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A Disparity in the Rate of Lateral Channel Cutting
Between Two Reaches of the Kansas River

by

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Thesis Committee

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A DISPARITY IN THE RATE OF LATERAL CHANNEL CUTTING

BETWEEN TWO REACHES OF THE KANSAS RIVER

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D50	median grain size
ø	phi, given by $\frac{-\ln \text{diameter}}{.693}$
M_z	Folk's graphic mean
1	Folk's inclusive graphic standard deviation
sk_1	inclusive graphic skewness
	standard deviation
2	variance
Ho	null hypothesis
H1	alternative hypothesis
n	number of samples (cases)
R	sum of ranks
*	statistically significant
R	Spearman's correlation coefficient
	stream power
c	tractive force
D	depth
	density
W	bankfull width
Q	discharge
M	weighted silt-clay percentage

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ABSTRACT

Two adjacent reaches of the Kansas River near the town of Wamego, Kansas, exhibit markedly differing rates of channel migration. An active reach upstream of Wamego, flowing entirely within sandy modern alluvium [< 3000 years B.P.], displays extensive bank erosion and channel migration. Downstream, the channel comes into contact with fine-grained terrace fill sediment of variable ages [> 3000 years B.P.] and manifests stable channel characteristics.

Evaluation of valley slope, channel slope, sediment load, and bank sediment characteristics of each reach suggest that locally steepened valley slope may initiate channel activity and meander growth but the rapidity of the growth is a function of the sediment character of the stream bank. Cut banks along the active reach consist primarily of sandy sediment [mean-Ø3.4] and are easily eroded by the channel within the growing meander. Nonetheless, these cut banks contain sufficient silt and clay [37%] to provide the necessary bank stability for the development of an asymmetrical channel profile. Development and maintenance of a scour pool along the outside bend of the active meander allows for the undercutting of the cut bank and provides a mechanism for continued bank erosion. The degree of bank erosion along

the active reach is accentuated by the segregation of fine-grained material into discrete stratigraphic intervals.

Along the inactive reach, the sediments of the cut banks generally consist of terrace fill deposits. These sediments consist primarily of silt and clay [mean=Ø4.99] but may contain coarse sand in their basal portions. Anomalously high values of stream power and tractive force indicate that the inactive channel has not fully adjusted to the slope of the valley due to the resistant nature of the bank sediment. At locations where sand is exposed along the inactive reach and is subject to erosion, clay-rich sediment from slumped upper portions of the terrace fills provide an armoring protecting these lower portions of the bank.

CHAPTER I

INTRODUCTION

The Kansas River and its tributaries drain approximately 61,440 square miles (98,857km2) of northern Kansas, southern Nebraska, and eastern Colorado. The main stem of the Kansas River begins at the confluence of the Republican and Smoky Hill Rivers near Junction City, Kansas, and flows 170 miles (273 km) east to its confluence with the Missouri River at Kansas City (Fig. 1).

The Kansas River is a moderate size stream with a mean annual discharge of 4113 cubic feet per second (1254 m3/sec) at the town of Wamego. In recent years, the main branch of the stream has come under increasing regulation by dams built on upstream tributaries. The largest dams, Milford and Tuttle Creek, were closed in 1962 and 1967 respectively.

The Kansas River transports sand (D50 = 0.4 to 2mm) as bed load and a finer suspended load composed of silt and clay. The composition of material transported by individual tributaries of the Kansas River is a function of the geology of the area drained. Isolated reaches, especially within the lower Kansas River valley, contain

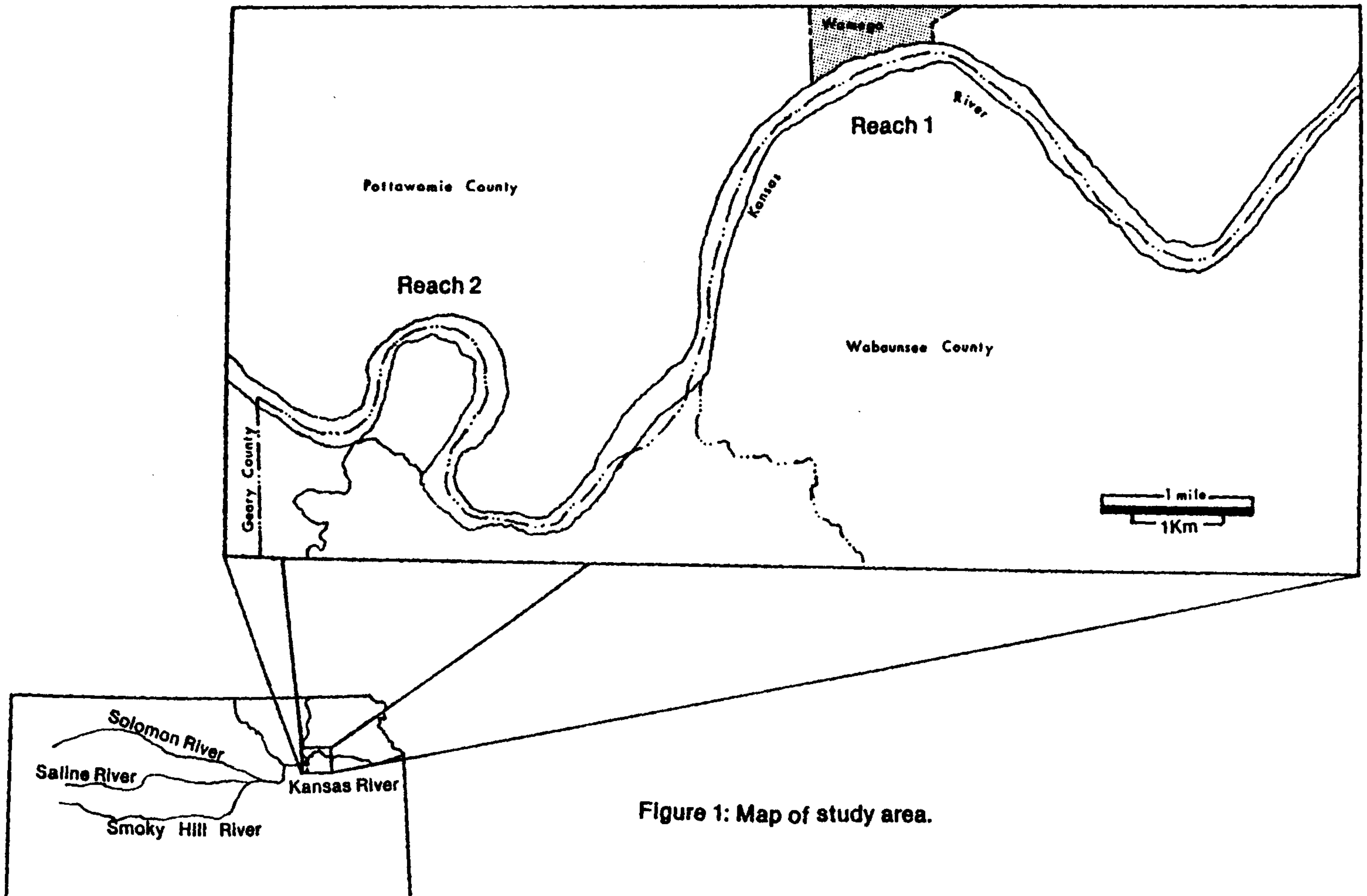


Figure 1: Map of study area.

gravel deposits which may serve to armor the channel against erosion.

CHANNEL ACTIVITY

Channel activity and instability occur locally but vary in intensity. Osterkamp and others [1982: 43] described channel activity as the lateral migration of the stream channel which is manifested in changes in the meander pattern. They defined channel instability as "the deviation from an adjusted or balanced condition that may be indicated in the cross-sectional geometry of the stream channel." To avoid confusion between the terms instability and activity, the definitions as stated above are used for the purpose of this study.

Osterkamp and others [1982] suggested that channel width varied in proportion to channel activity, the more active reaches containing wider channels. They identified a number of reaches of the Kansas River that have been historically active. If their assertion is correct, differing extents of channel activity may be identified by the range in channel width from over 1000 feet [305 m] near Paxico to just 400 feet [122 m] at Manhattan. Dort [1980] has also provided detailed information in the form of historic channel-change maps from which active reaches can be readily identified.

STATEMENT OF THE PROBLEM

This study examines two adjacent reaches of the Kansas River near Wamego: one that has undergone documented historical change and one that has remained relatively stable and inactive in historical times [Fig. 1]. The purpose of this study is to determine what conditions are responsible for the contrast in channel activity between the active reach and inactive reach of the study area.

The active reach, which has been characterized by rapid meander growth since 1919, has generated concern among local landowners and the United States Army Corps of Engineers [United States Army Corps of Engineers, 1980]. The anticipated cut off of a large meander endangers the 386 acres [156 hectares] of cropland created by prior meander growth [Fig. 1]. Downstream at Wamego, the channel within the inactive reach occupies approximately the same position as the 1885 channel [Dort, 1980]. Channel degradation occurred within the inactive channel during the 1951 flood, but the channel has remained relatively stable since that time [Osterkamp et al., 1982; United States Army Corps of Engineers, 1984].

Adjacent reaches were chosen for this study to ensure that crucial hydraulic characteristics undergo minimal variation between reaches. Discharge and sediment load are unlikely to change in the short distance as no major tributaries enter the river within the study area. Although Deep Creek does enter the Kansas River within the active reach, its discharge is small and comprises an insignificant percentage of the total discharge of the Kansas River. Because of the proximity of the two reaches, external controls on the fluvial system such as climate [e.g., Knox, 1972, 1976; Baker and Penteado-Orellana, 1977], flood magnitude and frequency [Schumm and Lichty, 1963; Burkham, 1972], land-use change [Escher et al., 1983], and the effects of United States Army Corps of Engineers impoundments [Smith, 1980; Osterkamp et al., 1982; Wolman and Williams, 1984] may be considered to be uniform.

CHAPTER II

BACKGROUND

Fluvial systems, when viewed through time, undergo continual change. Hack [1960] described the process of continual adjustment of the fluvial system as "dynamic equilibrium." The duration of dynamic equilibrium has since been defined as "cyclic time" by Schumm and Lichty [1965: 113]. They suggested that cyclic time spans a period required for the denudational evolution of a landscape. During this period, an exponential decrease in the stream gradient occurs, reflecting changes in the fluvial system.

The study of channel stability in the context of cyclic time is irrelevant to the purpose of this thesis. The duration of cyclic time is such that the channel rarely occupies a fixed position on the floodplain throughout a cycle. Hence, it is impossible to define individual reaches of a stream as active or inactive in terms of cyclic time.

"Graded time" consists of only a small portion of cyclic time during which the average channel slope remains relatively constant,but there will be fluctuations about this mean through time [Schumm, 1977]. It is within the context of graded time that changes in the fluvial system context of graded time that changes in the fluvial system are observed as it adjusts to attain a state of equilibrium. Mackin [1948] described a "graded stream" as one in which the morphological characteristics represent a balance between erosion and deposition. Thus, channel instability or activity may be manifested as a stream adjusts to maintain this balance.

Mackin [1948, 471] succinctly defined a graded stream as:

> "One in which over a period of years, slope is delicately adjusted to provide, with available discharge and prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium: its diagnostic characteristic is that any change in any controlling factor will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change."

Leopold and Maddock [1953] quantitatively described the interactions between the "controlling factors" and the hydraulic geometry of stream channels. In particular, they studied the effects of stream discharge and sediment load, progressively downstream and at a given river cross-section, on width, depth, and velocity. Their findings indicated a strong tendency towards establishment of a "quasi-equilibrium" [Leopold and Maddock, 1953: 51] in channels carrying water and sediment. The interactions between variables operate in both graded and ungraded reaches. They account for the maintenance of grade once the condition of equilibrium is reached, but their influence is sufficient even in ungraded reaches to cause the fluvial system to develop in a highly coordinated manner.

Leopold and Maddock [1953] suggested that slope is the one hydraulic factor which can be adjusted over a period of time by processes within the stream. Slope is potentially the factor which makes the final adjustment required for "quasi-equilibrium" after the interaction of all other factors has resulted in establishment of mutually adjusted values for those factors. Others [e.g., Friedken, 1945; Rubey, 1952; Wolman, 1955; Schumm, 1956; Hack, 1957; Lane, 1957; Leopold and Wolman, 1957; Brice, 1964; Schumm and Khan, 1972; Patton and Schumm, 1975; Schumm and Beathard, 1976; Osterkamp, 1978; Osterkamp and Hedman, 1982] have documented the effect of valley slope on channel stability.

The fluvial system continually adjusts to accomplish sediment transport with the least possible energy expenditure [Rubey, 1952: 129]. When the slope of the valley floor increases, the river may lengthen its course by meandering to maintain a constant channel gradient. Thus, if other factors remain constant, the river should display a greater sinuosity [length of channel divided by length of valley] where the valley slope is steeper. A threshold valley slope exists, however, that will result in the formation of a straight channel if exceeded. If this threshold is not exceeded, the meander may grow until the loop is cut off at the neck by the stream. At this point in time, meander growth is likely to be regenerated since no permanent adjustment to valley slope was accomplished.

The material comprising the perimeter of the channel strongly influences the geomorphic characteristics of the stream. Schumm [1960, 1963] found that rivers transporting high percentages of silt and clay have high sinuosities and small width-to-depth ratios due to the cohesiveness of the bank material. Schumm and Khan [1972], working with a flume, found that a truly meandering pattern developed only after they added substantial amounts of silt and clay to the stream load. The silt and clay became incorporated into the previously sandy banks and contributed to the overall stability of the bank. Daniel [1971] and Handy [1972] demonstrated that the expansion of a meander may be curtailed when the perimeter of the channel encounters fine-grained cohesive material more resistant than the material it had previously cut through.

Hjulstrom [1935] demonstrated how the size of the sediment particles affects the resistance of the sediment aggregate to erosion. As indicated in figure 2, the finest particles of alluvium, due to their cohesive nature, and the larger particles of alluvium, due to their greater density, are the most difficult to erode. Fine sand to coarse silt particles, on the other hand, are most easily eroded. Friedken [1945], also working with a flume, found that erodible bank material was a necessity for braided streams and that the texture of the alluvium strongly influenced bank stability. Leopold and others [1964] suggested that bank erosion, a condition necessary for braided streams to form, is often associated with coarse-grained heterogeneous material.

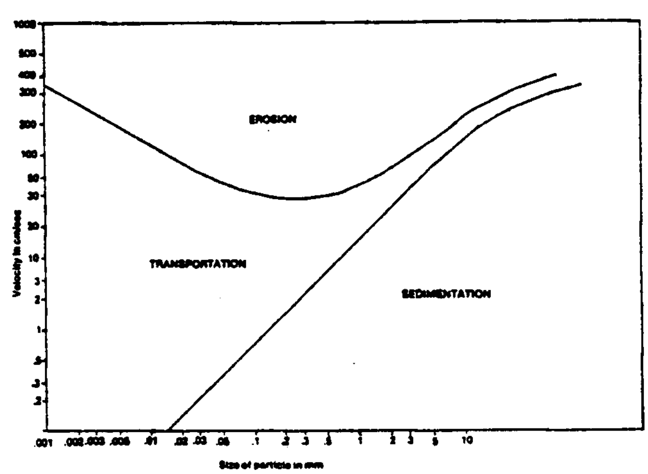


Figure 2: Hjulstrom's curve for erosion and deposition.
From Hjulstom (1935).

The alluvial valley consists of a wide variety of depositional environments each with a set of unique characteristics. Turnball and others [1966] suggested that channel stability in the lower Mississippi River valley is directly related to the type of deposits over which the channel is flowing. Natural levees and crevasse-splay deposits occur only as veneers on the surface and do not affect riverbank erosion. They suggested that two particular types of fluvial deposits, clay plugs, associated with abandoned meanders, and backswamp clays form barriers to channel migration. Clay plugs are generally too small to have widespread effects, but may cause local "hardpoints" or resistant protrusions from the bank. Backswamp deposits are more extensive than clay plugs and form more efficient barriers to channel migration. Both types of deposits may be undermined by subaqueous failure, especially if the substratum is sandy.

The thickness of the clay-rich layer is of importance as well. Within the alluvial valley of the Mississippi River, the topstratum is underlain by coarser, less cohesive material comprised of late Pleistocene deposits. As a meander forms, scour occurs along the cut bank and, if the channel bottom cuts into the underlying Pleistocene deposits, subaqueous failure of the bank may occur. This failure increases the risk of instability within the overlying clay-rich topstratum.

Turnball and others [1966] suggested that the stability and the low sinuosity of the deltaic distributary channels of the Mississippi River results from the much thicker clay-rich topstratum found within the deltaic plain. The distributary channels flow entirely within the thick topstratum making potential subaqueous failure unlikely. Other researchers, however, attribute the low sinuosity of Mississippi River distributaries to their very gentle slope [Schumm and Beathard, 1976]. This difference of opinion serves to illustrate a dichotomy that seems to exist among researchers. There exists a tendency in the literature for those researchers with an engineering background to interpret changes in the planiform characteristics of channels as a function of bank material, while those with an earth science background take a more comprehensive approach, emphasizing slope, and more recently, external controls [e.g., climate, land-use].

A third type of deposit studied by Turnball and others is the point-bar complex. Point-bar complexes usually contain swales in which silt and clay accumulate. Turnball and others stated, however, that these silt and clay deposits are too thin and localized to have an appreciable effect on bank stability. They added that point-bar deposits facilitate rapid bank erosion where the river has an active tendency to meander. Bank erosion is initiated by failure in the lower portion of the bank; the extent and type of failure being determined by the thickness of the point-bar deposit in which the failure occurrs. Where thick point-bar deposits occur, subaqueous failure is rare, but the bank may disintegrate due to partial liquification as well as by the shear stress applied by the adjacent stream. In thin point-bar deposits, subaqueous failure results in the slumping of any overlying silt and clay rich stratum.

Wolman [1955] suggested that erosion along Watts Branch in Maryland was most severe when increases in stage brought the water surface into contact with banks that were previously wetted thoroughly. He [p. 216] found that rates of erosion were "unexpectedly high and associated with moderate climatic events rather than the extreme and infrequent event." Conditions similar to those that existed for Watts Branch may exist in the Kansas River valley west of Wamego due to reservoir-induced fluctuations in the river level. This area contains extensive point-bar deposits within the meander belt that are subject to infiltration from relatively high river stages for long durations of time due to the draw-down of large upstream reservoirs. The banks in this area are largely devoid of trees, a factor Wolman observed in the reaches of Watts Branch where the severest bank erosion occurred.

The nature of the sediment transported within the channel also exerts an influence upon the resistance to flow which is encountered by water moving through the channel. Leopold and Maddock [1953] demonstrated how resistance to flow changes with the downstream change in the caliber of the load. Associated with this change in the caliber of the load is a change in the bedforms, with each form affecting flow resistance in the channel differently. The flow resistance created by the bedform, in turn, exerts an influence upon the morphological characteristics of the entire channel [Simons and Richardson, 1966]. Schumm [1960, 1961] found that the cross-sectional shape of the channel tends to reflect the proportions of the components of the total sediment load. In a wide, shallow channel, most of the sediment load is transported as bed load. In a narrow, deep channel most of the sediment is transported as suspended load.

The nature of the material along the channel perimeter does not necessarily reflect present flow conditions [e.g., Brackenridge, 1980; Grissenger and Murphey, 1983]. Grissenger and Murphey [1983: 250] found that Holocene and pre-Holocene alluvial deposits control present-day channel bed and bank stability and morphology of Johnson and Goodwin Creeks in northern Mississippi. They asserted that these channels are not alluvial channels because they are not "free to adjust and are not composed of material identical to their present sediment load." Instability within these systems is a result of "present climatic conditions [and its corresponding hydraulic characteristics] interacting with Holocene paleoclimatic conditions."

Holocene and pre-Holocene alluvial deposits occur extensively within the Kansas River valley (Davis and Carlson, 1952; Dufford, 1958; Beck, 1959; Fader, 1974). Within the study area these deposits come into contact with the Kansas River at numerous locations and, therefore, deserve consideration as a possible control of Kansas River activity at these locations.

It is evident from the literature that the bed and bank material exert a strong effect on the morphological and planimetric characteristics of a stream. Bank material is, in turn, dependent upon the hydraulic regime in control during deposition as well as the nature of the sediment which is available. The latter is determined by the geology of the drainage basin from which the sediment is derived.

Slope is the one variable that adjusts as the stream approaches a state of equilibrium. Wolman [1955] showed that slope is not related to bank material. The adjustment of slope allows the stream to maintain the necessary competency to transport the provided sediment load without unnecessary energy expenditure [Rubey, 1952].

CHAPTER III

STUDY AREA

The migration of the channel of the Kansas River within the study area is likely to have been influenced by valley slope and local bank conditions. Since these variables are products of the physical environment, the regional geology of the study area is discussed here. In addition, the activities of man in the study area may have profound effects on the Kansas River system and, therefore, also warrant discussion.

EXTENT OF THE STUDY AREA

The study area consists of a nine-mile [14.4 km] reach of the Kansas River within the Flint Hills physiographic region in east central Kansas [Fig. 3]. The Flint Hills derive their name from the flinty resistant Permian limestone beds that form conspicuous terrace-like benches on hillsides. The maximum relief in the region is approximately 320 feet [98 m] from the low point along the Kansas River to the divide between Antelope and Wells Creeks south of the village of Wabaunsee. The Kansas River valley consists of a broad, relatively flat plain ranging

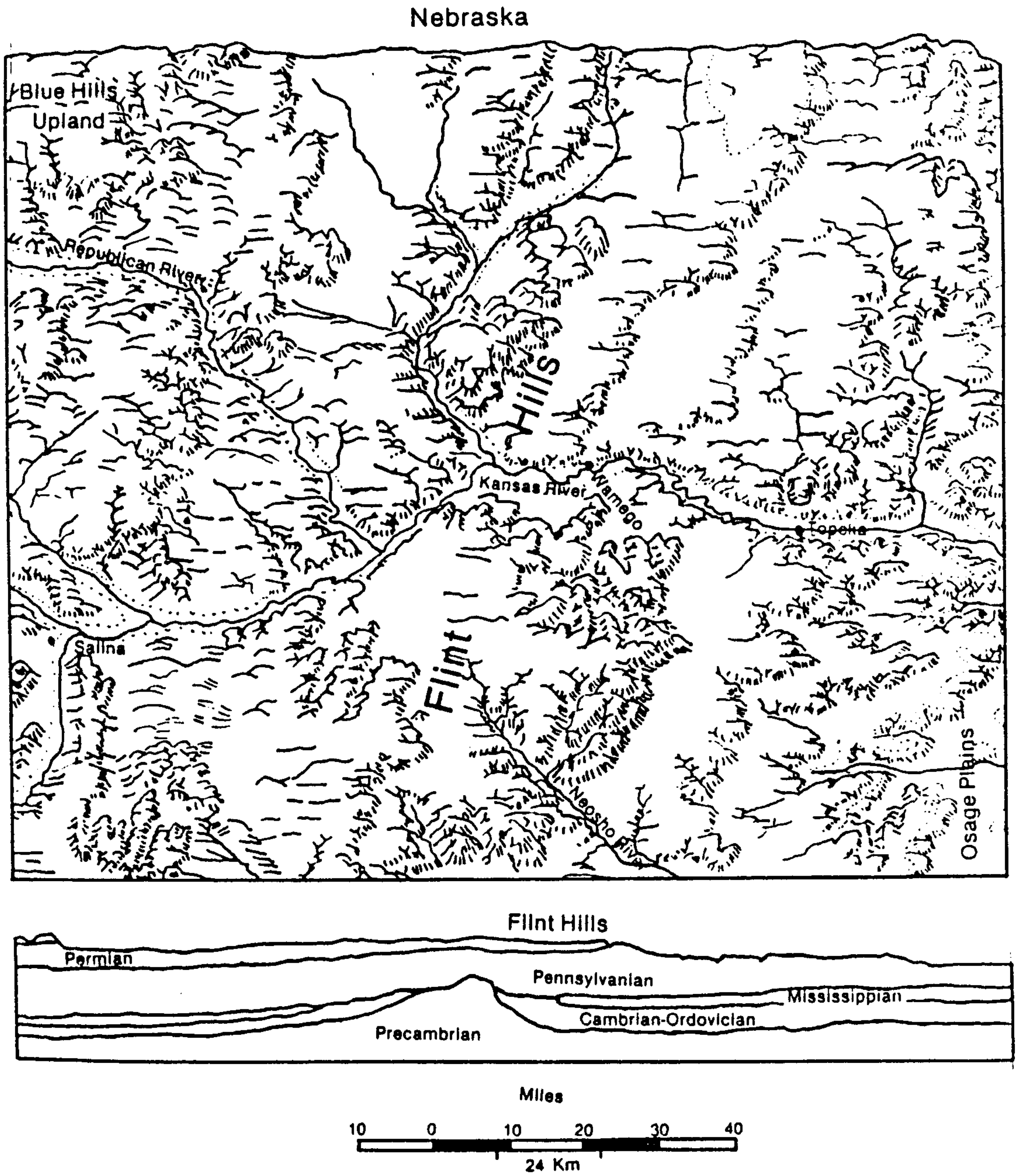


Figure 3: Physiographic map of northeastern Kansas.
From Moore (1935).

in width from 1.8 miles [2.89 km] at Wabaunsee to 3.2 miles [5.14 km] at the eastern end of the study area 2 miles [3.2 km] east of Wamego. The valley trends nearly due east almost perpendicular to the north-south strike of the Flint Hills.

The portion of the Kansas River under study begins at the village of St. George and flows to a point two miles [3.2 km] east of the town of Wamego [Fig. 1]. Within the study area, the Kansas River forms the boundary between Wabaunsee and Pottawatomie Counties.

For the purpose of this thesis, the study area has been divided into two distinct reaches. The upstream reach [reach 2], five miles [8.05 km] in length is characterized by a historically active channel. Figure 4 [A-D] illustrates the migration of the channel of the Kansas River within reach 2 and the change in its planimetric configuration between 1885 and 1978. Adjacent and downstream is a four-mile [6.43 km] reach [reach 1] in which the channel, although sinuous, has been comparatively inactive in historical time. Figure 5 illustrates the relative inactivity of the channel within reach 1 between 1885 and 1978.

The United States Army Corps of Engineers [1980] undertook a bank stabilization study of the upstream reach [reach 2] where anticipated channel migration may result in

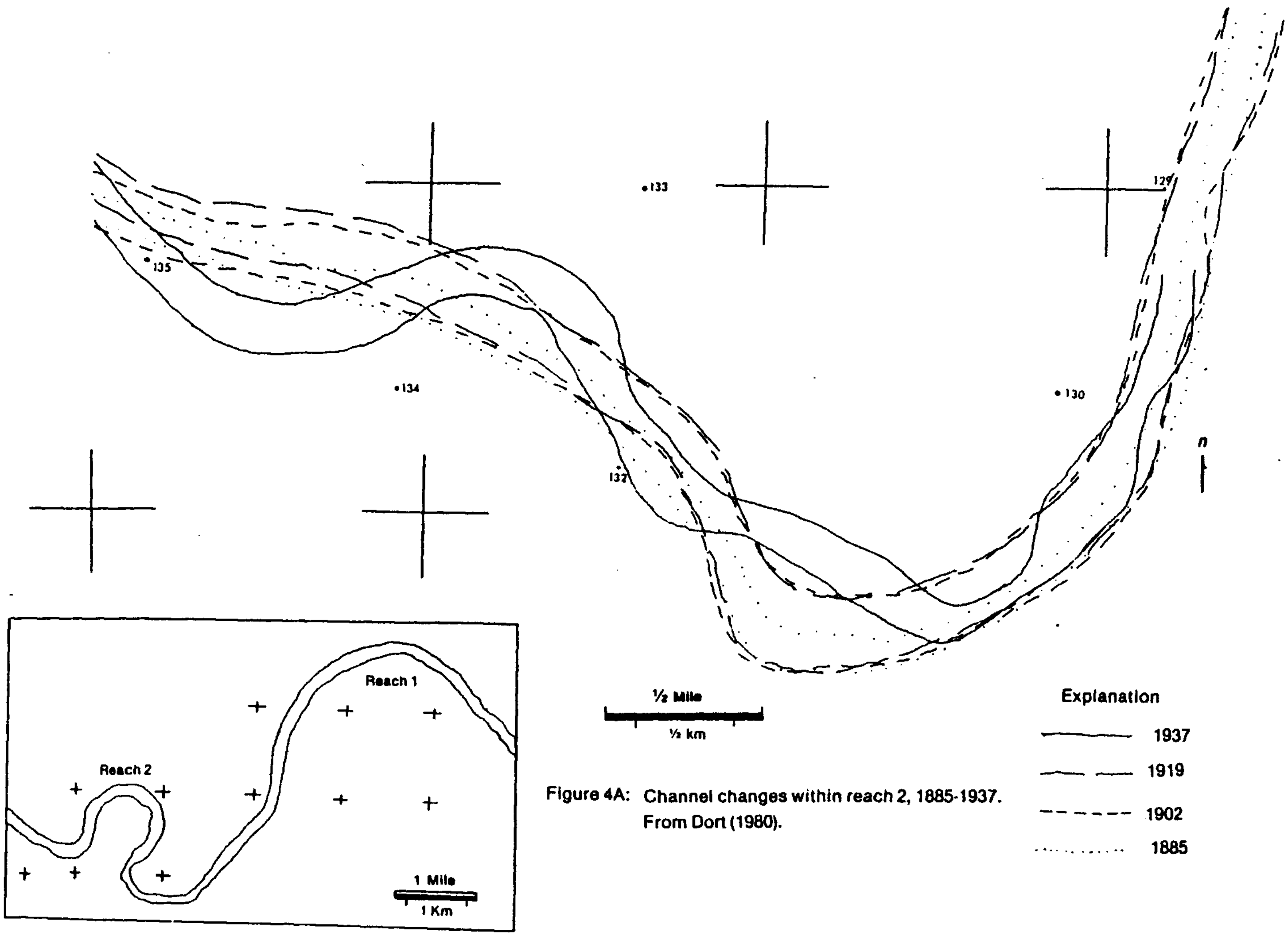


Figure 4A: Channel changes within reach 2, 1885-1937. From Dort (1980).

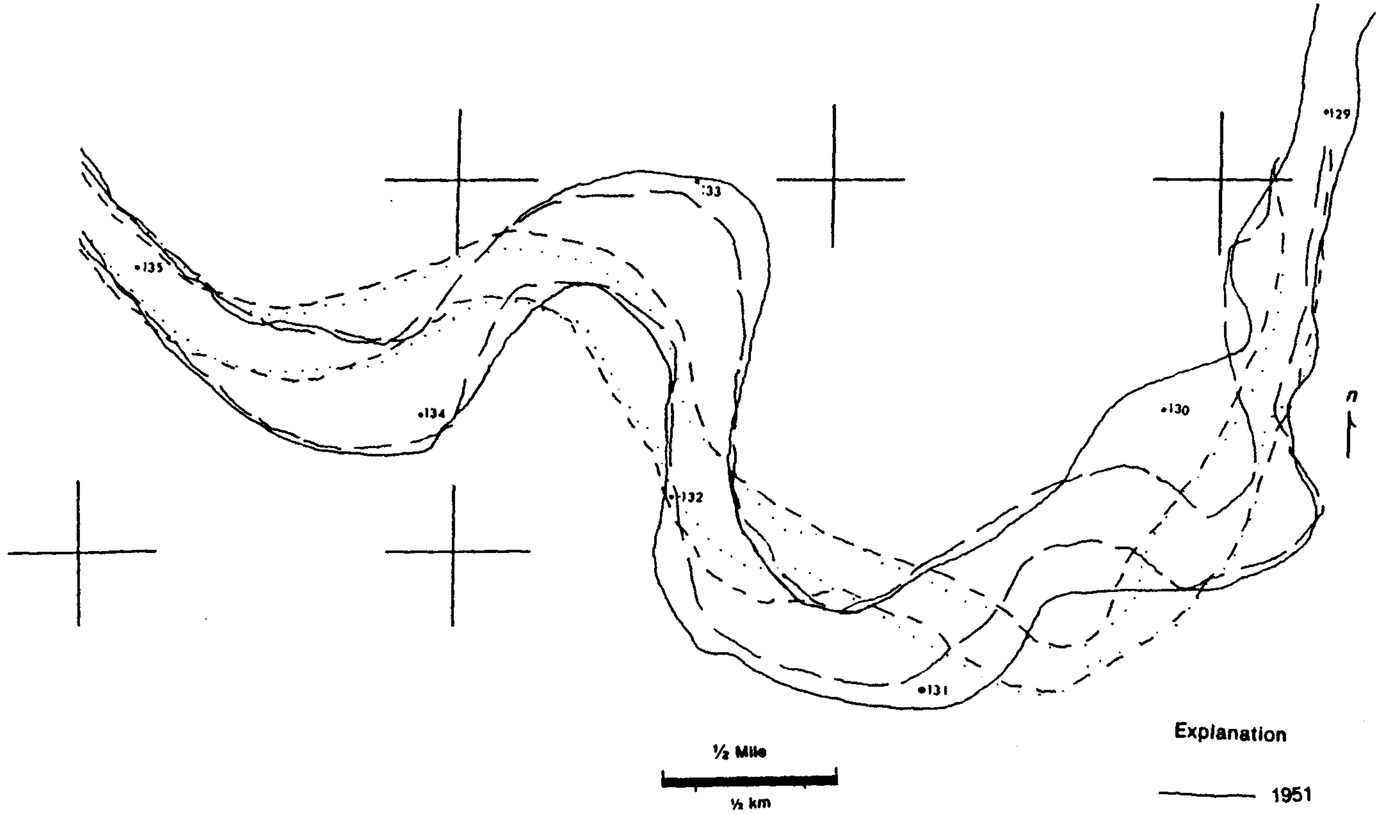


Figure 4B: Channel changes within reach 2, 1937-1951.
From Dort (1980).

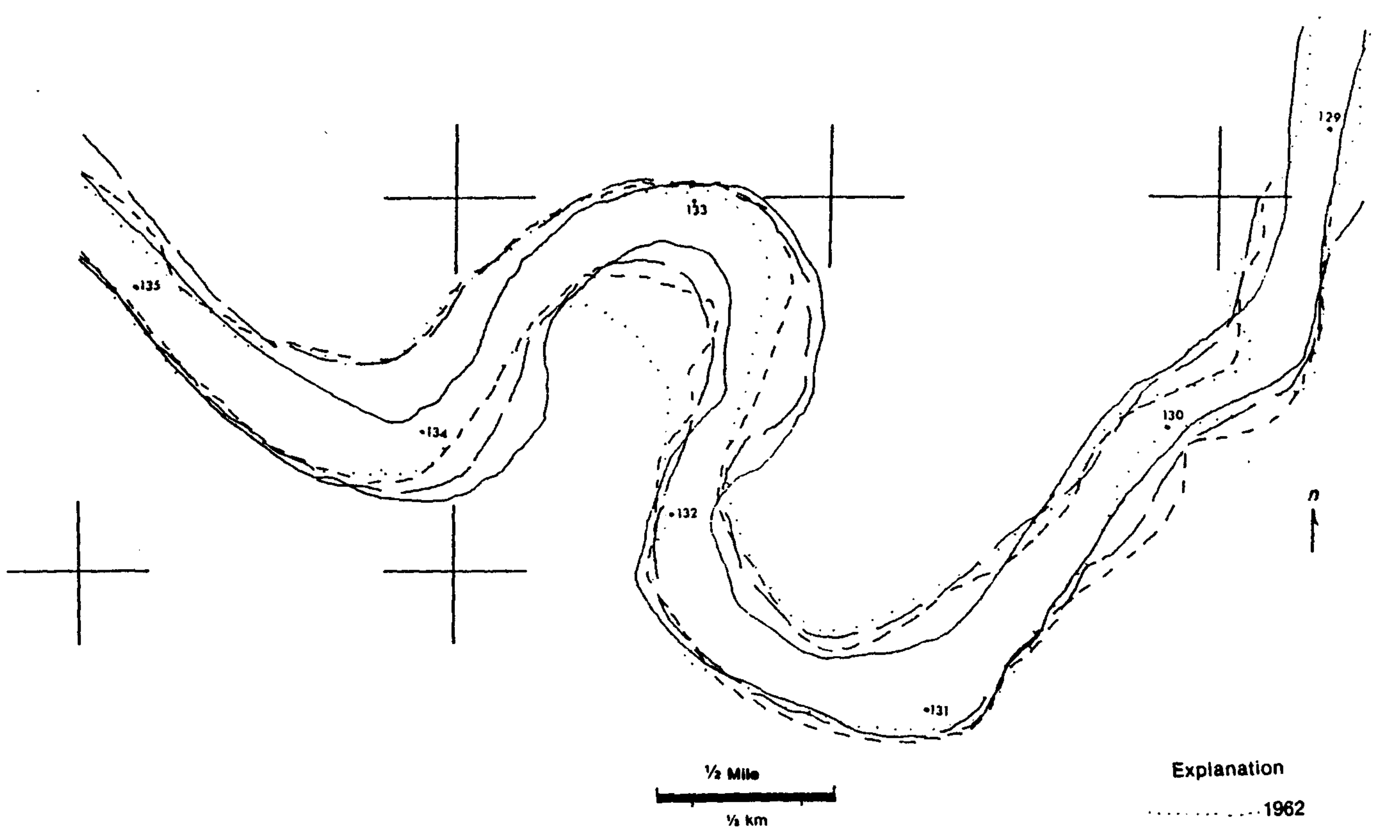


Figure 4C: Channel changes within reach 2, 1951-1962.
From Dort (1980).

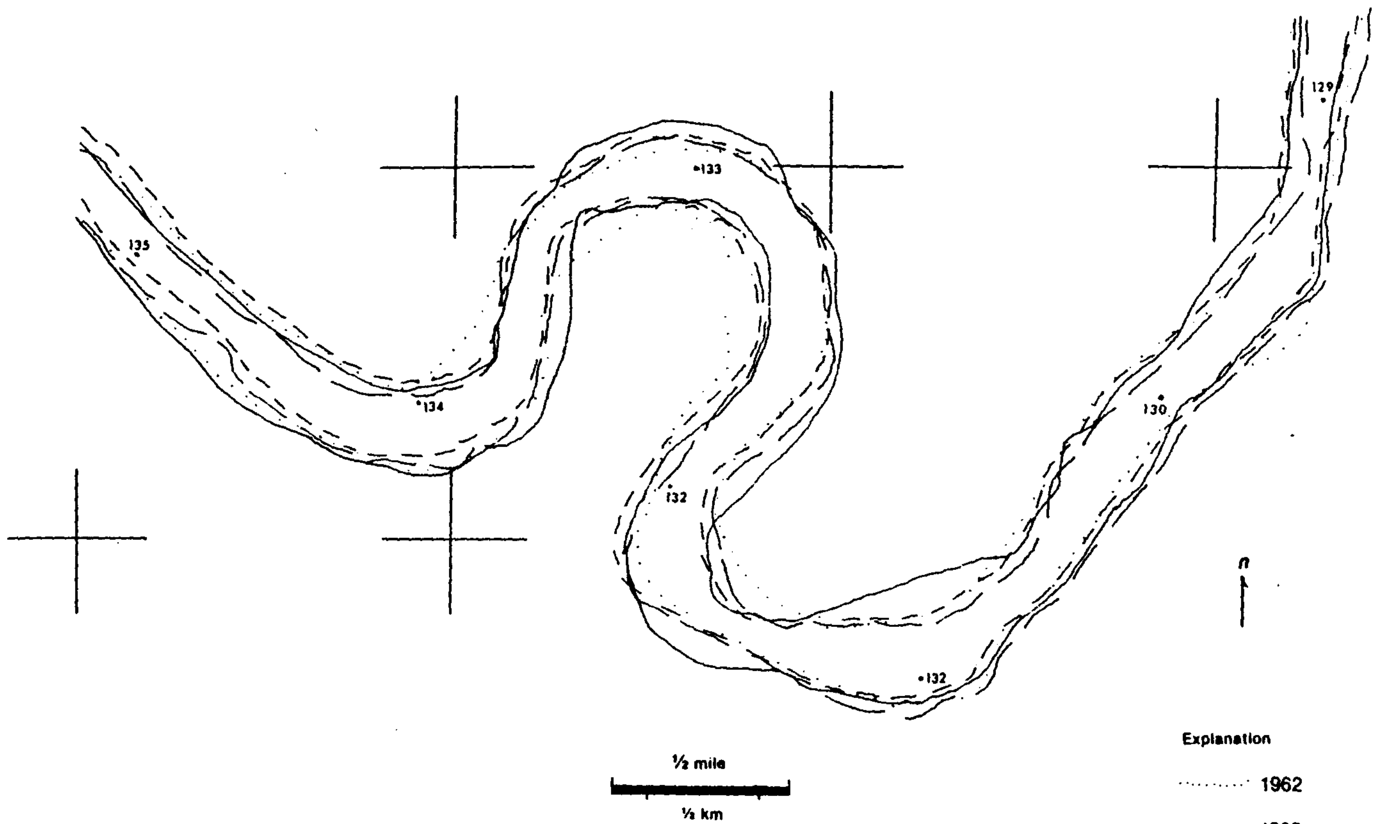


Figure 4D: Channel changes within reach 2, 1962-1979. From Dort (1980).

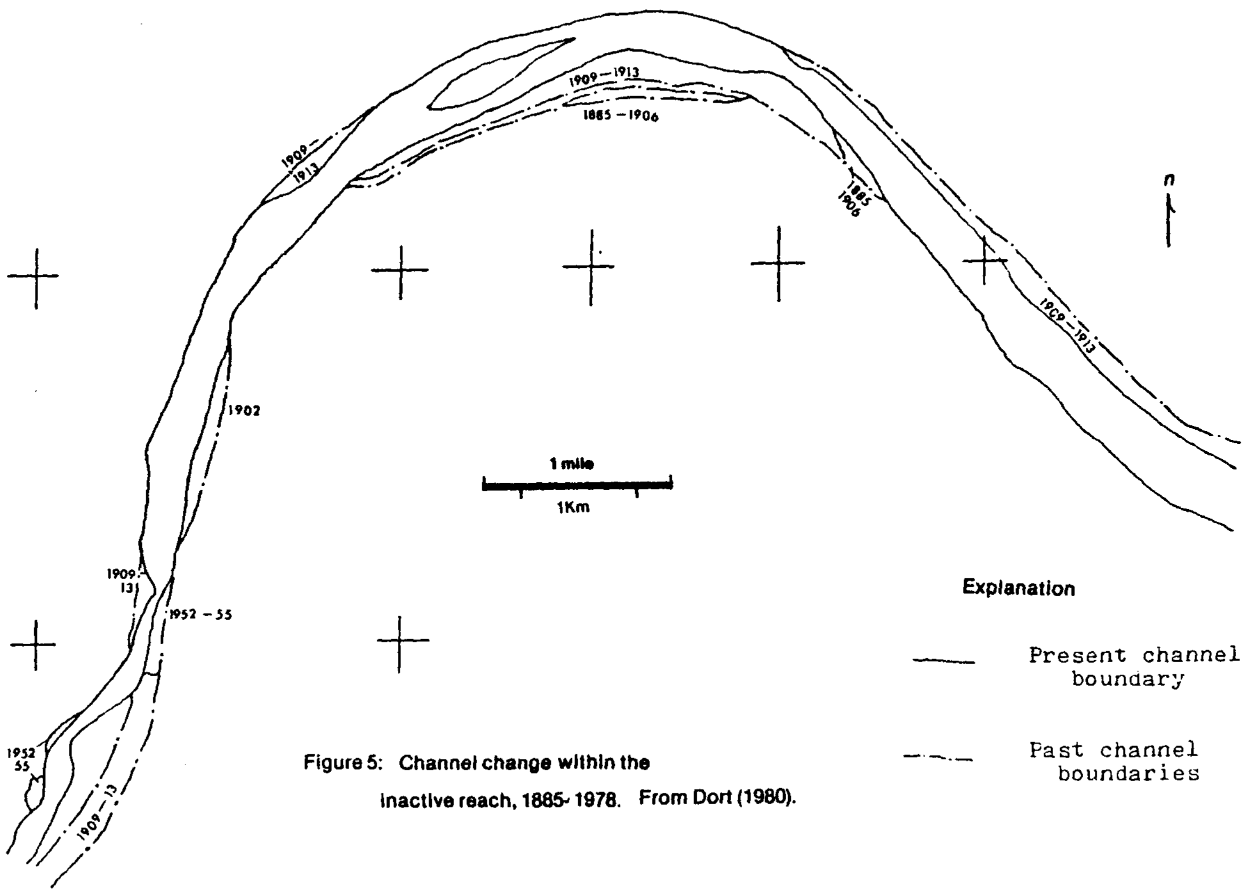


Figure 5: Channel change within the inactive reach, 1885- 1978. From Dort (1980).

the isolation of 386 acres [156 hectares] of cropland from its present owners. This isolation will be due primarily to the neck cut off of the large meander developing since 1919.

REGIONAL GEOLOGY

Bedrock Geology

Rocks of the Pennsylvanian and Permian systems commonly crop out within the study area. These rocks, consisting of alternating beds of limestone and shale, were formed by late Paleozoic cyclic sedimentation in shallow epicontinental seas [Mudge and Burton, 1959]. According to Merriam [1963], the Pennsylvanian-Permian contact is gradational and is without evidence of a major disconformity. These rocks dip to the west at 14 feet per mile [2.64m/km] and form a structure commonly known as the "Prairie Plains Homocline" [Chelikowski, 1972: 51].

Pennsylvanian rocks crop out at lower elevations than do Permian rocks and form a relatively flat plain with shallow valleys. These Pennsylvanian rocks are part of the Wabaunsee Group and consist of alternating thick, non-fossiliferous shale members separated by thin, fusilinid-bearing limestones.

Permian rocks within the study area occur in three groups known as the Wolfcampian Series. These groups are from oldest to youngest: the Admire Group, the Council Grove Group and the Chase Group. The lower 100 feet [305 m] of the Admire Group resembles the underlying Pennsylvanian rocks and contains thick, non-fossiliferous shale members. Ancient stream channels, represented by lens-shaped sandstone deposits, occur in almost all beds of shale within the upper Pennsylvanian and lower 100 feet [305 m] of Permian rocks in the study area. Unlike the Pennsylvanian rocks, the upper portion of the Wolfcampian Series consists of thick, fossiliferous limestone members separated by thin, fossiliferous shales.

The study area was inundated throughout the Cretaceous period but all Cretaceous deposits were eroded off prior to Quaternary time. Mudge and Burton [1959] stated that the evidence for pre-Quaternary removal of Cretaceous deposits is the lack of Cretaceous sandstone in the Quaternary gravel deposits of Wabaunsee County. The nearest deposits of Cretaceous sedimentary rocks are 40 miles [64.4 km] west of the study area.

The regional joint pattern [Fig. 6] consists of two sets of joints which trend nearly perpendicular to each other. The relationship between jointing and drainage in this part of Kansas has been described by Chelikowski [1972]. He noticed that upland drainage often assumed a pronounced angular pattern parallel to jointing. The influence of jointing on drainage is not limited to small upland streams. The Big Blue River valley, now occupied by Tuttle Creek Reservoir, trends northwest to southeast along a very straight course parallel to the regional joint pattern. Many tributaries of the Big Blue River enter at nearly right angles and flow parallel to the southwest-northeast trending set of joints. In the vicinity of Wamego, the longitudinal axis of the Kansas River valley also parallels the southwest-northeast trending joints.

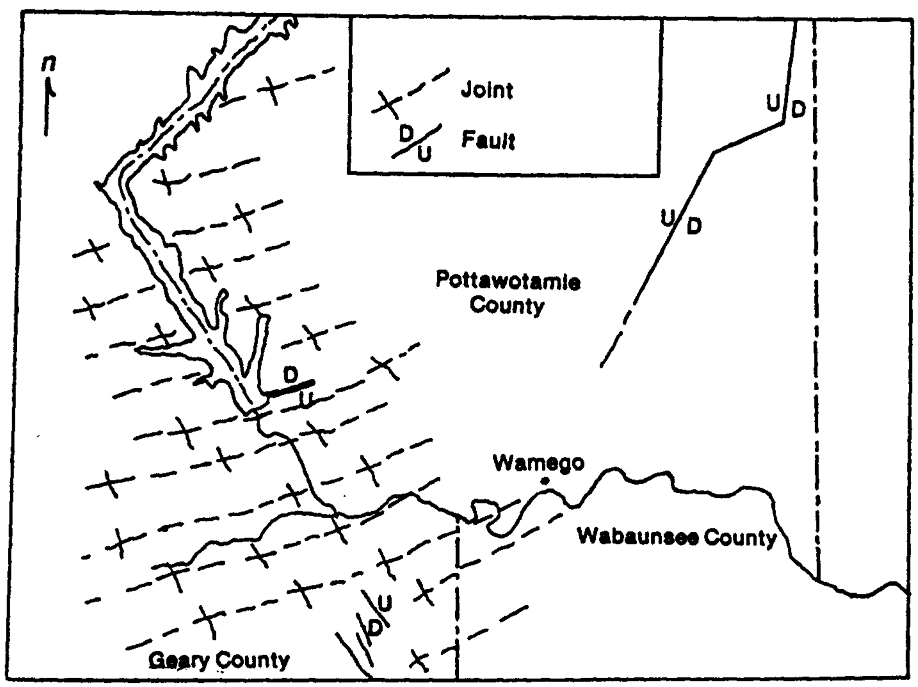


Figure 6: Structural geology of the study area. From Chelikowski (1972).

Pleistocene Drainage

The Kansan glacial advance extended well into the study area [Fig. 7]. The drainage of the Kansas River was considerably affected by this advance. Smyth [1898] recognized that the Kansas River and its north-flowing tributaries were dammed by the ice sheet and diverted across northern Wabaunsee County to the Wakarusa River in Shawnee County. Mudge [1955] suggested that before the advance of the Kansas glacier, the ancient Kansas River occupied most of its present valley. Its former channel is indicated by deposits of chert gravel exposed along the north side of the valley near Wamego, St. George, St. Mary's, and Topeka. These deposits lie approximately 60 to 120 feet [18.3 to 36.6 m] above the present channel. At St. George, the buried pre-Kansan valley of the Kansas River trends northwestwardly towards Louisville, leaving the contemporary valley only to join it again east of Wamego. During the Kansan glaciation, the ice sheet forced this portion of the valley south to its present position between St. George and Wamego.

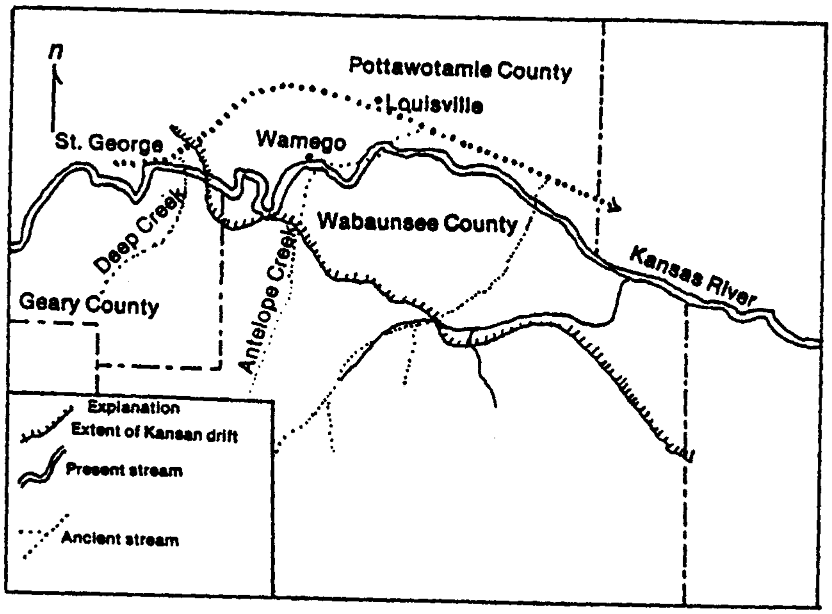


Figure 7: Pre-Kansan and recent drainage system of the Wamego area. From Mudge (1955).

In addition to the gravels deposited by the ancient Kansas River, gravel deposits also occur on strath terraces adjacent to two north-flowing tributaries of the Kansas River within the study area. Mudge [1955] contended that gravel deposits that occur along the west side of Deep and Antelope Creeks are probably pre-Kansan since they are characterized by large amounts of chert derived from local Permian rocks. At one location, approximately 1 mile [1.6 km] southeast of Wabaunsee, deposits of gravel along the west side of Deep and Antelope Creeks are overlain by glacial boulders. This occurrence of glacial deposits establishes that the Antelope Creek valley existed prior to the advance of the Kansas ice sheet.

Researchers [e.g., Frye and Leonard, 1952; Beck, 1959] have attributed episodes of the channel degradation and aggradation in the Kansas River system to changes in Quaternary climatic conditions and their associated hydraulic regimen. Dufford [1958] and Beck [1959] associated episodes of terrace formation in the Kansas River valley with the Kansan, Illinoian and Wisconsinan stages of the Pleistocene Epoch. Although these terrace dates represent broad generalizations, researchers [e.g., Holien, 1982] have only recently begun to re-evaluate the ages assigned to Kansas River valley terraces. The following section is a discussion of the nature of these terraces and their importance to this study.

Surfaces in the Kansas River Valley

Grissenger and Murphey [1983] acknowledged the effect of Holocene and pre-Holocene deposits on the stability of stream channels. They concluded that contemporary streams flowing through relict deposits are likely to be unstable since they are out of equilibrium with local bank conditions. Dufford [1958: 33], on the other hand, suggested that older surfaces within the Kansas River valley, being "underlain to depths of 15 feet or more by fine-textured alluvium" may act as a barrier to channel migration. The channel of the Kansas River comes into contact with banks comprised of sediments of various ages. These ages range from Illinoian [Buck Creek terrace fill] to contemporary point-bar deposits that occur at many locations. Since this study attempts to evaluate the effect of the nature of bank sediments on channel migration and bank stability, a discussion of the terraces within the Kansas River valley and their associated fills is necessary.

Three alluvial terraces have been mapped within the study area [Beck, 1959; Fader, 1974][Plate 1]. They include, from oldest to youngest: the Menokan terrace, the Buck Creek terrace, and the Newman terrace. The Menokan terrace is not an extensive terrace within the study area and never comes into contact with the contemporary channel of the Kansas River. Consequently, its occurrence is not relevant to the purpose of this thesis. An additional surface, the Holliday terrace, was not identified by Beck [1959] or Fader [1974] but occurs downstream of Wamego.

The Buck Creek terrace is situated approximately 40 feet [12.1 m] above the modern floodplain and is found extensively within the study area. According to Frye and Leonard [1952: 196], an episode of valley incision characterized most of the Illinoian stage of the Pleistocene epoch. This incision is believed to have resulted from the progressive increase in the size of the Kansas River drainage basin due to the capture of the then southwardly-flowing precursors of the present-day Smoky Hill, Saline and Solomon Rivers. During this episode of incision, the Kansas River valley was deepened by approximately 90 feet [27.4 m].

According to Beck [1959], the Kansas River valley was alluviated to a height of 40 feet [12.1 m] above the present-day floodplain in late Illinoian time. Dufford [1958] described this fill as predominantly reddish-brown silt and clay upon which the Sangamon soil is developed. He noted that the Buck Creek terrace may be highly eroded and does not display typical floodplain features such as meander scars and point-bar scrolls.

The Buck Creek terrace is found both north and south of the Kansas River within the study area. A well-preserved scarp of the Buck Creek terrace crosses Kansas state highway 99 2.66 miles [4.28 km] south of Wamego. The terrace comes into contact with the south bank of the Kansas River for a distance of 500 feet [152 m], 2.85 miles [4.58 km] west of this scarp. The Buck Creek terrace fill is well exposed at this location. This fill consists of a six-meter thick, tan-colored silt layer underlain by one meter of trough cross-bedded sand. An abrupt contact separates the silt layer from an overlying 2.5-meter thick, dark-brown clay layer. One meter below this contact, a well-developed paleosol occurs within the upper portion of the silt layer.

The Buck Creek terrace also comes into contact with the Kansas River at Wamego and forms the high surface on which the town is located. At Wamego, the Buck Creek terrace and the Newman terrace are adjacent to one another and occur in a belt along the valley margin trending southwest to northeast [Plate 1]. Both terraces are truncated at Wamego by the Kansas River but good exposures of the Buck Creek terrace fill are not found due to the densely forested banks. The forested portion of these banks begins at Wamego and continues westward for 1.4 miles

[2.25 km].

The Newman terrace fill is by far the most extensive terrace within the study area. It forms a broad, smooth and level surface 10 feet [3.04 m] above the modern floodplain. Like the Buck Creek terrace, the Newman terrace does not contain typical floodplain features [Dufford, 1958; Elks, 1979].

The Newman terrace fill is believed to be late Wisconsinan in age [Davis and Carlson, 1952]. The upper portion of the terrace consists of silt and clay in which a very well-developed surface soil has formed. The B and C horizons of this soil are generally gray to tan and contain abundant calcium carbonate nodules. The unaltered Newman terrace fill has a characteristic buff color.

Immediately east of Wamego, the Newman terrace fill is exposed for a distance of approximately 2600 feet [793 m] along the Kansas River. The fill consists of a thick buff-colored silty layer, loess-like in appearance, overlying a relict point-bar deposit comprised of trough cross-bedded sands. This sandy substratum is only exposed in the easternmost two-thirds of the fill where it becomes progressively higher in the section towards the east. At the extreme eastern end of the exposure, the silty buff-colored layer is absent and the entire section is comprised of the relict point-bar deposit.

A series of three paleosols is preserved in the silty layer. The basal paleosol, 12 feet [3.65 m] below the surface, has been 14C dated at 7250 years B.P. This assay and others, reported by Holien [1982] from another locality in the Newman terrace fill, suggest that the terrace fill is younger than previously believed. At this location, the Newman terrace fill comprises the cut-bank along the north side of the Kansas River within reach 1. Because one emphasis of this study is to evaluate the effect of various terrace fills and modern deposits on bank stability, the Newman terrace fill exposed at this location is discussed more thoroughly in chapter 5.

The Newman terrace also occurs south of the Kansas River within the study area but does not form as extensive surfaces as it does north of the river. Only at one location, immediately west of the Buck Creek terrace exposure northwest of Wabaunsee [Plate 1], does the Newman terrace come into contact with the south bank of the Kansas River. At this location, the Newman terrace exposure extends from the Buck Creek terrace west nearly to Deep Creek. This location is at the extreme eastern terminus of the prominent active meander within reach 2.

The Holliday terrace is an intermediate surface occupying a position below the Newman terrace but above the modern floodplain [McRae, 1954]. Unlike the Newman and

Buck Creek terraces, the Holliday terrace contains numerous floodplain features such as meander scars and point-bar scrolls. The Holliday terrace complex has been mapped extensively between Lawrence and Topeka [Dufford, 1958] but has not been previously identified in the study area. Intermediate surfaces, similar to those described by Elks [1979], are present in the eastern portion of the study area but have been mapped as modern floodplain [Beck,1959]. From this point on, these intermediate surfaces are referred to as the Holliday terrace. The Holliday terrace occurs along the north bank of the Kansas River approximately 3500 feet [1967 m] east of Wamego for a distance of 1000 feet [305 m][Plate 1]. Here the terrace surface is extensively forested but the cut-banks are well exposed.

The gray Holliday terrace fill contrasts abruptly with the adjacent buff-colored sediments of the Newman terrace fill. A similar contrast in colors was noted at the Newman-Holliday contact east of the study area near Bonner Springs, Kansas by Holien [1982]. Two paleosols are present within the Holliday terrace fill and are truncated to the west at the Newman terrace scarp. The Newman-Holliday contact here is abrupt and can be traced vertically through the bank. This abrupt traceable contact indicates that the Holliday terrace is a cut-and-fill terrace and is inset into the older Newman terrace. Although researchers [e.g., Beck, 1959: 32] have suggested that both the Buck Creek and Newman terraces are cut-and-fill terraces, no additional evidence within the study area was found either to support or refute these contentions.

To illustrate the succession of surfaces that come into contact with the channel along reach 1, the reader is again referred to Plate 1. Almost immediately west of Wamego, the Kansas River comes into contact with the valley wall for a short distance [600 m] although no bedrock is exposed in the channel or the banks. Here the channel seems to be deflected slightly to the east where it comes into contact with the Buck Creek, Newman, and Holliday terrace fills consecutively over a distance of 1.5 miles [2.41 km]. The extreme eastern portion of the meander abuts against modern sediments.

The large active meander of the Kansas River within reach 2 flows entirely within banks of modern sediments. Beck [1959] and Fader [1974] labelled all Kansas River sediments within the study area younger than the Newman terrace fill as modern. In this study, the term "modern" sediments is used to denote those sediments comprising the floodplain but does not include sediments of the Holliday, Newman and Buck Creek terrace fills.

Because no 14C dates were obtained of material from modern sediments, their age can only be estimated. As mentioned before, "modern" sediments are situated at a lower topographic position in the Kansas River valley than the Holliday terrace and are believed to be younger [McRae, 1954; Dufford, 1958]. Deposition of the material comprising the modern floodplain apparently occurred after an episode of incision that formed the Holliday terrace complex. Holien [1982] obtained a 14C date of 4290± 310 years B.P. from the lower of two paleosols exposed within the Holliday terrace fill near Bonner Springs in eastern Kansas. Allowing for the development of the upper paleosol and the deposition of the upper five meters of sediment within the terrace fill, it is probable that the episode of degradation resulting in the Holliday terrace occurred within the last 3000 years. Thus, the subsequent valley fill [modern alluvium] may range in age from very recent to approximately 3000 years old.

It is important here to also differentiate between the terms "modern" and "contemporary" deposits as used in this thesis. Contemporary deposits are those deposits being formed at the present time. Modern deposits, on the other hand, were formed in the recent past and may now be in position to be reworked by the river.

Dufford [1958: 33] recognized that modern sediments near Eudora, Kansas consist of "less-resistant sandy sediments, which are undercut much more rapidly [than finer sediments of older deposits]." Within the study area, modern sediments are markedly coarser than the sediments of the various terrace fills. Consequently, cut-banks along the outside bend of the active meander within reach 2 are comprised of predominantly coarse sediments. Towards the downstream portion of this meander, thin intervals of silt and clay appear interstratified with the cross-bedded sands [Fig. 8]. Modern sediments also comprise the entire south bank of the inactive meander within reach 1.

Soils

Soil surveys for Pottawatomie and Wabaunsee Counties are yet to be published, although advanced field maps for Pottawatomie County were made available by Bob Tricks of the Pottawatomie Soil Conservation Service. Wabaunsee County is yet to be mapped but some site-specific maps were provided by the Soil Conservation Service of Wabaunsee County. In addition, a 1951 flood survey of soils compiled by Harold Dickey [1952] was also made available through the Soil Conservation Service of Pottawatomie County.

Soils of the Kansas River valley within the study area are classified as mollisols and entisols. Mollisols have

Figure 8: Modern sediments comprised of sand interstratified with thin layers of silt exposed in the cut bank. The cut bank in this photograph is immediately downstream of the apex of the active meander in reach 2.

generally developed on terraces but may occur on the floodplain surface. The Eudora silt loam, classified as a fluventic Hapludoll (United States Department of Agriculture, 1975), occurs on high floodplain surfaces and the Holliday terrace but is not as well developed as mollisols that have developed on the Buck Creek and Newman terraces. Entisols within the study area are found only on the floodplains. These soils are underdeveloped and have only weakly expressed beginnings of natural genetic horizons or no genetic horizons at all.

Plate 2 is a soils map of the study area compiled from the sources mentioned above. For the purpose of this study, soils were grouped into three associations on the basis of topographic position, soil properties (mainly texture), and the tendency of two or more soils to occur regularly in close proximity. These soils associations are listed below.

1) <u>Eudora-Kimo</u>. The Eudora silt loam comprises the bulk of this association. It consists of a deep, well-drained, moderately permeable soil on the floodplain and low terraces. It is formed in silty alluvium. The Kimo silty clay loam regularly occurs adjacent to the Eudora silt loam but at lower topographic positions. The Kimo silty clay loam is formed in the clayey alluvium of old channel-fill material and is poorly drained and slowly

permeable. Kimo soils also occur adjacent to the Muir soil on the Newman terrace east of Wamego. Because they regularly occur in such close proximity, the Eudora and Kimo soils are often considered as a single mapping unit known as the Eudora-Kimo Complex [Soil Conservation Service, 1983].

2] Haynie-Sarpy-Paxico. These soils form on lower topographic positions than the Eudora silt loam. They represent a wide range of soil textures and consist entirely of soils classified as entisols. The Haynie soil is a silt loam similar to the Eudora silt loam except it is much more calcareous and has a lesser developed A horizon. Paxico and Sarpy soils form on the lowest portion of the floodplain. The Paxico series is commonly adjacent to the Sarpy soil and consists of deep, poorly drained soils formed in sandy or silty alluvium. The Sarpy soil is formed exclusively in sandy alluvium and is well-drained and very permeable. A transect from a point bar to the valley margin within reach 2 would typically reveal the following soil transition: Sarpy-Paxico-Haynie-Eudora.

3] Terrace Soils. The Buck Creek and Newman terraces contain soils that are generally unlike those formed on modern alluvium. They reflect differences in maturity and parent material. Whereas most of the soils formed in modern alluvium are entisols, those formed on terraces are mollisols and have undergone a much longer development period.

Terrace soils consist of the Muir silt loam, the Chase silty clay loam, and the Reading series. The Muir silt loam has formed on much of the Newman terrace except at the valley margins where the Chase silty clay loam is the dominant soil type. South of the Kansas River, Muir, Chase, Reading, and to a lesser extent, Kennebec soils have formed on the Buck Creek terrace. Although these soils tend to be located on particular terraces, the identification of a terrace cannot be based on the occurrence of particular soils alone.

The Muir silt loam is the most extensive soil of this association. It consists of a deep, well-drained, moderately permeable soil formed in silty alluvium. It is similar to the Reading silty clay loam except that the latter contains an argillic horizon. The Chase silty clay loam differs from the Muir silt loam in that it is poorly drained and is not confined particularly to terraces. The Chase silty clay loam has developed in low areas of the floodplain 1.2 miles [1.93 km] south of Wamego. The Chase soil also contains an argillic horizon. The Wabash silty clay and the Kennebec silt loam also occur on terraces within the study area. Since these soils are isolated and occupy small areas away from the contemporary channel in the study area, they do not warrant further discussion.

HYDRAULIC CHARACTERISTICS

The United States Geological Survey maintains a gaging station at Wamego [within reach 1] providing continual discharge and gage height data. Examination of stage-time relationships that correspond to the 25 and 10 percent flow duration rates [those discharges that are equaled or exceeded 25 and 10 percent of the time] show slight aggradation of the Kansas River before 1951. During the 1951 flood, one foot [.30 m] of degradation occurred, but the channel has been relatively stable since [Fig. 9]. Because no gaging station exists within reach 2, records are not available to document episodes of degradation or aggradation within the reach.

Sediment load characteristics vary little within the study area, although variations through time have occurred [Simons and Li, 1984]. Figure 10 reveals the spatial and temporal variation in bed-load caliber within the study area. It must be noted that the samples were obtained from different positions in the channel and some size variation therefore occurs. The solid line in figure 10 represents a 1983 Simons and Li survey in which four samples were taken at each cross section and the average size [D50] was

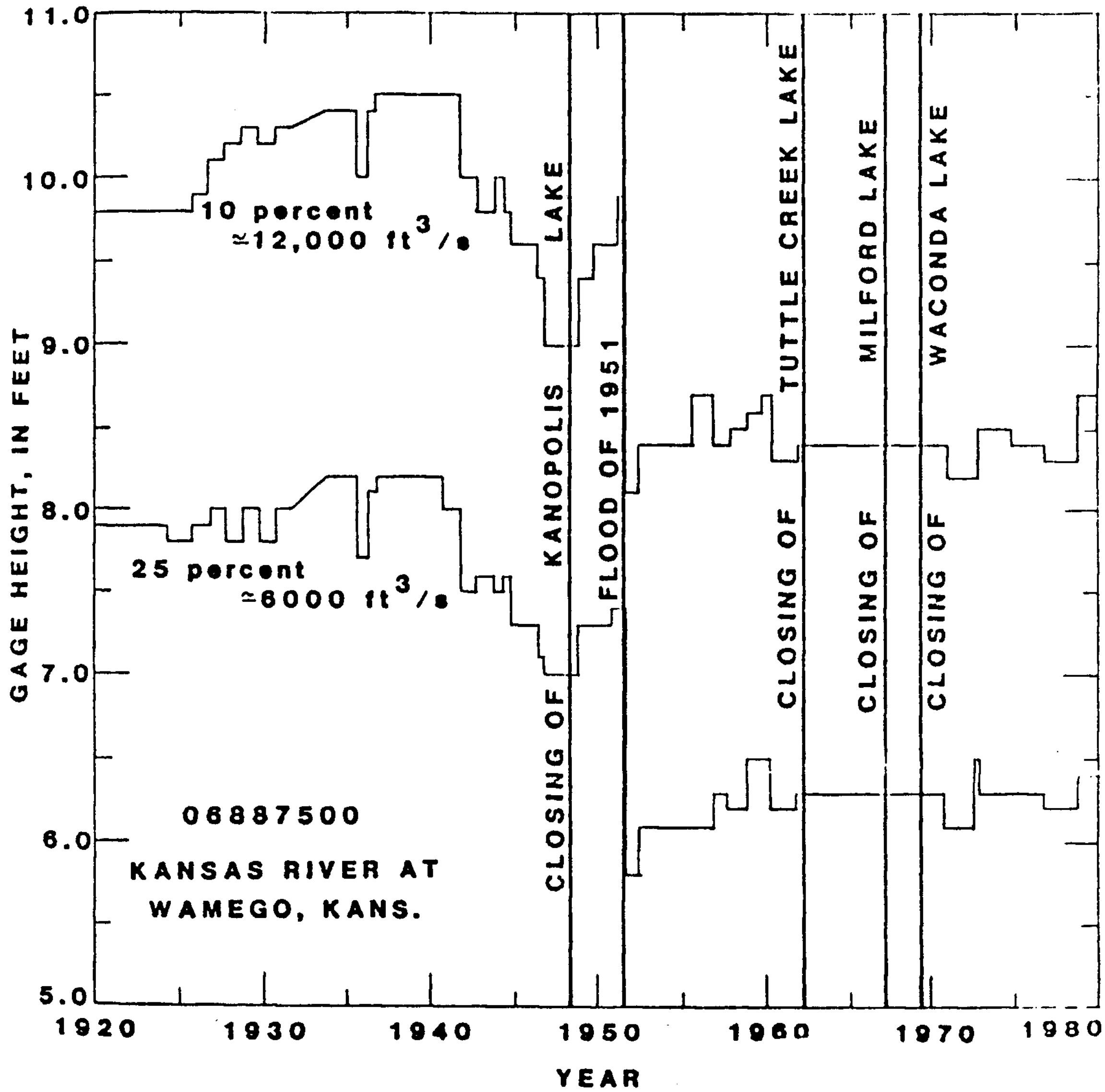


Figure 9: Stage-time relationships for the Wamego gaging station. From Osterkamp and others (1982).

plotted. This line shows little variation in bed load caliber within the study area except at river mile 132 where gravel size material occurs. Simons and Li [p. 391] suggested that the gravel bars at mile 132 represent a major geologic control; "this area may act as a vertical control and, while no outcrops of bedrock have been reported at this location, it seems to have been historically a lateral control." These gravels occur on channel bars and the point bar at the extreme eastern portion of the active meander within reach 2 [mile 132]. Simons and Li [1984] contended that the presence of these gravels at mile 132 has created a "pivot point" of stability which the channel has occupied continuously since 1885 [Fig. 4A-D]. A more detailed description and discussion of the importance of these gravels is presented in chapter 5.

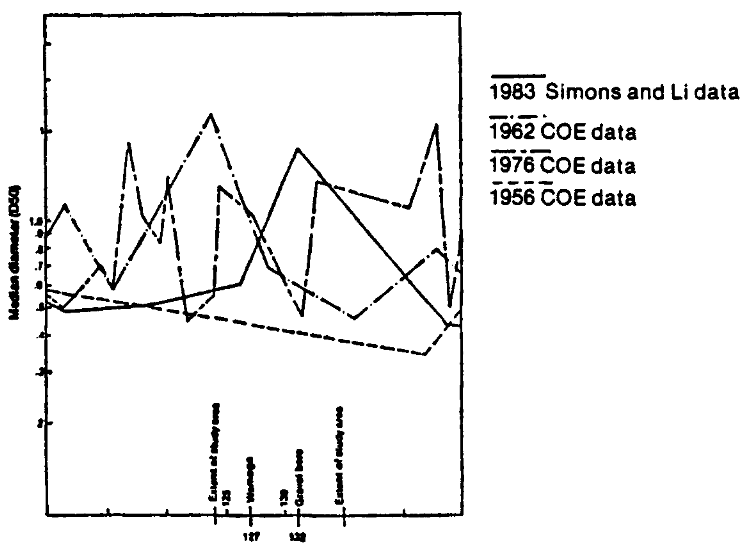
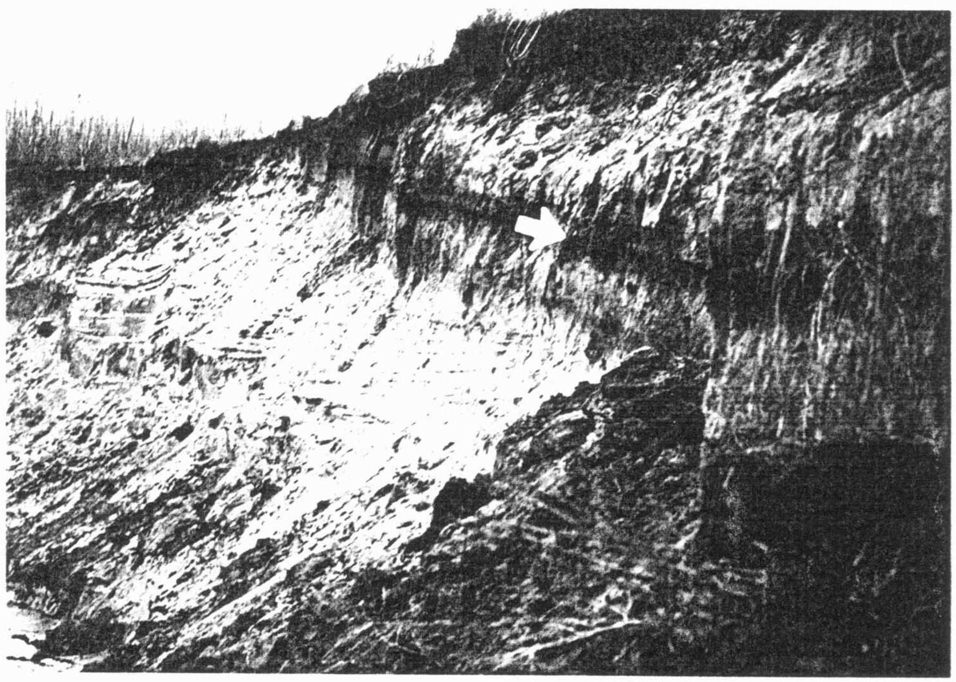


Figure 10: Historic D50 bed material versus river mile. From Simons and Li (1984)



Temporal variation in sediment yield reflects the effects of impoundments and streamflow regulation. The increased storage capacity of sediment in upstream reservoirs led to a decrease in the suspended sediment concentration at Wamego [Osterkamp et al., 1982]. The reduction in the influx of fine sediment into the system has produced a noticeable coarsening trend in the suspended-sediment load [Fig. 11]. Bed material size, on the other hand, has not undergone any apparent change.

Although the caliber of the sediment transported through the channel varies little within the study area [with the exception of gravel bar deposits at mile 132], channel width and the cross-sectional shape of the channel contrasts markedly between reaches. Channel width was measured at twelve locations within each reach at bankfull discharge from 1978 aerial photographs. The channel within reach 2, with an average width of 780.70 feet [238.08 km], is considerably wider than the channel within reach 1 which averages only 644.70 feet [196.5 m] wide. This difference in width was found to be statistically significant by use of a Mann-Whitney U test [Table 1]. This finding supports the contention made by Osterkamp and others [1982] that active reaches of the Kansas River display generally wider channels.

Channel width has also been linked to the caliber of

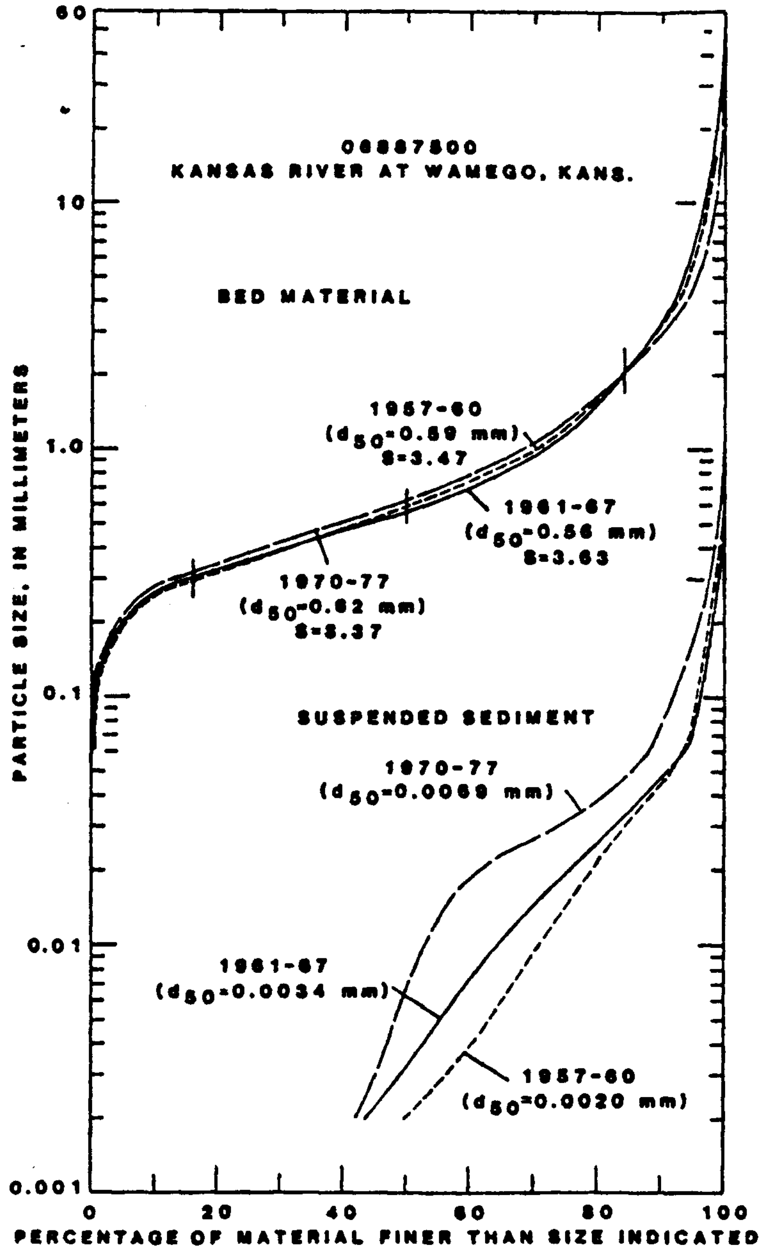


Figure 11: Temporal variation of particle size for bed material and suspended sediment at Wamego. From Osterkamp and others (1982).

Site	Width in meters Reach 1	Width in meters Reach 2
1	126	301.5
2	207	153
3	225	150.75
4	213.75	164.25
5	193.5	247.5
6	191.25	227.25
7	186.75	274
8	184.5	270
9	189	243
10	207	288
11	184.5	252
12	198	292.5

Table 1: Width of the Kansas River within the study area measured at bankfull discharge. Location of each measurement shown in Figure 12.

the sediment load transported by the stream [Schumm, 1960]. He showed that bed-load streams were generally wide and shallow whereas streams transporting mostly suspended load were narrow and deep. The examples used by Schumm, however, were all small streams in which the banks were comprised of material reflecting the load carried by the stream. Within the Kansas River valley, bank sediments do not always reflect the caliber of the load transported by the contemporary Kansas River. For example, the differences in the nature of the sediment between the modern floodplain and the Newman, Buck Creek and Holliday terrace fills reflects a change in the sediment characteristics deposited by the Kansas River through time. Bank sediments, reflecting the different hydraulic and geologic conditions of the past, still influence the morphological characteristics of the present-day channel.

Within reach 2, contemporary point-bar deposits are forming on the inside bend of the active meander and the thalweg is confined to the outside portion of the meander adjacent to the cut bank. Inflection points, where the thalweg flows from one side of the channel to the other, occur only at the upstream and downstream ends of the meander. The position of the thalweg against the cut bank results in an asymmetrical cross-sectional shape throughout the length of the meander. The cross-sectional shape of the Kansas River near the apex of the active meander [Fig. 12A] is similar to the cross-sectional shape of streams at bends described by Leopold and Wolman [1957]. The channel is deepest adjacent to the cut bank and becomes progressively shallower towards the point bar. At inflection points the channel shape is nearly symmetrical and is entirely contained between alternate point bars.

The cross-sectional shape of the channel in reach 1 is not as markedly asymmetrical as it is in reach 2. Unlike reach 2, the thalweg within reach 1 meanders within the channel and is not confined to the outside portion of the bend. Point bars form on both sides of the channel and numerous inflection points occur within the meander. At the apex of the meander [occurring at the Kansas state highway 99 bridge], a cross-section of the channel reveals a multiple thalweg and a more symmetrical shape than the cross-section at the apex of the meander in reach 2 [Fig. 12B].

In summary, differences in channel width and the cross-sectional shape of the channel between reach 1 and reach 2 are not likely attributable to sediment load characteristics since the caliber of the sediment load is essentially the same throughout the study area [Simons and Li, 1984]. On the other hand, differences in channel width and cross-sectional shape may reflect the nature and

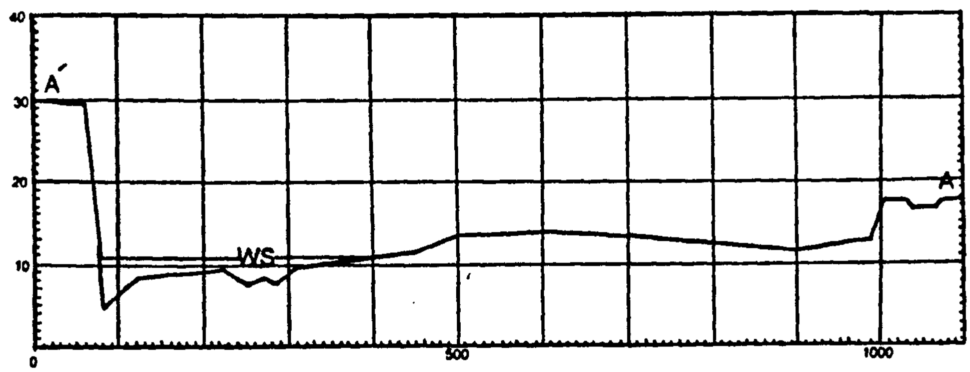


Figure 12A: Source: United States Army Corps of Engineers, surveyed October of 1978.

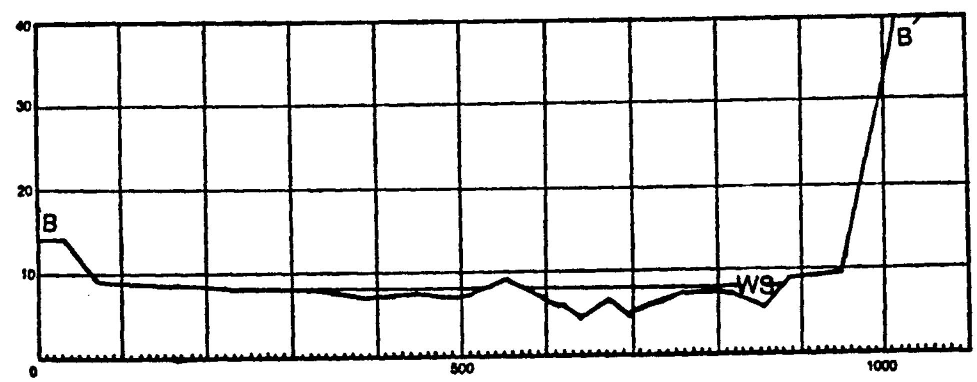


Figure 12B: Surveyed by author, October of 1983.

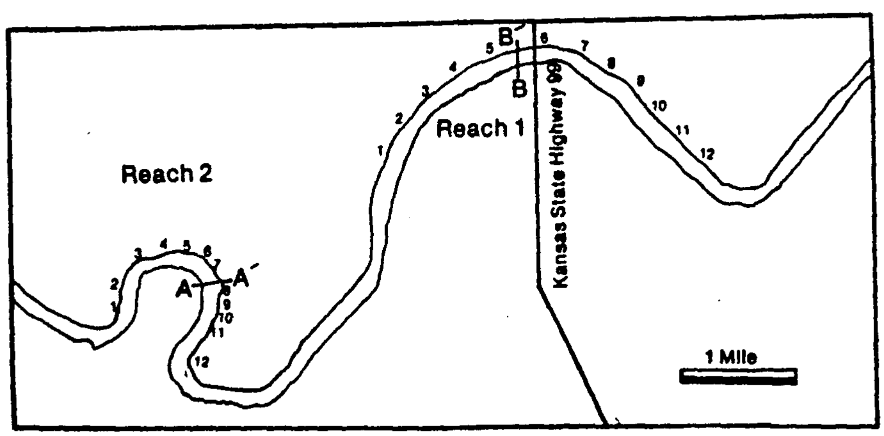


Figure 12: Channel cross sections of the Kansas River near the apex of each meander within reach and reach 2.

relative stability of the local bank sediment. For this reason, a discussion of the relationship the cross-sectional shape of the channel and the nature of the bank material is included in chapter 5.

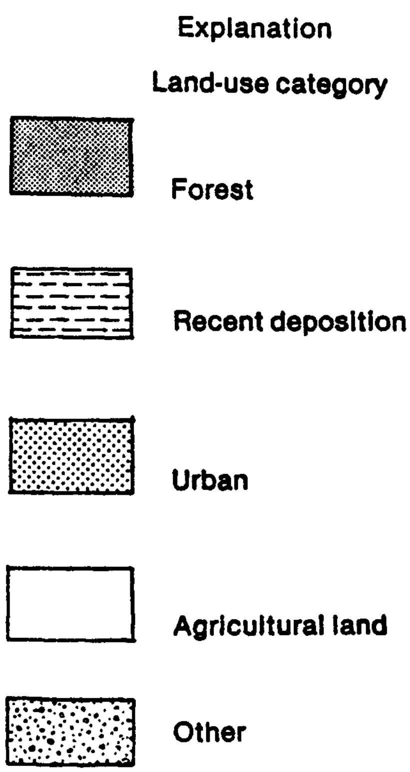
LAND USE

Researchers [e.g., Burkham, 1972; Costa, 1975; Escher et al., 1983] have documented the effects of land use change on fluvial channels. Destruction of natural vegetation and increased cultivation leads to an increase in run off and sediment concentration which results in channel aggradation. Episodes of aggradation are associated with channel widening and floodplain destruction [Knox, 1977]. Irrigation and increased streamflow regulation from upstream reservoirs has served to decrease peak flow conditions. This decrease may result in channel narrowing and floodplain formation. Escher and others [1983] cited that irrigation and streamflow regulation along the Platte River in Nebraska has resulted in the formation of a meandering channel where a braided channel existed before.

Change in regional land use within the Kansas River drainage basin is unlikely to affect adjacent reaches of the stream differently. Differences in historical channel activity between reaches, therefore, cannot be attributed to regional land use change. Differences in land use along the trunk of the stream, on the other hand, has potential to affect bank stability substantially. Land use maps, prepared for the Kansas River valley by the United States Army Corps of Engineers [1982] are summarized in Figure 13 [A through D]. The maps show land use change within the valley of the main stream from 1937 to 1982.

Land use practices along reach 2 differ markedly from those along reach 1. West of Wamego, reach 2 flows through an area under extensive cultivation [Fig. 13D]. Areas of recent deposition are presently being stabilized by thin belts of forest which have no effect on cut bank stability due to their position behind the migration channel. Since 1951, much of the land formed by the growth of the active meander has been progressively converted to agricultural use. Corn, often grown under irrigation, and wheat are the major crops grown in this portion of the Kansas River valley.

The presence of trees on the cut bank is known to have a stabilizing effect on the bank. Schumm and Lichty [1963: 79] pointed out that "the trees that border the channel [of the Cimarron River] offer considerable protection to the banks, and channel widening may be less easily accomplished under these conditions." Wolman [1955] also noted that



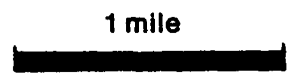


Figure 13A-D: Land-use maps for the Kansas River valley near Wamego, Kansas, 1937-1982. From the U.S. Army Corps of Engineers (1982).

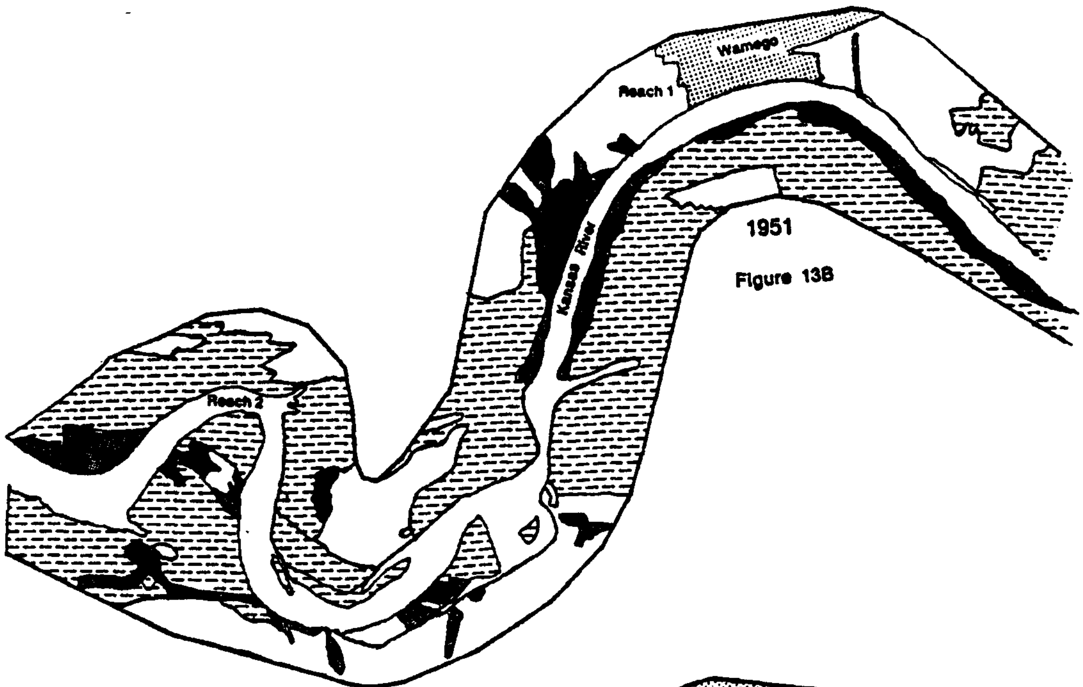


Figure 13B

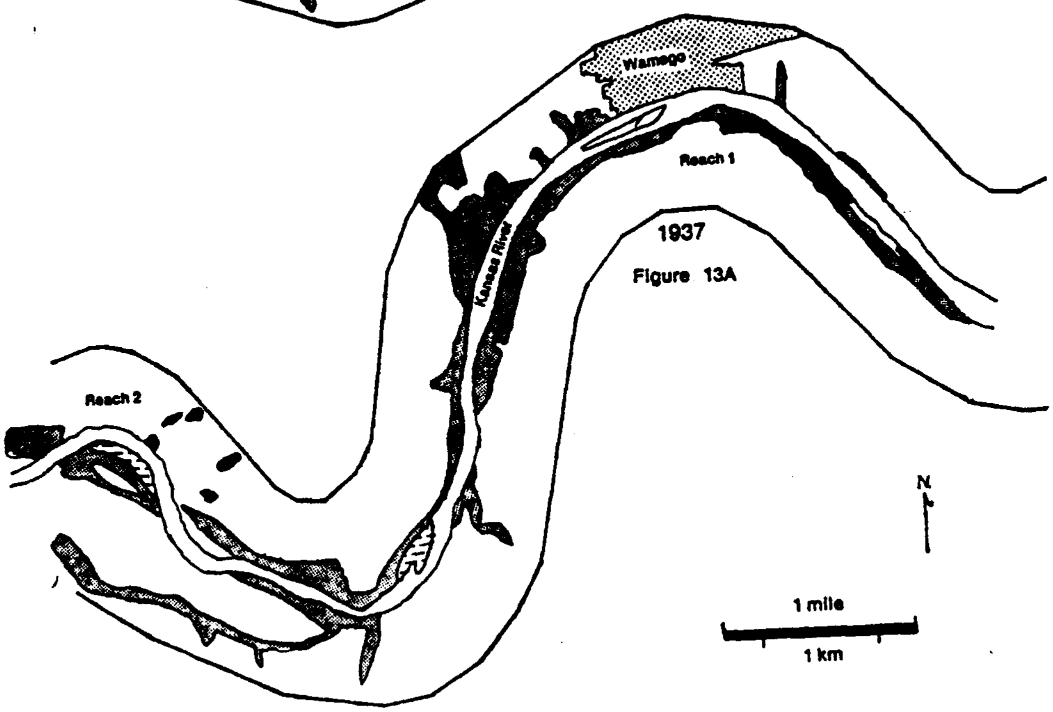
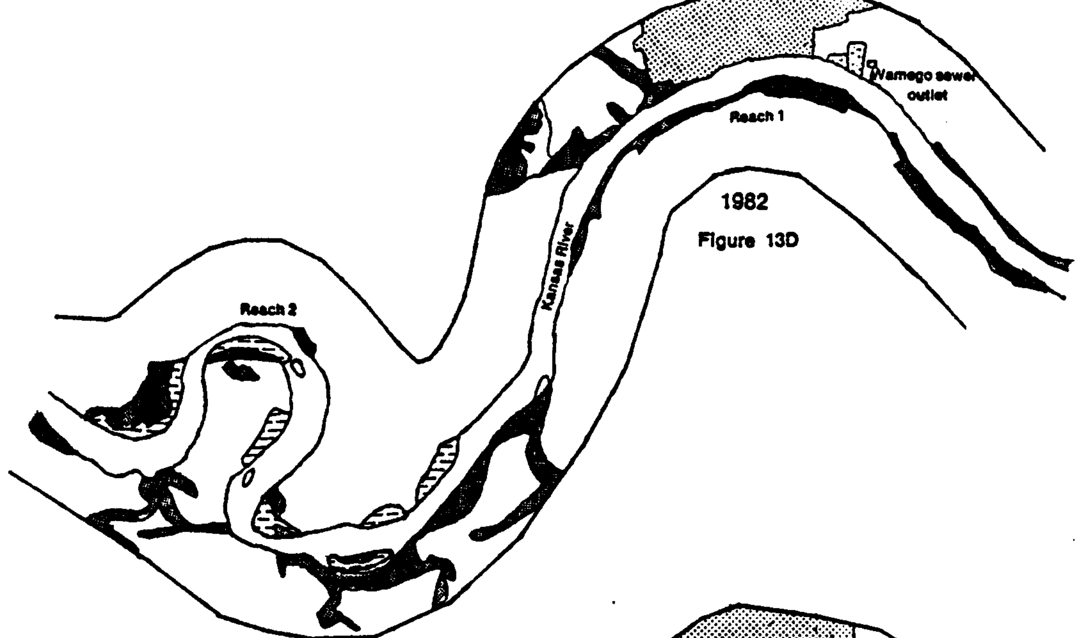
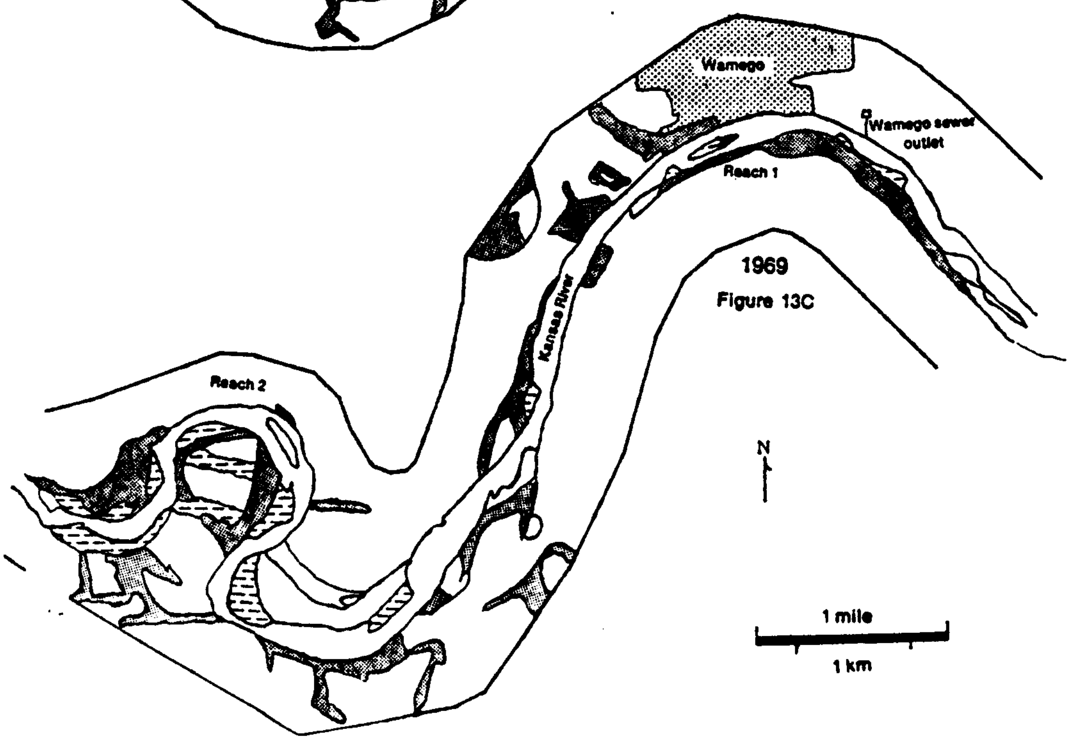


Figure 13A


Wamego sewer outlet
Reach 1
Kansas River
Reach 2
1982
Figure 13D


Wamego
Wamego sewer outlet
Reach 1
Kansas River
Reach 2
1969
Figure 13C
N
1 mile
1 km

bank erosion along Watts Branch in Maryland seemed to be most severe where the banks were devoid of trees. The cut banks along the active meander in reach 2 are generally steep and treeless. Bank recession along the downstream portion of this meander proceeds at such a rapid pace that cultivated portions of the floodplain are currently being eroded away (Fig. 14). Because of the severity of erosion along with the loose sandy texture of the sediments that comprise the bank, these cut banks are, in places, essentially unvegetated.

Land use practices along reach 1 include forested, urban, and agricultural areas. From a point 1.75 miles (2.81 km) west of Wamego to the Kansas state highway 99 bridge at Wamego, the north and south banks of the Kansas River are covered by dense forest. This forest is actually a relatively thin buffer separating the stream from agricultural areas to the south and the city of Wamego to the north. The cut banks along the north side of the Kansas River at Wamego, although forested, are extremely steep and may rise 30 feet (9.1 m) above the river level. These high, forested banks are formed in the Buck Creek terrace fill.

West of the Kansas highway 99 bridge at Wamego, the Newman terrace fill is exposed for a distance of 2600 feet (729 m) along the Kansas River. Although isolated clusters

Figure 14. Erosion of soybean (foreground) and winter wheat fields within reach 2 west of Wamego. Note the sandy nature of the sediment exposed in the cut bank in the upper portion of the photograph.

of trees occur along the exposure, forest cover is nowhere as continuous as it is west of Wamego along the Buck Creek terrace. East of the Wamego sewer outlet (Fig. 13D), the Newman terrace exposure becomes increasingly sandy and devoid of trees until finer sediments are encountered at the Newman-Holliday contact. This stretch contains the most severe bank erosion within reach 1. From the Holliday terrace to the east, the remainder of the cut bank along reach 1 is covered by dense forest growth.

As shown in figure 13A-D, there has been little permanent change in land-use patterns in the study area since 1937. The most noticeable change resulted from the 1951 flood when large agricultural areas were covered by flood deposits (Fig. 13B). Subsequent aerial photographs show that most of the floodplain has been slowly converted by deep plowing back to agricultural use.

The percent of forested bank cover has seemingly decreased since 1937 partly as a result of an increase in stream length within the study area. Within reach 2, there has been a decrease in forest cover on the floodplain. Careful examination showh that this decrease is largely due to the conversion of recent point bars, often occupied by dense riparian woodland, to agricultural use. Since deforestation of the point bars occurs in areas experiencing active deposition, deforestation has had little effect on bank stability.

In summary, the land area west of Wamego in which reach 2 flows is dominated by agricultural use. The cut banks are generally devoid of trees and bank erosion is common. Along reach 1, in contrast, forests appear to have offered some stability to the cut banks and the stream is considerably narrower than in reach 2. In addition, there seems to be a relationship between the density of forest cover on the banks and the nature of the bank sediments. Finer sediments create a stable environment which enhances the growth of dense forests, which in turn, contribute to the stability of the bank. On the other hand, agricultural areas are most susceptible to erosion and tend to occupy coarser floodplain alluvium (with the exception of contemporary point-bar deposition).

IMPACT OF MAN-MADE STRUCTURES

Bank stabilizing structures exist within both reaches of the study area. The major control structure situated within reach 1 is riprap immediately west of Wamego. The riprap was installed to protect the Union Pacific railway easement from bank erosion. It should be added that these structures were placed where the valley wall is nearly in contact with the channel itself (Fig. 15) providing a

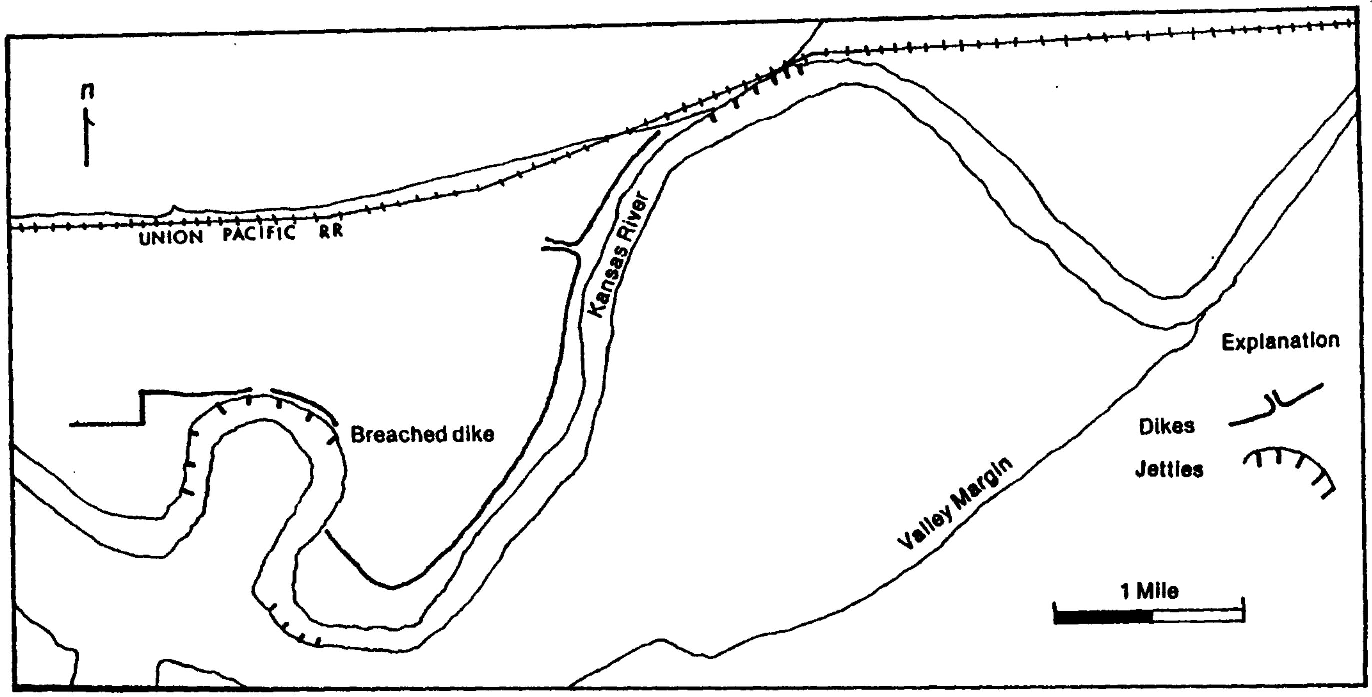


Figure 15: Map of man-made structures within the study area.
Modified from Simons and Li (1984).

natural geological control. Thus, the riprap protects the railroad from being undercut by erosion but its length [2000 feet or 610 m] and position do not affect the position of the channel throughout reach 1.

Immediately east of Wamego, sand is removed from the channel by a dredging operation. Although the impact of dredging on the stability of the lower Kansas River has been debated [United States Corps of Engineers, 1977], this is an isolated small-scale operation and probably has very little impact on the channel [Simons and Li, 1984].

Extensive local efforts to check bank erosion and provide flood control within reach 2 have met with limited success. Dikes were constructed after the 1951 flood, but have since been breached at two locations by channel migration. Figure 15 shows that these dikes have been destroyed throughout much of the downstream portion of reach 2. Jetties installed between 1969 and 1978 were intended to deflect the thalweg away from the cut bank. The jetties placed along the north bank from river miles 134.5 to 132.5 and on the south bank from miles 131 to 132 are now being isolated from the bank by the erosive effect of the eddying current behind them.

CHAPTER IV

METHODOLOGY

The methodology implemented in this study was designed to assess the effect of bank material and slope on channel activity. In addition, the position and characteristics of gravel deposits at mile 132 were studied to determine their impact on local channel conditions.

HYPOTHESES

The effect of the nature of bank material on channel activity is clearly demonstrated in the literature. Hjulstrom [1935], Fisk [1947], Schumm [1961], Wolman and Brush [1961], Schumm [1963], Turnball and others [1966], Daniel [1971], and Handy [1972] have suggested that banks containing high percentages of fine-grained material are more stable than banks containing coarse-grained homogeneous alluvium. Grissenger and Murphey [1983] noted that the nature of the alluvium is, in turn, dependent upon the fluvial history of the stream and the age of the fill. Within the study area, alluvial deposits of contrasting ages are exposed in the cut banks and are adjacent to the river in both reaches. Using the inactive reach as a control, grain-size data obtained from the active reach were examined to determine if a significant difference in bank material exists between reaches. Bank material is defined by the following grain-size parameters: mean, sorting, and skewness.

Slope has also been identified as a factor controlling channel activity [e.g., Lane, 1957; Leopold and Wolman, 1957; Schumm and Khan, 1972; Schumm and Beathard, 1976; Osterkamp, 1978; Osterkamp and Hedman, 1982]. Schumm and Beathard [1976] suggested that alluvial streams with a relatively steep valley slope may develop meandering channels in an effort to maintain just the necessary competence for the transportation of the load. They added that if the valley slope is excessively steep, a braided channel will develop. Channel and valley slope are compared much in the same manner that grain-size parameters are compared. Because the water-surface profile is a continuum within the study area and cannot be sampled like bank material, values of slope were compared in a qualitative, rather than a statistical manner.

As mentioned in chapter 3, gravel deposits at mile 132 have been postulated as a lateral control on the channel in the area [Simons and Li, 1984]. Schumm [1976] noted that an insignificant amount of gravel may significantly control the behavior and morphology of the channel. Holien [1982] suggested that the formation of a gravel lag in the channel of the Kansas River near Bonner Springs, east of the study area, has prevented further degradation of the channel. The extent and geomorphic history of the gravel were examined to determine its impact on channel stability.

The methodology was designed to test the following general hypotheses which were formulated on the basis of the literature. Hypothesis 1 lends itself to statistical testing and is stated below.

Hypothesis 1

Null hypothesis

There is no significant difference in grain-size parameters between the active reach and the inactive [control] reach within the study area.

Alternative hypothesis

There is a significant difference in grain-size parameters between the active reach and the inactive reach within the study area. The inactive reach contains the larger percentage of fine-grain material.

Hypotheses 2 and 3 are postulated, but are not accompanied by null hypotheses, thus they cannot be statistically supported.

Hypothesis 2

There is a difference in valley and channel slope between the active reach and the inactive reach within the study area. The active reach displays steeper valley slope.

Hypothesis 3

Gravel deposits at river mile 132 serve to armor the channel and create a local source of channel stability.

METHODS

Field work in this study involved three primary emphases. The first emphasis consisted of an intensive sampling program initiated along the cut bank, that is, the outside bank of each meander under study. A second emphasis consisted of surveying the water surface of the Kansas River throughout the study area to determine the water surface slope. A third emphasis of research attempted to identify the source and impact that gravel deposits, identified in a 1956 United States Army Corps of Engineers sediment survey at mile 132, have on the channel.

Grain-Size Analysis

Samples of bank sediments were obtained from sites spaced approximately every 500 feet (154 m) along the cut banks except where bank stabilizing material, debris, and dense vegetation precluded access to the bank. The number of sites was chosen to ensure that the amount of samples required for parametric tests (60 samples per test) were obtained.

Unfortunately, it was impossible to examine the bank material at many sites along reach 1 due to the density of the vegetation on the banks. Thus, the sampling density within reach 1 was less than the sampling density within reach 2 where all sites were accessible. To account for this difference, reach 1 samples were weighted by the necessary equivalent so they would approximately equal the bulk quantity of reach 2 samples.

At each site the cut bank was divided into discernible stratigraphic units and a sample was obtained from each unit. This sampling was done to test the effect that thinner stratigraphic units, which differed in grain size from the bulk of the bank sediment, have on bank stability. Samples were also taken at the water level from each site during low water periods of the summers of 1983 and 1984. An additional sample was obtained at the water level but approximately three feet deep into the cut bank using a hand auger (Fig. 16). Henceforth this will be referred to as the water-level removed sample. This procedure was invoked to ensure that a sample of the alluvium, at the water level, was obtained that was not contaminated by silt drapes remaining from higher water stages or by colluvium.

Samples were separated into a sand fraction [diam. > .0625 mm] and a silt-clay fraction [diam. < .0625 mm][Folk, 1980]. This separation was accomplished by sieving the samples through a Ø4 sieve. The coarser material was analyzed by mechanical sieving and the fine fraction was analyzed by hydrometer [Day, 1956]. For optimal results, the 1/4 Ø interval for sieving screens was used [Folk, 1980].

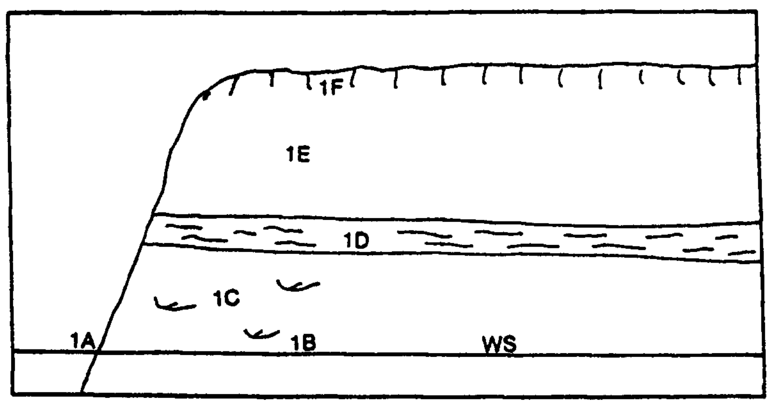


Figure 16: Example of method used to sample cut banks. Samples 1A and 1B represent the water level and water level removed samples respectively.

Cumulative frequency curves were constructed from data obtained from the analysis of each sample. On a cumulative frequency curve, cumulative percentages are plotted against phi diameter [Krumbein, 1938] on arithmetic probability paper. Using cumulative frequency curves, it is possible to graphically obtain the statistical parameters of mean, sorting, and skewness. Folk and Ward [1957] demonstrated that certain graphic methods approach the same degree of reliability and accuracy as do more quantitative grain-size parameter methods.

Analysis was conducted using Folk's [1957] mean [M_z] determined by the formula M_z =

$$\frac{\phi 16 + \phi 50 + \phi 84}{3}$$

where ϕ 16 is the average size of the coarsest third, ϕ 84 is the average size of the finest third, and ϕ 50 is the average size of the middle third. Folk [1980] suggested that M_z is the best graphic measure for determining the overall particle size of the sample.

There are several measures of uniformity [sortedness] of a sample, but Folk's [1957] Inclusive Graphic Standard Deviation was used for this study. It is calculated by

$$\frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Skewness determines if the distribution curve contains an excess of fine or coarse material. Inclusive graphic skewness includes ninety percent of the frequency curve and is determined by the formula Sk_1 =

$$\frac{\phi16 + \phi84 - 2[\phi50]}{2[\phi84 - \phi16]} + \frac{\phi5 + \phi95 - 2[\phi50]}{2[\phi95 - \phi5]}$$

Kurtosis measures the ratio of the sorting in the extremes of the distribution compared with the sorting in the central part. Values of kurtosis were calculated but not used in analysis because no trends were detected and the kurtosis statistic has little relevance concerning the stability of the bank.

Folk's grain-size parameters have primarily been applied to the analysis of sand. Sand, as opposed to silt and clay, can easily be analyzed by mechanical sieving. Fine clay is nearly impossible to segregate and thus is likely to form proportionately larger grain-size increments. Since Kansas River bank material includes relatively high percentages of clay, Folk's formulae have been altered slightly to accomodate the finer material. Using the Ø5-Ø95 interval for analysis, as Folk and Ward [1957] suggested, is impossible when a sample contains more than 5 percent clay. Instead, this study substitutes the Ø90-Ø10 interval to account for the higher proportion of fine material. Values of Ø10 are extrapolated if the sample contains in excess of 10 percent clay.

With the aid of the University of Kansas Honeywell mainframe computer, values of mean, sortedness, and skewness were calculated. Parameters obtained from the inactive reach were tested against parameters calculated from data of the active reach. The Statistical Package for Social Sciences subprogram [Nie et al., 1979] was used to execute all parametric tests while non-parametric tests were calculated by hand. The statistical level of rejection for all tests was set at .05, a threshold standard for most statistical purposes.

Surveying

The second emphasis of research consisted of determination of the valley slope and water-surface slope. The literature clearly suggests that slope constitutes a possible control on channel activity. Since a subtle change in slope may have profound effects on the fluvial system, more accurate calculations of slope are necessary than those which can be obtained from 7 1/2-minute topographic maps.

Surveying of the water slope was accomplished using an automatic level at low water during the fall of 1984. Very little change in stage occurred during the surveying. To control for this potential change in stage, stakes were first placed at the water level/point-bar interface to allow for the identification of the previous water surface in case changes in stage did occur.

Surveying involved the repetitive process of placing the instrument at a point on the point bar and the rod at the upstream end of the point bar at the water level. After each reading, the rod was moved a measured distance downstream and the process was repeated. When the rod progressed to a point that the numbers could no longer be accurately read, the instrument was moved to another site downstream of the rod. Low water allowed for the entire study area to be traversed in this manner. Error was introduced when the channel itself had to be crossed to progress to the next point bar. At crossing points, the width of the channel necessitated longer, less accurate measurements.

Gravel Bar Sampling

To determine the source and impact of the gravel deposits on channel stability, the following measures were undertaken. Exposures of gravel deposits were mapped at low water to determine their position on the point bar and nearby small channel bars. An effort was made to locate submerged gravel deposits by wading in the adjacent channel at low water along six transects and examining the sediment on the channel bottom. In addition, approximately 400 clasts of gravel were obtained from bar and bank sites near mile 132. While sampling the bar gravels, a transect was walked and a clast was obtained every one foot. The gravel bars in the area are not large or numerous so this method allowed for a representative sample to be obtained despite the relative small number of clasts taken. Where gravels were found in the bank, clasts of pebble size and larger [+4 mm] were obtained quantitatively from two fixed areas. Lithology and size of the gravel were determined in the laboratory. Size was measured along the median axis using a caliper square.

CHAPTER V

RESULTS AND DISCUSSIONS

This chapter is divided into three subchapters. The first subchapter describes the grain-size characteristics of the sediment that comprise the cut bank in each reach and discusses their effect on channel activity. The second subchapter deals with the nature and source of the gravel deposits at mile 132 as well as their effect on local channel conditions. The final subchapter describes the water-surface and valley profiles of the Kansas River within the study area and discusses their impact on channel activity. In addition, this final chapter reports the combined effect of slope and bank material on the activity of the chanel within the study area.

Impact of Material Comprising the Cut Bank

The literature demonstrates that the material comprising the margin of the channel along the cut bank consists of two entities: incised bank sediments [terrace fill deposits and modern floodplain deposits] deposited by precursors of the contemporary channel [e.g., Turnball et. al., 1966; Happ, 1974; Daniel, 1972; Grissenger and Murphey, 1983] and deposits of suspended sediment draped over the existing bank sediment exposed by incision along the cut banks [Schumm, 1961; Schumm and Khan, 1972]. This dichotomy forms the basis for the division of this subchapter. The first section of this subchapter describes the nature of the bank sediments within the study area and discusses their effect on channel activity. The second section deals with the impact of suspended-sediment deposition on bank stability. The accumulation of sediment, fallen from the upper portion of the banks [colluvium], is also included in this discussion since it cannot be separated from sediments deposited by the contemporary channel.

Information concerning the nature of the bank sediment within the study area was obtained from water-well logs and through sampling the exposed cut banks. Laboratory analysis to determine grain-size parameters for 183 samples was executed according to the method prescribed by Folk [1980]. An additional 14 cumulative frequency diagrams were provided by the United States Army Corps of Engineers.

BANK MATERIAL

Sediments comprising the cut banks within reach 1 and reach 2 stand in marked contrast to each other. The average value of the grain-size parameters [mean, sorting, and skewness) for each reach are shown in Table 2. In terms of grain-size parameters, reach 1 sediments tended to be coarse silt, very poorly sorted and strongly fine-skewed whereas reach 2 sediments tended to be poorly sorted, fine-skewed fine sand.

statistic	reach 1	reach 2
Mean	4.99	3.40
Sorting	2.56	1.55
Skewness	.469	.257

Table 2: Values of grain-size parameters for cut bank sediments from reach 1 and reach 2.

Statistical Analysis of Bank Sediment

T-tests were performed to determine if the differences in the grain-size parameters stated above were statistically significant. Since the T-test is a parametric, distribution-dependent statistical test, data were first scrutinized to determine if the requirements of the T-test were met. These requirements stipulate that the two populations (reach 1 and reach 2) have equal variances (Hammond and McCullagh, 1975). To determine if the populations had equal variances, an F-statistic was calculated. The F-statistic is given by

$$F = \frac{\text{larger } \sigma^2}{\text{smaller } \sigma^2}$$

where σ^2 is the variance of the sample. If the F-statistic was less than or equal to the rejection level (.05), T was based on a separate variance method. If the F-statistic exceeded the rejection level, the T-statistic was calculated from a pooled variance method (Nie et al., 1975).

T-tests were conducted by two different methods. First, T-tests were implemented to assess the difference in grain-size parameters (mean, sorting and skewness) between all reach 1 and reach 2 samples. Grain-size parameters for each sample were given a weight according to the thickness of the stratigraphic unit from which the sample was obtained. Secondly, T-tests were conducted in which grain-size parameters from all samples were given the same weight. This second set of tests were performed so that the thin layers of silt and clay in reach 2 would be emphasized. The total silt-clay content in the cut bank along reach 2 may be distributed in two ways: mixed with the extensive sand deposits as a matrix constituent or in thin, stratigraphically discernible layers. If silt and clay are generally confined to these thin stratigraphic units rather than evenly distributed within the bank, the null hypotheses for the non-weighted T-tests should be more difficult to reject than for the weighted T-tests. Hypotheses tested by T-test are stated in Appendix 1.

Samples were also separated into three bank intervals based upon their vertical position in the cut bank. Interval thickness was determined simply by dividing the height of the cut bank by three. These intervals consist of less than one-third bankfull, one-third to two-third bankfull, and greater than two-thirds bankfull. These criteria were implemented to provide a basis for comparison of specific bank-height intervals from reach to reach.

Results of the weighted T-tests are shown in Table 3. In all T-tests except test 4 the null hypotheses were rejected. These results indicate that the bank sediments along reach 1 constitute a population distinct from bank sediments along reach 2. It is important to note that this difference in grain-size parameters between reaches also reflects the age of the material in which the cut banks have formed. The cut banks along reach 1 are comprised of sediments of the Buck Creek, Newman and Holliday terrace fills whereas the sediments that comprise the cut banks in reach 2 are entirely modern.

Most of the difference in grain-size parameters between reach 1 and reach 2 was accounted for in the lower two-thirds of the bank [< 2/3 bankfull]. Results of

Variable name	Group 1	Group 2	Mean 1	Mean 2	2-tail prob.	Reject Ho	Inter-val	test #
sort	stable	active	2.56	1.55	0.00	*	all	
skew	stable	active	.469	.257	0.00	*	all	1
mean	stable	active	4.99	3.40	0.00	*	all	
sort	stable	active	2.58	1.41	0.00	*	<1/3	
skew	stable	active	.463	.185	0.00	*	<1/3	2
mean	stable	active	4.80	3.10	0.00	*	<1/3	
sort	stable	active	2.63	1.11	0.00	*	1/3-2/3	
skew	stable	active	.517	.238	0.00	*	1/3-2/3	3
mean	stable	active	5.17	3.10	0.00	*	1/3-2/3	
sort	stable	active	2.40	2.37	.898	-	>2/3	
skew	stable	active	.378	.413	.411	-	>2/3	4
mean	stable	active	5.11	4.32	0.00	*	>2/3	
sort	stable	active	2.60	1.28	0.00	*	<2/3	
skew	stable	active	.478	.204	0.00	*	<2/3	5
mean	stable	active	4.97	3.10	0.00	*	<2/3	
sort	stable	active	2.56	1.65	0.00	*	>1/3	
skew	stable	active	.476	.311	0.00	*	>1/3	6
mean	stable	active	5.15	3.63	0.00	*	>1/3	

Table 3: Results of weighted T-test for differences in grain-size parameters between reaches 1 and 2.

* = significant
\- = not significant

T-tests shown in Table 3 indicate that a significant difference does exist between reach 1 and reach 2 for grain-size parameters of all cut bank sediments below 2/3 bankfull. The mean grain size for reach 1 [< 2/3 bankfull] is Ø4.97 [coarse silt] whereas reach 2 sediments are considerably coarser with a mean of Ø3.10 [very fine sand]. The results of T-test 4 [Table 3], however, show that above 2/3 bankfull, the sorting and skewness of the sediment-size distributions, do not vary significantly between reaches 1 and 2. This lack of difference in these grain-size parameters may be due to the influence of pedogenic development in the upper two-thirds of the banks in both reaches.

The alteration of cut bank sediments above two-thirds bankfull has been especially pronounced along reach 1 where older surfaces have contributed to greater development of the surface soil. In addition, two paleosols are also present in the upper portion of the Newman and Holliday terrace fills. Along reach 2, soils exposed in the cut bank are generally immature [entisols] and are especially undeveloped in the downstream portion of reach 2 where truncation and deposition occurred as a result of the 1951 flood. Here pre-1951 surface soils are preserved at locations where low areas occurred in the slightly undulating pre-1951 floodplain [Fig. 17]. As shown in the

Figure 17. Pre-1951 soil (arrow) within the downstream portion of reach 2. Notice the cross-bedded point-bar deposits in the sub-stratum.

photograph, the poorly developed soil has formed in cross-bedded sand and was subsequently buried by more sandy material deposited by the 1951 flood. The soil becomes higher in the bank to the left where it comes into contact with the contemporary floodplain surface.

Unlike the values of skewness and sorting, the mean of the sediment distribution varied significantly between reach 1 and 2 for samples obtained above two-thirds bankfull. This difference in means may be attributed to the dissimilarities in the parent material of reaches 1 and 2 in which the soil is formed. The parent material of reach 1 soils is the fine [Ø4.99] sediment that comprises the Buck Creek, Newman Holliday terrace fill whereas the parent material of reach 2 soils consists entirely of modern sediment.

When considered together, mean, sorting, and skewness reveal much about the particle-size distribution of a sample but they do not make readily apparent the relative percentages of the different size fractions [sand, silt and clay]. In addition to the phi scale, these size fractions [sand > .0625 mm, silt = .0625 mm to .002 mm, and clay < .002 mm][Folk, 1980] were also used in statistical tests. A weighted composite of silt-clay percent and clay percent was calculated for each site. A Mann-Whitney U test was conducted to determine if a significant difference in silt-clay percent and clay percent existed between reach 1 and reach 2. The hypotheses tested are also included in Appendix 1.

As revealed by the results of the test [Table 4], the null hypotheses were rejected. Reach 2 sites have a mean silt-clay composition of 37.6% and a clay composition of 7.2% compared to a mean silt-clay composition of 50.5% and clay composition of 11.9% for reach 1 sites. The evidence presented in these statistical tests clearly reveals a difference in grain-size parameters, silt-clay percent, and clay percent between reaches. The cut banks along reach 1 contain material which is finer and more cohesive than the sediment that comprises the cut banks within reach 2.

Variable name	Reach1 mean	Reach 2 mean	U	Critical value	Significance
Silt-clay	50.5%	37.5%	16	21	*
Clay	11.9%	7.2%	15	21	*

Table 4: Results of Mann-Whitney U test for weighted silt-clay percent and clay percent between reach 1 and reach 2.

As shown in table 5, it was generally more difficult to reject the null hypotheses when the non-weighted

Variable name	Group 1	Group 2	Mean 1	Mean 2	2-tail prob.	Reject Ho	Inter val	test #
sort	stable	active	2.27	1.72	.002	*	all	
skew	stable	active	.406	.284	.006	*	all	1
mean	stable	active	4.34	3.34	.000	*	all	
sort	stable	active	2.15	1.50	.007	*	<1/3	
skew	stable	active	.367	.228	.031	-	<1/3	2
mean	stable	active	3.97	3.00	.010	*	<1/3	
sort	stable	active	2.35	1.29	.001	*	1/3-2/3	
skew	stable	active	.477	.228	.004	*	1/3-2/3	3
mean	stable	active	4.76	2.98	.000	*	1/3-2/3	
sort	stable	active	2.49	2.45	.914	-	>2/3	
skew	stable	active	.403	.426	.773	-	>2/3	4
mean	stable	active	4.81	4.22	.335	-	>2/3	
sort	stable	active	2.40	1.91	.062	-	<2/3	
skew	stable	active	.407	.228	.001	*	<2/3	5
mean	stable	active	4.78	3.64	.000	*	<2/3	
sort	stable	active	2.22	1.43	.000	*	>1/3	
skew	stable	active	.451	.333	.050	-	>1/3	6
mean	stable	active	4.25	2.99	0.00	*	>1/3	

Table 5: Results of non-weighted T-tests for differences in grain-size parameters between reaches 1 and 2.

* significant [reject null hypothesis]
\- not significant [accept null hypothesis].

grain-size parameters were subjected to the T-tests. Since samples from all stratigraphic units, regardless of their thickness, were assigned the same weight, thin silt-clay reach units along reach 2 received a disproportionate emphasis. The results suggest that fine material [silt and clay], although present as a minor constituent in the thick, sand-dominated stratigraphic units in the cut banks along reach 2, is largely concentrated in thin, silt-clay dominated stratigraphic units.

Distribution of Silt-Clay in Bank

Researchers have suggested that the distribution of silt and clay in the bank is as important to bank stability as the bulk quantity of silt and clay in the bank [e.g., Brice, 1966]. Friedken [1945] suggested that sinuosity is affected by the distribution of cement material [silt-clay] in the banks. His results showed that when cement was concentrated in discrete layers rather than evenly distributed throughout the bank, a sinuosity of 1.17 resulted. When silt and clay were distributed evenly, a sinuosity of 1.40 resulted. Simons and Li [1984: 84] noted that in areas of severe erosion "the bank was stratified with a fine silty layer, presumably deposited during flood events, overlying a layer of non-cohesive sand." They did not, however, elaborate as to the vertical position of this "silty layer" in the bank. The difficulty in rejecting the null hypotheses for the non-weighted T-tests suggests that silt and clay are present in both reaches in substantial quantities, but are generally concentrated in thin stratigraphic units in reach 2 and not evenly distributed within the bank.

The distribution of silt and clay in the bank is dependent on the depositional environment in which the sediments that comprise the cut bank were deposited. A point-bar complex, for instance, will be manifested by a different stratigraphic sequence than one formed by overbank deposition. Sediments exposed in the cut banks were deposited by precursors of the contemporary Kansas River under a variety of environmental conditions. Happ [1971] classified valley fill sediments and identified four locations of deposition within the valley [Table 6]. Although channel fill deposits are exposed at locations within the cut bank, vertical and lateral accretion deposits comprise the bulk of sediments exposed in the cut banks of the Kansas River within the study area.

Generalized profiles typical of reach 1 and reach 2 sites are shown in Figure 18. The measured section of the cut bank shown from reach 2 [site 8] was obtained immediately upstream [west] from the apex of the active

Place of deposition	Type of deposit	Characteristics
Channel	Transitory channel deposits	Primarily bed load temporarily at rest; part may be preserved in more durable channel fills or lateral accretions.
	lag deposits	Segregations of larger or heavier particles, more persistent than transitory channel deposits, and including heavy mineral placers.
	channel fills	Accumulations in abandoned or aggrading channel segments; ranging from relatively coarse bed load to fine-grained oxbow lake deposits.
Channel margin	Lateral accretion deposits	Point and marginal bars that may be preserved by channel shifting and added to overbank floodplain by vertical accretion deposits at top.
Overbank flood-plain	Vertical accretion deposits	Fine-grained sediment deposited from suspended load of overbank floodwater; including natural levee and back-land (backswamp) deposits.
	Splays	Local accumulations of bed load materials, spread from channels onto adjacent floodplains.
Valley margin	Colluvium	Deposits derived chiefly from unconcentrated slope wash and soil creep on adjacent valley sides.
	mass movement deposits	Earthflow, debris avalanche, and landslide deposits commonly intermixed with marginal colluvium; mudflows usually follow channels but also spill overbank.

Table 6: Classification of valley sediments (from Hopp, 1971).

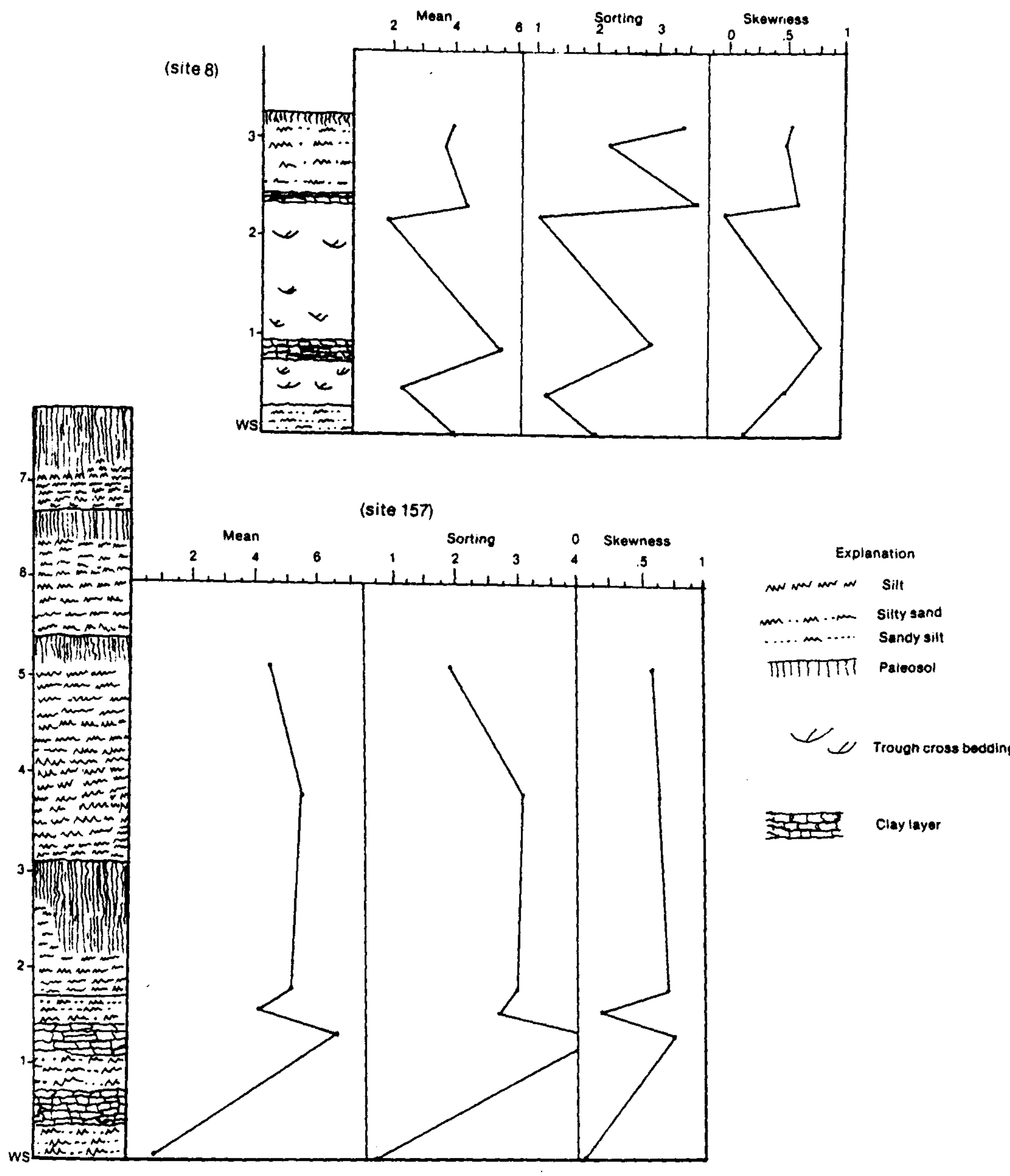


Figure 18: Generalized profiles from reach 1 and 2 showing the contrast between point-bar deposits (site 8) and overbank deposition (site 157).

meander. The cut banks along reach 2 are dominated by point-bar deposits formed by the accretion of sand-sized sediment as the channel migrated laterally. The stratigraphic sequence at site 8 consists of poorly-sorted trough cross-bedded sands that fine upward to silty sand in the upper one meter of the section. Individual sets of cross-beds may be draped by thin layers of silt and clay deposited under waning flow conditions. The gradation to silty sand near the top of the section is typical of fining-upward sequences found in point-bar deposits [Jackson, 1976].

A generalized profile from reach 1 is also presented in figure 18. The measured section is located in the Newman terrace fill exposure approximately 1000 feet [305 m] east of Wamego. The lower one meter of the section consists of interbedded layers of silt and clay. Above this meter of interbedded sediments is approximately seven meters of silty vertical accretion deposits. The entire vertical section at this location does not contain any sedimentary structures and deposition probably occurred in a low-energy environment such as a back swamp. These vertical accretion deposits have been modified by the development of three paleosols. Although the paleosols are continuous throughout most of the length of the Newman terrace fill exposure, there is much lateral change in the nature of the sediment that comprises the fill. About 2500 feet (762 m) west of Wamego (midway through the Newman Terrace exposure), point-bar deposits containing coarse sand and gravel are exposed in the lower portion of the cut bank. At the easternmost point of the exposure at the Newman-Holliday terrace contact, the entire exposure is comprised of these point-bar deposits. A more detailed description of the Newman and Holliday terrace fill along this exposure is provided later in this section.

Two distinct fluvial deposits dominate the cut bank exposures within the study area: overbank and point-bar deposits. This dichotomy is illustrated in figure 19 as a plot of values of sorting against mean. The values segregate fairly well with reach 1 (overbank deposits) generally occupying the area to the right of the line and reach 2 (point-bar deposits) occupying the area left of the line. The overlap shown in figure 19 is most likely due to the continuum existing between point-bar and vertical accretion deposits. Along reach 2, the point-bar deposits exposed in the banks may contain fining-upward sequences in which the upper portion of the bank is considerably finer than the lower portion. Samples taken from the upper portion of the banks or from the thin clay-rich units exposed in the banks plot to the right of the line in figure 19 and account for much of the overlap. As stated

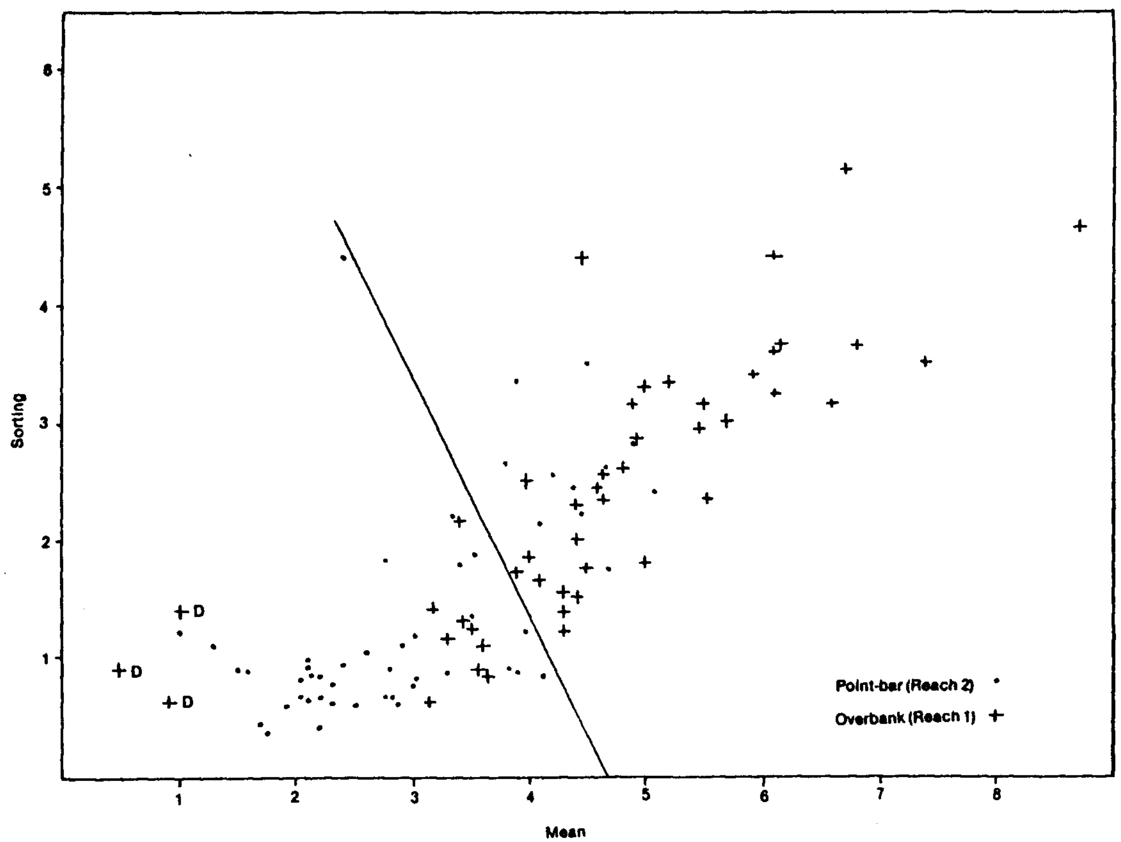


Figure 19: Mean-sorting relationships showing segregation of reach 1 and 2 samples.
D represents samples obtained from point-bar deposits exposed at the base of the Newman terrace alluvium within reach 1.

before, coarse sands and gravels are exposed in the easternmost portion of the Newman terrace fill along reach 1 and are generally indicative of point-bar deposits. These sand-sized sediments plot to the left of the line in figure 19 and are designated by the letter "D" adjacent to the plotted point.

Although point-bar sands are typically poorly sorted [Friedman, 1961], they are represented by those points in figure 19 which are coarser and better sorted than overbank deposits. This difference in sorting between overbank and point-bar deposits can be explained by examination of four cumulative frequency curves [Figs. 20 and 21]; two from reach 2 and two from reach 1. Although poorly sorted according to Folk's [1980] measure of sorting, the bulk of the samples in figure 20 are sand-sized [between 1Ø and 4Ø] and 75% of the particle-size distribution occurs within a 2Ø interval. On the other hand, reach 1 sediments [Fig. 21], indicative of overbank deposition, are predominantly silt and clay and 75% of the particle-size distribution occurs within a 3.6Ø interval and consequently are more poorly sorted.

As stated before, the silt-clay distribution of the cut banks along reach 2 is concentrated in thin stratigraphic units. Approximately 82% of the cut bank perimeter of reach 2 consists of point-bar deposits. Silt

Figure 20. Particle size distribution diagram for two reach 2 point-bar samples.

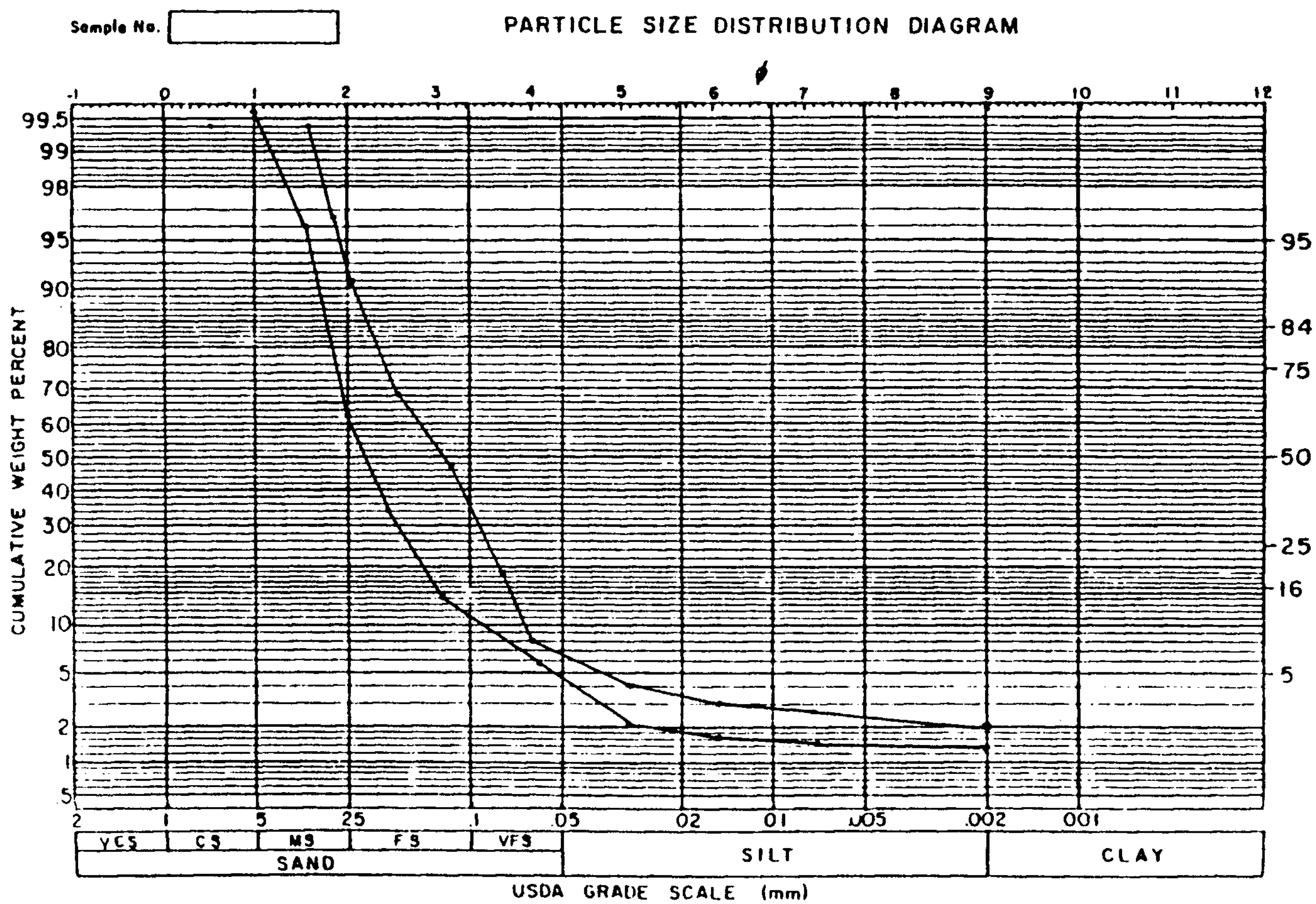
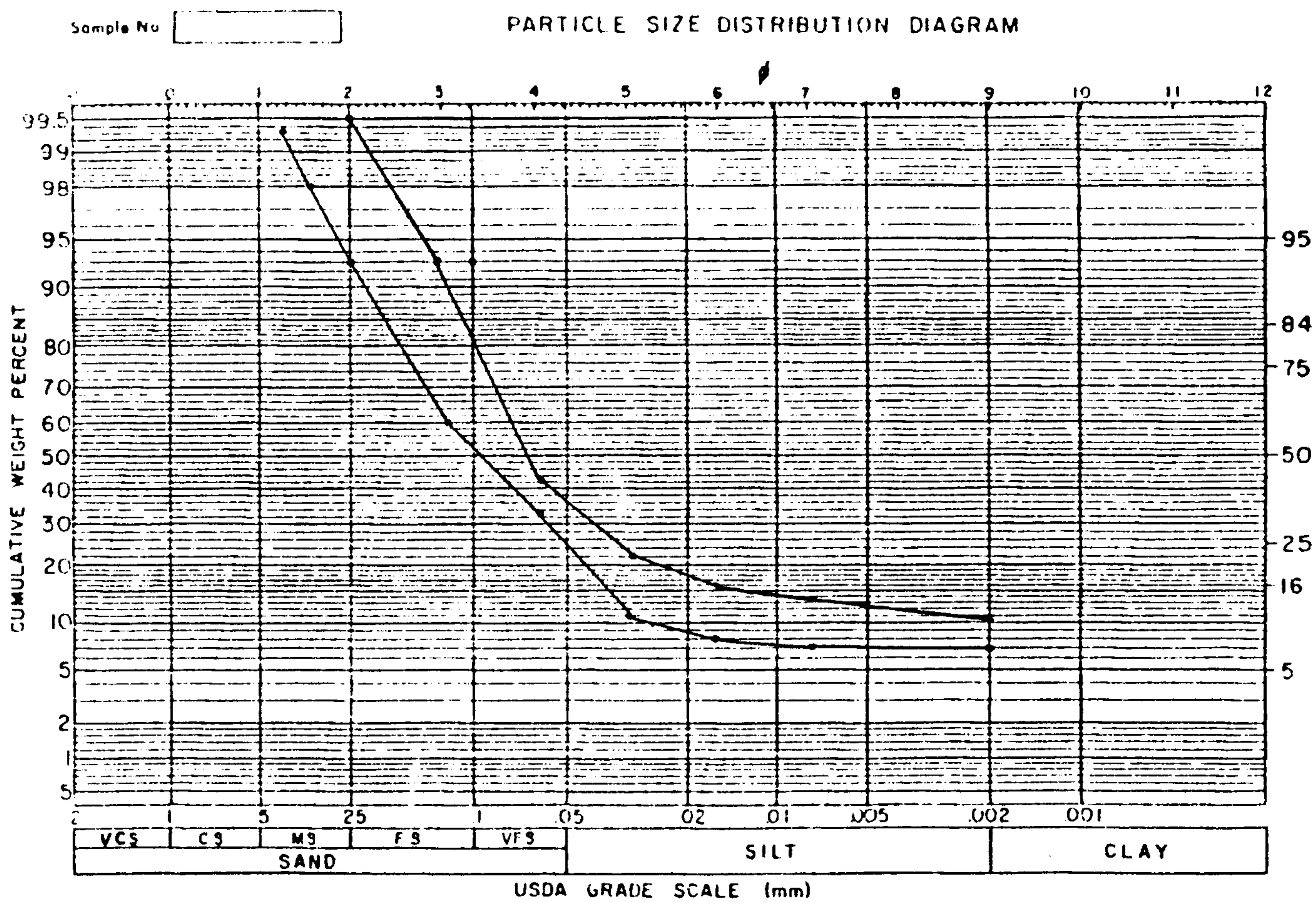

Sample No.
PARTICLE SIZE DISTRIBUTION DIAGRAM
ϕ
-1 0 1 2 3 4 5 6 7 8 9 10 11 12
CUMULATIVE WEIGHT PERCENT
99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5
95 84 75 50 25 16 5
2 1 .5 .25 .1 .05 .02 .01 .005 .002 .001
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

Figure 21. Particle size distribution diagram for two reach 1 samples of overbank deposition.



Sample No
PARTICLE SIZE DISTRIBUTION DIAGRAM
ϕ
CUMULATIVE WEIGHT PERCENT
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
95
84
75
50
25
16
5
2
1
.5
.25
.1
.05
.02
.01
.005
.002
.001
VCS
CS
MS
FS
VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

n.

and clay are found within these deposits but only as minor constituents. The average silt-clay percent in the point-bar sands is 21.3% and the average clay percent is 3.36%. If the sand was absolutely devoid of silt and clay, then braiding would certainly result due to bank erosion and channel widening [Schumm and Khan, 1972].

A relationship may exist between meander growth and the amount of silt and clay in the cut bank. Where the bulk of the cut bank sediment is comprised of point-bar deposits, relatively small amounts of silt and clay must be present within these deposits to provide necessary bank stability for meandering to occur. This meander growth may be rapid since the point-bar deposits do not provide the resistance necessary to prevent bank erosion and channel migration. Downstream along reach 1, the fine, cohesive nature of the sediments, as well as the incipient induration of the sediment comprising the terrace fills offers considerable resistance to channel migration.

The stratigraphy exposed in the cut banks along reach 2 becomes more complicated in the downstream direction. West of the apex of the active meander, the point-bar sands generally contain fining-upward sequences [Fig. 22, site 1]. As the apex of the meander is approached to the east of site 1, the fining-upward sequence is less evident and a silt-rich stratigraphic unit appears in the section one

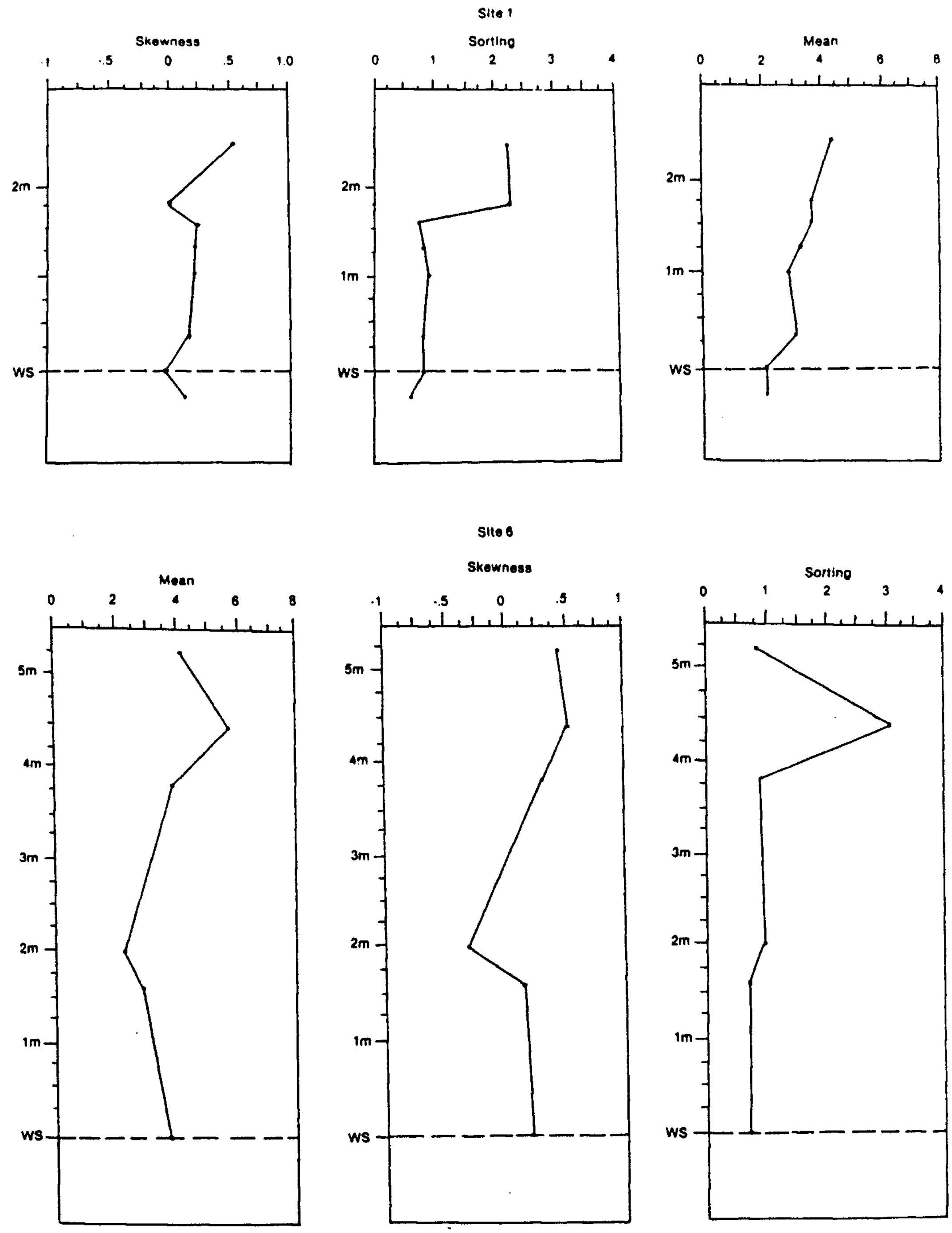


Figure 22: Variation in Grain-size parameters with depth for sites 1 and 6. Note the fining of the sediment upward in the bank at site 1.

meter below the top [Fig. 22, site 6].

Downstream of the meander's apex, the cut banks are stratified with as many as three distinct silt-clay layers. Sites 13 and 14 [Fig. 23] contain two intervals in which the mean grain size is finer than Ø4 [silt]. The lower silt-clay interval [mean=Ø5.75] at site 14 is a 1.4 m thick channel fill deposit. Above this deposit is one meter of sand overlain by an upper silt layer .25 meters in thickness [mean=Ø5.5]. This upper layer of silt is not laterally continuous and was probably deposited on low portions of the relict point bar as discharge waned. This upper fine layer is overlain by .75 m of silty sand that does not contain sedimentary structures.

At many locations downstream from the apex of the active meander, a third silt layer is present and is pedogenic in nature. This silt layer is thin [.3 m] and slightly undulating [Fig. 24]. The dark layer in figure 24 [arrow] is actually a buried soil as evidenced by its gradational lower contact with the underlying sand. The soil is preserved only in low areas of the former floodplain surface where it has been since buried by silty flood material.

Approximately 4500 feet [1371 m] downstream from the apex of the active meander, a prominent scarp appears, trending nearly east-west on the floodplain and is

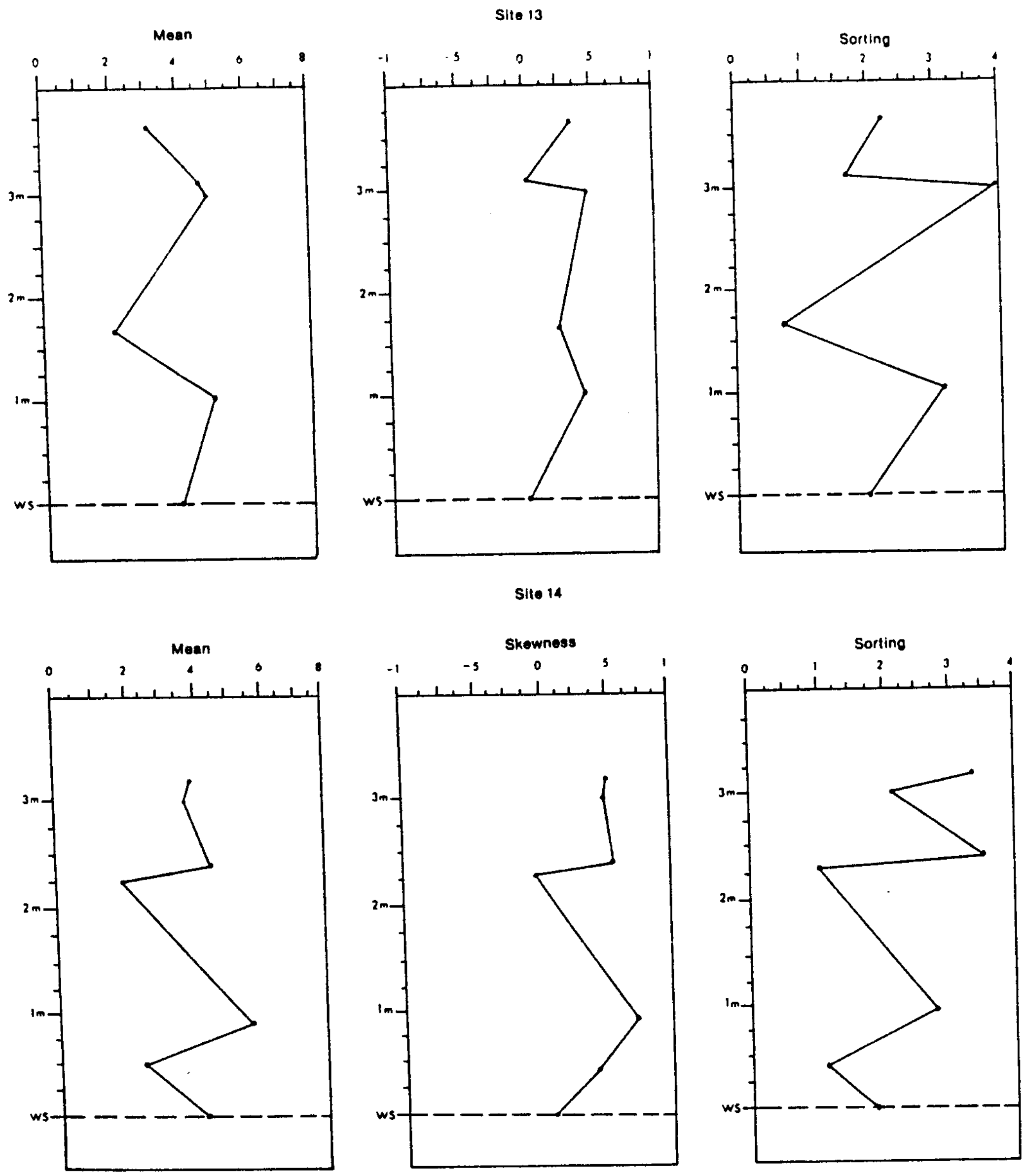


Figure 23: Variation in grain-size parameters with depth for sites 13 and 14. The variability in grain-size parameters is due to the presence of discrete fine sediment intervals within the bank.

Figure 24. Buried soil (arrow) formed in lower areas of the former floodplain along reach 2.

of

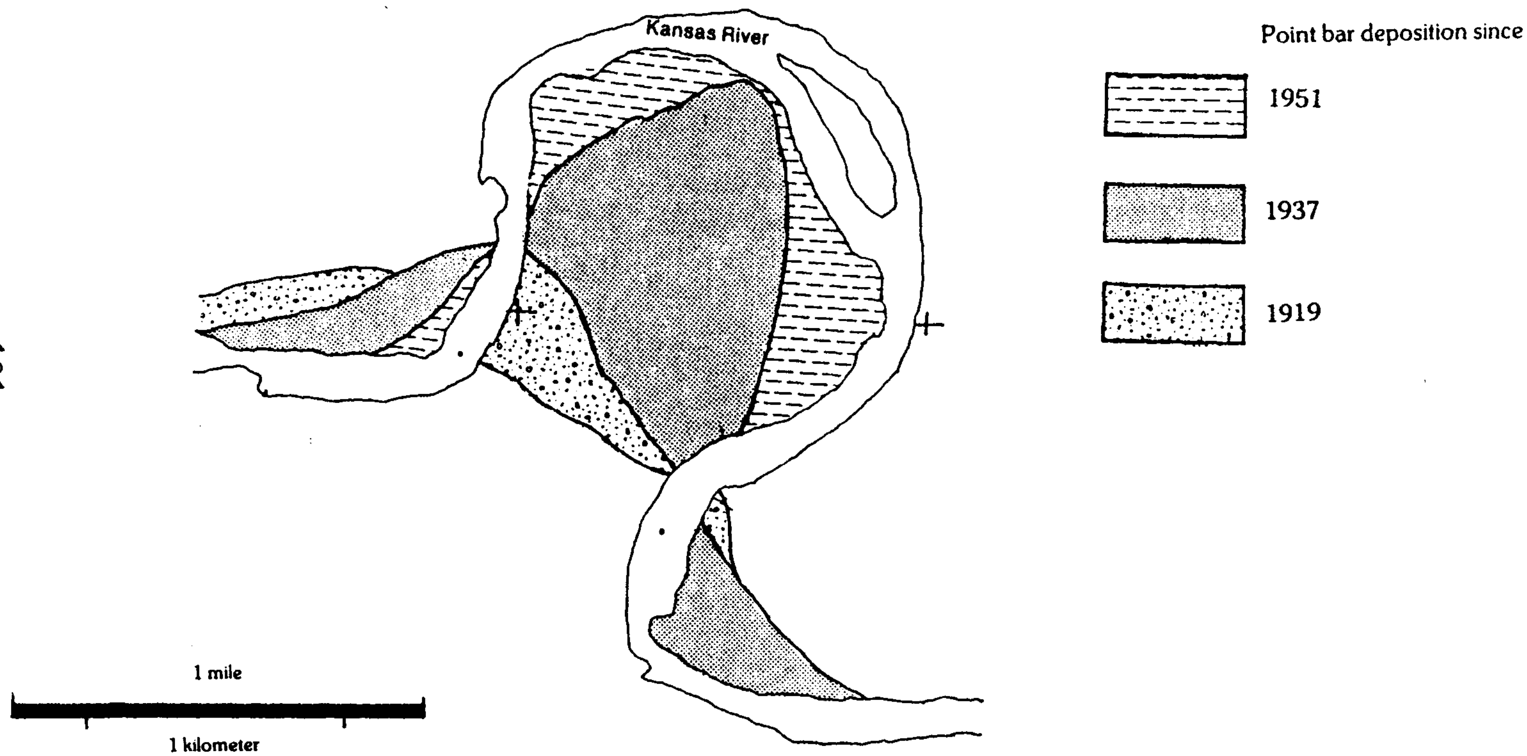


Figure 25: Point-bar deposition along reach 2 since 1919.
Source: 1937, 1951, 1978 aerial photographs and Dort (1980).

truncated by the contemporary channel of the Kansas River (Fig. 25). The scarp delineates the north bank of the 1940 channel of the Kansas River. Since 1940, the channel has migrated south to its present position. As the channel migrated south, point-bar deposition occurred along the northern side of the channel and is presently occurring adjacent to the contemporary stream. The older point bar deposits south of the scarp contain very little silt or clay (Fig. 26) and an immature surface soil attests to the youthfulness of the sediment. Near the bottom of the cut bank, gravel deposits are present for a lateral distance of 200 feet (61 m) along the cut bank. A detailed description of these gravels is presented later in this chapter.

The distribution of silt and clay in the bank has a pronounced effect on the type of erosion that occurs (Turnball et al., 1966). Where substantial amounts of silt and clay exist in the topstratum overlying permeable sand (Fig. 27), the collapse of this fine material may occur. As the river rises due to run-off, or as in this case, reservoir draw down, the permeable sands become saturated and remain so until the water level drops. This drop in water level usually occurs in mid-summer. The saturated sands drain quickly, resulting in the collapse of overlying finer sediments (Fig. 28). The examples provided in figure 23 (sites 13 and 14) are from an area where the collapse of

Figure 26. Trough cross-bedded sand in the cut bank at the downstream portion of reach 2. The immature surface soil attests to the youthfulness of this deposit.

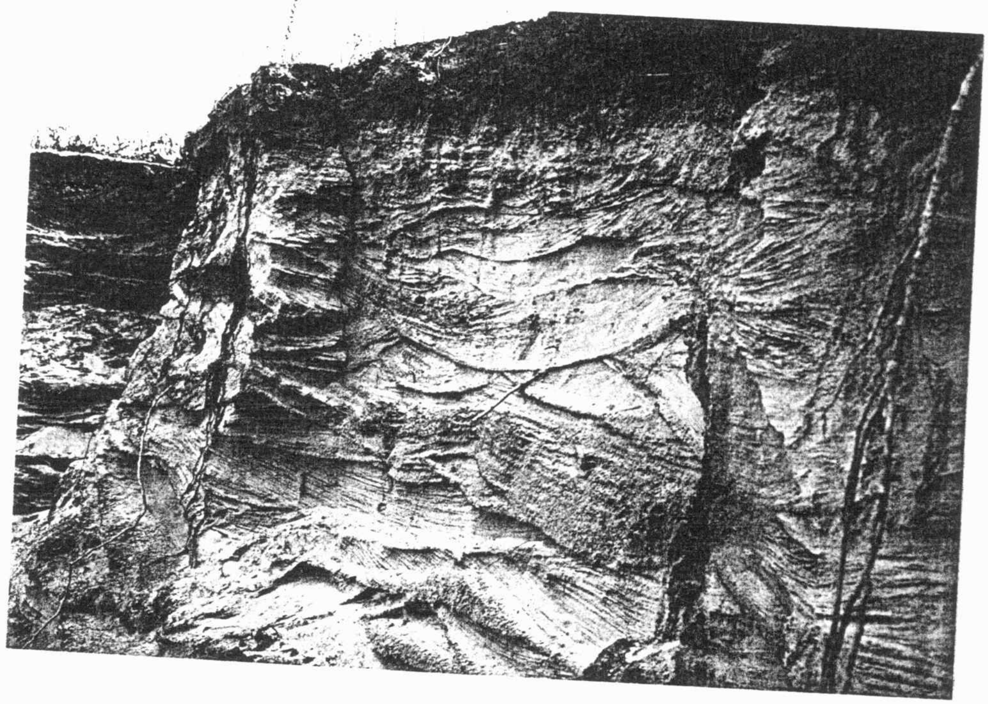
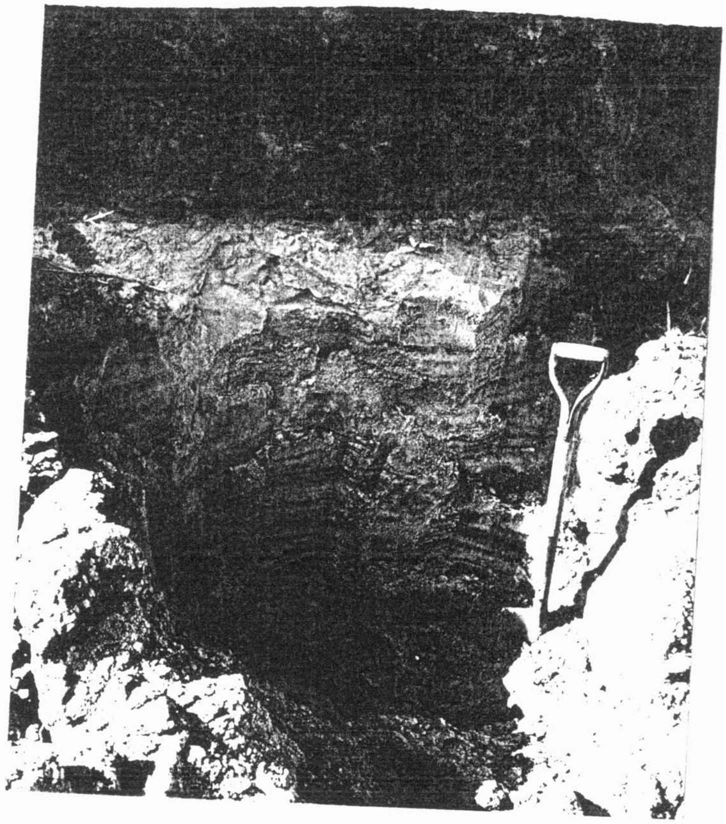
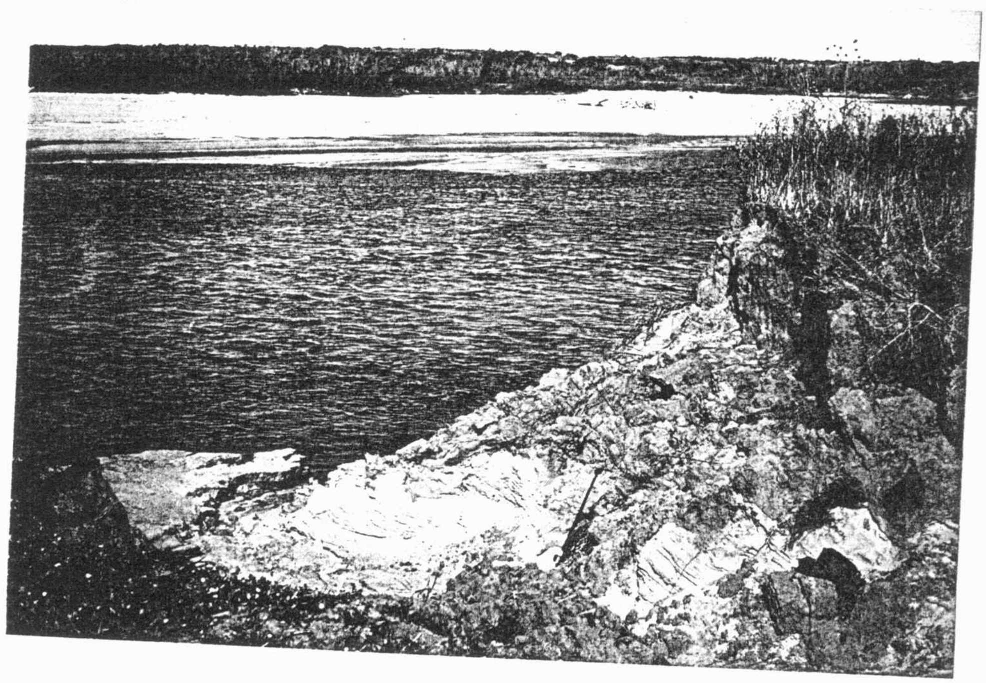


Figure 27. Silt-clay-rich topstratum overlying permeable sand at site 13 along reach 2.

Figure 28. Gully formed by the collapse of fine sediments overlying coarse point-bar deposits near site 13 along reach 2.

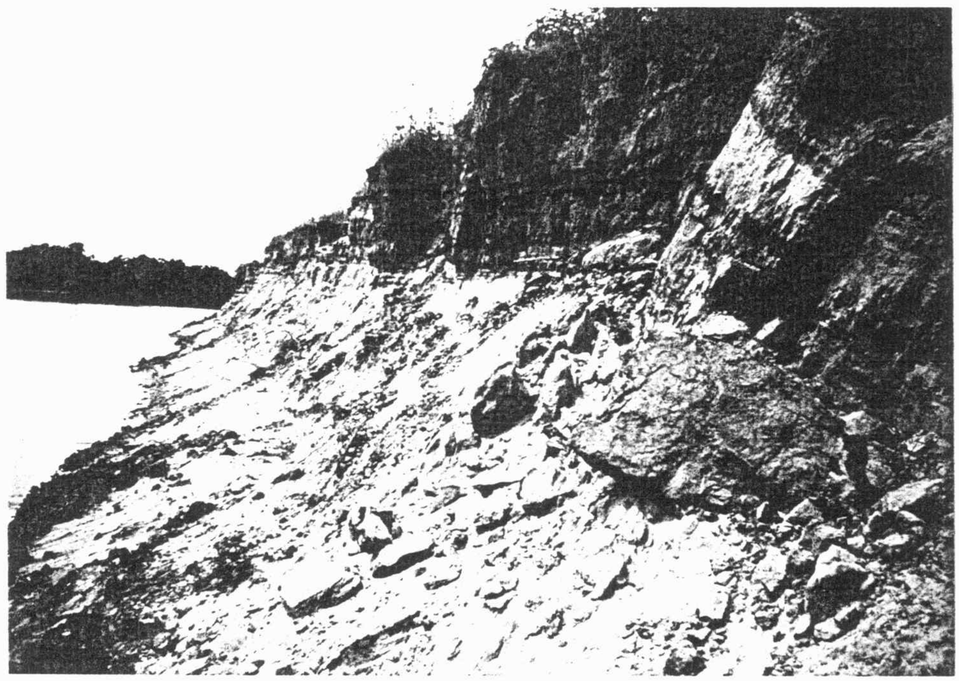




fine sediment has occurred. In this example, an unusually thick layer [for reach 2] of clay was underlain by fine to medium sand. The collapse of the silt-clay-rich topstratum resulted in the formation of a gully adjacent to the channel accentuating the erosion of cropland bordering the Kansas River.

Bank slumping, the movement of cohesive blocks of bank material down the cut bank slope, occurs where silt-clay percentages are high enough to promote cohesiveness. The vertical extent of the slump depends upon the thickness of the silt-clay-rich topstratum. Along reach 2, the top-stratum is usually thin and resulting slumps were derived only from the extreme upper portion of the bank. Because of their small size, they progressed down the cut bank slope by rotation and invariably were destroyed in the process [Fig. 29]. Along reach 1, slump blocks often consist of the entire bank and remain a cohesive unit after slumping occurs. Where sand underlies the slumping material along reach 1, the fine slumped material armors the lower portion of the banks, making them more resistant to erosion. This occurs where Newman and Buck Creek terrace fills abut against the channel and point-bar sands are exposed in the lower portion of the bank. Where silt-clay-rich topstratum is negligible, sand particles accumulate at the angle of repose on the banks and are

Figure 29. Rotational slumping of the fine top-stratum near site 16 within the downstream portion of reach 2.



easily entrained during high discharge periods.

In summary, sediments comprising the cut banks of reach 1 are both more cohesive and finer than the sediments exposed in the cut banks along reach 2. Point-bar sands, which comprise the bulk of the cut bank sediments along reach 2, contain enough silt and clay to provide the bank stability necessary for meander growth but not enough to retard bank erosion and channel migration. Most of the silt and clay along reach 2 is found in thin layers stratified within the bank. Where these layers overlie sandy material, bank erosion may be accentuated by the collapse of the overlying fine cohesive layer resulting in the formation of gullies trending perpendicular to the bank.

Along reach 1, the cut banks are comprised of sediments of the Buck Creek, Newman and Holliday terrace fills. As mentioned before, these sediments are unlike the modern sediments that comprise the cut banks along reach 2. A more detailed description of these terrace fill deposits is presented in the following two parts of this section.

Analysis of Terrace Sediment

Dufford (1958) contended that sediments in older valley fills in the lower Kansas River valley were finer and more cohesive than modern sediments and therefore were better able to resist erosion. To test this contention, a T-test was conducted to determine if grain-size parameters differed significantly between terrace fill sediments and modern sediments. Results of the T-test (Table 7) indicate that terrace fill sediments have clearly different grain-size characteristics than does modern alluvium. Modern sediment within the study area tends to poorly sorted, fine-skewed fine sand whereas terrace fill sediment, in general, is very poorly sorted, strongly fine-skewed silt.

Variable name	Group 1	Group 2	Mean 1	Mean 2	2-tail probability	Reject Ho	Test #
sort	Newman Holliday	modern	2.61	1.59	0.00	*	
skew	Newman Holliday	modern	.456	.267	0.00	*	1
mean	Newman	modern	5.15	3.46	0.00	*	
sort	Buck Creek	modern	2.41	1.59	0.00	*	
skew	Buck Creek	modern	.479	.267	0.00	*	2
mean	Buck Creek	modern	4.60	3.46	0.00	*	

Table 7: Results of T-test for differences in grain-size parameters between modern and terrace fill deposits.

* significant (reject null hypothesis)
- not significant (accept null hypothesis)

Having established that a difference exists between terrace fill sediments and modern sediments, a more detailed discussion of the nature of the terrace fill sediments is necessary. Three 30-foot [9.14 m] cores drilled by the United States Army Corps of Engineers as part of a 1980 bank stabilization study provided information as to the nature and stratigraphy of the Buck Creek and Newman terrace fills, these cores are augmented by three valley cross-sections constructed using water-well logs provided by the Kansas Geological Survey, the Strader Drilling Company and the United States Army Corps of Engineers.

Before entering a discussion of the cores and valley cross-sections, it is necessary to first discuss the relationship between the various terrace fills. The literature [e.g., Beck, 1959; Fader, 1974] describes the Newman and Buck Creek terraces as cut-and-fill terraces where the Newman terrace is inset into the Buck Creek terrace and the Buck Creek terrace is inset into the Menokan terrace. No evidence to support or refute these contentions was found within the study. For this reason, valley cross-sections were drawn in accordance with those presented by Beck and Fader treating the material below each successive terrace surface as separate fills, although this actually may not be the case. Evidence does suggest, on the other hand, that the Holliday terrace is indeed a cut-and-fill terrace. East of Wamego, within the Newman-Holliday terrace exposure, the contact between the contrasting alluvium of the Newman and Holliday terrace fills can be traced vertically through the exposure. The presence of this contact indicates that the Holliday terrace fill and the Newman terrace fill are separate fills.

Four cores, two from the Newman terrace, one from the Buck Creek terrace, and one from the modern alluvium are presented in figure 30. As revealed, the thickness of the silt-clay topstratum is different for each core. In core AD-24 (modern) only the top 1.5 feet (.45 m) are comprised of silt and clay. The remaining 27.5 feet (8.38 m) of the core consist of sand which contains interbedded clay in the upper 7 feet (2.13 m) and gravel in the lower 9 feet (2.75 m). The two Newman terrace cores shown in figure 30 are separated by 2500 feet (762 m). The westernmost core (AD-30) contains a silt-clay topstratum 25 feet (7.62 m) thick whereas sand is confined to the lower 5 feet (1.52 m). To the east, core AD-31 has only 8.5 feet (2.59 m) of silt and clay at the top of the core. The remainder of the core consists of sand and interbedded sand and silt. The radical difference in the thickness of the topstratum within AD-30 and AD-31 over a distance of 2500 feet (762 m)

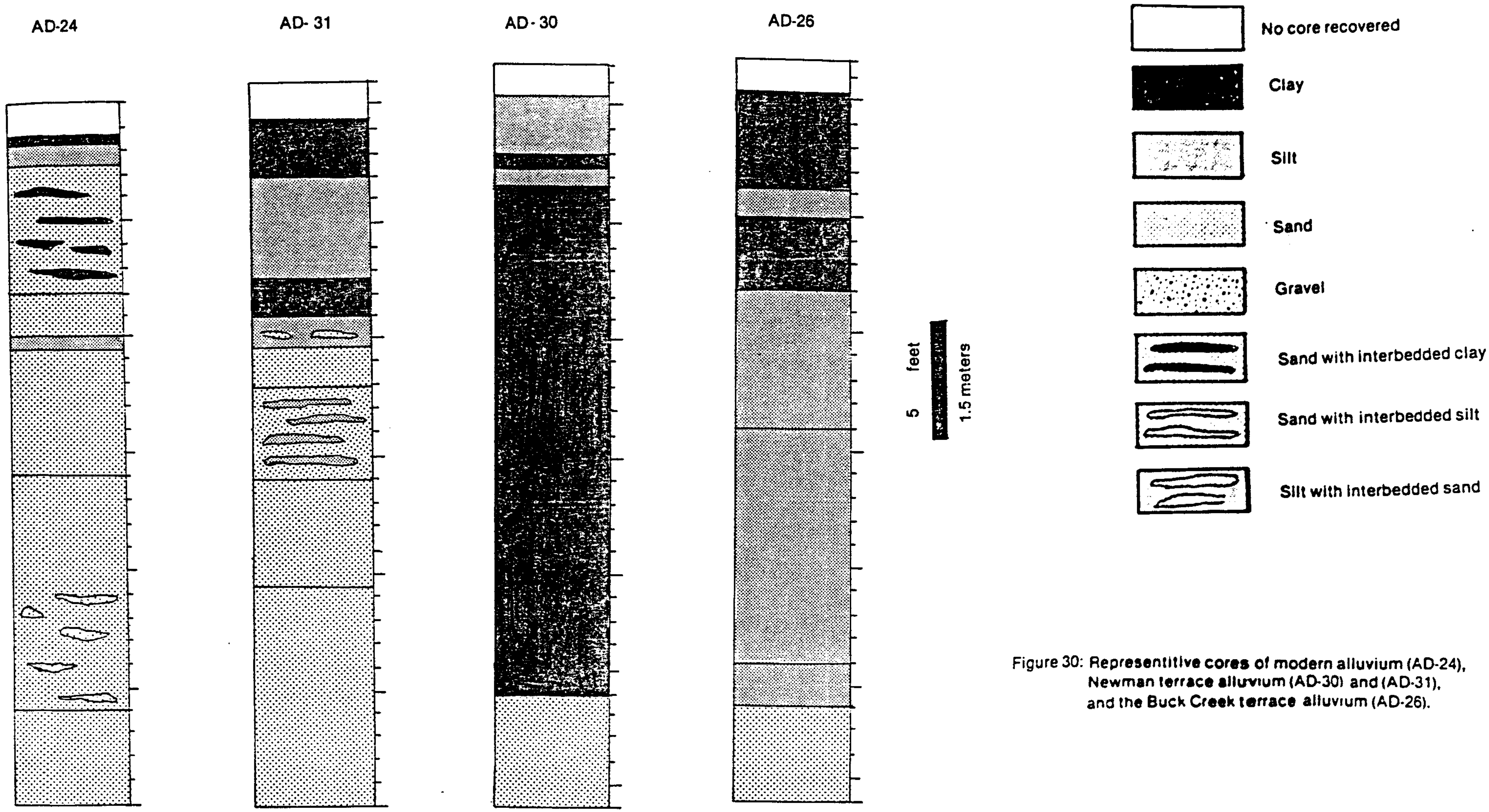


Figure 30: Representitive cores of modern alluvium (AD-24), Newman terrace alluvium (AD-30) and (AD-31), and the Buck Creek terrace alluvium (AD-26).

indicates that a substantial amount of lateral variation occurs in the sediments of the Newman terrace fill. This lateral variation is also observable in the Newman-Holliday terrace exposure east of Wamego. The sediments exposed along the cut bank here are discussed in detail in the next part of this section.

Evidence provided by these cores supports the conclusions gained from the two measured sections presented earlier in figure 18; the Newman terrace fill contains a greater proportion of overbank [vertical accretion deposits] than does modern alluvium which is predominantly point-bar [lateral accretion] deposits.

The core from the Buck Creek terrace [AD-26] is similar to AD-30 from the Newman terrace and contains very little sand. The upper 25 feet [7.62 m] of the core consist of silt and clay and the uppermost 5 feet [1.52 m] are comprised particularly of clay. At most locations where the Buck Creek terrace fill comes in contact with the Kansas River, fine silt and clay are exposed at the river level. Near mile 132, however, where the Buck Creek terrace also comes into contact with the Kansas River, trough cross-bedded sand is exposed in the lower one meter of the fill. At this location, the sloughing of clay-rich material from the topstratum may provide an armor protecting these basal sands from erosion. This location, approximately 1500 feet [457 m] southeast of mile 132, is immediately across the channel from gravel deposits identified by Simons and Li [1984]. They postulated that these gravel deposits have provided a "pivot point" of channel stability which the channel has occupied continuously since 1885. The effect of these gravels and the Buck Creek terrace fill on channel migration at this location is discussed in the following subchapter.

Examination of valley cross-sections [Fig. 31 A-D] revealed that the cores shown in figure 30 are generally representative of their respective fills. There is some discrepancy between the terminologies used for sediment in figure 30 and 31 because of the different sources from which the data were obtained. The valley cross-sections, constructed from drillers' logs, do not contain the detail that the United States Army Corps of Engineers' core descriptions provided. In addition, drillers' logs often referred to the entire silt and clay topstratum of the terrace fills solely as clay whereas the Corps of Engineers differentiated between silt and clay in the descriptions of the cores they provided.

The Buck Creek terrace is present in all three cross-sections and contains 25 to 35 feet [7.62 m to 10.67 m] of clay in the upper portion of the fill. The Newman terrace fill, only present in cross-section A-A', contains

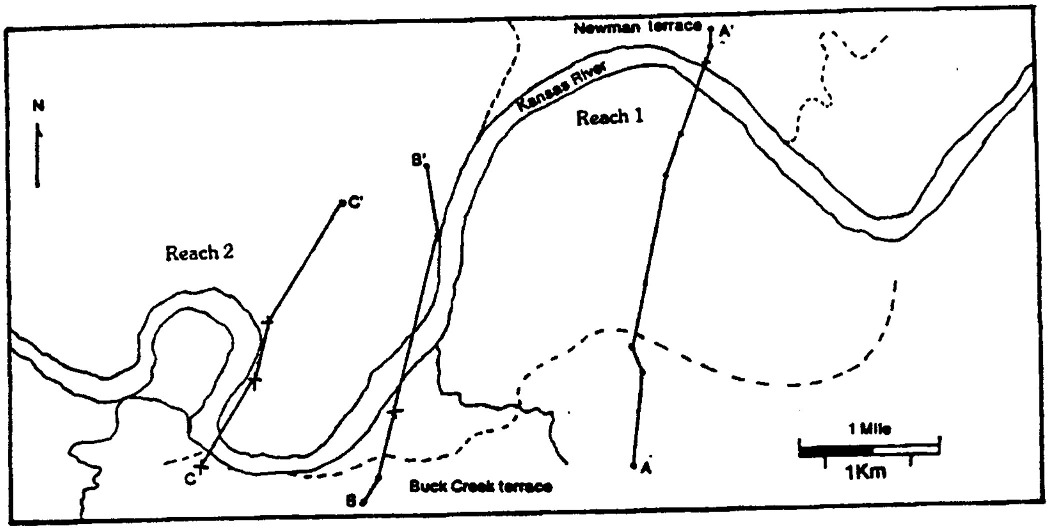
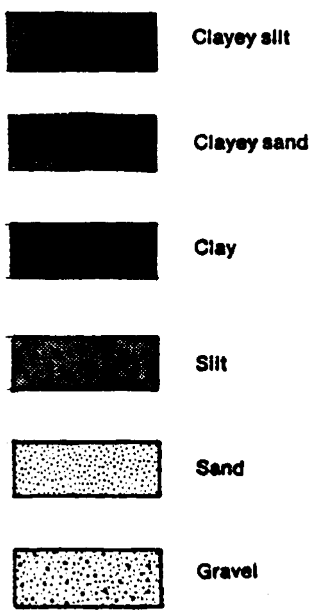
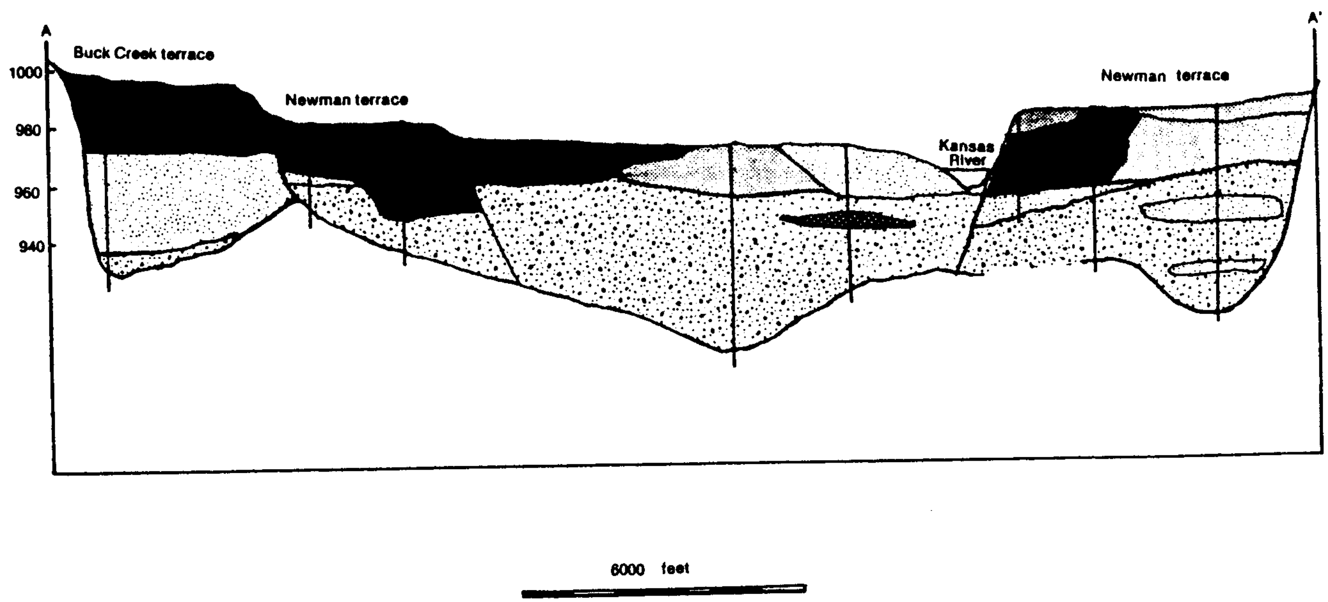
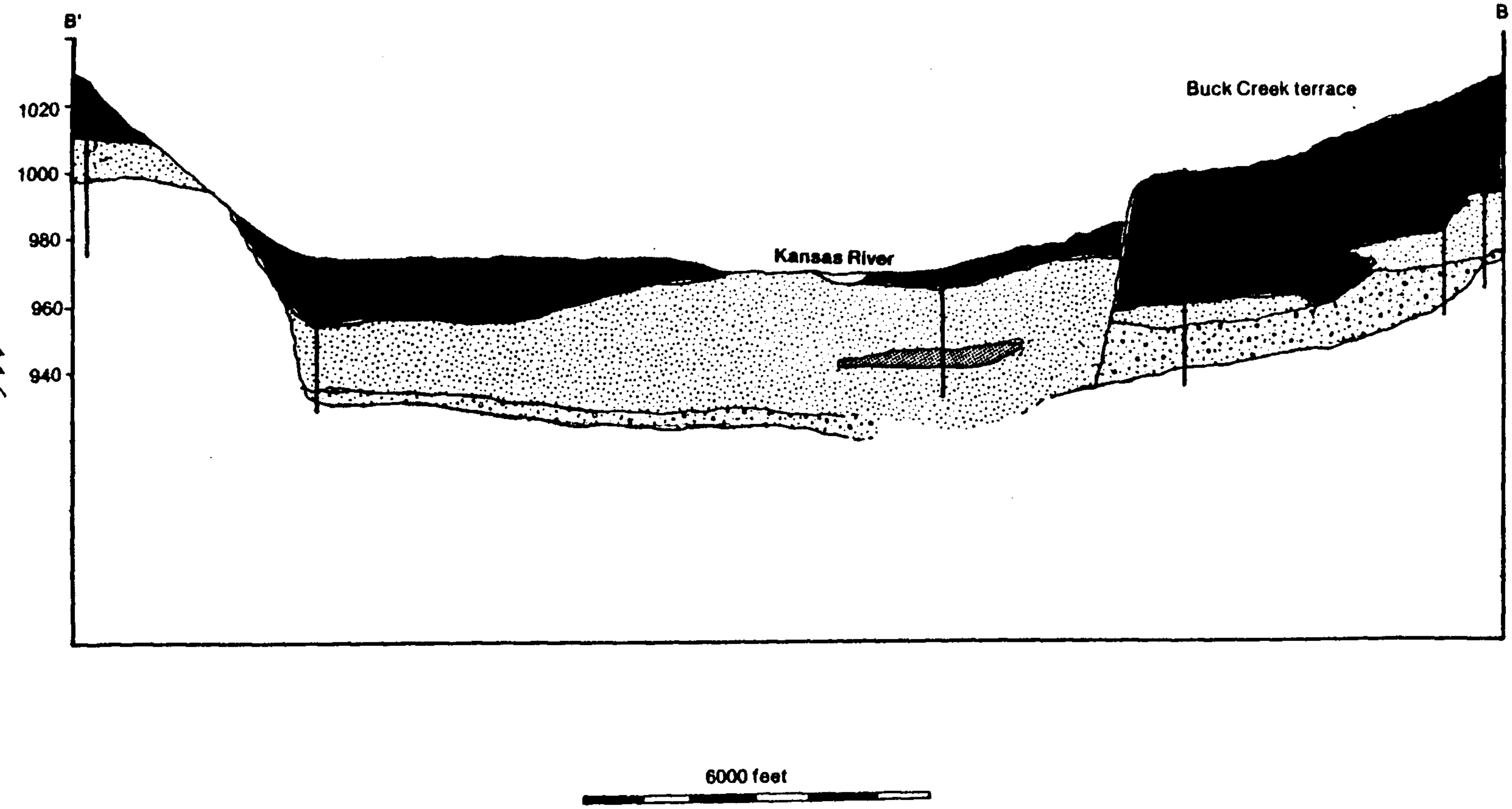


Figure 32A-C: Map and cross-section of the Kansas River Valley at Wamego, Kansas.

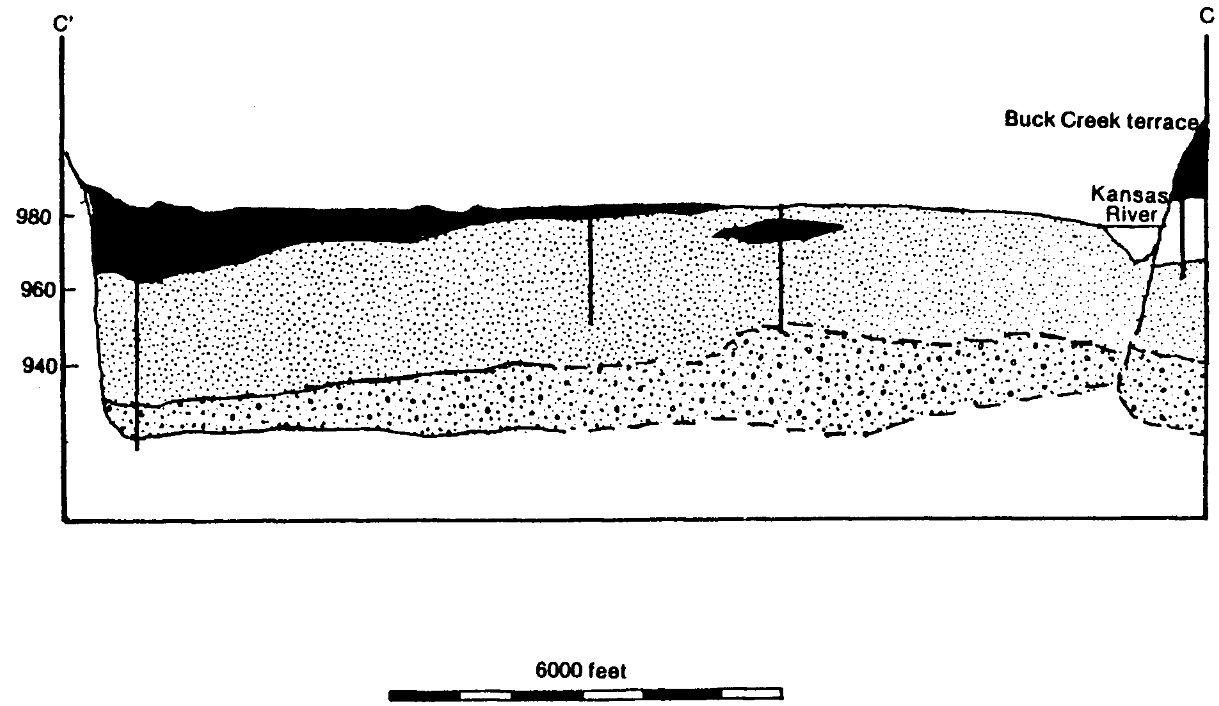
Explanation for cross-sections; A-A', B-B', C-C'.




A
A'
Buck Creek terrace
Newman terrace
Newman terrace
Kansas River
1000
980
960
940
6000 feet



B'
B
Buck Creek terrace
1020
1000
980
960
940
Kansas River
6000 feet


C'
C
Buck Creek terrace
Kansas
River
980
960
940
6000 feet

a thick clay-rich topstratum south of the Kansas River. North of the Kansas River, the topstratum of the Newman terrace fill consists of a 30-foot [9.14 m] layer of silt and clay adjacent to the channel but grades to silt and becomes thinner to the north. Near the margin of the valley, the silt-rich topstratum is only 4 feet [1.22 m] in thickness.

The modern sediments are comprised chiefly of sand but at the margins of the floodplain, thick wedges of silt and clay have accumulated in back swamp areas. These wedges are distal to the contemporary channel and separated from it by point-bar deposits suggesting that they formed as overbank deposits as the channel migrated away. Each of these wedges are underlain by extensive sand deposits.

A contemporary meander belt exists between the thick wedge of clay at the valley margins and the terrace fill deposits. Between these two entities, the channel is seemingly free to meander since the resistance from the non-cohesive sand is minimal. To prove this theory would require a substantial amount of evidence this paper does not present. Yet it seems a viable theory in light of the coarser nature of the sediments along reach 2 and the resulting active channel compared to the relative inactivity of the channel in reach 1 where the cut banks are dominated by silt and clay.

In summary, sediment characteristics of the Newman, Buck Creek and Holliday terrace fills differ significantly from those of modern sediment. The fine nature of the Buck Creek and Newman terrace fills are revealed in figures 30 and 31. Although the Buck Creek and Newman terrace fills are very similar, there seems to be more lateral variation in the Newman terrace fill but this may only be due to a shortage of information owing to poor preservation of the Buck Creek terrace. Nonetheless, where the channel abuts against these terrace fills within the study area, it generally encounters fine-grained, cohesive sediment more resistant to erosion than the coarse sediments that comprise the modern alluvium.

The Holliday terrace comes into contact with the Kansas River for a distance of only 700 feet [213 m] at a location 2600 feet [792 m] downstream of Wamego. No cores of the Holliday terrace were drilled by the United States Army Corps of Engineers nor could water-well data be found of wells within the terrace fill. The exposure along the Kansas River is discussed along with the Newman terrace exposure in the next part of this section.

Stratigraphy of the Newman-Holliday Exposure

An excellent exposure of the Newman-Holliday terrace fill along reach 1 allows for a more detailed analysis of how the fluvial history of the Kansas River has affected channel stability. This exposure is located immediately east of Wamego and continues .5 miles [.8 km] downstream. Within this exposure, three paleosols are exposed within the Newman terrace fill and two within the Holliday terrace fill. The Newman terrace is easily identified within this area by its position above the floodplain, by the lack of paleochannel features on its surface, and by the presence of the Muir soil. Furthermore, Beck [1959] and Fader [1974] have mapped this surface as the Newman terrace.

Three stratigraphically discernible units are present within the Newman terrace fill at this exposure. These units along with the Holliday terrace fill exposure are shown in Plate 3. Plate 3 is a generalized profile constructed from four measured sections of the Newman-Holliday terrace exposure. The upper unit in the Newman terrace fill, herein designated Tn-1, consists of buff-colored silt and contains no apparent sedimentary structures. The thickness of Tn-1 decreases considerably from 7.25 meters at the easternmost point of the exposure to less than 1 meter at the Newman-Holliday terrace contact. Below Tn-1 is a stratigraphic unit comprised of alternating silt and clay [Tn-2]. The sediment comprising Tn-2 becomes progressively coarser downstream until it eventually pinches out near site 158. The lowest stratigraphic unit [Tn-3] consists of coarse, trough cross-bedded sand and gravel. This unit is exposed only in the lower .5 m of the Newman terrace fill at site 157 but becomes increasingly higher in the section towards the east until, at the Newman-Holliday terrace contact, sediments of Tn-3 comprise the entire Newman terrace fill.

At site 157, the three paleosols have developed entirely in the sediment that comprises unit Tn-1 [Fig. 32]. Tn-1 is comprised of silty [mean = Ø4.4], buff-colored sediments which are loess-like in appearance. These sediments are remarkably similar to descriptions of other mid-Holocene deposits of the central United States. Among these are the Canon Bend Formation [Brackenridge, 1984], the early Holocene alluvium of southwest Wisconsin [Knox et al., 1981], and the Cahokia alluvium in Illinois [Barries, 1972]. Butzer [1977] interpreted similar deposits dated from 5000 to 10,000 years B.P. at the Kozer site Illinois to be "reworked Eolian sediment, mainly loess." Brackenridge [1984] suggested a late Wisconsin to early Holocene loess origin for similar deposits along the Pomme de Terre River in Missouri.

The basal paleosol in figure 33 has been ^{14}C dated at 7250 $\pm$ 110 years B.P. This paleosol continues the entire length of the Newman terrace fill exposed in the cut bank

Figure 32. Three paleosols (labelled 1, 2, and 3) within the Newman terrace alluvium immediately east of the town of Wamego. The basal paleosol (#3) has been ^{14}C dated at 7250 $\pm$ 110 years B.P. Unit Tn-1 is the buff-colored sediment containing the three paleosols and is underlain by the thin alternating silt and clay layers of unit Tn-2.

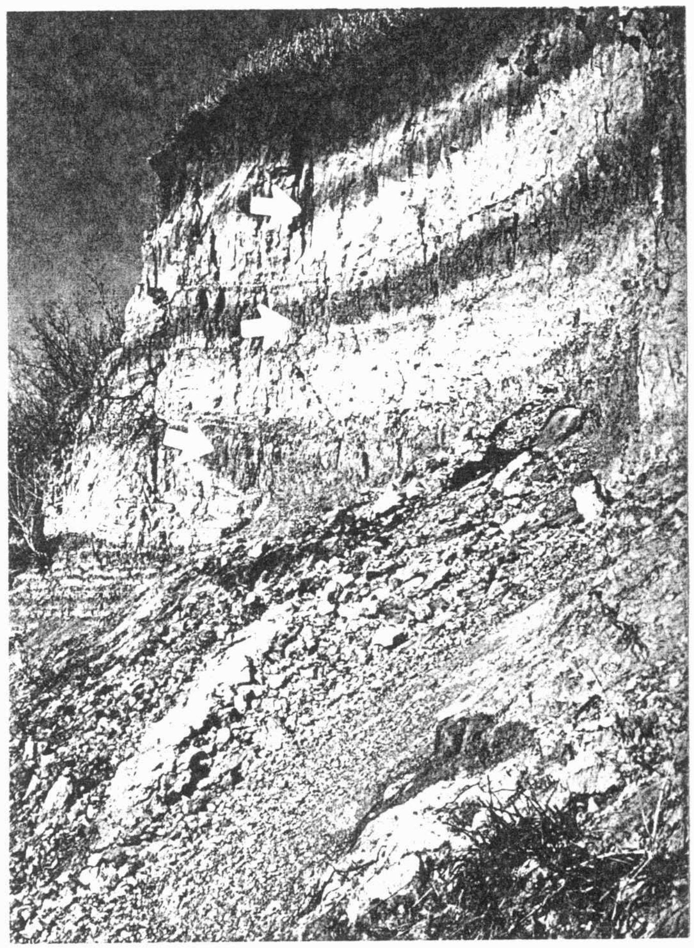


Figure 33. Paleosol formed in sandy alluvium near the Newman-Holliday terrace contact.

east of Wamego. As shown in plate 3, the basal paleosol is a time-stratigraphic marker that is formed in each of the units discussed above. Near the Newman-Holliday scarp, the basal paleosol is formed in the sandy alluvium of Tn-3 less than 1 meter below the surface of the Newman terrace (Fig. 33). At this location (downstream of site 158 on plate 3) Tn-2 is absent and only one paleosol is present in the exposure. The uppermost paleosol forms a couplet with the modern soil throughout much of the length of the exposure but is not present east of site 158. The middle soil is present throughout much of the exposure but disappears as the banks become sandier downstream.

The sediments that comprise Tn-3 are indicative of point-bar deposition as evidenced by the trough cross-bedded sand and the gradational contact with finer sediment above. Near the eastern edge of the Newman terrace fill, gravel-sized material appears in the lower part of this unit. This gravel becomes more abundant nearer the Holliday-Newman terrace contact, but is not present in the Holliday terrace fill. The alternating layers of silt and clay that comprise unit Tn-2 and overlie much of unit Tn-3 were probably deposited in low areas behind the expanding point bar (Tn-3). These layers become increasingly sandy towards the east possibly signifying deposition more proximal to the source of sediment.

As mentioned before, unit Tn-1 is a thick deposit of buff-colored silt without sedimentary structures. This silt was probably deposited in a quiescent environment by vertical accretion. Deposition was apparently interrupted by three periods of relative stability allowing for the formation of three paleosols.

Because these paleosols are rather well developed, the time required for the deposition of Tn-1 must have been very long. This long period of deposition suggests that a large quantity of sediment of similar characteristics was available in the Kansas River basin for the length of time required for deposition. Such deposits of late Wisconsinan and early Holocene loess, such as the Bignell Formation, were certainly present in northeast Kansas during the period in which Tn-1 was deposited [Frye and Leonard, 1952]. Similar deposits of late Wisconsinan and early Holocene loess have been reported as close to the study area as the Pomme De Terre River basin in Missouri [Brackenridge, 1980].

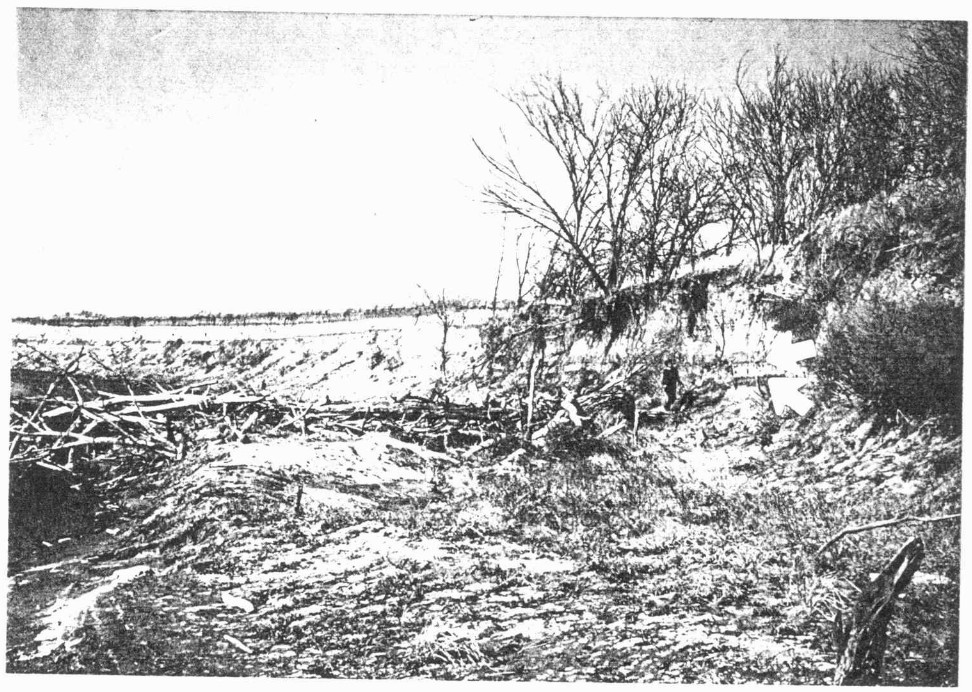
As suggested above, the deposition of Tn-1 required a long period of time as indicated by the thickness of the unit and the presence of three well-developed paleosols within the unit. The 7250 years B.P. date on the basal paleosol, as well as the length of time required for the deposition of Tn-1, indicates that it would be impossible for the Newman terrace and much of its fill to be Wisconsinan in age. Accounting for the time required for the development of the upper two paleosols in Tn-1, the upper portion of the Newman terrace and the surface is more likely to be mid-Holocene in age.

Previous work on the lower Kansas River has yielded similar results (Holien, 1982: 88). Holien presented a strong case using 14C dates of the Newman terrace fill to indicate that much of the Newman terrace fill, and certainly the surface, are early Holocene to mid-Holocene in age.

The Holliday terrace, not previously mapped within the study area, is also exposed at this site. The terrace exposure begins at the Newman terrace scarp and continues only a short distance downstream. The most obvious feature of the Holliday terrace fill is the contrast in color it presents with the Newman terrace fill (Fig. 34). The Holliday terrace has a characteristic gray-to-brown color which contrasts with the buff-colored fill of the Newman terrace. The units within the Holliday terrace fill are laterally continuous, but change rapidly in vertical cross-section. Figure 35 shows the change in grain-size parameters at depth for site 160.

The terrace fill consists of fine alluvium and contains two paleosols (Fig. 34, arrows). Unfortunately,

Figure 34. The Holliday-Newman terrace contact. The contact occurs in the center of the photo. The Newman terrace alluvium is the lighter colored alluvium to the left of the line of trees. Within the Holliday terrace, two paleosols appear in the lower portion of the bank (arrows).



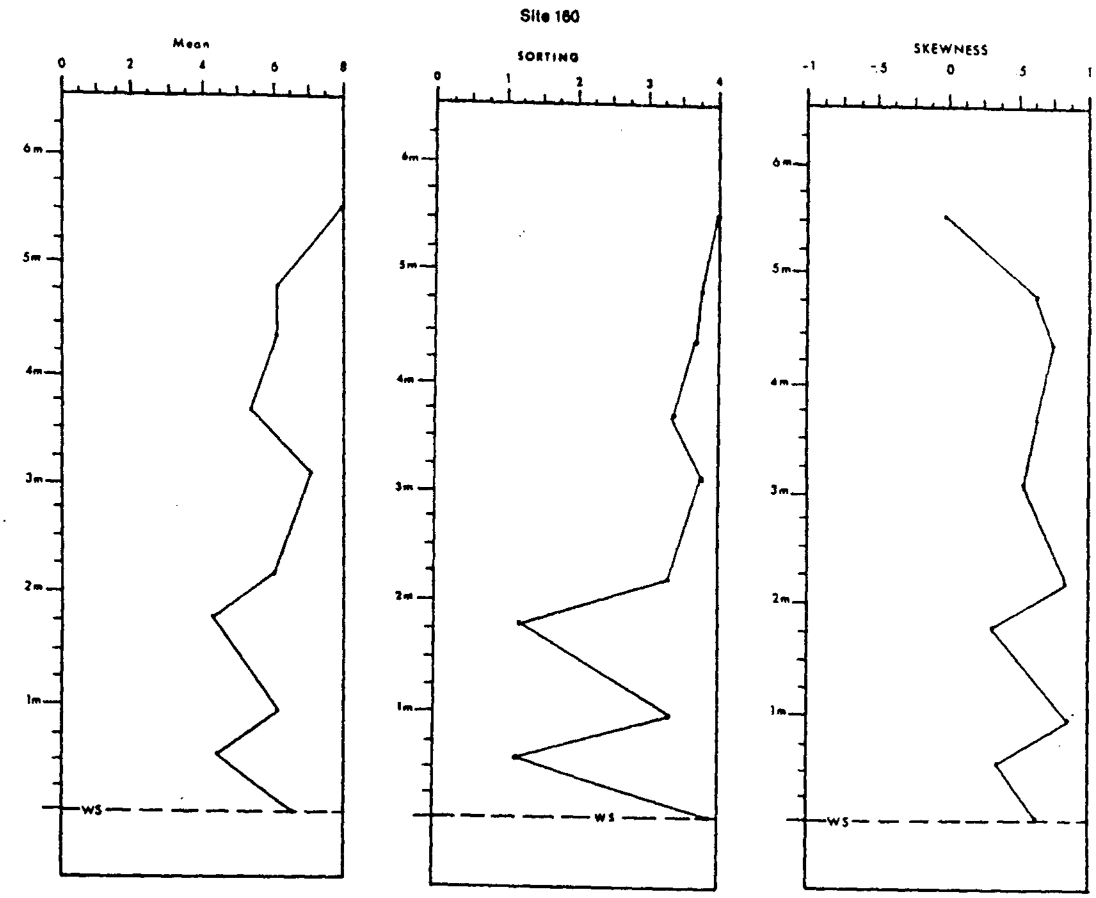


Figure 35: Changes in grain-size parameters with depth for site 160 within Holliday terrace alluvium.

neither of these soils have been ^{14}C dated, but dates on the Holliday terrace have been obtained downstream from Wamego at Bonner Springs (Holien, 1982). The lower of the two paleosols found within the Holliday terrace fill yielded a date from soil humates. The date of 4290 ± 310 years B.P. indicates that the fill is mid-to-late Holocene in age. The paleosol found within the study area cannot be correlated with Holien's just on the basis of position for the distance between the sites is great. Nonetheless, this date is what one might expect for the lower of the two paleosols based on the age of the adjacent and older Newman terrace fill.

EFFECT OF COLLUVIUM AND SUSPENDED-SEDIMENT DEPOSITION ON BANK STABILITY

Schumm (1961) found that the sinuosity of rivers on the Great Plains was related to the mean silt-clay content of the perimeter of the channel. He also suggested that channel characteristics are dependent on the proportion of the components of the total sediment load. Wide shallow channels are associated with streams carrying mostly bed load whereas deep, narrow channels result from streams transporting mostly suspended load. In a subsequent experimental study, Schumm and Khan (1972) reported that a meandering stream developed only when a critical amount of kaolinite was added to the suspended load of the stream. They suggested that this finer material became "incorporated" into the bank increasing the cohesiveness of the sediment and, thus, the stability of the banks. The alternate bars were also stabilized in this way which prevented their erosion. When the thalweg was subjected to scour, a drop in the water level caused the submerged alternate bars to emerge and form point bars resulting in a sinuous channel.

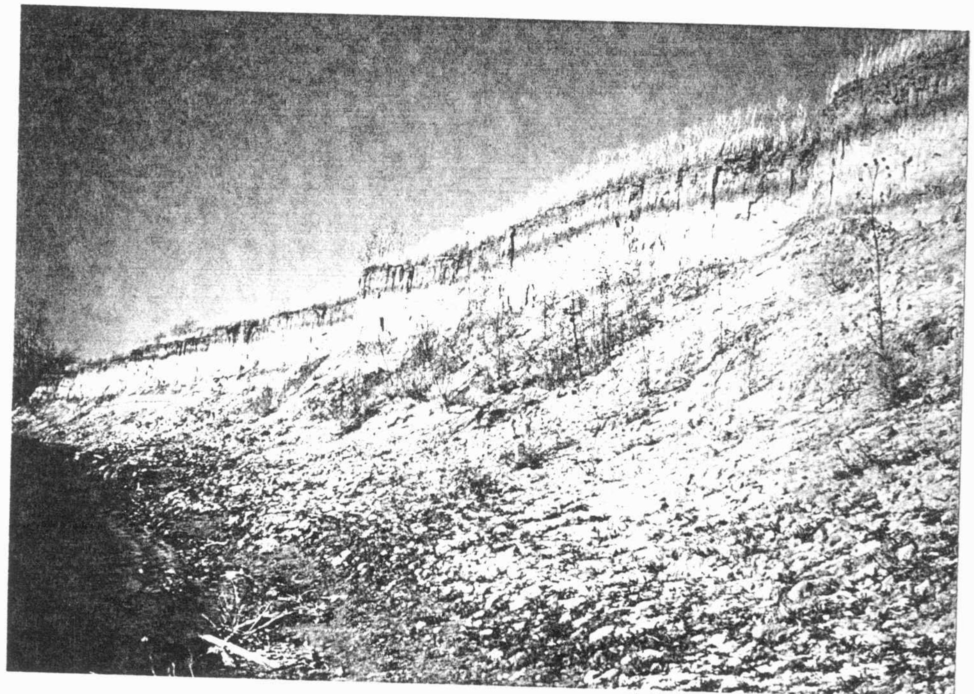
Within the study area, the lower portions of the cut banks were often covered by a thin [< 3 cm] veneer of silt and clay. These silt-clay veneers have two possible sources: deposition of suspended sediment from the stream during waning flow regimes following periods of high discharge and the accumulation of sediment derived from the upper portions of the cut bank through mass wasting processes [e.g., slump, grainfall]. The occurrence and longevity of these silt-clay veneers are dependent on the nature of the underlying material, the degree of the slope of the bank, and the texture of the sediment derived from the upper portion of the cut bank [colluvium].

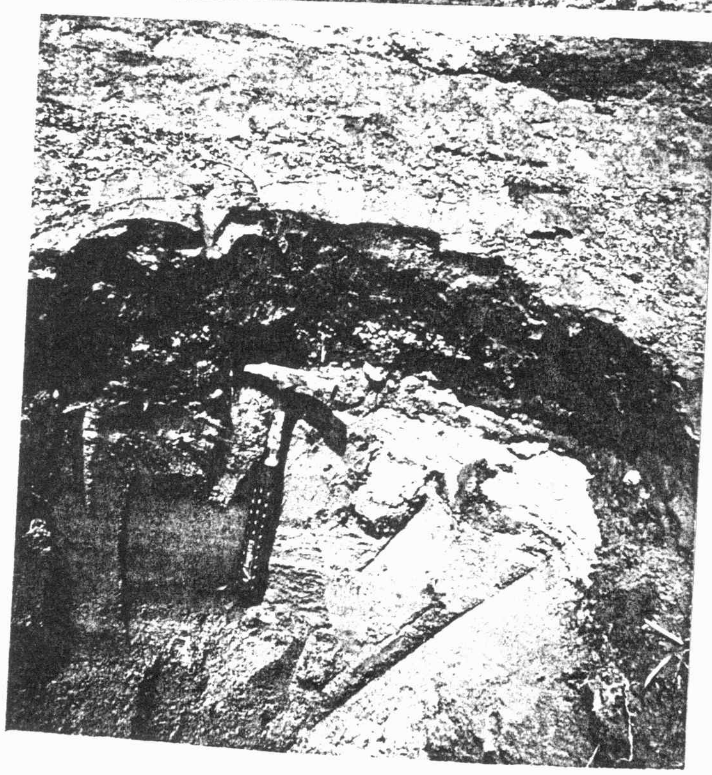
The accumulation of mass wasting products on the lower portions of the cut banks has resulted in breaks in the degree of slope of the cut bank. The portion of the cut bank below the slope break consists of colluvium and is less steep than the bank face above the slope break (Fig. 36). The portion of the cut bank below the slope break was the zone of suspended-sediment deposition during the period of observation for this thesis. Even after periods of discharge great enough for the river level to come into contact with the bank face, there was no evidence of incorporation of sediment into the bank or adherence of suspended sediment on the face.

The lower line in figure 36 indicates the position of the river level two days before the photograph was taken. This photograph is of the Newman terrace fill approximately 2000 feet (609 m) east of Wamego. A thin (5 cm) silt-clay veneer was deposited on the surface below the lower line as the water level dropped. 800 feet (244 m) upstream, an unusually thick (20 cm) veneer was found on the relatively flat surface in figure 37. It is important to note that the sand underlying the veneer in figure 37 is actually in-place bank material and part of the point-bar complex that comprises the lower portion of the Newman terrace fill in the exposure. Fine sediments (mean = $\phi 5.25$), slumped from the upper portion of the Newman terrace fill augments the formation of thick silt-clay veneers over this point-bar complex except at the extreme eastern portion of the exposure where point-bar sands comprise the entire

Figure 36. Slope break on cut bank along reach 1 (upper line). The upper line divides the bank face (above) from colluvial material below. Suspended sediment deposit left after high water stage occurs below the lower line.

Figure 37. Silt-clay veneer formed on relatively flat sandy bank material near site 157. Note the abrupt contact between the veneer and the coarser bank material below.





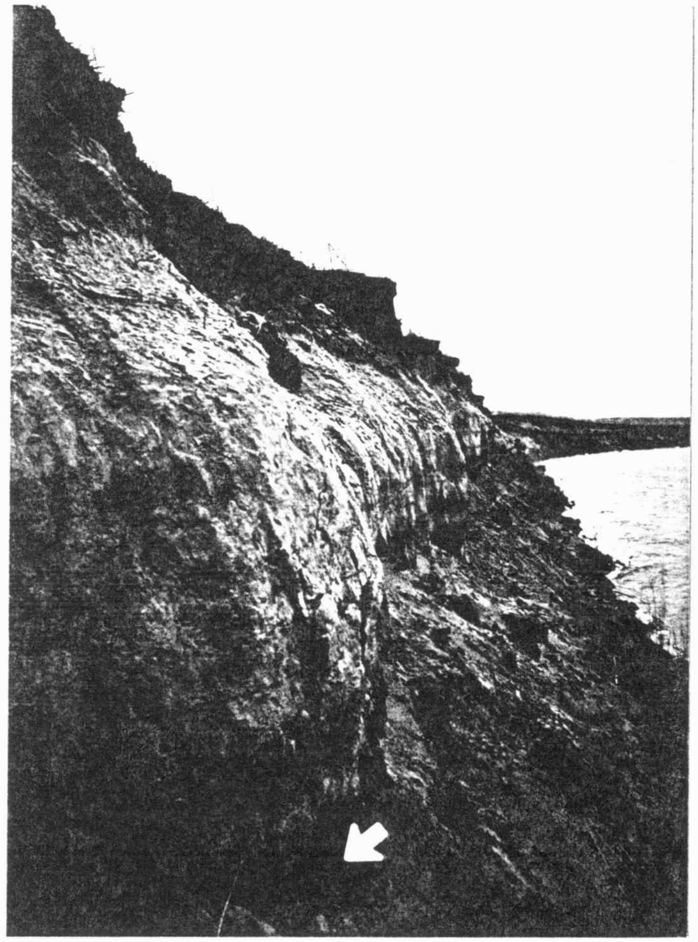
bank. It is possible that this slumping of silt and clay has armored the point-bar sands making them more resistant to erosion.

Another possible instance of silt-clay armoring also exists 1000 feet (304 m) downstream of river mile 132 along the south bank of the river where the channel comes into contact with the Buck Creek and Newman terrace fills. Here, point-bar sand is exposed in the lower one meter of the cut bank and is covered by a thick (30-40 cm) layer of clay. Much of the slump material is derived from the upper 2.5 meters of the Buck Creek terrace fill which is extremely clay-rich (62% clay) and prone to slumping.

Along reach 2, suspended-sediment deposition occurred on steep, sandy colluvium below the slope break (Fig. 38). The sediment below the slope break is mostly unconsolidated sand and sediments derived from thin silt-clay-rich stratigraphic units probably did not contribute to local bank stability. Where present, silt-clay veneers were easily undercut and eroded due to the unstable nature of the underlying sediment.

Silt-clay veneers formed in each reach manifested different grain-size characteristics. Figure 39 shows plots of values of mean and sorting for samples obtained from the water level at low water stages during August of 1983 along reaches 1 and 2. The mean grain size of reach 2

Figure 38. Unconsolidated sandy sediment below the slope break on the cut bank within reach 2. The thin silt-clay-rich unit (arrow) probably contributes very little to local bank stability. Notice the proximity of the bank face to the channel when compared to the bank face in Figure 36.



water level samples ranged from Ø2.5 to Ø6 with an overall mean of Ø3.4. The means of reach 1 water level samples, on the other hand, were all finer than Ø3.75 with an overall mean of Ø4.43. This difference reflects the contribution to the silt-clay veneers by the slumping of material from the upper portion of the Newman and Buck Creek terrace fills along reach 1. Along reach 2, in contrast, rapid bank erosion continually removes the thin silt-clay veneers by undercutting the unconsolidated sandy sediment exposed at the river level.

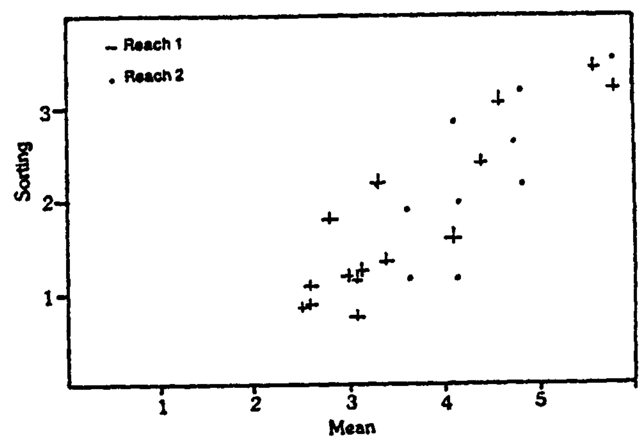
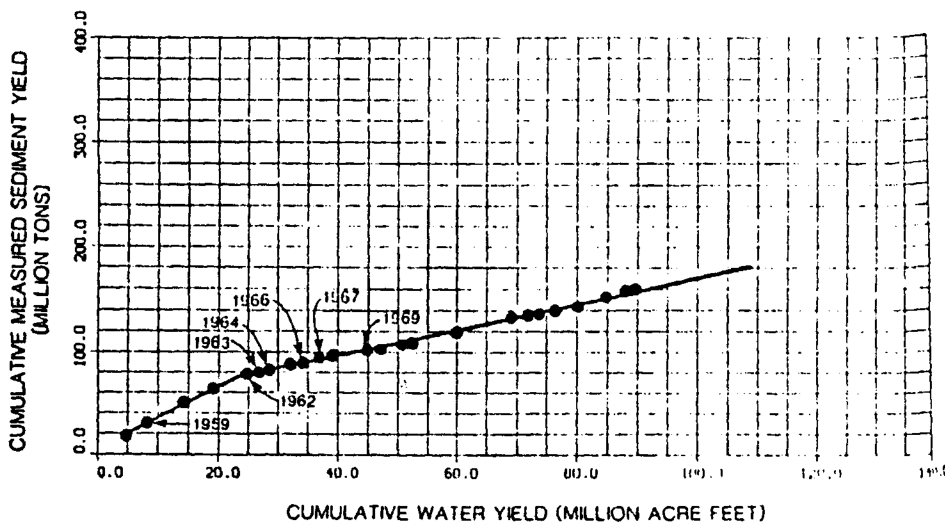


Figure 39: Mean-sorting relationships for water level samples from reaches 1 and 2.

Where rapid bank erosion occurs along reach 2, the bankface above the slope break is considerably closer to the contemporary channel of the Kansas River than it is in reach 1. This difference in proximity of the bank face to the channel is evident in figure 36 [reach 1] and 38 [reach 2]. Two possible theories are put forth to explain this difference in cut bank morphology and components of both may affect the banks contemporaneously. As discussed in chapter 3, the thalweg of the channel in reach 2 abuts against the outside bend of the active meander for the entire length of the meander and the channel cross-section is markedly asymmetrical. This positioning of the thalweg has resulted in the formation of a scour pool along the outside bend of the meander causing the undercutting of the cut bank. The unconsolidated material is easily eroded and removed by the river. Secondly, the upper portion of the cut bank in reach 2 lacks the abundance of fine material [silt and clay] present in the upper portions of the Newman Buck Creek fill deposits along reach 2. These sediments may have armored the lower portion of the banks against erosion making the removal of colluvial material more difficult. In addition, the thalweg within reach 1 meanders between alternate point bars and does not form scour pools which initiate the undercutting of the cut banks.

The significance of the effect of suspended-sediment deposition on channel stability has been asserted by landowners within the study area. They contend that bank erosion has accelerated since the closure of Tuttle Creek and Milford Reservoirs. They suggest that the federal impoundments serve to decrease the amount of silt and clay held in suspension by the river. Deposition of suspended-sediment following periods of high discharge "coated" the banks making them more resistant to erosion. Data presented by Simons and Li [1984] supports their contention revealing a decrease in sediment yield since the large federal reservoirs were closed [Fig. 40]. Since figure 40 displays changes in cumulative sediment yields, the decrease is evidenced by the change in the slope of the line near 1962. Simons and Li [1984: 44] noted, however, that there is no evidence to support the contention that bank erosion has increased since the closure of Milford and Tuttle Creek Reservoirs.

The decrease in the suspended-sediment concentration of the Kansas River at Wamego [Fig. 41] is likely to have long-term rather than short-term effects on bank stability. The development of point bars is usually accompanied by silt and clay deposition on the point-bar surface during waning flow regimes [Reading, 1982]. With a decrease in the suspended-sediment concentration, the ratio of sand to silt-clay will increase substantially. Thus contemporary point bar deposits may contain less fine material to act as cement for non-cohesive sand. As these deposits are reworked in the future, braided conditions may result due



RESERVOIR INFORMATION:

RESERVOIR	DATE OF CLOSURE	DATE OF INITIATION OF PERMANENT STORAGE
TUTTLE CREEK	1959	1963
MILFORD	1964	1967
PERRY	1966	1969

Figure 40: Temporal variation in sediment yield-water yield relations for the Wamego gaging station, 1959-1969. From Simons and Li (1984).

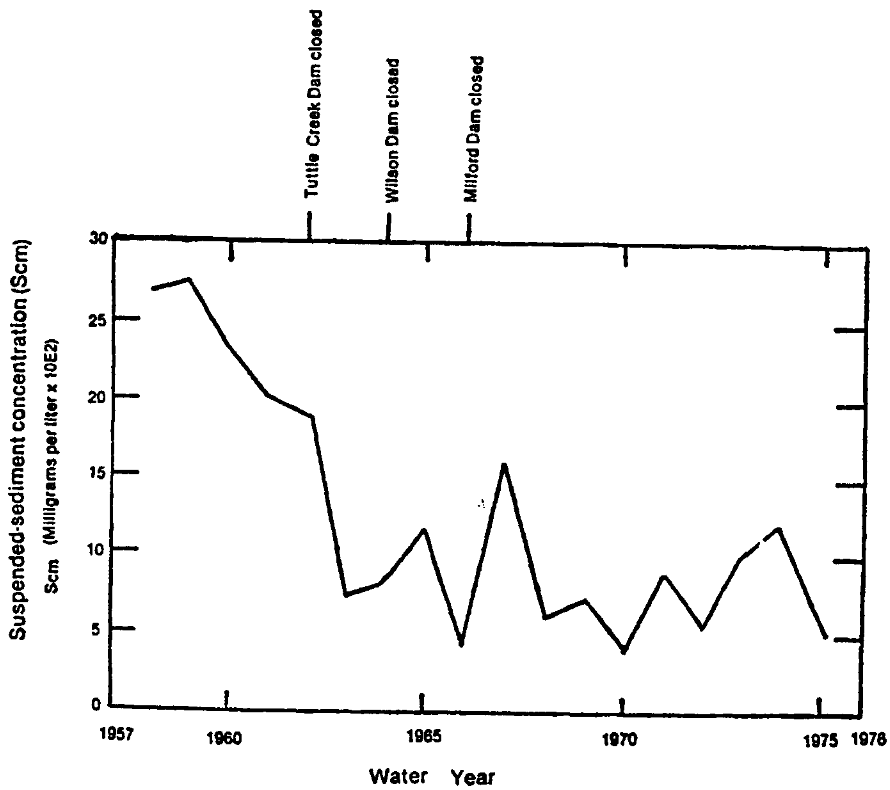


Figure 41: Annual values of mean suspended-sediment concentration for the Kansas River at Wamego from 1957 to 1976. From Osterkamp and others, (1982).

to the lack of fine material in the bank to act as cement.

In summary, no evidence was found within the study area to indicate that suspended sediment either became incorporated into the bank face or adhered to it. Suspended-sediment deposition did occur on banks throughout the study area below the slope breaks but only contributed to bank stability if it was augmented by silt-clay-rich material derived from the upper portion of the cut bank. Rapid bank erosion along reach 2 resulted in the continual removal of sandy colluvium and erosion of silt-clay veneers formed on the lower portions of the bank. Along reach 2, in contrast, silt and clay slumped from the upper portion of the Newman and Buck Creek terrace fills may armor erodible material at the base of the exposed fill. Although area landowners assert that decreased suspended-sediment concentration after 1962 has led to increased bank erosion, no evidence exists to support their contention [Simons and Li, 1984]. Decreases in suspended-sediment yield and concentration are more likely to have a long-term rather than short-term impact on bank stability.

SUBCHAPTER CONCLUSIONS

The following conclusions are based upon the examination of bank material by grain-size analysis and construction of valley cross-sections. This section summarizes the first subchapter of chapter 5, pages 73 through 139 in the text.

1. The grain-size parameters of the sampling population varies significantly between reaches. Most of the difference is accounted for in the lower 2/3 of the banks. Reach 2 samples are generally coarser [Ø3.10], better sorted [Ø1.28], and finer skewed [.204] than reach 1 alluvium. Reach 1 cut bank sediment tends to be silt [Ø4.97], very poorly sorted [Ø2.60], and strongly fine-skewed [.478]. These deposits are indicative of overbank deposition.

2. Reach 2 sediment contains generally less silt-clay [37.6%] than reach 1 [50.5%]. The silt-clay present in reach 2 is generally confined to thin silt-clay dominated intervals and to the extreme top-stratum where soil development has altered the grain-size distribution. The mean is reflective of the soil parent material while the sorting and skewness values are affected by pedogenic processes.

3. The bulk of reach 2 alluvium is point-bar deposits which contain only small amounts of silt-clay. Nonetheless, the small amount of fine material has apparently provided enough stability to enable the channel to form the broad meander with the reach. The rapid

development of the meander since 1920 may be a function of the coarse, non-cohesive bank material [Daniel, 1971].

4. Finer alluvium is associated with terrace fills while reach 2 [point-bar] alluvium represents modern valley fill. The Buck Creek, Newman, and Holliday terrace fills have apparently been deposited under conditions quite unlike the present. Grissenger and Murphey [1983] have suggested that valley fills out of equilibrium with the contemporary fluvial regimen may result in channel instability. In this case, the finer nature of the fills seem to contribute to bank stability with reach 1.

5. Recent 14C dates [this study; Holien, 1982] from Newman fill paleosols indicate that the fill is apparently younger than previously believed.

6. Evidence from cross-sections constructed with water well data suggests that the contemporary channel meanders within a defined meander belt. The meander belt typically is flanked by modern back-swamp clay deposits on one side of the valley and terrace fill on the other.

7. Suspended-sediment deposition, when augmented by fine sediment derived from the upper portion of the Newman and Buck Creek terrace fills may armor sandy material at the base of exposures of these fills along reach 1 and near mile 132 on the south bank of the Kansas River. Along reach 2, however, slumped material [mean = Ø3.4] does not

contain sufficient silt and clay to armor the bank and suspended-sediment deposits are easily eroded off. The decrease in suspended-sediment load may lead to a decreased silt-clay content in contemporary point-bar deposits and reduce bank stability as these deposits are reworked in the future.

Gravel Deposits

Researchers have documented the armoring effect of concentrated lag gravels on the stability of river channels [Livesay, 1963; Schumm, 1977]. As channel degradation occurs, older valley deposits may be reworked, concentrating gravel-sized material within the channel as a lag deposit. Livesay [1963] contended that scouring of the Missouri River channel below Fort Randall dam was not as severe as expected due to the development of an armor of gravel only one grain thick. Schumm [1977] suggested that gravel does not have to be continuous to have a considerable impact on channel stability. He added that [p. 119] "under certain conditions an insignificant fraction of the alluvium [lowest one percent] may significantly control the behavior and morphology of the channel."

OCCURRENCE OF GRAVEL IN THE KANSAS RIVER VALLEY

The occurrence of lag gravel deposits in the lower Kansas River valley has been documented by Holien [1982] and Simons and Li [1984]. Simons and Li [1984: 10] reported that documented reaches where armoring occurs include river miles 9.7, 12-13, 21.5 and 132. They suggested that at these sites the "river may be flowing on paleo-channel material or old terraces, reflecting the past river which carried much coarser sediment than the river today." Holien [1982: 102] contended that the occurrence of gravel in the lower Kansas River valley "may have an armoring effect on the channel bottom, making it more resistant to degradation."

The occurrence of gravel deposits at river mile 132 [212 km] within the study area was documented by a United States Army Corps of Engineers survey in 1956 [Tom Gurss, personal communication]. Although the "thickness and effectiveness of the armor layer at mile 132 is uncertain", Simons and Li [1984: 84] suggested that "this area has acted as a pivot point about which the channel has laterally migrated [since 1919]".

Gravel-sized material is exposed on the west side of the contemporary point bar located at the eastern terminus of the active meander in reach 2 [Fig. 42]. In addition, gravel was also found on two small channel bars immediately west of the point bar [Fig. 43]. The point bar on which the gravel is located has been forming since 1919. Between 1929 and 1941, the channel was located adjacent to the scarp shown in figure 42 and has subsequently migrated south to its present position.

The surface of the point bar complex in figure 42 is slightly undulating and slopes gently away from the

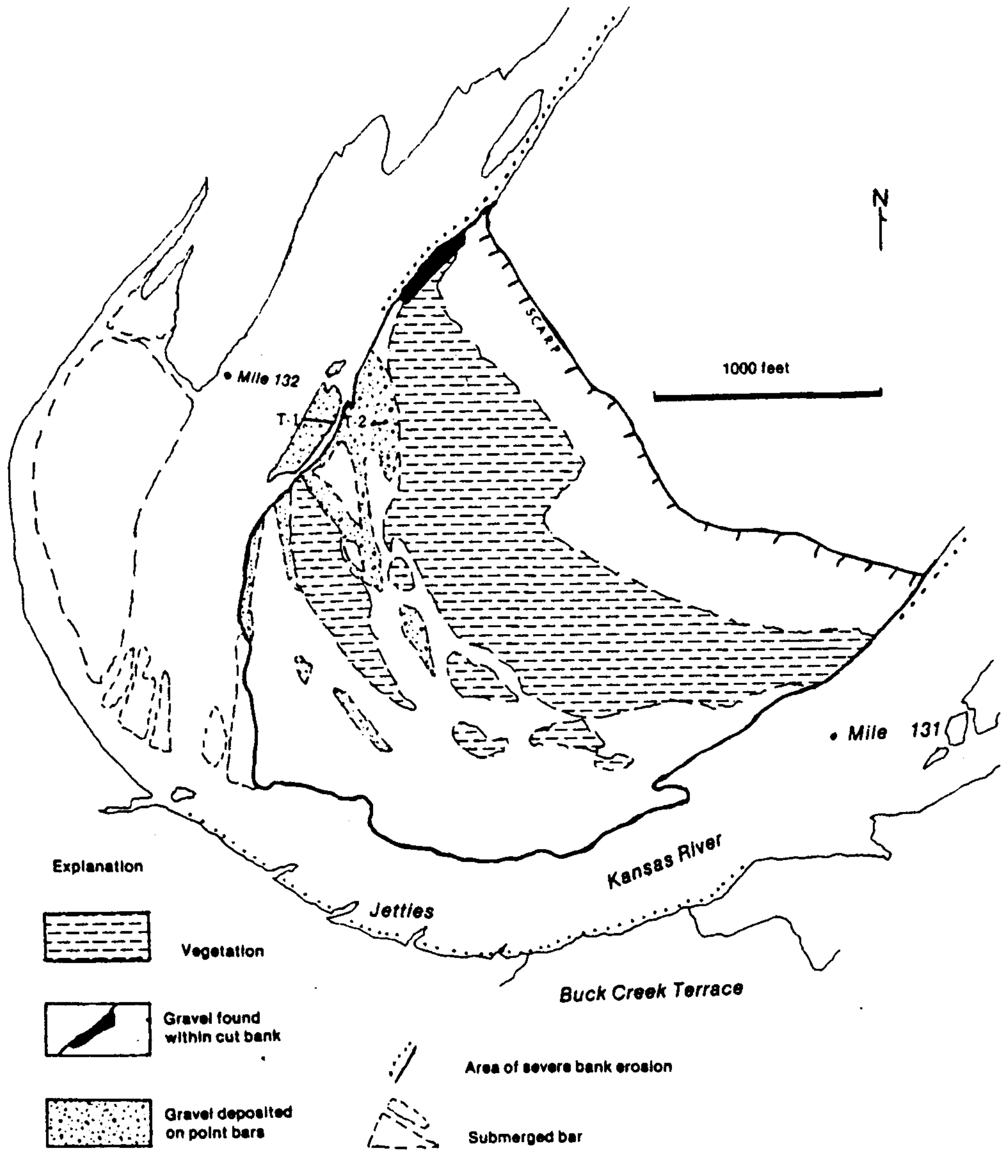


Figure 42: *Extent of bank and bar gravel deposits near mile 132.*

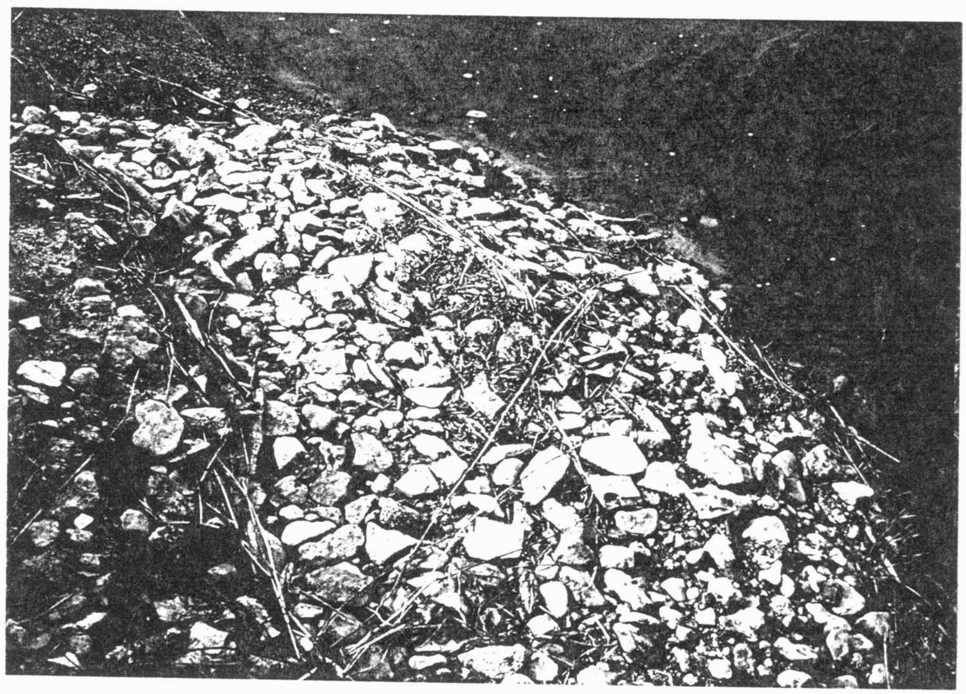
Figure 43. Small channel bar covered with gravel at low water in October, 1984. This location is at river mile 132.

prominent scarp towards the contemporary channel of the Kansas River. Higher portions of point-bar complex are utilized for cropland or stabilized by riparian woodland, mostly black willow [Salix Nigra] and cottonwood [Populus Deltoides][see Fig 42].

The lower portion of the point-bar complex is commonly flooded from early spring to mid-summer and contains gravel-sized material which occurs in linear deposits oriented parallel to the direction of high water flow across the point bar [northwest to southeast]. These deposits are most extensive along the channel of the Kansas River on the western portion of the point bar near mile 132 and occur only sporadically towards the east.

The northern portion of the point-bar complex along the Kansas River starting approximately 600 feet [183 m] upstream of mile 132 is currently being eroded by the channel as the active meander within reach 2 expands. Approximately 700 feet [213 m] upstream of mile 132, gravel-sized material is found in the cut bank and is currently being eroded out [Fig. 44]. The gravel occurs in two 10-20-cm-thick layers separated by coarse to medium sand. Above and below the gravel layers are trough cross-bedded sands that extend from the water level to the top of the bank. The source of these gravels is discussed later in this subchapter.

Figure 44. Gravel being eroded out of cut bank near mile 132. This photograph was taken immediately upstream of the gravel bar in figure 43.



SIZE, LITHOLOGY AND ROUNDNESS OF GRAVELS

Approximately 400 clasts of gravel were collected and examined to determine size, lithology and roundness. Gravel from the point bar was collected along two 100-foot transects [Fig. 42; T1 and T2]. One clast was obtained every one foot along the transect by leaning over with the eyes closed and taking the first clast that the index finger came in contact with. Gravel was obtained from the cut bank by marking off two areas six feet square on the bank and quantitatively collecting all gravel-sized material one foot deep into the bank.

Figure 45 is a histogram showing the relative size frequencies of gravels found on the point bar and gravel obtained from the cut bank. As shown, the gravels found on the downstream bars are slightly finer than gravels obtained from the cut bank. The mode of the bar gravels is 34 mm and the mean of 200 samples is 36.7 mm. The histogram is coarse-skewed [skewed to the right]. Bank gravels are coarser, with the mode occurring at 43 mm [mean = 42.9 mm] and the histogram is fine-skewed [skewed to the left]. Grain-size distributions of the two populations suggest that some degree of hydraulic sorting has occurred within the short distance between the bank and the bar. This sorting may result from the selective entrainment of

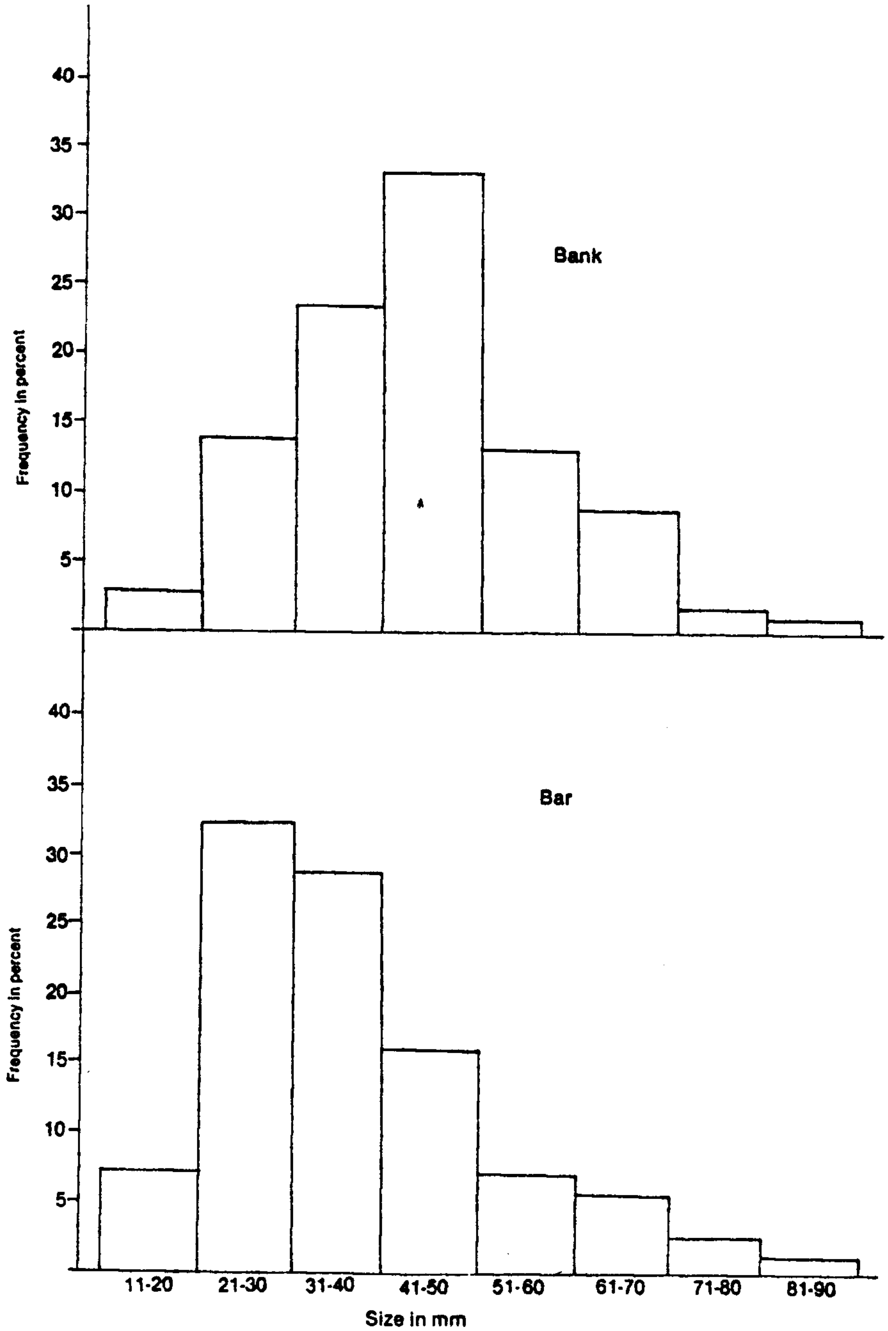


Figure 45: Histogram showing size frequencies of bank and bar gravels.

smaller gravel-size particles during high discharges while larger material remained on the bank.

The lithology of the gravel clasts differed little between bank and bar locations (Fig. 46). The predominant lithology at both locations was limestone which comprised 81.05% of all gravel clasts. Shale was found within the bank deposit but apparently disintegrated before redeposition occurred on the downstream point bar. Less chert (5.4%) was found in the bar gravel deposits than was found within the bank (18.4%). The small amount of chert gravel found on the point bar may be due to the high specific gravity of chert, making it less likely to be transported downstream. The results presented here are similar to those reported by Holien (1982: 107) for gravel deposits in the lower Kansas River valley near Bonner Springs (limestone, 61.5%; chert, 29.6%; quartz, 3.9%; Sioux quartzite, .1%). It should be noted that, while Holien differentiated between Sioux quartzite and quartz, they are reported in figure 46 (this thesis) as one lithology.

Gravels collected both from on the point bar and from within the cut bank were found to be surprisingly angular (Fig. 46). Angularity was particularly prevalent in limestone and chert. Quartzite and quartz fragments were considerably more rounded. Roundness was determined

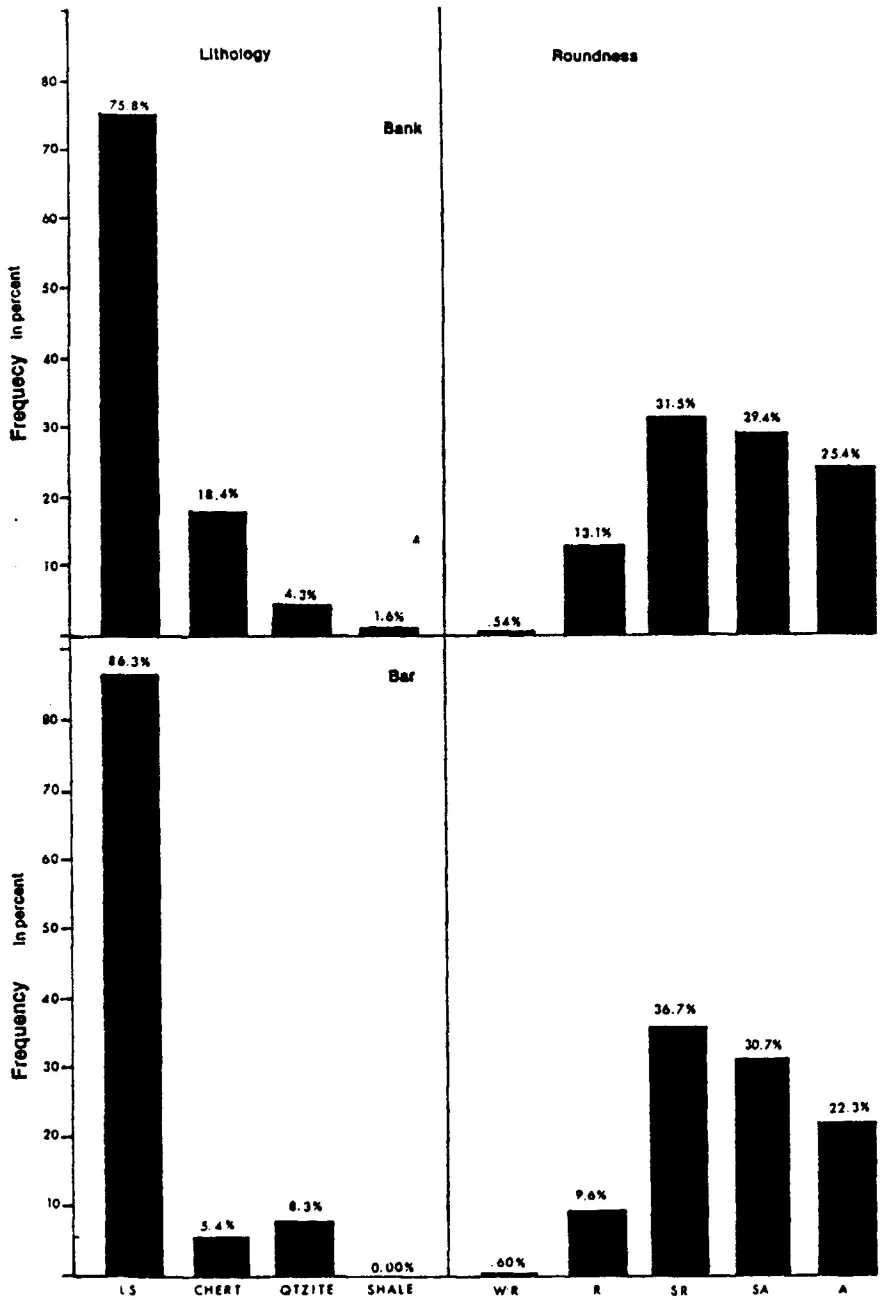


Figure 46: Composition and roundness of bar and bank gravels at mile 132

qualitatively using criteria suggested by Pettijohn (1975). There was essentially no difference between the roundness of point-bar and bank gravels. Whereas most gravel ranged from subrounded to subangular (64%), a substantial amount (23.8%) was determined to be angular. The relatively high proportion of angular gravel may indicate that the gravels were not transported far by the Kansas River once they entered the system. The fact that these gravels were not found more than one mile downstream of where they occur in the bank is an indication that they are not transported far by the contemporary Kansas River.

SOURCE OF THE GRAVEL

The similarity and proximity of gravel found on the point bar to gravel found upstream within the cut bank suggest that these point-bar and channel bar gravel deposits are derived from the gravel eroded out of the bank (Fig. 42). Gravel found within the cut bank upstream of mile 132 is located in an area occupied by the 1929-1940 channel of the Kansas River. Between 1885 and 1919 the channel of the Kansas River in this area was apparently inactive and relatively straight, flowing northwest to southeast. Between 1919 and 1929, a meander began to form upstream of mile 132 resulting in point-bar deposition on the downstream limb of the meander immediately east of mile 132 [Fig. 47]. As the active meander within reach 2 grew between 1941 and the present, point-bar expansion continued to occur near mile 132. No later than 1956, when gravel at mile 132 was first documented by the United States Army Corps of Engineers, meander expansion resulted in the erosion of the older portion of the point-bar complex exposing the gravel in the cut bank. The erosion of the upstream portion of the point-bar complex may have been initiated during the 1951 flood when the largest single instance of meander expansion occurred within the study area.

An argument can be made that the gravel deposits described in this subchapter were deposited by Deep Creek which issues into the Kansas River approximately 1500 feet [457 m] downstream of mile 132. If these gravel deposits had their source in Deep Creek, then the mouth of Deep Creek would have had to have been located upstream of mile 132 some time prior to 1956. Examination of 1937 aerial photographs, however, reveals that Deep Creek entered the Kansas River approximately one mile [1.6 km] downstream [east] of where it enters today. They could not have been deposited where they are today prior to 1937 because the point bar on which the gravel occurs did not exist prior to that date. The photographs also reveal that the channel of

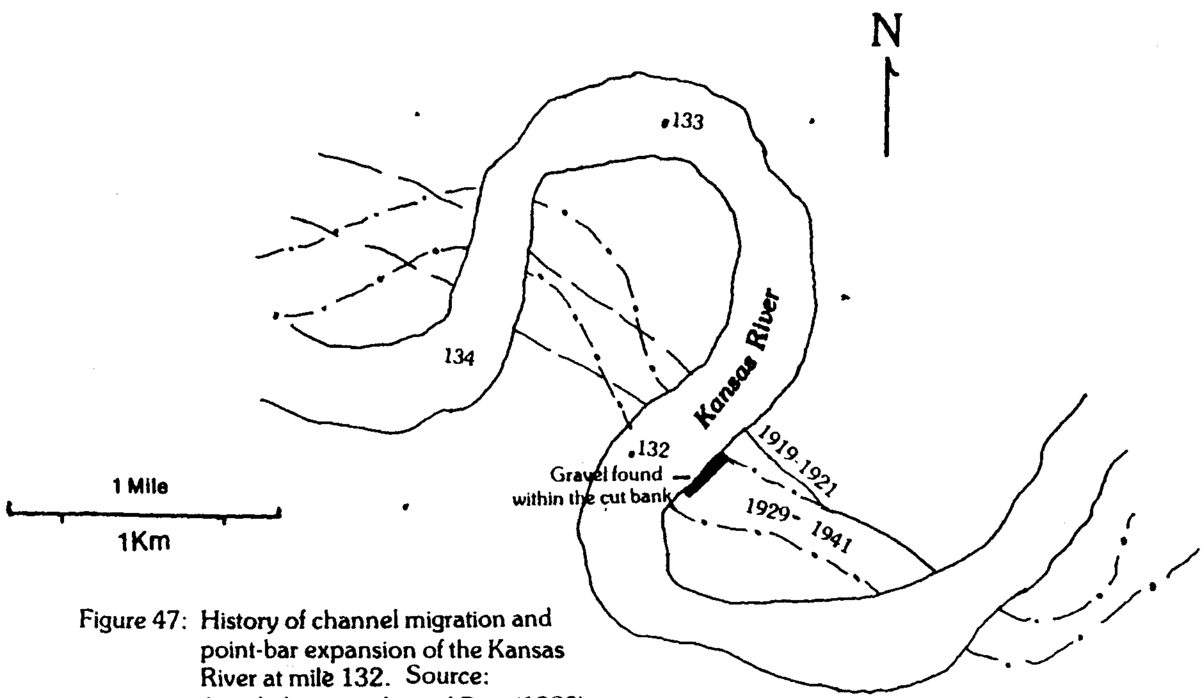


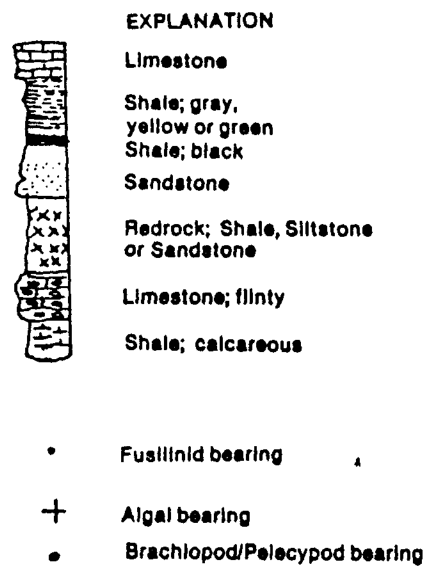
Figure 47: History of channel migration and point-bar expansion of the Kansas River at mile 132. Source: Aerial photographs and Dort (1980).

Deep Creek has been inactive since 1937 and the change in the mouth of the creek has been due to the southward migration of the Kansas River. Therefore, it is impossible that the gravel deposits near mile 132 could have been deposited directly by Deep Creek or entered the Kansas River system through Deep Creek.

The obvious question remains as to how these gravels were deposited in the 1929-1941 channel. A possible explanation involves the initial formation of the active meander within reach 2. Meander growth is accompanied by the scouring of the thalweg along the outside of the bends and the development of an asymmetrical channel shape in cross-section [Leopold and Wolman, 1957]. As the meander began to form between 1919 and 1941, the development of a scour pool may have exposed gravel from paleochannel material below the 1930's era channel to erosion. Redeposition on the downstream limb of the meander would have occurred, forming a channel lag deposit near mile 132. Eventually these gravel lag deposits were covered by the advancing point bar as the channel migrated to the south. Erosion of the point-bar complex since 1951 may have exposed the gravel deposits, now in the cut bank, to the channel allowing them to be redeposited on the downstream contemporary point bar.

A similar scenario of incorporation of gravel into the present river system was described by Holien [1982: 120]. He contended that "coarse-grained material is continually being reworked to a lower position in the valley alluvium during periods of degradation of the Kansas River. Thus the gravel on the channel bars is exposed for only a brief time before it is buried within the river alluvium, possibly to be exposed again at some later time due to ongoing stream activity."

The ultimate source of the gravel is the bedrock exposed in the Kansas River basin and material carried into the basin during the Kansan glaciation. Limestone is by far the most abundant gravel lithology and many of the limestone clasts contain fossils present in the Permian limestone units cropping out in the study area. The limestone gravel can be subdivided into four groups: Fusilinid-bearing [31%], Brachiopod-Pelecypod-bearing [20%], Algal-bearing [9%], and clasts in which no apparent fossils were found [40%]. Two local units of the Permian system contain abundant fusilinids; the Hughes Creek Shale Member of the Council Grove Group [Wolfcampian Series] and the Cottonwood Limestone Member also of the Council Grove Group [Fig. 48]. Brachiopod-Pelecypod-bearing limestones may originate from the fossiliferous Bennett Shale Member of the Eskridge Shale. Algal-bearing limestones occur in many limestones of the Wolfcampian Series. Members in



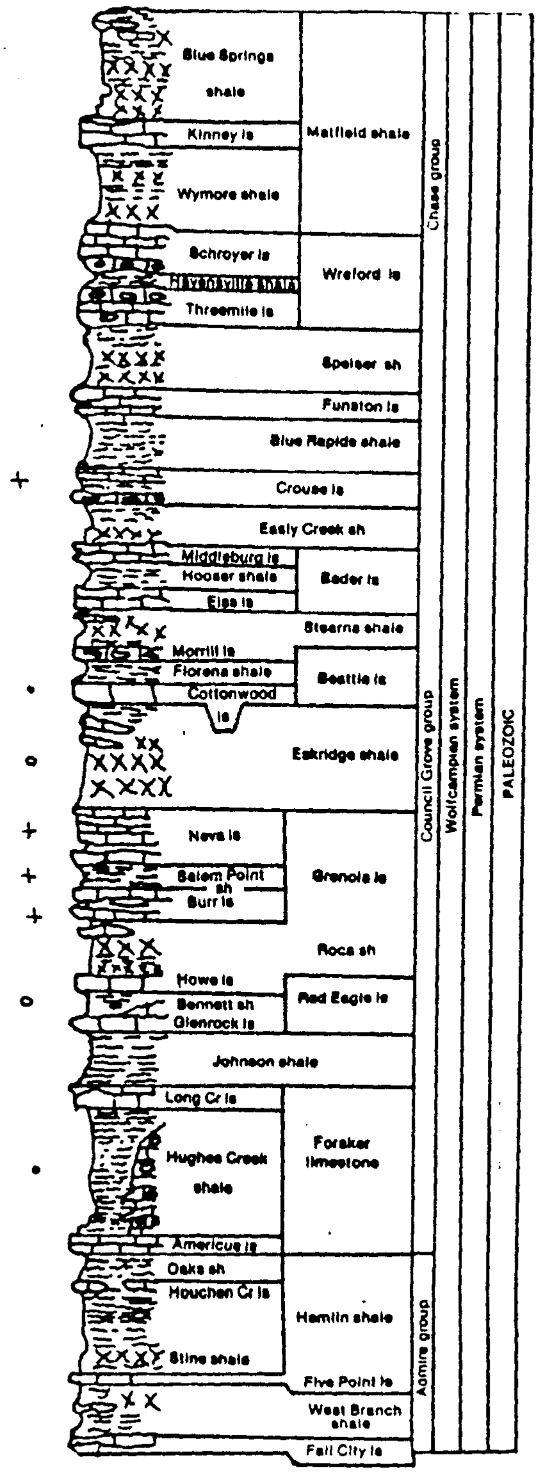


Figure 48: *Generalized section of the lower Permian rocks of Kansas.*

which they are particularly prevalent are the Crouse limestone and the Grenola limestone adjacent to the Eskridge Shale [Fig. 48][Johnson, 1963].

Much of the chert gravel originates from cherty limestones of the Permian system. Flint is contained in the Cottonwood Limestone Member [Council Grove Formation] and quartz nodules are common in the Long Creek Limestone Member [Council Grove Formation]. Additional sources of chert gravel are the weathering out of pre-Kansan chert gravel in upland paleochannels of the Kansas River north of St. George and on strath terraces along Deep and Antelope Creeks. Gravels found in the pre-Kansan paleochannels of the Kansas River described by Beck [1959: 29], are similar to the contemporary deposits of gravel described in this chapter; "the constituent particles of chert and limestone are subangular to subrounded fragments, which could have been derived from Paleozoic limestones cropping out west of the area."

Sioux Quartzite was transported into the study area during the Kansan glaciation from outcrop areas in southwest Minnesota, northwest Iowa and southeast South Dakota. Large boulders of Sioux Quartzite are found 4.5 miles [7.42 km] south of Wamego along Kansas state highway 99. The presence of Sioux Quartzite in contemporary gravel deposits indicates that glacial sediments have been incorporated into the Kansas River system and are being recycled as the channel reworks older valley deposits.

IMPACT OF GRAVEL

As noted by Schumm [1976, 119], discontinuous gravel deposits which comprise "an insignificant amount of the alluvium [coarsest 1%] may significantly control the behavior and morphology of the channel." Simons and Li [1984] contended that gravel deposits at mile 132 have acted as a lateral control on the channel and the creation of a "pivot point" about which the channel has migrated. It can be demonstrated that the gravel found on the point bar at mile 132 was eroded out of the cut bank along the east side of the Kansas River 700 feet [213 m] upstream. Since gravel found within the cut bank was deposited in the 1929-1941 channel of the Kansas River and subsequently eroded out as the active meander in reach 2 expanded, it would be impossible for gravel deposits at mile 132 to have been a lateral control throughout the development of the meander since 1919.

Examination of aerial photographs reveals that the point bar at mile 132 containing the gravel deposits expanded southward as the channel cut through modern alluvium. During the 1951 flood, the southward movement of the channel resulted in the interception of Deep Creek (Fig. 49, A and B). By 1951 the channel of the Kansas River had been displaced approximately 1870 feet (572 m) south of the position of the inactive channel prior to 1919. Although the active meander within reach 2 continued to expand between 1951 and 1978, the channel south of mile 132 migrated only 285 feet (87 m) to the south (Fig. 49D).

Between 1956 and 1969 (Fig. 49C), the channel began to come into contact with sediments of the Buck Creek and Newman terrace fills. These sediments are generally finer and more cohesive than the modern sediments the channel had previously cut through. As a result, the southward migration of the channel in the downstream portion of reach 2 has been retarded since 1956. The resistance to erosion encountered by the Kansas River channel here may explain the occurrence of the "pivot point" reported by Simons and Li (1984).

SUBCHAPTER CONCLUSIONS

The following conclusions are based upon the discussion presented in this subchapter, pages 139 to 161 in the text.

1. Gravel bar deposits, documented by the United States Army Corps of Engineers' 1956 sediment survey and Simons

Figure 49A 1937

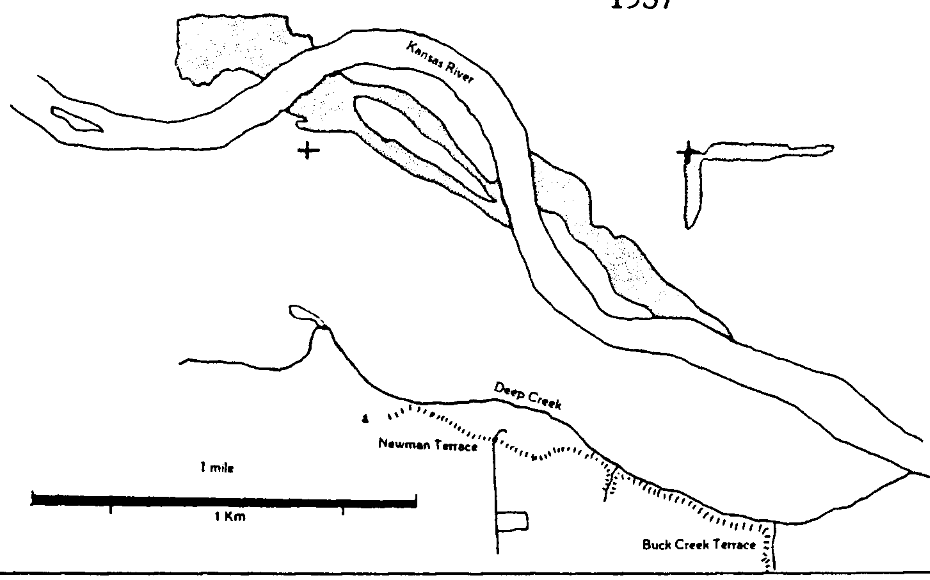


Figure 49B 1951

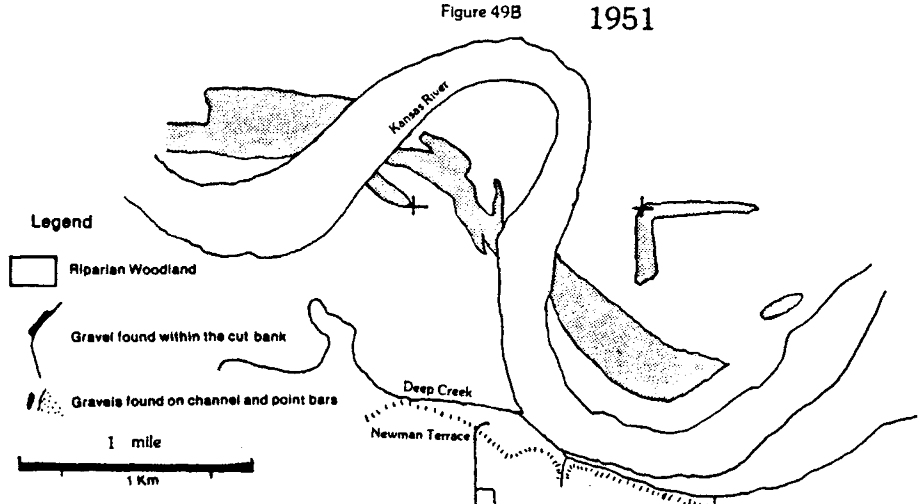


Figure 49 A-D: Position of the Buck Creek and Newman terraces in relation to the channel of the Kansas River, 1937-1978. Source: Aerial photorgaphs; Beck (1958); Fader (1974).

Figure 49C

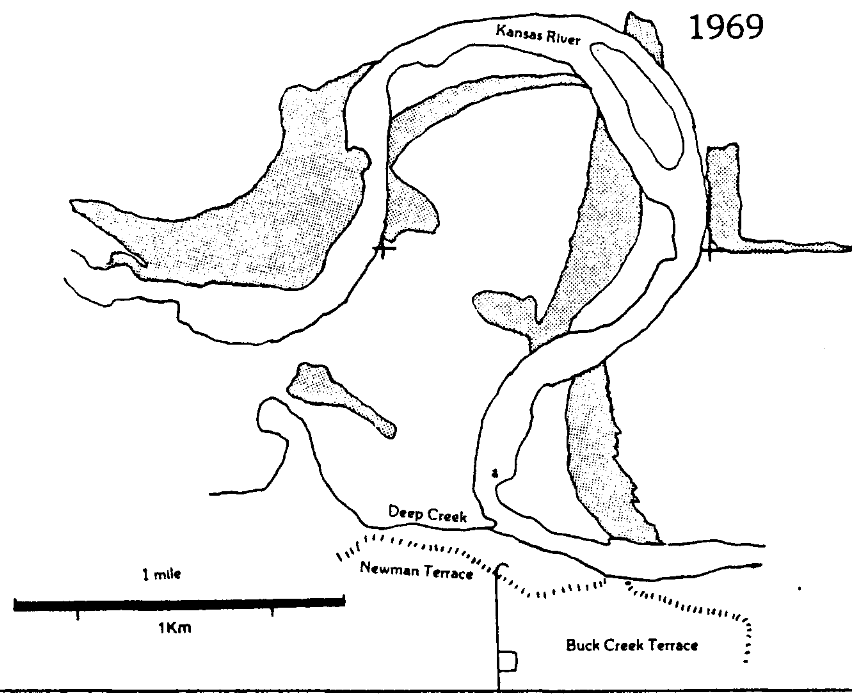
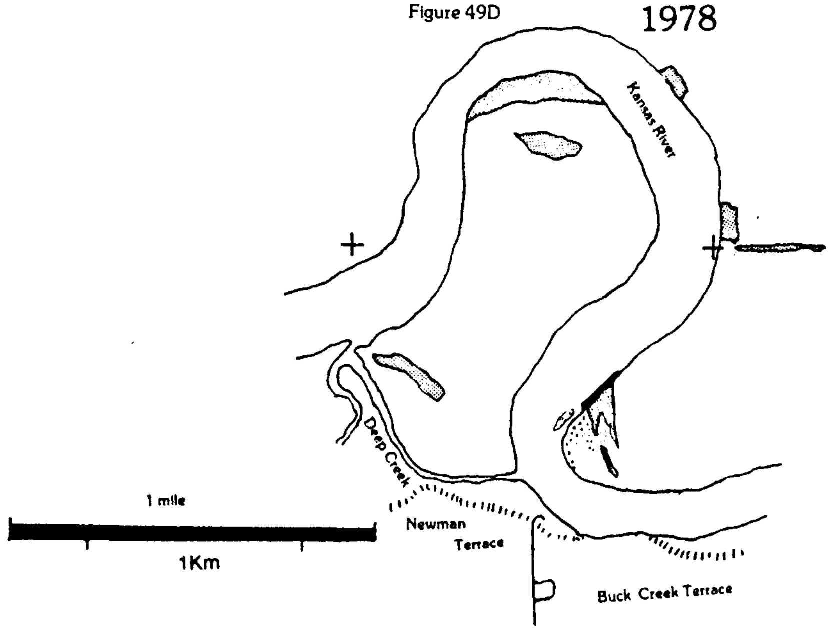


Figure 49D



and Li [1984], have their source in the cut bank 700 feet [213 m] upstream of mile 132. Active erosion and channel migration have introduced the gravels into the contemporary river system. Since the gravel bars occur in an area of relative stability, Simons and Li postulated that an armoring effect may result from the gravel.

2. Similarities in lithology and roundness, as well as proximity, suggest that the gravel found in the cut bank is eroded out and redeposited on the downstream point bar. The location of these gravels in the area occupied by the 1929-1941 channel of the Kansas River indicates that deposition of the gravel on the downstream bars has occurred relatively recently.

3. Much of the gravel is derived from Permian and Pennsylvanian rocks cropping out in the study area. Additional sources of gravel include upland paleochannel deposits near St. George, strath terrace gravel lags along Deep and Antelope Creeks, and glacial material transported into the area during the Kansan glaciation.

4. Gravel deposits found on the point bar at mile 132 have been deposited too recently to have been responsible for the formation of the "pivot point" reported by Simons and Li [1984]. Prior to 1956, the expansion of the active meander within reach 2 resulted in the southward migration of the channel and point bar at mile 132. Although the

meander has continued to expand since 1956, the southward migration of the channel at mile 132 has proceeded very slowly. This relative lack of channel migration since 1956 is more likely due to the resistance of the fine, cohesive sediments of the Buck Creek and Newman terrace fills south of the channel than to the occurrence of gravel bars at mile 132.

Impact of Slope on Channel Activity

Researchers [e.g., Friedken, 1945; Schumm and Khan, 1972; Schumm and Beathard, 1976] have documented the effect of valley slope on the activity of the stream channel. When the slope of the valley floor increases, the river may lengthen its course by meandering to maintain just the gradient necessary to carry its load. Schumm and others [1976] suggested that sinuosity is generally low for alluvial streams with extremely low valley slopes but increases with increasing slope until a threshold is exceeded where a braided channel may result. Leopold and Wolman [1957] and Lane [1957] attempted to classify alluvial streams as meandering or braided based on slope-discharge relationships. They found that, for a given discharge, a threshold slope exists above which a braided channel develops. Schumm and Beathard [1976] utilized these relationships to evaluate the relative stability of modern channel patterns. They found that braided streams that plotted as meandering, or meandering streams that plotted as braided, were likely to manifest instability.

This final subchapter is divided into four sections: the first section describes the water-surface profile of the Kansas River in the study area; the second section deals with the slope-discharge relationships of each reach both at the present time and historically; the third section describes the valley profile of the Kansas River in the study area and the final section presents a model for future changes in slope and planiform characteristics of e study area.

CHANNEL SLOPE

The slope of the Kansas River within the study area is 1.532 feet/mile ± 0.163 feet/mile [0.289 m/km ± 0.03 m/km]. Slope was measured using an automatic level over a distance of 8.283 miles [13.32 km]. The error of 0.163 feet/mile comprises a total of 1.33 feet [.405 m] within the entire study area. This error is small when compared to slope measurements from 7-1/2-minute topographic maps with 10-foot contour intervals.

Slope measurements were accomplished using an automatic level at low water in September and October of 1984. Stakes were placed prior to surveying on the point bar-water surface interface to ensure that slope measurements were not affected by changes in stage. The water-surface profile was obtained by placing the rod next to the stakes at successive downstream points and measuring the drop in the water surface between those points with the automatic level. When the rod points were out of accurate range of the instrument, the automatic level was moved downstream to a new station and the entire procedure was repeated.

In addition to the two reaches described in chapter 3 (reaches 1 and 2), a third reach (reach 3) was designated between reach 1 and reach 2 for the purpose of this discussion (Fig. 50). Whereas reaches 1 and 2 conform to their original descriptions, reach 3 is a transitional reach between the active and inactive meanders within the study area. Reach 3 has been relatively inactive in historical time and channel changes since 1919 are shown in figure 51. Between 1921 and 1952, the channel at river miles 130 and 131 migrated approximately 1800 feet (549 m) to the northwest but has been inactive since 1952. The downstream portion of the reach has not manifested channel activity and is much more like the adjacent inactive channel in reach 1. Although the Kansas River in the study area has been divided into "reaches" for the basis of comparison, it is important to point out here that the fluvial system is actually a continuum in which no actual boundary exists between the reaches that have been delineated.

Water-surface slope, presented herein as the drop in elevation of the water surface divided by the length of the channel, is as follows for each reach: reach 1, .000293; reach 2, .000224; reach 3, .000384. The magnitude of the

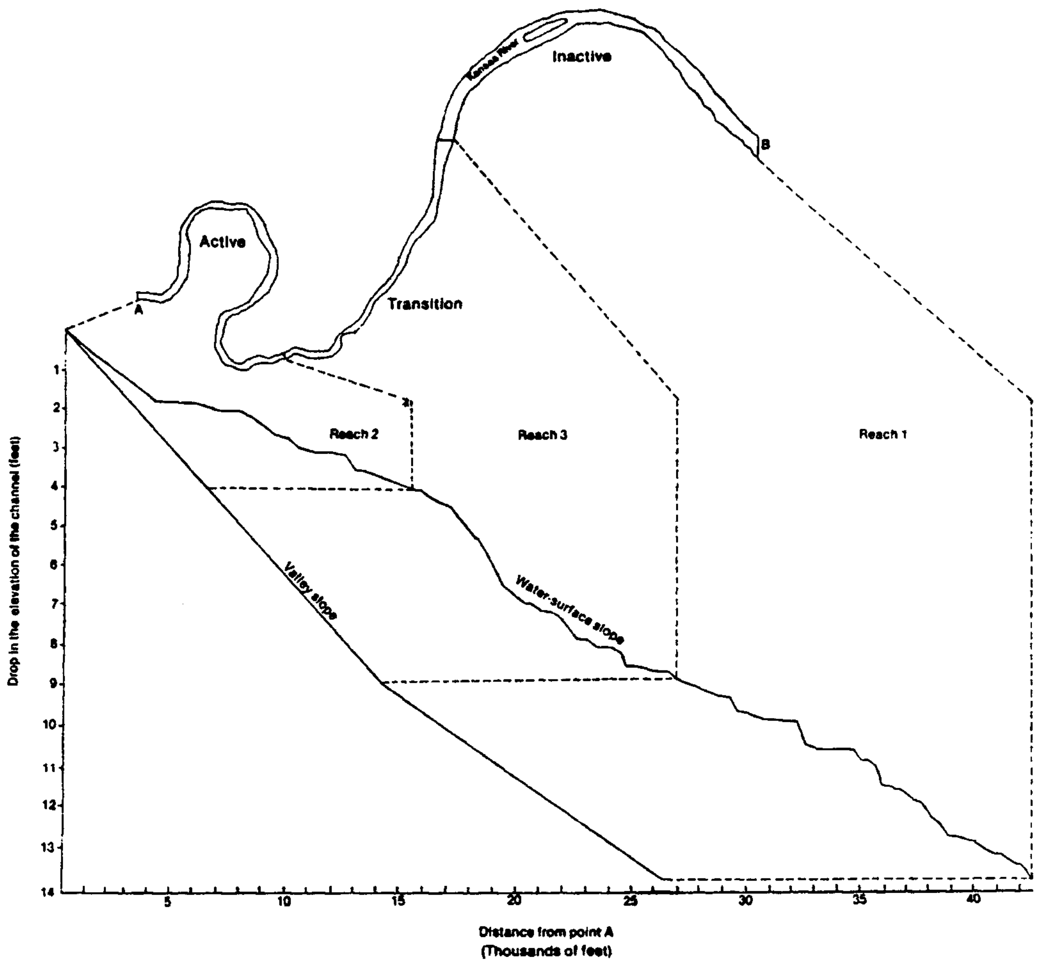


Figure 50: Water-surface and valley slope of the Kansas River within the study area.

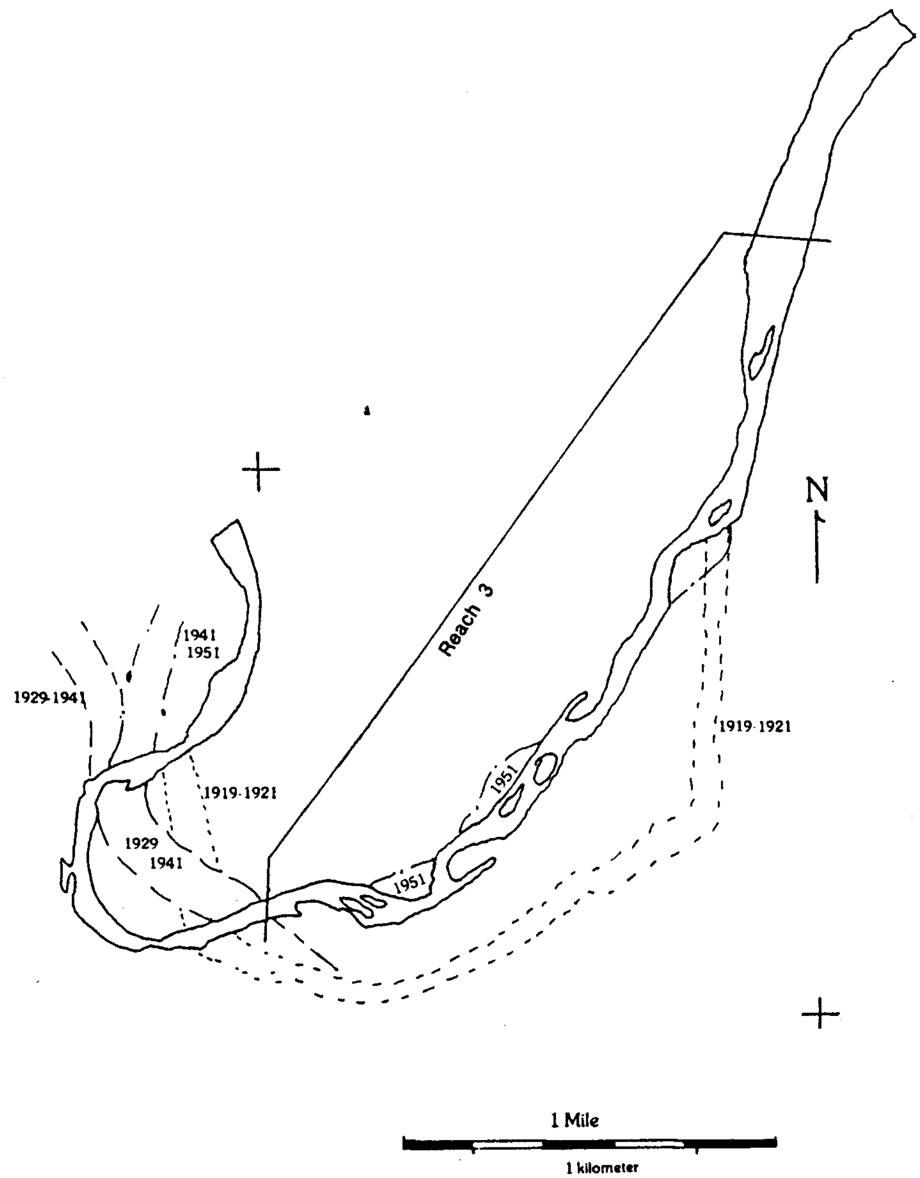


Figure 51: Migration of the Kansas River within reach 3, 1885-1978. From Dort (1980).

slope values will always be very small since the drop of alluvial streams relative to length is very small.

The water-surface profile of the Kansas River within the study area is presented in figure 50 and Plate 4. It is evident that the water-surface slope is steepest between the two meanders whereas slope is relatively gentle in the bends themselves. Also evident in figure 50 [Plate 4] is the step-like profile of the water-surface slope in reaches 1 and 3 when compared to the profile of reach 2. Whereas the water surface in reach 2 has a continuously sloping profile, the water-surface profile of reach 1 and the downstream portion of reach 3 is broken into alternating relatively flat and steep slopes resulting in a step-like appearance. The difference in the shape of the longitudinal profiles of reaches 1 and 2 is a result of the morphological characteristics of the channel in each reach.

As discussed in chapter 3, the thalweg within reach 2 is confined to the outside portion of the bend throughout the active meander. Crossing points, where the thalweg crosses from one side of the channel to the other, occur only at the extreme upstream and downstream ends of the meander. Although the channel of the Kansas River within reach 1 manifests a meandering configuration, the thalweg actually meanders within the channel and is not confined to a location on the outside of the bend against the cut bank.

Crossing points are numerous within reach 1 as the thalweg flows around alternate bars at low water. The sequence of relatively steep crossing points and relatively flat "pools" results in the step-like appearance of the longitudinal profile of reaches 1 and 3.

The position of the thalweg in the channel is likely to have been subject to change and the channel characteristics presented above may only reflect temporal slope conditions. Aerial photographs were examined to determine if the positioning of the thalweg in the channel had undergone radical historical change. The earliest aerial photographs from 1937 and 1951 were taken during periods of relatively high water and the position of the thalweg was not discernible. Nonetheless, as early as 1937, photographs show the development of a point bar along the south side of the incipient meander in reach 2 and the formation of a cut bank of the north side of the channel. No 1937 aerial photographs of reach 1 were available. 1956 and 1969 aerial photographs clearly show the thalweg positioned along the outside portion of the meander in reach 2. The two crossing points at the upstream and downstream ends of the meander that exist today are also evident in the aerial photographs. Although the number and position of crossing points in reaches 1 and 3 are different for 1956, 1969, and 1983, the thalweg was not confined to the outside portion of the bends but meandered between alternate bars formed on both sides of the channel. Thus, the position of the thalweg in the channel has varied slightly since 1956 but the channel has maintained the same morphological characteristics.

The water-surface slope of reach 1 was found to be steeper than the water-surface slope of reach 2. The significance of this .00049 difference is not readily apparent. Some insight may be gained from comparing slope related functions. Figures 52 and 53 show the relationships between slope and tractive force as well as slope and stream power respectively. Stream power [Bagnold, 1966: 5] is "the available power supply, or time rate of energy supply, to unit length of a stream", or "time rate of liberation in kinetic form of the liquid's potential energy as it descends the gravity slope". Stream power, as used in this paper, is given by the algorithm

$$\omega = \frac{Q\gamma S}{W}$$

where Q is the mean annual discharge, γ is the density of the liquid, W is the width of the stream, and S is the water-surface slope [Williams, 1984]. Tractive force was first introduced by Duboys in 1879 and is defined as the magnitude of the friction developed on the channel bottom [Bogardi, 1971]. Tractive force is given by

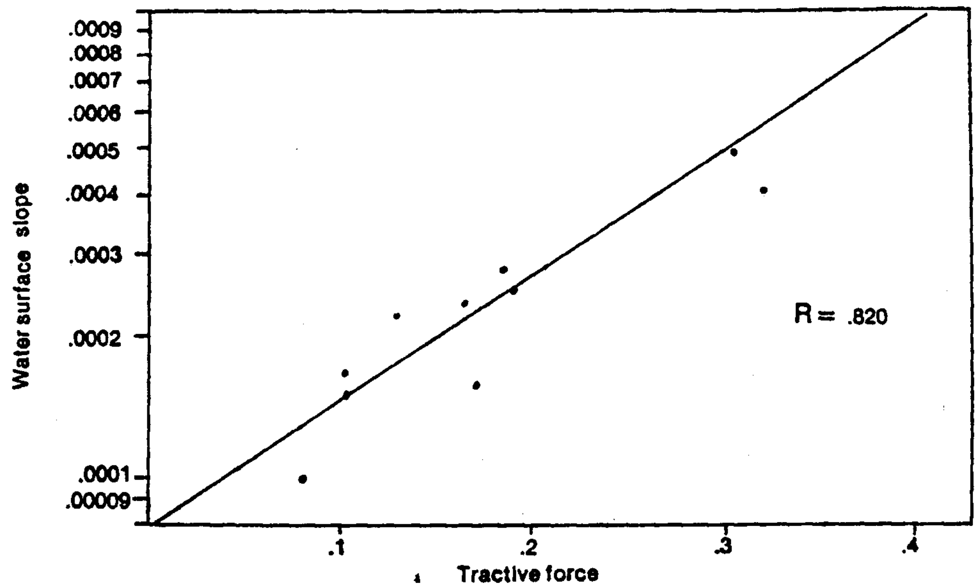


Figure 52: Tractive force plotted against slope on semi-log paper.

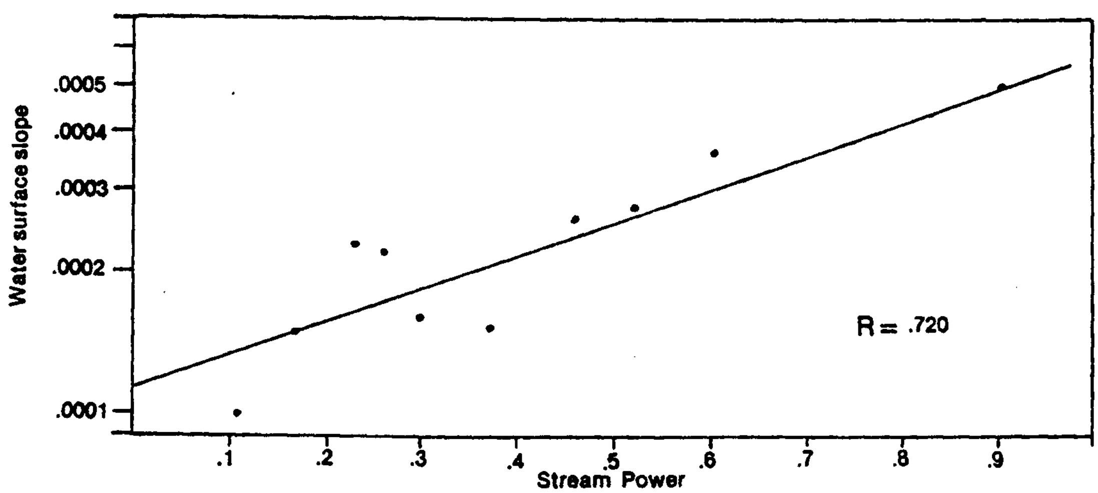


Figure 53: Stream power plotted against slope on semi-log paper.

$$\tau_c = \gamma DS$$

for a given discharge of 4113 cubic feet per second [1254 m3/sec] which is the mean annual discharge of the Kansas River. γ is the density of water, S is the water-surface slope of the channel and D is the average depth at 4113 cubic feet per second [1254 m3/sec]. Since no measurements of depth were taken in the field, depth was calculated indirectly by

$$D[\text{at } 4113 \text{ cfs}] = .54M^{.36}\ Qm^{.26}$$

where M is the weighted silt-clay percentage of the channel perimeter and Qm is the mean annual discharge of the Kansas River [Schumm, 1968]. Although the depth of the channel is subject to change as the morphology of the channel changes, it has already been demonstrated that reaches 1 and 2 have maintained their general morphological characteristics since at least 1956.

Schumm and Beathard [1976] contended that a slight increase or decrease in stream power can significantly alter sinuosity if the river's discharge-slope relationships place it near a threshold between braided and meandering streams. Figures 52 and 53 show that tractive force and stream power are related to changes in slope. Khan [1971] found that sinuosity varies with stream power in the same manner that sinuosity varies with slope. Increasing stream power results in increasing sinuosity until some threshold is exceeded and a braided channel is developed.

Figure 54 is a plot of tractive force against stream power for ten sampling sites within reach 1 and reach 2. Slope values were measured for a distance approximately 100 feet [30 m] upstream and downstream of each sampling site. Of the variables used to calculate tractive force and stream power, slope, width, and depth [$D = .56M \quad Q \quad$] will vary between reaches.

The plots of reach 1 and reach 2 separate into two distinct populations. Surprisingly, the highly sinuous reach 2 manifests lower values of stream power and tractive force than does the less sinuous reach 1. This is contrary to what is predicted by Khan's experimental results [1971]. This separation suggests that differences in water-surface gradient, and consequently stream power and tractive force, cannot fully explain differences in channel activity within the study area. Brice [1964: 40] contended that

> "no generalities about the relation between the valley slope and the channel pattern are valid without the specification of other variables, of which bank erodibility, bed material and discharge are the most significant."

It is possible that the finer, more cohesive material of reach 1 results in a higher threshold of stream power that must be overcome before erosoion occurs. Reach 2, on the other hand, contains coarser, less cohesive bank

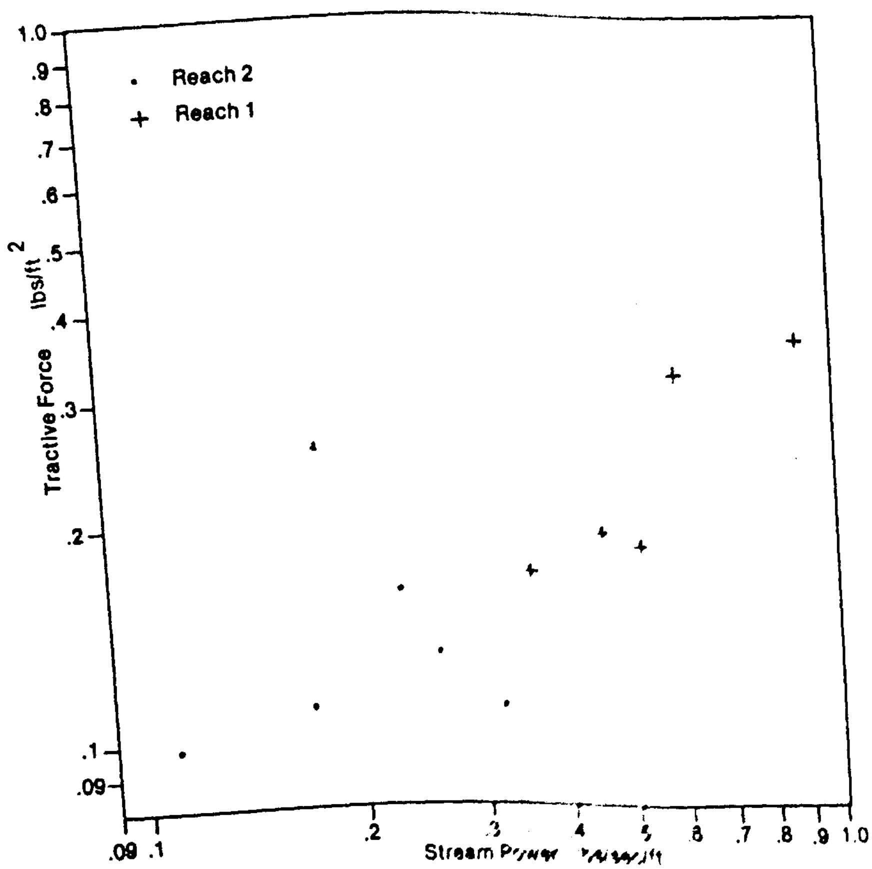


Figure 54: Tractive force plotted against stream power. Note the degree of segregation between reach 1 and reach 2 sites.

material and erosion occurs at much lower values of stream power.

It is also important to be cognizant of the differences between flume and field results if comparisons of data are to be made. Flume results are obtained from a controlled system that does not necessarily replicate conditions in the field. Whereas Schumm and Khan [1972] used poorly sorted sand typical of fluvial systems, there was no little or no vertical or lateral change in sediment as there is in the Kansas River. Experimental results are also obtained using streams with much smaller discharges than those of a natural system such as the Kansas River. Comparisons between field and experimental data must be made with such differences in mind and should be expected to vary.

SLOPE-DISCHARGE THRESHOLDS

Thresholds between braided and meandering streams have been determined using water-surface slope/discharge relationships [Lane, 1957; Leopold and Wolman, 1955]. They have found that when a critical slope is exceeded in a meandering stream, a braided stream will form. Schumm and others [1972] and Schumm and Khan [1972] described the relationship between valley slope and sinuosity, and have attempted to identify critical thresholds for valley slope.

Values of water-surface slope have been plotted against mean annual discharge [Lane, 1957][Fig. 55] and bankfull discharge [Leopold and Wolman, 1957][Fig. 56]. Using Lane's [1957] slope-discharge relations, all reaches within the study area plot as meandering. The mean annual discharge of the Kansas River at Wamego in Figure 55 is 4113 ft3/sec [1254 m3/sec] for the period 1919-1980.

When bankfull discharge is placed on the abscissa in figure 56, reaches 1 and 2 plot much nearer to the braided threshold and reach 3 plots as a braided stream. The threshold is defined by the regression line $S = .06Q^{-.44}$ and was obtained empirically with data from 63 streams. The bankfull discharge was estimated at 102,000 ft3/sec [31,090 m3/sec] from rating curves with stage estimated in the field [Leopold and Wolman, 1957]. It should be noted that, although the three reaches plot closely together in figure 56, the magnitude of the differences in slope is not critical as long as the threshold is crossed [Schumm and Beathard, 1976]. Reach 3 plots in the braided zone in figure 56. Although reach 3 marks the transition between two meanders, it has some characteristics of braided channels such as low sinuosity, a wide and shallow channel, and multiple thalwegs at many locations within the reach.

Slope discharge relationships are also shown over a

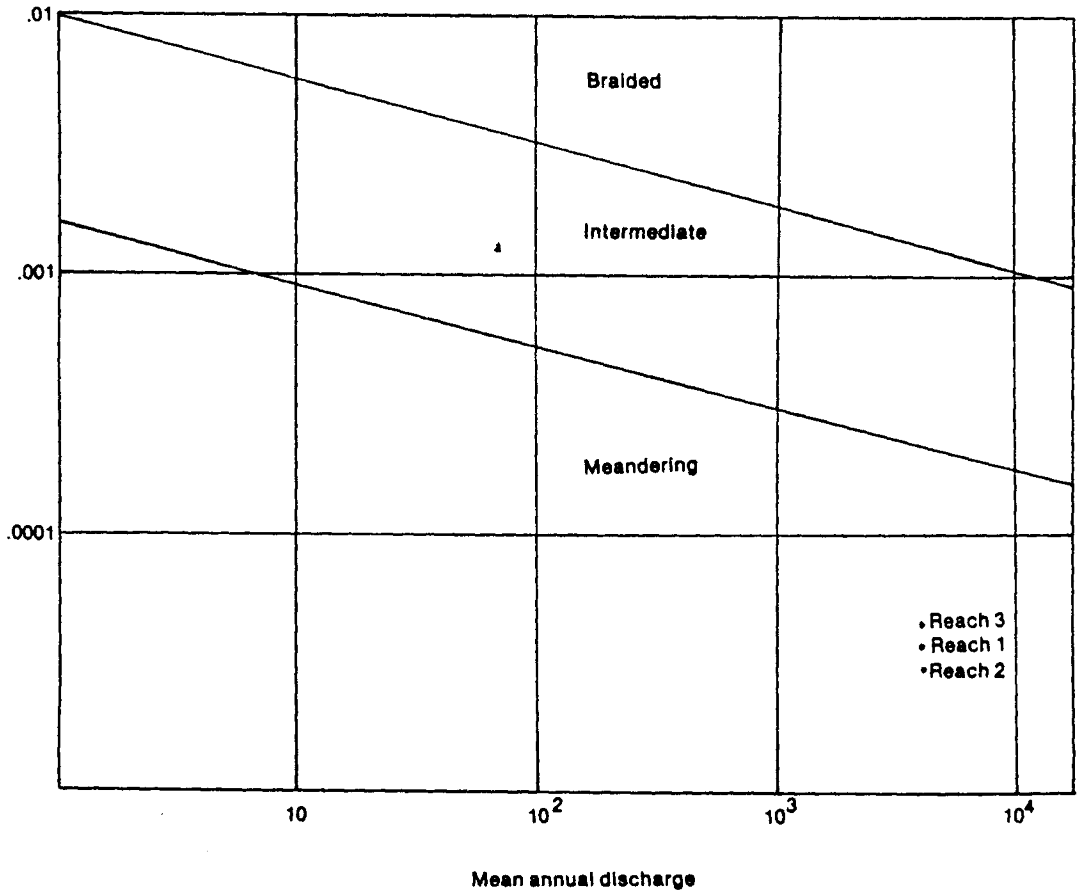


Figure 55: Slope-discharge relations for reaches 1, 2 and 3. Graph adapted from Lane (1957).

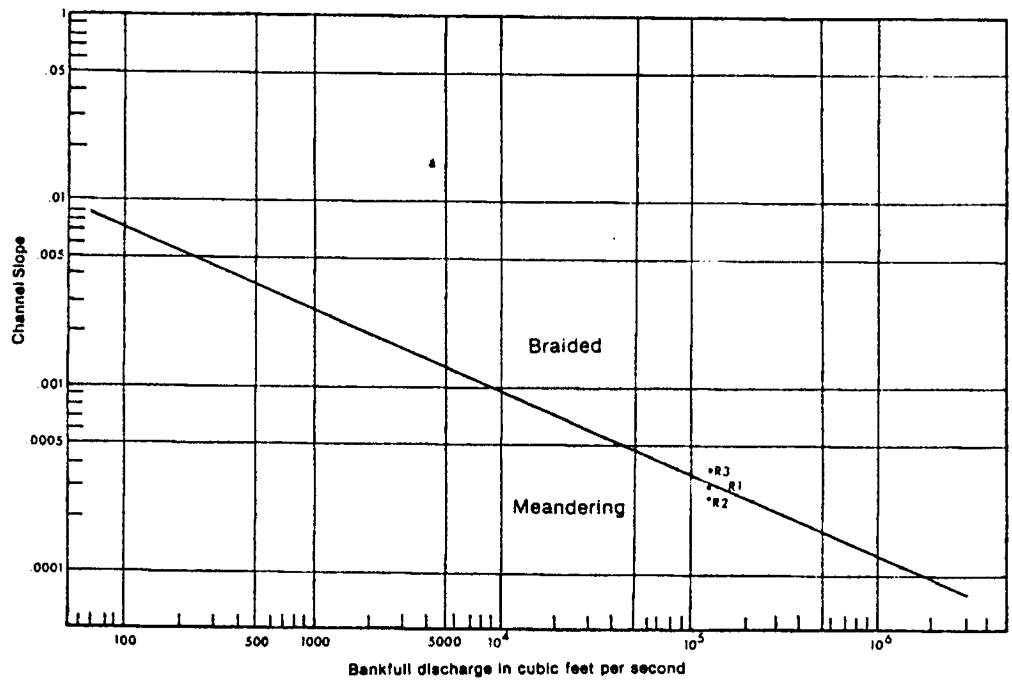


Figure 56: Slope-discharge relations for reaches 1, 2 and 3. Graph adapted from Leopold and Wolman (1957).

period of time for reach 2 where channel migration has decreased the water-surface slope (Fig. 57). The values of slope in figure 57 are based upon the assumption that extensive channel aggradation or degradation has not occurred since 1885. Stage-time relationships reported by Osterkamp and others (1982) reveal that one foot (.30 m) degradation has occurred at Wamego during the 1951 flood but the channel has been stable since. No data, however, was available to document episodes of aggradation or degradation with reach 2.

The drop of the water surface within reach 2 was measured and divided by channel lengths measured from historical maps (Dort, 1980). Results show that the channel plotted as braided in 1885 but the slope decreased as the meander grew. As recent as 1951, the channel still plotted as braided and the threshold between braided and meandering streams was only recently crossed. The channel has icreased its sinuosity progressively since 1885. Historic slope-discharge relationships are not shown for reach 1 since little change has occurred since 1885.

Schumm and Beathard (1976) suggested that potentially "unstable" (active) river patterns may be identified by evaluating slope-discharge relationships. They added that "if a braided river plots among the meandering channels or vice versa, it is a likely candidate for change because it

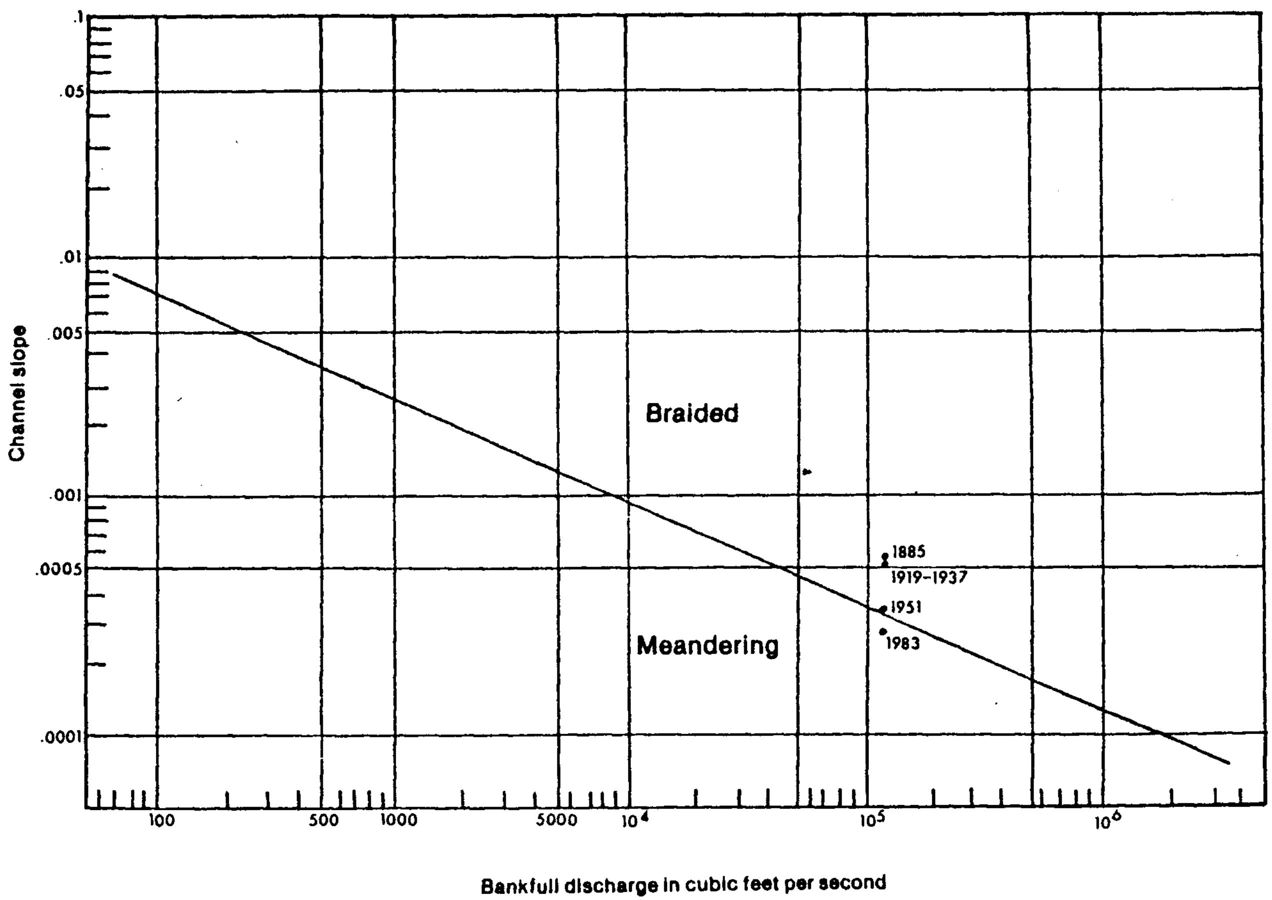


Figure 57: Historical slope-discharge relations for reach 2. Graph adapted After Leopold and Wolman (1957).

is unstable." Schumm and Beathard [1976] used the Chippewa River as an example to demonstrate how slope-discharge relationships have affected historic channel changes. In the case of the Chippewa River, a clearly braided reach of the river plotted in the meandering zone as defined by Leopold and Wolman [1957]. The channel within this reach was unstable and severe bank erosion occurred. Schumm and Beathard [1976] contended that if the channel could be induced to assume a meandering pattern, stability would result.

Historical slope-discharge relationships for reach 2 may be evaluated in the same manner used by Schumm and Beathard. As late as 1951, the channel in reach 2 plotted in the braided zone on the basis of its water-surface slope. Aerial photographs, however, reveal that as early as 1937 the channel clearly exhibited characteristics of meandering streams. These characteristics include a single thalweg which has been confined to the outside portion of the meander from at least 1937 to the present. Therefore, when the present episode of meander growth began in 1919, the channel within reach 2 was unstable according to slope-discharge relationships. This instability may have initiated the channel activity which has continued to the present as the channel has become increasingly less active. Since 1969, aerial photographs reveal that the most severe bank erosion and meander growth is occurring on the extreme downstream portion of the meander. This occurrence may indicate that the meander may be at what Hicken [1974] termed the "terminal stage" of meander growth where meander expansion is confined to the downstream limb of the bend.

VALLEY SLOPE

Valley slope in this thesis is defined by the total drop of the Kansas River for a given reach divided by the length of the reach measured as the shortest distance between the terminals of the reach. The line of measurement for the length of the reach generally conformed to the longitudinal axis of the valley. Valley slope is shown with corresponding water-surface slopes in figure 50 and Plate 4.

As revealed in figure 50, the valley slope is steeper within the western portion of the study area but becomes considerably less steep toward the east. The actual values of valley slope are as follows: reach 1, .000335; reach 2, .000593; and reach 3, .000579. There is some degree of subjectivity to these values because the beginning and end of each reach are arbitrarily determined. Nonetheless, valley slope clearly diminishes toward the east within the study area.

Valley slope has a direct influence on sinuosity [Schumm et al., 1972; Schumm and Khan, 1972]. They suggested that the sinuosity of alluvial streams is low for extremely low valley slopes but generally increases with increasing slope until a threshold is crossed and a braided channel results. Schumm and others [1972] have studied the relationship between valley slope and sinuosity for the Mississippi River and their results are shown in figure 58. The wide scatter of points occurs because sinuosity is not constant but varies about a mean through time. Schumm and Khan [1972] also experimentally illustrated the relationship between valley slope and sinuosity [Fig. 59]. Note the conformity of the points to the line in figure 59 as compared to the scatter of points about the line in figure 58.

Valley slope data from the Kansas River have been plotted in the same manner [Fig. 60]. Because the discharge of the Kansas River differs greatly from the Mississippi River and from Schumm's experimental stream, slopes and thus sinuosity may also vary significantly. Because only three points were plotted, one for each reach, the line drawn can only simulate the work of Schumm and others [1972] and Schumm and Khan [1972]. The data are in agreement with the findings of Schumm and others [1972] only when reaches 1 and 2 are considered. Low values of

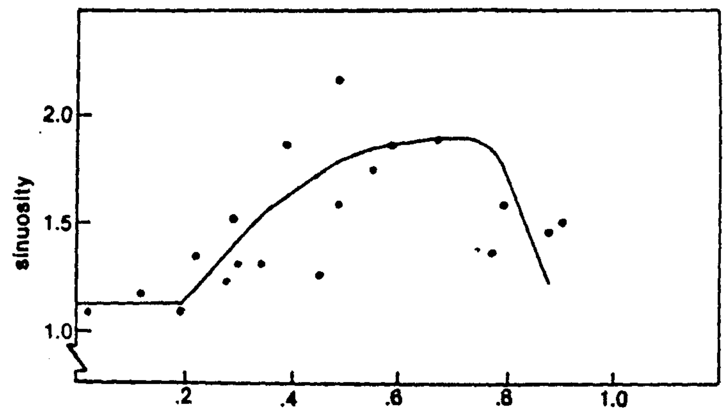


Figure 58: Relation of sinuosity to valley slope for Mississippi river data, Cairo, Illinois, to Head of Passes, Louisiana. From Schumm and others (1972).

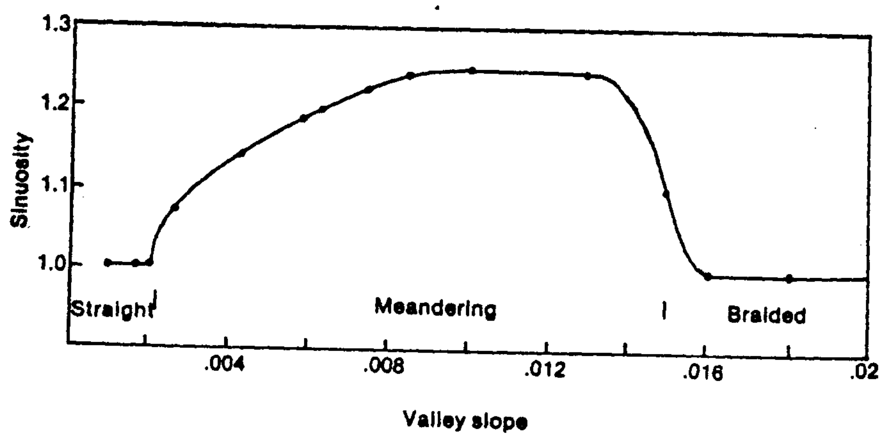


Figure 59: Relation of sinuosity to valley slope, experimental streams. From Schumm and Khan (1972).

valley slope result in relatively low sinuosity (reach 1). The steeper valley slope within reach 2 results in higher sinuosity. If valley slope were to increase for reach 2, a

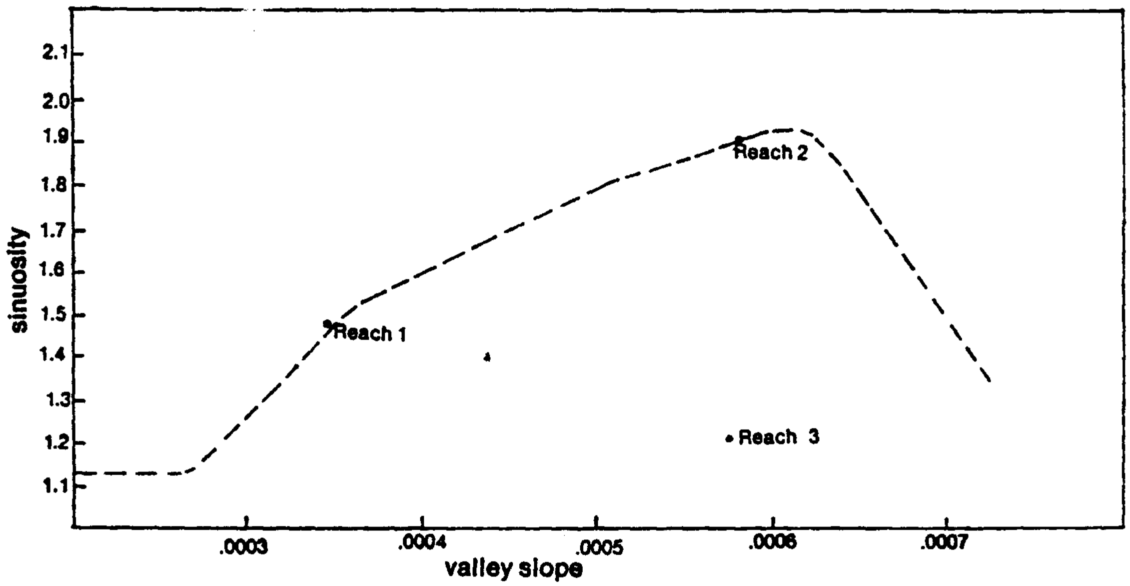


Figure 60: Valley slope-sinuosity relations for the Kansas river within the study area. Graph adapted from Schumm and Khan (1972).

braided stream would be likely to form. Thus the channel within reach 2 results in higher sinuosity. If valley slope were to increase for reach 2, a braided stream would be likely to form. Thus the channel within reach 2 has adjusted to maintain just the necessary competence to transport the supplied sediment load. In the effort to achieve this stable configuration, the channel has manifested activity since 1919. The inactive channel (reach 1), on the other hand, has not had to adjust nearly as much due to its low valley slope. Adjustment within reach 1, nonetheless, may still be occurring, as suggested by the high values of tractive force and stream power, but has been proceeding at a very slow pace due to the resistant nature of the Buck Creek, Newman, and Holliday terrace fills.

When reach 3 is considered, there is less agreement with the work of Schumm and others [1972][Fig. 60]. The valley slope of reach 3 [.000579] is only slightly less steep than that of reach 2 [.000593] and it plots in the meandering zone as defined by Schumm and Khan [1972] although it exhibits characteristics of braided channels. Thus the development of the relatively straight channel of reach 3 [sinuosity = 1.2] and the manifestation of some of the characteristics common to braided streams [e.g., multiple thalwegs] may not be explained in terms of exceeding a threshold alone.

POTENTIAL FOR CHANGES IN SLOPE

Valley slope is an independent variable with respect to the geologic and geomorphic processes that occur within graded time. Thus it is not likely that changes in valley slope will affect the activity of the Kansas River within the graded time span. Within reach 2, the channel is currently eroding the cut bank along the downstream portion of the active meander. In this manner the channel increases its length, which results in a corresponding decrease in slope.

Water-surface slope is more likely to increase due to the capture of the Kansas River by Deep Creek within reach 2. Deep Creek, a Kansas River tributary, flows northeast out of the Flint Hills and into the Kansas River valley. Near mile 134, Deep Creek nearly empties into the Kansas River but instead turns abruptly east and empties into the Kansas River at mile 132 (Fig. 61). At mile 134, the water surface of Deep Creek is lower than the water surface of the Kansas River and they are separated by only a few feet. During high discharges, an estimated ten percent of the Kansas River discharge flows into Deep Creek at mile 134. This portion of the captured Kansas Discharge then flows approximately .39 mile (.62 km) through the channel of Deep Creek and into the Kansas River again at the mouth of Deep Creek near mile 132. The United States Army Corps of Engineers anticipates the eventual capture of the entire Kansas River by Deep Creek and the resulting cut-off of the large meander within reach 2 (Bob Pierce, personal communication). If this cut off occurs, an estimated 386 acres (156 hectares) of cropland would be isolated from its owner.

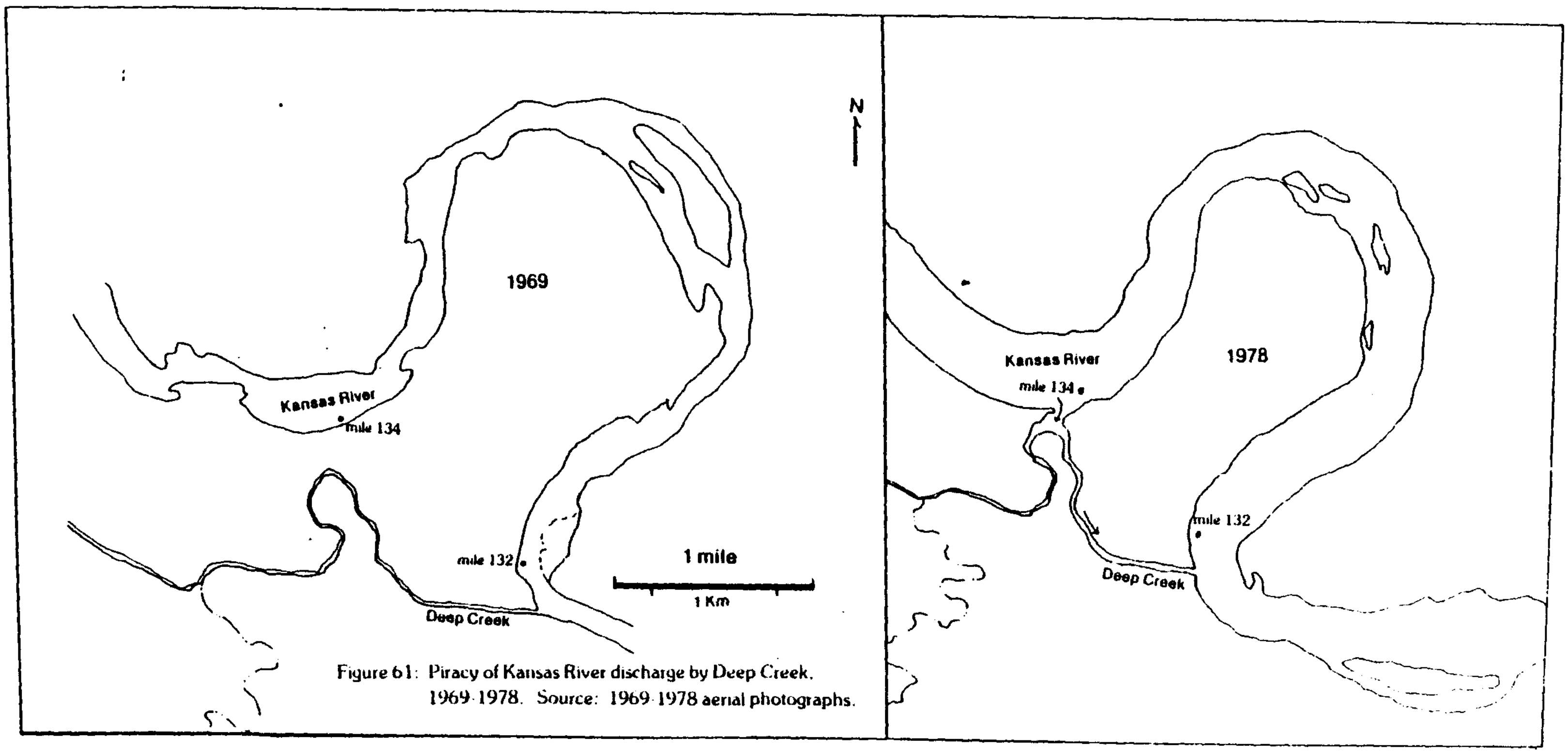


Figure 61: Piracy of Kansas River discharge by Deep Creek, 1969-1978. Source: 1969-1978 aerial photographs.

If the active meander of reach 2 is cut off, the length of the channel would be reduced from 3.4 km to .62 km and the water-surface slope would increase from approximately .00023 to .0015. This slope value would plot within the braided zone as defined by Leopold and Wolman [1957]. Slope conditions similar to those in 1885, when the length of the channel of reach 2 was the shortest and the sinuosity value was the lowest, would occur. The entire meander-forming process would be likely to be reinitiated in order for the river in this location to again achieve equilibrium.

SUBCHAPTER CONCLUSIONS

The following conclusions summarize pages 161 through 192 of the text.

1. The transitional reach between meanders [reach 3] displays a steeper water-surface slope than the profile of the channel in the meanders.

2. The inactivity of reach 1 cannot be explained by water-surface slope since its steeper slope contributes to higher values of stream power and tractive force.

3. The fine cohesive bank material of reach 1 enables the banks to resist erosion that would occur at the greater values of stream power and tractive force.

4. The steep valley slope of reach 2 has initiated the channel activity within this reach. The channel has meandered to maintain just the slope necessary to transport the supplied sediment load. The coarser, less resistant bank material has accentuated channel activity.

5. Whereas the valley slope of reach 1 is gentler than reach 2, the channel may still be in a stage of adjustment. The resistant nature of the bank sediment has served to inhibit this adjustment and water-surface slope has remained high.

6. The gradual capture of flow of the Kansas River by Deep Creek threatens to decrease the length of reach 2 and consequently increase its water-surface slope. If the active meander is cut off in this way, the increased slope may initiate another episode of channel migration and meander formation.

CHAPTER VI

THESIS CONCLUSIONS

The methodology used in this thesis was implemented to evaluate causes of channel activity and local bank erosion on the basis of long standing theories. Many researchers have provided the framework and assumptions upon which the methodology was formulated. Findings generally support the models described in the text which offer possible causes for channel activity. The following conclusions are postulated upon data presented in this thesis.

1. Steepened local valley slope within reach 2 (active) may be responsible for initiating rapid meander growth since 1885. The channel has apparently meandered to maintain just the slope necessary to transport the supplied sediment load. The meander grew until a water-surface slope that was in equilibrium with the bed load was accomplished. Within reach 1 (inactive), channel adjustment has been limited by the fine nature of the bank material. The bank alluvium within much of reach 1 (inactive) consists of Newman, Buck Creek, and Holliday terrace fills which are considerably finer than the modern alluvium of reach 2 (active). Although the valley slope within reach 1 (inactive)is relatively gentle, the barrier presented to channel migration has resulted in the

maintenance of anomalously high values of water-surface slope as well as tractive force and stream power with this reach.

2. Alluvium within reach 2 (active) contains less silt-clay (37.6%) than reach 1 (inactive)(50.5%). Whereas the genesis of channel migration within reach 2 seems to have been the anomalously steepened valley slope, the rapidity with which the migration proceeded is probably due to the noncohesive alluvium that comprises the floodplain. Nonetheless, the small amounts of silt-clay within reach 2 has apparently provided the bank stability necessary for meanders to form (Schumm, 1961, 1974). If a threshold of silt-clay composition exists where a meandering rather than braided stream will form, the banks within reach 2 exceed that threshold. The rapidity of channel migration, on the other hand, may vary with the amount of silt-clay present in the stratum beyond that threshold (Daniel, 1971).

3. Terrace alluvium within the Kansas River valley contains a high percentage of overbank deposition and is, thus, an effective lateral channel control. Modern alluvium is generally coarser and less indurated above the water level and is relatively easily eroded. Recent 14C dates suggest that the fill beneath the Newman terrace is younger than previously believed.

4. Gravel bars occurring at mile 132 have their

source in nearby cut bank sediments exposed by the growth of the active meander. The gravel found in the bank was apparently deposited in the 1929-1941 channel of the Kansas River. Consequently, they could not have been historically a factor in the development of the "pivot point" which began in 1919. A much more viable explanation for the occurrence of the "pivot point" is the resistance of erosion encountered by the Kansas River south of mile 132 due to the presence of the Buck Creek and Newman terraces. The fine, cohesive sediment of the terrace fills has retarded the southward migration of the channel, causing the stream to continuously occupy the channel at mile 132 in spite of the formation of the active meander since 1919.

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APPENDIX A

This appendix summarizes hypotheses corresponding to results of statistical tests presented in tables 3, 4, 5 and 7.

Table 3

T-tests for determining differences in grain-size parameters for weighted samples between the active and inactive reach.

Test 1

Ho: There is no significant difference in the grain-size parameters of all samples between the active and inactive reach within the study area.

H1: There is a significant difference in the grain-size parameters of all samples between the active and inactive reach within the study area.

Test 2

Ho: There is no significant difference in grain-size parameters for samples above 1/3 bankfull between the active and inactive reach.

H1: There is a significant difference in grain-size parameters for samples above 1/3 bankfull between the active and inactive reach.

Test 3

Ho: There is no significant difference in grain-size parameters for samples between 1/3 and 2/3 bankfull between the active and inactive reach.

H1: There is a significant difference in grain-size parameters for samples between 1/3 and 2/3 bankfull between the active and inactive reach.

Test 4

Ho: There is no significant difference in grain-size parameters for samples above 2/3 bankfull between the active and inactive reach.

H1: There is a significant difference in grain-size parameters for samples above 2/3 bankfull between the active and inactive reach.

Test 5

Ho: There is no significant difference in grain-size parameters for samples below 2/3 bankfull between the active and inactive reach.

H1: There is a significant difference in grain-size parameters for samples below 2/3 bankfull between the active and inactive reach.

Test 6

Ho: There is no significant difference in grain-size parameters for samples below 1/3 bankfull between the active and inactive reach.

H1: There is a significant difference in grain-size parameters for samples below 1/3 bankfull between the active and inactive reach.

Table 4

Mann-Whitney U test for determining differences in silt-clay percent and clay percent between the active and inactive reach.

Ho: There is no significant difference in silt-clay percent and clay percent for all samples between the active and inactive reach.

H1: There is a significant difference in silt-clay percent and clay percent for all samples between the active and inactive reach.

Table 5

T-tests for determining differences in grain-size parameters for non-weighted samples between the active and inactive reach.

Test 1

Ho: There is no significant difference in the grain-size parameters of all samples between the active and inactive reach within the study area.

H1: There is a significant difference in the grain-size parameters of all samples between the active and inactive reach within the study area.

Test 2

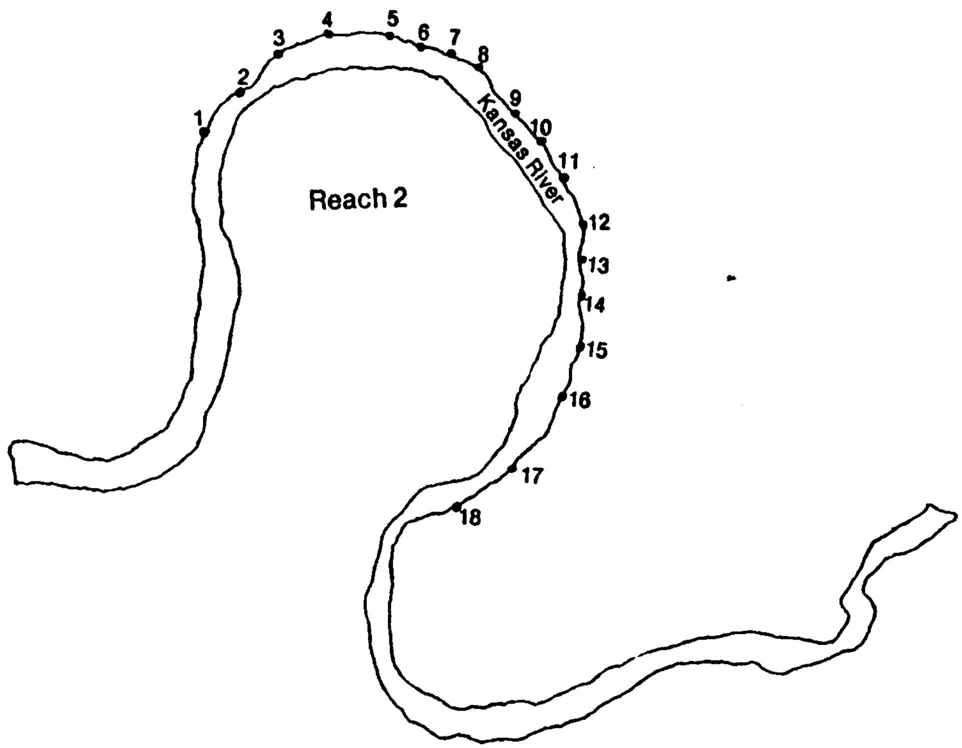
Ho: There is no significant difference in grain-size parameters between Buck Creek terrace fill sediments and modern sediments.

APPENDIX B

Part 1: Sampling locales.

Part 2: Generalized sections of selected sampling locales.

Part 3: Cumulative frequency curves for samples of locales shown in part 2.


Reach 2
Kansas River
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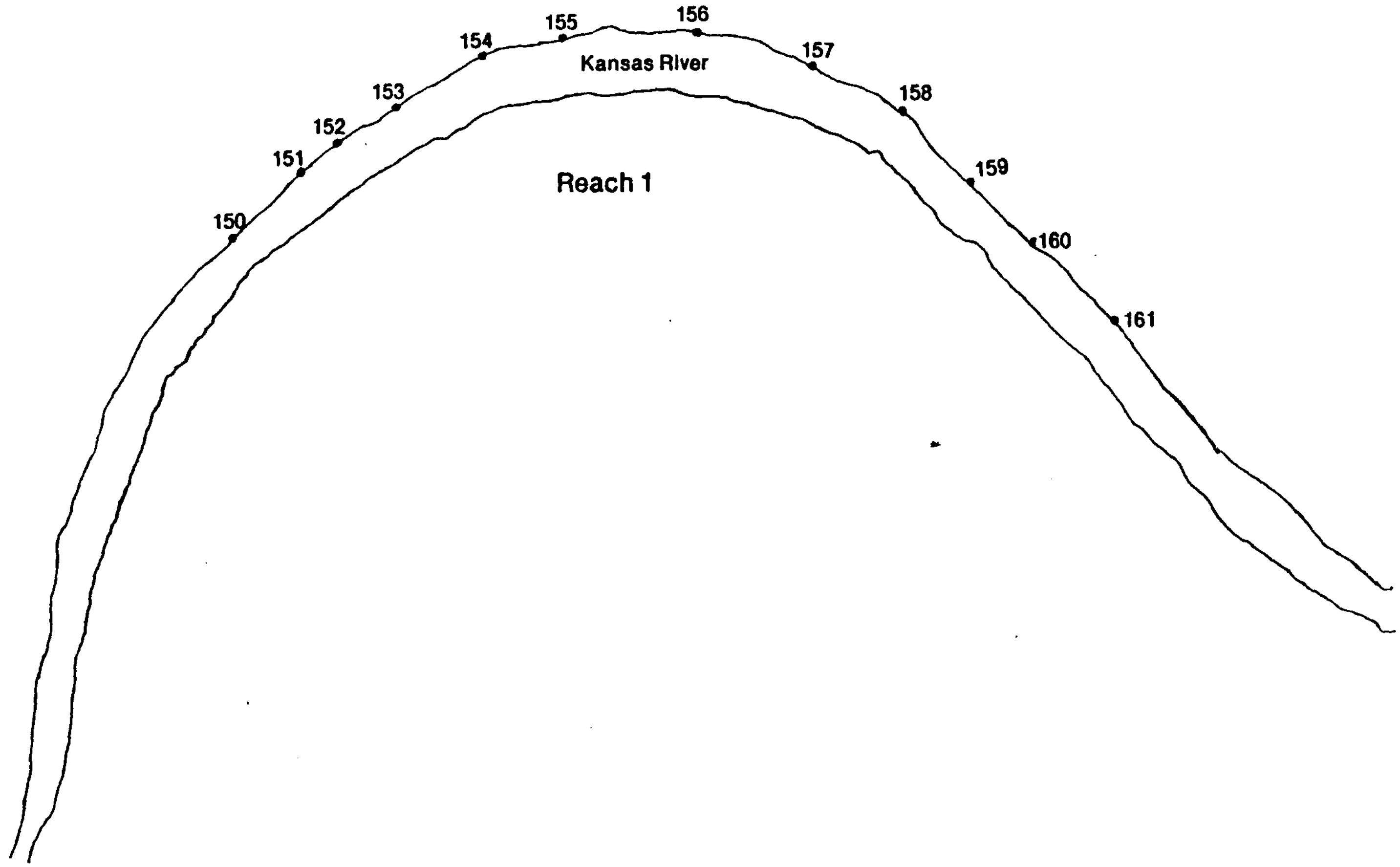
17
18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151
152
153
154
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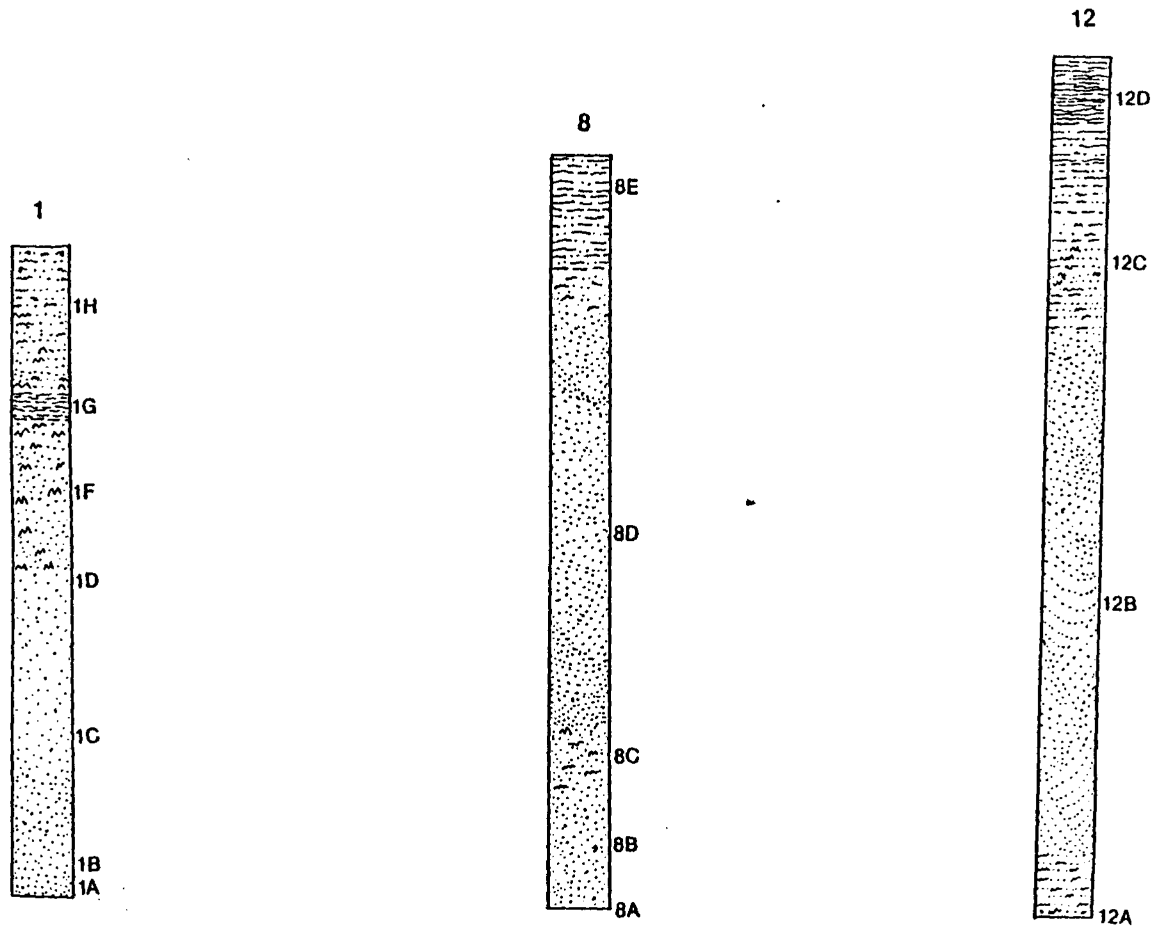
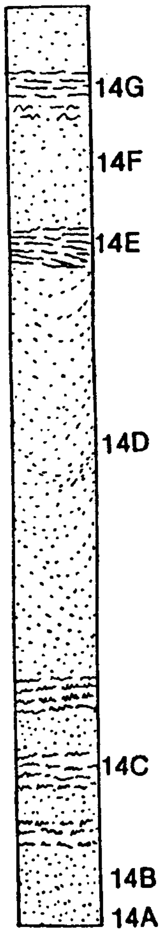
158
159
160
161
Kansas River
Reach 1


1
1H
1G
1F
1D
1C
1B
1A
8
8E
8D
8C
8B
8A
12
12D
12C
12B
12A

14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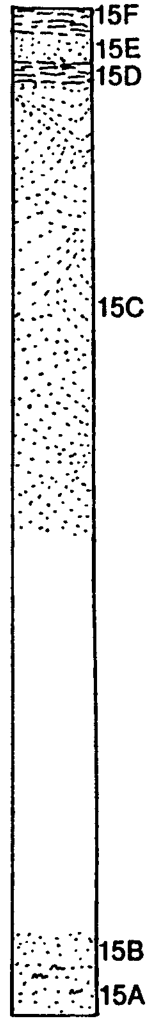
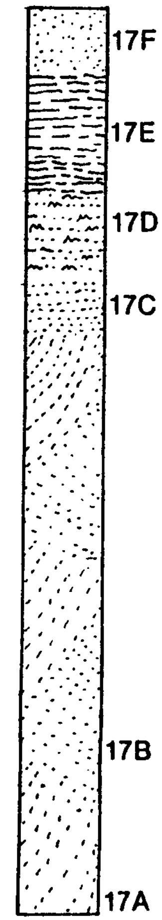
14F
14E
14D
14C
14B
14A

15


15F
15E
15D
15C
15B
15A

17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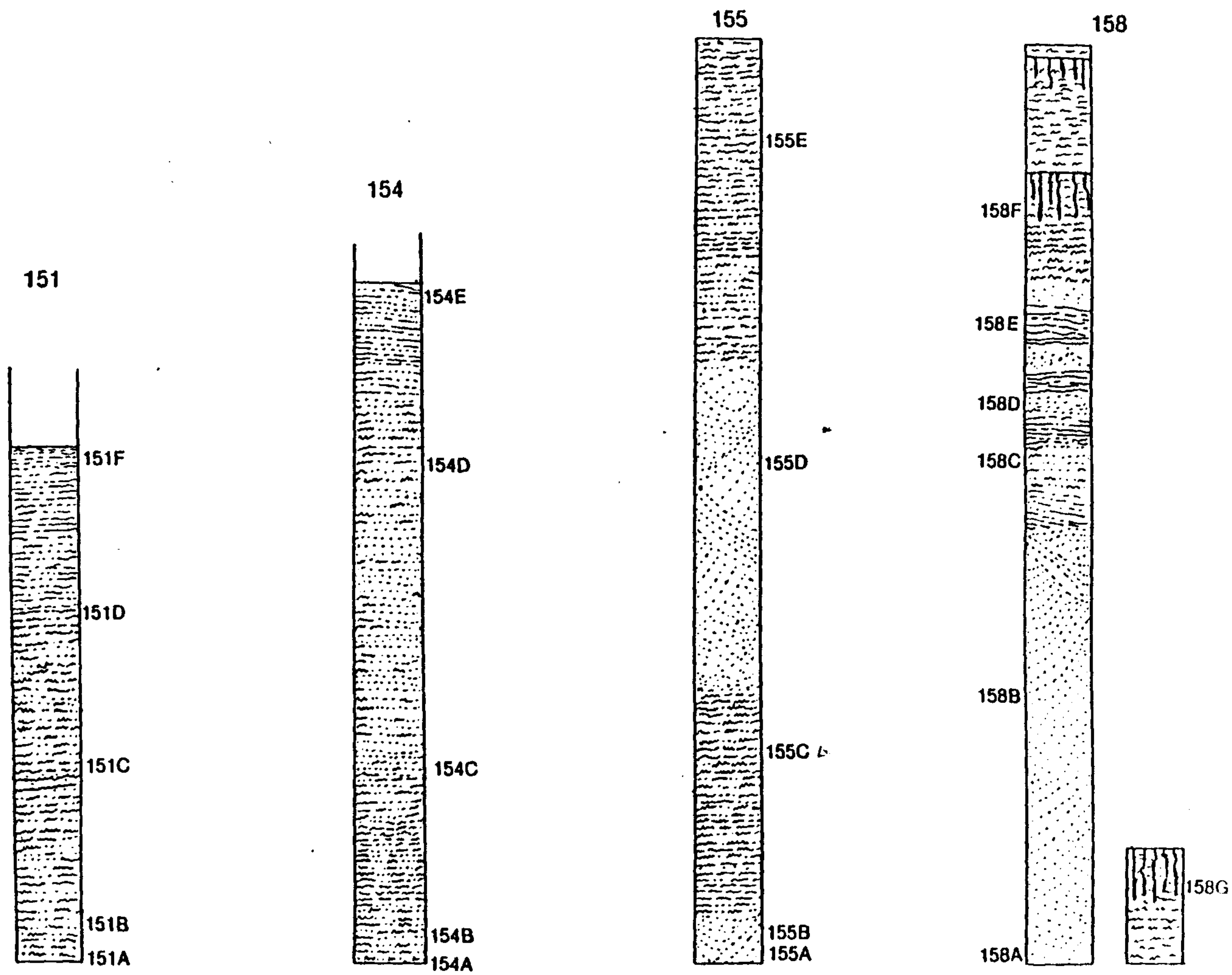
17D
17C
17B
17A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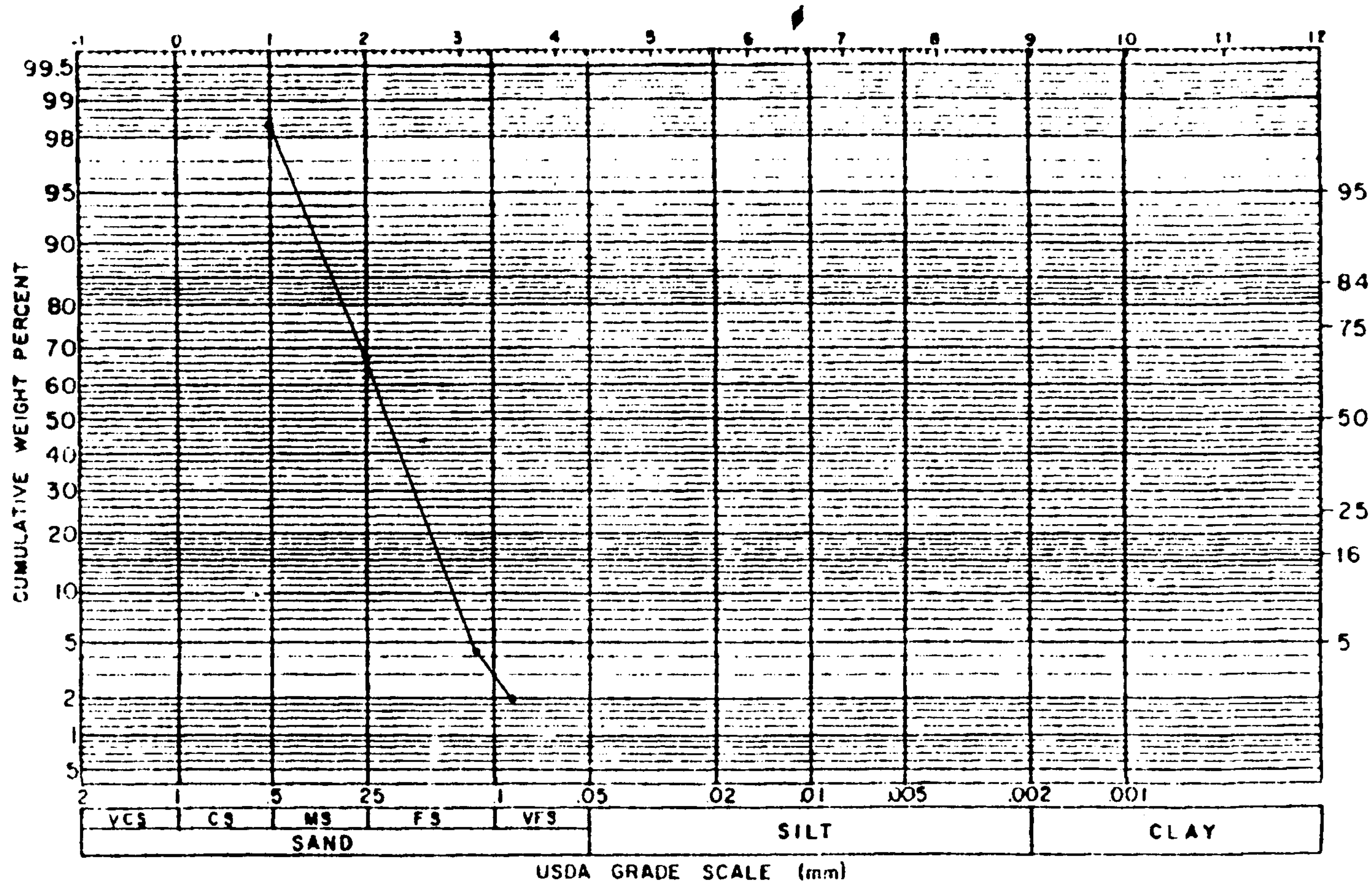
154C
154B
154A
155
155E
155D
155C
155B
155A
158
158F
158E
158D
158C
158B
158A
158G

Sample No 1B

PARTICLE SIZE DISTRIBUTION DIAGRAM



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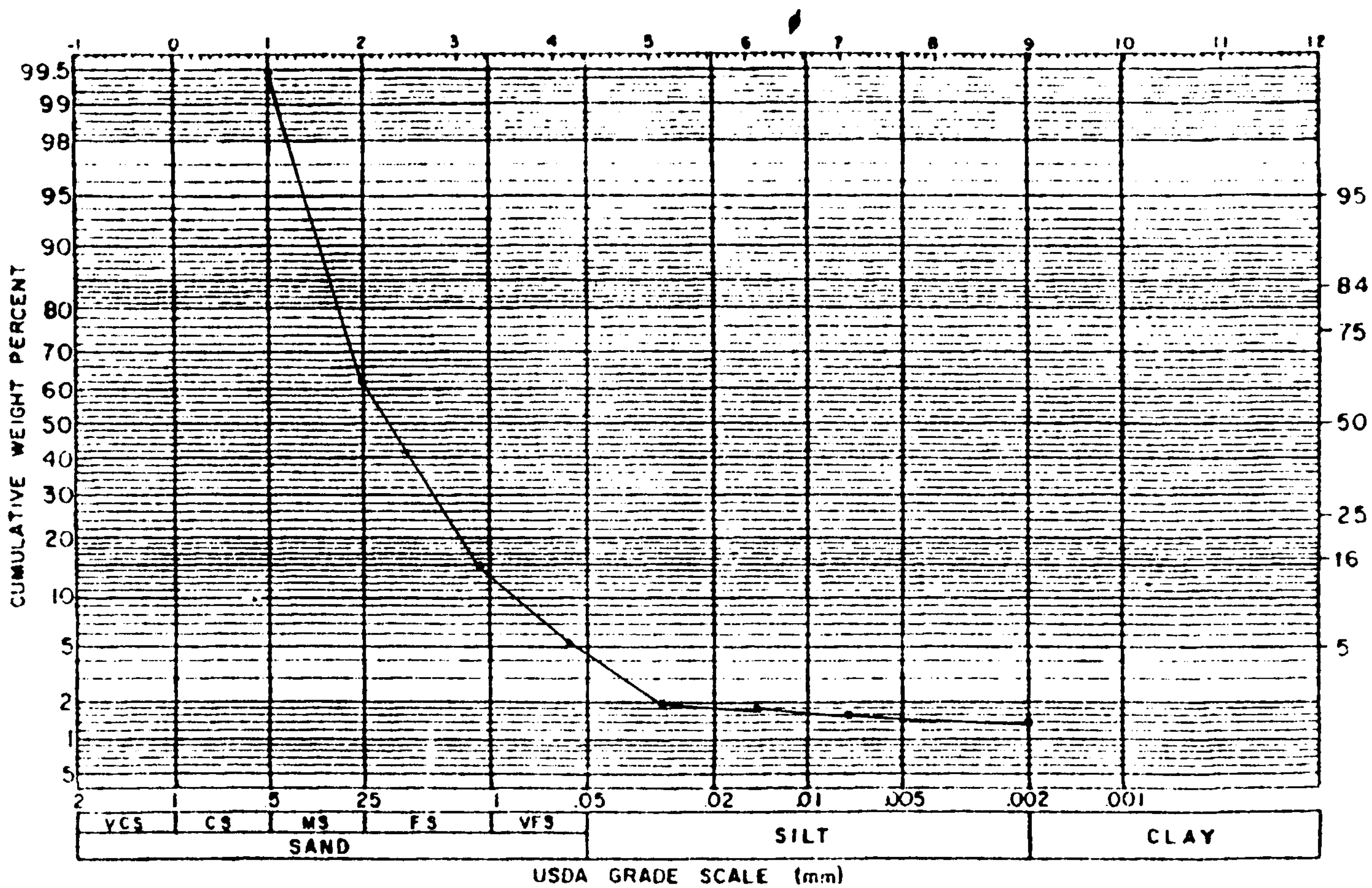

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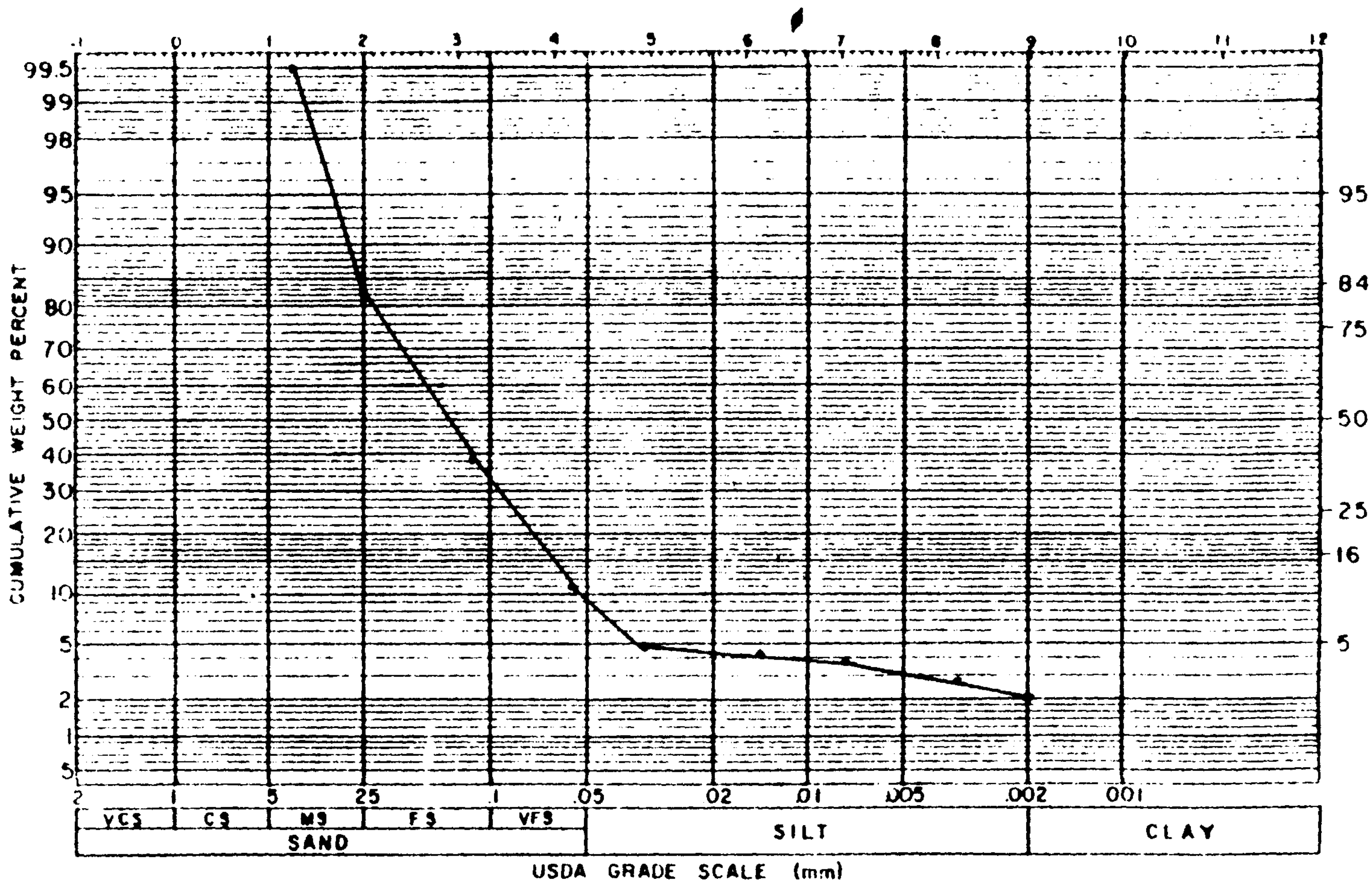

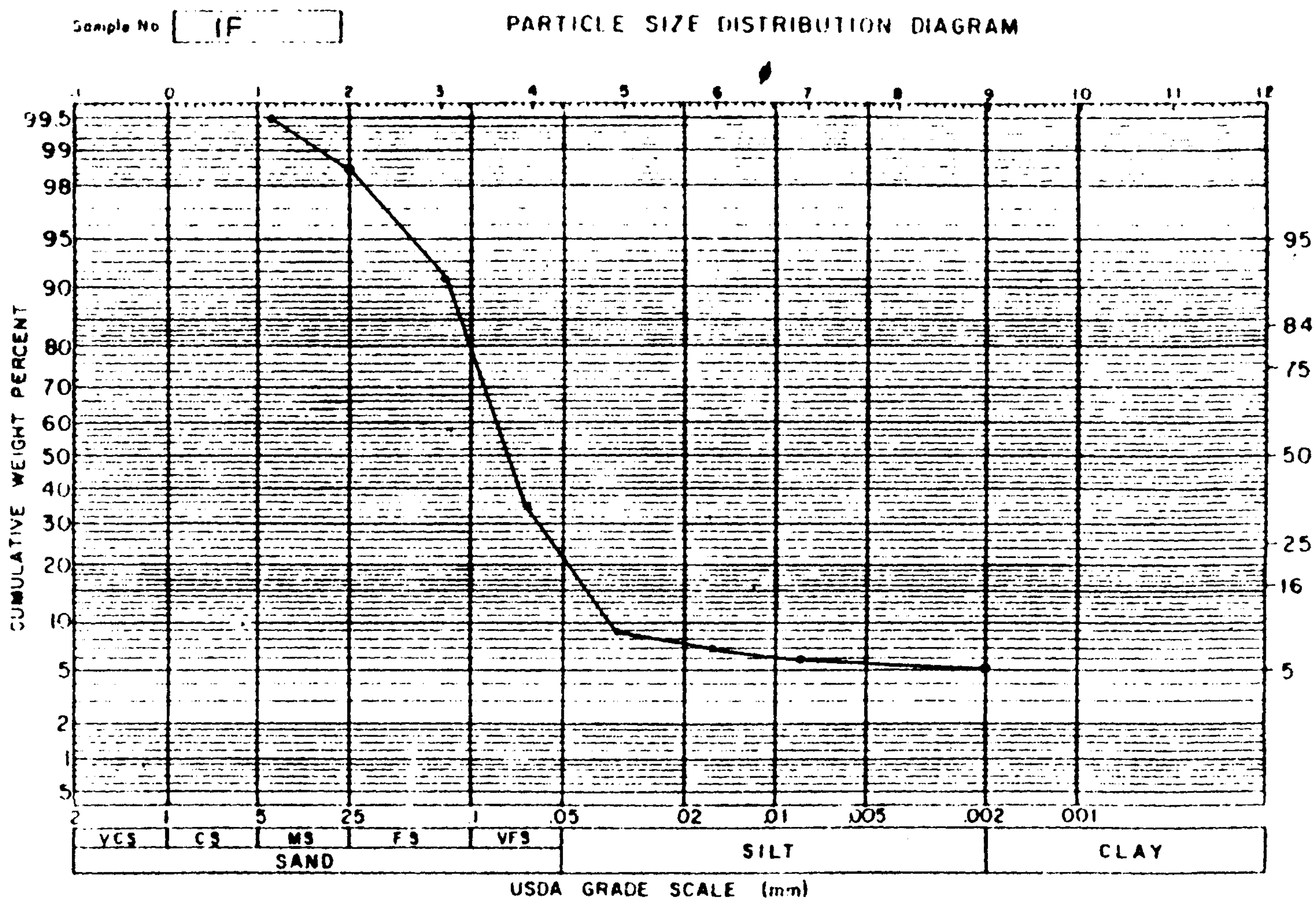

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ϕ
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CUMULATIVE WEIGHT PERCENT
95 84 75 50 25 16 5
2 1 .5 .25 .1 .05 .02 .01 .005 .002 .001
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

Sample No 1G

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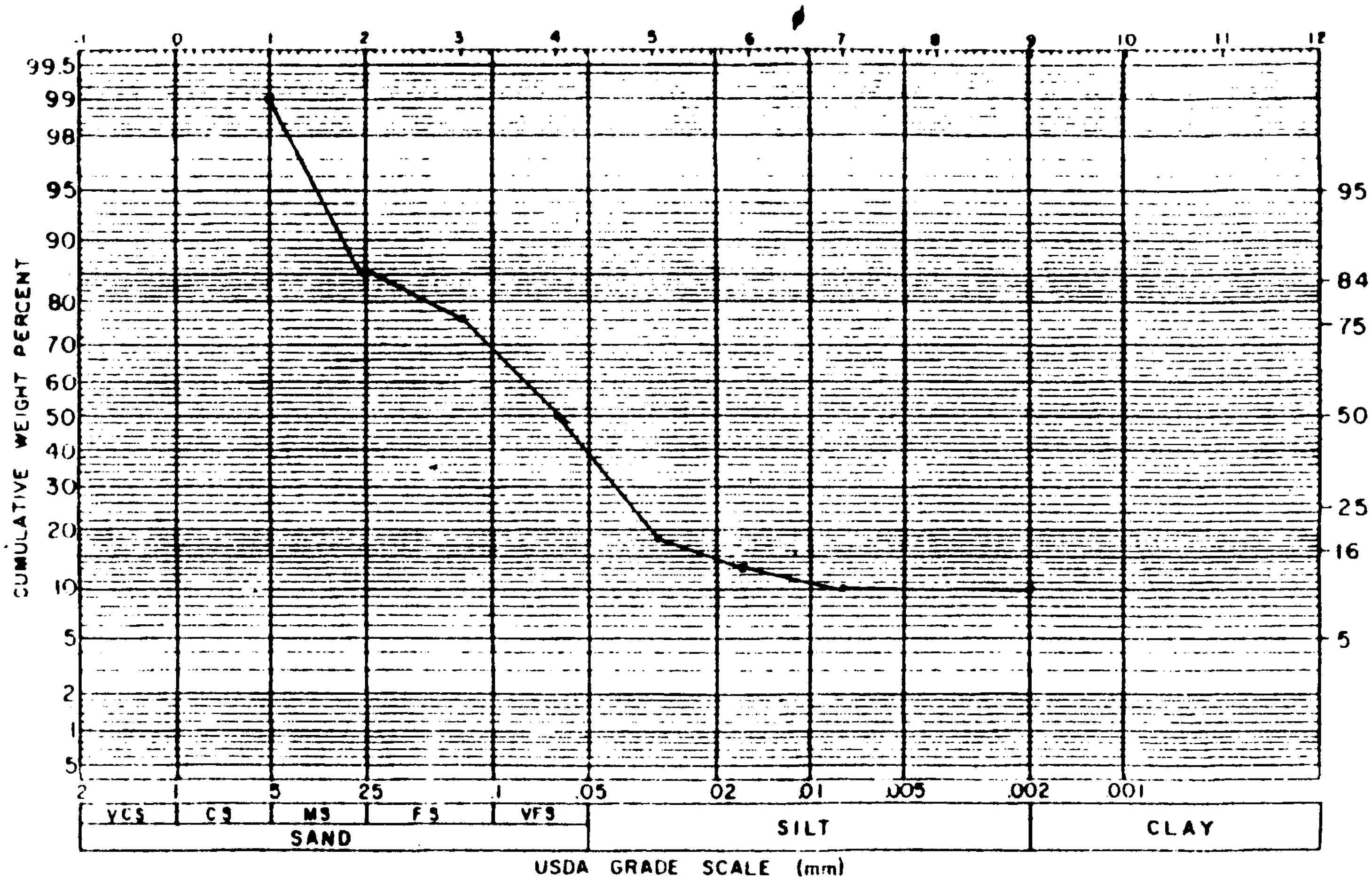

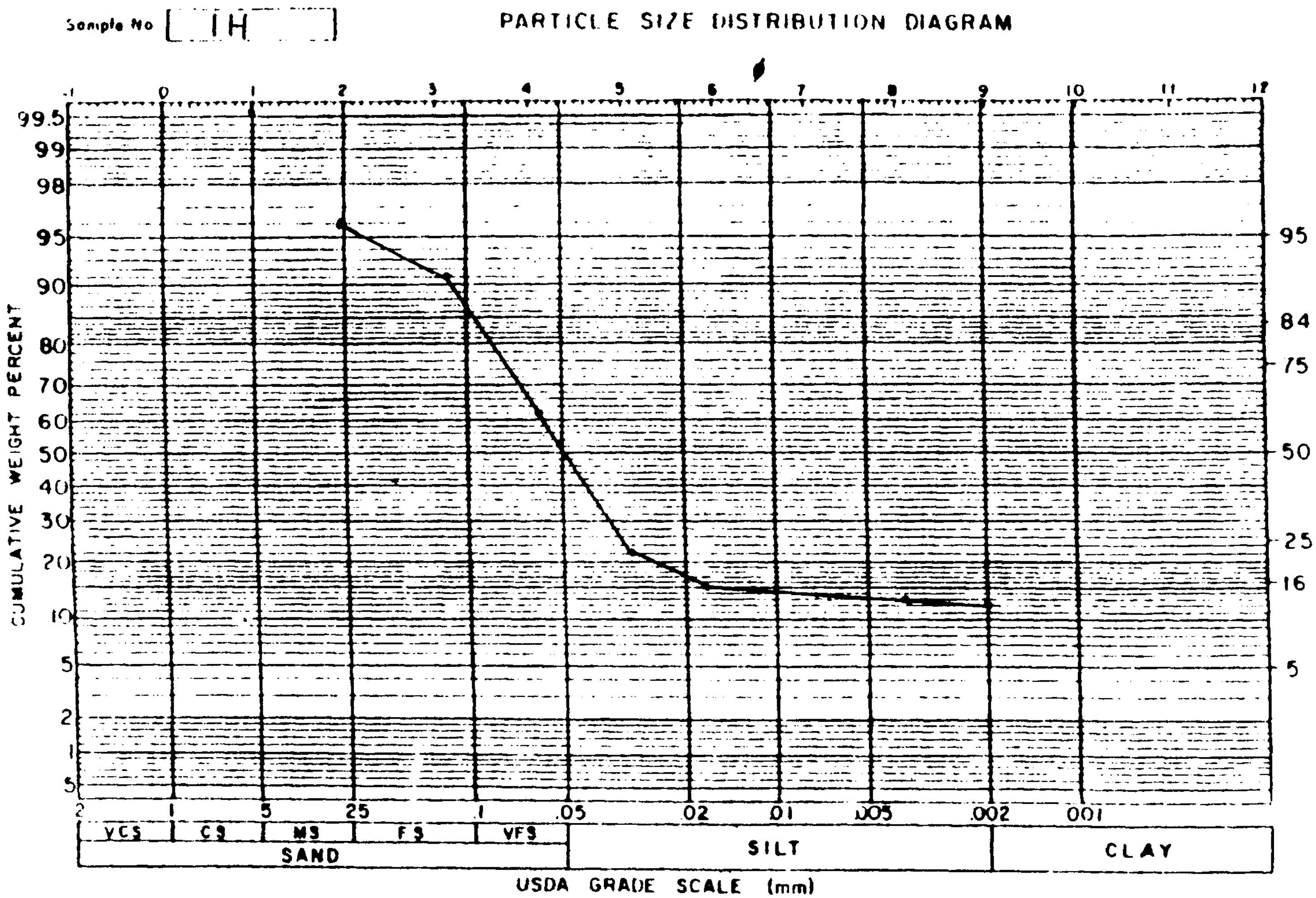
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95 84 75 50 25 16 5
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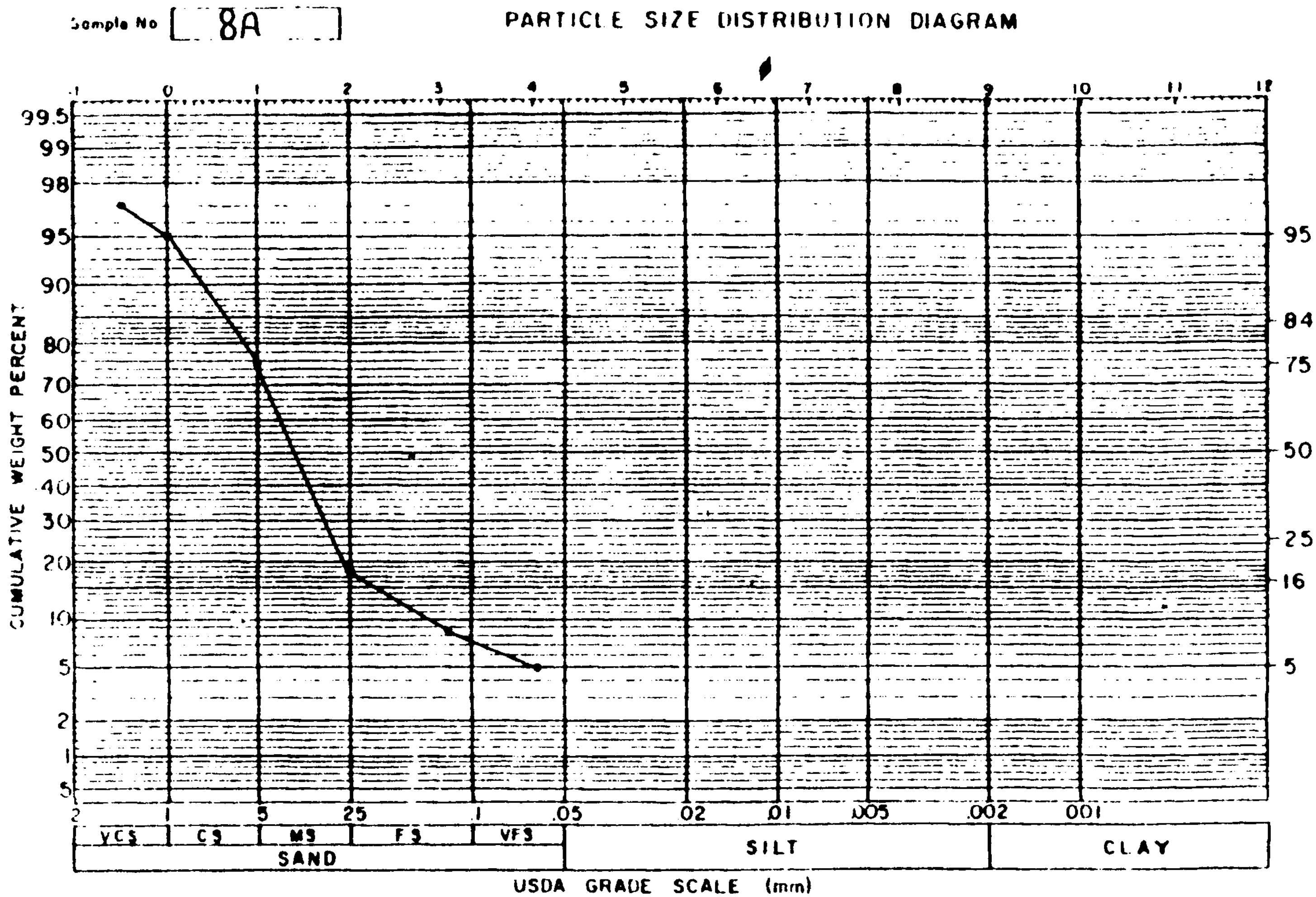
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)



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VCS
CS
MS
FS
VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

Sample No 8B

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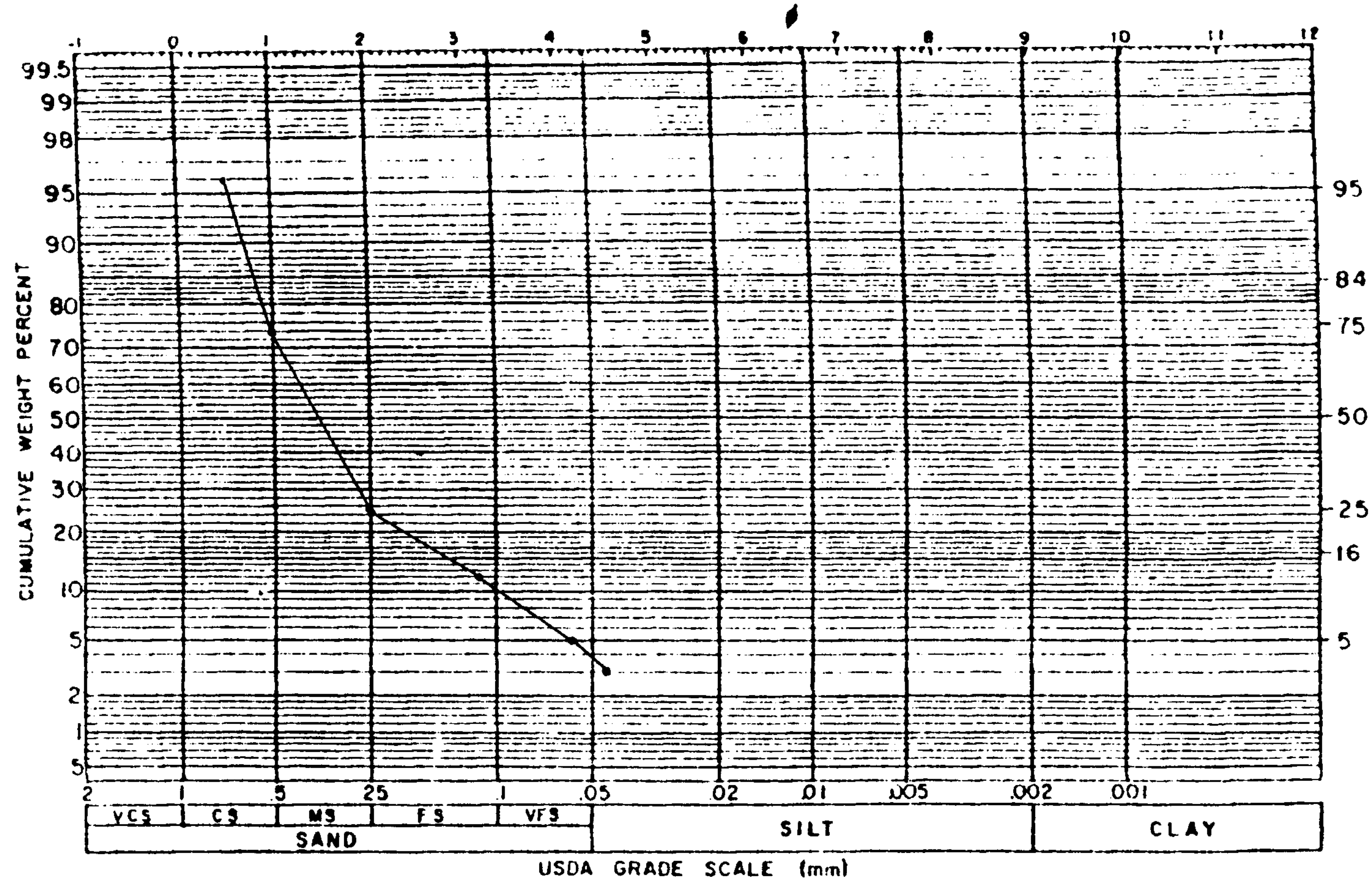

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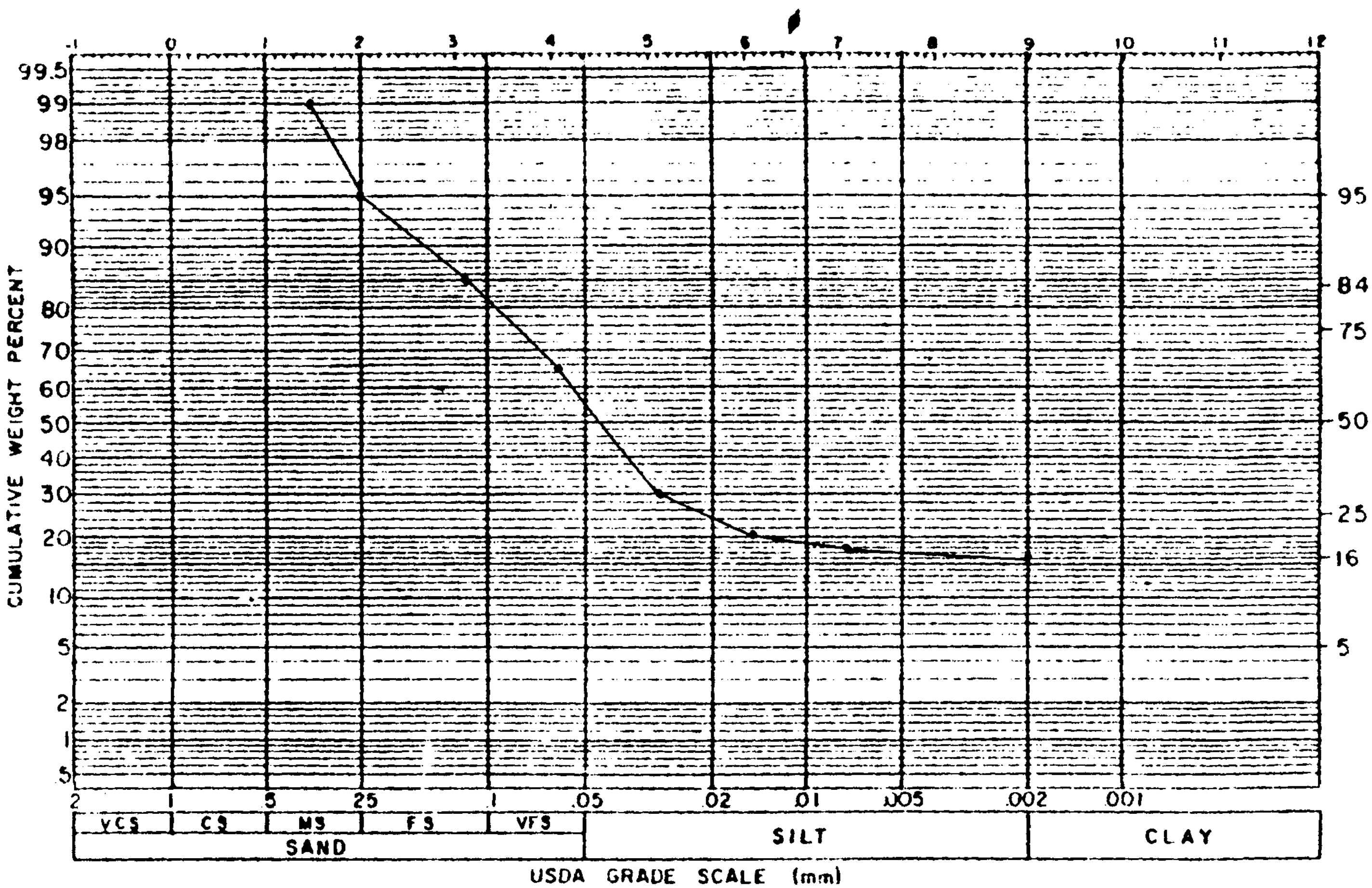

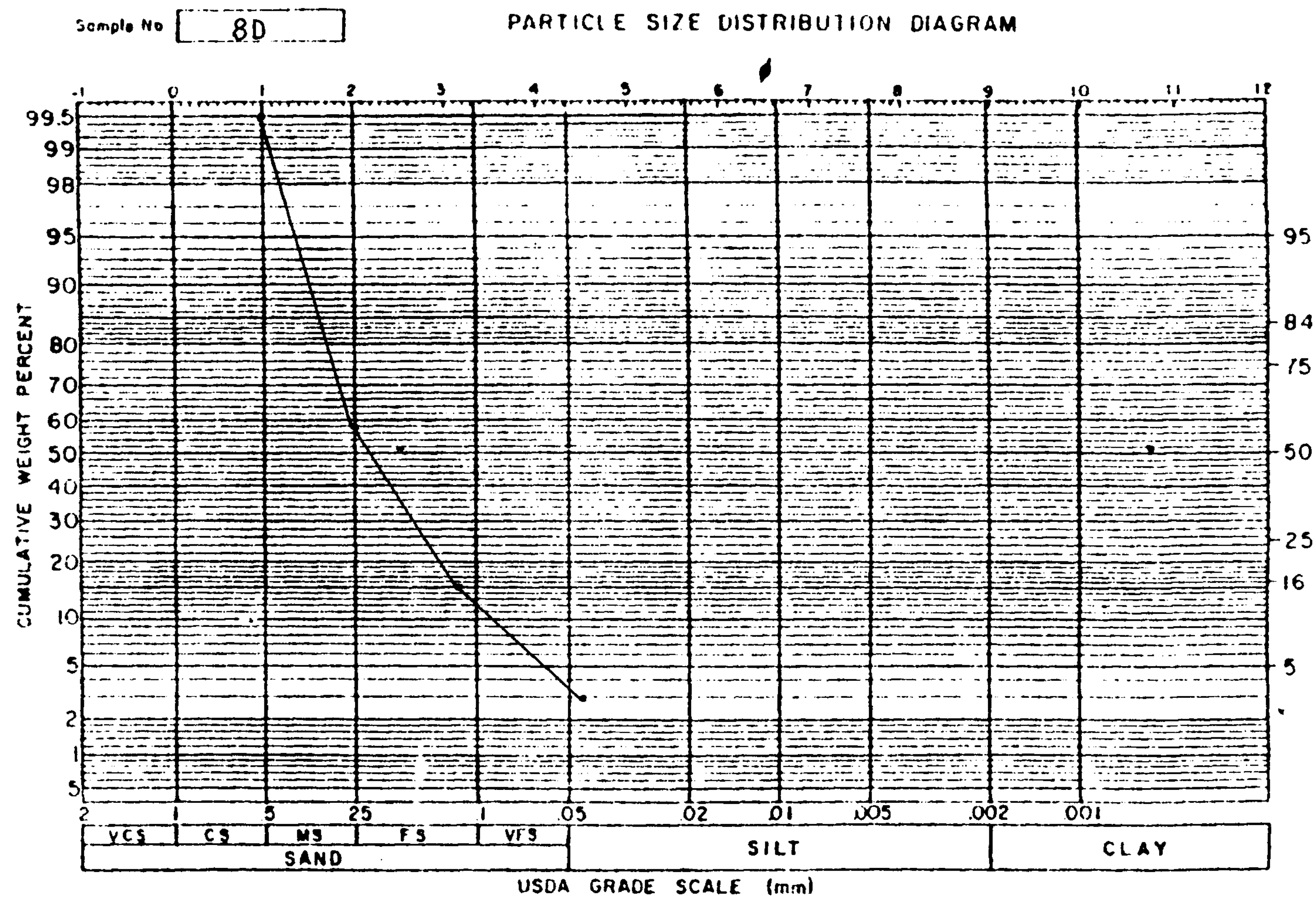
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95 84 75 50 25 16 5
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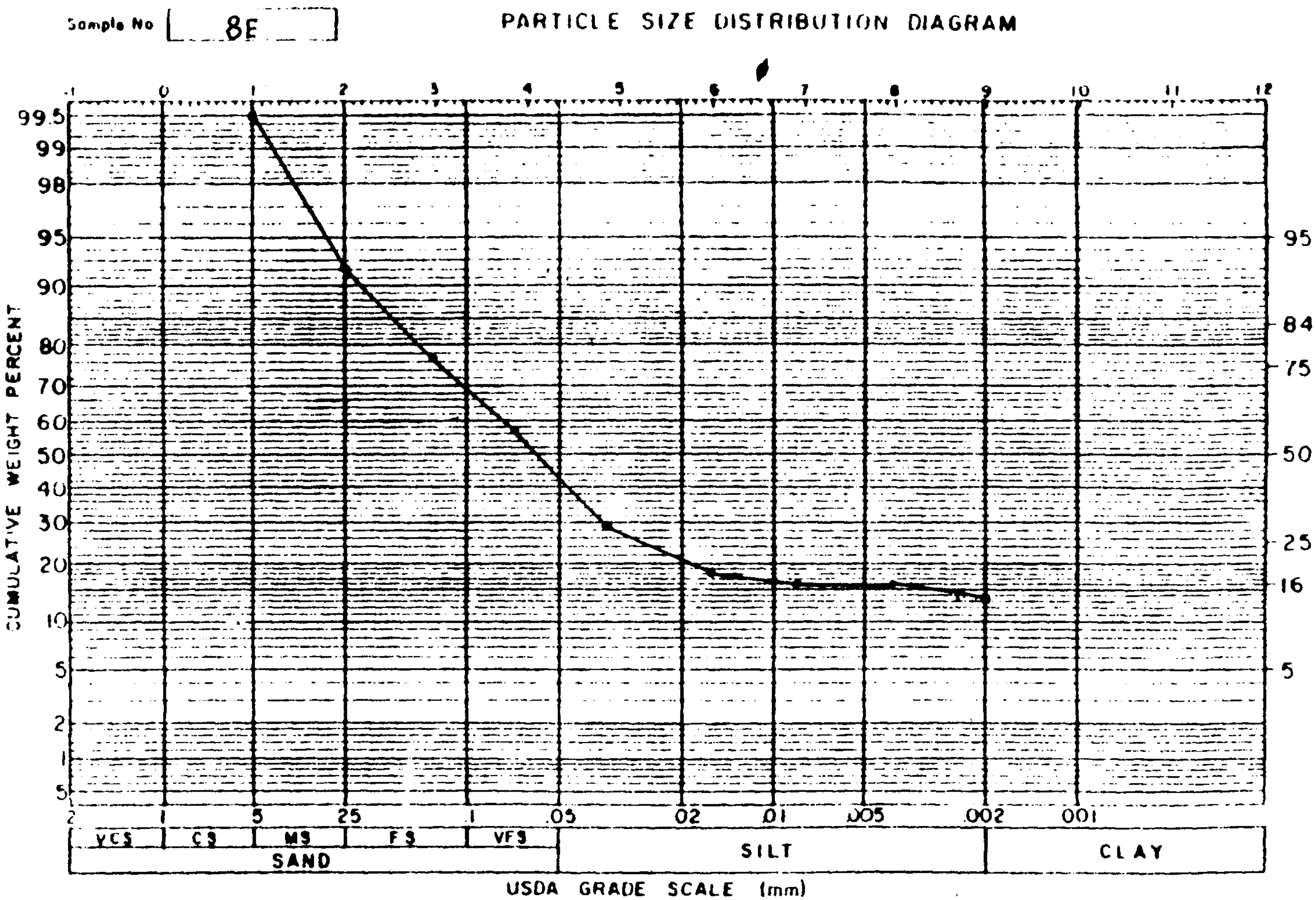
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)



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95 84 75 50 25 16 5
2 1 .5 .25 .1 .05 .02 .01 .005 .002 .001
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

Sample No 12 B

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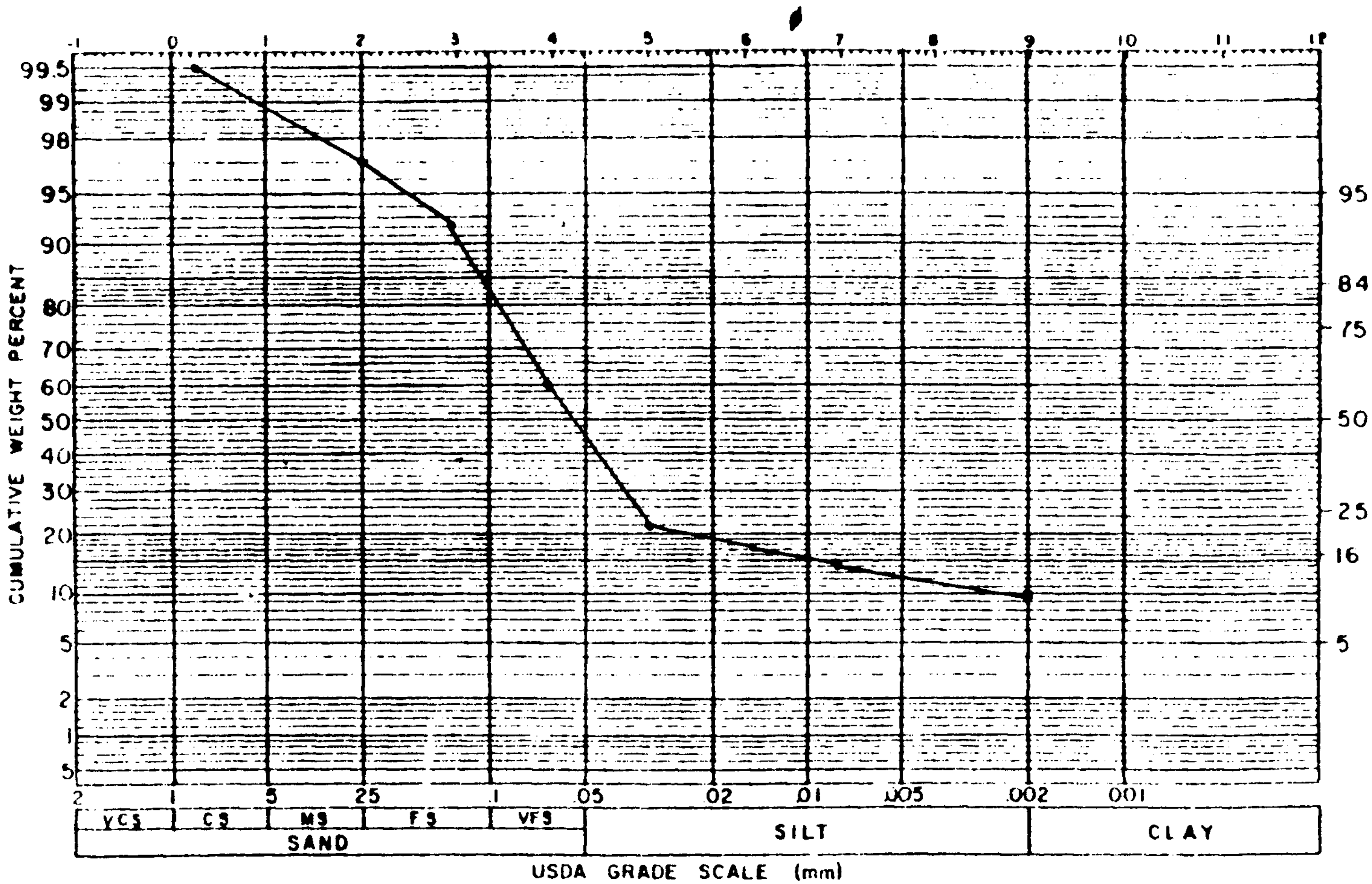

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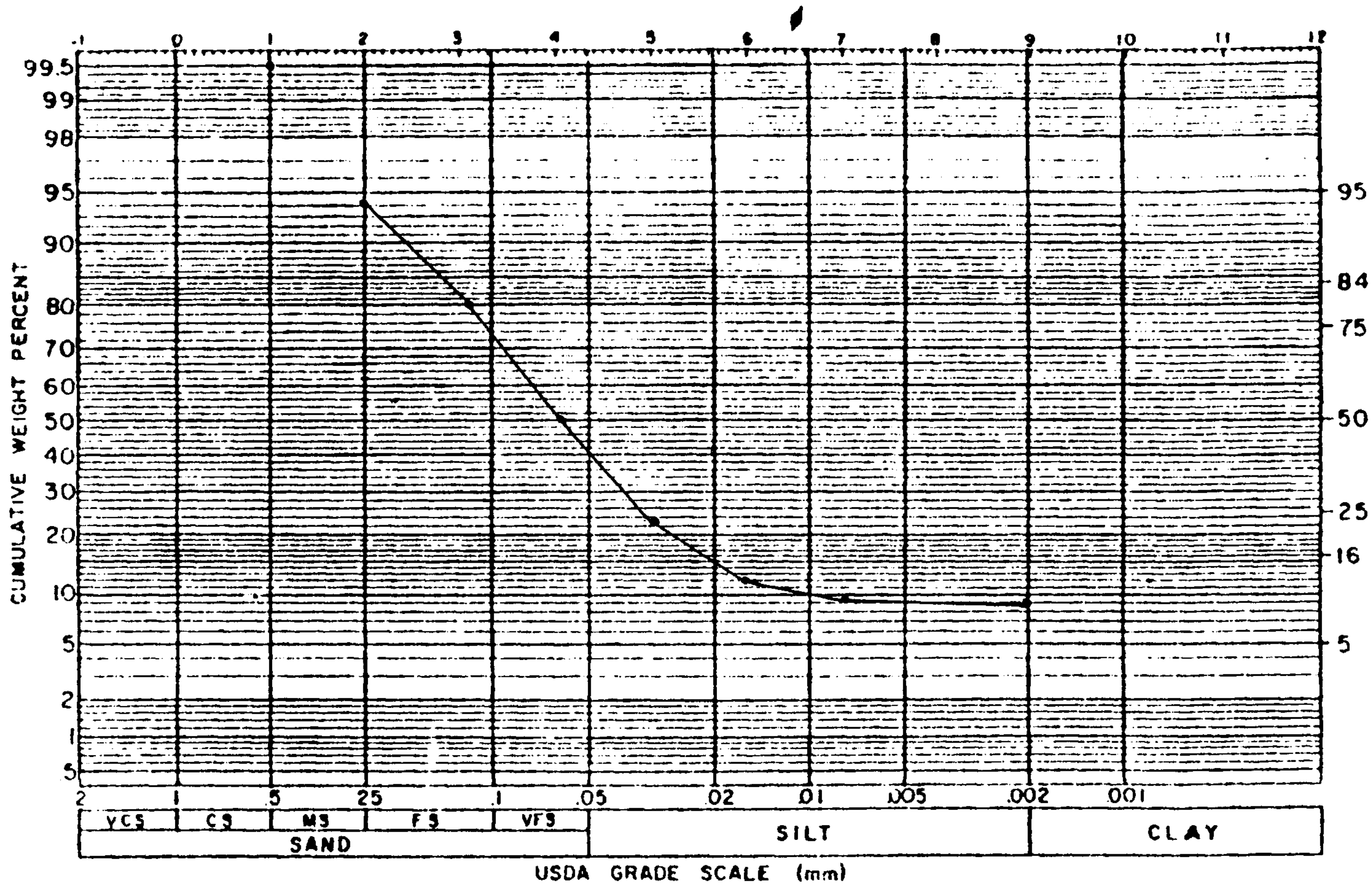

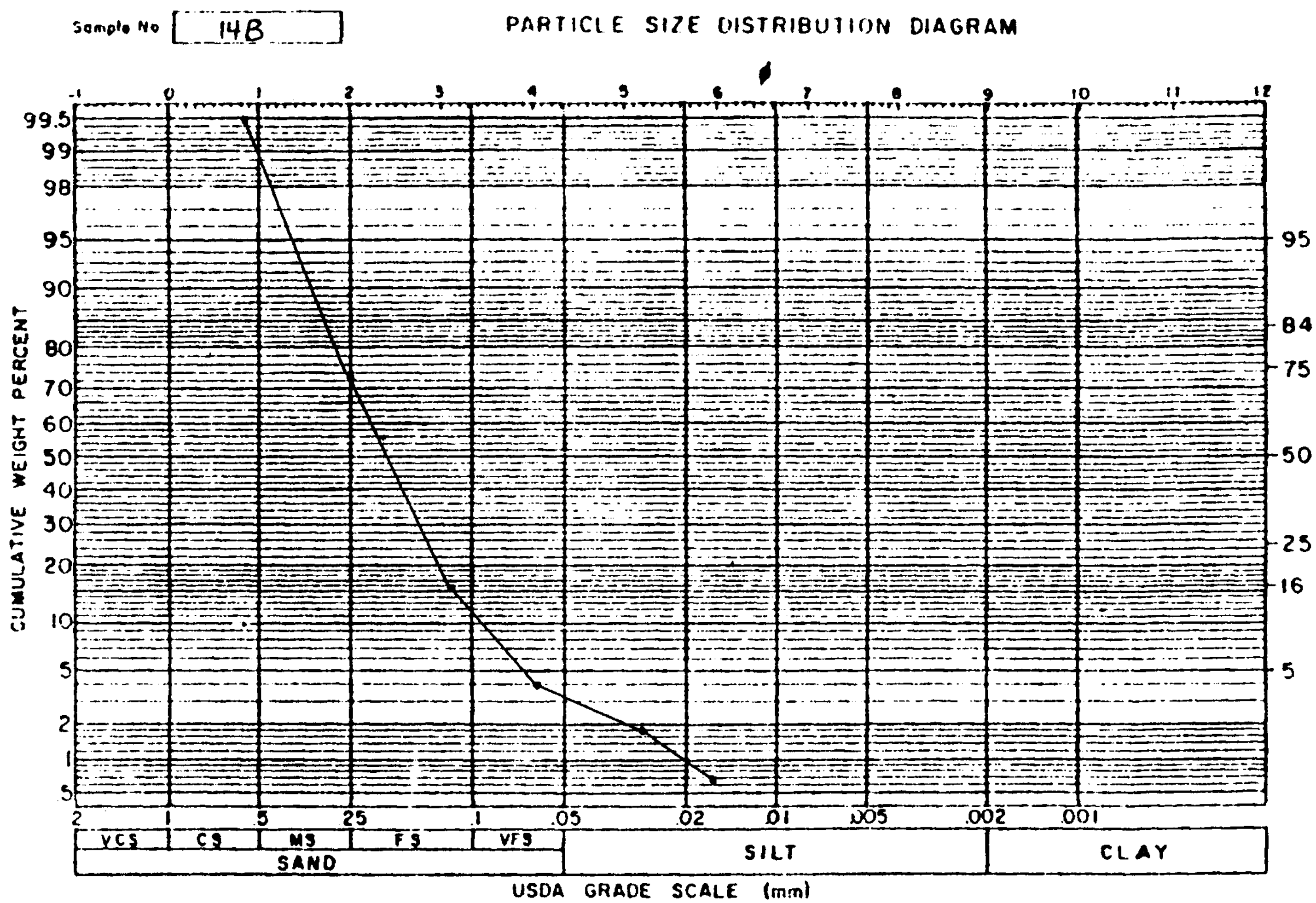
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SILT
CLAY
USDA GRADE SCALE (mm)

Sample No 14C

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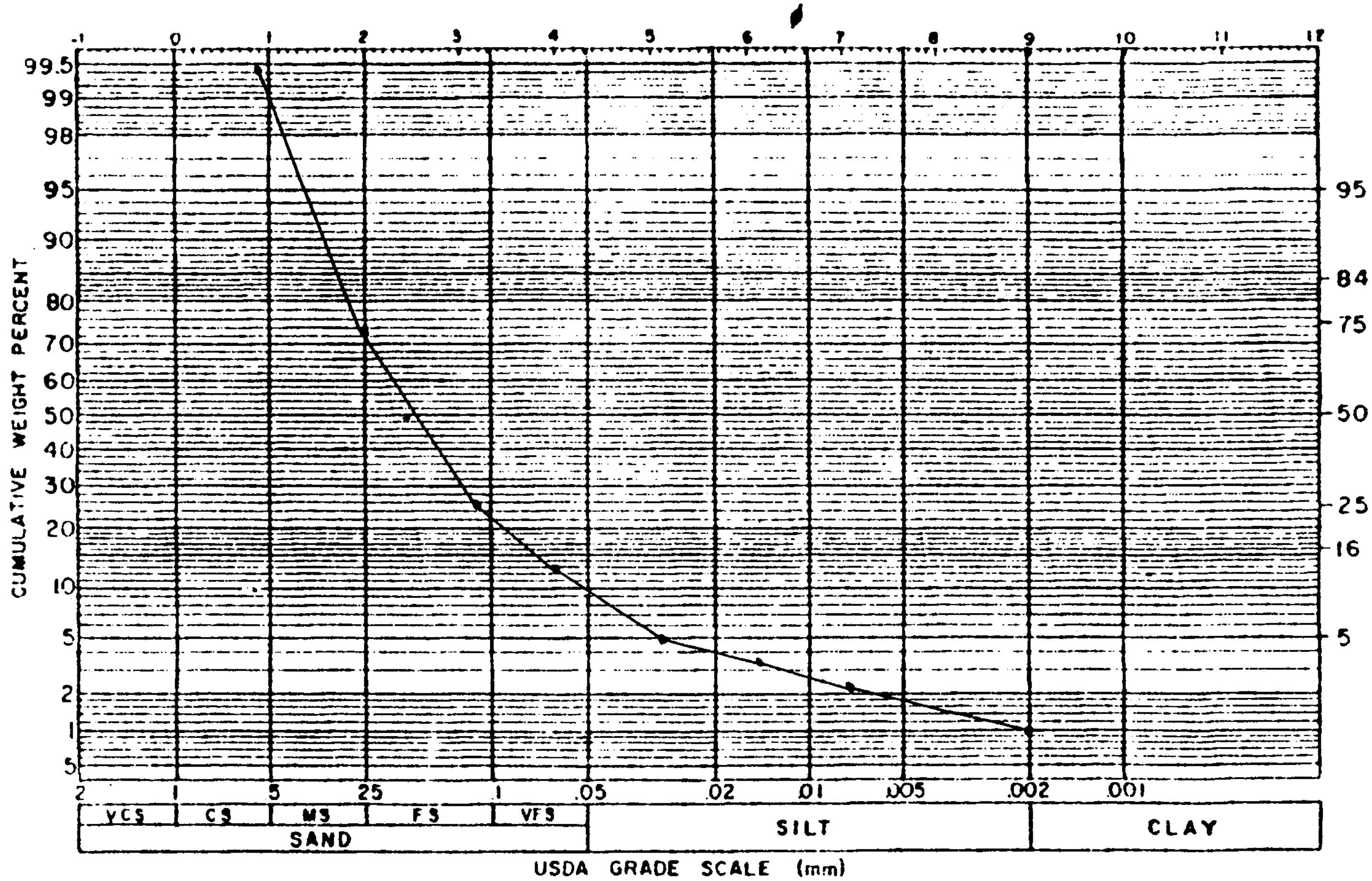
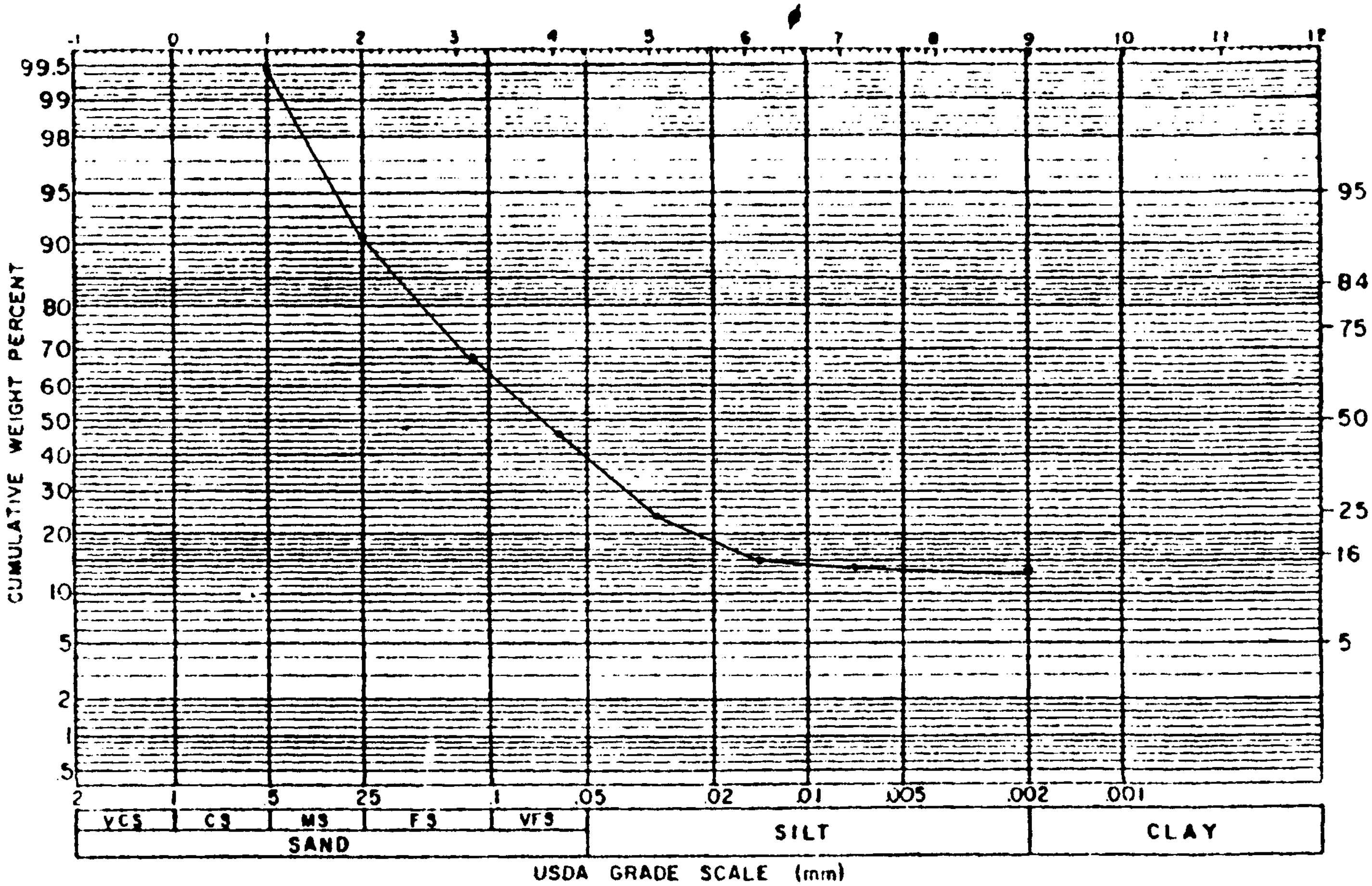


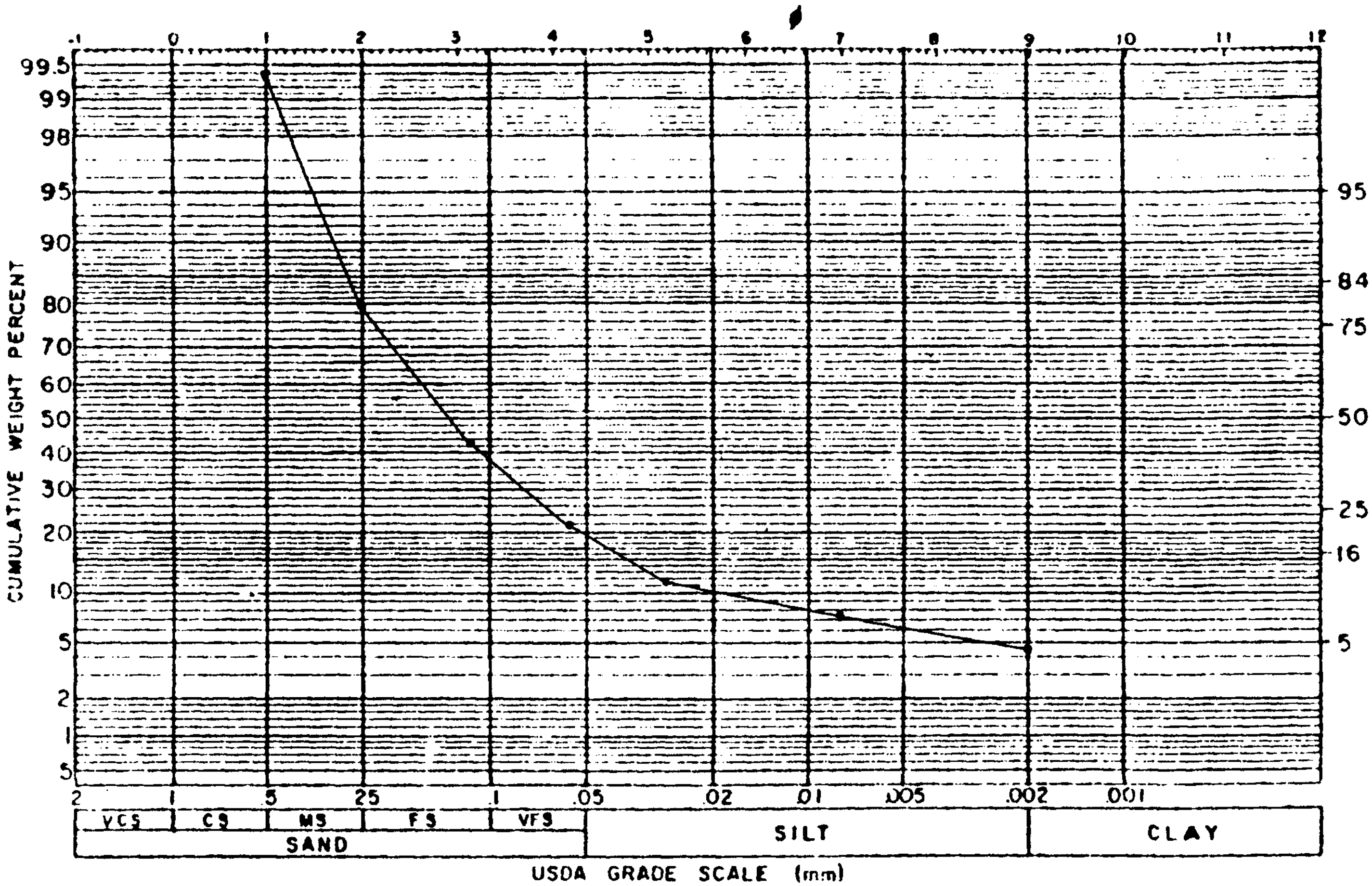
Sample No 14E

PARTICLE SIZE DISTRIBUTION DIAGRAM

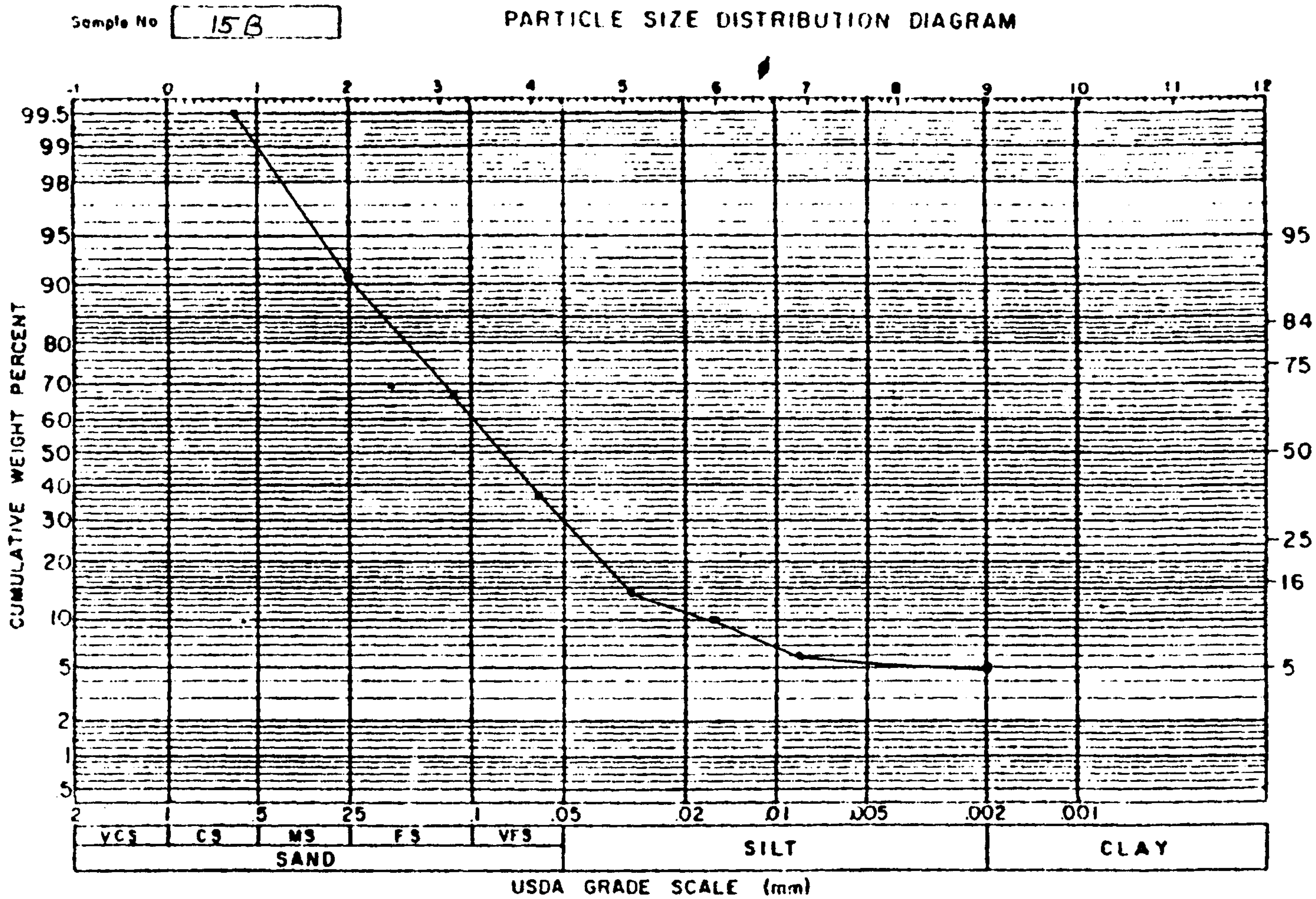


Sample No 15A

PARTICLE SIZE DISTRIBUTION DIAGRAM

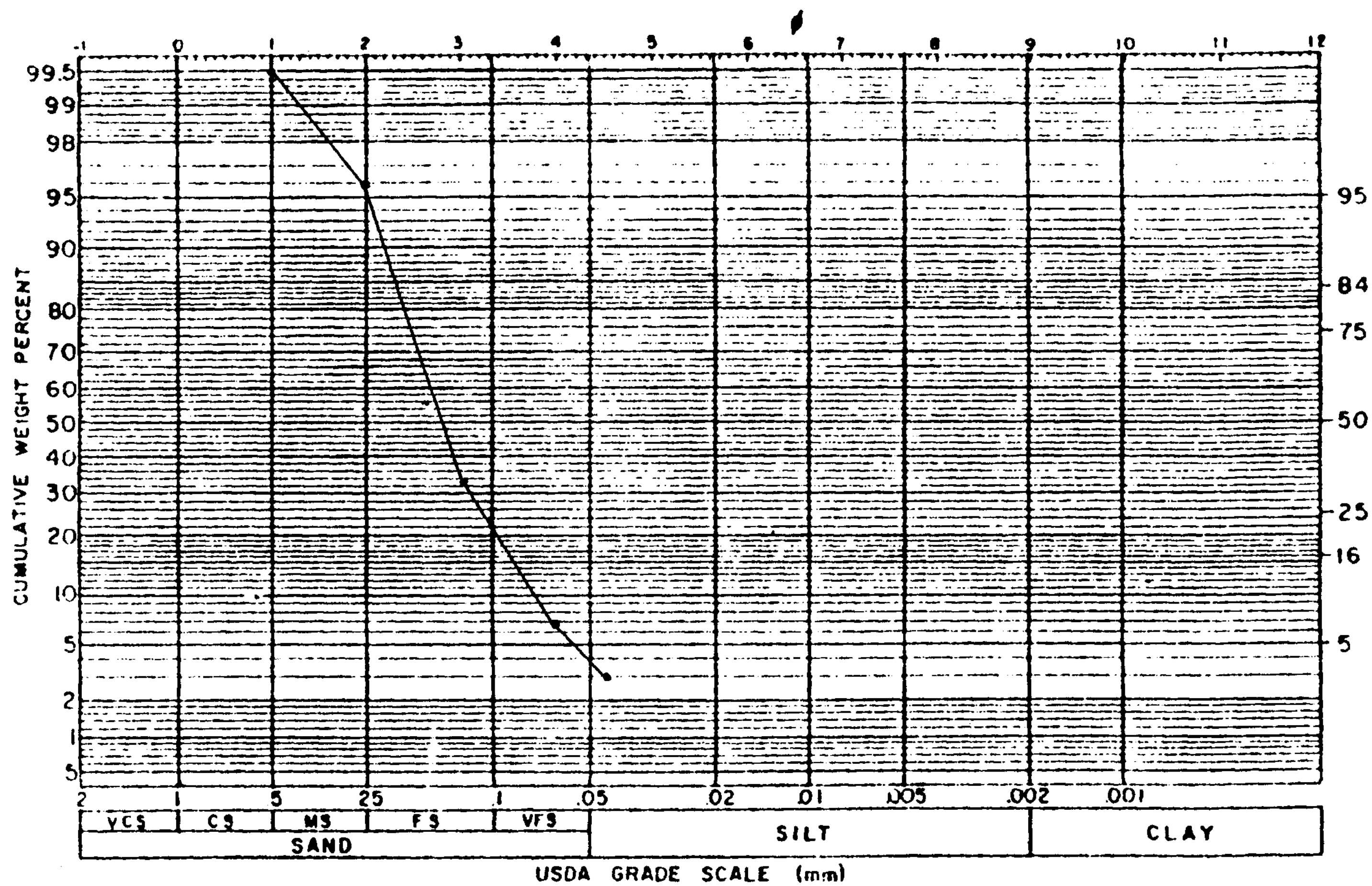


Sample No 15B



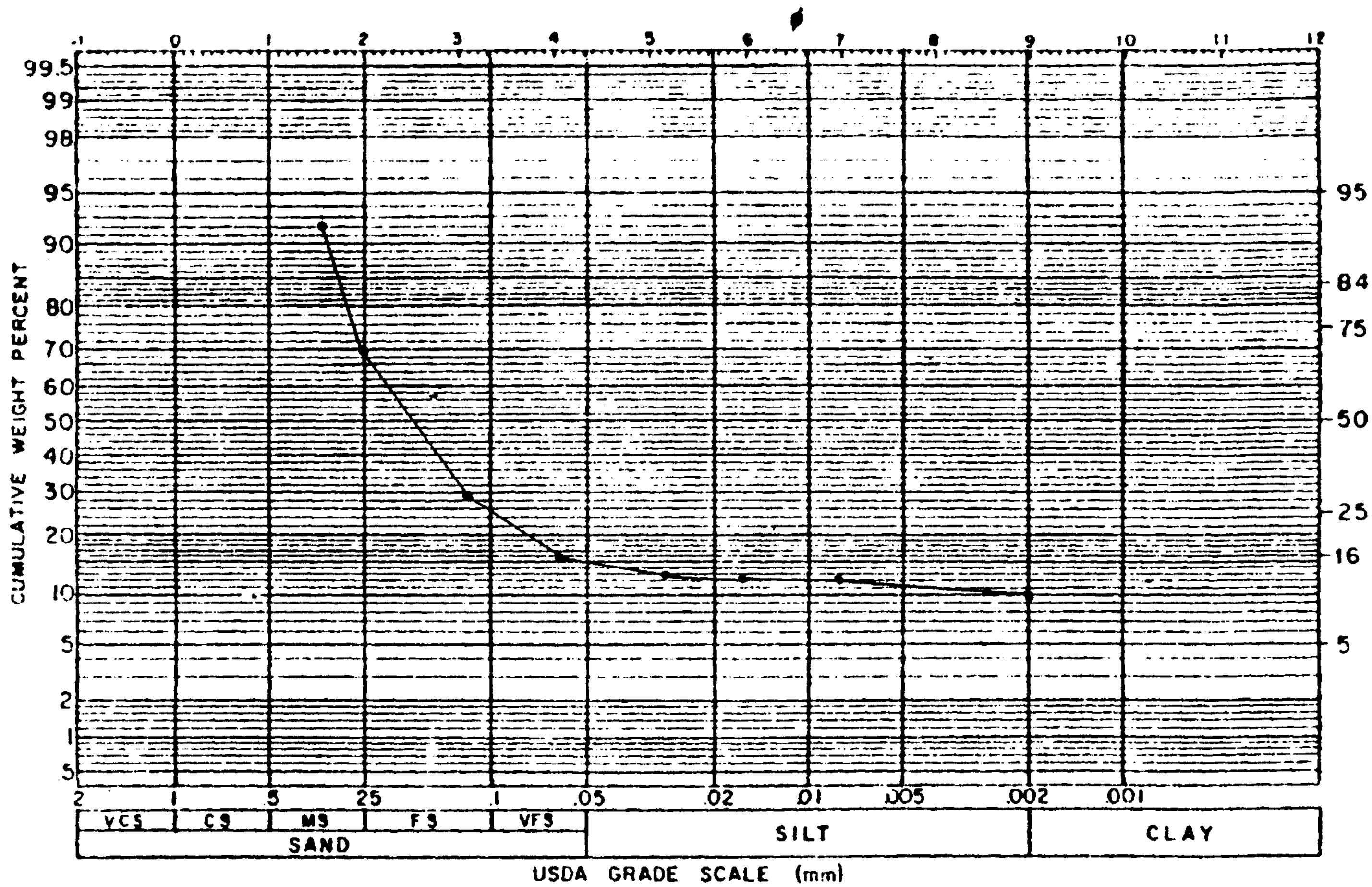
Sample No 178

PARTICLE SIZE DISTRIBUTION DIAGRAM



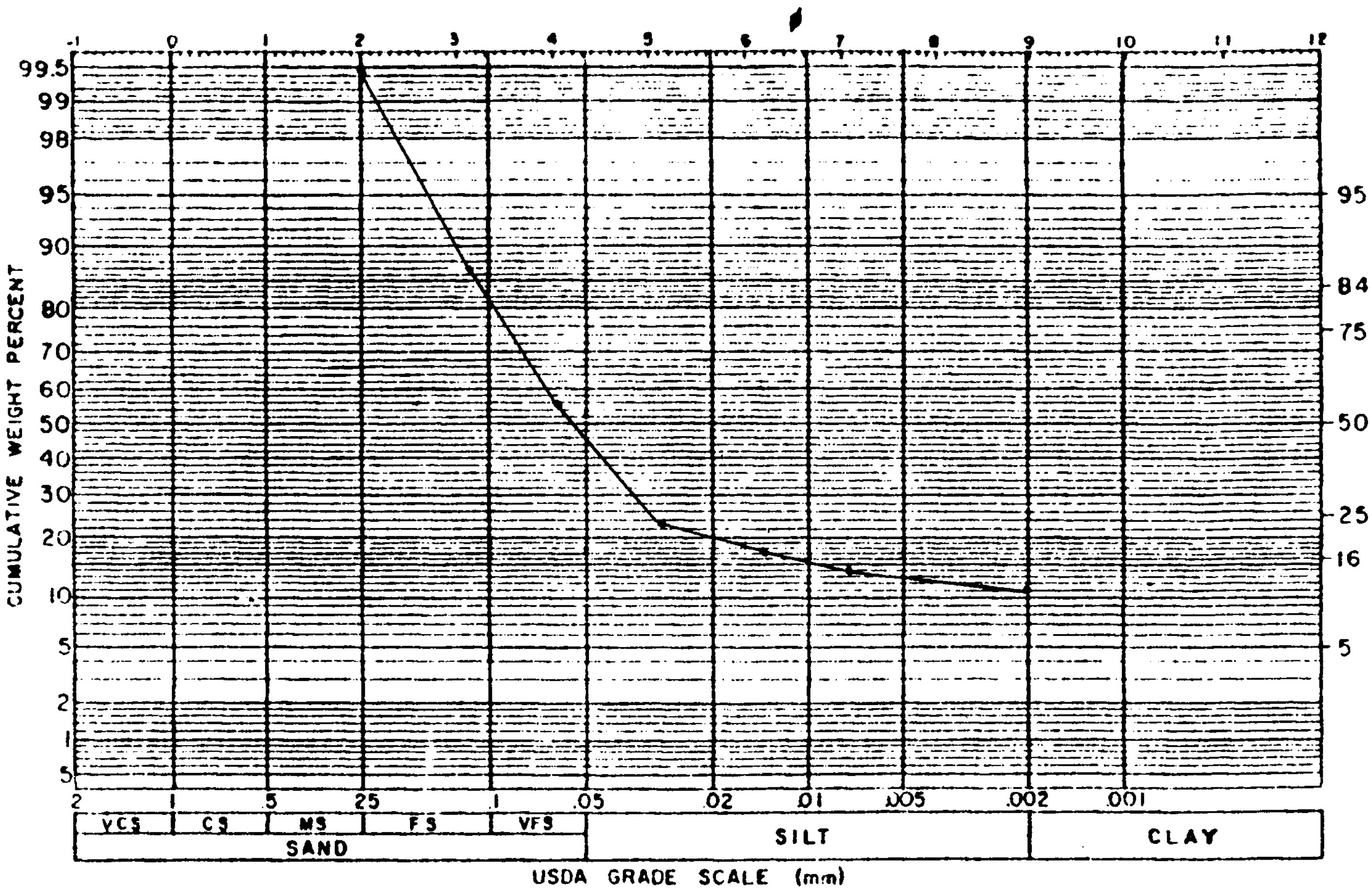
Sample No 17E

PARTICLE SIZE DISTRIBUTION DIAGRAM



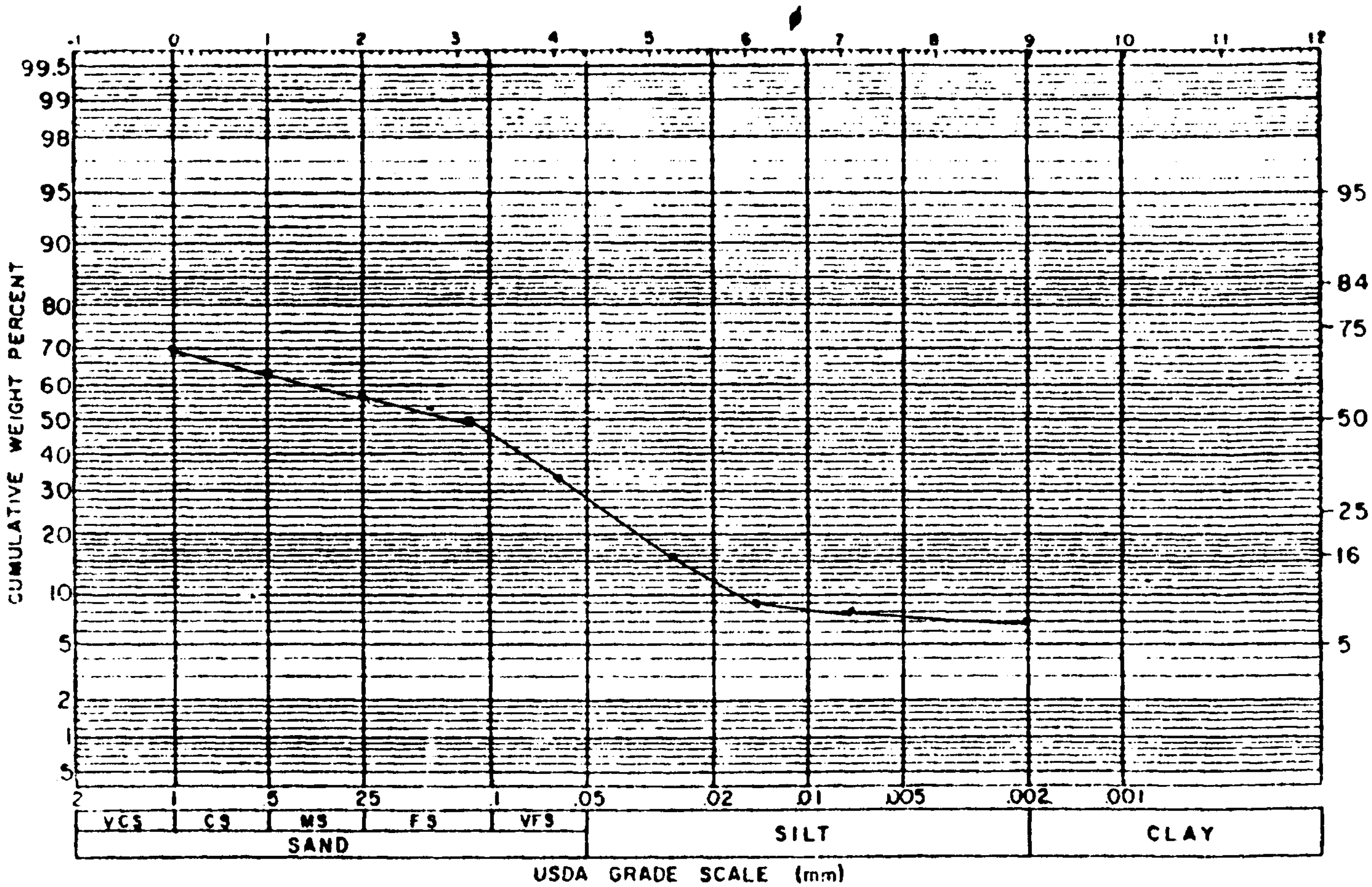
Sample No 151C

PARTICLE SIZE DISTRIBUTION DIAGRAM



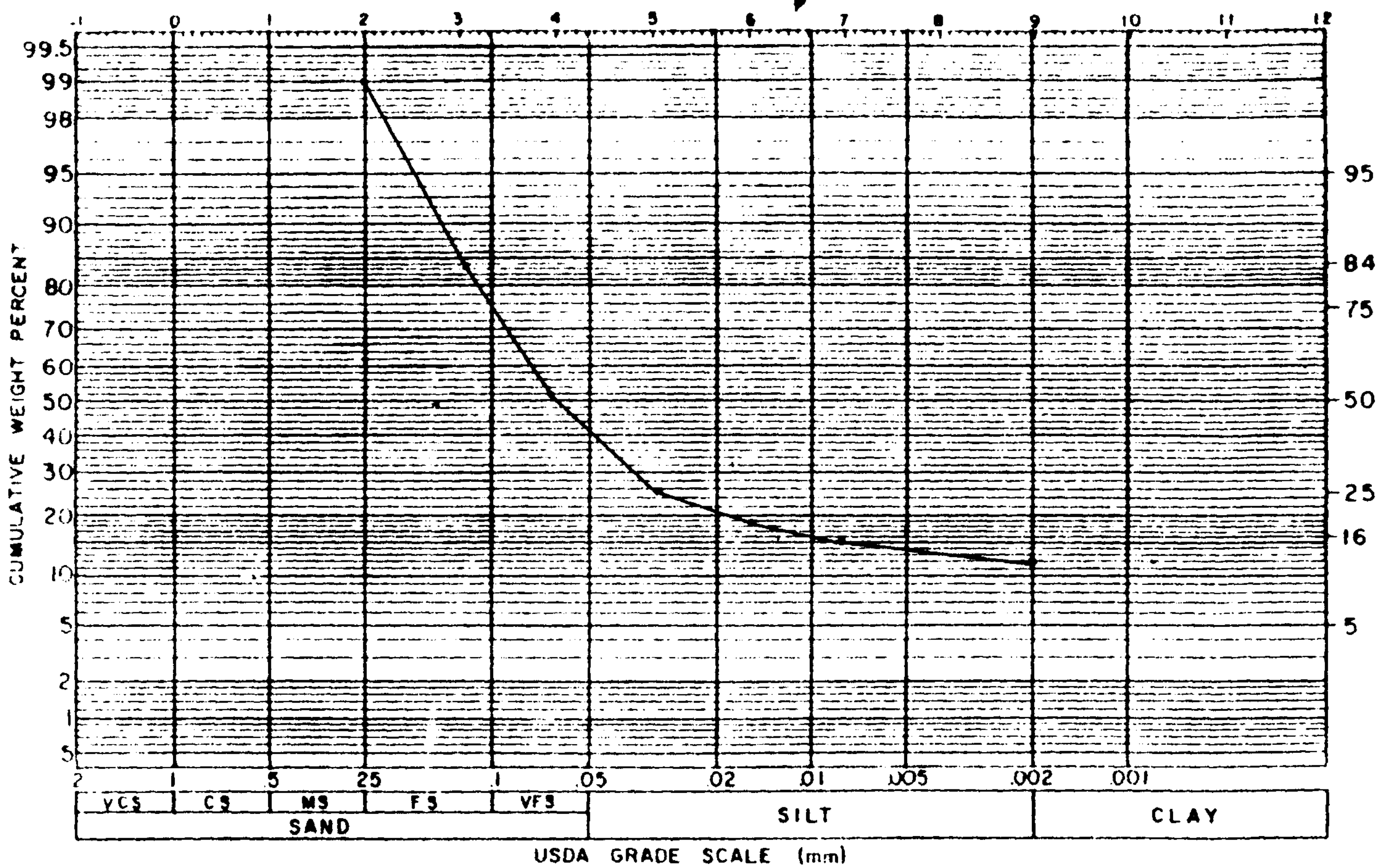
Sample No 151D

PARTICLE SIZE DISTRIBUTION DIAGRAM



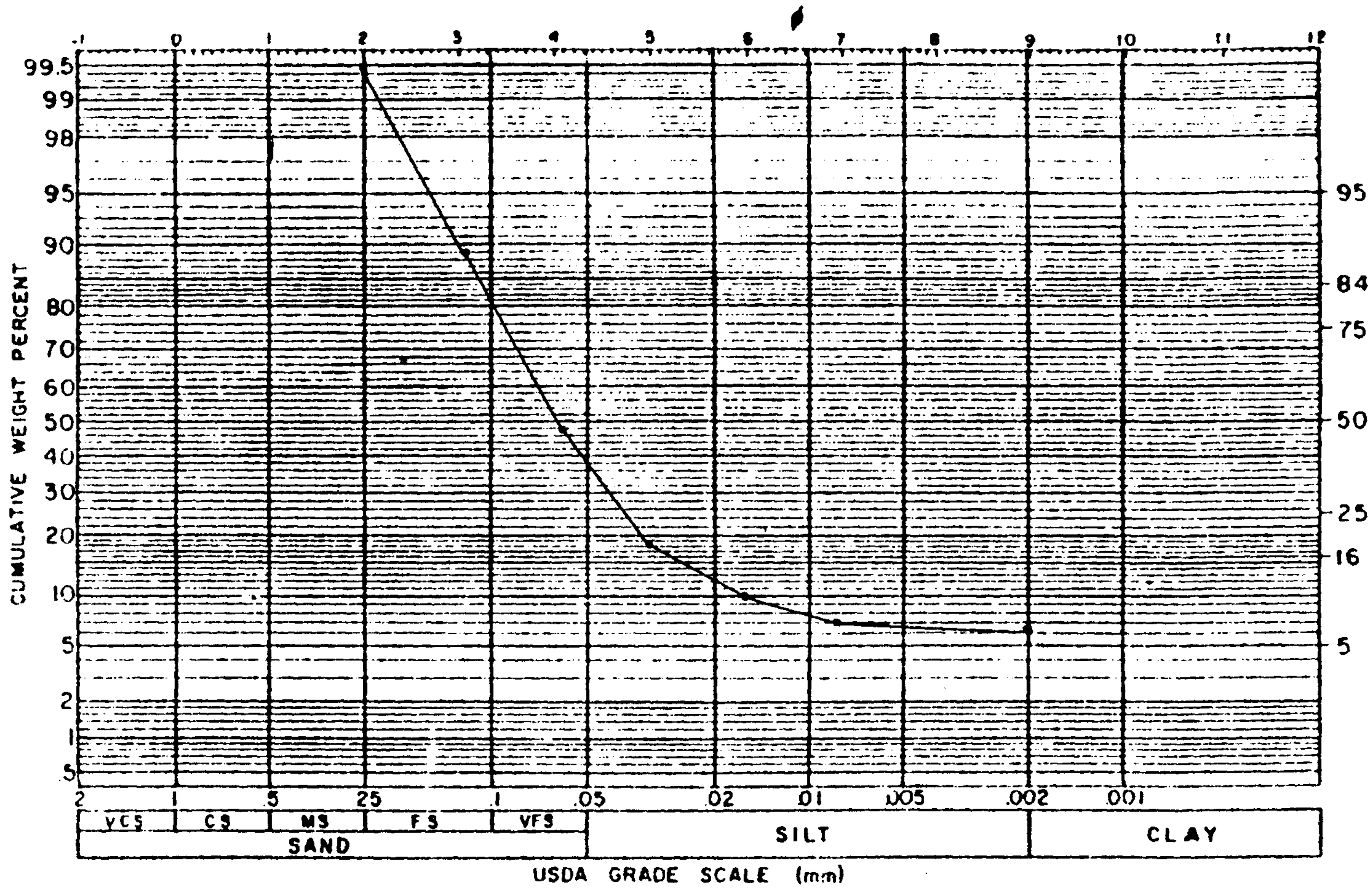
Sample No 151F

PARTICLE SIZE DISTRIBUTION DIAGRAM



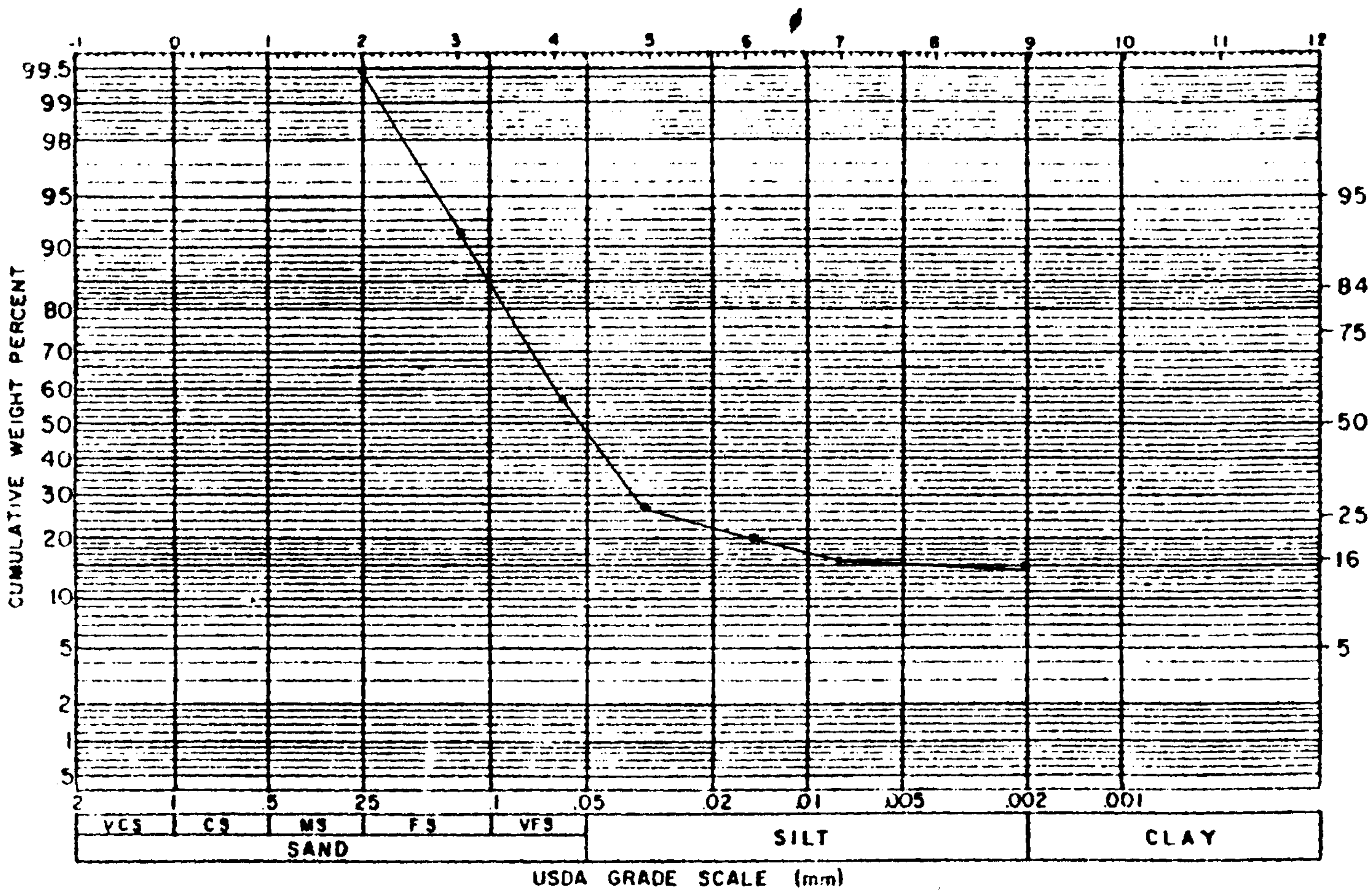
Sample No 154A

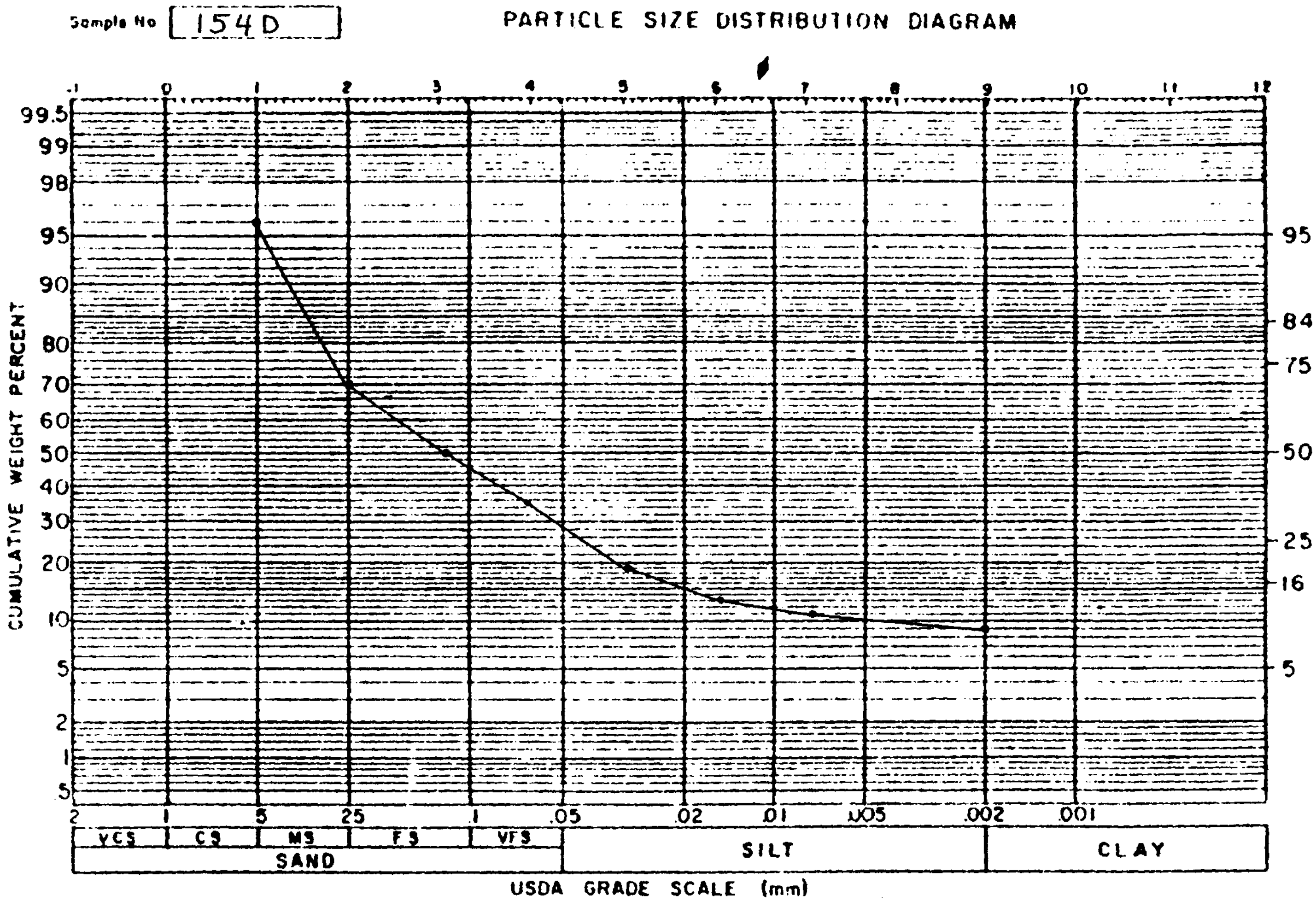
PARTICLE SIZE DISTRIBUTION DIAGRAM



Sample No 154 B

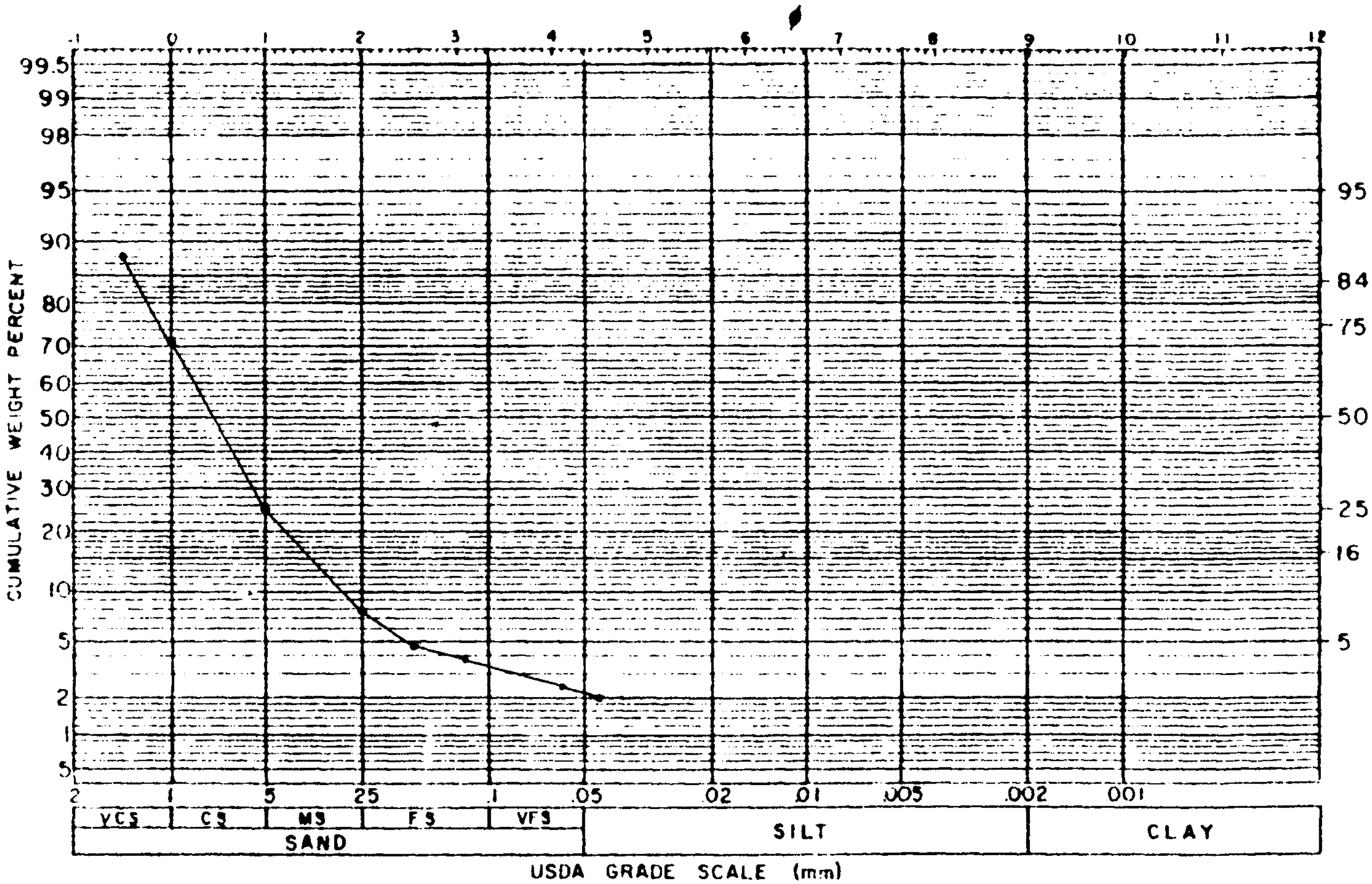
PARTICLE SIZE DISTRIBUTION DIAGRAM




Sample No 154D
PARTICLE SIZE DISTRIBUTION DIAGRAM
ϕ
-1 0 1 2 3 4 5 6 7 8 9 10 11 12
99.5 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5
CUMULATIVE WEIGHT PERCENT
95 84 75 50 25 16 5
2 1 .5 .25 .1 .05 .02 .01 .005 .002 .001
VCS CS MS FS VFS
SAND
SILT
CLAY
USDA GRADE SCALE (mm)

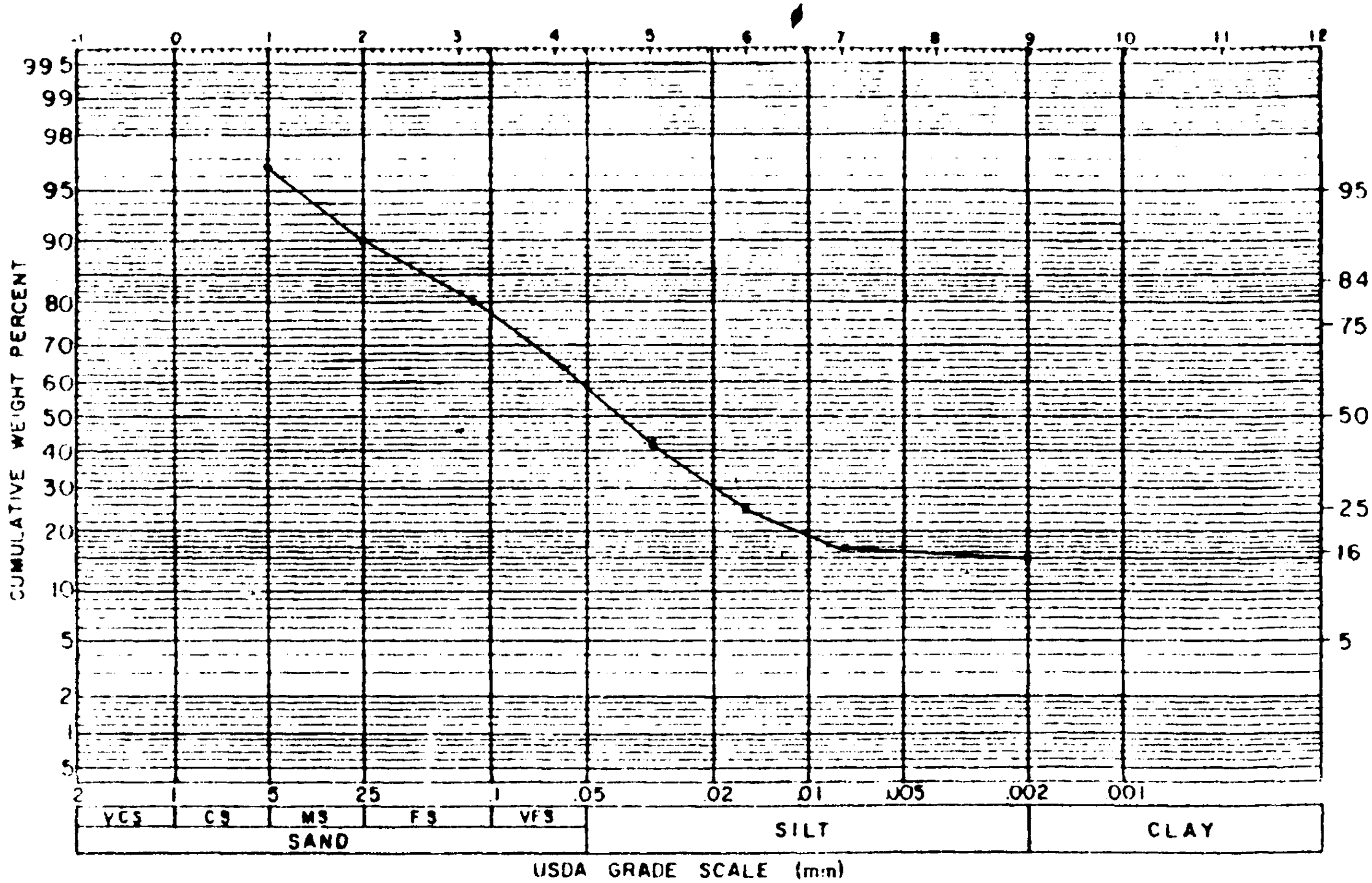
Sample No 155 B

PARTICLE SIZE DISTRIBUTION DIAGRAM



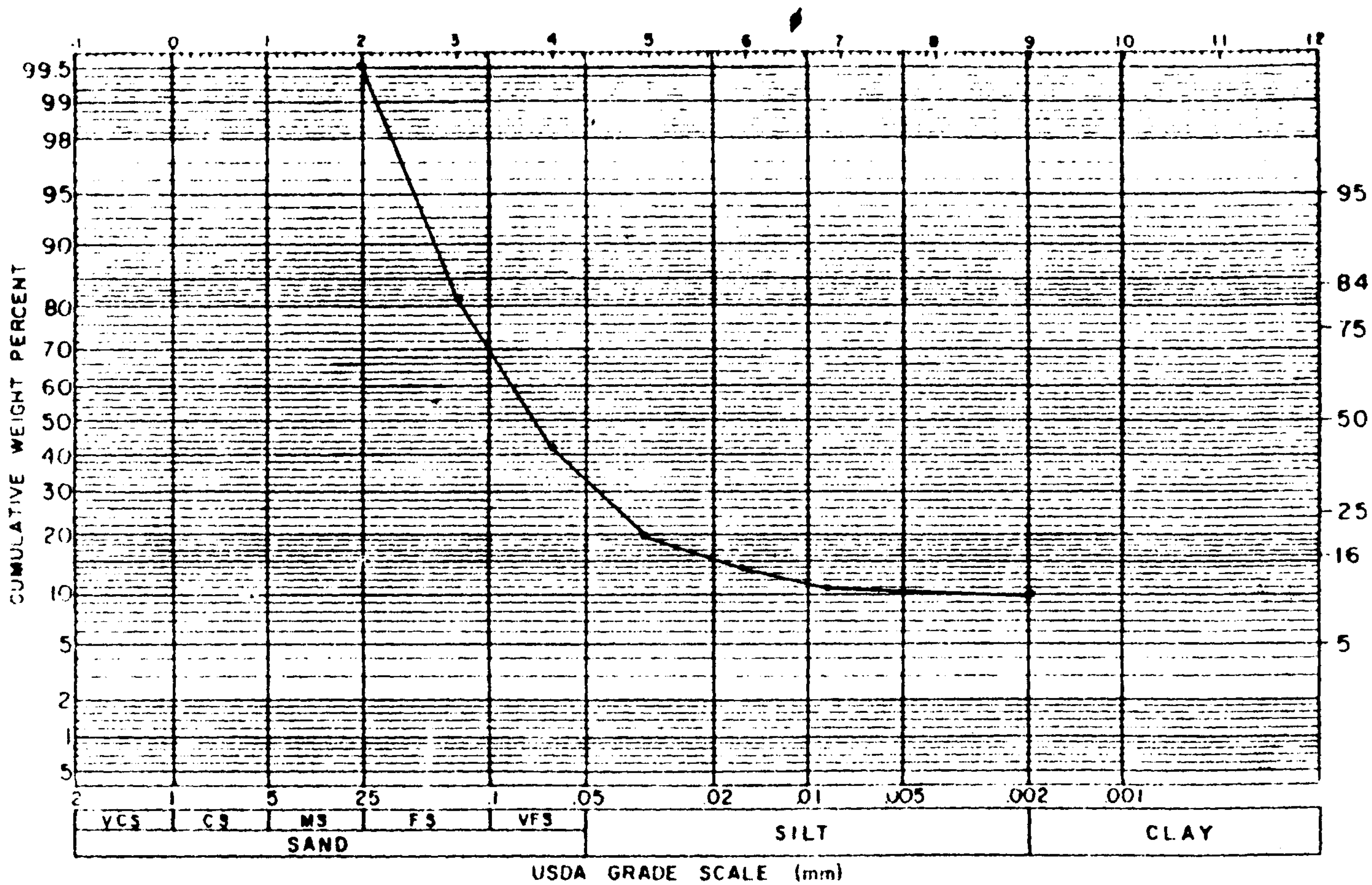
Sample No 155-C

PARTICLE SIZE DISTRIBUTION DIAGRAM



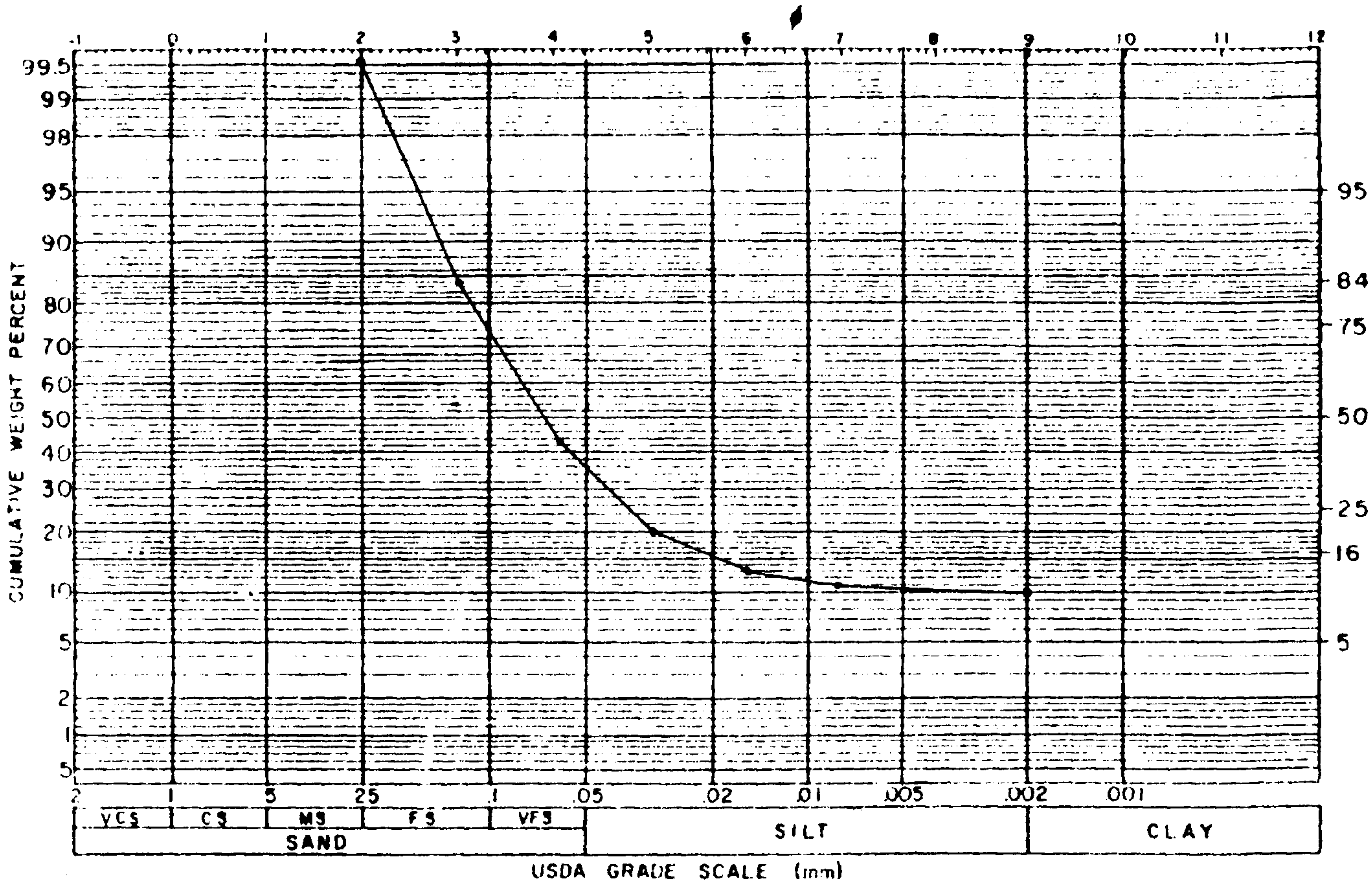
Sample No 155D

PARTICLE SIZE DISTRIBUTION DIAGRAM



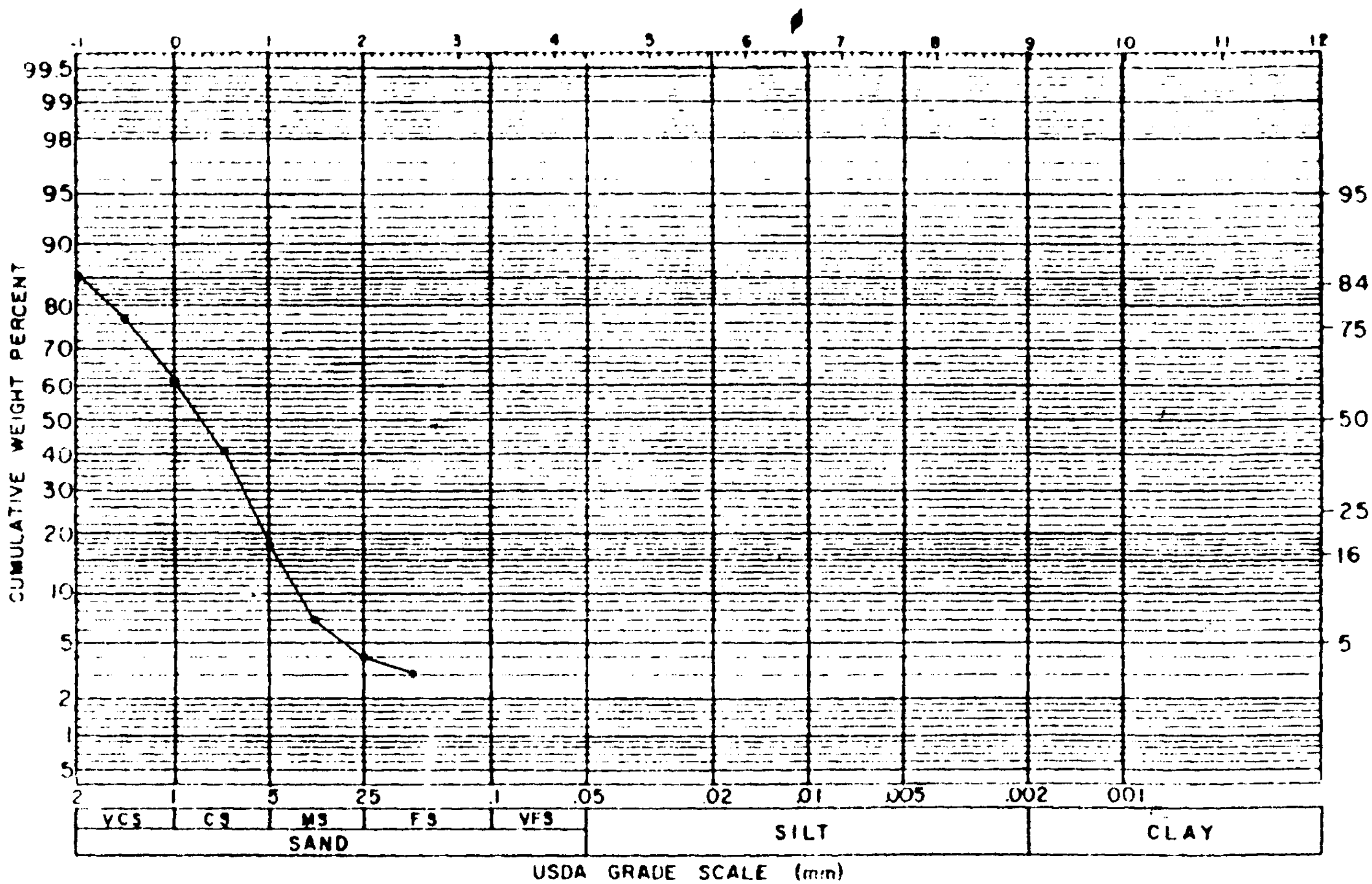
Sample No 155E

PARTICLE SIZE DISTRIBUTION DIAGRAM



Sample No. 158 A

PARTICLE SIZE DISTRIBUTION DIAGRAM



Sample No 158E

PARTICLE SIZE DISTRIBUTION DIAGRAM