DEPOSITIONAL AND DIRECTIONAL FEATURES
OF A BRAIDED-MEANDERING STREAM

By

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DEPOSITIONAL AND DIRECTIONAL FEATURES OF A BRAIDED-MEANDERING STREAM

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PREFACE

This thesis is primarily a study of depositional and directional features of the Cimarron River in north-central Oklahoma. It contains description of the geologic setting, geometry, and internal features of the river deposit. Data presented include a bedrock configuration map, cross sections, sequential maps and aerial photographs of changes in the river during the last 35 years, stream discharge, directional features, grain-size parameters, and petrographic features.

The writer expresses his appreciation to Dr. J. W. Shelton, principal adviser, who offered constructive criticism and suggestions during research and writing. Advisory committee members, Drs. G. F. Stewart and A. R. Ross, provided useful suggestions as well as aid in locating references unfamiliar to the author. Appreciation is also extended to Drs. T. B. Thompson and Z. Al-Shaieb, who assisted in the thin-section study; to Dr. J. E. Stone, who provided information related to geomorphology; to Dr. J. D. Naff for advisory assistance in completing the study; to Richard Burman for field assistance and criticism of the manuscript; to Dr. R. Steinmetz for suggestions and advice; to the Oklahoma State University Arts and Sciences Research for financial support; and to E. L. Hemphill of Hemphill

Corporation, H. L. Bules of Bules Water Well Supply Company, J. H. Irwin, District Chief of the Oklahoma Water Resources Division of the U. S. Geological Survey, and the Perry Division of the Oklahoma State Highway Department for assistance in collecting various data. Permission from Mr. E. Scott to excavate the trenches is appreciated, as well as assistance of Theodore Arthur and other residents of Perkins.

The author owes a special debt of thanks to his wife, Kathryn, whose sacrifice, understanding, encouragement, and help made completion of this thesis possible, and to his parents, Mr. and Mrs. P. R. Noble.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

ABSTRACT

The Cimarron River in north-central Oklahoma shows characteristics intermediate between typical braided and meandering streams. In the Perkins area, the gradient is 1.8 ft per mi; the sinuosity is 1.5; the monthly average discharge varies from about 2 cfs to 17,800 cfs; and average channel depth at bankfull stage is 15 ft. During the period of aerial photography the river has tended to become more sinuous. Accretion ridges which form mainly on the downstream sides of bars characterize the straighter reaches, whereas accretion ridges which form on both the upstream and downstream sides of bars occur in the more sinuous reaches. Permian red beds, which have been channeled and terraced, underlie the alluvial deposits.

The deposits show upward fining; they are generally fine- to medium-grained, well-sorted sand, with scattered quartz and intraformational pebbles. Porosity is about 35 percent. Horizontal bedding and medium-scale and small-scale cross-bedding are the dominant sedimentary structures; clay drapes are present as thin discontinuous layers.
The sand is an arkose, which suggests the southern Rocky Mountains and the Wichita uplift as ultimate source

areas.

Irregularities and discontinuities in the sand deposits are due primarily to channel shifts during times of major floods and secondarily to deposition of clay during recession of high-water stages. Irregularities resulting from the dissection of transverse dunes and superposition of ripples on dunes are thought to be of minor significance.

Cross-bedding, parting lineation, and grain orientation all define the sand trend very well and indicate that directional features of this type are useful in estimating reservoir trend.

Compared to typical meandering-stream deposits, the Cimarron River deposits are thinner but possibly wider, and they contain less fine-grained clastics in the upper part of the sequence and as clay interbeds. The Cimarron sediments are finer grained and better sorted than sands of typical braided streams. They contain more horizontal bedding than either braided- or meandering-stream deposits. The type of sand deposit represented by the Cimarron River sand may be similar to certain ancient alluvial sandstones which were deposited during either subsidence or eustatic rise in sea level.

CHAPTER II

INTRODUCTION

The Cimarron River originates in northeastern New Mexico and flows east-northeastward into Kansas and then generally east-southeastward through Oklahoma into the Keystone Reservoir west of Tulsa. At this point it joins the larger Arkansas River.

The Cimarron is a relatively small, shallow river, with a length of 698 river-miles and a drainage basin area of approximately 19,000 square mi. In Oklahoma the terrain traversed by the river consists of gently rolling prairie hills. Dense growth of vegetation occurs along the river banks in most of Oklahoma.

Alluvium and a series of terraces form a long narrow belt paralleling the Oklahoma section of the river. The width of these deposits ranges from 15 mi in the western part of the state to 5 mi in the east. The flood plain occupies a position adjacent to the stream, whereas terraces are found topographically higher and beyond the flood plain.

Deposits of the Cimarron River south of Perkins, Oklahoma, were studied because the river in that area shows characteristics of both braided and meandering streams. Selected for detailed study is the river bar just west of the

Cimarron River bridge, 1 mi south of Perkins on Oklahoma State Highway 177 (Fig. 1). It is located in the southern part of Section 12 and the northern part of Section 13, T17N, R2E.

Geologic Setting

Underlying the Cimarron valley at Perkins are Lower Permian red beds, composed of shale or claystone and fine-grained lenticular sandstones (Ross, 1972). Alluvium of the river consists mainly of sand with interbeds of clay, but scattered clay, sandstone, and quartz pebbles are also present. The terrace deposits are primarily composed of sand, with silt, clay, and gravel (Ross, 1972).

Sand dunes are commonly present north of the river and are easily recognized by their hummocky appearance which contrasts with the relatively flat terraces. Loess deposits are also present in the Perkins area.

Data recorded at Gage Station #7-161000, located at the eastern edge of the study area on the Cimarron River bridge, show that discharge rates of the stream are highly variable. For example, the average monthly maximum of 17,800 cfs recorded in May, 1957, is approximately 8,300 times the average monthly minimum of 2.15 cfs recorded in November, 1955.

This study was conducted primarily during a low-flow stage when the sediment being transported was fine- to medium-grained sand in the form of linguoid ripples superimposed on migrating lobe-shaped transverse dunes. During

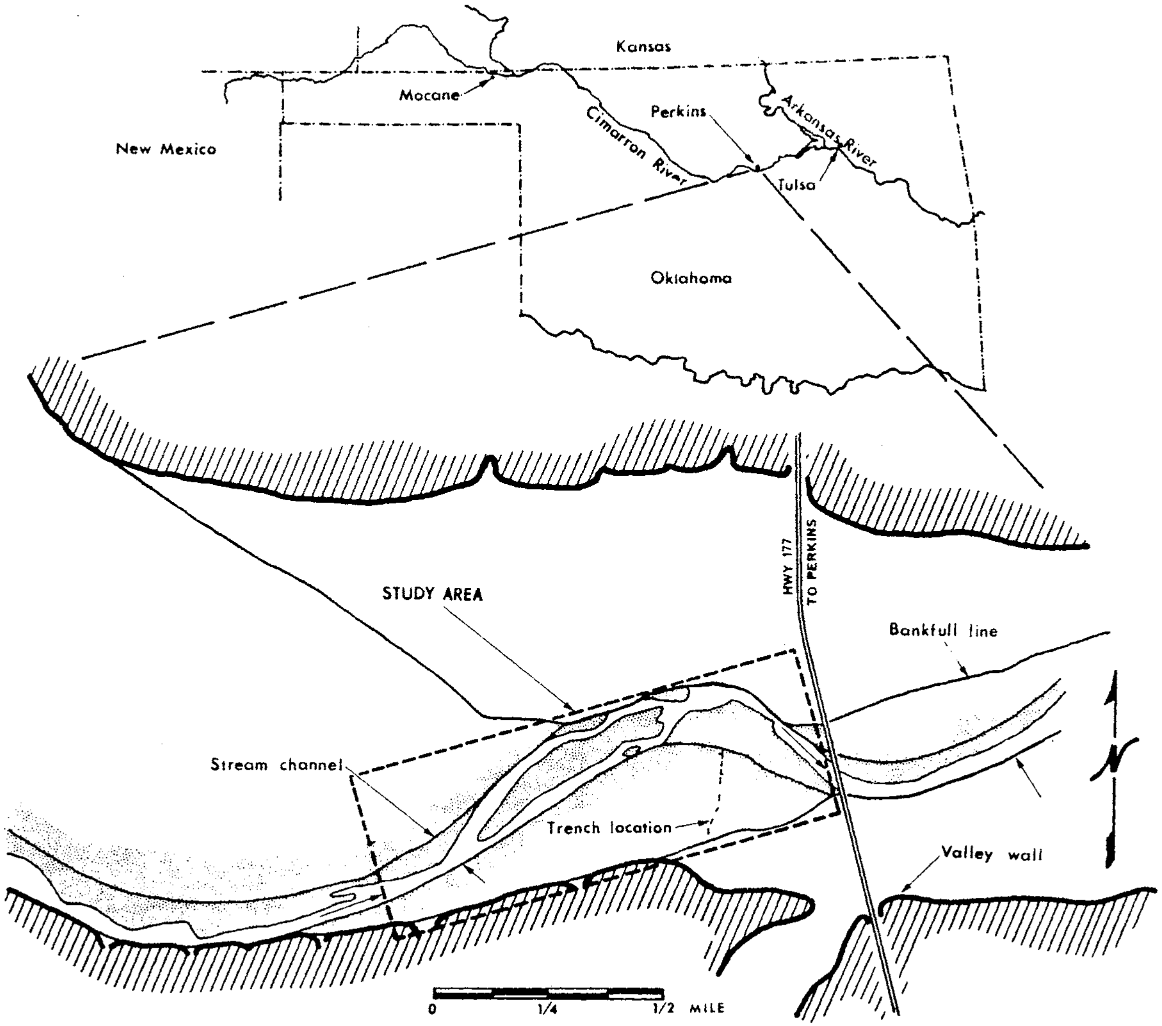


Fig. 1.-Index map of study area.

such a low-flow stage the suspended load is low, a feature in contrast to the higher amounts during stages of increased flow.

The water of the Cimarron River is especially highly mineralized at low-flow stages when the total dissolved solids content may be as much as 20,000 ppm. During periods of high discharge, however, the total dissolved solids content is low, about 300 ppm. High chloride and sulfate values, which account for most of the total dissolved solids, render the water unsuitable for either domestic or agricultural use. Sodium chloride and calcium sulfate, occurring naturally in the formations across which the river flows, are the primary sources of the dissolved solids.

The alluvial and terrace deposits along the river, thinnest to the west and locally as thick as 120 ft to the east of Perkins, serve as a major source of water. Although the water contains moderate amounts of magnesium and calcium, it is generally suitable for most uses.

Objectives

The primary objective of this study is to characterize the sedimentary features of a river that appears to have both braided and meandering reaches so that similar ancient deposits in the geologic record might be recognized with a fair degree of certainty. For comparative purposes features are noted of 2 meandering streams, the Brazos River in Texas and the Amite River in Louisiana, and of 2 braided streams, the South Platte River in Colorado and the Donjek River in Canada.

Corollary objectives of the study are to (1) determine the accuracy of directional features in depicting the trend of the river deposits, and (2) construct a cross section and bedrock configuration map of the river valley.

Methods

Most of the field work was conducted during August, 1972. The river bar was surveyed and mapped by pace and compass procedures. Sampling and trenching operations were also performed.

Sampling sites were established on a 100-ft grid system, although in actual sampling a number of sites had to be repositioned or omitted because of dense vegetation. At each site, measurements of current direction in the observed sedimentary structures (parting lineation and small-scale and medium-scale cross-bedding) were made in a shallow trench. Samples of the different stratification types were collected for grain-size analysis.

Eight large trenches, ranging from 10 to 64 ft in length, were dug by a tractor-mounted backhoe along a line, striking N10°E, that approximately bisects the bar. The trenches were between 4 and 9 ft deep, depending upon the depth of water table below the surface. The walls of the trenches were smoothed with a machete in order to make the stratification clearly visible for observation and photography.

The stream pattern and gradient for 10 river-miles in each direction from the study area were determined from 15-minute topographic maps. Surface elevations along the line containing the trenches were surveyed from the north bank to the southern end of the bar with a telescopic level and stadia rod. Subsurface and stream-discharge data were also collected.

Previous Investigations

Stream patterns, based on the appearance of channels in plan view, have been characterized by Leopold and Wolman (1957) as braided, meandering, or straight, with the last being the least common. Russell (1954) noted that certain reaches of some rivers resemble meandering streams during high flow and braided streams during low flow. Classification of stream types, primarily according to sinuosity, has been proposed by Schumm (1963) as well as by Leopold _et al._ (1964). Although the terminology differs between the classifications, in both sinuosity is expressed as the ratio of stream length to valley length. Schumm categorizes channel patterns into 5 types: straight, transitional, regular, irregular, and tortuous. Straight channels are the least sinuous with a sinuosity value of about 1.0; regular channels are intermediate with a value of about 1.5; and tortuous channels are the most sinuous with values in the neighborhood of 2.0. In the classification by Leopold _et al._ (1964), streams with low-sinuosity values are braided and those with high values are meandering; streams with sinuosity of 1.5 are intermediate between braided and meandering types.

Depositional features have been studied along various braided and meandering streams. For the Mississippi River, detailed lithologic descriptions of various deposits were first given by Fisk (1944; 1947), and sedimentary structures were initially described by Frazier and Osanik (1961). Harms _et al_. (1963) studied a point bar on the Red River, and Harms and Fahnestock (1965) studied stratification types in deposits of the Rio Grande River. Bernard _et al_. (1970) made a detailed study of deposits on the Brazos River in the Richmond, Texas, area which has become the primary reference for meandering streams, and McGowen and Garner (1970) made a similar study of the Amite River near Magnolia, Louisiana. A comprehensive review of Recent alluvial sediments with emphasis on geometry and internal features has been made by Allen (1965). Other workers who have studied and described depositional features are McKee (1938), who observed sedimentary structures of the Colorado River deposits, Lane (1963) in his study of the San Bernard River in Texas, and Visher (1965) in a comparative study of ancient and Holocene alluvial deposits.

Characteristics have been described of both coarse- and fine-grained deposits along braided rivers. Doeglas (1962), in his study of the Durance and Ardeche Rivers in France, and Williams and Rust (1969), in study of the Donjek River, Yukon Territory, Canada, provide examples of coarse-grained stream deposits. An example of relatively fine-grained deposits is the alluvium of the South Platte River in northeastern Colorado, which has been studied by Ore (1963; 1964) and Smith (1970; 1972).

Flume experiments have also rather clearly defined the origin of most alluvial sedimentary structures which have been documented by field studies. Allen (1970) has determined that the size of dunes and ripples is proportional to the depth of flow. Simons _et_ _al_. (1965) and Allen (1970) have characterized the various types of cross-bedding according to bed form and their sequence of formation. These workers, along with Harms and Fahnestock (1965), have classified alluvial channel flow into lower and upper flow regimes. In the former the resistance to flow is large; sediment transport is relatively low; ripples and dunes are the dominant bed forms; and water-surface undulations are out of phase with the bed surface. In the upper flow regime the resistance to flow is small; sediment transport is relatively high; horizontal beds or antidunes are the usual bed forms; and the water surface is generally in phase with the bed surface. The relationship between channel shape, flow characteristics, and bed forms has been studied by Leopold and Maddock (1953), Colby (1964), and Dawdy (1961). Wilcock (1971) found that channel shape, which changes as rate of flow changes, influences the competence of the stream. Simons _et_ _al_. (1965) have shown that grain size, as well as flow characteristics, is an important factor in the formation of sedimentary structures. Cross-bedding in dunes and ripples has also been produced in flumes by Brush (1958), Jopling (1963), and McKee (1965).

Directional features (cross-bedding, parting lineation, and grain orientation) have been used by many workers as reliable trend indicators in alluvial deposits. Rubey and Bass (1925) were among the earliest workers to recognize the potential of sedimentary structures as indicators of depositional trend. Later workers, such as Frazier and Osanik (1961), Harms *et al*. (1963), Shelton and Mack (1970), Rust (1972), and Burman (1973), have used various directional features in Holocene deposits to substantiate their validity as trend indicators. Steinmetz (1972) has studied directional features in deposits of the Arkansas River near Tulsa, Oklahoma, which at that location is a braided-meandering stream similar to the Cimarron River. Cross-bed dip directions there deviate considerably from valley trend, and even the average direction of all measurements is significantly different from the valley trend.

CHAPTER III

GEOMETRY OF RIVER DEPOSITS

Bedrock Configuration

At Perkins, Oklahoma, the Cimarron River channel and associated flood plain and terraces lie within a valley which has been excavated in rocks of the Permian System. The bedrock valley is about 3½ mi wide and 50 ft deep, except in the flood plain, where the depth of alluvium is approximately 30 ft (Fig. 2). The bedrock has been channeled and terraced in a fashion similar to the present land surface. Although the gradient of the bedrock channel is unknown, eastward thickening of alluvial and terrace deposits suggests that it is somewhat greater than that of the present channel.

Channel Pattern and Bar Relationships

The channel pattern of the Cimarron River at Perkins, characterized by a gradient of 1.8 ft per mi and a sinuosity of 1.5, is intermediate between typical braided and meandering streams. At bankfull stage, one channel exists and the Cimarron resembles a meandering stream. Due to erosion of the stream bed at such a time, the average depth of the channel is about 15 ft, or 3 ft greater than the height of the flood plain above the channel at low-flow stage (Fig. 3). During the generally prevailing low-flow stage, however, the channel resembles a braided stream. According to Ore (1963) the universal feature of a braided stream is a divided, or branched, channel. The anastomosing channels of the Cimarron result from the exposure of transverse dunes (or bars) during decreasing stages of flow. Once the dunes are above the water level, minor fluctuations in the discharge rate cause the channel to cut diagonally across the dunes, thereby increasing the braided appearance.

According to Leopold and Wolman (1957), a braided stream is one which is incompetent to transport the coarsest fraction furnished to a given reach. This relationship is valid for the type of braided river characterized by longitudinal bars, steeper gradients, and poorly sorted sediment. However, in the Cimarron River at Perkins, the dominant bed form consists of transverse dunes (or bars); the gradient is relatively low; and the sediments are well sorted. It is, therefore, suggested that the braided nature of the Cimarron is due to the inability of the river at low-flow stages to transport the total amount of sediment furnished to a given reach, without regard to maximum grain size.

The pattern of the river appears to have changed significantly during the last 100 years. Aerial photographs of the study area for the years 1938, 1949, 1956, 1963, and 1969, reveal characteristics which suggest that the river

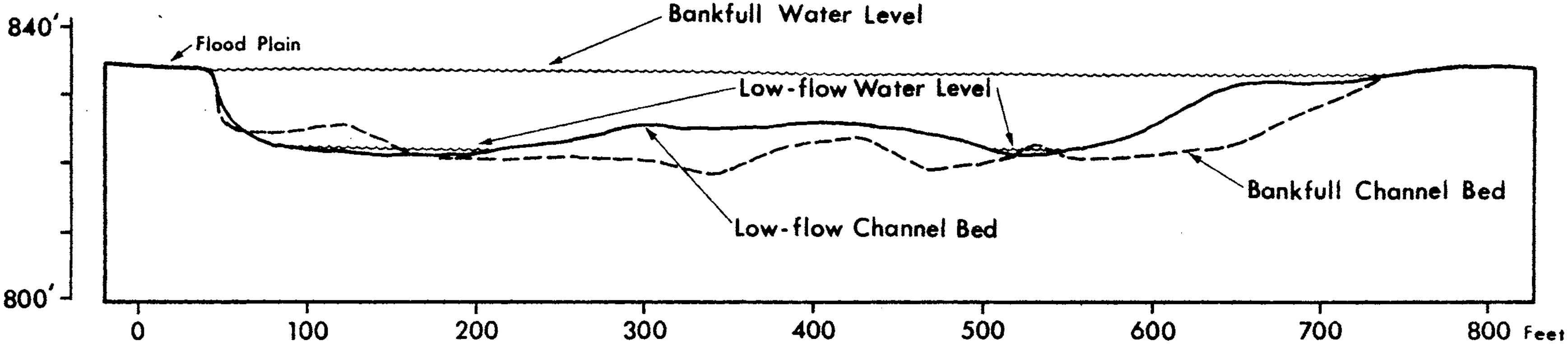


Fig. 3.-Channel configuration and flow depths during bankfull and low-flow stages. Measurements were made from Cimarron River bridge.

was more sinuous prior to 1938. Abandoned meanders, similar to those associated with typical meandering streams, exist in the Perkins area. One of these abandoned meanders is mapped in Figures 4-8. During the more sinuous stage, point-bar deposits similar to those described by Bernard *et al*. (1970) formed on the convex bank of the meandering portion of the stream, and the gradient necessarily during that stage was less than it is today. In point-bar deposits, arcuate accretion ridges commonly form on both the upstream and downstream sides of bars as they build in a direction toward the concave bank. Old accretion ridges of this type, shown best in Figure 4, are interpreted as remnants of the meandering conditions. During the period of aerial photography, the river has tended, once again, to become more sinuous through continual processes of erosion and deposition.

The sinuous pattern was probably altered in May, 1914. At that time, according to Schumm and Lichty (1963), the maximum flood on record for the Cimarron River occurred. Discharge of 120,000 cfs was recorded at Mocane, Oklahoma, in the northwestern part of the state. The portion of the Cimarron River in Kansas abandoned its meandering course during that flood and assumed a shorter, less sinuous path with a slightly steeper gradient. Once the meander pattern of the river had been destroyed, the resulting less sinuous path was maintained by subsequent floods near average peak discharge. Similar changes, but of less magnitude, are

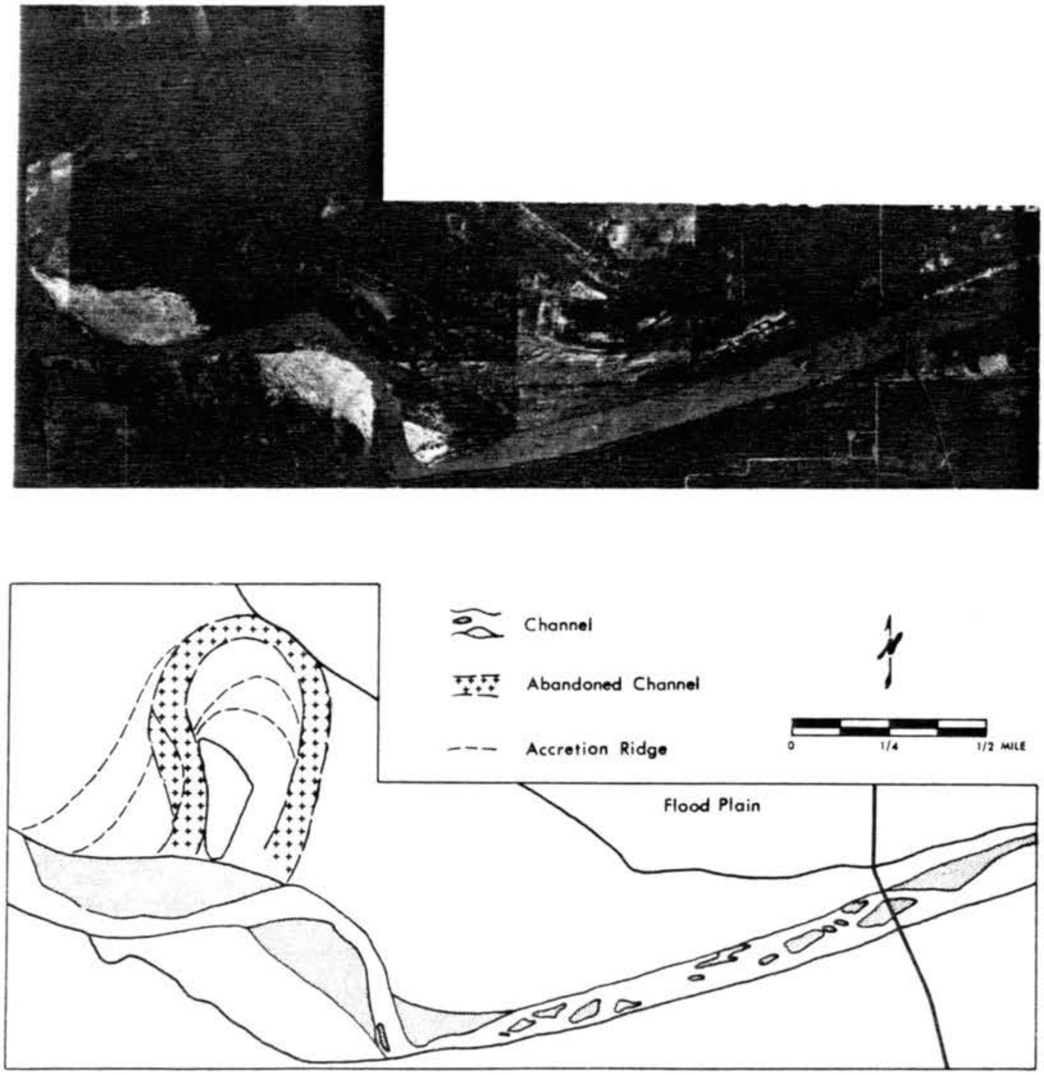


Fig. 4.-Aerial photograph with corresponding map of Cimarron River, Perkins area, April 16, 1938.

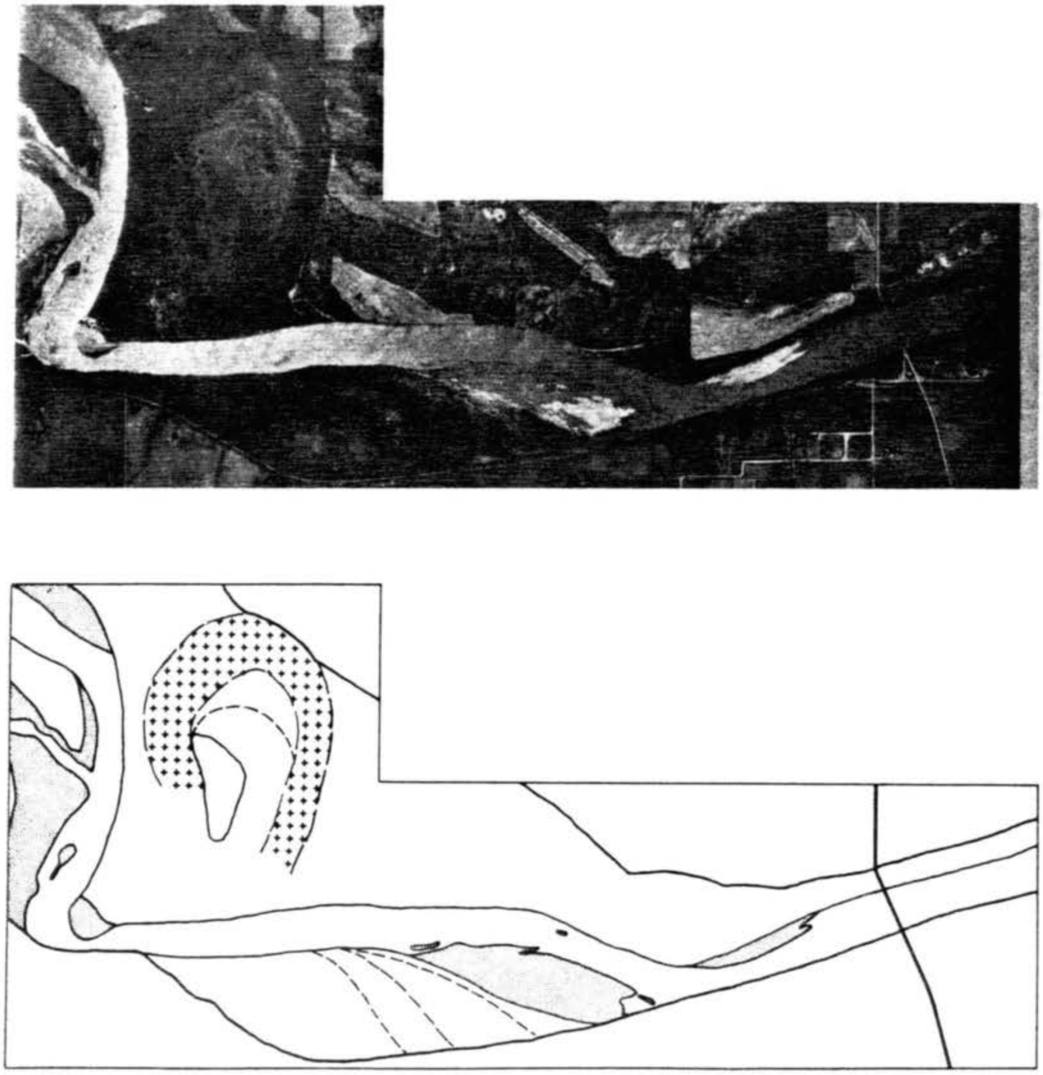


Fig. 5.-Aerial photograph with corresponding map of Cimarron River, Perkins area, May 10, 1949. See caption for Figure 4.

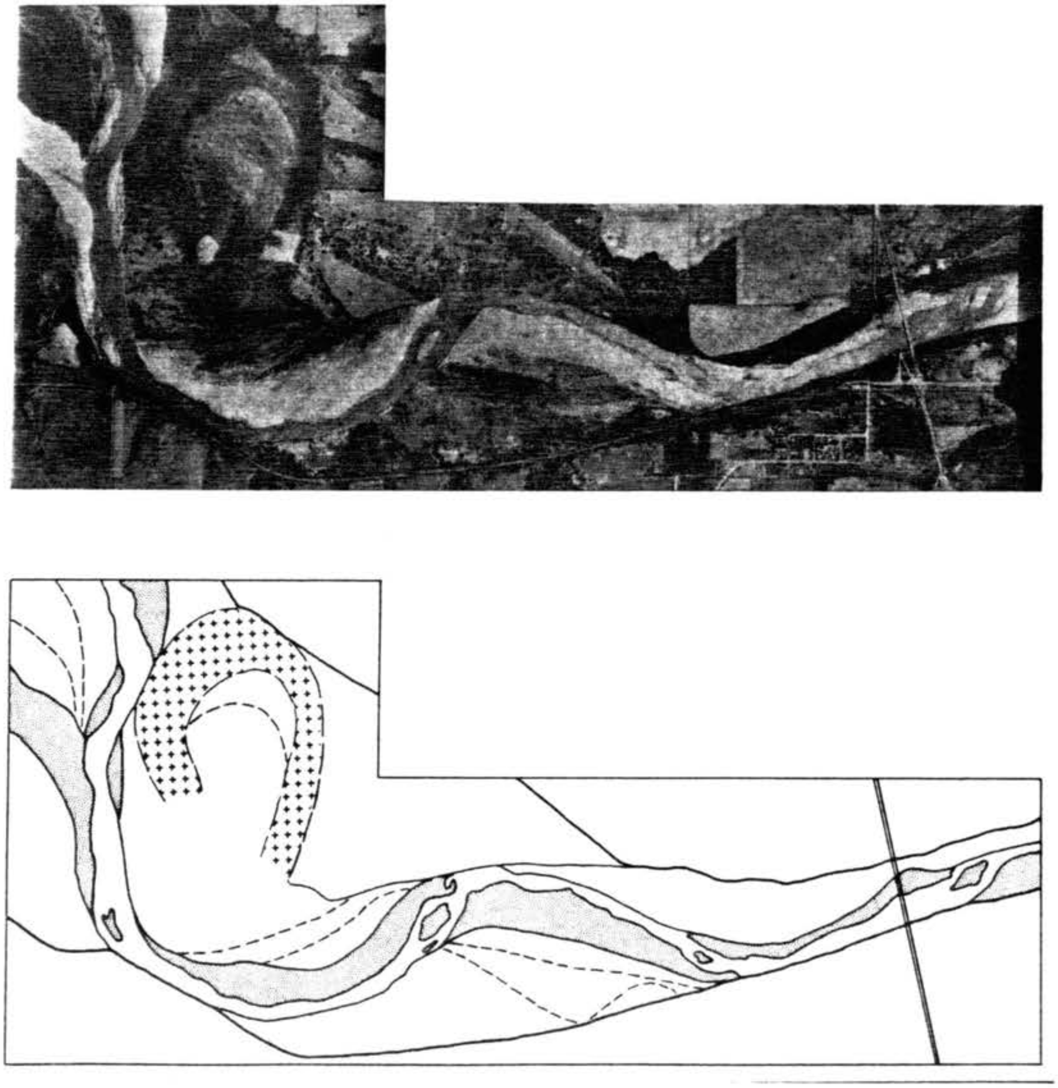


Fig. 6.-Aerial photograph with corresponding map of Cimarron River, Perkins area, July 13, 1956. See caption for Figure 4.

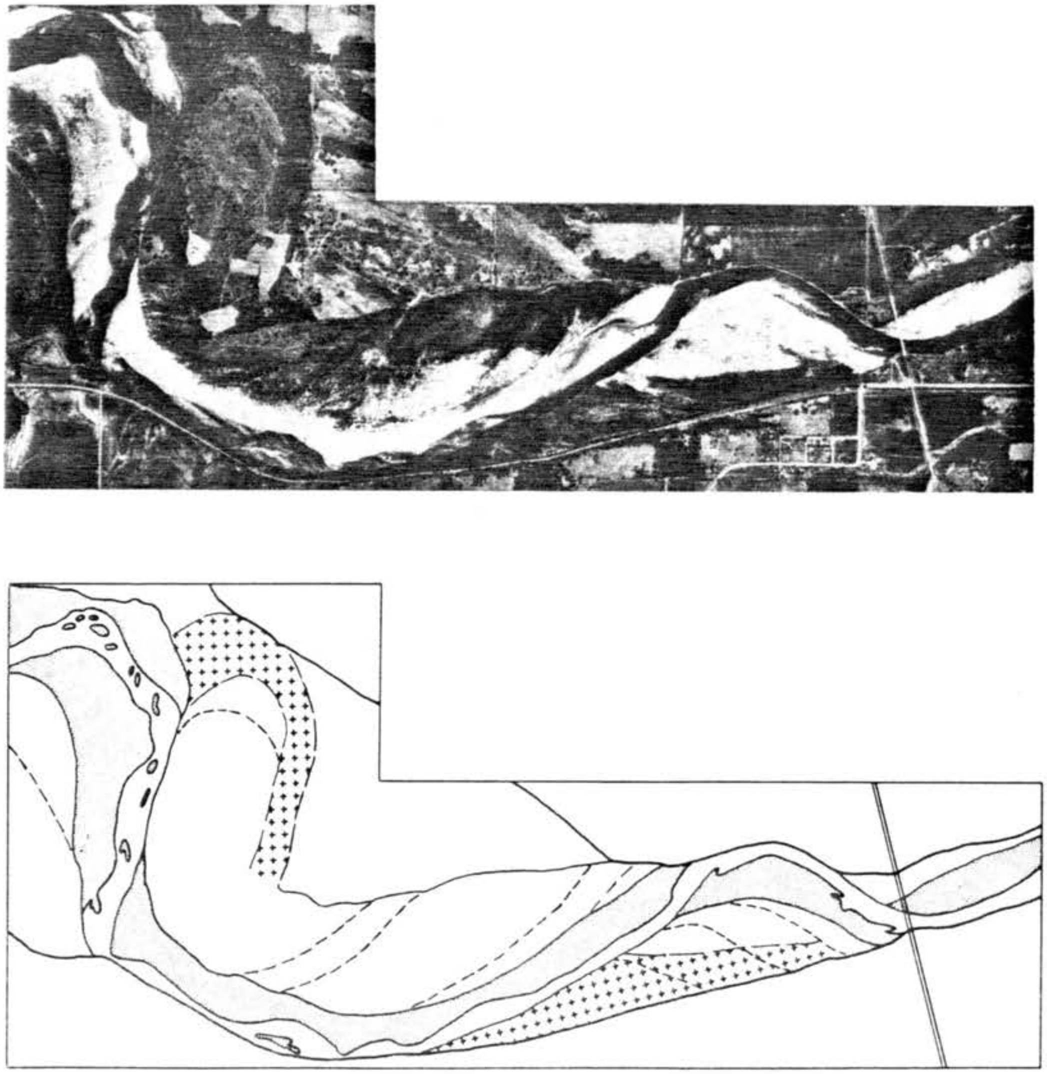


Fig. 7.-Aerial photograph with corresponding map of Cimarron River, Perkins area, April 19, 1963. See caption for Figure 4.

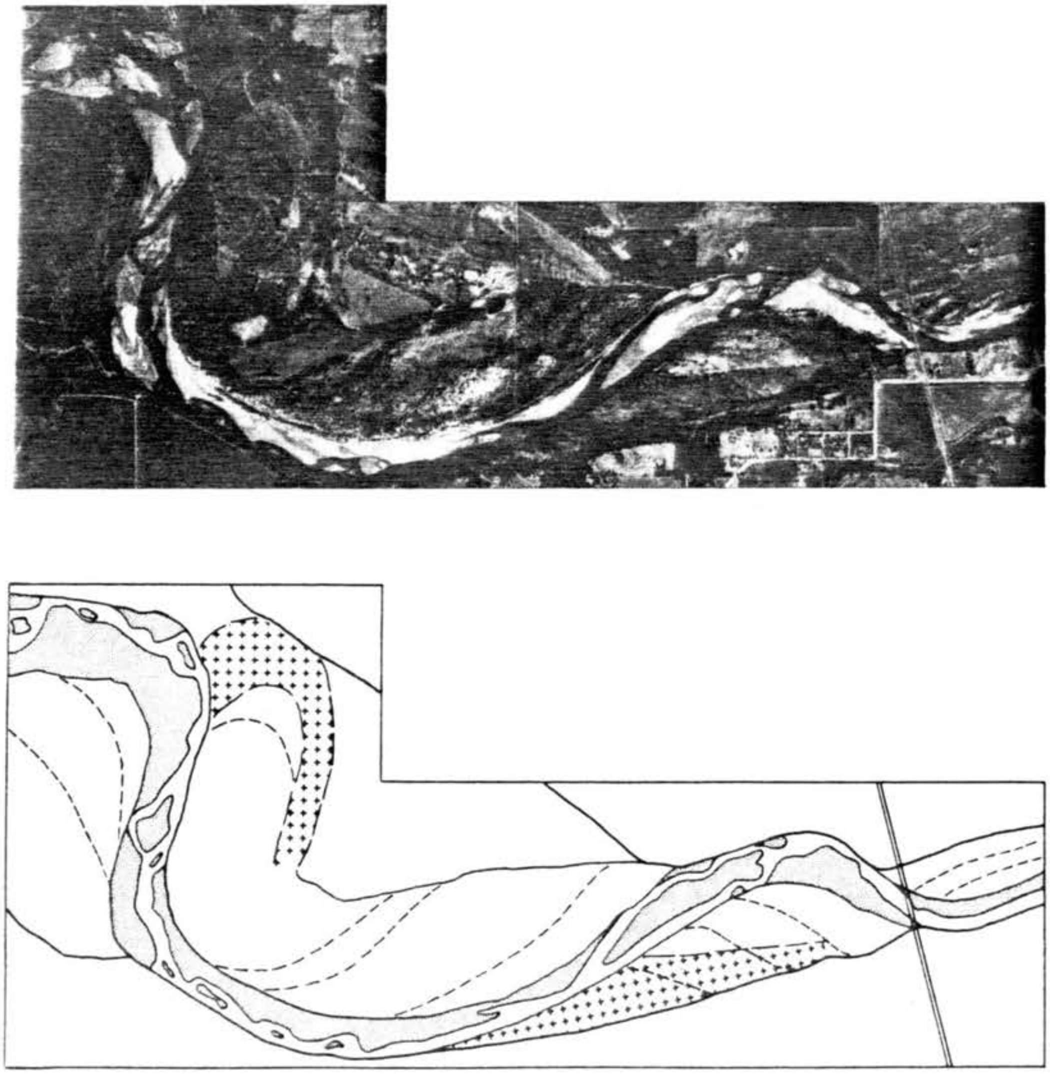


Fig. 8.-Aerial photograph with corresponding map of Cimarron River, Perkins area, November 30, 1969. See caption for Figure 4.

suggested for the Cimarron River in the Perkins area.

Accretion ridges associated with highly sinuous streams are observed on the abandoned meander (Fig. 4) and presently existing meander in the western part of Figure 8. They did not begin to form on the latter until about 1963. Ridges of this type indicate a trend toward the more sinuous pattern which apparently characterized the stream before the 1914 flood. The other type of ridge, which is developed in most of the study area, also migrates toward the concave bank but forms mainly on the downstream side of the bar. This type of accretion characterizes the straighter reaches of the river.

A significant change observable during the period of coverage by aerial photography was the appearance of an abandoned channel in the eastern part of the study area between 1956 and 1963 (Figs. 6-8). During the largest flood for the period covered by aerial photography, in May, 1957, the river apparently assumed a somewhat more direct course downstream by forming a temporary secondary channel along the south bank. This secondary channel was abandoned when the flow reverted to its original path as discharge rates decreased. During the period from 1956 to 1963 (Figs. 6 and 7), erosion, specifically along the north bank, and bar formation appear to have progressed faster than during any other period for which data are available. Greater-than-average discharge (Fig. 9) probably was responsible for initiating and maintaining the change.

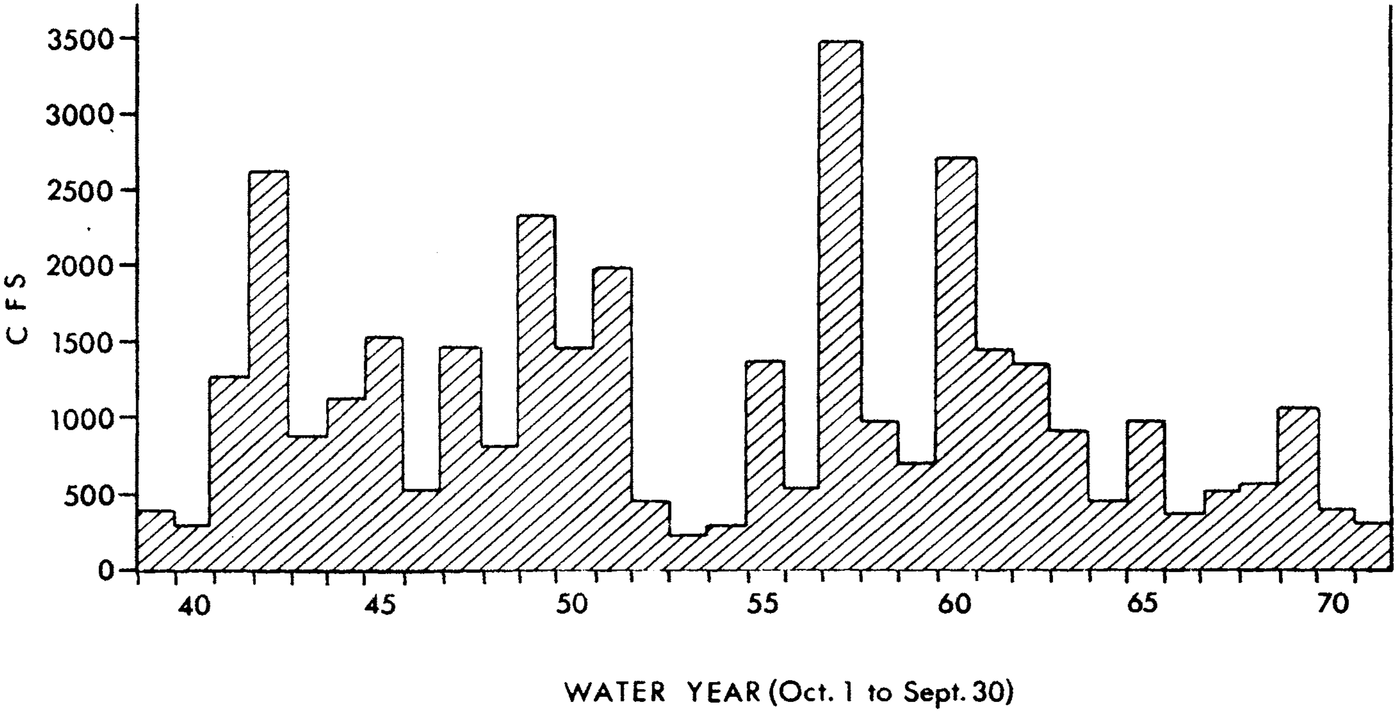


Fig. 9.-Histogram showing average annual discharge rates from 1939 to 1971 for Cimarron River at Perkins, Oklahoma. (Data provided by Oklahoma Water Resources Division, U. S. Geological Survey).

Although the discharge rates were variable from 1941 to 1962, on the average they were higher than for the period from 1963 to 1972. The differences in these 2 periods are reflected by the amount of vegetation on the bars. The regularity with which flooding occurred during the earlier period, coupled with the prior drought, were conditions that proved unfavorable for establishment of new vegetation of the bars (Figs. 4-7). Lower discharge rates during the period after 1962, accompanied by adequate precipitation, allowed dense growth of salt cedar and Johnson grass to cover large portions of the bars. The vegetation stabilizes and protects the bars during periods of increased discharge.

CHAPTER IV

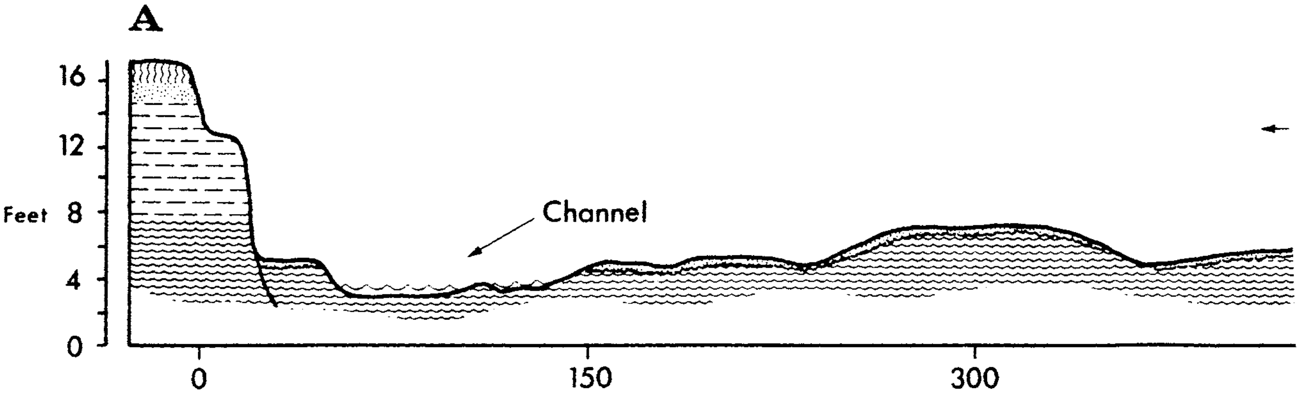
INTERNAL FEATURES

Sedimentary Structures

The 3 most abundant sedimentary structures in Cimarron River sand are horizontal bedding, medium-scale trough and tabular cross-bedding, and small-scale cross-bedding. The distribution of the structures observed on the river bar is shown in Figure 10. Clay, draping the bar, and small- to medium-scale eolian dunes are also present but are volumetrically less significant.

Clay-drape material, which forms as an interbed at the top of an individual depositional sequence as water level recedes, preserves the initial dip (or slope) of the bar. Sand-filled dessication cracks are common in these clay units which are as much as several inches thick. Greater thicknesses form where ponded water deposits its suspended load.

In analysis of sedimentary structures and texture, the river bar is divided into upper and lower levels which are distinguishable on the basis of elevation, slope, and the amount of vegetation. The lower part is essentially vegetation-free, and topographically it occupies the area up to about 4 ft above the low-flow water level in the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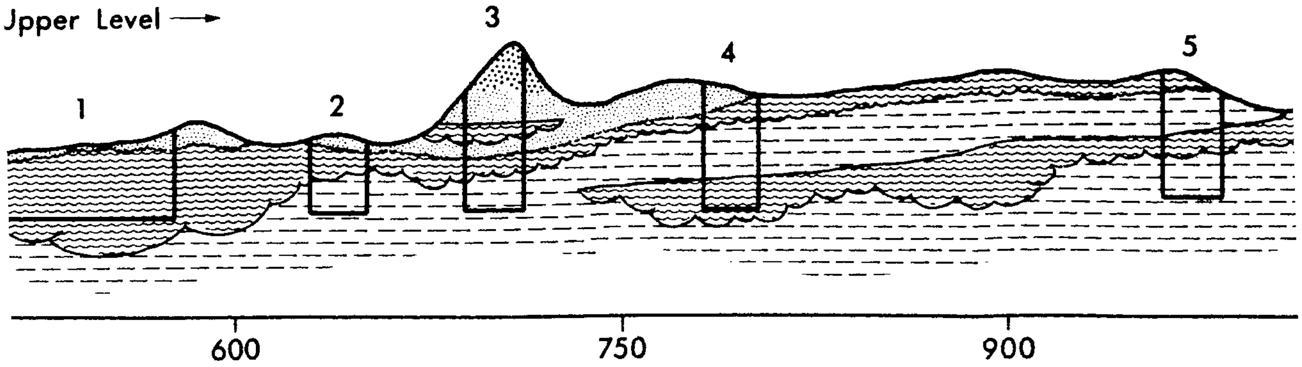
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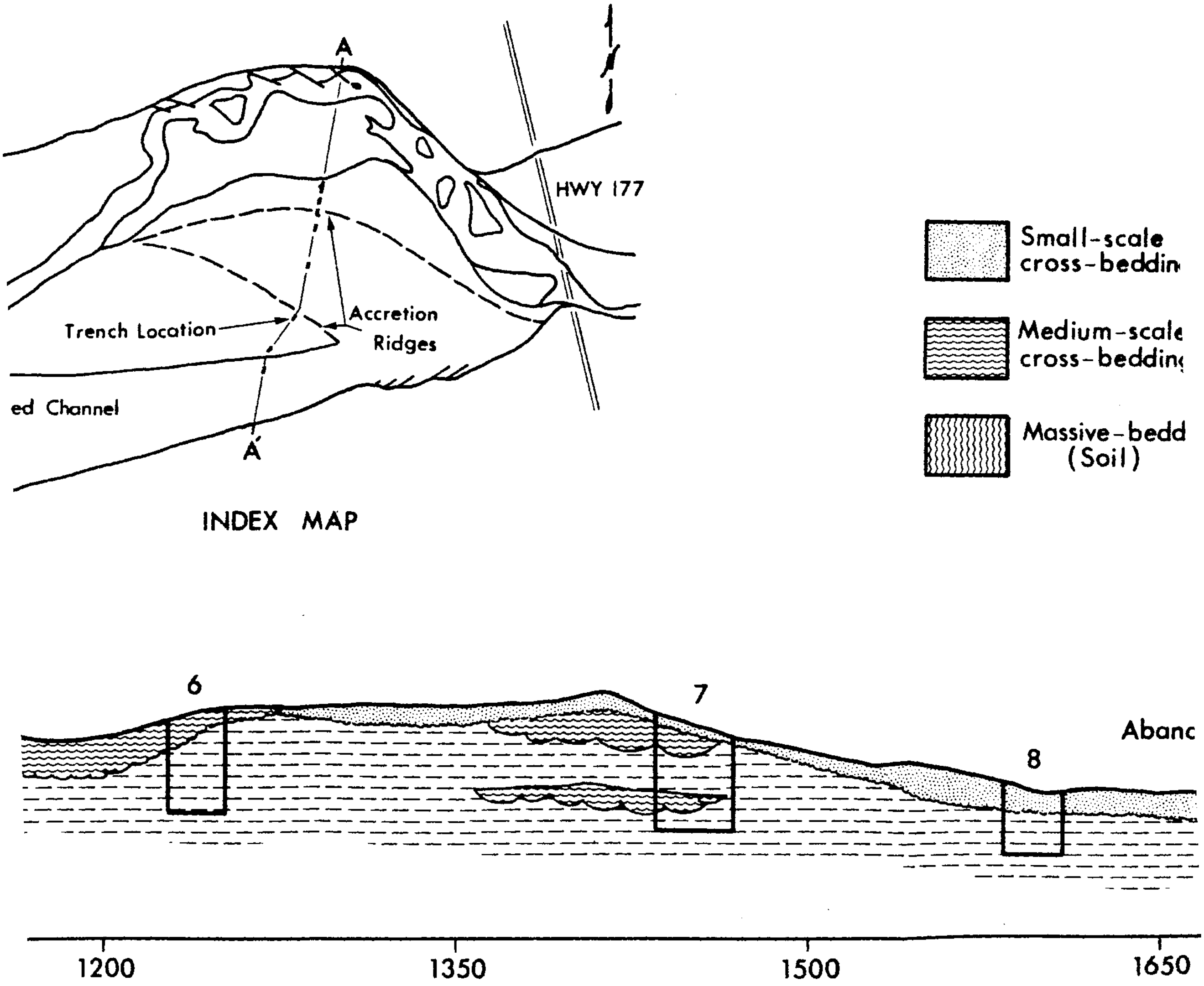

Fig. 10.-Cross section of bar sho
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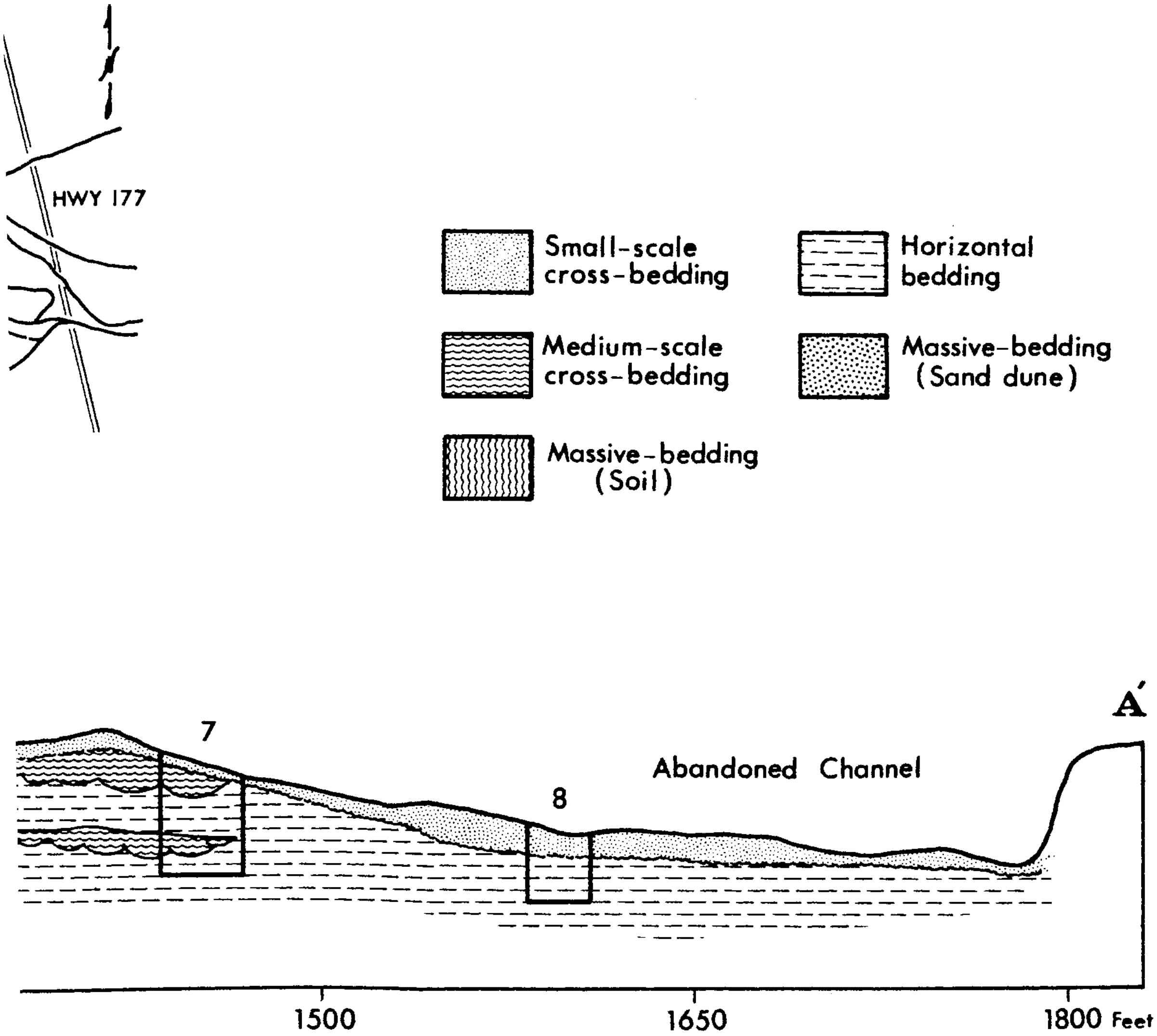

Fig. 10.-Cross section of bar showing the distribution and relationship of stratification types (sedimentary structures). Clay drapes are not shown. Numbers and outlined areas show trench locations.

channel. The upper part of the bar, with a varying amount of vegetation, extends from about 4 ft above the low-flow water level to the highest point on the bar, which is about 15 ft above the low-water level. The uppermost part is inundated only during bankfull and flood stages.

Horizontal Bedding

Horizontal bedding, some of which was observed with initial dip, is the most abundant type of stratification on the bar, and, based on field examination, it is thought to comprise a large portion of the sediments in the north bank. These beds, which are generally 2 to 4 ft thick, were observed directly only in the upper part of the bar. However, it is thought that they are also present in deposits of the lower part of the bar. Horizontal beds are characterized by distinct, persistent, even laminae, with no irregularities except for an occasional burrow (Fig. 11). Locally, heavy-mineral concentrations accentuate the horizontality of the bedding.

The base of an apparently persistent zone containing horizontal beds was not observed, but in 2 trenches medium-scale trough cross-bedding lies within horizontal beds. The lower contact of the cross-bedded units is scalloped and the upper contact is sharp but planar. This relationship suggests (1) trough-type scouring of the lower horizontal beds, (2) deposition of trough-shaped cross-beds, (3) horizontal scouring, and (4) deposition of horizontal beds.

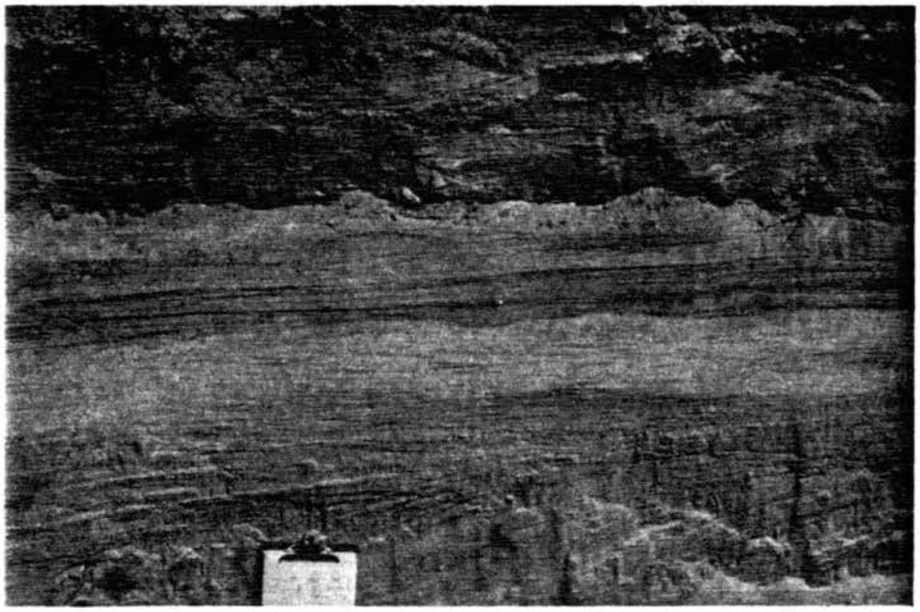

Fig. 11.-Horizontal bedding with heavy-mineral concentrations, observed on east wall of Trench 2, overlies beds with initial dip. Overlying medium-scale cross-bedding grades upward into small-scale cross-bedding. Stream flow is away from viewer.

Deposition of the horizontal beds is thought by most workers to occur during the lower part of the upper flow regime (Simons et al., 1965; Harms and Fahnestock, 1965; and Allen, 1970). Deposition of this type of stratification is associated with high-flow stages, such as bankfull or flood conditions. However, certain characteristics of these beds suggest that conditions for formation of horizontal bedding are not fully understood. For example, horizontal beds contain finer grained sediments than medium-scale cross-bedding, formed during the lower flow regime. Also, they are commonly associated with the fine-grained deposits of clay drapes rather than with pebbles and clay galls. It is suggested, therefore, that some horizontal bedding may form as flow rates lessen and water depths decrease.

Cross-bedding

Cross-stratification develops in bar deposits as both medium-scale (dune) and small-scale (ripple) cross-bedding. The former type is present as trough (festoon) and tabular beds, whereas only trough bedding is observed in the latter.

Medium-scale Trough Cross-bedding. Medium-scale trough cross-bedding, the second most abundant stratification type, was observed to be more prominent in the upper part of the bar. The largest observed structure of this type, with the characteristically scalloped lower contact, was approximately 4 ft thick and 15 ft wide. Most structures, however, were from 1 to 2 ft thick and 2 to 4 ft wide (Fig. 12). Lengths

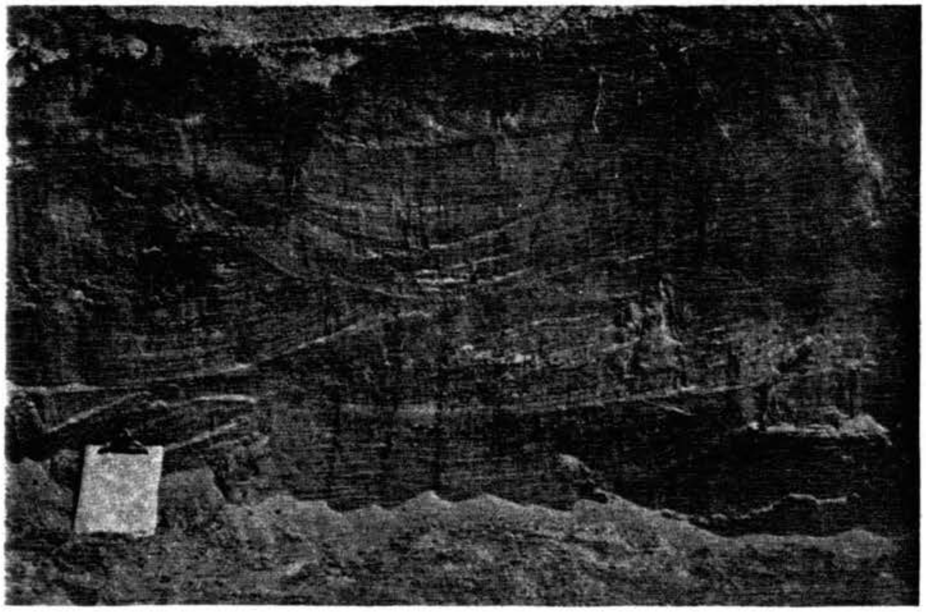

Fig. 12.-Medium-scale trough cross-bedding with scattered pebbles and clay galls on east wall of Trench 1. Stream flow is away from viewer.

of these structures were not measured, but Harms *et al.* (1963) and Harms and Fahnestock (1965) have reported that structures similar to those described herein range from 30 to 45 ft in length.

Medium-scale trough cross-bedding forms as elongated scour troughs become filled with curved laminae during the continuous downstream migration of dunes. Although the dunes were not actually observed, it is thought that they are of the linguoid or bow-shaped (convex downstream) type. These structures typically form during the upper part of the lower flow regime and their heights are 10 to 20 percent of the mean-flow depth; wave lengths are several times the mean depth; and crest lengths are of the same order of magnitude as, but less than, the wave length (Allen, 1970). As flow rates decline, size of the trough-type cross-sets decreases. Many of the trough sets undergo significant erosion by the scour action of younger, smaller dunes.

Tabular Cross-bedding. Tabular cross-beds, which are apparently restricted to the lower part of the river bar, are deposited as transverse dunes (or bars) migrate downstream. These features are somewhat regularly spaced in the channel (Fig. 13). Their crests, which in plan view are convex downstream with a large, smooth radius of curvature, extend across most of the full-channel width. The length and width of these structures are measured in tens of ft. A dune of this type which was exposed above the low-flow water level is shown in Figure 14. Thicknesses range from

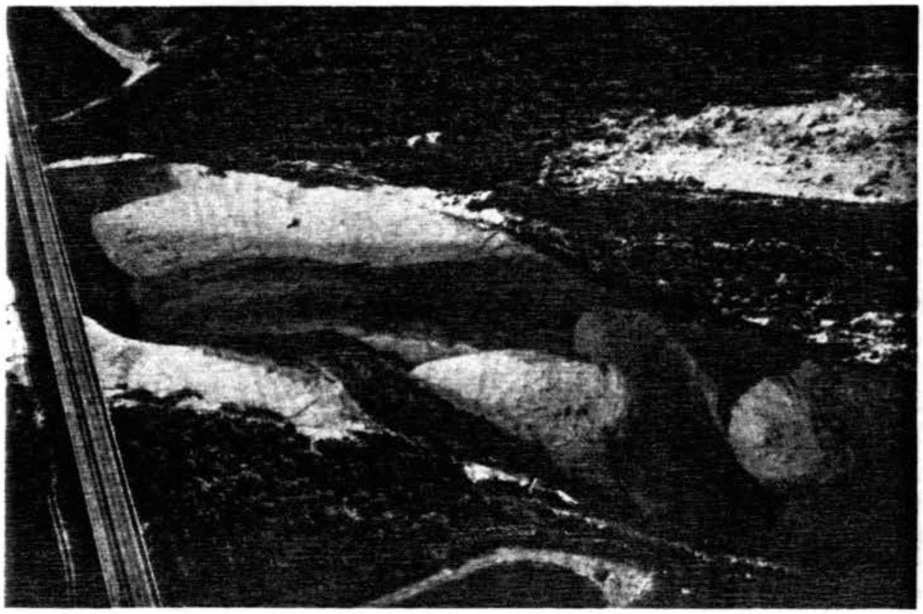

Fig. 13.-Series of subaqueous transverse dunes (t) showing fluted surface (f) of the stoss side. Stream flow is from right to left.

Fig. 14.-Transverse dune exposed above low-flow water level. Stream flow is from left to right.

3 to 18 in., but thicker beds probably exist where transverse dunes cross thalwegs. Ripples which form on the stoss side of transverse dunes bury previously deposited tabular cross-beds with a thin veneer of small-scale cross-beds (Fig. 15). With slightly higher flow rates the small cross-beds on the stoss sides of dunes are replaced with a lower flow regime, planar-type deposit (Jopling, 1963).

Subaqueous transverse dunes (Fig. 13), with flutes (spoon-shaped depressions) on the stoss side, possibly resemble the troughs associated with medium-scale cross-bedding. However, the shape of the laminae within the tabular sets indicates that their deposition is not controlled by the configuration of the lower surface (Harms and Fahnestock, 1965). Tabular structures of this type are depositional features which require no erosional preparation. In deposition of tabular cross-beds, sediment is transported up the stoss side and deposited by gravity on the lee side. Avalanching sand comes to rest on the slope formed by previously deposited foreset laminae at the angle of repose, which is steepest when stream velocities are lowest (Jopling, 1963).

Small-scale Trough Cross-bedding. Small-scale trough cross-bedding is present in all areas of the bar. This type is similar in shape but dissimilar in size to medium-scale cross-bedding. Thickness is approximately 1 in.; width is to 4 in.; and length is 2 to 3 ft. Small-scale cross-beds are best developed in the lower part of the channel during

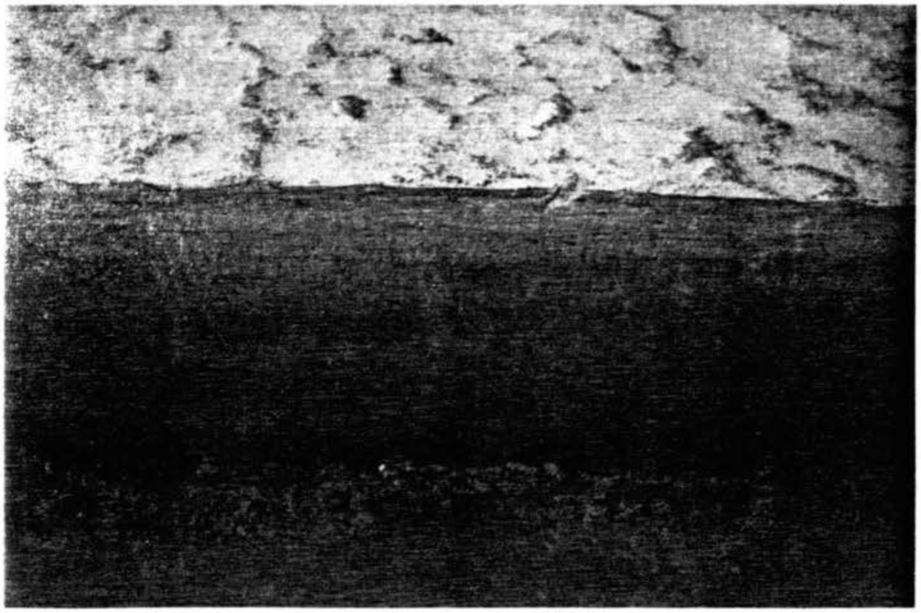

Fig. 15.-Tabular cross-bedding with veneer of small-scale cross-bedding in cross section and plan view. Stream flow is from left to right. Wall of trench is approximately 12 in. high.

low-water stage as they become superimposed on transverse dunes. These structures, shown as climbing ripples, were observed only in an abandoned channel-way in the upper part of the bar (Figs. 16 and 17).

Small-scale cross-beds form overlapping series of small trough sets as ripples migrate downstream in shallow, relatively slow-moving water (McKee, 1965). These ripples (like the larger dunes) are also of the linguoid type with crests that are characterized as being straight to sinuous but generally convex downstream (Fig. 18). Climbing ripples form under similar conditions, requiring however a slight but progressive increase in stream-flow velocity and a large sediment supply (McKee, 1965). As the water becomes shallower and the velocity slower, sediment transport by saltation ceases; ripple migration is checked; and some of the suspended sediment is deposited as thin clay coating the ripples.

Directional Features

Measurements were made of 257 sedimentary features bserved at 190 sample sites. At each site, dip directions f cross-beds, parting-lineation trends in horizontal beds, nd current directions of ripples were recorded. Grain-rientation measurements by H. R. Burman (1973) were also ecorded at selected sites. The directions for small- and edium-scale cross-beds were determined by observing in plan iew those features which were exposed at the sample sites.

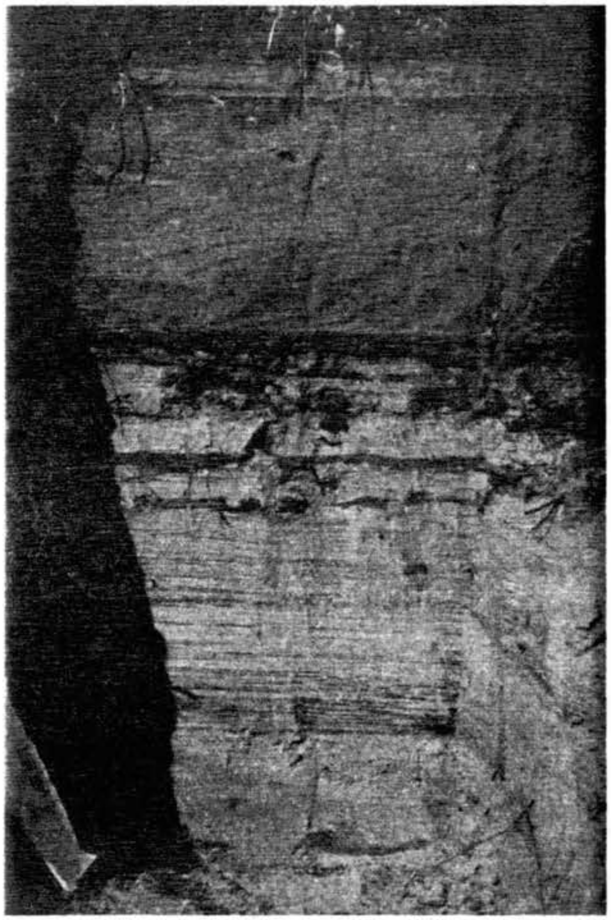

Fig. 16.-Horizontal bedding with clay-drape interbeds, overlain by climbing ripples on north end of Trench 8. Stream flow is from left to right.

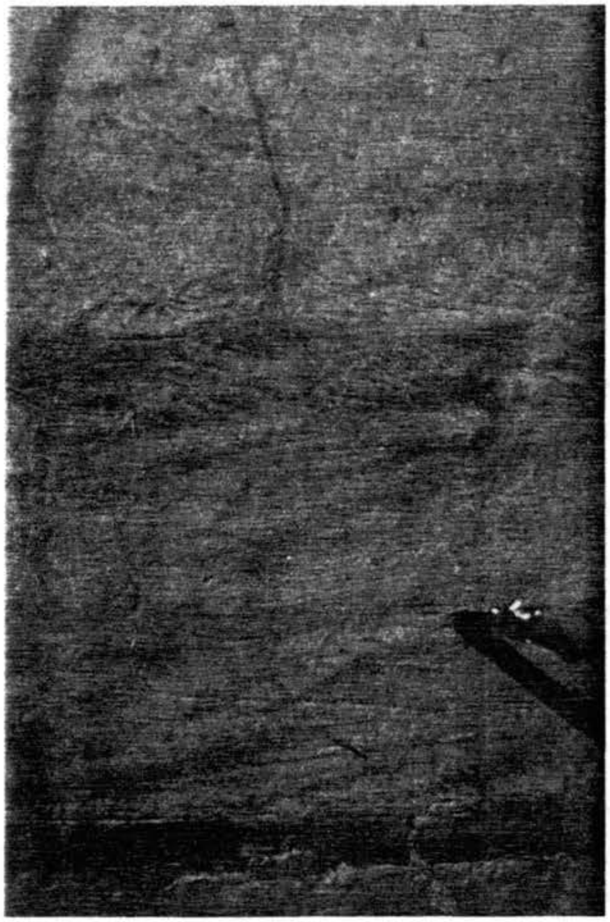

Fig. 17.-Detailed view of climbing ripples shown in Figure 16. Stream flow is from left to right.

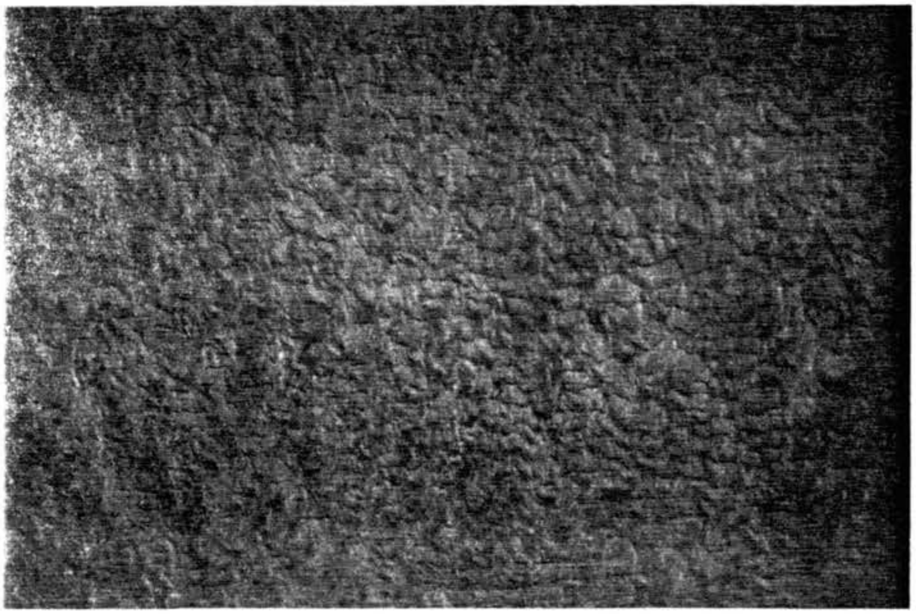

Fig. 18.-Ripples forming small-scale trough sets on the stoss side of a transverse dune. Stream flow is from top to bottom.

Parting lineation was observed by hand separation of horizontal laminae exposed at trench sites (Fig. 19). Sample-site locations (Fig. 23) and measurements of directional data (Table III) are given in the Appendix.

The range in mean directions for the different types of features is less than 30° (Fig. 20). Small- and medium-scale cross-beds show the greatest directional variation, with a spread of 210° and 200°, respectively. In spite of diverse measurements, the mean directions of S80°E for the small-scale cross-beds and S65°E for the medium-scale cross-beds give a reasonable approximation of the east-west sand (and river) trend.

Parting lineation, in horizontal or slightly inclined beds with an azimuthal spread of 120°, is considered to be the best current indicator. Stratification of this type forms during times of higher flow when the current tends to assume the valley trend rather than the meandering path during lower flow stages. However, the average direction of S75°E deviates some from that of the present valley trend.

Grain-orientation measurements by Burman (1973) also show some variation, but the average direction in horizontal beds on the north bank of the river is consistent with the valley and river trend, a relationship noted by Shelton and Mack (1970). Some of the variations in measurements reflect the determination of the horizontal component of grain orintation in medium-scale cross-beds. Although the average for measurements in medium-scale cross-beds depicts fairly

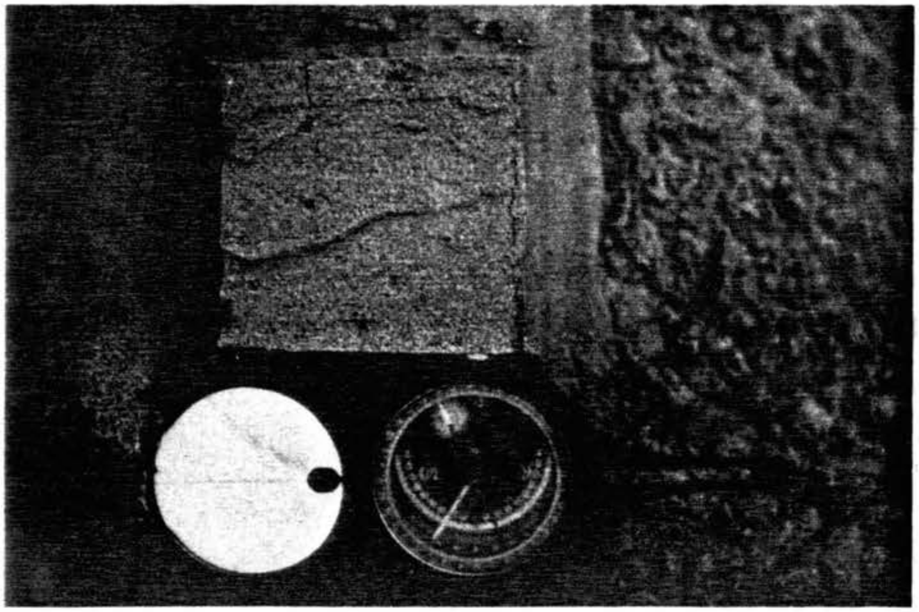

Fig. 19.-Parting lineation in unconsolidated sediment of the Cimarron River bar measures S70° E. Stream flow is from left to right.

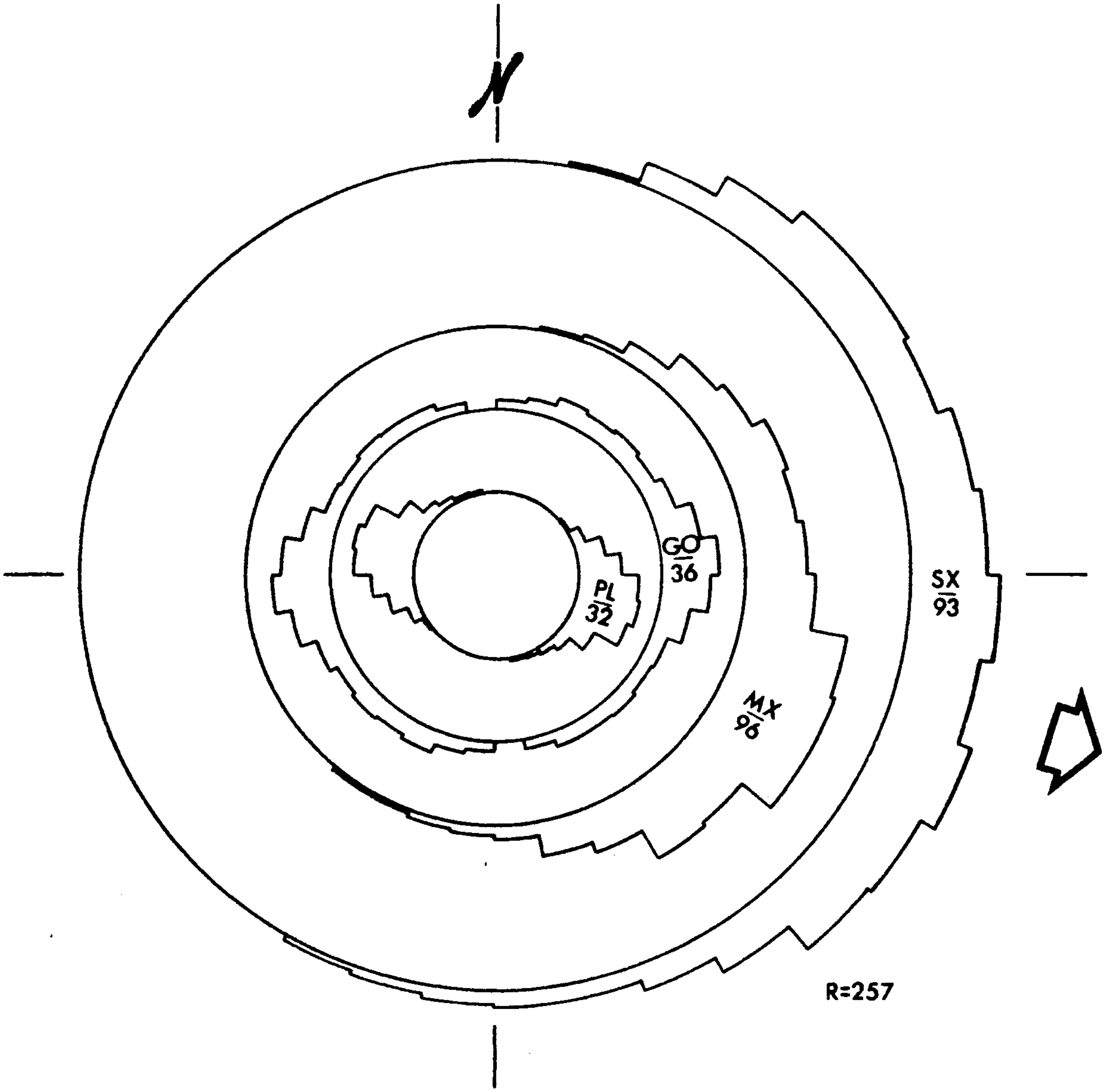

Fig. 20.-Directional features of Cimarron River deposits at Perkins, Oklahoma, show an overall direction of S75°E, which corresponds closely to the river trend. PL = parting lineation, GO = grain orientation, MX = medium-scale cross-bedding, SX = small-scale cross-bedding, R = total number of readings. A 30°-sliding average was used in preparation of this diagram.

well the river trend, grain orientation shows considerable variation within cross-beds, which in turn reflects the local current depositing them. Grain orientation and parting lineation in horizontal beds correlate best with the overall river trend.

The grand average for all current indicators is approximately S75°E, or about 15° south of the valley trend. The difference in direction is thought to be related to those processes of bar formation wherein sedimentary structures are preserved on the accretionary downstream side of the bar and structures on the upstream side are destroyed or strongly modified by erosion (Figs. 5-8). Under these conditions, a grand average in an east-southeast direction is expected for features of a sand bar on the south side of a river trending east-west.

From thin-section study, grain imbrication dips upstream in the horizontal beds but downstream in cross-beds. However, the average downstream angle is less than the dip of the foreset laminae. These observations are consistent with those of Ore (1963) and Shelton and Mack (1970).

Texture and Derived Properties

The sediments of the Cimarron River are approximately 90 percent sand and 10 percent silt and clay. The sand contains scattered quartz, sandstone and intraformational pebbles. Coarser sediments occur on the bar than on the north bank. Both areas are characterized by an overall upward decrease in grain size.

Grain-size analyses were made of 62 sand samples using the visual accumulation tube (Subcommittee on Sedimentation, 1958). Thirty-three additional samples analyzed in the Oklahoma State University sedimentology laboratory have also been included in the textural characterization of the river deposits. Sample-site locations and results of the analyses are given in the Appendix. The following parameters for each of the samples listed in Tables IV and V of the Appendix are summarized in Table I: (1) median diameter; (2) mean diameter (Inman, 1952); (3) Trask's sorting coefficient; and (4) Inman phi standard deviation.

The medium-scale cross-beds are composed of fine- to coarse-grained sand, with median diameters ranging from .129 mm (2.95ø) to .351 mm (1.51ø), and mean diameters from .176 mm (2.51ø) to .361 mm (1.47ø). The phi standard deviation is .30 to 1.21, and the range in sorting coefficient is from 1.13 to 1.98. On the average, sand of medium-scale cross-beds is medium-grained (.252 mm, 1.99ø) and well-sorted (1.25, Trask).

The median diameter of sand in small-scale cross-beds varies from .116 mm (3.11ø) to .276 mm (1.86ø), and mean diameters range from .115 mm (3.12ø) to .280 mm (1.84ø). The range in phi standard deviation is .28 to .62, and the sorting coefficient is 1.15 to 1.45. This type of stratification is generally fine-grained (.212 mm, 2.24ø),

TABLE I

AVERAGE GRAIN-SIZE PARAMETERS OF CIMARRON RIVER SAND

Stratification Type	Number of Samples	Median Diameter		Mean Diameter		Trask's Sorting Coefficient	Inman Standard Deviation
		mm	ϕ	mm	ϕ		
Medium-scale Cross-bedding	34	.250	2.00	.252	1.99	1.25	.48
Small-scale Cross-bedding	12	.212	2.24	.212	2.24	1.26	.47
Horizontal Bedding	49	.152	2.72	.139	2.76	1.29	.54

well-sorted (1.26, Trask), and slightly more consistent in grain size than medium-scale cross-bedding.

The range of median diameter of sand in horizontal bedding is from .046 mm (4.54ø) to .352 mm (1.50ø) and .043 mm (4.54ø) to .359 mm (1.48ø) for mean diameter. Phi standard deviation varies from .31 to 1.12, and sorting coefficient is 1.12 to 1.66. These sediments typically are fine-grained (.139 mm, 2.76ø) and slightly less well-sorted (1.29, Trask) than the medium- and small-scale cross-beds.

From petrographic analysis of 3 thin sections, the ands are fine- to medium-grained and well-sorted, with generally subrounded grains. Most grains show point conacts, and bridged grains are common. The porosity was stimated from comparators (Beard and Weyl, 1973) to be pproximately 35 percent.

Pebbles are found mainly in the medium-scale crossedding. Clay galls are as much as 3 in. in maximum imension, and they are generally coated with sand. Sandtone and quartz pebbles range in size from 5 to 40 mm. The lay-size sediments compose clay drapes which are present as hin interbeds in the bar deposits.

From these analyses, Cimarron River sand may be haracterized as upper fine-grained and well-sorted. Horiontal beds show the greatest variation in grain size. They ontain the finest sand, and medium-scale cross-beds contain he coarsest sand (Fig. 21).

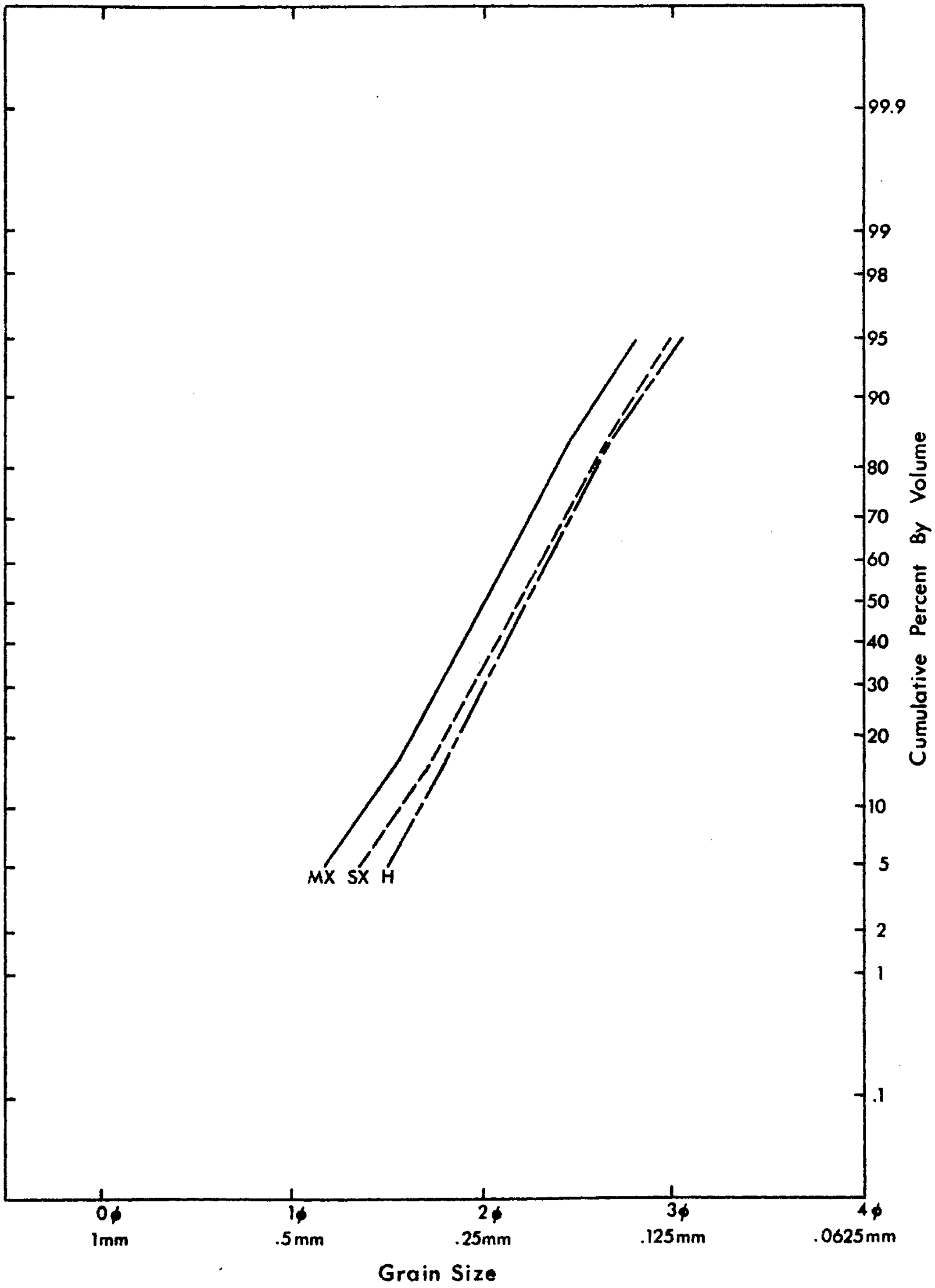

Fig. 21.-Average grain-size distributions for medium-scale cross-beds (MX), small-scale cross-beds (SX), and horizontal beds (H) in Cimarron River deposits.

Constituents

From study of the 3 thin sections, Cimarron River sand (Fig. 22) contains approximately 48 percent quartz, 39 percent potassium feldspar, 6 percent chert, 4 percent plagioclase, and 2 percent rock fragments. Accessory constituents include magnetite, muscovite, and calcite. The sand is an arkose according to the classification of McBride (1963). Many of the feldspar grains show some alteration to sericite. The alteration is apparently a type which occurs at high temperature rather than during low-temperature, authigenic-diagenetic alteration (Z. Al-Shaieb, personal communication, 1973).

The feldspathic sediments of the Cimarron River are thought to have originated ultimately from a northwestern source (Fay, 1962) and also from a southern source area. The Pliocene Ogallala Formation, which forms a wide belt from Texas to South Dakota, is a major source. The river flows for about 160 miles across the Ogallala, a complex of massive to cross-bedded, arkosic gravel, sand, and silt (Bayne and O'Connor, 1968). These sediments were deposited by streams flowing eastward from the Rocky Mountains where weathering and erosion of crystalline rocks provided grains of quartz and potassium feldspar. For approximately 200 miles upstream from the study area the Cimarron River flows across Permian units, which were derived in part from the Wichita tectonic element.

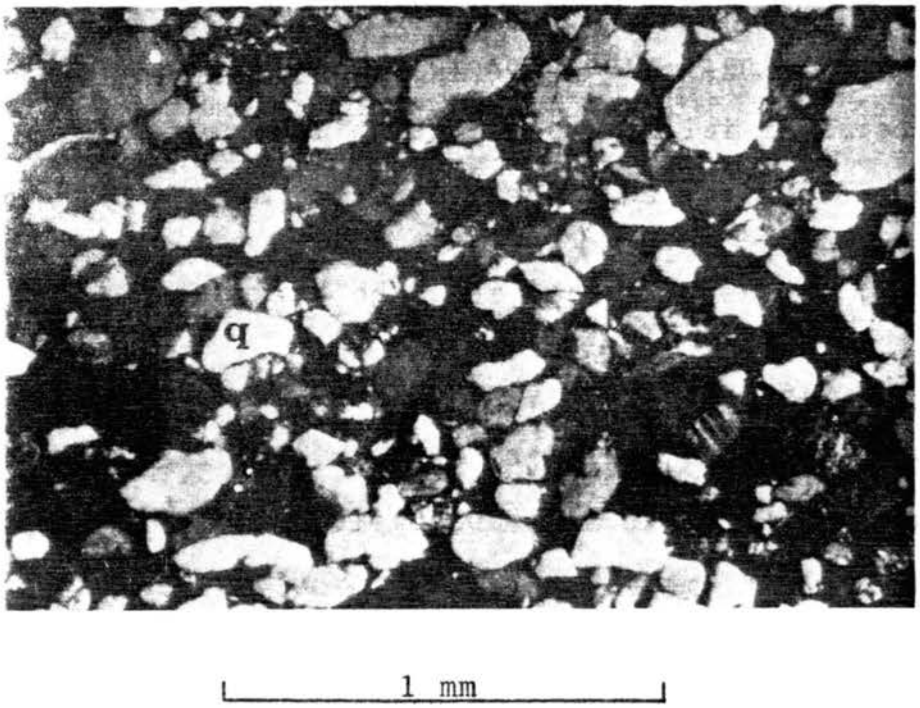

Fig. 22.-Photomicrograph of arkosic Cimarron River sand. It is composed primarily of subrounded, well-sorted, fine-grained quartz (q) and potassium feldspar (f). Flow from left to right is indicated by average imbrication in the horizontally-bedded sand. Crossed nicols.

CHAPTER V

SEDIMENTOLOGIC SIGNIFICANCE

The primary significance of the Cimarron River is that it possesses some characteristics of meandering streams and others of braided streams. Of secondary significance is the likelihood that ancient streams with similar features deposited sand which presently is a subsurface reservoir.

Features of Other Stream Types

The Brazos River at Richmond, Texas (Bernard *et al.*, 1970) and the Amite River near Magnolia, Louisiana (McGowen and Garner, 1970) are well-documented examples of meandering streams. Investigations of braided streams include those of the South Platte River in northeastern Colorado by Ore (1963; 1964) and Smith (1970; 1972) and the Donjek River at Mile 1133 of the Alaska Highway, Yukon Territory, Canada, by Williams and Rust (1969).

Meandering Streams

The Brazos River, as well as portions of larger rivers uch as the Red River (Harms *et al.*, 1963) and the Mississippi River (Fisk, 1944, 1947; Frazier and Osanik, 961), is a meandering stream which is highly sinuous (1.9) and has a low gradient (1.3 ft/mi). Natural levees, or overbank deposits, and extensive meander belts, with promi- ent point-bar deposits, are well developed along meandering streams of this type. Discharge is regular and continuous s the river flows in an undivided channel. Point-bar eposits are commonly characterized by the formation of ccretion ridges on both the upstream and downstream sides f bars. The width of the Brazos River is approximately 50 ft at low-flow stage and about 1500 ft at bankfull stage. he depth varies from less than 10 ft at low-flow stage to bout 55 ft at bankfull stage. The average thickness of a enetic unit for the Brazos River is approximately 55 ft, ith a total thickness of about 90 ft for 2 units. Ripples nd dunes are the main bed forms. A typical section from ottom to top consists of the following sedimentary struc- ures: (1) massive bedding, (2) medium-scale cross-bedding, 3) horizontal bedding, and (4) small-scale cross-bedding. ese deposits, showing upward fining, contain sediment with average range in grain size from clay-silt (.0039 mm) d very fine sand (.094 mm) in the upper part of the quence to very coarse sand (2.00 mm) and gravel in the wer part.

In another type of meandering stream, represented by e Amite River, the sinuosity (1.4-1.7) is less and the adient (3.2 ft/mi) is steeper. Discharge is continuous t irregular due to seasonal short-duration peak flow; tural levees, or overbank deposits, are absent or subtly eveloped. The width of the stream is about 250 ft at ankfull stage and 70 ft at low-flow stage. The depth anges from approximately 22 ft at high-flow stage to about ft at low-flow stage, and a genetic unit exceeds 25 ft in hickness. Bed forms consist mainly of dunes but ripples ccur locally where fine-grained sediments exist. Typical edimentary structures of these deposits are medium-scale ross-bedding with lesser amounts of small-scale cross- edding and horizontal bedding. The sediment, which has an verage range in grain size from fine sand (.177 mm) to very oarse sand (2.00 mm), is somewhat coarser than sediment of he Brazos River. More significantly, grain size is gener- lly uniform in a vertical sequence.

raided Streams

The South Platte River is a braided stream characterized low sinuosity (1.1), and steep gradient (6.7 ft/mi). ighly variable discharge rates, together with abundant ediments, result in the divided channel characteristic of aided rivers. The dominant bed form consists of longitu- nal bars, with some dunes and ripples. Massive bedding d medium-scale cross-bedding are the main sedimentary ructures. The mean grain size of the sediments ranges om coarse sand to granule gravel and decreases downstream.

The Donjek River also has low sinuosity (1.0-1.3), and scharge rates, like the South Platte River, are highly riable. Individual channels are numerous, and they increase in number during low-flow stage. The width of the river is about 5250 ft during bankfull stage, with depths of approximately 10 ft at high-flow stage and about 5 ft at low-flow stage. The thickness of a genetic unit is about 45 ft; the total thickness of the deposits is greater than 125 ft. Longitudinal bars, ripples, and some dunes are the dominant bed forms. Small-scale cross-bedding, medium-scale cross-bedding, and horizontal bedding are the dominant sedimentary structures. Sediments, on the average, range in grain size from medium-grained (.33 mm) and coarse-grained (.71 mm) sand to pebble-cobble gravel (16 mm to 250 mm). Grain size shows both upward and downstream fining.

Comparison With Other Stream Types

In an attempt to determine those characteristics of the Cimarron River which are common to meandering and/or braided streams, features are compared with those of the Brazos and Amite Rivers, and those of the South Platte and Donjek Rivers (Table II).

The sinuosity of the Cimarron River is 1.5, a value which is lower than that of meandering streams, like the Brazos River, but very similar to less-sinuous meandering streams, such as the Amite River. Braided rivers have lower inuosity than the Cimarron River. The gradient of 1.8 ft/mi s higher than that of the Brazos River but less than the gradient of the steeper Amite River. Braided streams enerally have steeper gradients, as shown by a gradient of

TABLE II

COMPARISON OF STREAM TYPES

		MEANDERING STREAMS		BRAIDED STREAMS		BRAIDED-MEANDERING STREAM
FEATURE		BRAZOS [1] Richmond, Tex	AMITE [2] Magnolia, La	SOUTH PLATTE [3] Dearfield, Colo	DONJEK [4] Mile 1133, Alaska Hwy Yukon, Canada	CIMARRON Perkins, Okla
Sinuosity		1.9	1.4-1.7	1.1	1.0-1.3	1.5
Gradient		1.3 ft/mi	3.2 ft/mi	6.7 ft/mi	---	1.8 ft/mi
Maximum Width	High Flow	1500 ft	250 ft	800 ft	5250 ft	1800 ft
	Low Flow	350 ft	70 ft	200 ft	300 ft	200 ft
Maximum Depth	High Flow	55 ft	22 ft	---	10 ft	15 ft
	Low Flow	10 ft	6 ft	---	5 ft	3 ft
Thickness	Genetic Unit	55 ft	>25 ft	---	45 ft	15 ft
	Total	90 ft	---	---	>125 ft	30 ft
Dominant Bed Form*		Dunes Ripples	Dunes ripples	Longitudinal Bars ripples dunes	Longitudinal Bars Ripples	Dunes Ripples
Prominent Sedimentary Structures*		Small-scale Cross-bedding Horizontal Bedding Medium-scale Cross-bedding Massive Bedding clay drape	Medium-scale Cross-bedding small-scale cross-bedding horizontal bedding	Massive Bedding small-scale cross-bedding medium-scale cross-bedding	Massive Bedding Small-scale Cross-bedding horizontal bedding medium-scale cross-bedding	Small-scale Cross-bedding Medium-scale Cross-bedding Horizontal Bedding clay drape
Texture	Vertical Sequence	upward fining	constant grain size		upward fining	upward fining
	Lateral Sequence			downstream fining in longitudinal bars	downstream fining in longitudinal bars	
	Dominant Grain Size	clay-silt and very fine- to medium-grained sand (.094 to .250 mm) in upper portion, very coarse-grained sand (2.00 mm) and gravel at base	fine- to very coarse-grained sand (.177 to 2.00 mm)	coarse-grained sand (1.00 mm) to granule gravel (2.85 mm)	pebble-cobble gravel (16 to 250 mm) with medium- to coarse-grained sand (.35 to .71 mm)	fine- to medium-grained sand (.139 to .252 mm), with clay-silt

*Relative prominence indicated by capitalization.

[1] Data from Bernard *et al*. (1970)

[2] Data from McGowen and Garner (1970)

[3] Data from Ore (1963; 1964) and Smith (1970; 1972)

[4] Data from Williams and Rust (1969)

6.7 ft/mi for the South Platte River.

Flow in the Cimarron River is continuous but seasonally irregular, whereas flow is more regular in meandering streams but more irregular in braided streams. During times of high flow the Cimarron resembles a meandering stream, but it resembles a braided stream at low-flow stages. Accretion ridges along the Cimarron form mainly on the downstream sides of river bars, whereas accretion ridges of meandering streams commonly form on both the upstream and downstream sides of point bars. Accretion ridges generally do not form along braided streams in which longitudinal bars are the dominant bed form. Levee, or overbank, deposits characterize highly sinuous meandering streams but are subtly developed along the Cimarron River.

A width of 1800 ft for the Cimarron River at high-flow stage is greater than those of the Brazos and Amite Rivers, but a width of 200 ft for it at low-flow stage is between those of the 2 meandering rivers at a corresponding stage. In comparison to braided streams, the width of the Cimarron River at high-flow stage is between those of the South Platte and Donjek Rivers but equal to or less than their widths at low-flow stage. Depths of the Cimarron River at oth high- and low-flow stage are less than those of the eandering streams, whereas the depth of the Donjek River is ess than that of the Cimarron River at high-flow stage ut greater at low-flow stage. Deposits of the Cimarron iver are thinner than those of the meandering streams and of the Donjek River deposits.

Sedimentary structures of the Cimarron River consist mainly of cross-bedding and horizontal bedding, whereas meandering streams generally show minor development of the latter type. Braided streams contain massive bedding and cross-bedding. In the Cimarron River and in the meandering streams, bed forms are dunes and ripples; braided streams contain longitudinal bars, with fewer dunes and ripples.

The fine- to medium-grained, well-sorted sand of the Cimarron shows upward fining. These parameters are similar to deposits of those meandering streams with more silt-clay and gravel. Deposits of braided streams are coarser and more poorly sorted; they characteristically contain sand to cobble-size sediments and generally insignificant amounts of clay and silt. Downstream fining is common in braided streams, and upward fining, although present in the sediments of the Donjek River, is thought to be uncommon.

Potential Use in Determination of Genesis and Trend of Sandstones

Characteristics which are most likely to be of potenial use in recognizing sandstones of environments similar o the Cimarron River include both geometry and internal eatures. The depth and corresponding thickness of a genetic nit are less than those of meandering streams and the dth-depth ratio is greater than that for meandering reams. Horizontal bedding is much more abundant along braided-meandering streams than in deposits of either braided or meandering streams. Sedimentary structures of the latter are otherwise quite similar to those along the Cimarron River, whereas the braided stream generally contains massive bedding with some cross-bedding. Typical braided-stream deposits are much coarser, more poorly sorted, and generally are not characterized by the upward-fining sequence displayed by the finer grained deposits of the Cimarron River.

Most alluvial deposits, except those of meandering streams near sea level, are probably preserved only under special conditions. Upstream deposits of braided or non-meandering streams might be preserved as a result of basinal subsidence or because of eustatic changes in sea level. It is thought that the same conditions necessary to preserve braided-stream deposits are also required for preservation of river deposits similar to those of the Cimarron at Perkins.

The Silurian Tuscarora, Mississippian Pocono, and Pennsylvanian Pottsville Formations are examples of thick wedge-shaped alluvial deposits which formed on subsiding coastal plains flanked by eastern and southeastern source areas. The Tuscarora has been described as a meandering-stream deposit by Yeakel (1962) and a distal braided-stream deposit by Smith (1970). Some of the deposits of the Tuscarora Formation might have formed in a braided-meandering stream environment. It is also thought that some nits of the Pocono Formation, described by Pelletier 1958), and the Pottsville Formation, described by Meckel 1967), might also be similar in origin to the Cimarron eposits at Perkins.

Lenticular alluvial sandstones of the Pennsylvanian ystem in the Mid-Continent, which in part may be composed f braided-meandering stream deposits, include the Kisinger andstone in Texas, studied by Lee <u>et</u> <u>al</u>. (1938), the Anvil ck Sandstone (Hopkins, 1958; Potter and Simon, 1961) and e Trivoli and the Ingleside Formations (Andresen, 1961) the Illinois basin, and the inland part of the Bartles- lle Sandstone of northeast Oklahoma and Kansas (Visher, 68).

It is thought that the trend of ancient braided- andering stream deposits can be accurately determined by equate sampling of directional features. Parting linea- on in horizontal bedding is the most reliable current dicator. Determination of trend at the surface requires tcrop continuity, as opposed to isolated exposures. r subsurface determination, vertically continuous sampling a requirement which might be met by a downhole modifica- n of the procedure used by Burman (1973) in confirming in orientation as a valid paleocurrent indicator.

CHAPTER VI

SUMMARY

This sedimentologic study of the Cimarron River at Perkins, Oklahoma, has the following as principal conclusions:

1. Discharge rates of the river are highly variable, with a recorded average monthly maximum of 17,800 cfs and an average monthly minimum of 2.15 cfs.
2. Permian bedrock in the valley has been channeled and terraced in a fashion similar to the present land surface.
3. The channel is characterized by a gradient of 1.8 ft per mi and a sinuosity of 1.5.
4. During the greatest flood on record, in 1914, the Cimarron River developed a slightly steeper gradient and a less sinuous path. Since that change, the river has tended to revert gradually to a more sinuous path.
5. Two types of accretion ridges are present within a short stretch of the river at Perkins. One type, which is more commonly associated with point bars of highly sinuous streams, is characterized by the formation of ridges on both upstream and downstream sides of the convex bank. Accretion ridges of the second type form in straighter reaches on the downstream side of the convex bank.

). Secondary channels which form during bankfull and flood
;tages become abandoned and filled with finer grained
;ediments.

'. Variability in discharge rates affects the amount of
'egetation on river bars. With periods of low-discharge
'ates but adequate precipitation, vegetation can stabilize
he bar. Regular flooding or periods of higher discharge
imit the amount of new vegetation which can become estab-
ished, and the bar is thereby subject to erosion during
igh flow.

. The 3 most abundant sedimentary structures in the
imarron River are horizontal bedding, medium-scale trough
nd tabular cross-bedding, and small-scale cross-bedding.
lay drapes are also present but volumetrically are less
ignificant.

. Cross-bedding, parting lineation, and grain orientation
l1 define the river trend very well and indicate that
irectional features in this type of sand deposit are useful
ı estimation of trend. Parting lineation in horizontal
:dding yields the most reliable directional data.

). Average grain imbrication is upstream in horizontal
:ds and downstream in cross-beds, at an angle less than the
p of the foreset laminae.

. The sediments consist of approximately 90 percent fine-
medium-grained, well-sorted sand, and 10 percent silt and
ay, with scattered pebbles ranging in diameter from 5 mm
about 70 mm. Overall, the sediments decrease in grain

size upward.

12. Grains are generally subrounded; most contacts are point, and bridged grains are common. Porosity is about 35 percent.

13. The sand is an arkose. Ultimate source areas are thought to be the southern Rocky Mountains and the Wichita uplift.

14. The sinuosity and gradient of the Cimarron River are intermediate between those of braided and highly sinuous meandering streams but are very similar to the less sinuous type of meandering streams.

15. The depth of the Cimarron River is less than that of meandering streams, and it has a greater width-depth ratio than meandering streams.

16. The thickness of a genetic unit of the Cimarron River is less than those for meandering streams.

17. Bed forms in the Cimarron River and meandering streams are dunes and ripples, whereas longitudinal bars are dominant in braided streams.

18. The Cimarron River contains more horizontal bedding than either braided or meandering streams.

19. Levee, or overbank, deposits are subtly developed along the Cimarron River, the braided streams, and the less sinuous meandering streams, but they are well developed along highly sinuous meandering streams.

20. Texture of the Cimarron River sediments is similar to that of meandering streams. The deposits contain less

fine-grained clastics than the highly sinuous meandering streams but more than the less sinuous meandering streams. Braided-stream deposits contain sediments which are coarser and less well-sorted than deposits of the other stream types.

21. An upward-fining sequence is present in the Cimarron River and in the highly sinuous meandering streams but apparently is not developed in less sinuous meandering streams.

22. The type of sand deposit represented by the Cimarron River alluvium may be similar to certain ancient alluvial sandstones which were deposited during either subsidence or eustatic rise in sea level.

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APPENDIX

DIRECTIONAL DATA AND GRAIN-SIZE PARAMETERS

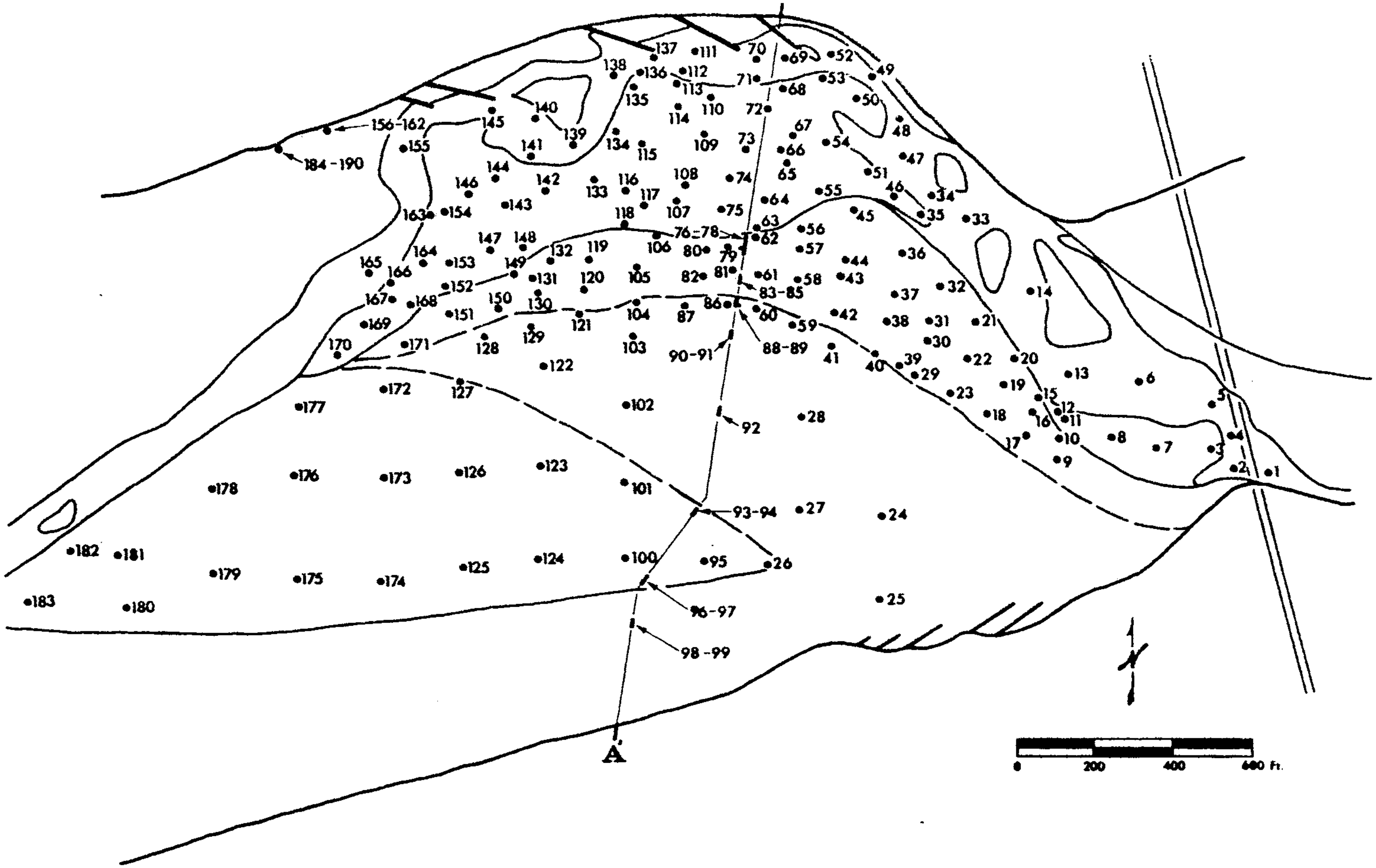

Fig. 23.-Locations in study area along Cimarron River where directional features were measured and deposits sampled for grain-size analysis.

TABLE III

DIRECTIONAL INDICATORS, CIMARRON RIVER DEPOSITS

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
1				S45° E
2				S58° E
3			S45° E	
4				S 1° E
5				S35° E
6				S55° E
7				S64° E
8			S30° E	S52° E
9			S64° E	
10			S60° E	N33° E
11			S68° E	S67° E
12				S52° E
13				S55° E
14				N90° E
15			S32° E	S59° E
16			S45° E	
17	N90° E		N70° E	
18			S50° E	
19			S65° E	
20			S44° E	
21			S47° E	
22	N90° E		S39° E	S75° E
23			S50° E	S55° E
24				N90° E
25				S60° E
26			N90° E	
27		S75° E		
28			S45° E	
29			S75° E	S14° E

TABLE III (Continued)

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
30			S55°E	
31			N75°E	N48°E
32			S19°E	
33				S35°E
34				S10°W
35				S 2°E
36	S79°E*		S81°E	S47°E
37			S70°E	
38			S60°E	S40°E
39		S70°E		
40			S45°E	
41				
42	N90°E		S60°E	
43			S65°E	
44			S80°E	
45			N55°E	S54°E
46				S53°E
47				S10°W
48				S20°E
49				S40°E
50	N37°E		S 2°E	S52°E
51	S60°E		N59°E	S56°E
52				S80°E
53				N80°E
54	N60°E		S50°E	N45°E
55				N43°E
56			S60°E	N33°E
57	N90°E		S65°E	
8			S70°E	
9				

TABLE III (Continued)

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
60			S70°E	
61			S65°E	
62			S70°E	
63			S70°E	N80°E
64				N85°E
65				N83°E
66			N88°E	N88°E
67				S85°E
68			S 2°E	S75°E
69				N45°E
70				S20°E
71				S80°E
72				S49°E
73			S85°E	N74°E
74				S75°E
75				S77°E
76	N30°E		S85°E	
77	N15°E		S45°E	
78	N45°E		N85°E	
79	N30°E		S70°E	
80			S80°E	
81			N80°E	
82			N90°E	
83	N60°E	S72°E		
84	N60°E		N55°E	
85	S55°E			
86		S30°E		
87				S40°E
88	S30°E	S75°E	N80°E	
89	S60°E		N55°E	

TABLE III (Continued)

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
90	S30° E		S25°E	
91	N90° E	S73°E		
92	N90° E			
93	S30° E		S25° E	
94	N90° E	S60°E		
95			S40° E	
96	N30° E		S30° E	
97	N90° E		S25° E	
98	N90° E	S65°E		
99	S60° E			S77°E
100			S20° E	
101		S45°E		
102		S80°E	S30° E	S75°E
103			S65° E	
104		S75°E	S50° E	
105			S35° E	N90°E
106	N90°E		N65° E	
107			S10° E	S67°E
108			S40° E	
109				S46°E
110			S64°E	N73°E
111	S30°E			S25°E
112				S65°E
113				S58°E
114			S70°E	N70°E
115			S 2°W	N63°E
116			S69°E	N83°E
117			S82°E	S82°E
118				N78°E
119	N90°E		N80°E	

TABLE III (Continued)

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
120			S65° E	
121		S60°E		
122		N75°E		
123		N90° E		
124		S60°E	S25°W	
125		N85°E	S55°E	
126		N75°E	N75°E	
127			S70° E	
128		N90° E		
129		S80°E		
130				
131	N60°E		N45°E	
132			N75°E	
133			N45°E	N80° E
134				S79° E
135	N90°E		N75°E	S82° E
136				N36° E
137				N65° E
138				N40° E
139				N90°E
140				S45° E
141				S50° E
142			S70° E	N85° E
143			S25° E	N50° E
144			S75° E	N51° E
145				S75° E
146			N70° E	N36° E
147			N65° E	N69° E
148	N90°E		S80° E	S68°E
149				N60°E

TABLE III (Continued)

Sample No.	Grain Orientation	Parting Lineation	Medium-scale Cross-beds	Small-scale Cross-beds
150				
151				
152	N75° E		S60°E	
153			N50°E	N65° E
154				N55° E
155				N30° E
156	N15° E	N75°E	N70°E	
157	N73° E*		S30°E	N35° E
158			N60°E	N49° E
159				N45° E
160			N38°E	N53° E
161			N28°E	N58° E
162			N50°E	N90° E
163			N78°E	N68° E
164			N56°E	N68° E
165				S80° E
166		N90° E	S70°E	
167		S80° E		
168		N70° E		
169		S70° E		
170		S80° E		
171		N85° E		
172		S60° E		
173		N90° E		
174		S75° E		
175		S70° E		
176		S80° E		
177		S60° E		
178	N73° E			

*Measurement by Shelton and Mack (1970)

TABLE IV

GRAIN-SIZE PARAMETERS OF CIMARRON RIVER DEPOSITS

HORIZONTAL BEDDING: BAR

Sample No.	Median Diameter		Mean Diameter		Trask's Sorting Coefficient	Inman Standard Deviation
	mm	ø	mm	ø		
15	.208	2.27	.206	2.28	1.15	.32
17	.283	1.82	.278	1.85	1.17	.34
83	.242	2.05	.238	2.07	1.23	.43
85	.212	2.24	.204	2.30	1.19	.42
92Top	.263	1.93	.261	1.94	1.24	.44
92Bot	.337	1.57	.359	1.48	1.31	.58
91	.195	2.36	.188	2.41	1.23	.47
94	.150	2.74	.146	2.78	1.27	.53
98	.133	2.91	.127	2.98	1.24	.47
129	.209	2.26	.208	2.27	1.16	.34
Average	.213	2.22	.212	2.24	1.22	.43
HORIZONTAL BEDDING: BANK						
156	.106	3.27	.104	3.28	1.12	.35
157	.352	1.50	.299	1.74	1.55	1.02
158	.190	2.40	.209	2.26	1.66	1.01
159	.137	2.86	.152	2.71	1.40	.76
160	.141	2.82	.133	2.91	1.37	.73
161	.123	3.04	.129	2.95	1.26	.55
162	.125	3.00	.120	3.07	1.15	.38
184	.146	2.78	.200	2.33	1.65	1.12
185	.139	2.85	.135	2.89	1.27	.50
186	.128	2.97	.128	2.97	1.40	.51
187	.124	3.02	.132	2.92	1.31	.58
188	.092	3.44	.099	3.34	1.54	.49
189	.112	3.17	.112	3.16	1.25	.73
190	.127	2.96	.130	2.94	1.28	.52
Average	.113	2.86	.142	2.82	1.37	.66
MEDIUM-SCALE CROSS-BEDDING: BAR						
3	.247	2.02	.254	1.98	1.15	.33
15	.205	2.29	.200	2.33	1.23	.49
17	.224	2.16	.222	2.17	1.19	.48
23	.264	1.92	.252	1.99	1.20	.36
30	.314	1.67	.332	1.59	1.26	.49
31	.190	2.40	.186	2.43	1.16	.30
45	.284	1.80	.290	1.79	1.19	.38
51	.226	2.15	.232	2.11	1.26	.50
56	.214	2.23	.218	2.20	1.17	.40
66	.210	2.25	.201	2.32	1.24	.48
77	.351	1.51	.361	1.47	1.35	.61
80	.238	2.07	.250	2.00	1.24	.49
84	.304	1.72	.308	1.70	1.22	.44
89	.230	2.12	.224	2.16	1.20	.41
90	.224	2.16	.225	2.15	1.19	.38

TABLE IV (Continued)

Sample No.	Median Diameter mm	 ø	Mean Diameter mm	 ø	Trask's Sorting Coefficient	Inman Standard Deviation
93	.268	1.90	.268	1.90	1.28	.49
96	.187	2.42	.176	2.51	1.29	.55
97	.258	1.96	.259	1.95	1.14	.35
104	.222	2.17	.224	2.16	1.18	.37
110	.208	2.27	.206	2.28	1.15	.31
117	.250	2.00	.243	2.04	1.20	.39
132	.321	1.64	.316	1.66	1.36	.64
144	.304	1.72	.306	1.71	1.34	.68
158	.272	1.88	.254	1.98	1.30	.57
170	.321	1.64	.344	1.54	1.13	.49
Average	.250	2.00	.250	2.00	1.22	.45
MEDIUM-SCALE CROSS-BEDDING: BANK						
156	.129	2.95	.191	2.39	1.98	1.21
SMALL-SCALE CROSS-BEDDING: BAR						
7	.270	1.89	.264	1.92	1.23	.44
23	.242	2.05	.223	2.17	1.29	.56
45	.276	1.86	.280	1.84	1.22	.43
54	.191	2.39	.195	2.36	1.26	.50
56	.201	2.32	.205	2.29	1.15	.28
66	.169	2.56	.181	2.47	1.33	.62
67	.218	2.20	.214	2.23	1.28	.49
99	.116	3.11	.115	3.12	1.45	.52
110	.258	1.96	.250	2.00	1.21	.41
117	.221	2.18	.215	2.22	1.23	.45
144	.254	1.98	.263	1.93	1.19	.38
164	.198	2.34	.194	2.37	1.25	.53
Average	.212	2.24	.212	2.24	1.26	.47

TABLE V

GRAIN-SIZE DATA OF CIMARRON RIVER DEPOSITS ANALYZED BY STUDENTS IN OKLAHOMA STATE UNIVERSITY SEDIMENTOLOGY LABORATORY, 1969-1972

Sample No.	Median Diameter mm	Median Diameter ø	Mean Diameter mm	Mean Diameter ø	Trask's Sorting Coefficient	Inman Standard Deviation
HORIZONTAL BEDDING: BANK						
1	.340	1.56	.334	1.58	1.29	.47
2	.095	3.40	.082	3.53	1.27	.54
3	.127	2.98	.125	3.00	1.30	.65
4	.091	3.43	.088	3.51	1.33	.64
5	.177	2.50	.158	2.67	1.17	.38
6	.046	4.45	.043	4.54	1.52	.83
7	.282	1.83	.284	1.82	1.14	.47
8	.129	2.95	.134	2.90	1.40	.66
9	.342	1.55	.324	1.63	1.24	.53
10	.109	3.20	.100	3.30	1.16	.35
11	.119	3.09	.128	2.97	1.41	.72
12	.245	2.03	.259	1.95	1.22	.35
13	.160	2.65	.158	2.67	1.15	.43
14	.145	2.80	.141	2.82	1.23	.48
15	.103	3.29	.104	3.28	1.25	.53
16	.122	3.04	.130	2.94	1.27	.56
17	.140	2.84	.138	2.85	1.30	.55
18	.125	3.00	.123	3.01	1.23	.49
19	.122	3.04	.130	2.94	1.25	.48
20	.115	3.12	.135	2.89	1.36	.71
21	.250	2.00	.226	2.14	1.16	.41
22	.108	3.20	.107	3.22	1.22	.44
23	.101	3.30	.104	3.26	1.17	.31
24	.138	2.85	.067	3.90	1.31	.50
25	.145	2.80	.134	2.90	1.34	.60
Average	.139	2.84	.135	2.89	1.27	.52
MEDIUM-SCALE CROSS-BEDDING: BAR						
26	.259	1.95	.259	1.95	1.31	.55
27	.223	2.17	.245	2.03	1.31	.58
28	.230	2.12	.226	2.14	1.20	.42
29	.310	1.69	.319	1.65	1.28	.55
30	.298	1.75	.292	1.78	1.23	.60
31	.250	2.00	.264	1.92	1.20	.29
32	.344	1.54	.306	1.71	1.22	.47
33	.272	1.88	.254	1.98	1.17	.39
Average	.270	1.89	.268	1.90	1.24	.48

VITA

Raymond Lee Noble

Candidate for the Degree of

Master of Science

Thesis: DEPOSITIONAL AND DIRECTIONAL FEATURES OF A BRAIDED-MEANDERING STREAM

Major Field: Geology

Biographical:

Personal Data: Born in Stamford, Texas, January 24, 1944, the son of Mr. and Mrs. Preston Riley Noble.

Education: Graduated from Hirschi High School, Wichita Falls, Texas, in May, 1963; received Bachelor of Science degree from Midwestern University, Wichita Falls, Texas, in May, 1971, with a major in geology; completed requirements for the Master of Science degree at Oklahoma State University, Stillwater, in July, 1973, with a major in geology.

Professional Experience: Undergraduate Teaching Assistant, Department of Geology, Midwestern University, 1969-71; Field Instructor Assistant, Department of Geology, Midwestern University, summer, 1972; Graduate Teaching Assistant, Department of Geology, Oklahoma State University, 1971-73; Junior Member of the American Association of Petroleum Geologists; Member of the Geological Society of America.