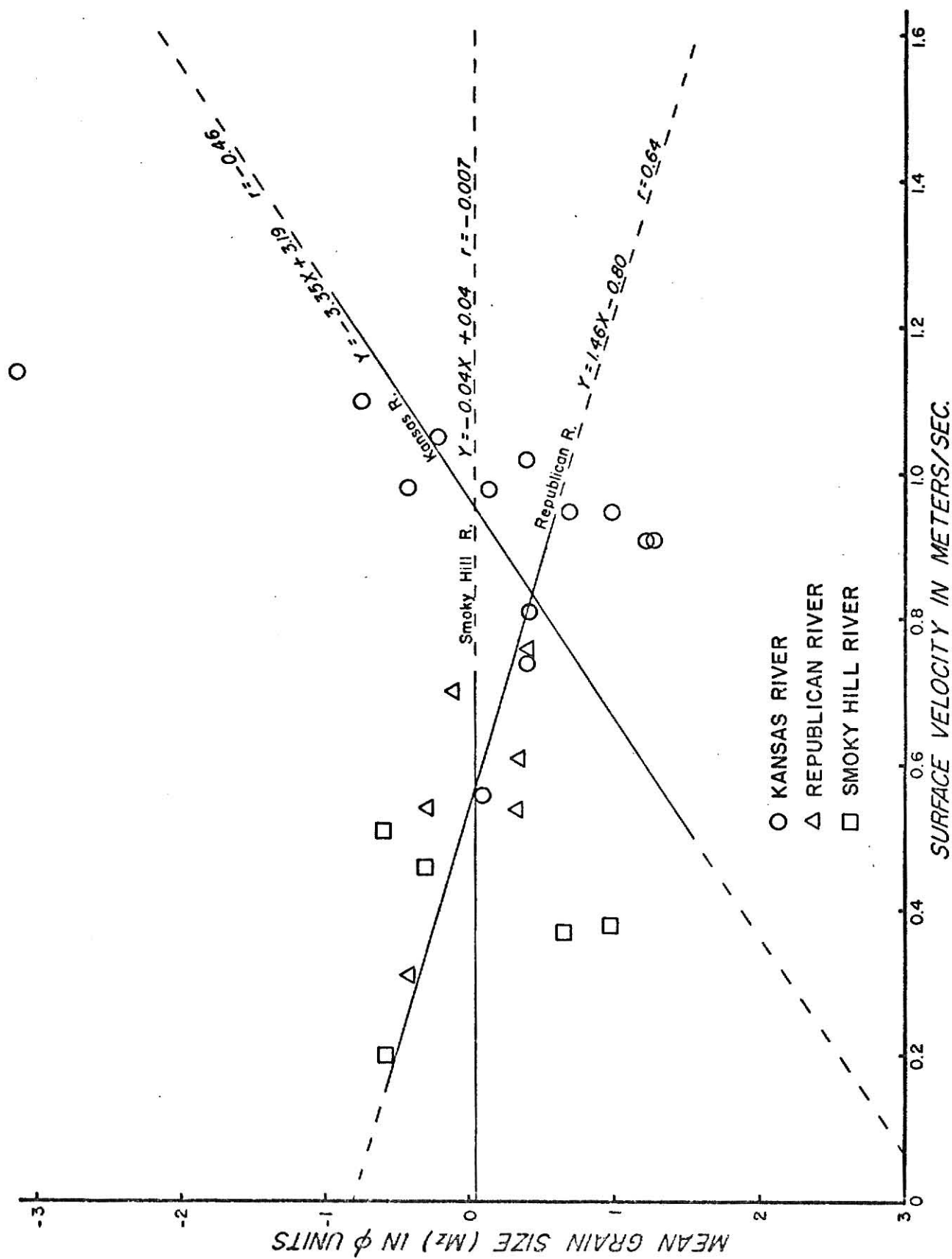


Figure 9. Mean grain size vs. surface velocity (linear regression).

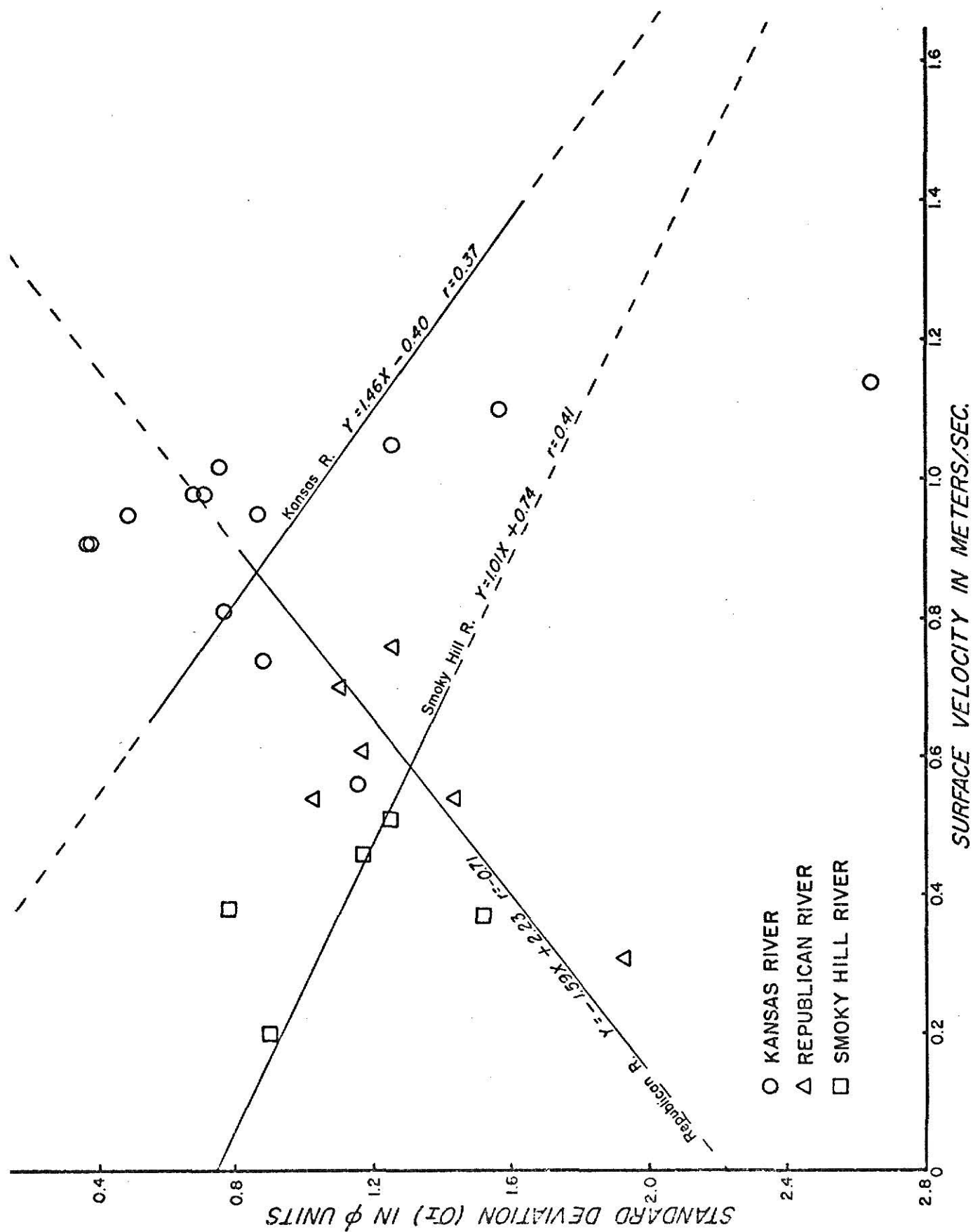


Figure 10. Grain-size standard deviation vs. surface velocity (linear regression).

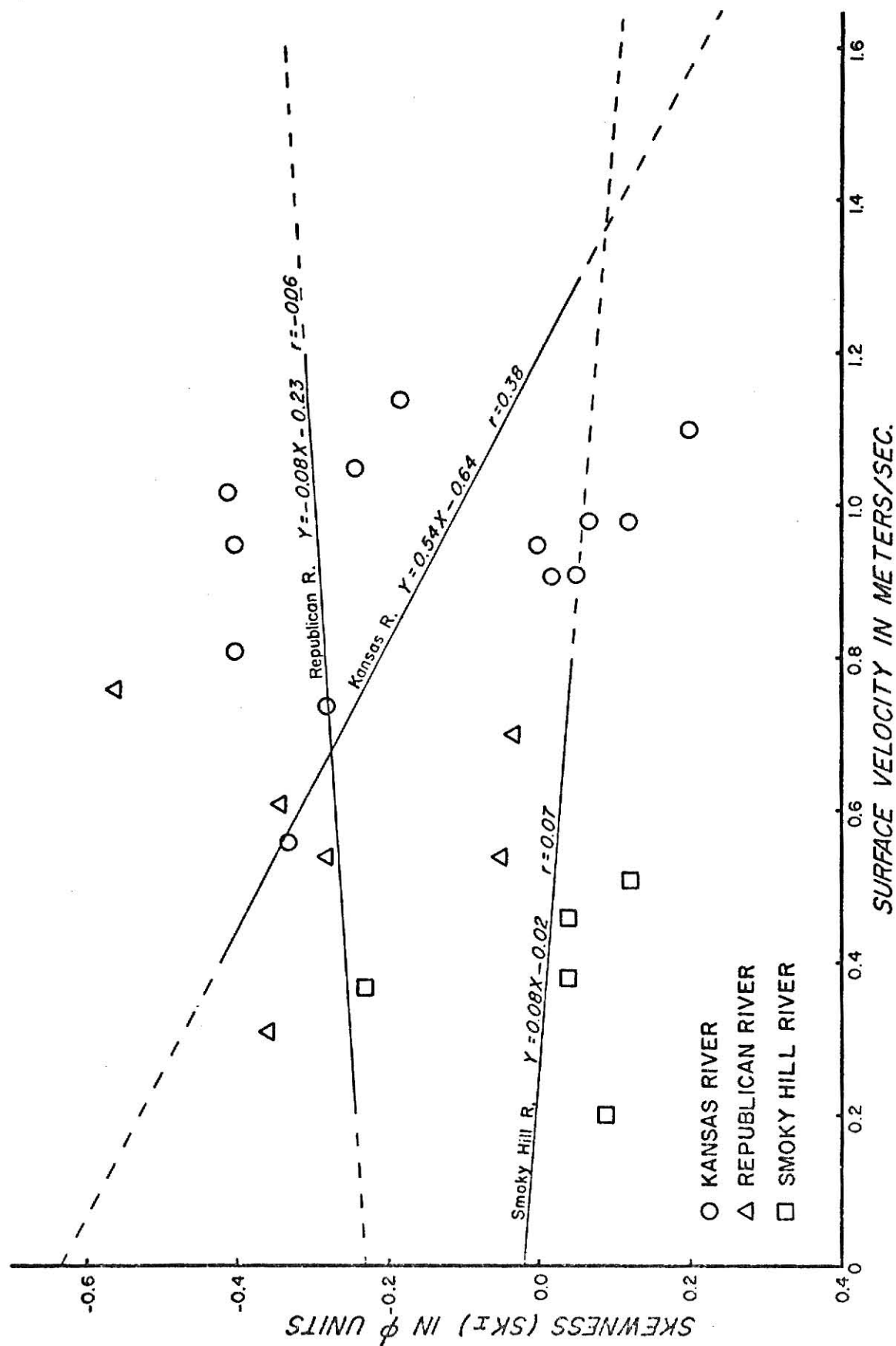


Figure 11. Grain-size skewness vs. surface velocity (linear regression).

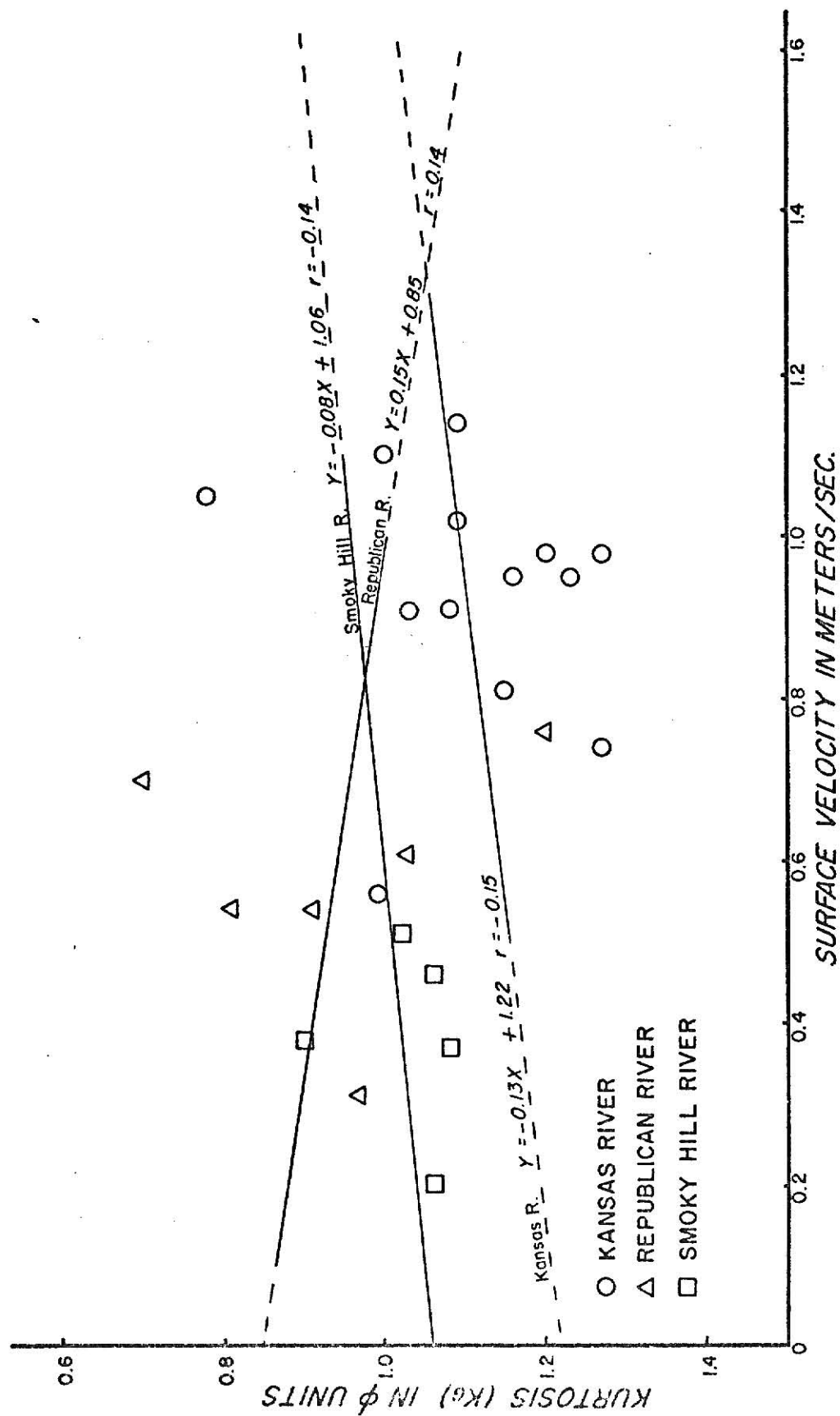


Figure 12. Grain-size kurtosis vs. surface velocity (linear regression).

particle size with increased water depth; Republican River samples also have good positive correlation between surface velocity and mean grain size which shows that grain size also diminishes with increased velocity.

Sorting values of the Republican River correlate well with both water depth and surface velocity. The correlation is negative which indicates that as either surface velocity or water depth increases sorting values will decrease.

The Smoky Hill River shows strong negative correlation between skewness values and water depth indicating an increase in positive skewness with decreased water depth.

Comparison of Grain-Size Parameters Among Rivers: Scatter Plots

Scatter plots (Fig. 13-19) of mean grain size vs. sorting, mean grain size vs. skewness, mean grain size vs. kurtosis, skewness vs. kurtosis, and median vs. diameter of coarsest one percentile were made of the Republican, Smoky Hill, and Kansas River sands near Junction City, and Husain's Kansas River samples near Manhattan, to determine whether or not differences existed among rivers. All samples from each river sand were included in the scatter plots and no attempt was made to separate channel-lag, bank, and point-bar deposits from each other. When considering all the points on the mean grain size vs. sorting scatter plot (Fig. 13), there seems to be a decrease in size as sorting increases. In general, however, no differentiating patterns among rivers are seen.

Comparison of Grain-Size Parameters Among Rivers: One-way Analysis of Variance

Mean grain size, sorting, skewness, and kurtosis values of the different river sands (including Husain's Kansas River samples) were compared by using a one-way analysis of variance statistical test. Three sets of data were analysed. The first set included all samples from each river sand (Tables 5-8); the second, all samples under water (Tables 9-11; Husain's work was not included

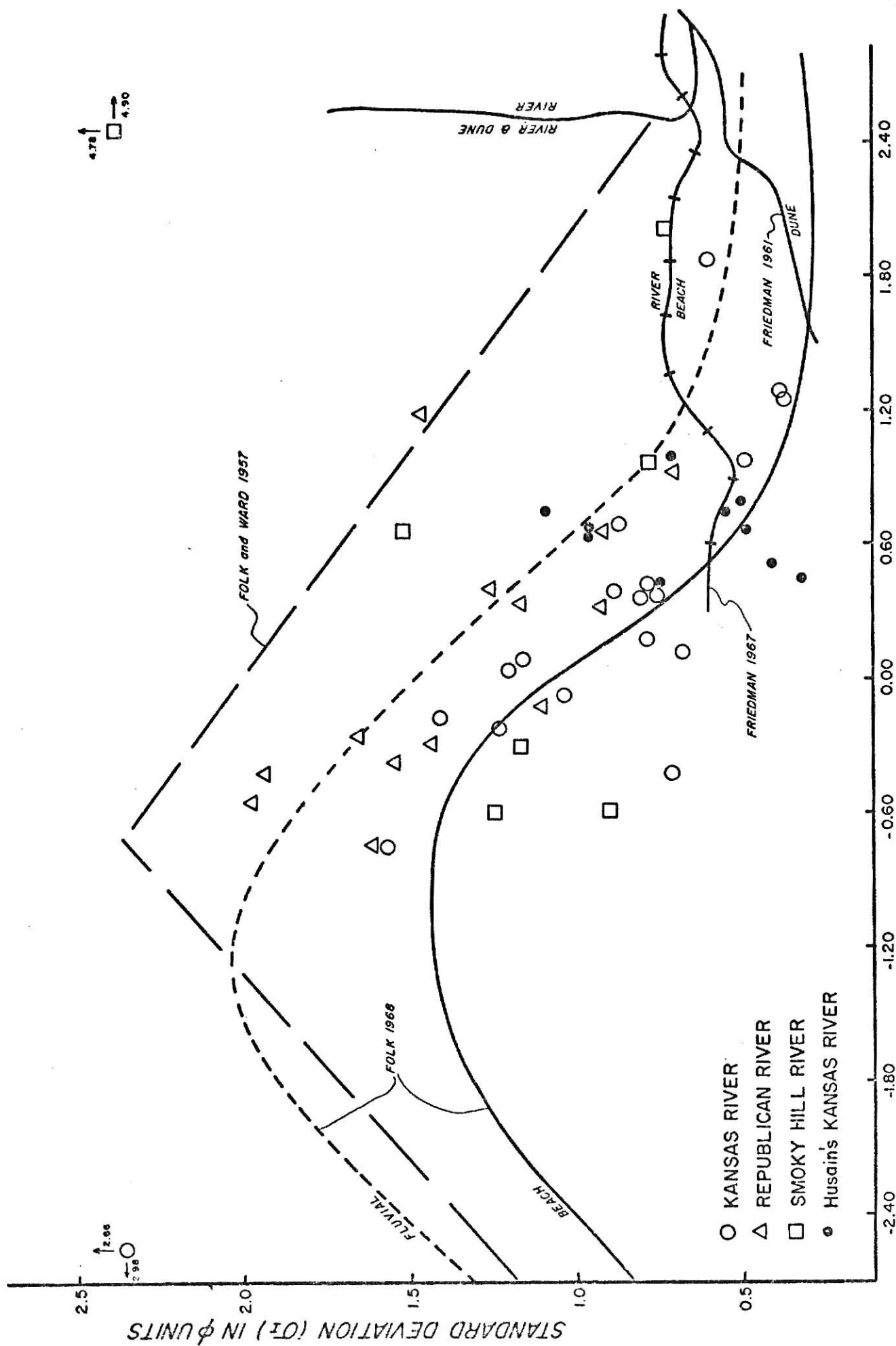


Figure 13. Mean grain size vs. grain-size standard deviation.

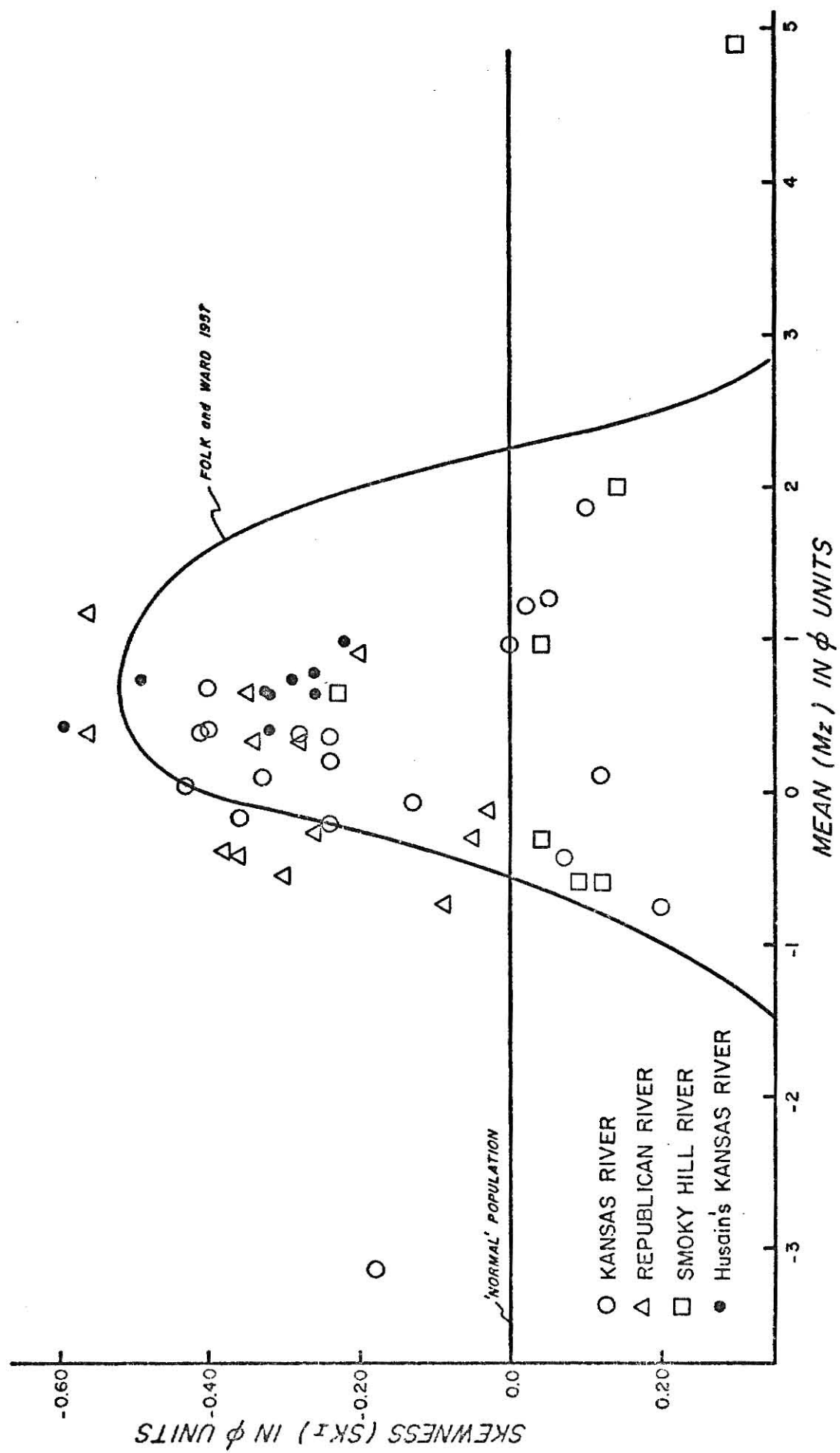


Figure 14. Mean grain size vs. grain-size skewness.

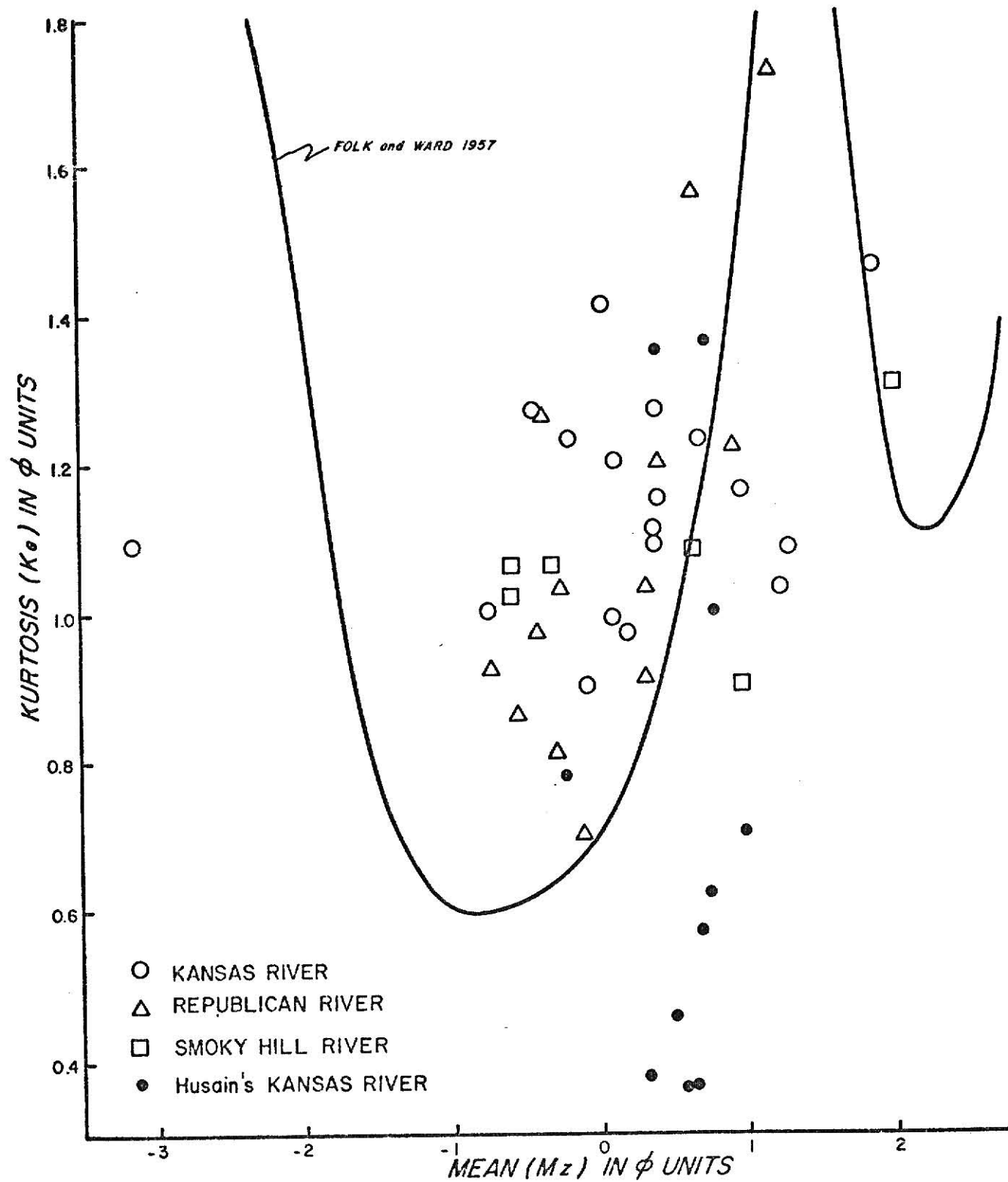


Figure 15. Mean grain size vs. grain-size kurtosis.

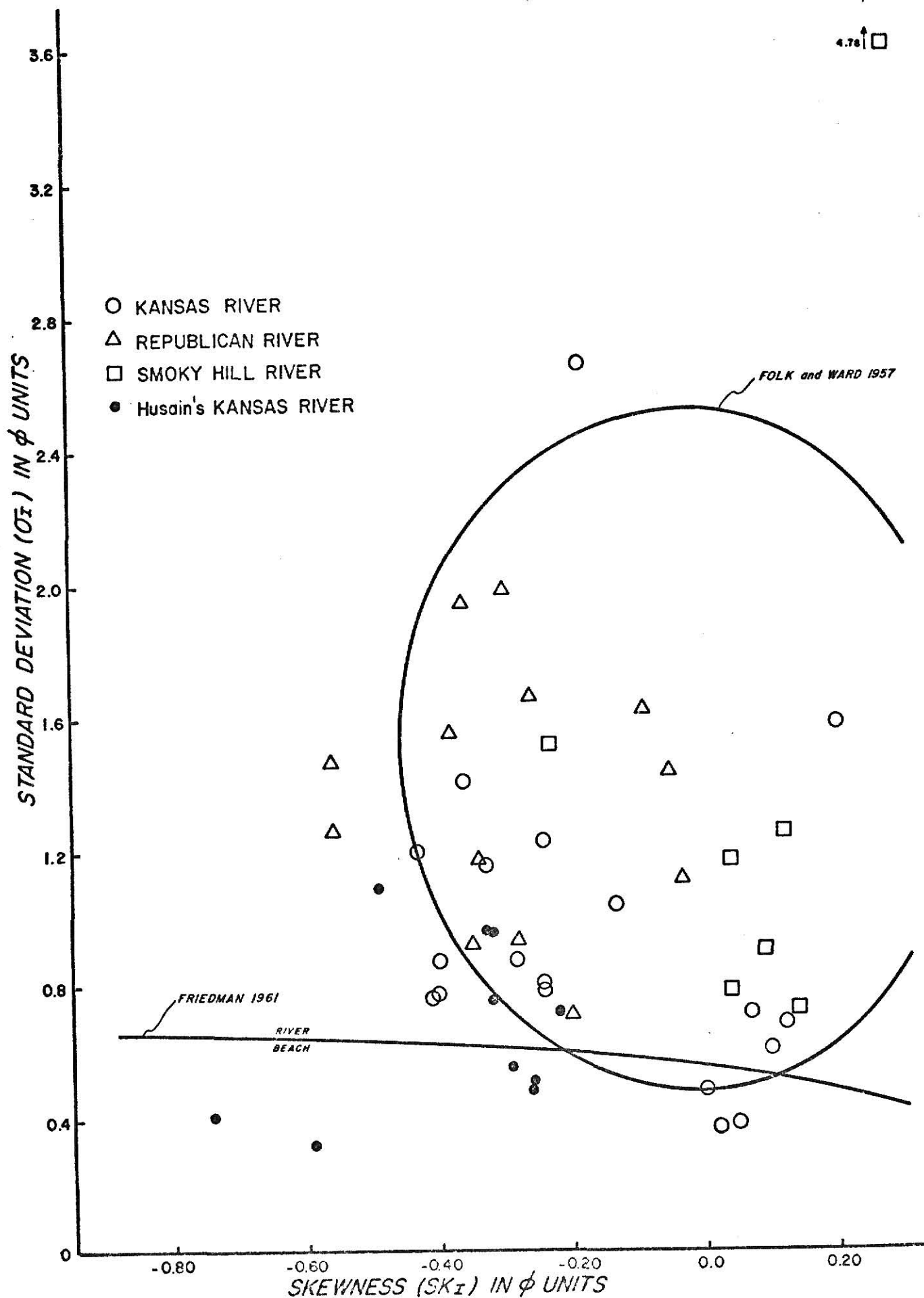


Figure 16. Grain-size standard deviation vs. grain-size skewness.

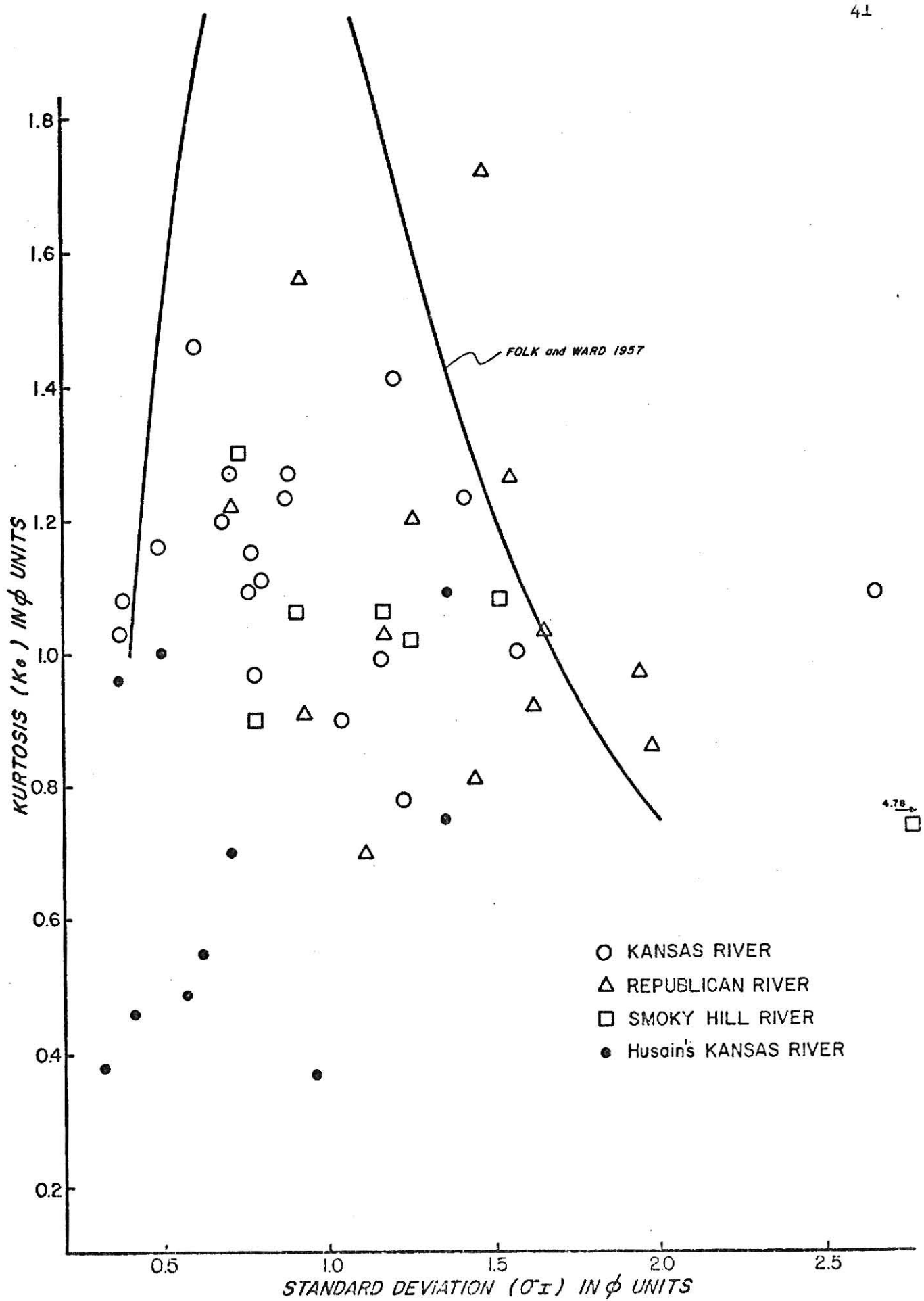


Figure 17. Grain-size standard deviation vs. grain-size kurtosis.

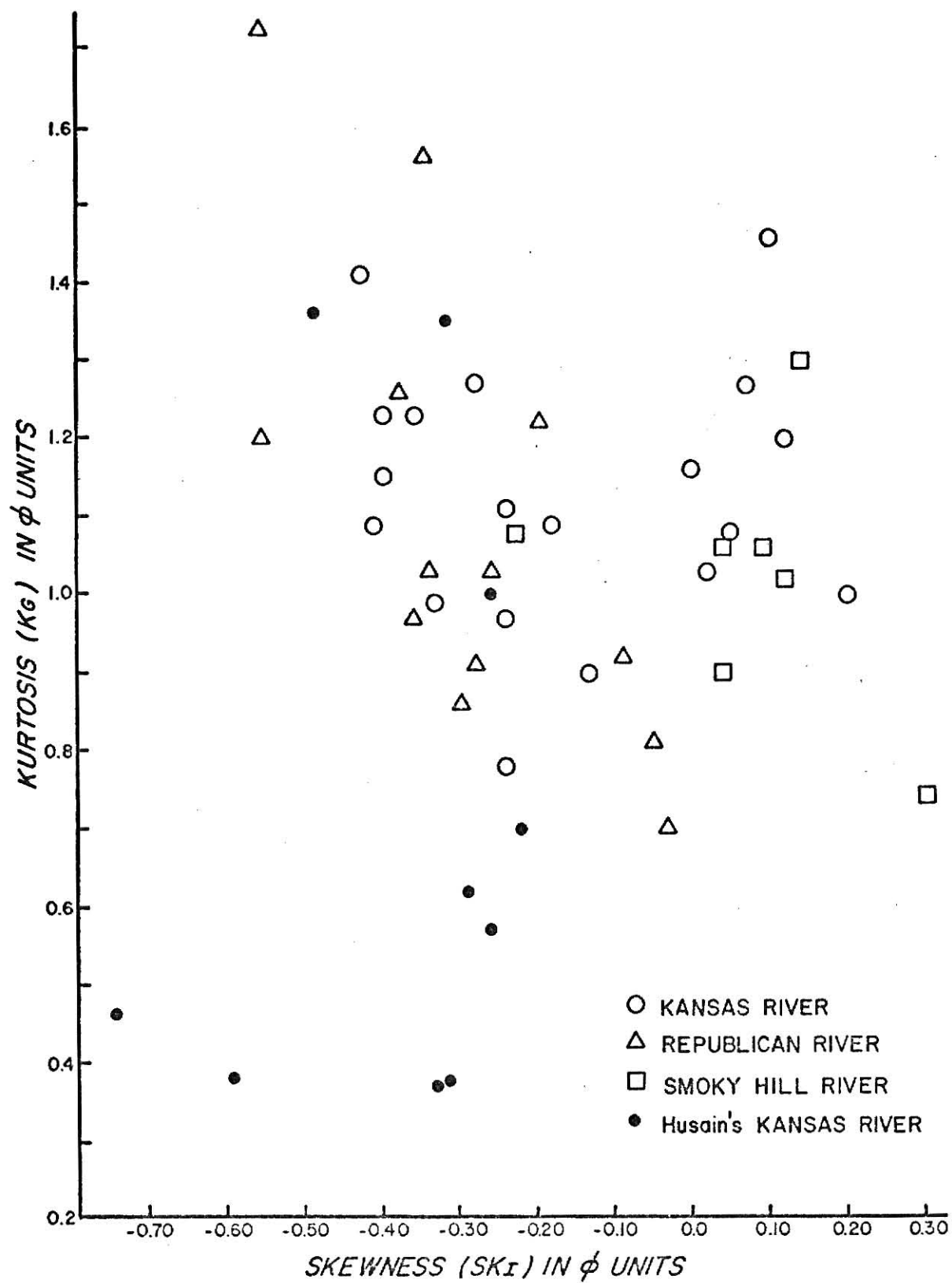


Figure 18. Grain-size skewness vs. grain-size kurtosis.

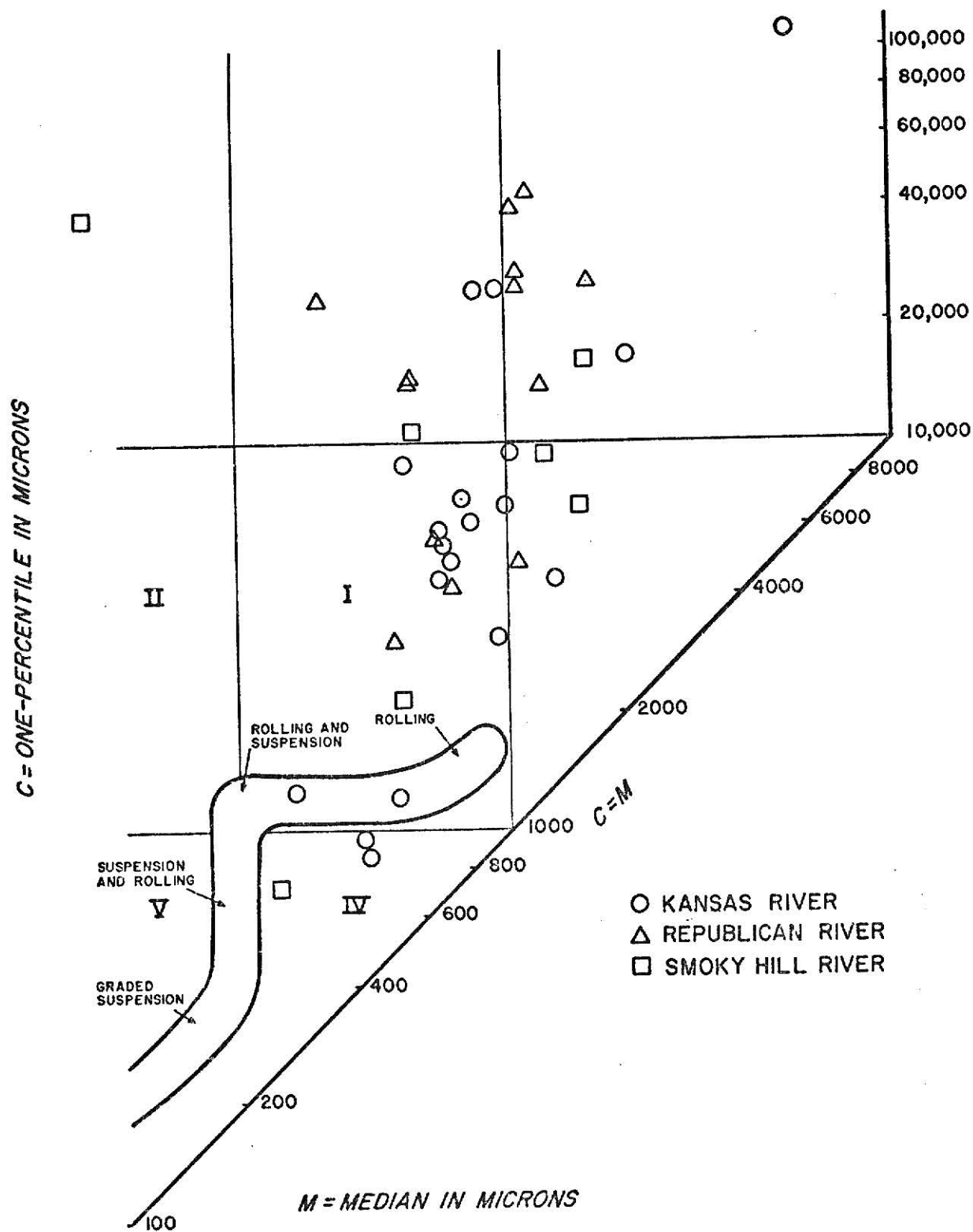


Figure 19. C-M diagrams (after Passega).

because he collected no samples from within the river); and third, all samples under water, excluding bank samples (Tables 12-13).

Comparison of Grain-Size Parameters from Four Rivers, All Samples Included

In comparing grain-size parameter values of the four river sands, Bartlett's homogeneity of variance test revealed that variances about the means of mean grain size, sorting, and kurtosis values of the four river sands differed significantly (Tables 5a, 6a, and 8a). Because this invalidated the analysis of variance test for these parameters, they were compared by using the ordinary "t" test.

The mean grain size of the Republican and Husain's Kansas River sands differed significantly at the 0.5 percent level (Table 5b). Fig. 13 shows that Husain's Kansas River sand is finer than the Republican River sand. The mean grain size of the Kansas River also differs significantly from Husain's Kansas samples, but only at the 10.0 percent level.

Sorting values of the Republican and Husain's Kansas Rivers, and the Republican and Kansas Rivers, differed significantly at the 0.1 and 2.5 percent levels respectively (Table 6b). Fig. 13 shows that both Husain's Kansas and Kansas samples are better sorted than Republican samples. Sorting values of Husain's Kansas and Kansas Rivers differed significantly at the 10.0 percent level with Husain's Kansas samples better sorted than Kansas samples (Fig. 13).

Kurtosis values of Husain's Kansas samples differed significantly from those of the Kansas, Republican, and Smoky Hill River samples at the 0.5, 2.5, and 5.0 percent levels respectively (Table 8b). Husain's samples are platykurtic whereas samples of the Kansas, Republican, and Smoky Hill Rivers are mesokurtic (Fig. 15).

The variances about the means of the skewness values of the four rivers were homogeneous so the analysis of variance test was used to check skewness

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differences among rivers (Table 7a). The test revealed a significant difference among the four rivers at the 0.1 percent level. The Least Significant Difference (LSD) table shows that rivers differing at the 5.0 percent level are the Smoky Hill and Husain's Kansas, Republican and Smoky Hill, Husain's Kansas and Kansas, and Smoky Hill and Kansas. These differences are also shown by the supplemental table of "t" values and their alpha levels (Table 7b). The Smoky Hill River samples are positively skewed whereas the other three river sands tend to be negatively skewed (Fig. 14).

Comparison of Grain-Size Parameters of Under-Water Samples

Variances about the means of mean grain size and sorting of underwater samples of the Republican, Smoky Hill, and Kansas Rivers were significantly different (Table 9a and 9c). Therefore, the analysis of variance test could not be used to compare grain size and sorting; a "t" test was used instead (Table 9b and 9d). No significant difference of grain size was found among the three rivers; a significant sorting difference between the Kansas and Republican Rivers exists but only at the 10.0 percent level.

Variances about the means of skewness and kurtosis values of the underwater samples of the Republican, Smoky Hill, and Kansas Rivers were homogeneous and, therefore, the analysis of variance test was valid. Skewness values among the rivers differed significantly at the 1.0 percent level (Table 10a). The LSD table shows this difference to be between the Republican and Smoky Hill Rivers. The ordinary "t" test shows that significant differences exist between the Smoky Hill and Republican, Smoky Hill and Kansas, and Republican and Kansas at the 0.5, 5.0, and 10.0 percent levels respectively (Table 10b).

Analysis of variance of kurtosis values among the three rivers are not significant (Table 11a).

Comparison of Grain-Size Parameters of Under-Water Samples Excluding Bank Samples

Samples R13, S1, S7, and K23 were not included in the analysis of variance test of grain-size parameters of under-water samples of the three rivers. Variances about the means of sorting, skewness, and kurtosis values were homogeneous so the analysis of variance test was valid (Table 12c, 13a, and 13c). It showed no significant difference of sorting, skewness, or kurtosis among the three river sands.

Variances about the means of mean grain size of the three rivers were significantly different so the analysis of variance test for this parameter was invalid. The "t" test showed, however, no significance of mean grain size among rivers (Table 12b).

COMPARISON OF GRAIN-SIZE PARAMETERS WITH THOSE OF OTHER DEPOSITIONAL SITES

Folk and Ward, 1957

Scatter plots of grain-size parameters of Folk and Ward's Brazos River bar were compared with scatter plots of this study. Brazos River bar consists of a strongly bimodal mixture of pebble gravel and medium to fine sand whereas the sands of the Republican, Smoky Hill, and Kansas Rivers are mostly unimodal with primary modes of coarse sand in almost every sample (Fig. 52, Tables 24 and 25). Scatter plot trends of Folk and Ward's bimodal sediment were superimposed upon scatter plots of the unimodal river sands of this study (Fig. 13-18); little relationship between the two is seen. This, however, was expected because trends of scatter plots are dependent on the modal characteristics of a sediment. The modal characteristics of the two study areas were clearly different.

In general, samples of the Republican, Smoky Hill, and Kansas Rivers tend to be better sorted than those of the Brazos River bar although sorting in each

TABLE 5A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS
FROM FOUR RIVERS

Analysis for variable no. 1 - mean grain size					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	13	0.08077	0.35816	0.59846
2	Smoky Hill	7	1.00571	3.85426	1.96323
3	Kansas	19	0.16947	1.04760	1.02353
4	Husain's Kansas	10	0.66200	0.02988	0.17287

Bartlett's test of homogeneity of variance

Chi-square = 34.97362*** D.F. = 3 Alpha hat = 0.0000

*** Significant at the 0.1% level.

Analysis of variance of mean grain size

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	3	5.5322628	1.8440876	1.7827129*	0.1640198
Within rivers	45	46.5492859	1.0344276		
Total	48	52.0815582			

* Not significant.

TABLE 5B. ORDINARY "t" TEST OF MEAN GRAIN SIZE OF FOUR RIVER SANDS

River	D.F.	"t"
1-2	18	-1.216
1-3	30	-0.309
1-4	21	-3.326***
2-3	24	1.075
2-4	15	0.462
3-4	27	-2.043*

* Significant at the 10.0% level.
*** Significant at the 0.5% level.

TABLE 6A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS
FROM FOUR RIVERS

Analysis for variable no. 2 - standard deviation					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	13	1.36615	0.15351	0.39180
2	Smoky Hill	7	1.59000	2.05747	1.43439
3	Kansas	19	0.96579	0.27397	0.52342
4	Husain's Kansas	10	0.67400	0.06869	0.26209

Bartlett's test of homogeneity of variance

Chi-square = 27.28328*** D.F. = 3 Alpha hat = 0.0000

*** Significant at the 0.1% level.

Analysis of variance of sorting

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	3	4.7584534	1.5861511	3.6164684*	0.0201147
Within rivers	45	19.7366028	0.4385911		
Total	48	24.4950562			

* Significant at the 2.5% level.

Table of differences of sorting

Significance or alpha level = .05, "t" = 2.014

	Means	4	3	1
2	1.590	0.916	0.624	0.224
LSD		0.657	0.590	0.625
1	1.366	0.692	0.400	
LSD		0.561	0.480	
3	0.966	0.292		
LSD		0.521		
4	0.674			

TABLE 6B. ORDINARY "t" TEST OF SORTING OF FOUR RIVER SANDS

River	D.F.	"t"
1-2	18	-0.405
1-3	30	2.472**
1-4	21	5.065***
2-3	24	1.124
2-4	15	1.670
3-4	27	2.000*

* Significant at the 10.0% level.

** Significant at the 2.5% level.

*** Significant at the 0.1% level.

TABLE 7A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS
FROM FOUR RIVERS

Analysis for variable no. 3 - skewness					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	13	-0.28923	0.02827	0.16815
2	Smoky Hill	7	0.07143	0.02541	0.15942
3	Kansas	19	-0.16211	0.04361	0.20882
4	Husain's Kansas	10	-0.38200	0.02866	0.16930

Bartlett's test of homogeneity of variance

Chi-square = 1.10510* D.F. = 3 Alpha hat = 0.7758

* Not significant.

Analysis of variance of skewness

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	3	0.9751010	0.3250337	9.5308304*	0.0000547
Within rivers	45	1.5346527	0.0341034		
Total	48	2.5097542			

* Significant at the 0.1% level.

Table of differences of skewness

Significance or alpha level = .05, "t" = 2.014

	Means	4	1	3
2	0.071	0.453	0.361	0.234
LSD		0.183	0.174	0.164
3	-0.162	0.220	0.127	
LSD		0.145	0.134	
1	-0.289	0.093		
LSD		0.156		
4	-0.382			

TABLE 7B. ORDINARY "t" TEST OF SKEWNESS OF FOUR RIVER SANDS

River	D.F.	"t"
1-2	18	-4.734****
1-3	30	-1.901*
1-4	21	1.307
2-3	24	3.034**
2-4	15	5.626****
3-4	27	3.061***
* Significant at the 10.0% level.		
** Significant at the 1.0% level.		
*** Significant at the 0.5% level.		
**** Significant at the 0.1% level.		

TABLE 8A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS
FROM FOUR RIVERS

Analysis for variable no. 4 - kurtosis					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	13	1.09154	0.08683	0.29467
2	Smoky Hill	7	1.02286	0.02966	0.17221
3	Kansas	19	1.12737	0.02812	0.16769
4	Husain's Kansas	10	0.71800	0.14955	0.38672

Bartlett's test of homogeneity of variance

Chi-square = 10.56028* D.F. = 3 Alpha hat = 0.0144

* Significant at the 2.5% level.

Analysis of variance of kurtosis

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	3	1.1976395	0.3992131	5.8477802*	0.0018403
Within rivers	45	3.0720367	0.0682675		
Total	48	4.2696762			

*Significant at the 2.5% level.

Table of differences of kurtosis

Significance or alpha level = .05, "t" = 2.014

	Means	4	2	1
3	1.127	0.409	0.105	0.036
LSD		0.206	0.233	0.189
1	1.092	0.374	0.069	
LSD		0.221	0.247	
2	1.023	0.305		
LSD		0.259		
4	0.718			

TABLE 8B. ORDINARY "t" TEST OF KURTOSIS OF FOUR RIVER SANDS

River	D.F.	"t"
1-2	18	0.657
1-3	30	-0.397
1-4	21	2.540**
2-3	24	-1.382
2-4	15	2.201*
3-4	27	3.193***

* Significant at the 5.0% level.

** Significant at the 2.5% level.

*** Significant at the 0.5% level.

TABLE 9A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM THREE RIVERS EXCLUDING POINT-BAR SAMPLES

Analysis for variable no. 1 - mean grain size					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	7	0.20000	0.29310	0.54139
2	Smoky Hill	7	1.00571	3.85426	1.96323
3	Kansas	14	0.20571	1.43092	1.19621

Bartlett's test of homogeneity of variance

Chi-square = 7.95837* D.F. = 2 Alpha hat = 0.0187

* Significant at the 2.5% level.

Analysis of variance of mean grain size

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	3.3761692	1.6880846	0.9704743*	0.3927208
Within rivers	25	43.4860840	1.7394428		
Total	27	46.8622589			

* Not significant.

TABLE 9B. ORDINARY "t" TEST OF MEAN GRAIN SIZE OF THREE RIVER SANDS EXCLUDING POINT-BAR SAMPLES

River	D.F.	"t"
1-2	12	-1.047
1-3	19	-0.015
2-3	19	0.990

TABLE 9C. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR SAMPLES

Analysis for variable no. 2 - standard deviation					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	7	1.33143	0.10711	0.32728
2	Smoky Hill	7	1.59000	2.05747	1.43439
3	Kansas	14	0.93714	0.35387	0.59487

Bartlett's test of homogeneity of variance

Chi-square = 12.98604* D.F. = 2 Alpha hat = 0.0015
* Significant at the 0.5% level.

Analysis of variance of river standard deviations

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	2.1528940	1.0764465	1.5301075*	0.2361094
Within rivers	25	17.5877533	0.7035101		
Total	27	19.7406616			

* Not significant.

TABLE 9D. ORDINARY "t" TEST OF SORTING OF THREE RIVER SANDS
EXCLUDING POINT-BAR SAMPLES

River	D.F.	"t"
1-2	12	-0.465
1-3	19	1.957*
2-3	19	1.156

* Significant at the 10.0% level.

TABLE 10A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR SAMPLES

Analysis for variable no. 3 - skewness					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	7	-0.31143	0.04588	0.21420
2	Smoky Hill	7	0.07143	0.02541	0.15942
3	Kansas	14	-0.12000	0.04892	0.22119

Bartlett's test of homogeneity of variance

Chi-square = 0.77805* D.F. = 2 Alpha hat = 0.6777

* Not significant.

Analysis of variance of skewness

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.5130284	0.2565142	6.0284204*	0.0073013
Within rivers	25	1.0637703	0.0425508		
Total	27	1.5767994			

* Significant at the 1.0% level.

Table of differences of skewness

Significance or alpha level = .05, "t" = 2.060

	Means	1	3
2	0.071	0.383	0.191
LSD		0.227	0.197
3	-0.120	0.191	
LSD		0.197	
1	-0.311		

TABLE 10B. ORDINARY "t" TEST OF SKEWNESS OF THREE RIVER SANDS EXCLUDING
POINT-BAR SAMPLES

River	D.F.	"t"
1-2	12	-3.794***
1-3	19	-1.910*
2-3	19	2.268**

* Significant at the 10.0% level.
 ** Significant at the 5.0% level.
 *** Significant at the 0.5% level.

TABLE 11A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR SAMPLES

Analysis for variable no. 4 - kurtosis					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	7	1.04857	0.11298	0.33613
2	Smoky Hill	7	1.02286	0.02966	0.17221
3	Kansas	14	1.12857	0.02607	0.16148

Bartlett's test of homogeneity of variance

Chi-square = 5.25319* D.F. = 2 Alpha hat = 0.0723

* Not significant.

Analysis of variance of kurtosis

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.0626713	0.0313357	0.6556692*	0.5277905
Within rivers	25	1.1947966	0.0477919		
Total	27	1.2574682			

* Not significant.

TABLE 11B. ORDINARY "t" TEST OF KURTOSIS OF THREE RIVER SANDS
EXCLUDING POINT-BAR SAMPLES

River	D.F.	"t"
1-2	12	0.180*
1-3	19	-0.596
2-3	19	-0.354

* Significant at the 10.0% level.

TABLE 12A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR AND BANK SAMPLES

Analysis for variable no. 1 - mean grain size					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	6	0.03667	0.12763	0.35725
2	Smoky Hill	5	0.02600	0.53808	0.73354
3	Kansas	13	0.07769	1.30159	1.14087

Bartlett's test of homogeneity of variance

Chi-square = 6.33190* D.F. = 2 Alpha hat = 0.0422
* Significant at the 5.0% level.

Analysis of variance of mean grain size

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.0128492	0.0064246	0.0073287*	0.9927007
Within rivers	21	18.4094543	0.8766407		
Total	23	18.4223175			

* Not significant.

TABLE 12B. ORDINARY "t" TEST OF MEAN GRAIN SIZE OF THREE RIVER SANDS
EXCLUDING POINT-BAR AND BANK SAMPLES

River	D.F.	"t"
1-2	9	0.030
1-3	17	-0.118
2-3	16	-0.113

TABLE 12C. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR AND BANK SAMPLES

Analysis for variable no. 2 - standard deviation					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	6	1.30833	0.12406	0.35222
2	Smoky Hill	5	1.12400	0.08583	0.29297
3	Kansas	13	0.96308	0.37316	0.61087

Bartlett's test of homogeneity of variance

Chi-square = 3.44682* D.F. = 2 Alpha hat = 0.1785

* Not significant.

Analysis of variance of sorting

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.5000145	0.2500072	0.9648396*	0.3973047
Within rivers	21	5.4414768	0.2591179		
Total	23	5.9414921			

* Not significant.

TABLE 12D. ORDINARY "t" TEST OF SORTING OF THREE RIVER SANDS
EXCLUDING POINT-BAR AND BANK SAMPLES

River	D.F.	"t"
1-2	9	0.948
1-3	17	1.554
2-3	16	1.293

TABLE 13A. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR AND BANK SAMPLES

Analysis for variable no. 3 - skewness					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	6	-0.27000	0.04064	0.20159
2	Smoky Hill	5	0.01200	0.01947	0.13953
3	Kansas	13	-0.13692	0.04866	0.22058

Bartlett's test of homogeneity of variance

Chi-square = 0.98489* D.F. = 2 Alpha hat = 0.6111

* Not significant.

Analysis of variance of skewness

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.2170262	0.1085131	2.6345549*	0.0953069
Within rivers	21	0.8649564	0.0411884		
Total	23	1.0819826			

* Not significant.

TABLE 13B. ORDINARY "t" TEST OF SKEWNESS OF THREE RIVER SANDS
EXCLUDING POINT-BAR AND BANK SAMPLES

River	D.F.	"t"
1-2	9	-2.730*
1-3	17	-1.298
2-3	16	1.704

* Significant at the 2.5% level.

TABLE 13C. ONE-WAY ANALYSIS OF VARIANCE OF GRAIN-SIZE PARAMETERS FROM
THREE RIVERS EXCLUDING POINT-BAR AND BANK SAMPLES

Analysis for variable no. 4 - kurtosis					
No.	River	No. of samples	Means	Variances	Standard deviations
1	Republican	6	0.93667	0.03039	0.17432
2	Smoky Hill	5	1.02400	0.00528	0.07266
3	Kansas	13	1.10308	0.01839	0.13561

Bartlett's test of homogeneity of variance

Chi-square = 2.67056* D.F. = 2 Alpha hat = 0.2631

* Not significant.

Analysis of variance of kurtosis

	D.F.	Sums of squares	Mean square	F-test	Prob.
Between rivers	2	0.1164693	0.0582347	3.1060085*	0.0658132
Within rivers	21	0.3937297	0.0187490		
Total	23	0.5101991			

* Not significant.

TABLE 13D. ORDINARY "t" TEST OF KURTOSIS OF THREE RIVER SANDS
EXCLUDING POINT-BAR AND BANK SAMPLES

River	D.F.	"t"
1-2	9	-1.116
1-3	17	-2.067*
2-3	16	-1.591

* Significant at the 5.0% level.

study tends to increase with decreasing size (Fig. 13). Most samples of the three river sands fall in non-normal areas of the skewness vs. kurtosis scatter plot (Fig. 18) which was also true of the bimodal sediment of Folk and Ward's study.

Friedman, 1961 and 1967

Friedman successfully separated sediments from dune and river environments (1961, p. 521) and beach and river environments (1967, p. 339) by plotting scatter diagrams of mean grain size vs. standard deviation. These environmental boundaries were superimposed on a mean grain size vs. sorting scatter plot of the Republican, Smoky Hill, and Kansas River samples of this study (Fig. 13). All samples of the Republican, Smoky Hill, and Kansas River sands fell in the combination river and dune area of the 1961 study thereby consistent with Friedman's results. All Republican and Smoky Hill samples fall in the area of river samples of the 1967 study whereas half of Husain's river samples and about 20 percent of the Kansas River samples of this study fell outside the river boundary and into the area of beach samples. Few rivers have such well-sorted sediments.

Friedman was also successful in separating beach from river sediments by plotting scatter diagrams of skewness vs. standard deviation. The boundary separating river and beach sands of his 1961 study is superimposed on a corresponding scatter plot of the Republican, Smoky Hill, and Kansas River samples (Fig. 16). Well-sorted samples of the Kansas River again fall outside Friedman's river area whereas all samples of the Republican and Smoky Hill Rivers remained within the river boundary.

Passega, 1957 and 1964

Passega differentiated agents of deposition by plotting a sediments median diameter vs. its coarsest one-percentile. C-M patterns of tractive currents

included areas corresponding to transporting media of uniform suspension, graded suspension, suspension and rolling, rolling and suspension, and rolling (Passega, 1964, p. 831). Samples of the Republican, Smoky Hill, and Kansas Rivers were plotted on a C-M diagram upon which the above C-M patterns were superimposed (Fig. 19). As a group, these river samples are much coarser than those of Passega and are widely dispersed above the higher energy C-M patterns.

Visher, 1969

Visher found that both marine and fresh water geological environments could be divided into three modes of transport: saltation, suspension, and surface creep and rolling (1969, p. 1078). Each mode is represented by a straight line segment of the log-probability curve of the grain-size frequency distribution. No straight line segments of log-probability curves of Republican, Smoky Hill, or Kansas River samples correlated with Visher's.

GRAIN ROUNDNESS

Relationship of Grain Roundness to Depositional Environments

Abrasional history and maturity of sediments are reflected in the roundness of clastic particles which compose the sediment (Pettijohn, 1957, p. 66). Rates of rounding depend on energy of transporting and depositional environments, length of time within that particular environment, and physical characteristics of the mineral grain or rock fragment such as its size and hardness. Experiments have shown that rounding of grains is a very slow process requiring tremendous amounts of energy and that large sedimentary particles round easier than small ones (Pettijohn, Potter, and Siever, 1972, p. 83). Many cycles of transport or intensive abrasion in high energy environments are responsible for well-rounded grains although petrographers are not in agreement as to which process

correctly reflects geologic history (Pettijohn, Potter, and Siever, 1972, p. 83).

Roundness proceeds at different rates in different depositional environments. Aeolian sands tend to round faster than beach sands because of greater impact between grains in air than in water (Folk, 1974, p. 15), although rounding differences between beach and dune sands have been attributed to selective sorting of dune sand from the beach environment (Beal and Shepard, 1956, p. 56). Beach sands, in turn, round faster than river sands because much greater amounts of energy are in beach environments. Very little or no rounding occurs in rivers. Rounded grains in a river environment are attributed to abrasion in previous cycles of erosion and deposition.

Three practical uses of roundness illustrated by Rittenhouse (1946, p. 1193) are differentiation of producing zones, outlining petrographic provinces, and interpretation of geologic history. In this study roundness of heavy and light minerals was used in an attempt to define better the source areas of the Republican, Smoky Hill, and Kansas Rivers.

Quartz Roundness Values of Each River

Quartz roundness values of the Republican, Smoky Hill, and Kansas Rivers are in Table 14. Mean roundness values of all samples fall within the subangular class of Power's roundness images. Roundness standard deviation values are quite uniform among rivers and range from a low of 0.7 in the Republican River to a high of 0.9 in the Smoky Hill River. A "t" test was used to compare mean roundness and roundness standard deviation among rivers; no significant difference of either parameter was found (Table 15a and 15b).

TABLE 14. QUARTZ ROUNDNESS VALUES OF THREE RIVERS

Sample	Mean roundness	Roundness standard deviation
R11	2.3	0.8
R12	2.3	0.7
S3	2.3	0.7
S5	2.5	0.9
K14	2.3	0.8
K21	2.5	0.8

TABLE 15a. ORDINARY "t" TEST OF QUARTZ MEAN ROUNDNESS VALUES OF THREE RIVERS

Rivers compared	"t" value	D.F.	Probability of a larger value
Republican-Smoky Hill	1.60	2	>0.20
Republican-Kansas	1.39	2	>0.20
Smoky Hill-Kansas	0.29	2	>0.50

TABLE 15b. ORDINARY "t" TEST OF QUARTZ ROUNDNESS STANDARD DEVIATION VALUES OF THREE RIVERS

Rivers compared	"t" value	D.F.	Probability of a larger value
Republican-Smoky Hill	0.8944	2	>0.40
Republican-Kansas	0.9539	2	>0.40
Smoky Hill-Kansas	0.4176	2	>0.50

Heavy Mineral Roundness Values of Each River

Mean roundness values of heavy minerals in differentiated size classes of the Republican, Smoky Hill, and Kansas Rivers are given in Tables 27a and 27b. Samples R9, S2, and K11 were divided into two size classes: $<2.0\phi$ and $>2.0\phi$ (Table 27a) whereas samples R12, S4, and K14 were divided into three size classes: $<3.0\phi$, $<2.0\phi$, and $<1.0\phi$ (Table 27b). Garnet, hornblende, epidote, and ore minerals in each of these size classes were plotted on graphs with their corresponding percentages and roundness values to determine whether or not a

relationship existed between size and rounding of these heavy minerals and whether or not any rounding anomalies existed among rivers (Fig. 20 and 21).

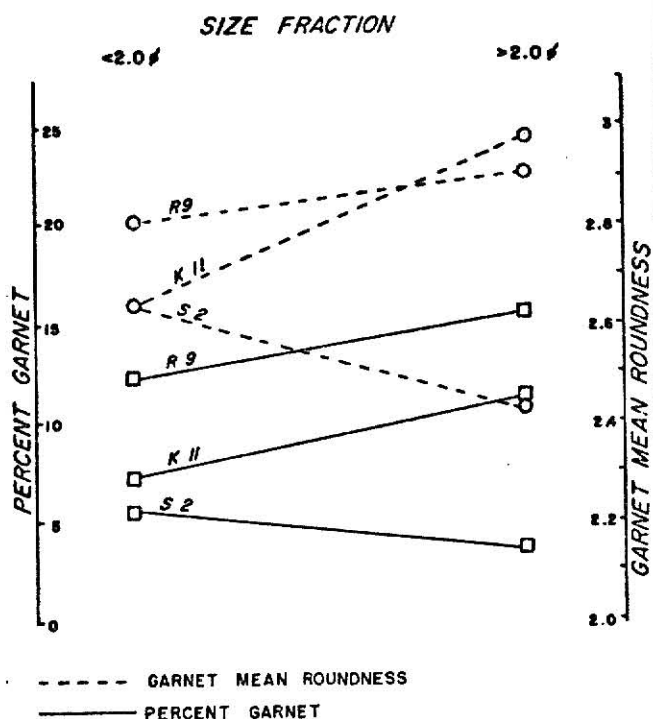
No consistent relationships between rounding and size of garnet, hornblende, epidote, or ore minerals were detected within rivers. Increasing roundness with increasing size occurred 12 times, decreasing roundness with increasing size occurred seven times, both increasing and decreasing roundness within the same sample occurred four times, and no change in rounding occurred once. The changes in roundness which do occur are within one Power's roundness class and, therefore, might easily be attributed to evolutionary operator bias, developed over the length of time taken for examination of the heavy mineral slides.

Roundness values of quartz and heavy mineral grains of the three river sands are consistent with those of other river environments.

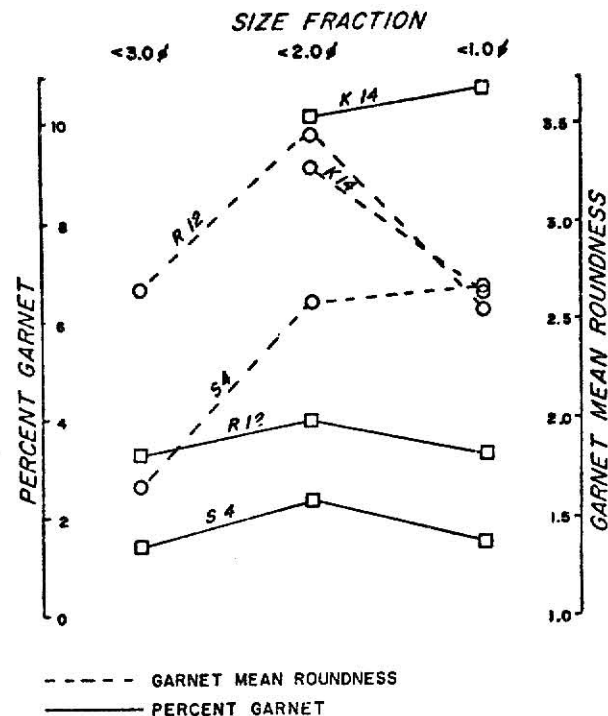
QUARTZ GRAIN SURFACE FEATURES

Relationship of Quartz Surface Features to Depositional Environments

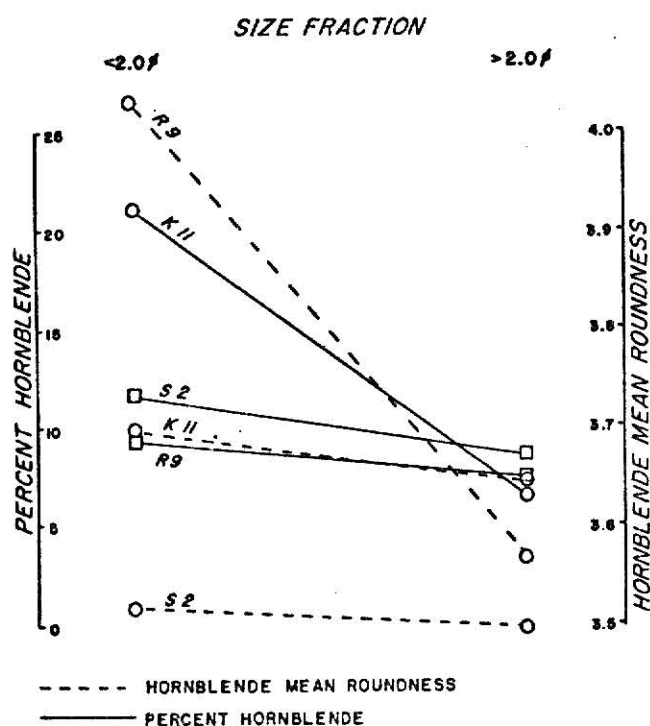
Modern depositional environments are thought to leave unique "fingerprints" upon mineral and rock particles transported and deposited in them. Two common examples of unique surface features associated with their respective depositional environments are frosted sand grains in an aeolian environment and striations on gravel from a glacial environment (Pettijohn, 1957, p. 68). Other surface features thought to uniquely characterize depositional environments are polished surfaces, common on beaches where the grains are repeatedly rolled back and forth; unpolished surfaces, from freshly weathered sediments; and percussion marks, which are on pebbles of chert or quartzite and indicate high-velocity impact (Folk, 1974, p. 12). Low energy river environments tend to preserve surface features of previous cycles of transportation and deposition



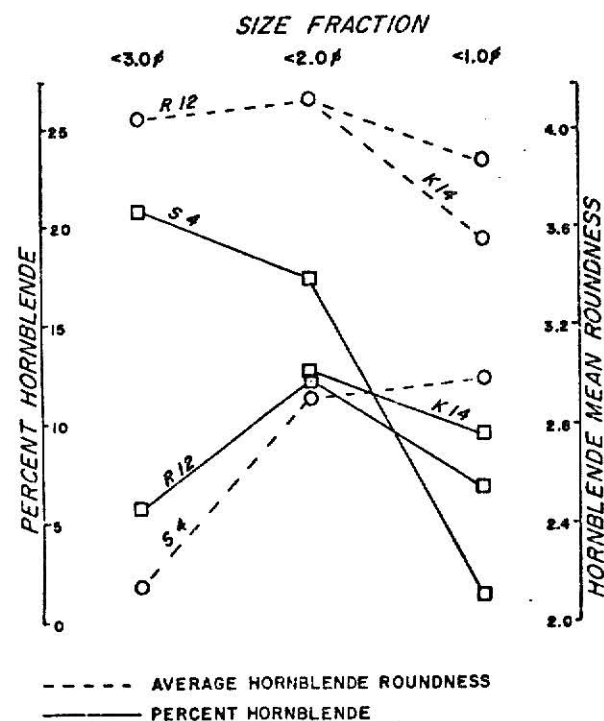
Relationship of garnet size to percent garnet and garnet mean roundness in samples R9, S2, & K11



Relationship of garnet size to percent garnet and garnet mean roundness in samples R12, S4, & K14

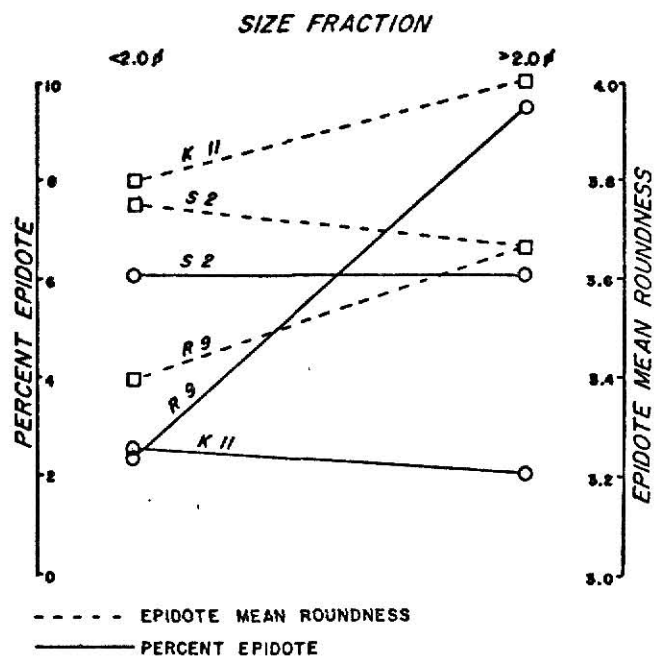


Relationship of hornblende size to percent hornblende and hornblende mean roundness in samples R9, S2, & K11

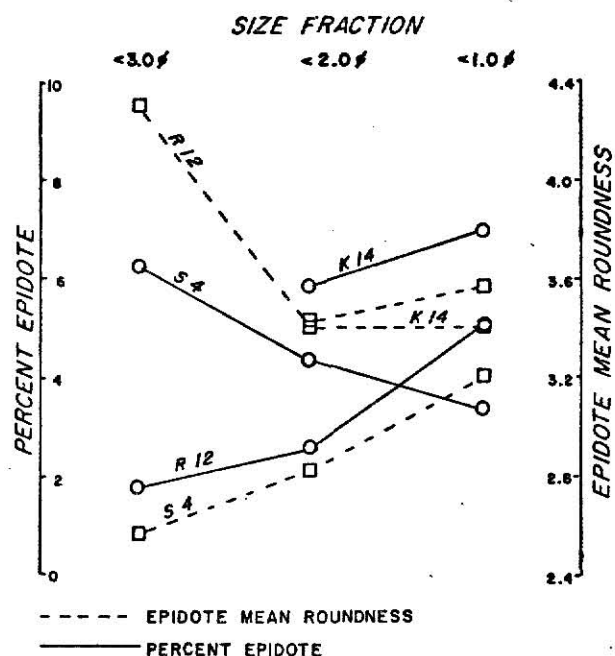


Relationship of hornblende size to percent hornblende and hornblende mean roundness in samples R12, S4, & K14

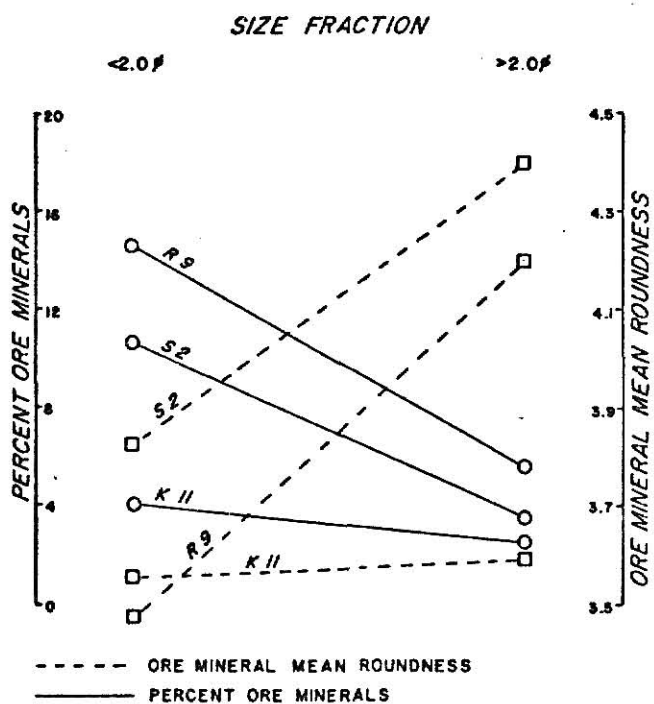
Figure 20. Size, roundness, and percentage relationships of garnet and hornblende.



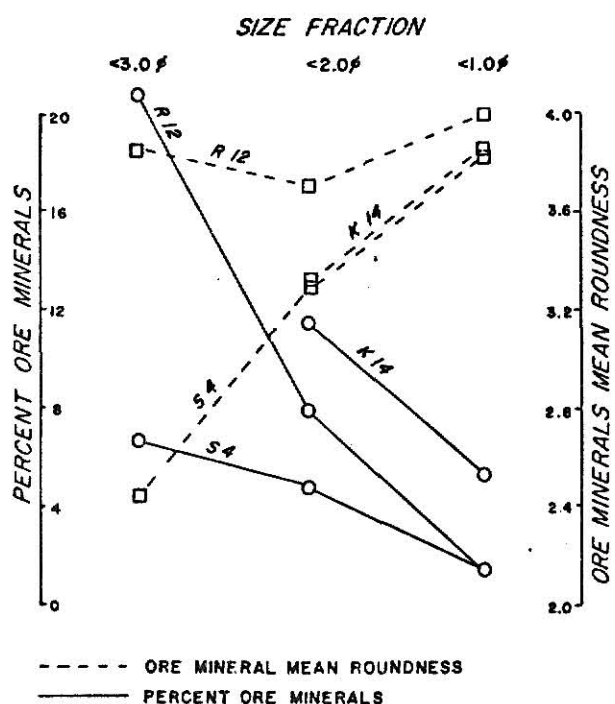
Relationship of epidote size to percent epidote and epidote mean roundness in samples R9, S2, & K11



Relationship of epidote size to percent epidote and epidote mean roundness in samples R12, S4, & K14



Relationship of ore mineral size to percent ore minerals and ore mineral mean roundness in samples R9, S4, & K11



Relationship of ore mineral size to percent ore minerals and ore mineral mean roundness in samples R12, S4, & K14

Figure 21. Size, roundness, and percentage relationships of epidote and ore minerals.

although precipitation-solution activity within the river environment may heal or destroy impact features derived from other environments.

The scanning electron microscope brought renewed interest in studying surface features of quartz grains. Krinsley and Doornkamp (1973) published an atlas of quartz surface features which are uniquely associated with modern depositional environments. They stress that no environment can be characterized by one surface feature alone but that suites of features may be characteristic of a particular environment. The following descriptions of surface feature suites, characteristic of depositional environments and weathered granitic material, are taken from Krinsley and Doornkamp, 1973, p. 10-15.

Surface features diagnostic of freshly weathered granites or granite gneisses are conchoidal breakage patterns, upturned cleavage plates, flat upper and lower crystal faces, and precipitation-solution alteration of these features.

Large quartz grains of glacial environments contain conchoidal fractures whereas flat cleavage surfaces, upturned plates, and conchoidal breakage patterns are characteristic of the smaller grains. Both large and small grains are extremely angular and may be affected by solution and precipitation.

Surfaces of quartz grains from subaqueous environments show mechanical V-shaped impact patterns, straight or curved grooves, and oriented V-shaped pits. Low energy subaqueous environments are distinguished from high energy environments by fewer impact "Vs" persquare micron of grain surface. Increasing numbers of "Vs" characterize river, low-turbulence beach, moderate to high-turbulence beach and shelf, and deep-sea turbidite environments respectively.

Aeolian environments produce surfaces of grains that contain upturned plates on fractured grains, single or multiple dish-shaped concavities (solution-precipitation features), and surface cracking (chemical phenomenon). Flat

upper and lower surfaces, conchoidal breakage features, and flat cleavage plates covered with quartz precipitation are common features of smaller grains.

Brown (1973), Ingersoll (1974), and Scholle and Hoyt (1973) conducted carefully controlled investigations to test whether suites of surface features, previously assigned to specific depositional environments, uniquely characterize those environments or whether, in actuality, large overlap does exist among environments.

Brown (1973, p. 396-397) studied surface features of sand grains from freshly weathered granite and beach sands collected from an area devoid of glacial deposits and found that many of the grains showed textures closely resembling those described as glacial. He concluded that glacial features may be produced in any environment where there are high energy conditions and where a large range of particle sizes exists.

Ingersoll (1974, p. 156) studied textures of first cycle quartz grains from Montara Beach, California, and found them similar to surface features previously described as being from high energy beaches.

Scholle and Hoyt (1973, p. 798) showed that different source rocks contain surface features that have been assigned previously to specific depositional environments.

Description and Discussion of SEM Photomicrographs of River Quartz Grains

Each river contained approximately 85-90 percent frosted to semi-frosted quartz grains and 10-15 percent clear or polished grains as seen under the binocular microscope. All grains were about 0.5 mm in diameter.

Clear or polished grains from the Republican River contained abundant conchoidal breakage patterns (Fig. 22 and 32), deep grooves and striations (Fig. 30 and 31), and stepped parallel and upturned cleavage plates (Fig. 30 and 32). Chemical solution and precipitation has altered these grain surfaces

as evidenced by solution cavities (Fig. 22 and 23), precipitated quartz crystals (Fig. 30), and semiparallel ridges and grooves smoothed by solution-precipitation (Fig. 31). These features are very similar to those described by Krinsley and Doornkamp (1973, p. 60) as belonging to a combined glacial and subaqueous environment. Conchoidal breakage patterns are also known to result during weathering of source rocks. The conchoidal breakage patterns of the clear or polished quartz grains of the Republican River, therefore, probably resulted from a glacial environment, weathering of source material, or from some other high energy environment. The solution-precipitation modification of these breakage patterns probably took place in the river environment.

Frosted quartz grains of the Republican River are characterized by regular and irregular V-shaped impact and solution indentations (Fig. 26, 27, 28, and 29), parallel steps within conchoidal scallops (Fig. 24 and 28), and up-turned cleavage plates associated with breakage patterns and solution cavities (Fig. 24, 25, 27, and 28). The fracture zone of a polycrystalline grain is progressively enlarged in Fig. 26-28. The granulated-sutured boundary between the quartz crystals appears to have been smoothed by chemical solution-precipitation activity (Fig. 28); mechanical V-shaped indentations and a linear impact feature on this grain are characteristic of Krinsley and Doornkamp's (1973, p. 53) subaqueous environment (Fig. 29). The walls of the solution cavity in grain R2 (Fig. 24 and 25) exhibit beautiful examples of cleavage plates and precipitated quartz crystals; a unique particle, probably a coccolith, has found its way into the cavity. Chemical etching in the river environment is responsible for the frosted appearance of this grain. Grain R5 (Fig. 33) contains many mechanical impact features including conchoidal scallopes, irregular curved depressions, and stepped parallel cleavage plates. The origin of these features is not known; they differ from those characteristic of a subaqueous

**THIS BOOK
CONTAINS
NUMEROUS
PICTURES THAT
ARE ATTACHED
TO DOCUMENTS
CROOKED.**

**THIS IS AS
RECEIVED FROM
CUSTOMER.**

Figure 22

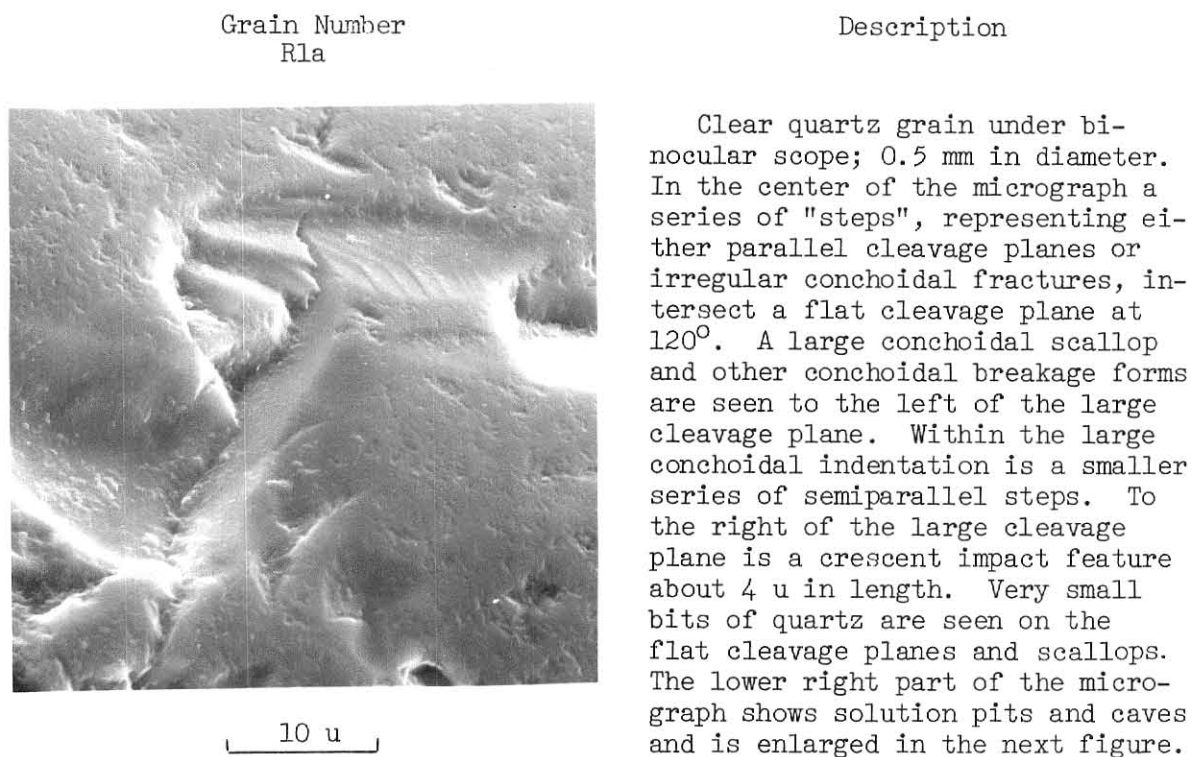


Figure 23

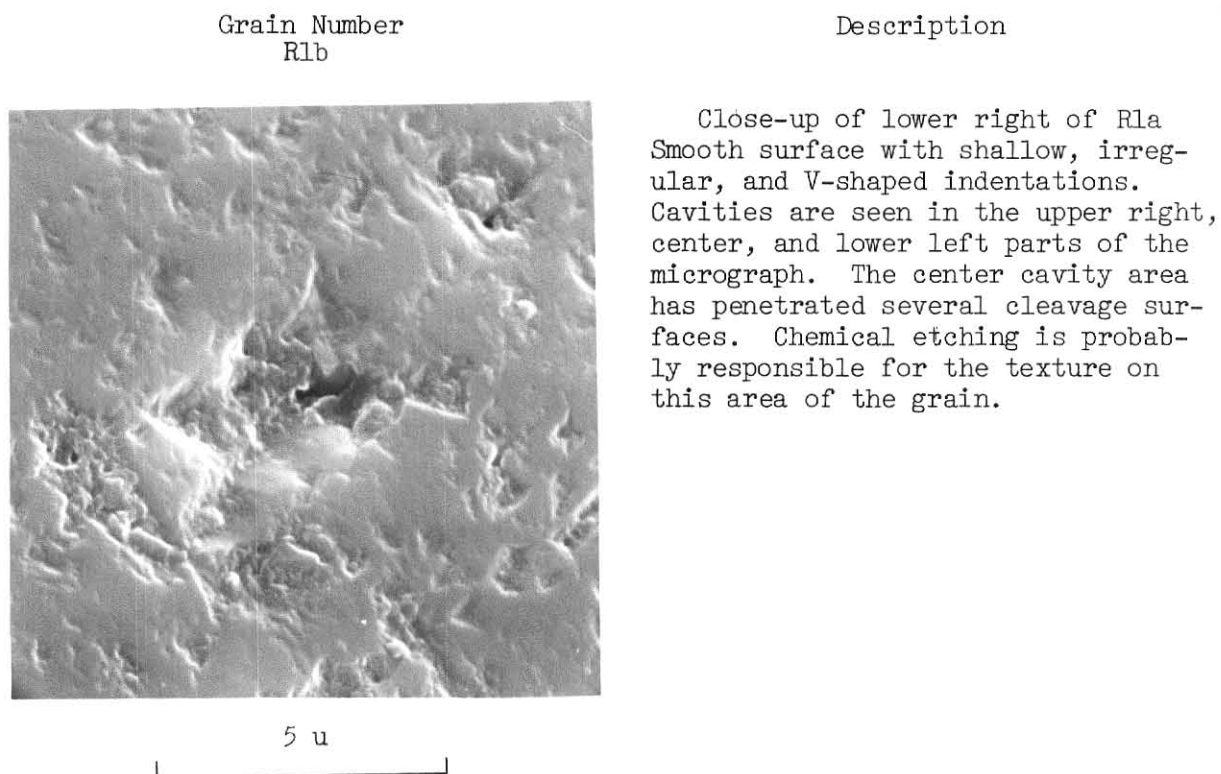
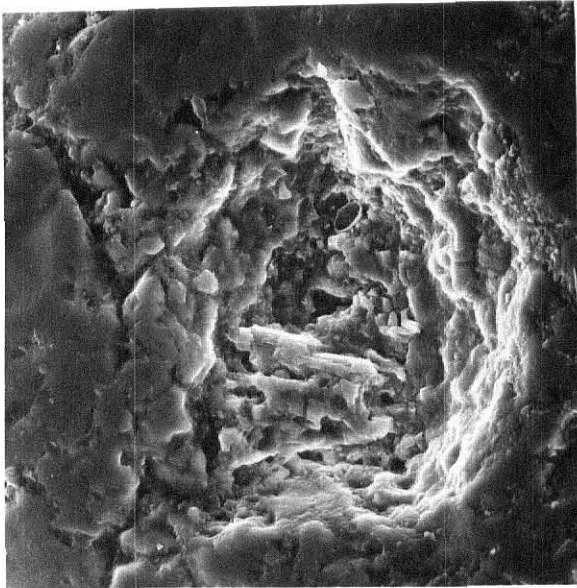


Figure 24

Grain Number
R2a

Description



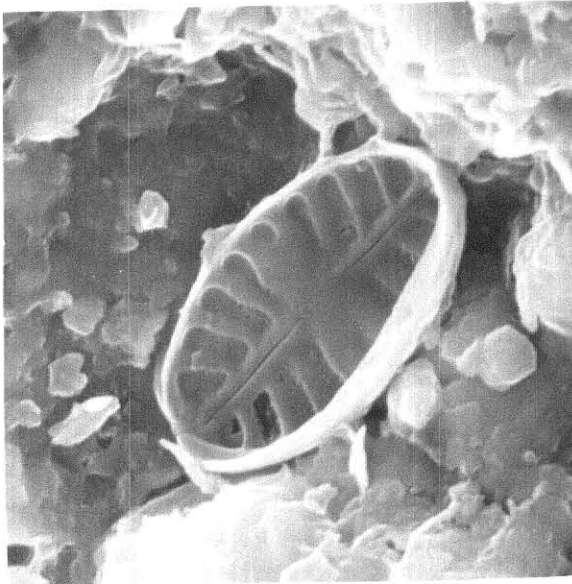
Frosted quartz grain under binocular scope. Large depression with flat cleavage plates visible on cavity wall and bottom of cavity. Semiparallel steps within a conchoidal scallop are seen in the left part of the micrograph. Quartz precipitation is evident in the area to the right of the cavity. A unique particle, about 4 u in length, is seen on the bottom of the cavity.

20 u

Figure 25

Grain Number
R2b

Description



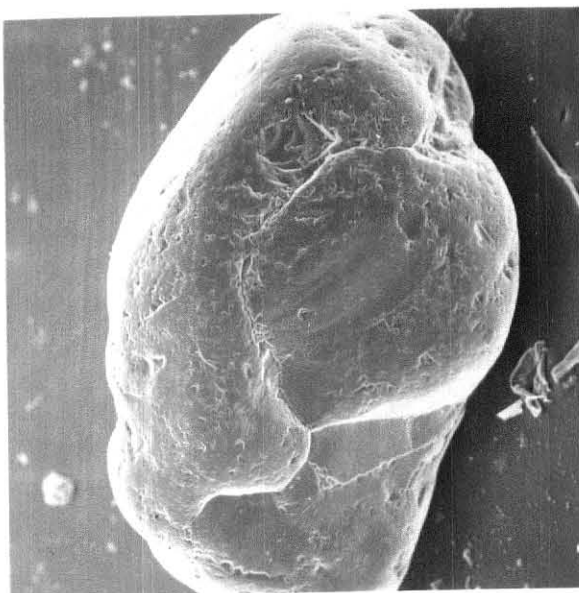
Close-up of R2a. A unique particle (probably a coccolith) with quartz cleavage plates and quartz precipitation crystals around perimeter.

5 u

Figure 26

Grain Number
R3a

Description



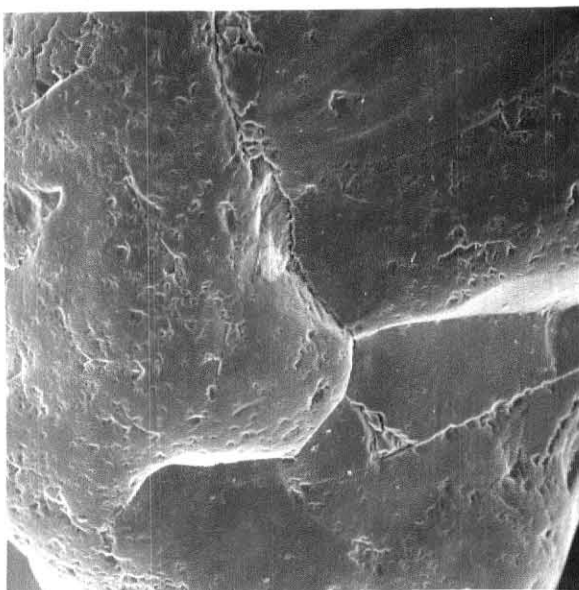
200 u

Frosted, well rounded, poly-crystalline quartz grain with regular and irregular V-shaped impact and solution indentations. Quartz crystals are bordered by granulated, sutured boundaries. An apparent healed conchoidal fracture in the central part of the micrograph is the result of solution-precipitation activity.

Figure 27

Grain Number
R3b

Description



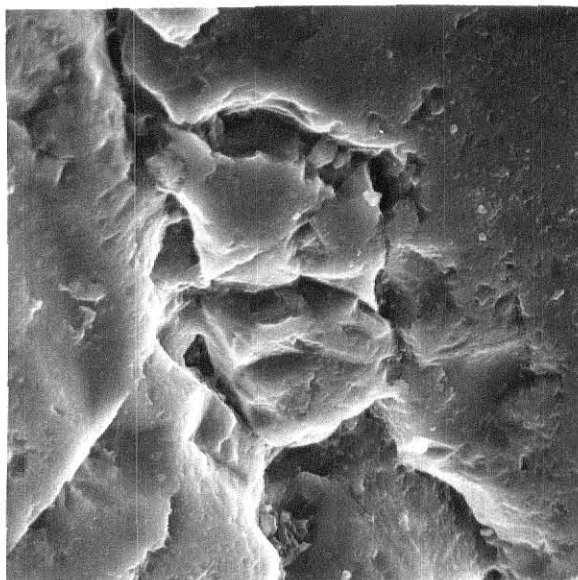
100 u

Close-up of R3a. Granulated texture between quartz crystals is more apparent than in R3a. Note the smooth surfaces between the "Vs" in the lower right corner of the micrograph as well as the smooth flat cleavage planes in the same area. Upturned cleavage plates are visible along the left and bottom edges of the grain. A series of semi-oriented "Vs" is seen in the upper left part of the micrograph.

Figure 28

Grain Number
R3c

Description



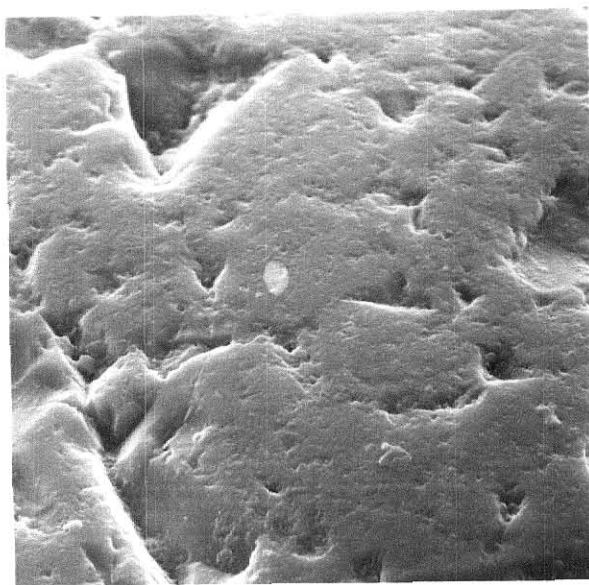
Close-up of upper center of R3b; fracture zone between quartz crystals. A beautiful example of cleavage plates is seen along the border of the granulated zone. On the left crystal there is a shallow conchoidal scallop, about 10 u in length, with parallel steps transverseing it in its upper part. A linear fracture feature, about 15 u in length, as well as several un-oriented impact "Vs" are also on this crystal.

10 u

Figure 29

Grain Number
R3d

Description



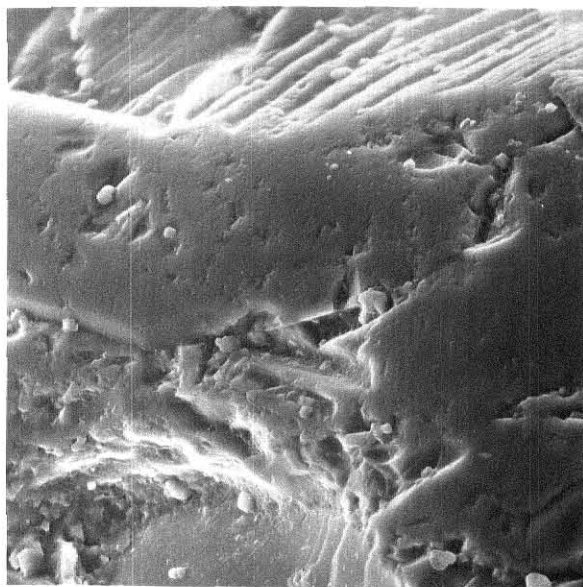
Close-up of upper left of R3b. Mechanical V-shaped depressions are abundant and range in size from 1-10 u. Several "Vs" form a linear impact feature about 20 u in length in the lower left part of the micrograph. To the left of this feature semiparallel steps are seen within a conchoidal scallop which is approximately 8 u in length. Precipitated quartz is also in this area. Minute indentations appear on the surface of the grain between the described impact features.

10 u

Figure 30

Grain Number
R4a

Description



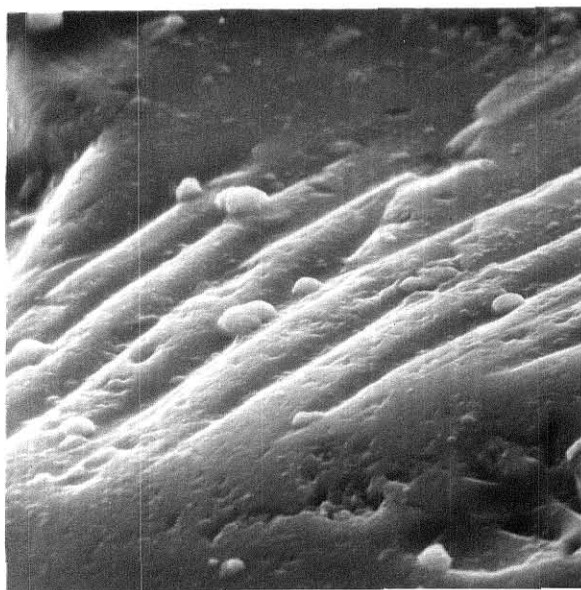
20 u

Clear quartz grain under binocular scope. A smooth platform separates two depressed fractured areas. In the above area, stepped parallel cleavage plates, on the left, grade into deep grooves, which in turn grade into striations near the right edge of the micrograph. A beautiful example of stepped cleavage plates is seen in the lower area. These steps lead down into a depression which is bounded by individual upturned cleavage plates and contains precipitated quartz crystals. The lower left edge of the platform is a smooth cleavage face. Note that this cleavage face does not parallel the stepped cleavage plates in other parts of the micrograph.

Figure 31

Grain Number
R4b

Description



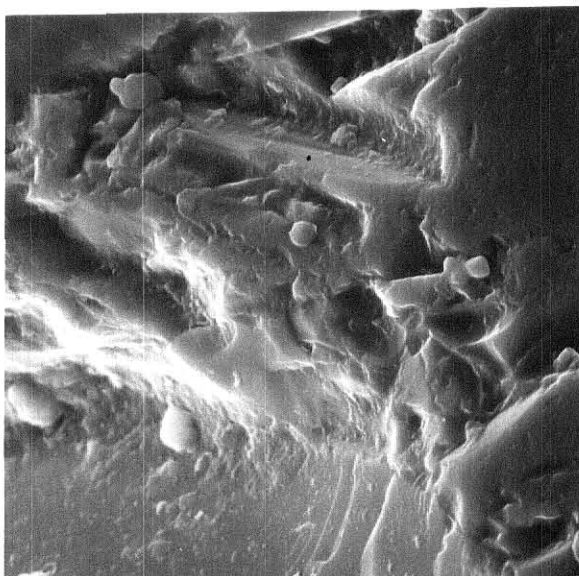
10 u

Close-up of the upper part of R4a. Semiparallel ridges and grooves have been smoothed by solution-precipitation activity. The groove and ridge system was originally a series of stepped cleavage plates. Precipitated quartz crystals are abundant in and on the grooves and ridges.

Figure 32

Grain Number
R4c

Description



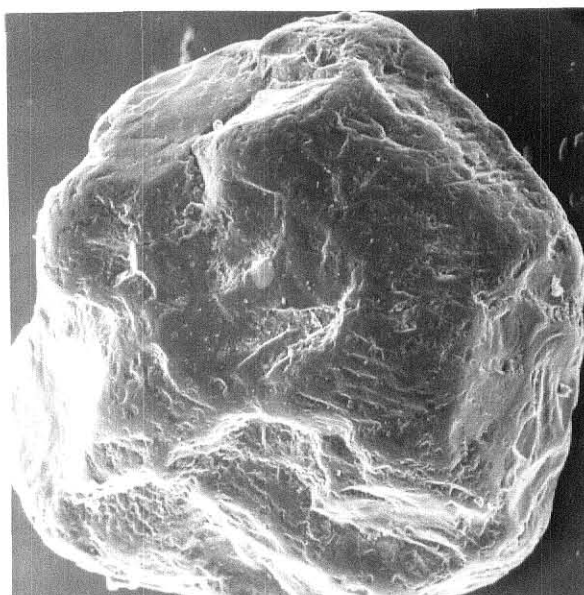
Close-up of lower part of R4a. The smooth areas in the upper and right parts of the micrograph along with the smooth round quartz crystals, 2-5 u in diameter, found on various parts of the grain surface, indicate that solution-precipitation activity has taken place. A horst-graben type feature is seen in the upper part of the micrograph and is a physical impact fracture partially healed by solution. Upturned cleavage plates are abundant in the lower part of the micrograph as are various conchoidal scallops in the lower right.

10 u

Figure 33

Grain Number
R5

Description



Mechanical impact features are abundant on all parts of the grain surface. The right edge of the grain displays various conchoidal scallops and irregular curved depressions. Large healed conchoidal scallops are seen on the upper-left and lower-left edges of the grain. Stepped parallel cleavage plates are abundant on sides of many fractured depressions which are seen on all parts of the grain surface but especially on the lower edge.

100 u

environment (Fig. 26-29) and those produced by chemical etching (Fig. 24 and 25).

The clear quartz grains of the Smoky Hill River are characterized by parallel grooves, irregular conchoidal scallops, and crescent-shaped impact features (Fig. 34, 39, and 40), all of which have been modified by chemical solution and precipitation. Large flat areas of grain S1 (Fig. 34) are unmodified crystal faces of the grain as it weathered from the parent material. The fractured features are, therefore, interpreted as having developed upon weathering of parent material and were later modified by chemical solution and precipitation activity in the river environment.

Regular and irregular V-shaped indentations are seen on frosted grain S3 (Fig. 36-38) and are probably caused by chemical etching in the subaqueous river environment. Conchoidal scallops and other impact features have been modified by this solution-precipitation process (Fig. 36). Surface features of Krinsley and Doornkamp's (1973, p. 58) subaqueous environment are very similar to those seen on grain S3 (Fig. 37). Grain S2 is a lightly frosted grain which has many conchoidal scallops modified only slightly by chemical action.

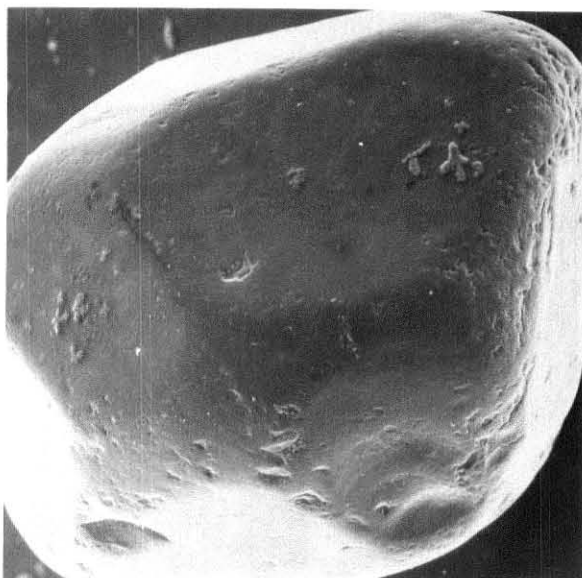
All surface features on quartz grains in the Republican and Smoky Hill Rivers are also characteristic of grains in the Kansas River. Clear grains show conchoidal fractures, subparallel and arc-shaped steps, and striations within conchoidal scallops (Fig. 41, 45, and 46). Precipitated quartz crystals (Fig. 45) and silica "plastering" (Fig. 46) have modified many of the fracture patterns.

Frosted quartz grains of the Kansas River exhibit semi-oriented chemically etched V-shaped indentations (Fig. 42), series of aligned V-shaped depressions (Fig. 42 and 43), and large mechanical impact features (semi-parallel steps, crescent shaped fractures, and inclined cleavage plates) which have been modified by chemical solution and precipitation activity (Fig. 42-44). The V-shaped

Figure 34

Grain Number
S1

Description



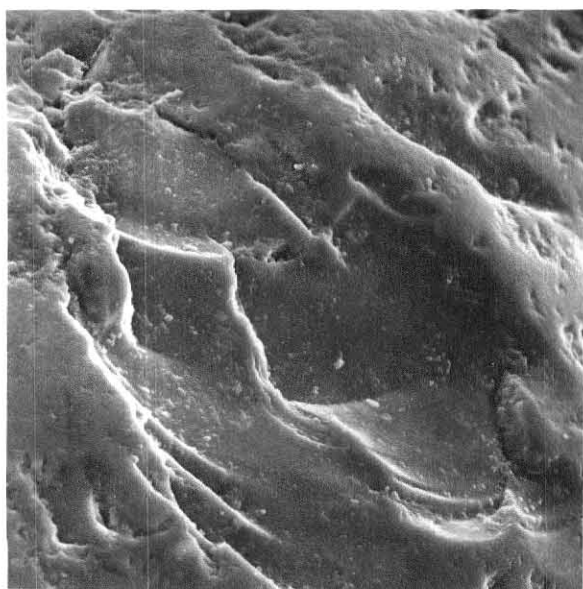
100 u

Well-rounded clear quartz grain under binocular scope. Healed conchoidal fractures are on the lower right part of the grain. A crescent-shaped impact feature, about 80 u long, is seen in the lower left part of the micrograph. Large flat areas are unmodified crystal faces of the grain as it weathered from the parent rock. Precipitated quartz crystals are on a crystal face in the left part of the micrograph.

Figure 35

Grain Number
S2

Description



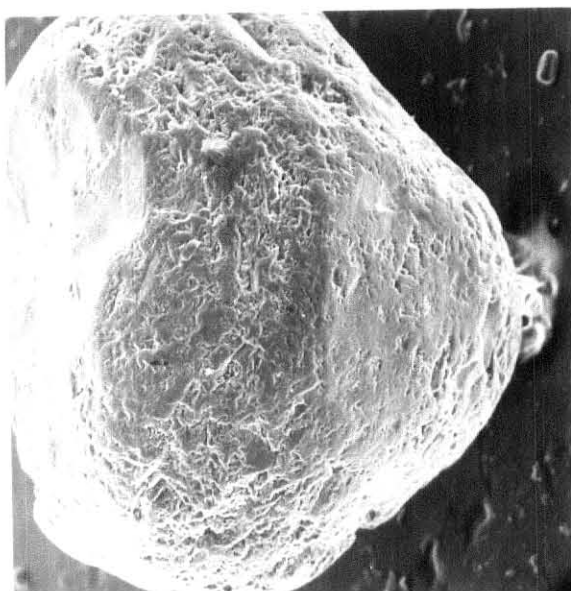
20 u

Lightly frosted quartz grain under binocular scope. Abundant conchoidal scallops are covered lightly with precipitated quartz crystals. In the upper left part of the micrograph is a fractured indentation which shows many parallel cleavage plates. Several solution cavities are on the lower left part of the grain.

Figure 36

Grain Number
S3a

Description



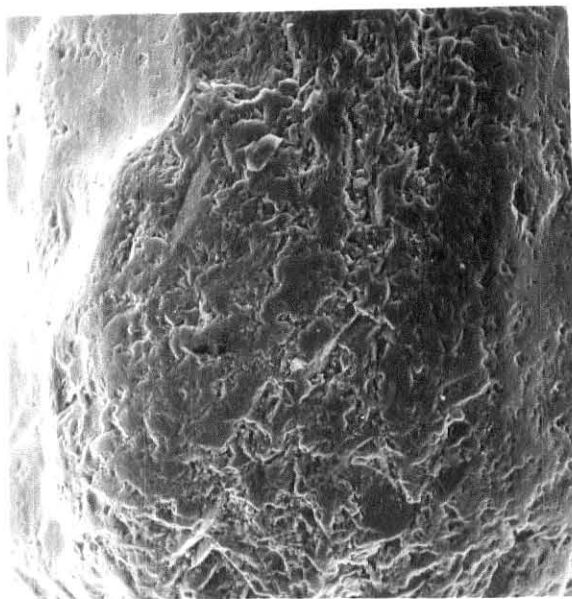
Frosted quartz grain under binocular scope. Regular and irregular V-shaped indentations cover most of the grain. Healed conchoidal scallops are on the left part of the grain whereas a few other physical impact features are in the pitted area. Many upturned cleavage plates are on the lower edge of the grain.

100 u
└───┘

Figure 37

Grain Number
S3b

Description



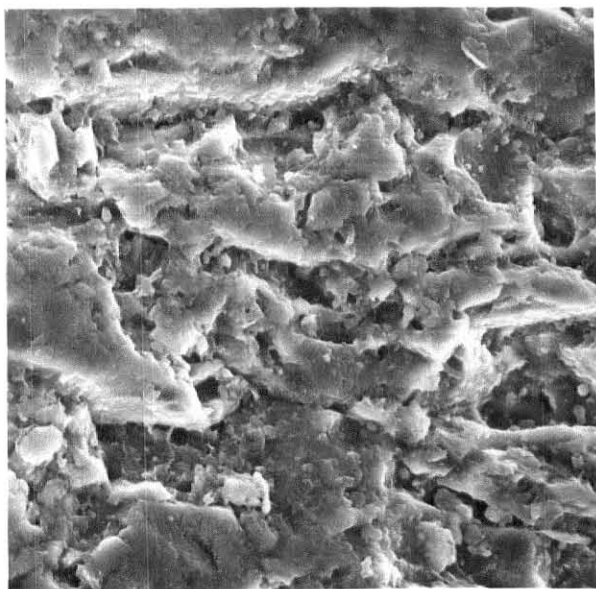
Close-up of S3a; same features enlarged.

50 u
└──┘

Figure 38

Grain Number
S3c

Description



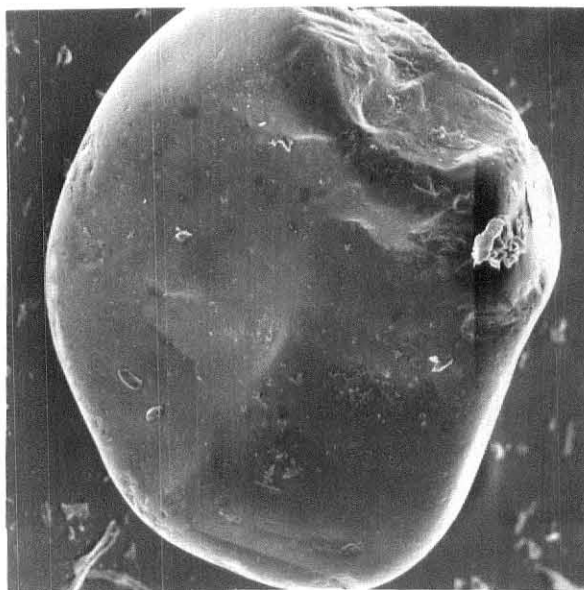
10 u
└───┘

Close-up of S3b. A chemically etched surface with parallel cleavage plates in many of the cavities.

Figure 39

Grain Number
S4a

Description



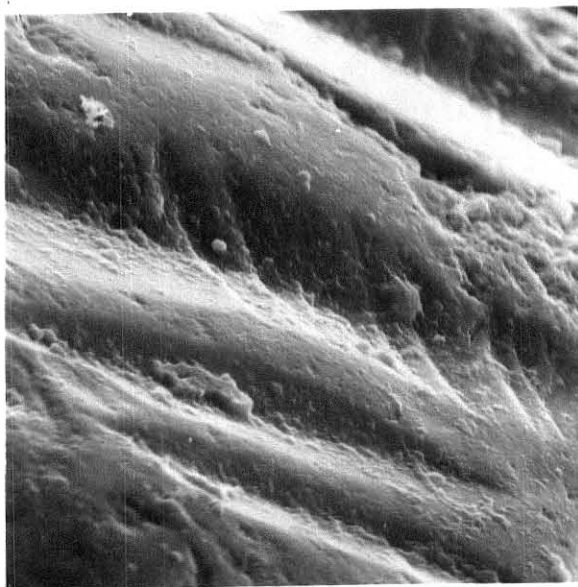
100 u
└───┘

Clear quartz grain under binocular scope. Large healed grooves and scallops cover most of the well rounded, smooth grain. The large fractured area on the upper right part of the grain is enlarged in figure 40 and includes parallel grooves, irregular conchoidal scallops, and crescent-shaped indentations.

Figure 40

Grain Number
S4b

Description



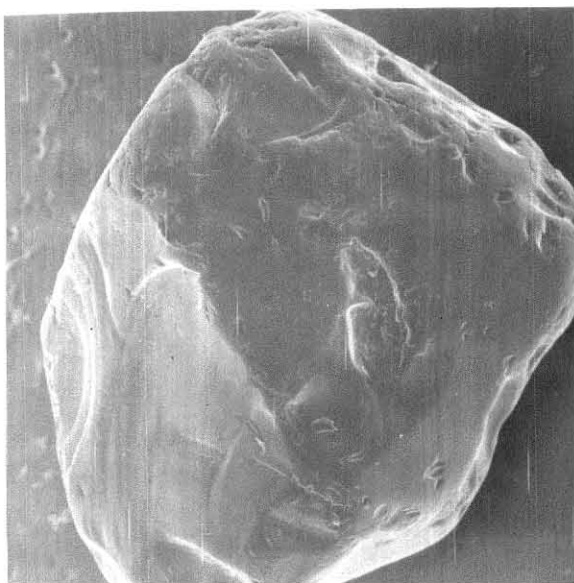
Close-up of S4a. The large groove in the center of the micrograph is transversed by a series of conchoidal scallops on the left, which grade into stepped cleavage plates on the right. Both the crescent-shaped grooves and the larger groove contain precipitated quartz crystals. This is evidence that the other parts of the grain were smoothed by solution-precipitation activity.

10 u
└───┘

Figure 41

Grain Number
K1

Description



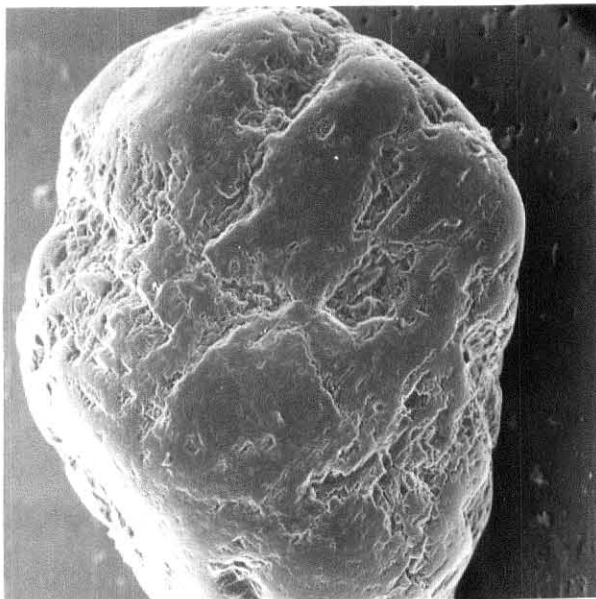
Clear quartz grain under binocular scope. Conchoidal fractures are abundant and are on all parts of the grain. Subparallel steps or striations are evident on a shallow scallop on the lower left part of the grain. The striations are about 100-150 u long and are 5-10 u apart and probably 3-5 u deep. Quartz precipitation is responsible for the smooth and polished appearance under the binocular scope.

200 u
└───┘

Figure 42

Grain Number
K2

Description



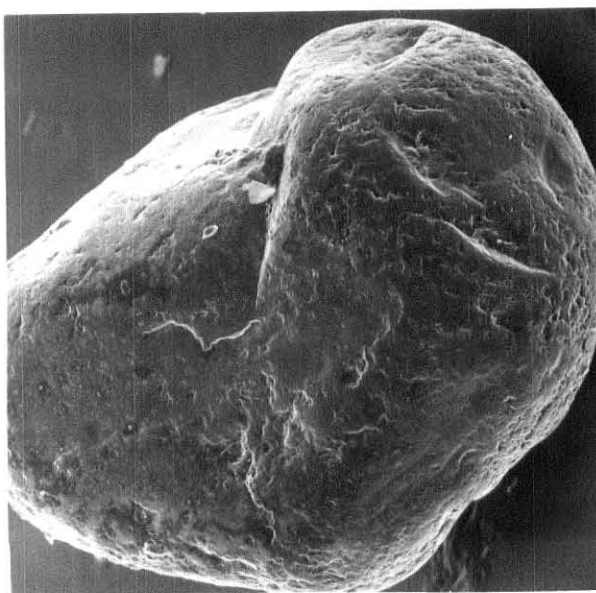
100 u
└───┘

Frosted quartz grain under binocular scope; oriented chemically etched V-shaped indentations are abundant. The left side of the grain shows several series of aligned V-shaped depressions about 5-15 u in length. Parallel cleavage plates are abundant on the left and right edges of the grain. High areas of the grain are very smooth and probably resulted from precipitation of quartz.

Figure 43

Grain Number
K3a

Description



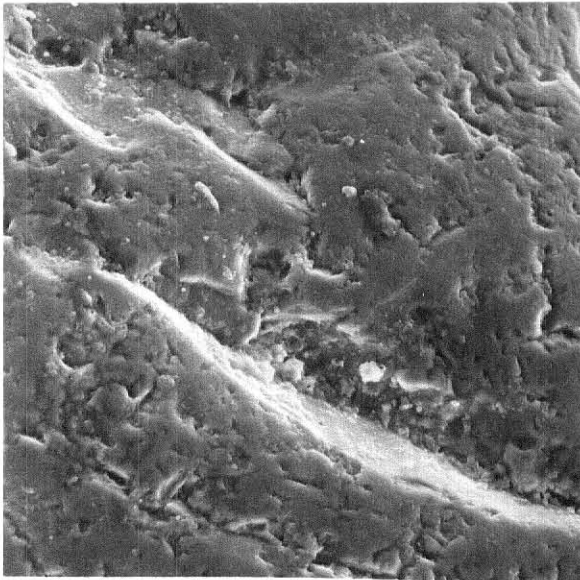
100 u
└───┘

Frosted quartz grain under binocular scope; well-rounded with several large mechanical impact indentations (100-300 u). Semi-parallel steps (or striations or grooves), 20-150 u long, are on the lower right part of the grain. V-shaped and crescent-shaped impact features are in the same area. Inclined cleavage plates are seen along the right and lower edges of the grain. Many tiny irregularities are probably caused by chemical etching whereas precipitation has smoothed areas between some irregularities. Solution cavities are in the lower central part of the grain and have diameters of 10-40 u.

Figure 44

Grain Number
K3b

Description



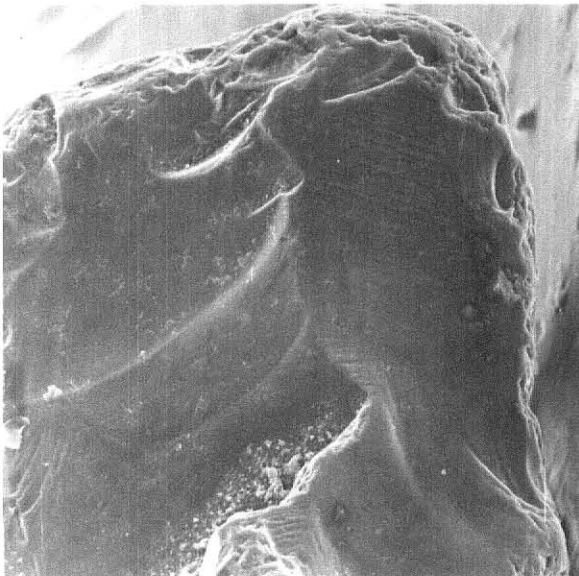
Close-up of K3a. Flat cleavage planes and conchoidal dishes range in length from 100-200 u. "Upturned cleavage plates" are in the depression in the center of the micrograph. Combination V-shaped impact features modified by chemical etching cover most of the grain. Stepped flat cleavage plates are in the depressed area in the upper left part of the micrograph. Solution cavities with upturned cleavage plates around the edges are on the left edge of the grain.

20 u
└───┘

Figure 45

Grain Number
K4a

Description



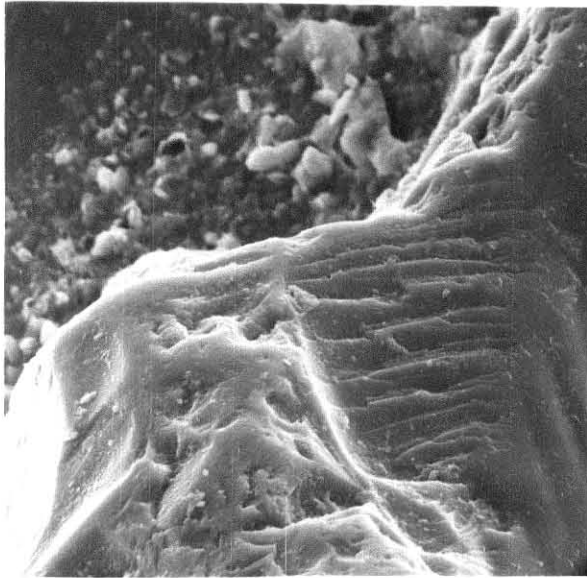
Clear subangular quartz grain under binocular scope. Conchoidal breakage patterns are abundant. Arc-shaped steps are below and to the left of the large conchoidal fracture in the left central part of the micrograph. Parallel striations, about 40-100 u long and spaced 10-20 u apart are on the upper right part of the grain. Upturned cleavage plates, quartz precipitation and "silica plastering" also occur.

100 u
└───┘

Figure 46

Grain Number
K4b

Description



Close-up of K4a. The lower left quadrant of the micrograph shows a flat cleavage face with particles of quartz adhering to its surface. Adjacent to this cleavage plane are two conchoidal scallops about 8 u wide and 15-20 u long. The right half of the micrograph shows a series of semiparallel steps representing successive upturned cleavage plates. In the lower right hand corner precipitation has smoothed a series of grooves or cleavage plates. Quartz precipitation on upturned cleavage plates and quartz debris is seen in the upper part of the micrograph.

10 u
└───┘

indentations are most characteristic of Krinsley and Doornkamp's subaqueous environment (1973, p. 53).

S O U R C E A R E A

RELATIONSHIP OF MINERALOGY TO SOURCE AREA

Suites of heavy and light minerals of sands of modern depositional environments characterize sediment source rocks whereas maturity of a mineral suite gives an indication of source area climate and relief. Certain mineral species are diagnostic of general rock types (Table 16). For example, a heavy mineral assemblage of garnet, epidote, and sillimanite reflects a dynamothermal metamorphic source whereas a hornblende, rutile, and zircon suite is characteristic of silicic igneous rock (Pettijohn, Potter, and Siever, 1972, p. 304). Quartz is abundant in almost all sands and its many varieties have been used as indicators of source rocks. Metamorphic quartz is characterized by its polycrystallinity, mineral inclusions, undulose-extinction, and elongate form; igneous quartz by a lack of inclusions other than those of liquid or gas, straight extinction, and equidimensional form; and sedimentary quartz by overgrowths, highly rounded and frosted grains, and chalcedonic forms of silica (Pettijohn, 1957, p. 514).

Because heavy minerals are accessory minerals of igneous and metamorphic rocks and are relatively unstable as compared to quartz, they usually make up only small percentages of sediment sand bodies. Folk has estimated that an average orthoquartzite contains 0.05-0.2 percent heavies; graywacke, 0.2-0.8 percent; and arkose, 1.0-2.0 percent (1974, p. 96). The more abrasion and chemical action a sediment encounters the fewer heavy minerals it will contain. Some heavy minerals are more stable than others; a stability ranking is in Table 17 (Pettijohn, Potter, and Siever, 1972, p. 304). The ratio of unstable

to stable minerals of a heavy mineral suite is an index of sediment maturity. Generally, a low ratio indicates that the source area had low relief and a warm humid climate; source rocks are allowed to weather completely before being deposited. A high unstable-stable ratio indicates high relief and mild climate; source rocks are eroded and deposited before weathering has completely destroyed the unstable minerals. Reworked sediments also have low unstable-stable ratios and consideration must be given as to whether the sediment is a first or multicycle sand (Pettijohn, Potter, and Siever, 1972, p. 305).

TABLE 16. HEAVY MINERAL ASSOCIATIONS AND PROVENANCE (FROM PETTIJOHN, POTTER, AND SIEVER, 1972, p. 304, AS MODIFIED FROM FEO-CODECIDO, 1956, p. 997)

Association	Source
Apatite, biotite, brookite, hornblende, monazite, muscovite, rutile, titanite, tourmaline (pink variety), zircon	Acid igneous rocks
Cassiterite, dumortierite, fluorite, garnet, monazite, muscovite, topaz, tourmaline (blue variety), wolframite, xenotime	Granite pegmatites
Augite, chromite, diopside, hypersthene, ilmenite, magnetite, olivine, picotite, pleonaste	Basic igneous rocks
Andalusite, chondrodite, corundum, garnet, phlogopite, staurolite, topaz, vesuvianite, wollastonite, zoisite	Contact metamorphic rocks
Andalusite, chloritoid, epidote, garnet, glaucophane staurolite, titanite, zoisite-clinozoisite, kyanite, sillimanite	Dynamothermal metamorphic rocks
Barite, iron ores, leucoxene, rutile, tourmaline (rounded grains), zircon (rounded grains)	Reworked sediments

TABLE 17. STABILITY OF SOME DETRITAL HEAVY MINERALS (FROM PETTIJOHN, POTTER, AND SIEVER, 1972, p. 305)

Ultrastable	Rutile, zircon, tourmaline, anatase
Stable	Apatite, garnet (iron poor), staurolite, monazite, biotite, ilmenite, magnetite
Moderately stable	Epidote, kyanite, garnet (iron-rich), sillimanite, sphene, zoisite
Unstable	Hornblende, actinolite, augite, diopside, hypersthene andalusite
Very unstable	Olivine

HEAVY AND LIGHT MINERAL SUITES OF THE THREE RIVERS

Heavy Mineral Suites

Weight percentages of heavy minerals of differentiated sand samples from the Republican, Smoky Hill, and Kansas Rivers are in Table 18. Total weight percentages of heavy minerals in the sand fractions of samples R9, S2, and K11 are 0.72, 0.50, and 0.35 respectively. The 1-4 ϕ sand fraction of samples R12, S4, and K14 contain 1.28, 0.69, and 0.62 percent heavy minerals respectively. A breakdown of the 1-4 ϕ size class of samples R12, S4, and K14 shows that for each river heavy mineral percentages increase with decreasing size.

Six heavy minerals of the Republican River were sufficiently abundant to be positively identified by X-ray diffraction. Diffraction patterns of almandine, epidote, sillimanite, titanite, magnetite, and hornblende are in Fig. 47-49; d-spacings, peak intensities, and Miller indices of the crystal structure of each of these minerals is in Table 28.

Suites of heavy minerals from the Republican, Smoky Hill, and Kansas Rivers consist of different proportions of garnet, hornblende, sillimanite, epidote,

TABLE 18. WEIGHT PERCENTAGE OF HEAVY AND LIGHT MINERALS IN DIFFERENTIATED SAMPLES OF RIVER SAND

Sample		R12	S4	K14
3-4 ϕ Fraction	Total Weight (gm)	0.216	1.810	0.033 (included in the 2-3 ϕ fraction below)
	Total Weight of Heavy Minerals (gm)	0.095	0.022	
	Percent Heavy Minerals	44.00	1.19	----
	Total Weight of Light Minerals (gm)	0.120	1.767	----
	Percent Light Minerals	55.40	97.63	----
	Percent Separation Error	0.60	1.18	
2-3 ϕ Fraction	Total Weight (gm)	5.841	2.850	1.344
	Total Weight of Heavy Minerals (gm)	0.198	0.024	0.036
	Percent Heavy Minerals	3.39	0.83	2.71
	Total Weight of Light Minerals (gm)	5.584	2.774	1.298
	Percent Light Minerals	95.61	97.31	96.54
	Percent Separation Error	1.00	1.86	0.75
1-2 ϕ Fraction	Total Weight (gm)	23.968	19.309	11.493
	Total Weight of Heavy Minerals (gm)	0.094	0.119	0.044
	Percent Heavy Minerals	0.39	0.62	0.38
	Total Weight of Light Minerals (gm)	23.699	19.132	11.432
	Percent Light Minerals	98.88	99.08	99.39
	Percent Separation Error	0.73	0.30	0.23
Combined 1-4 ϕ Fraction	Total Weight (gm)	30.025	23.969	12.837
	Total Weight of Heavy Minerals (gm)	0.387	0.165	0.080
	Percent Heavy Minerals	1.28	0.69	0.62
Sample		R9	S2	K11
-1-4 ϕ Fraction	Total Weight (gm)	146.300	150.957	136.889
	Total Weight of Heavy Minerals (gm)	1.056	0.751	0.474
	Percent Heavy Minerals	0.72	0.50	0.35

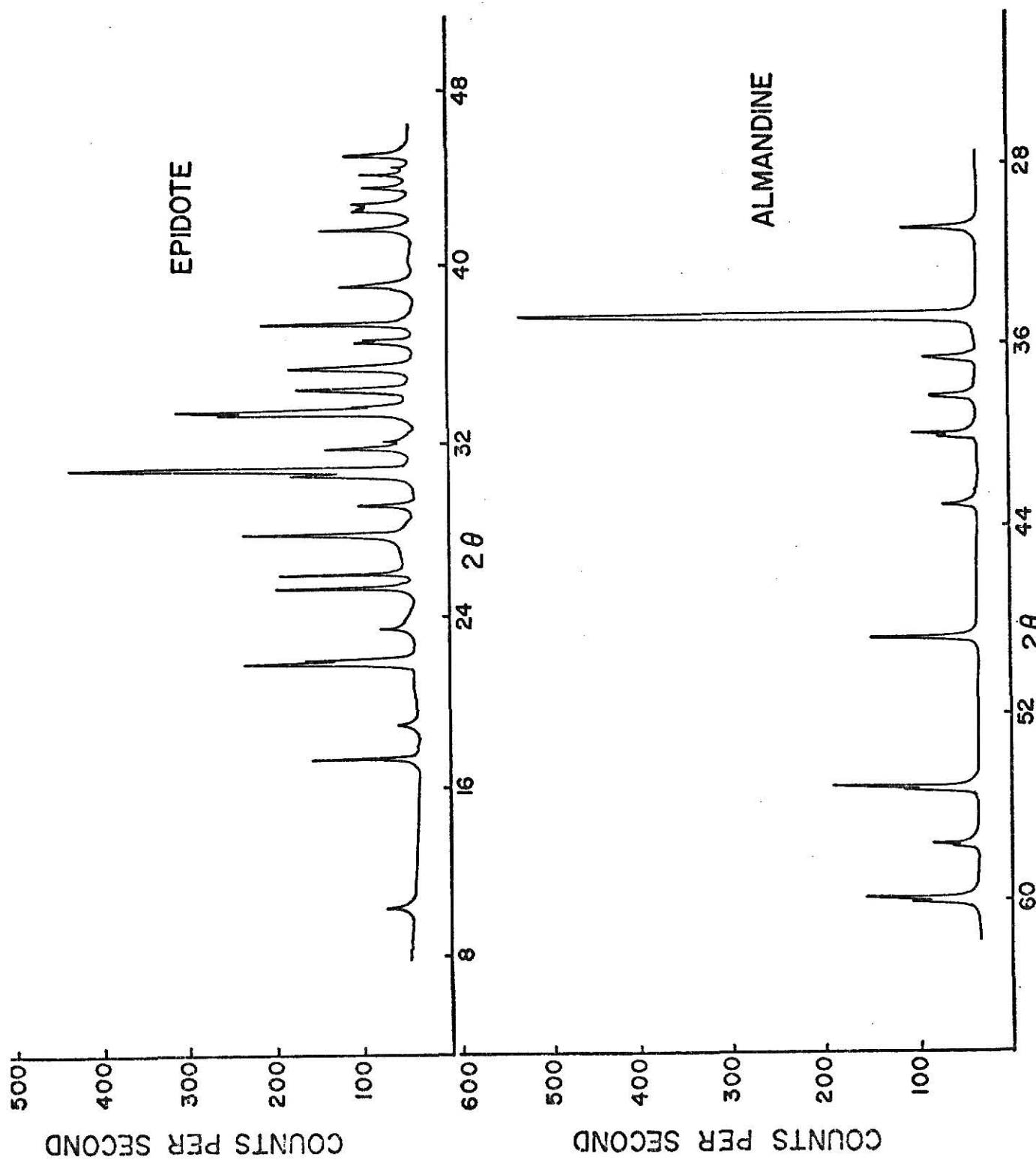


Figure 47. X-ray diffraction pattern for epidote and almandine from the Republican River (Ni-filtered Cu K radiation).

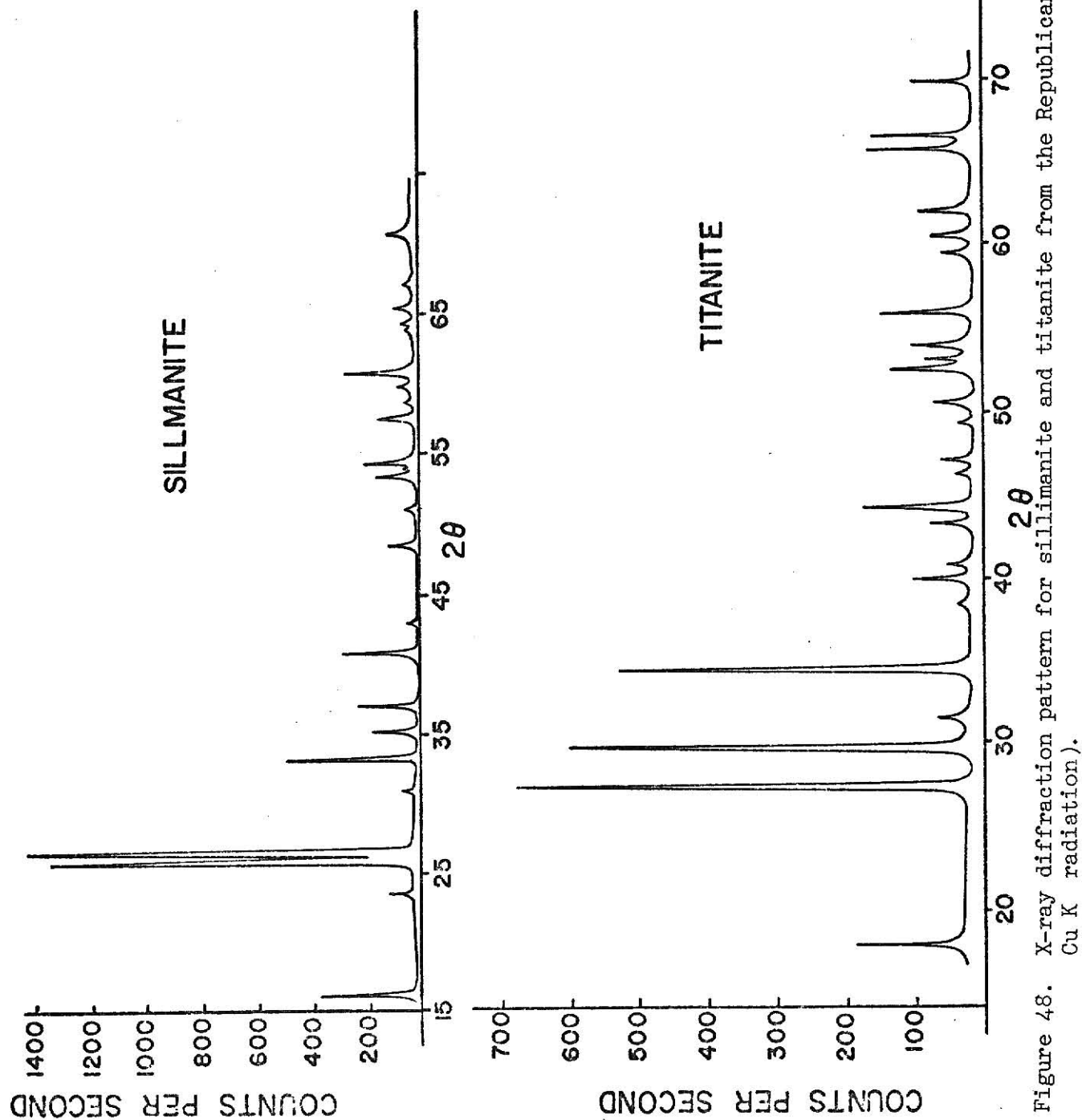


Figure 48. X-ray diffraction pattern for sillimanite and titanite from the Republican River (Ni-filtered Cu K radiation).

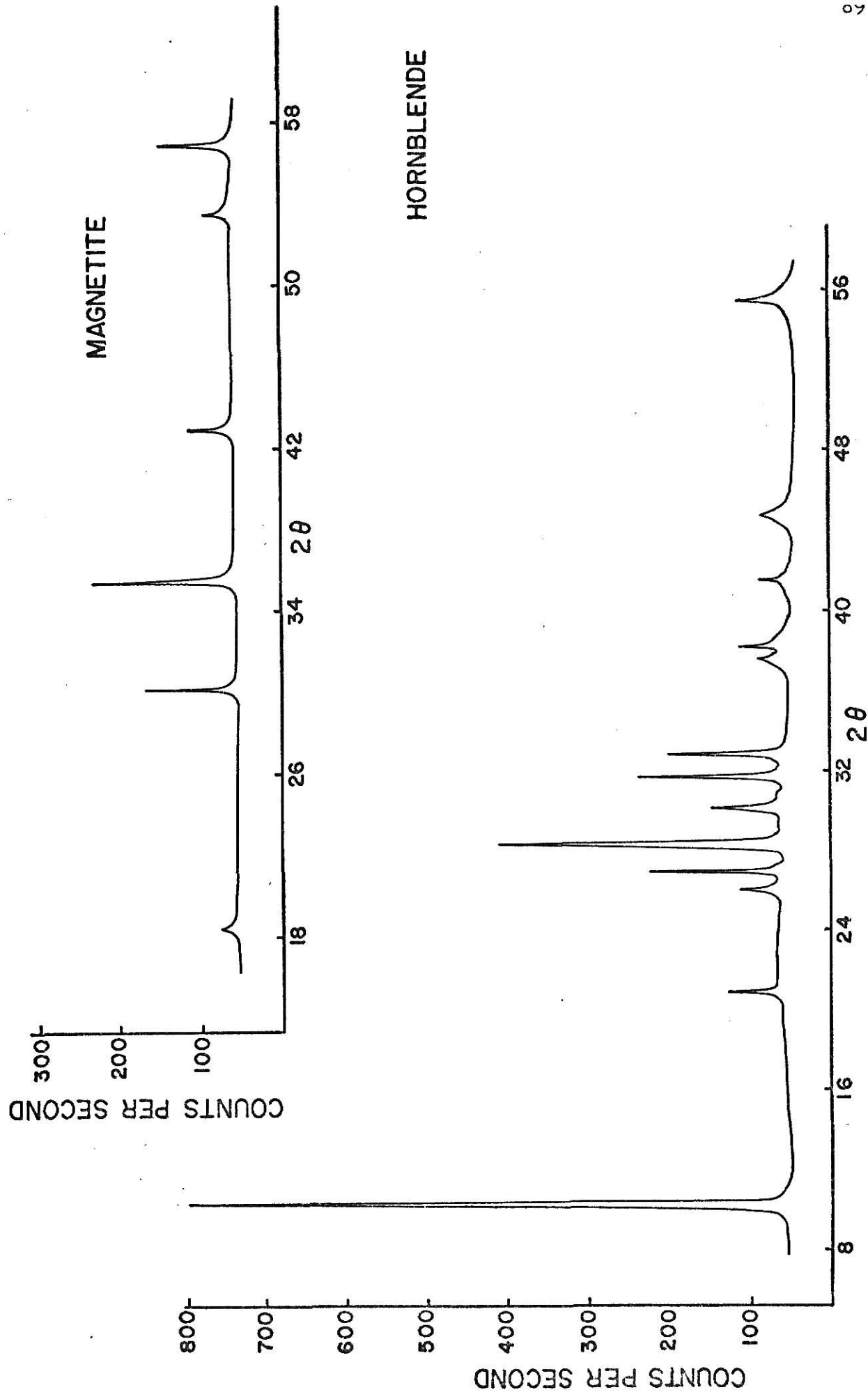


Figure 49. X-ray diffraction pattern for magnetite and hornblende from the Republican River (Ni-filtered Cu K radiation).

epidosite, and ore minerals (Fig. 50, Table 19). Minor amounts of zircon, tourmaline, lamprobolite, staurolite, titanite, and IRF's complete each river's heavy mineral assemblage.

A zircon-tourmaline-rutile index was used to estimate mineralogical maturity of average heavy mineral suites from each river (Hubert, 1960, p. 208). The ratio of zircon plus tourmaline to the other heavy minerals in each suite was used for the index because rutile was absent in all samples. The Republican River ratio was 21/482 or 0.044, whereas the ratios of the Smoky Hill and Kansas Rivers were 28/377 or 0.075 and 13/373 or 0.035 respectively. The low ZTR index of each river indicates that the sediment of the three rivers is immature and has not been subjected to prolonged abrasion or weathering.

Light Mineral Suites

Light mineral suites of each sample contain quartz, microcline, orthoclase, chert, and rock fragments (Table 20). No plagioclase and only traces of rock fragments occur in the river sands. Quartz in the Republican, Smoky Hill, and Kansas River sands averages 78, 82, and 82 percent respectively; average feldspar percentages range from 20 percent in the Republican River to 17 and 19 percent in the Smoky Hill and Kansas Rivers; and 1, 4, and 1 percent rock fragments are in the Republican, Smoky Hill, and Kansas Rivers respectively. Because more than 75 percent quartz is in each sample and more feldspar than rock fragments, the sands are subarkoses.

About 50 percent of the light minerals of the Republican River were unstrained quartz grains with straight extinction; of these 40 percent contained vacuoles, 10 percent contained rutile needles, 20 percent contained microlites, and 30 percent contained no inclusions. About 10 percent of the Republican River quartz grains were composite grains with strong undulose extinction (metamorphic quartz). Light minerals of the Smoky Hill contained an average of 44 percent

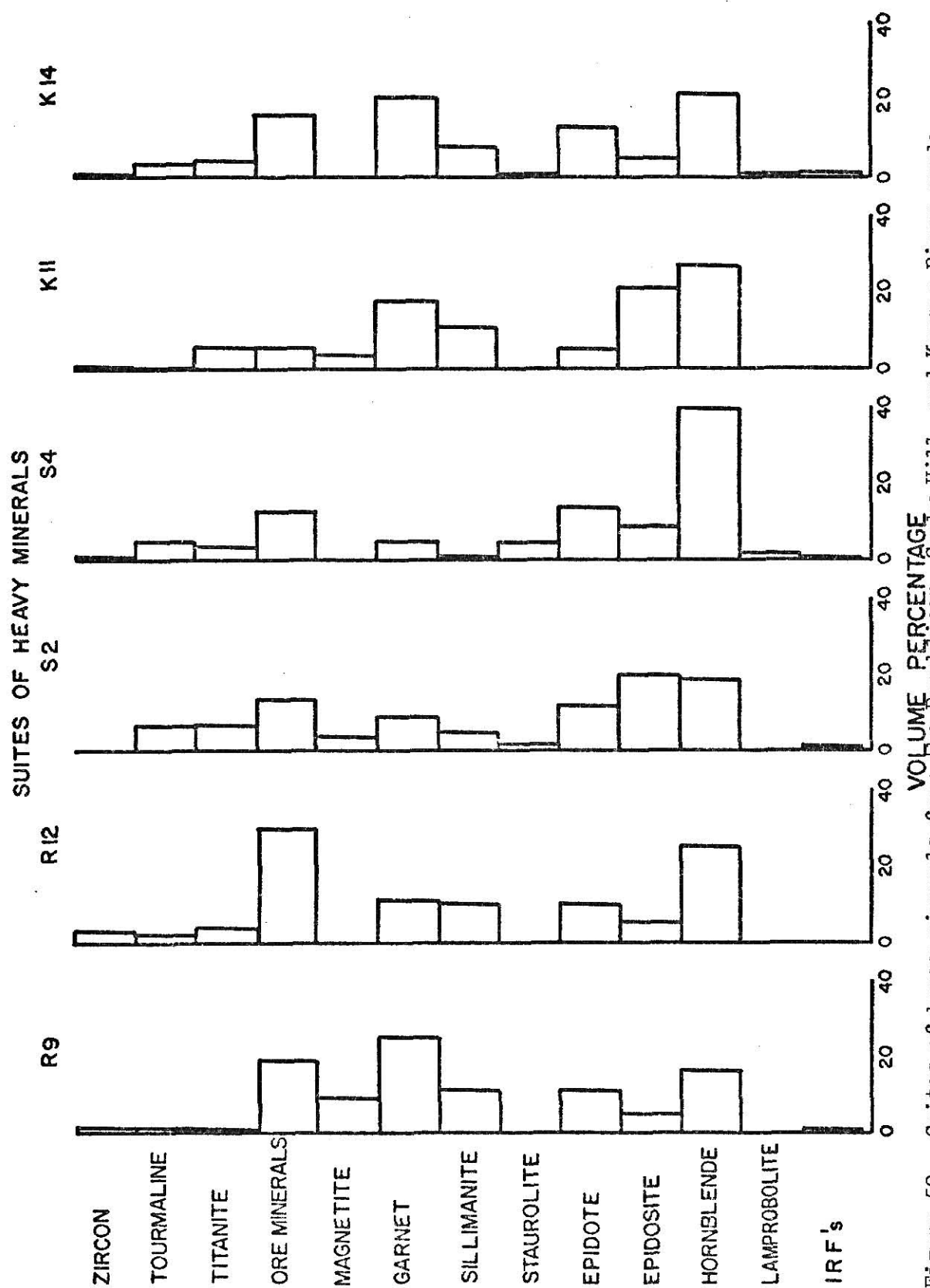


Figure 50. Suites of heavy minerals from the Republican, Smoky Hill, and Kansas River sands.

TABLE 19. VOLUME PERCENTAGE OF HEAVY MINERALS IN REPUBLICAN, SMOKY HILL, AND KANSAS RIVER SANDS

	R9	R12	S2	S4	K11	K14
Zircon	1	3	0	1	1	1
Tourmaline	1	2	7	5	1	4
Titanite	1	4	7	4	6	5
Ore minerals*	19	30	14	13	6	17
Magnetite	9	--	4	--	4	--
Garnet	25	11	9	5	18	21
Sillimanite	11	10	5	1	11	8
Staurolite	0	0	2	5	0	1
Epidote	11	10	12	14	5	13
Epidosite	5	5	20	9	21	5
Hornblende	16	25	19	40	27	22
Lamprobolite	0	0	0	2	0	1
IRF's	1	0	1	1	0	2
Total	100	100	100	100	100	100

* Magnetite removed from samples R9, S2, and K11 with hand magnet.

TABLE 20. VOLUME PERCENTAGE OF LIGHT MINERALS IN REPUBLICAN, SMOKY HILL, AND KANSAS RIVER SANDS

	R7	R11	S5	S3	K15	K21
Orthoclase	12	13	17	8	10	10
Microcline	5	9	5	3	6	8
Plagioclase	0	0	0	0	0	0
Chert	0	1	0	4	1	1
Quartz type						
1a	16	28	18	16	19	19
1b	6	5	1	2	4	4
1c	11	10	7	5	5	6
1d	16	13	18	20	26	20
2a	8	3	4	9	2	5
2b	1	1	1	3	0	1
2c	0	1	2	2	0	1
2d	3	0	5	10	2	7
3a	0	0	5	3	4	1
3b	0	0	0	0	0	0
3c	0	2	0	0	0	0
3d	1	0	1	3	2	1
4a	1	0	1	0	0	1
4b	0	0	0	0	0	0
4c	0	0	1	0	0	0
4d	0	0	0	0	0	0
5a	3	2	1	3	2	0
5b	0	0	1	0	0	0
5c	2	0	0	0	0	0
5d	1	0	0	1	0	1
6a	4	6	9	4	9	5
6b	0	0	1	0	1	0
6c	5	0	0	0	1	0
6d	3	2	0	3	5	5
Coated	2	4	0	0	1	2
IRF's	0	0	0	1	0	0
SRF's	0	0	2	0	0	0
Quartz Overgrowths	0	0	0	0	0	2
Total	100	100	100	100	100	100

unstrained quartz grains; 34 percent of these contained vacuoles whereas 38 percent were common quartz. Approximately eight percent of the light minerals of the Smoky Hill River were metamorphic quartz grains. The Kansas River contained about 52 percent unstrained quartz grains of which 19 percent contained vacuoles. There were 13 percent metamorphic quartz grains in the light mineral fraction of the Kansas River.

Chi-Square Test of Light and Heavy Mineral Suites

The Chi-square test showed significant differences between samples of each river and among samples of the three rivers (Table 21). Two possible reasons are proposed to explain differences in the mineral suites within rivers. One, hydraulic conditions of the two samples may have been different and consequently different heavy mineral grains deposited, i.e., the difference is real. Two, because only 100 mineral grains were counted on each slide, suite percentages may not have been statistically accurate, i.e., the differences are not real.

Mineral suites did not agree among rivers because of differences in source areas, grain size, or hydraulic equivalency.

CORRELATION OF MINERALOGY WITH SOURCE ROCKS

Source rocks in the Republican and Smoky Hill River valleys must account for large amounts of garnet, hornblende, sillimanite, epidote, epidosite, and ore minerals in the heavy fractions of the Republican, Smoky Hill, and Kansas River sands. Garnet, sillimanite, epidote, epidosite, traces of staurolite and titanite, and significant amounts of metamorphic quartz are diagnostic of a dynamothermal metamorphic source; hornblende and minor amounts of IRF's, zircon, and tourmaline are derived from silicic igneous rocks; and the ore minerals are characteristic of igneous, metamorphic, or reworked sedimentary rocks

TABLE 21. STATISTICAL ANALYSIS OF HEAVY AND LIGHT MINERALS OF THREE RIVERS

Observed Frequency of Groups of Minerals in Samples							
Group	Minerals in group	R9	R12	S2	S4	K11	K14
1	Garnet Titanite Sillimanite Epidote Epidosite	124	107	113	77	123	98
2	Zircon Tourmaline	6	15	14	14	3	10
3	Hornblende IRF	38	69	41	83	54	46
4	Opaques	61	83	36	27	20	32
5	Orthoclase	12	13	17	8	10	10
6	Microcline	5	9	5	3	6	8
7	Type 1a quartz	16	28	18	16	19	19
8	Type 1b + 1c quartz	17	15	8	7	9	10
9	Type 6 quartz	12	8	10	7	16	7

Chi-square Test

Rivers compared	X ² value	D.F.	Probability of a greater value
R9-R12	18.05	8	<0.025
R9-S2	13.18	8	<0.250
R9-S4	46.73	8	<0.005
R9-K11	26.44	8	<0.005
R9-K14	13.34	8	<0.250
R12-S2	20.63	8	<0.010
R12-S4	27.31	8	<0.005
R12-K11	44.81	8	<0.005
R12-K14	12.77	8	<0.250
S2-S4	26.03	8	<0.005
S2-K11	17.26	8	<0.050
S2-K14	4.59	8	<0.900
S4-K11	29.52	8	<0.005
S4-K14	17.50	8	<0.050
K11-K14	13.09	8	<0.250

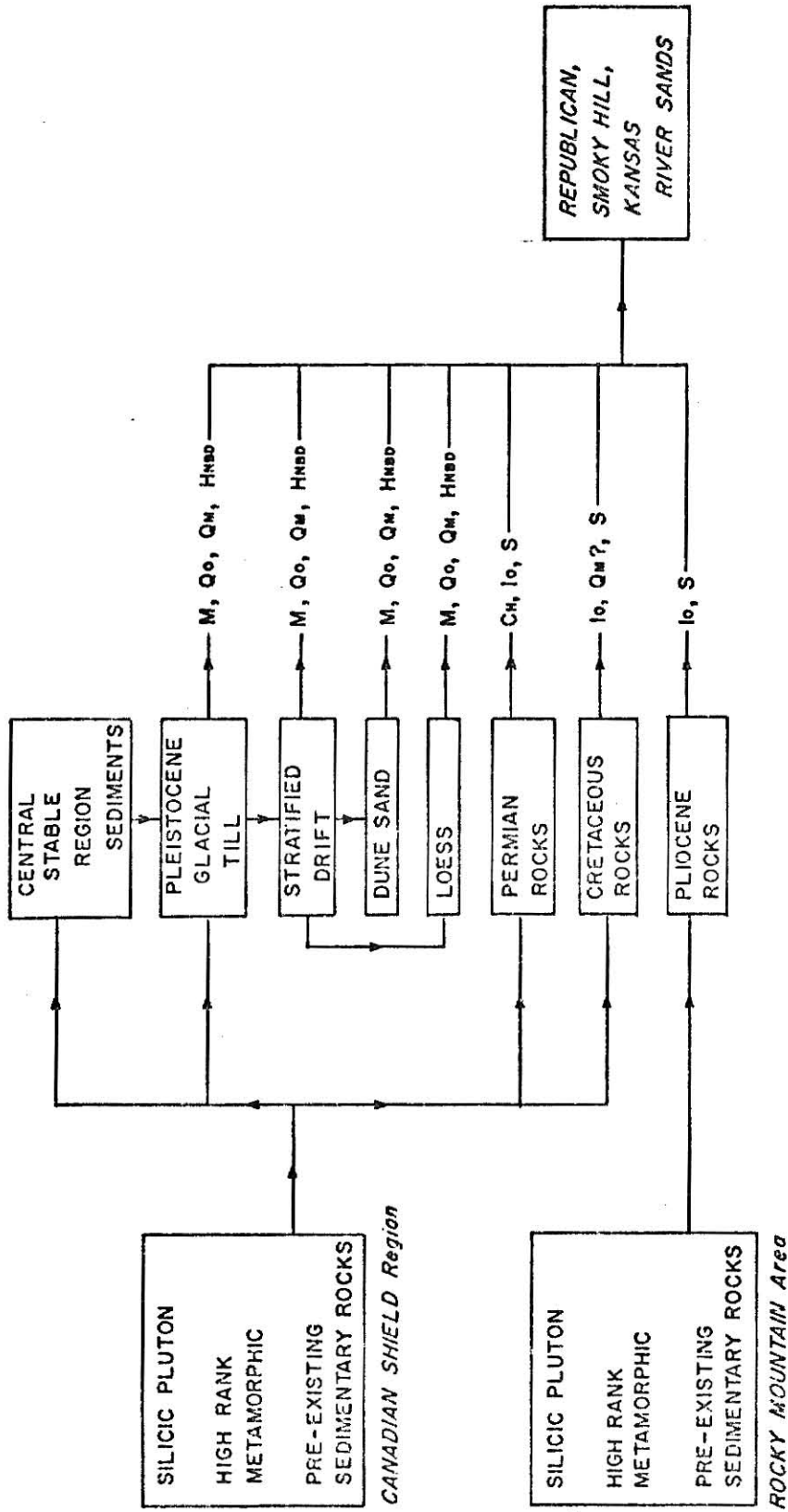
(Pettijohn, Potter, and Siever, 1972, p. 304). Possible source rocks in the Republican and Smoky Hill River valleys are Permian, Cretaceous, and Pliocene sedimentary rocks, and Quaternary loess, dune sand, and terrace deposits (Fig. 51).

Permian Limestones

Permian limestones of the Republican and Smoky Hill drainage basins are restricted to the Flint Hills Upland Province and are responsible for chert and traces of quartz and heavy minerals in the sediment of the Republican, Smoky Hill, and Kansas River sands. Insoluble residues of the limestones of the Council Grove Group of Riley and Geary Counties contain approximately 60 percent chalcedony, 18 percent quartz, 6 percent orthoclase, 13 percent plagioclase, and one percent microcline in the light fraction, whereas the heavy mineral fraction contains 60-90 percent celestite, 40-70 percent muscovite, and 60-100 percent pyrite; hornblende, zircon, and apatite are found only in traces (Wilbur, 1956, p. 60). Twiss (1955, p. 29, 31, and 34) reported that light fractions of insoluble residues of some Permian limestones near Manhattan, Kansas, were composed chiefly of quartz, chalcedony, and opal, whereas muscovite was the dominant mineral in the heavy fractions. Biotite, chlorite, ilmenite, leucoxene, limonite, pyrite, tourmaline, garnet, zircon, staurolite, and corundum were minor constituents. Coarse residues ranged from 0.02 to 17.1 percent of the Permian limestones studied; most detrital grains were subrounded, indicating considerable abrasion by transportation.

Permian Shales

Permian shales probably contribute minor amounts of heavy and light minerals to the Republican, Smoky Hill, and Kansas River sediments. Johnson (1949, p. 60) reported that the light fraction of shale insoluble residues contained 71 percent chalcedony and 13 percent quartz whereas heavy mineral



Key¹

Qo	--	ordinary quartz
Qm	--	metamorphic quartz
Ch	--	chert
M	--	metamorphic heavy minerals
Hnsd	--	hornblende
lo	--	iron ore minerals
S	--	traces of heavy minerals

Figure 51. Sources of terrigenous sediment in the Republican, Smoky Hill, and Kansas River sands.

fractions contained less than two percent hornblende, epidote, and garnet.

Cretaceous Sedimentary Rocks

Little petrographic information is available on Cretaceous sedimentary rocks but because insoluble residues of these limestones, shales, and chalk beds were derived from the Canadian Shield Region they probably contain heavy and light mineral suites similar to those of the Permian System, although much less chert is found in the Cretaceous limestones. Clastic grains of the Dakota Formation and Kiowa Shale are predominantly quartz, with minor quantities of feldspar (plagioclase, microcline, orthoclase), chert, and quartzite (Swineford, 1947, p. 72). Heavy minerals include tourmaline, zircon, glauconite, pyrite, and barite. Cements include iron oxide, calcite, dolomite, and silica (quartz, chert, and chalcedony). Cretaceous sandstones are a probable source of metamorphic quartz grains found in the three river sands.

Pliocene Ogallala Formation

Metz (1954, p. 30) reported that light minerals of the Ogallala Formation in Phillips County, Kansas, contained 61 percent quartz, 18 percent orthoclase, 17 percent plagioclase, and minor amounts of microcline, chalcedony, and volcanic ash. The heavy fractions were rich in hornblende, epidote, and zircon. Most mineral grains were quite angular. The bulk of the Ogallala is composed of unconsolidated calcareous sands and gravels which is locally cemented by silica (opal).

Glacial Sediments

How much sediment of the Republican, Smoky Hill, and Kansas River sands was derived directly or indirectly from glacial sediments (in the form of loess, river terraces, or dune deposits) is not known, but suites of heavy

minerals from the three river sands contain large amounts of hornblende, epidote, ore minerals, and garnet, which are characteristic of glacial sediments of northeast Kansas. Glacial till near Manhattan, Kansas, contains an average of 14 percent epidote, 20 percent hornblende, and 30 percent opaques, whereas stratified drift in the same area is enriched with hornblende, epidote, ore minerals, and garnet (Harned, 1940, p. 11a). Glacial-fluvial deposits in Washington and Marshall Counties, north of Manhattan, contain abundant hornblende, epidote, and opaque minerals and lesser amounts of biotite, garnet, muscovite, zircon, and other metamorphic minerals (Lill, 1946, p. 47).

S U M M A R Y A N D C O N C L U S I O N S

ENVIRONMENT OF DEPOSITION AND TRANSPORT

The Republican, Smoky Hill, and Kansas Rivers, near Junction City, Kansas, have similar gradients, flow through similar physiographic provinces, and erode similar source rocks. Textural characteristics of each river sand were compared with each other and those of other depositional environments. The following is a summary of these textural relationships.

1. Sediment of the Republican, Smoky Hill, and Kansas Rivers is mostly unimodal, submature, and is classified as subarkose. Sediment of the three rivers is quite similar and ranges from pebbly silt to pebble gravel, is poorly to well sorted, fine to strongly coarse-skewed, and leptokurtic to platykurtic.

2. Comparison of grain-size parameters of the Republican, Smoky Hill, and Kansas Rivers to each river's depth and surface velocity showed that little relationship exists among the parameters and water depth or surface velocity.

A linear regression analysis of the four grain-size parameters and depth and surface velocity revealed the following relationships: (1) particle size of the Republican and Smoky Hill River sands decreased with increasing water depth (2) particle size of the Republican River sand also decreased with increasing surface velocity (3) sorting of the Republican River sand increased with increasing water depth and surface velocity and (4) positive skewness of the Smoky Hill River increased with decreasing water depth. Decreasing particle size with increasing energy conditions in the Republican and Smoky Hill Rivers is consistent with Hjultrom's curve which shows that increasing amounts of energy are needed to erode particles both larger and smaller than medium sand grains (Leet and Judson, 1965, p. 143). Better sorting of the Republican River sand with increasing surface velocity and water depth is consistent with the concept that, in general, better sediment sorting occurs in sands of higher-energy environments. It is thought that increasing positive skewness with decreasing water depth of the Smoky Hill River was caused by a mixing of bank samples, which were in shallow water and composed of fine sand, and the main tractive load of the river.

3. Scatter plots of grain-size parameters of the Republican, Smoky Hill, and Kansas River sands showed no differentiating patterns among rivers. A one-way analysis of variance test of mean grain size, sorting, skewness, and kurtosis values of underwater samples (excluding bank samples) of the three river sands showed no significant difference of these four grain-size parameters among rivers. The analysis of all underwater samples showed a significant difference of skewness between the Republican and Smoky Hill Rivers, but differences of mean grain size, sorting, and kurtosis were not significant among rivers. Bank samples, therefore, are responsible for differing skewness values of the Smoky Hill and Republican River sands. When all samples of each

river were included in the analysis, the following grain size-parameters were significantly different among rivers: (1) mean grain size of the Republican and Husain's Kansas River samples (2) sorting of the Republican and Husain's Kansas River samples (3) sorting of the Republican and Kansas River samples of this study (4) skewness values of the Smoky Hill and Republican, Kansas, and Husain's Kansas River samples (5) skewness values of Husain's Kansas and Kansas River samples of this study and (6) kurtosis values of Husain's Kansas and Republican, Smoky Hill, and Kansas River samples of this study. These differences are attributed to different combinations of channel-lag deposits, point-bar deposits, and bank sediments at each study location. To summarize: there is no difference among channel-lag deposits of the three rivers;; there is a difference between the Smoky Hill and Republican Rivers when channel-lag and bank sediments are considered together; and many differences among rivers appear when channel-lag, point-bar, and bank sediments are analysed together.

4. Comparison of scatter plots of grain-size parameters of the unimodal Republican, Smoky Hill, and Kansas River sands with those of Folk and Ward's Brazos River bar (1957) revealed few similarities between general river environments. River sands of this study have better sorting than the Brazos bar, but both river studies show increased sorting with decreasing grain size. Most samples of the three river sands fall in non-normal areas of the skewness vs. kurtosis scatter plot which was also true of the bimodal sediment of Folk and Ward's study.

All samples of the Republican, Smoky Hill, and Kansas Rivers fell within the combination river and dune area of Friedman's 1961 mean grain size versus standard deviation scatter plot of dune and river sediments. In superimposing the scatter plot of mean grain size versus standard deviation on Friedman's 1967 plot of beach and river sediments, half of Husain's Kansas samples and approximately 20 percent of the Kansas River samples fell in the area of beach

sediments. The sorting of these sediments is unusually high for river sands. The same Kansas samples again fall outside the river boundary and into the area of beach sediments on Friedman's 1967 scatter plots of standard deviation versus skewness values of river and beach sands.

Superposition of the C-M diagram on Passega's tractive current patterns showed that sediment of the Republican, Smoky Hill, and Kansas Rivers is much coarser than that in Passega's studies. No distinctive pattern of the river sediments is seen in the C-M diagram.

5. Quartz grains of the Republican, Smoky Hill, and Kansas River sands are subangular. No significant difference of quartz mean roundness or roundness standard deviation was found among rivers.

Most heavy minerals in the three river sands are subangular to subrounded, but a few rounded grains of sillimanite, zircon, and titanite occur in each river. No relationship between size and roundness of garnet, hornblende, epidote, or ore minerals was detected among rivers.

6. About 85-90 percent of the quartz grains in the 1.0 ϕ size class of the Republican, Smoky Hill, and Kansas River sands are frosted to semi-frosted under the binocular microscope; 10-15 percent are clear or polished grains. Differentiation of surface features among rivers was not possible with the binocular microscope. SEM examination of the polished or clear grains showed an abundance of conchoidal breakage patterns, grooves and striations, and crescent-shaped impact features. These breakage patterns were produced in a glacial environment, by mechanical weathering of source sediment, or produced in some other high energy environment. Solution precipitation modification of these fractures took place in the river environment.

SEM examination of frosted and semi-frosted grains from the three rivers revealed regular and irregular V-shaped impact and solution indentations, up-turned cleavage plates associated with breakage patterns and solution cavities,

and parallel steps within conchoidal scallops. Many fractures have been modified by chemical etching and solution-precipitation activity. V-shaped indentations, linear impact features, chemical etching, and smoothing of fractures by solution-precipitation activity are characteristic of the river environment.

SOURCE AREA

Heavy mineral suites of the Republican, Smoky Hill, and Kansas River sands near Junction City, Kansas, consist of different proportions of garnet, hornblende, sillimanite, epidote, epidosite, and ore minerals. Small percentages of zircon, tourmaline, staurolite, titanite, and IRFs are also present. Light minerals in each sand include ordinary quartz, metamorphic quartz, orthoclase, microcline, and chert; no plagioclase and only traces of rock fragments were present. Because more than 75 percent quartz and more feldspar than rock fragments compose the sands they are classified as subarkoses. A Chi-square test of groups of heavy and light minerals showed significant differences within, as well as among the three rivers. ZTR indices indicate that sediment of each river is immature and has not been subjected to prolonged abrasion or weathering; Smoky Hill sediments are more mature than those of the Republican River, which in turn are more mature than those of the Kansas River.

Minerals in the three river sands are diagnostic of three general types of source rocks. Garnet, sillimanite, epidote, epidosite, minor amounts of staurolite and titanite, and significant amounts of metamorphic quartz are diagnostic of a dynamothermal metamorphic source; hornblende and minor amounts of IRFs, zircon, and tourmaline are derived from silicic igneous rocks; and the ore minerals are characteristic of igneous, metamorphic, or reworked sedimentary rocks. Possible source rocks in the Republican and Smoky Hill River valleys are Permian, Cretaceous, and Pliocene sedimentary rocks, and Quaternary loess, dune sand, and terrace deposits.

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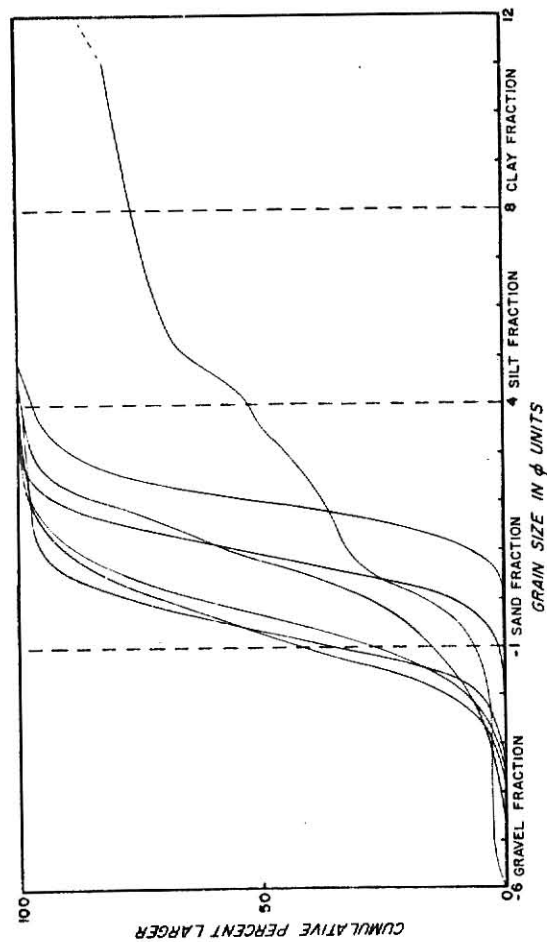
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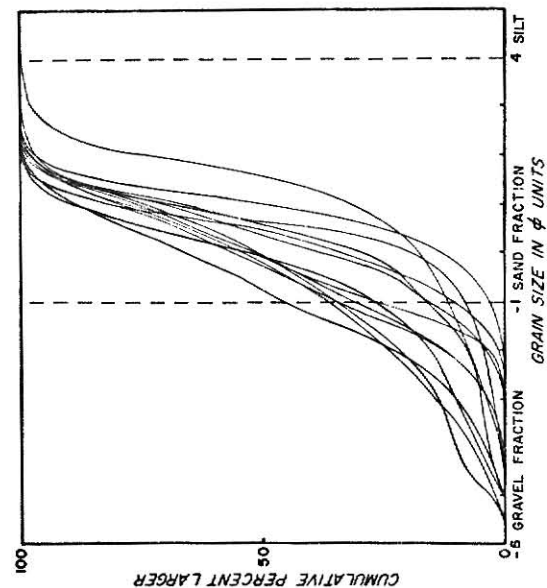
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APPENDIX 1
GRAIN-SIZE DATA

SMOKY HILL RIVER SAND



REPUBLICAN RIVER SAND



KANSAS RIVER SAND

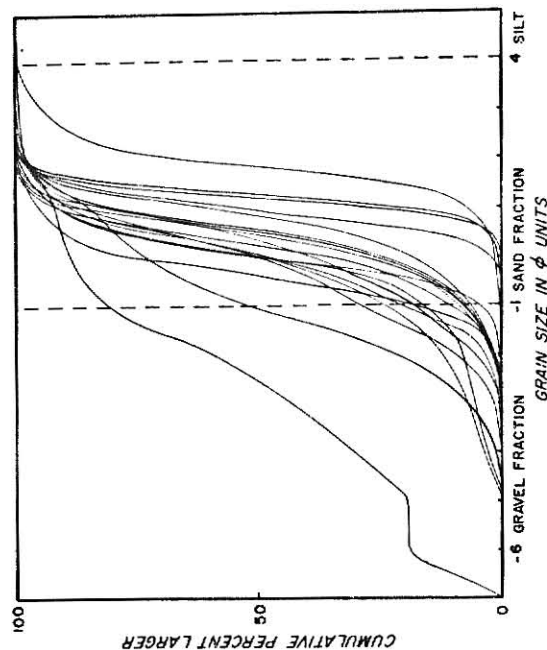


FIG. 52.— Cumulative grain size frequency curves of the Republican, Smoky Hill, and Kansas River sands.

TABLE 22. PHI-PERCENTILE VALUES OF THE REPUBLICAN RIVER SAMPLES

	Ø1	Ø5	Ø16	Ø25	Ø50	Ø75	Ø84	Ø95	Ø84-Ø16	Ø95-Ø5
R1	-3.84	-1.72	-0.16	0.24	0.80	1.17	1.35	1.82	1.51	3.54
R2	-1.60	-0.60	+0.22	0.52	0.98	1.37	1.55	1.93	1.33	2.53
R3	-4.62	-3.92	-1.93	-1.30	-0.09	0.96	1.25	1.75	3.18	5.67
R4	-4.73	-4.13	-1.95	-1.15	-0.10	0.64	0.91	1.37	2.86	5.50
R5	-4.65	-3.77	-2.41	-1.90	-0.70	0.44	0.88	1.48	3.29	5.25
R6	-5.40	-4.28	-2.83	-1.90	-0.18	1.01	1.36	1.83	4.19	6.11
R7	-5.30	-4.64	-2.55	-1.66	-0.06	1.03	1.34	1.75	3.89	6.39
R8	-3.79	-2.72	-1.80	-1.38	-0.28	0.89	1.22	1.74	3.02	4.46
R9	-3.81	-2.52	-1.03	-0.24	0.83	1.22	1.40	1.74	2.43	4.26
R10	-2.28	-1.85	-1.33	-1.05	-0.11	0.91	1.08	1.48	2.41	3.33
R11	-2.05	-1.43	-0.71	-0.33	0.48	1.00	1.19	1.52	1.90	2.95
R12	-2.45	-1.83	-1.01	-0.35	0.62	1.14	1.38	1.90	2.39	3.73
R13	-4.51	-2.85	-0.28	0.75	1.59	2.06	2.23	2.66	2.51	5.51

SMOKY HILL RIVER SAMPLES

S1	0.49	0.97	1.38	1.61	2.00	2.47	2.66	3.70	1.28	2.73
S2	-0.10	-0.35	0.18	0.37	0.91	1.50	1.81	2.12	1.63	2.47
S3	-3.40	-2.42	-0.93	-0.18	0.82	1.76	2.05	2.68	2.98	5.10
S4	-3.18	-2.21	-1.46	-1.10	-0.34	0.40	0.86	1.65	2.32	3.86
S5	-4.00	-2.52	-1.78	-1.44	-0.69	0.23	0.70	1.63	2.48	4.15
S6	-2.76	-2.01	-1.44	-1.20	-0.64	-0.03	0.30	1.02	1.74	3.03
S7	-5.25	-1.20	-0.08	0.45	3.64	7.60	11.14	11.80	11.22	13.00

TABLE 23. PHI-PERCENTILE VALUES OF THE KANSAS RIVER SAMPLES

	Ø1	Ø5	Ø16	Ø25	Ø50	Ø75	Ø84	Ø95	Ø84-Ø16	Ø95-Ø5
K5	-4.60	-3.62	-1.57	-0.95	0.07	0.78	0.95	1.55	2.52	5.17
K6	-2.77	-1.88	-1.17	-0.77	0.01	0.75	0.94	1.45	2.11	3.33
K7	-4.60	-3.25	-1.08	-0.50	0.25	0.83	0.95	1.32	2.03	4.57
K8	-2.62	-1.30	-0.67	-0.30	0.30	0.78	0.90	1.27	1.57	2.57
K9	-2.30	-1.28	-0.42	-0.12	0.48	0.92	1.04	1.55	1.46	2.83
K10	-2.81	-2.06	-1.23	-0.61	0.38	0.94	1.13	1.68	2.36	3.74
K11	-2.43	-1.45	-0.48	-0.07	0.54	0.95	1.10	1.70	1.58	3.15
K12	-2.55	-1.36	-0.40	-0.03	0.59	0.94	1.03	1.37	1.43	2.73
K13	-2.13	-1.26	-0.43	-0.06	0.58	0.92	1.02	1.35	1.45	2.61
K14	-3.22	-2.45	-1.63	-1.19	-0.03	0.82	0.98	1.37	2.61	3.82
K15	-3.10	-1.25	-0.22	0.25	0.90	1.25	1.40	1.76	1.62	3.01
K16	0.08	0.62	0.91	1.00	1.25	1.49	1.64	1.92	0.73	1.30
K17	0.24	0.59	0.87	0.97	1.22	1.47	1.60	1.85	0.73	1.26
K18	-0.27	0.14	0.49	0.70	0.97	1.29	1.45	1.81	0.96	1.67
K19	-1.66	-0.98	-0.49	-0.36	0.07	0.46	0.77	1.42	1.26	2.40
K20	-2.14	-1.45	-1.07	-0.85	-0.41	-0.03	0.20	1.09	1.27	2.54
K21	-4.03	-3.19	-2.25	-1.86	-1.05	0.15	1.05	1.71	3.30	4.90
K22	-6.80	-6.70	-6.23	-4.44	-2.48	-1.28	-0.70	1.67	5.53	8.37
K23	-0.32	0.87	1.37	1.53	1.85	2.17	2.40	3.14	1.03	2.27

TABLE 24. PHI-STATISTICAL PARAMETER VALUES OF THE REPUBLICAN RIVER SANDS

Sample Number	M_z	Md_ϕ	Md_{mm}	Mode(s)	$\sigma-I$	Sk_I	K_G
R1	0.66	0.80	0.57	0.75	0.92	-0.35	1.56
R2	0.92	0.98	0.51	1.00	0.71	-0.20	1.22
R3	-0.26	-0.09	1.06	0.40	1.66	-0.26	1.03
R4	-0.38	-0.10	1.07	1.00	1.55	-0.38	1.26
R5	-0.74	-0.70	1.63	0.95	1.62	-0.09	0.92
R6	-0.55	-0.18	1.13	1.35	1.98	-0.30	0.86
R7	-0.42	-0.06	1.04	-4.55 1.00	1.94	-0.36	0.97
R8	-0.29	-0.28	1.21	0.95	1.44	-0.05	0.81
R9	0.40	0.83	0.56	0.80	1.26	-0.56	1.20
R10	-0.12	-0.11	1.08	0.95	1.11	-0.03	0.70
R11	0.32	0.48	0.72	1.00	0.93	-0.28	0.91
R12	0.33	0.62	0.65	1.00	1.17	-0.34	1.03
R13	1.18	1.59	0.33	2.00	1.47	-0.56	1.72

SMOKY HILL RIVER SANDS

S1	2.01	2.00	0.25	2.00	0.73	0.14	1.30
S2	0.97	0.91	0.53	1.00	0.78	0.04	0.90
S3	0.65	0.82	0.57	0.90	1.52	-0.23	1.08
S4	-0.31	-0.34	1.27	-0.20	1.17	0.04	1.06
S5	-0.59	-0.69	1.61	-0.25	1.25	0.12	1.02
S6	-0.59	-0.64	1.56	-0.15	0.90	0.09	1.06
S7	4.90	3.64	0.08	-5.50 0.20 5.00	4.78	0.30	0.74

TABLE 25. PHI-STATISTICAL PARAMETER VALUES OF THE KANSAS RIVER SANDS

Sample Number	M_z	Md_ϕ	Md_{mm}	Mode(s)	σ_I	Sk_I	K_G
K5	-0.18	0.07	0.95	0.80	1.41	-0.36	1.23
K6	-0.07	0.01	0.99	0.85	1.04	-0.13	0.90
K7	0.04	0.25	0.84	0.85	1.20	-0.43	1.41
K8	0.18	0.30	0.81	0.65	0.78	-0.24	0.97
K9	0.37	0.48	0.72	0.80	0.80	-0.24	1.11
K10	0.09	0.38	0.77	0.85	1.16	-0.33	0.99
K11	0.39	0.54	0.68	0.90	0.88	-0.28	1.27
K12	0.41	0.59	0.66	0.90	0.77	-0.40	1.15
K13	0.39	0.58	0.67	0.90	0.76	-0.41	1.09
K14	-0.23	-0.03	1.02	0.85	1.23	-0.24	0.78
K15	0.69	0.90	0.54	1.00	0.87	-0.40	1.23
K16	1.27	1.25	0.42	1.35	0.38	0.05	1.08
K17	1.23	1.22	0.43	1.25	0.37	0.02	1.03
K18	0.97	0.97	0.51	1.00	0.49	0.00	1.16
K19	0.12	0.07	0.95	0.00	0.68	0.12	1.20
K20	-0.43	-0.41	1.33	-0.30	0.71	0.07	1.27
K21	-0.75	-1.05	2.07	-1.10 1.35	1.57	0.20	1.00
K22	-3.14	-2.48	5.58	-6.50 -1.55 1.90	2.65	-0.18	1.09
K23	1.87	1.85	0.28	1.80	0.60	0.10	1.46

TABLE 26. COMPLETE SEDIMENT NAMES OF REPUBLICAN, SMOKY HILL, AND KANSAS RIVER SANDS

R1	Pebbly coarse sand, moderately sorted, strongly coarse-skewed, very leptokurtic: submature subarkose
R2	Slightly granular medium sand, moderately sorted, coarse-skewed, leptokurtic: submature subarkose.
R3	Sandy granule gravel, poorly sorted, coarse-skewed, mesokurtic: submature subarkose.
R4	Pebbly coarse sand, poorly sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
R5	Sandy pebble gravel, poorly sorted, near-symmetrical, mesokurtic: submature subarkose.
R6	Sandy pebble gravel, poorly sorted, strongly coarse-skewed, platykurtic: submature subarkose.
R7	Sandy pebble gravel, poorly sorted, strongly coarse-skewed, mesokurtic: submature subarkose.
R8	Sandy granule gravel, poorly sorted, near-symmetrical, platykurtic: submature subarkose.
R9	Granular coarse sand, poorly sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
R10	Granular coarse sand, poorly sorted, near-symmetrical, platykurtic: submature subarkose.
R11	Granular coarse sand, moderately sorted, coarse-skewed, mesokurtic: submature subarkose.
R12	Granular coarse sand, poorly sorted, strongly coarse-skewed, mesokurtic: submature subarkose.
R13	Pebbly medium sand, poorly sorted, strongly coarse-skewed, very leptokurtic: submature subarkose.
S1	Medium sand, moderately sorted, fine-skewed, leptokurtic: submature subarkose.
S2	Slightly granular coarse sand, moderately sorted, near-symmetrical, mesokurtic: submature subarkose.
S3	Granular coarse sand, poorly sorted, coarse-skewed, mesokurtic: submature subarkose.
S4	Granular very coarse sand, poorly sorted, near-symmetrical, mesokurtic: submature subarkose.
S5	Sandy granule gravel, poorly sorted, fine-skewed, mesokurtic: submature subarkose.
S6	Sandy granule gravel, moderately sorted, near-symmetrical, mesokurtic: submature subarkose.
S7	Pebbly silt, extremely poorly sorted, fine-skewed, platykurtic: immature subarkose.

TABLE 26 CONTINUED.

K5	Pebbly coarse sand, poorly sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
K6	Granular coarse sand, poorly sorted, coarse-skewed, mesokurtic: submature subarkose.
K7	Granular coarse sand, poorly sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
K8	Granular coarse sand, moderately sorted, coarse-skewed, mesokurtic: submature subarkose.
K9	Granular coarse sand, moderately sorted, coarse-skewed, leptokurtic: submature subarkose.
K10	Granular coarse sand, poorly sorted, strongly coarse-skewed, mesokurtic: submature subarkose.
K11	Granular coarse sand, moderately sorted, coarse-skewed, leptokurtic: submature subarkose.
K12	Granular coarse sand, moderately sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
K13	Granular coarse sand, moderately sorted, strongly coarse-skewed, mesokurtic: submature subarkose.
K14	Granular coarse sand, poorly sorted, coarse-skewed, platykurtic: submature subarkose.
K15	Granular coarse sand, moderately sorted, strongly coarse-skewed, leptokurtic: submature subarkose.
K16	Slightly pebbly medium sand, well sorted, near-symmetrical, mesokurtic: mature subarkose.
K17	Slightly granular medium sand, well sorted, near-symmetrical, mesokurtic: mature subarkose.
K18	Slightly granular coarse sand, well sorted, near-symmetrical, leptokurtic: mature subarkose.
K19	Granular coarse sand, moderately well sorted, fine-skewed, leptokurtic: submature subarkose.
K20	Granular very coarse sand, moderately sorted, near-symmetrical, leptokurtic: submature subarkose.
K21	Sandy granule gravel, poorly sorted, fine-skewed, mesokurtic: submature subarkose.
K22	Pebble gravel, very poorly sorted, strongly coarse-skewed, mesokurtic: submature subarkose.
K23	Slightly granular medium sand, moderately well sorted, near-symmetrical, leptokurtic: immature subarkose.

APPENDIX 2
HEAVY MINERAL DATA

TABLE 27a. MEAN ROUNDNESS AND PERCENTAGE OF HEAVY MINERALS IN DIFFERENTIATED RIVERS SANDS

Sample R9		<2 ϕ Fraction		>2 ϕ Fraction		Combined fractions	
Mineral		Mean % roundness		Mean % roundness		Mean % roundness	
Garnet		12.3	2.8	15.6	2.9	27.9	2.9
Zircon		1.4	3.5	0.0	---	1.4	3.5
Tourmaline		0.5	---	1.1	3.8	1.5	3.8
Hornblende		9.5	4.0	7.6	3.6	17.1	3.8
Lamprobolite		0.0	---	0.0	---	0.0	---
Sillimanite		1.0	4.5	10.9	4.4	11.9	4.8
Staurolite		0.0	---	0.0	---	0.0	---
Epidote		2.4	3.4	9.5	3.7	11.9	3.6
Epidosite		1.4	2.7	4.3	4.1	5.7	3.8
Titanite		1.4	3.7	0.0	---	1.4	3.7
Ore Minerals		14.7	3.5	5.7	4.2	20.4	3.7
IRF's		0.0	---	1.0	2.5	1.0	2.5

Sample S2		<2 ϕ Fraction		>2 ϕ Fraction		Combined fractions	
Mineral		Mean % roundness		Mean % roundness		Mean % roundness	
Garnet		5.6	2.6	3.6	2.4	9.2	2.6
Zircon		0.0	---	0.0	---	0.0	---
Tourmaline		2.6	4.3	4.6	3.2	7.2	3.6
Hornblende		11.7	3.5	8.7	3.5	20.4	3.5
Lamprobolite		0.0	---	0.0	---	0.0	---
Sillimanite		0.5	4.5	4.6	4.0	5.1	4.1
Staurolite		0.5	4.5	1.5	2.8	2.0	3.3
Epidote		6.1	3.8	6.1	3.6	12.2	3.7
Epidosite		5.1	3.2	16.3	3.0	21.4	3.0
Titanite		7.7	3.8	0.0	---	7.7	3.8
Ore Minerals		10.7	3.8	3.6	4.4	14.3	4.0
IRF's		0.0	---	0.5	3.5	0.5	3.5

Sample K11		<2 ϕ Fraction		>2 ϕ Fraction		Combined fractions	
Mineral		Mean % roundness		Mean % roundness		Mean % roundness	
Garnet		7.3	2.6	11.4	3.0	18.7	2.9
Zircon		0.5	4.5	0.0	---	0.5	4.5
Tourmaline		0.0	---	1.0	2.8	1.0	2.8
Hornblende		21.2	3.7	6.7	3.7	27.9	3.7
Lamprobolite		0.0	---	0.0	---	0.0	---
Sillimanite		1.6	3.8	10.4	3.9	12.0	3.9
Staurolite		0.0	---	0.0	---	0.0	---
Epidote		2.6	3.8	2.1	4.0	4.7	3.9
Epidosite		7.8	2.3	14.0	2.5	21.8	2.4
Titanite		5.2	3.2	1.6	4.5	6.8	3.5
Ore Minerals		4.2	3.5	2.6	3.6	6.8	3.6
IRF's		0.0	---	0.0	---	0.0	---

TABLE 27b. MEAN ROUNDNESS AND PERCENTAGE OF HEAVY MINERALS IN DIFFERENTIATED RIVER SANDS CON'T.

Sample R12	<3 ϕ Fraction		<2 ϕ Fraction		<1 ϕ Fraction		Combined fractions	
Mineral	Mean		Mean		Mean		Mean	
	%	roundness	%	roundness	%	roundness	%	roundness
Garnet	3.3	2.7	4.0	3.5	3.3	2.6	10.6	2.9
Zircon	3.3	4.3	0.0	---	0.0	---	3.3	4.3
Tourmaline	0.7	3.8	1.1	4.3	0.4	4.0	2.2	4.1
Hornblende	5.8	4.1	12.4	4.1	6.9	3.9	25.1	4.0
Lamprobolite	0.0	---	0.0	---	0.0	---	0.0	---
Sillimanite	0.0	---	0.7	4.8	9.1	4.2	9.8	4.2
Staurolite	0.0	---	0.0	---	0.0	---	0.0	---
Epidote	1.8	4.3	2.6	3.4	5.1	3.6	9.5	3.7
Epidosite	0.0	---	0.0	---	4.8	3.4	4.8	3.4
Titanite	0.4	3.5	2.6	4.4	1.5	4.4	4.5	4.3
Ore Minerals	20.8	3.9	8.0	3.7	1.5	4.0	30.3	3.8
IRF's	0.0	---	0.0	---	0.0	---	0.0	---

Sample S4	<3 ϕ Fraction		<2 ϕ Fraction		<1 ϕ Fraction		Combined fractions	
Mineral	Mean		Mean		Mean		Mean	
	%	roundness	%	roundness	%	roundness	%	roundness
Garnet	1.5	1.7	2.4	2.6	1.5	2.7	5.4	2.4
Zircon	1.5	2.8	0.0	---	0.0	---	1.5	2.8
Tourmaline	2.4	3.3	2.0	2.9	1.0	2.9	5.4	2.9
Hornblende	21.0	2.2	17.6	2.9	1.5	3.0	40.1	2.5
Lamprobolite	2.0	2.0	0.0	---	0.0	---	2.0	2.0
Sillimanite	0.0	---	0.0	---	0.5	5.5	0.5	5.5
Staurolite	1.5	1.3	2.9	1.9	0.5	2.5	4.9	1.8
Epidote	6.3	2.6	4.4	2.8	3.4	3.2	14.1	2.8
Epidosite	2.4	2.7	2.0	2.9	4.4	3.1	8.8	2.9
Titanite	0.5	1.0	2.0	3.5	1.5	4.3	4.0	3.5
Ore Minerals	6.8	2.5	4.9	3.3	1.5	3.8	13.2	2.9
IRF's	0.0	---	0.5	2.0	0.0	---	0.5	2.0

Sample K14	<2 ϕ Fraction		<1 ϕ Fraction		Combined fractions	
Mineral	Mean		Mean		Mean	
	%	roundness	%	roundness	%	roundness
Garnet	10.2	3.3	10.7	2.7	20.9	3.0
Zircon	1.6	3.3	0.0	---	1.6	3.3
Tourmaline	2.1	4.1	1.6	3.0	3.7	3.6
Hornblende	12.8	4.1	9.6	3.6	22.4	3.9
Lamprobolite	0.0	---	0.5	5.0	0.5	5.0
Sillimanite	0.5	3.0	8.0	3.8	8.5	3.8
Staurolite	0.5	4.0	0.0	---	0.5	4.0
Epidote	5.9	3.4	7.0	3.4	12.9	3.4
Epidosite	2.7	3.4	2.1	3.5	4.8	3.4
Titanite	2.7	4.1	2.1	4.1	4.8	4.1
Ore Minerals	11.8	3.3	5.4	3.9	17.2	3.5
IRF's	0.5	3.0	1.6	2.0	2.1	2.2

TABLE 28. D-SPACINGS, PEAK INTENSITIES AND MILLER INDICES OF DIFFRACTION PATTERNS OF SIX HEAVY MINERALS FROM THE REPUBLICAN RIVER

	A.U.	I _o /I	hkl		A.U.	I _o /I	hkl
Almandine	1.54	24	642	Titanite	4.93	25	$\bar{1}\bar{1}1$
	1.60	10	640		3.23	100	111, 002
	1.66	32	444		3.00	89	$\bar{2}02$
	1.87	23	611		2.83	7	200
	2.11	7	521		2.61	78	$\bar{2}21, 022$
	2.26	14	510		2.37	3	$\bar{1}13, 220$
	2.35	10	422		2.26	11	112, $\bar{1}32$
	2.58	100	420		2.23	5	131
	2.88	40	400		2.10	10	$\bar{3}12$
Epidote					2.06	25	$\bar{3}11$
	8.04	9	100	Sillimanite	1.98	5	221
	5.02	30	101, $10\bar{2}$		1.95	7	$\bar{3}13$
	4.60	6	002		1.85	5	$\bar{2}04, 310$
	4.02	51	200		1.80	9	042, $\bar{2}41$
	3.99	32	202		1.74	18	$\bar{3}32$
	3.77	6	111		1.73	8	240
	3.49	41	$21\bar{1}$		1.71	14	$\bar{2}24$
	3.40	38	102		1.64	32	$\bar{3}33$
	3.21	48	201		1.55	7	151, $\bar{2}41$
	3.06	18	003		1.53	10	043, $\bar{1}34$
	2.92	34	112		1.50	12	133
	2.90	100	113		1.42	23	400
	2.82	24	020		1.41	23	$\bar{2}44, 331$
	2.79	9	211		1.35	15	$\bar{3}57, 223$
	2.69	57	021				
	2.68	67	300		5.36	24	110
	2.66	17	120		3.74	6	200
	2.60	34	$31\bar{1}$		3.41	93	120
	2.53	34	103, 202		3.35	100	210
	2.46	17	121		2.89	4	121
	2.40	43	022		2.68	33	220
	2.30	22	220, 004		2.54	11	112
	2.17	27	122		2.42	15	130
	2.13	18	014		2.20	19	122
	2.12	15	221		2.09	4	320
	2.11	19	$22\bar{3}$		1.87	8	400
	2.07	15	$41\bar{2}, 023$		1.79	3	330
	2.05	17	$20\bar{3}$		1.71	10	240
	2.03	6	$41\bar{3}$		1.69	2	322
	2.01	20	400		1.68	13	420
Hornblende					1.57	3	402
	8.42	100	110		1.54	5	412
	4.23	9	220		1.52	17	332
	3.39	7	041, 150^+		1.45	2	422
	3.28	21	240		1.44	4	004
	3.13	47	310		1.42	5	250
	2.96	13	$\bar{1}51, 221$		1.39	3	520
	2.81	23	330		1.34	5	440
	2.71	19	151	Magnetite	4.83	14	111
	2.38	5	400		2.96	67	220
	2.35	5	$\bar{3}51$		2.53	100	311
	2.17	5	261		2.10	31	400
	2.02	4	351		1.71	17	422
	1.65	8	461		1.62	50	511

PETROLOGY OF REPUBLICAN, SMOKY HILL, AND
KANSAS RIVER SANDS NEAR JUNCTION CITY, KANSAS

by

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B. S., Kansas State University, 1968

AN ABSTRACT OF A MASTER'S THESIS

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Texture and mineralogy of channel-lag and point-bar deposits of the Republican, Smoky Hill, and Kansas Rivers near Junction City, Kansas, are described in relation to their respective drainage basins and depositional environments. Grain-size analyses, roundness determinations of quartz and heavy mineral grains, Scanning Electron Microscope photomicrographs of quartz grain surface features, and suites of heavy and light minerals are compared among rivers, and with those of other depositional environments.

The Republican, Smoky Hill, and Kansas Rivers have similar gradients, flow through similar physiographic provinces, and erode similar source rocks. Sediment from each river is mostly unimodal, submature, and subarkosic. Sediment of the three rivers is quite similar and ranges from pebbly silt to pebble gravel, is poorly to well sorted, fine to strongly coarse-skewed, and leptokurtic to platykurtic.

Linear regression analyses of grain-size parameters (dependent variables) and depth and surface velocity (independent variables) of the Republican, Smoky Hill, and Kansas Rivers showed that little relationship exists among the parameters and water depth and surface velocity. Scatter plots of grain-size parameters of the three river sands showed no differentiating patterns among rivers. A one-way analysis of variance test of mean grain size, sorting, skewness, and kurtosis values of underwater samples (excluding bank samples) of the three rivers also showed no significant difference of grain-size parameters among rivers.

Quartz grains of the Republican, Smoky Hill, and Kansas River sands are subangular; no significant differences of quartz mean roundness or roundness standard deviation was found among rivers. Most heavy minerals in the three rivers are subangular to subrounded. No relationship between size and roundness of garnet, hornblende, epidote, or ore minerals was detected among rivers.

About 85-90 percent of the quartz grains in the 1.0 ϕ size class of the Republican, Smoky Hill, and Kansas River sands are frosted to semi-frosted under the binocular microscope; 10-15 percent are clear or polished grains. SEM examination of the polished or clear grains showed an abundance of conchoidal breakage patterns, grooves and striations, and crescent-shaped impact features. Frosted to semi-frosted grains contained regular and irregular V-shaped impact and solution indentations, upturned cleavage plates associated with breakage patterns and solution cavities, and parallel steps within conchoidal scallops. Most grains have been modified by chemical etching and solution-precipitation.

Heavy mineral suites of the Republican, Smoky Hill, and Kansas River sands consist of different proportions of garnet, hornblende, sillimanite, epidote, epidosite, and ore minerals. Small percentages of zircon, tourmaline, staurolite, titanite, and IRF's are also present. Light minerals in each sand include metamorphic quartz, ordinary quartz, orthoclase, microcline, and chert. Garnet, sillimanite, epidote, epidosite, minor amounts of staurolite and titanite, and metamorphic quartz are diagnostic of a dynamothermal metamorphic source; hornblende and minor amounts of IRF's, zircon, and tourmaline are derived from silicic igneous rocks; and the ore minerals are characteristic of igneous, metamorphic, or reworked sedimentary rocks. A Chi-square test of groups of heavy and light minerals showed significant differences within, as well as among the three rivers. Possible source rocks in the Republican and Smoky Hill River valleys are Permian, Cretaceous, and Pliocene sedimentary rocks, and Quaternary loess, dune sand, and terrace deposits.