Geology

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Progress Report

MISSOURI RIVER STUDIES:
ALLUVIAL MORPHOLOGY AND ENGINEERING SOIL CLASSIFICATION

by

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EXPERIMENT
STATION

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INTRODUCTION

The greater part of the state of Iowa is covered by a surficial blanket of geologically young glacial drift and loess. Consolidated materials suitable for use as coarse aggregate for road building purposes are not, therefore, easily obtainable.

For several years the Iowa Engineering Experiment Station has conducted research aimed at developing ways of stabilizing the surficial blanket materials and making suitable low-cost roads from them. The glacial drift and loess deposits were investigated first because of their greater aerial extent. Preliminary stages of this investigation have been completed for most areas of the state, and this investigation has been directed toward the materials of fluvial origin underlying the flood plains of the rivers of Iowa.

The present study differs from previous studies in many aspects. The physical properties to be determined remain the same; but methods of classifying, mapping and sampling alluvial deposits had to be developed. Unlike glacial drift or loess deposits which may vary little or predictably both with depth or horizontally, deposits produced by fluviatile action are complexly interwoven and extremely variable both horizontally and vertically, especially in the upper few tens of feet, Another contrast between this and previous studies is the nature and rapidity of transformations which may act to fundamentally change an alluvial deposit. A stream such as the Missouri River is a dynamic agent and is constantly cutting on the concave banks of bends and scouring its channel bed while actively depositing on convex banks and during floods.

The primary purposes of this investigation are:

1) To delineate flood plain deposits with different geologic and engineering properties.

2) To provide basic data necessary for any attempt at stabilizing flood plain deposits.

Tha alluvial valley of the Missouri River adjacent to Iowa was chosen as the logical place to begin this study. The river forms the western boundary of the state for an airline distance of approximately 139 miles; and the flood plain varies from a maximum width of approximately 18 miles (Plates 2 and 3, Sheets 75 and 75L) to approximately 4 miles near Crescent, Iowa (Plate 8, Sheet 66). The area studied includes parts of Woodbury, Monona, Harrison, Pottawattamie, Mills, and Fremont counties in Iowa and parts of Dakota, Thurston, Burt, Washington, Douglas, Sarpy, Cass and Otoe counties in Nebraska. Plate 1 is an index map of the area under consideration.

LITERATURE REVIEW

Streams

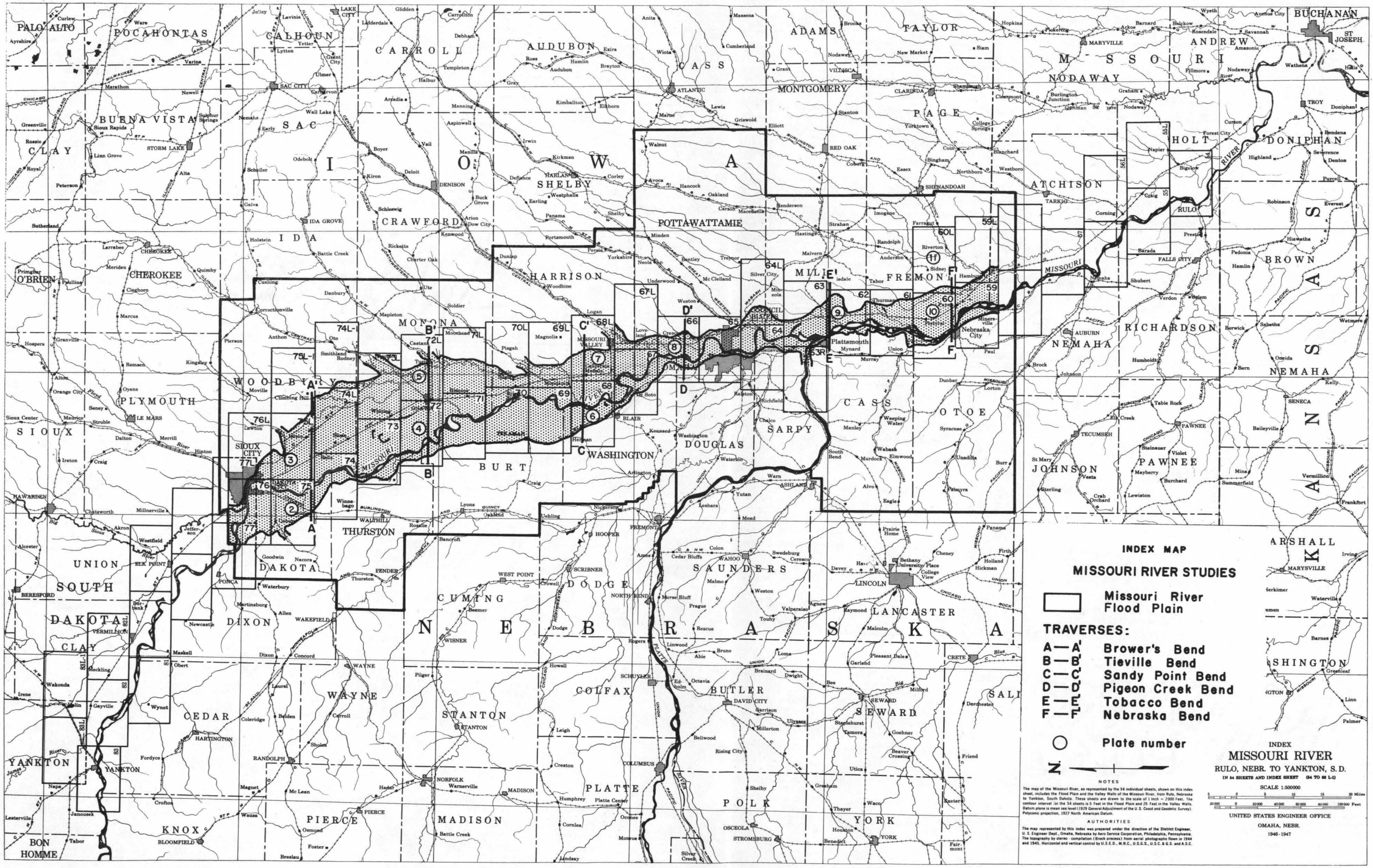
During the past thirty years many major revisions have been made in what had been considered substantiated ideas of stream processes, landform development and sedimentation. Only in recent years, however, have ideas been advanced to explain the origin and development of flood plains and various other alluvial valley features. Those publications on the phases of stream action necessary for a better understanding of the nature and processes of stream erosion and deposition will be discussed. For basic background on stream activity, the interested reader is referred to various papers by Gilbert (14), Hjulstrom (16) and Rubey (24).

During the latter half of the 19th Century and early 20th Century, an American School of Geomorphology evolved and developed many of the early concepts of stream action which have remained little changed until the present time.

The first of these concepts was proposed by Powell (23) in 1875 and augmented by Dutton (8) in 1882. Powell introduced the idea of a limiting level of land reduction which he called "base level", defined as being a level below which lands cannot be eroded by subaerial processes. Powell's original statement is not clear as to whether he envisioned two or three types of base level. He defined sea level as the grand or ultimate level of land reduction but considered also "for local and temporary purposes, other base levels of erosion which are the levels of the beds of the principal streams which carry away the products of erosion". Under this concept, the level to which the Missouri River could erode is the level of the Mississippi River at the point where the Missouri enters the Mississippi. The Mississippi is, in turn, controlled by the level of the Gulf of Mexico. Local or temporary base levels could exist on both streams where they cross such features as hard-rock barriers or enter lakes.

The second fundamental concept to come from this early American School of Geomorphology was the concept of the graded stream. Davis (7), in 1894, building on the ideas of Gilbert (13), suggested that "a stream in the condition of balance between degrading and aggrading might be called a graded stream". Kesseli (17) in 1941, questioned the validity

Plate 1. Index map Missouri River Valley adjacent to Iowa.


INDEX MAP
MISSOURI RIVER STUDIES
Missouri River Flood Plain
TRAVERSES:
A—A' Brower's Bend
B—B' Tieville Bend
C—C' Sandy Point Bend
D—D' Pigeon Creek Bend
E—E' Tobacco Bend
F—F' Nebraska Bend
Plate number
N
NOTES
The map of the Missouri River, as represented by the 54 individual sheets, shown on this index sheet, includes the Flood Plain and the Valley Walls of the Missouri River, from Rulo, Nebraska to Yankton, South Dakota. These sheets are drawn to the scale of 1 Inch = 2000 Feet. The contour interval for the 54 sheets is 5 Feet in the Flood Plain and 25 Feet in the Valley Walls. Datum plane is mean sea level (1929 General Adjustment of the U.S. Coast and Geodetic Survey). Polyconic projection, 1927 North American Datum.
AUTHORITIES
The map represented by this index was prepared under the direction of the District Engineer, U. S. Engineer Dept., Omaha, Nebraska by Aero Service Corporation, Philadelphia, Pennsylvania. The topography by stereo - compilation (Brock process) from aerial photographs flown in 1944 and 1945. Horizontal and vertical control by U.S.E.D., M.R.C., U.S.G.S., U.S.C. & G.S. and A.S.C.
INDEX
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S.D.
IN 54 SHEETS AND INDEX SHEET
SCALE 1:500000
Miles
Feet
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
IOWA
NEBRASKA
MISSOURI
KANSAS
SOUTH DAKOTA

and usefulness of the concept of grade and suggested that it should mean only a stream characterized by an absence of rapids and waterfalls. Mackin (22), in 1948, restated and clarified the concept in the following form:

> A graded stream is one in which, over a period of years, slope is delicately adjusted to provide, with available discharge and with 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 of the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change.

Straub (31), in 1935, discussing the influence of bed load of tributary streams upon the regimen of the Missouri River, noted the change in slope of the Missouri caused by the entrance of the Platte River with its heavy sand and gravel bed load. Whipple (34), in 1942, calculated the mean low water slope of the Missouri for a 31 mile segment above the mouth of the Platte River and compared this with the mean slope of a 44 mile segment below the mouth of the Platte. He noted an increase of .5 foot per mile in the lower segment. Mackin (22) ascribes this type of change to the ability of a graded stream to accomodate itself to the transportation of increased load supplied at any point, usually by an increase in slope. This increase in slope is not only necessary in order to transport the load supplied but also to compensate for the loss of efficiency to transport due to the change in the regimen which the Missouri undergoes below the mouth of the Platte.

In 1899, Davis (5) introduced the concept of the "geographical cycle" in discussing the evolution of land forms. Lobeck (21) later discussed this same cyclic sequence under the more appropriate heading of the "geomorphic cycle".

Davis (6), in 1909, published a series of essays in which he traced the evolution of a landscape through three stages which he termed "youth, maturity and old age". During each of these stages, stream valleys and streams themselves have particular features which are indicative of the progress in regional landscape evolution. Davis' work led to a systematic classification of landscapes and to the development of a genetic method of land form description.

Alluvial Morphology

Alluvial land form origin and description, however, was largely neglected in these early papers. The origin of broad flats of very low relief (flood plains) extending sometimes many miles from the river and bounded by valley escarpments was formerly attributed by Gilbert (13) and Davis (6) to lateral corrasion during maturity and old age when the stream no longer possessed the energy to cut downward. Fenneman (9) considered the alluvium under flood plains to represent only a thin veneer resting on a laterally planed bed-rock surface.

During the late 1930's and early 1940's the first concentrated attempt to describe and classify alluvial land forms was initiated with the investigation of the alluvial valley of the lower Mississippi River. Many of the techniques and concepts developed in that investigation were adopted or used with little modification during the present study.

In 1938, Fisk (12), from detailed borings in the alluvial valley of the lower Mississippi, found that the valley fill was many times deeper than the present maximum depth of scour. He also found that the bedrock surface beneath the alluvium, far from being level, exhibited considerable topographic complexity. Fisk attributed the uneven bedrock topography to a preceding stage of slow valley cutting during a period of lower sea level accompanying glacial advance. This was followed by relatively rapid alluviation during deglaciation and rising sea level until grade was reached and the modern flood plain surface formed. Leighton and Willman (19), however, suggest exactly the opposite sequence of events, i.e., alluviation during lowering sea level and valley cutting during rising sea level. Fisk (11), using terminology employed by Russell and Howe (28), described the process by which the deep fill of alluvium accumulated as being the result of "alluvial drowning".

Although this manner of origin for a major alluvial fill such as that of the lower Mississippi seems valid, considerable controversy exists as to the controlling force(s) of stream erosion and deposition on streams farther from the sea. Thornbury (33) suggests that the upper part of a pro-glacial stream may be subject to erosion during rising sea level accompanying glacial retreat and deposition during accumulation of glacial ice and concordant lowering of sea level.

Two classifications of alluvial deposits merit discussion. Happ _et al_. (15), in 1940, introduced a classification based on particle size and manner of origin. They recognized six types of materials which may accumulate on the flood plain of an alluvial stream. These were: 1) channel fill deposits, which are primarily bed load materials; 2) vertical accretion deposits, composed of suspended load materials; 3) flood plain splays, a term applied to materials left on the flood plain by floods; 4) deposits of lateral accretion, or materials deposited along the insides of stream bends; 5) lag deposits, or coarse materials left by sorting in the stream channel; and 6) colluvial deposits, consisting of the products of slope wash and downslope movement under the influence of gravity.

Fisk (11) subdivides the alluvial section in the lower Mississippi Valley into graveliferous deposits and nongraveliferous deposits. The graveliferous deposits are concentrated at the base of alluvial fill and progressively grade upward into finer sands, silts and clays of the nongraveliferous unit. Fisk (10), in a discussion of the upper fine-grained alluvial deposits, further subdivides this unit into those of the meander belt region and those of the backswamp or "flood basin" region. Each of these natural subdivisions can be separated from the others on the basis of geomorphic and/or sediment analysis. Those of the meander belt region are further subdivided into point bar deposits, abandoned channel fills, and natural levee deposits. These natural subdivisions form the basis of the classification adopted for use in the present study. The methods and techniques used to outline particular deposits are primarily geomorphic in nature; and their application requires the use of large scale, small contour interval, topographic maps and aerial photographs. The final verification of the exact mechanical composition of most alluvial deposits depends, however, on field sampling, the control of which should rest on prior study of topographic maps and aerial photos if the maximum desired information is to be obtained.

The correct evaluation of alluvial geomorphic features and their corresponding deposits rests on a basic understanding of stream processes. Many of the broader concepts have been introduced in the works of Fisk, previously discussed. Russell (25, 26, 28), in a series of papers dealing with alluvial morphology, discusses in some detail the various controlling forces which act to determine whether a stream meanders or braids.

In recent years, the United States Geological Survey has published a series of Professional Papers presenting analytical relationships between various controlling factors responsible for stream development. Leopold and Wolman (20), in 1957, concluded that different channel patterns observed in nature result from the adjustment of several variables toward the establishemnt of a quasi-equilibrium in the channel. Braiding was found to be one of the many channel forms adopted by streams in an attempt to reach quasi-equilibrium and does not necessarily indicate an excess of total load. They found that the mechanics which may lead to meandering operate in straight channels and that:

> There is a continuum of natural stream channels having different characteristics that are reflected in combinations of values of the hydraulic factors.

Wolman and Leopold (35), in 1957, concluded that overbank deposits are relatively insignificant in the total quantity of material underlying a flood plain. They suggest that the reasons for the relatively small quantity of overbank deposits are related to the high velocities which may occur in overbank flow and to the fact that the highest concentration of materials being carried by the stream does not necessarily correspond to the overflow stage during a particular flood.

Engineering Geology

The engineering classification of soils used in this report is the revised Public Roads System or Highway Research Board System as adopted by the American Association of State Highway Officials (1) (A.A.S.H.O Designation: M145-49). Unless otherwise indicated, the particle size classification used is that of the American Society for Testing Materials (2) (A.S.T.M. Designation: D422-54T) and the American Association of State Highway Officials (1) (A.A.S.H.O. Designation: M146-49). The grade limits used by these two classifications are sand 0.074 to 2 mm. diameter, silt 0.005 to 0.074 mm. diameter, and clay less than 0.005 mm diameter.

Additional information as to the engineering classification of alluvial soils may be found in the Soil Survey of Monona County, Iowa (29).

GEOMORPHOLOGY

General Description of the Missouri River Basin

The Missouri River Basin comprises an area of approximately 529,000 square miles (31). Situated between the meridians 90°W and 114°W and the parallels 37°N and 50°N, the basin is a diamond or lens-shaped area having a length of approximately 1400 miles in a northwesterly direction and a breadth of about 680 miles. Figure 1 is an index map of the Missouri River Basin.

The basin is bounded on the west by the Continental Divide, on the north by a Canadian divide separating it from the Hudson Bay drainage, on the east by a low divide separating Missouri and Mississippi drainage, and on the south by the Ozark Uplift and an east-west ridge across central Kansas.

The upper Missouri River Basin lies in the Rocky Mountain System physiographic division whereas the middle and lower portions of the basin are in the Interior Plains and Interior Highlands divisions. The segment of the Missouri River Basin which is of importance to the present study lies entirely within the Central Lowland province of the Interior Lowlands division.

The principal and longest tributaries of the Missouri enter chiefly from the right. Streams entering from the left are relatively short and drain only about one-quarter of the total drainage area of the Basin. Topographically, the Missouri River Basin is an asymmetrical trough with the west limb extending much farther away from the main stem and rising to a much higher elevation than the east limb.

Missouri River

The Missouri River is the longest river in the United States and the principal stream of the Missouri River Basin. Beginning at the junction of the Jefferson, Madison and Gallatin Rivers at Three Forks, Montana, the Missouri flows 2,546 miles (31) to its confluence with the Mississippi near St. Louis, Missouri. From the head of the river to the mouth, the Missouri River drops 3,627 feet, giving it an unusually high average gradient for so large a stream. Table 1 (modified from

Figure 1. Index map, Missouri River Basin.

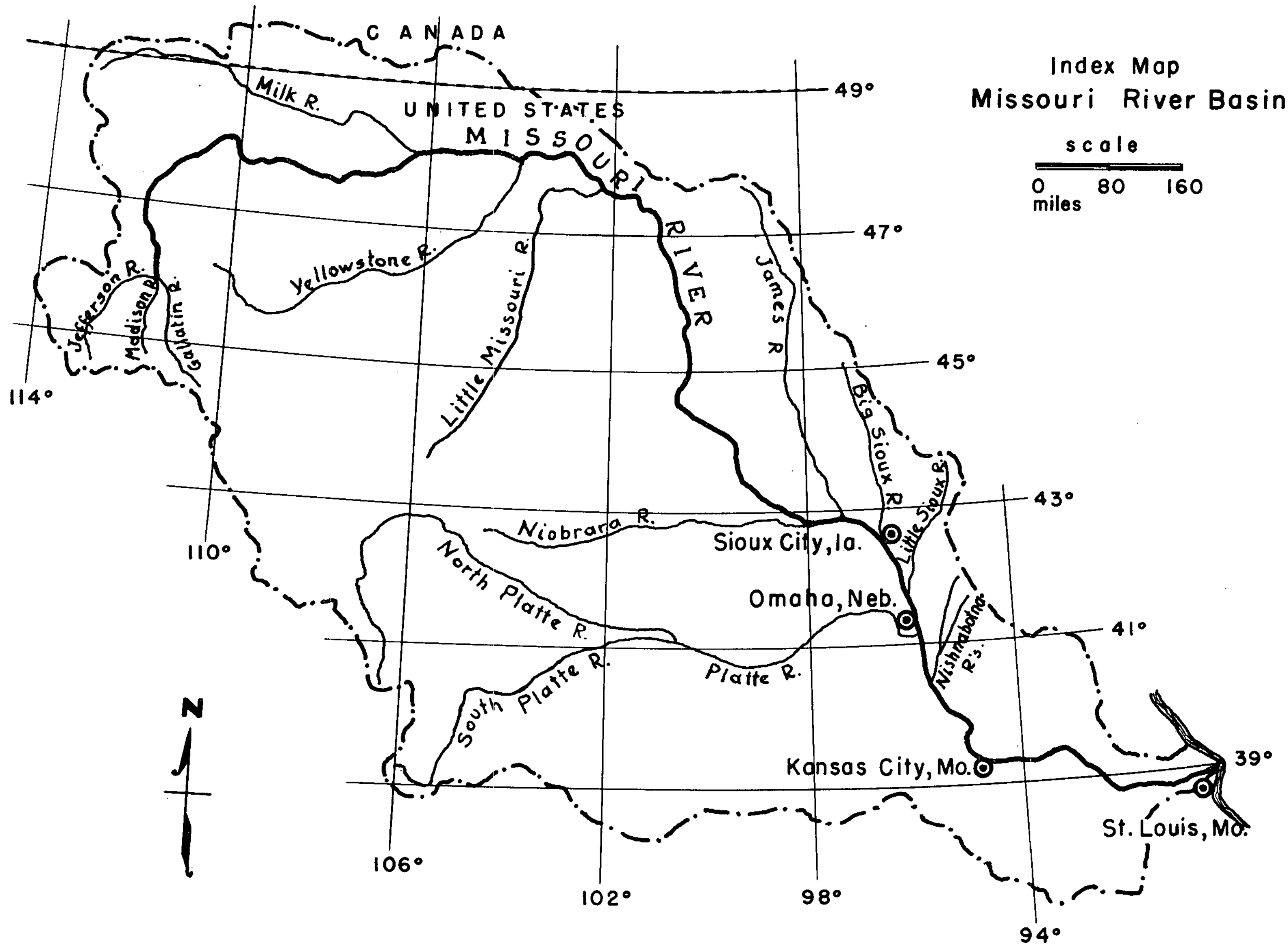

Index Map
Missouri River Basin
scale
0 80 160
miles
CANADA
UNITED STATES
MISSOURI RIVER
Milk R.
Yellowstone R.
Little Missouri R.
James R.
Big Sioux R.
Little Sioux R.
Jefferson R.
Madison R.
Gallatin R.
Niobrara R.
North Platte R.
South Platte R.
Platte R.
Nishnabotna R's.
Sioux City, Ia.
Omaha, Neb.
Kansas City, Mo.
St. Louis, Mo.
49°
47°
45°
43°
41°
39°
114°
110°
106°
102°
98°
94°
N

Table 1. Missouri River low water slope data.*

1890 Miles above mouth	Locality	Elevation	Slope in feet per mile
2,546.3	Head of River	4,026.0	
			4.27
2,384.0	Head of "Long Pool"	3,333.6	
			0.44
2,333.4	Great Falls (foot of "Long Pool")	3,311.6	
2,322.0	Foot of "The Great Falls"	2,898.8	
2,314.5	Portage Coulee	2,758.8	
			4.81
2,284.8	Fort Benton, Montana	2,615.8	
			2.57
2,155.0	Foot of "Cow Island"	2,282.0	
			1.04
1,720.1	Williston, North Dakota	1,828.0	
			0.76
1,450.1	Bismarck, North Dakota	1,621.5	
			0.75
1,172.6	Bad River, Fort Pierre, S.D.	1,414.2	
			0.85
1,067.5	Chamberlain, South Dakota	1,324.5	
			0.94
938.1	Running Water, South Dakota	1,202.8	
			0.94
807.5	Sioux City, Iowa	1,000.6	
			0.80
633.6	Plattsmouth, Nebraska	941.9	
			1.23
607.7	Nebraska City, Nebraska	910.0	
			0.97
537.5	Rulo, Nebraska	841.7	
			0.83
390.7	Kansas City, Missouri	720.2	
			0.82
205.8	Boonville, Missouri	568.9	
			0.82
103.3	Hermann, Missouri	484.9	
			0.84
28.0	St. Charles, Missouri	421.9	
			0.84
0.0	Mouth of River	398.5	

*Modified from Straub (31, p. 734.)

Straub, p. 734) contains low water slope data for selected reaches from the head of the river to the mouth. The high gradient and nature of the drainage basin coupled with a relatively high velocity of flow, calculated by Suter (32) as being 2 to 3 miles per hour during low stage and 10 miles or greater during flood, allows the Missouri River to carry the tremendous load which has earned it the title "Big Muddy".

Above the Milk River (1,866 miles above the mouth), the Missouri has an average gradient of 2.6 feet per mile and is considered to be a stable nonalluviating river (31). From the Milk River and to the mouth of the Missouri, the average gradient is 0.88 feet per mile; and the Missouri assumes the characteristics of an alluvial stream. At Sioux City, Iowa, the average annual sediment load is 140,000,000 tons (4). From Sioux City to the mouth, the annual sediment load increases to about 270,000,000 tons. The average annual discharge increases from about 22 million acre feet at Sioux City to 52 million acre feet at the mouth, and the average sediment concentration in grams per liter (parts per thousand by weight) decreases from 4.7 to 3.8. Suter (32), in 1881, calculated the minimum total sediment carried in suspension past St. Charles, Missouri, during 1879 as being 5,508,229,008 cubic feet, enough to annually cover a square mile area to a depth of almost 200 feet. He concluded that the total sediment in transport would approximately double both figures.

From Sioux City to the mouth, the sediment load consists of 20 to 30 percent fine sand and 70 to 80 percent silt and clay according to the American Geophysical Union size classification (4). Of the finer fraction, 20 to 30 percent is clay sized material. The median particle diameter of the sand in transport is 0.1 millimeter, and the bulk of the total load is composed of quartz.

The Missouri River follows an alternating series of east to southeast trends along the course of its flow toward the Mississippi. The general trend of east to southeast flow is broken in the uppermost reaches of the river where the stream follows a general northward trend. Through Montana and to the margin of the mid-continent glaciated area in North Dakota, the river flows almost due east. From this point to 40 miles west of Yankton, South Dakota, the river flows southeast, paralleling the margin of the interior glaciated region. The Missouri then continues eastward to near Sioux City, Iowa. At Sioux City the Missouri again makes a near right-angle bend and flows southeastward across the dissected till plains of the Central Lowlands. From Kansas City, Missouri, the river flows almost due east to its junction with the Mississippi.

The Missouri River flows in a deep valley cut below the general level of the surrounding country. It begins in an area underlain by Miocene rocks and successively cuts through Pre-Cambrian, Cretaceous, Tertary and Cretaceous rocks to a point near Onawa, Iowa. From this point to its junction with the Mississippi, the Missouri crosses rocks of Pennsylvanian, Mississippian, and Ordovician age. Straub (31), from analysis of the stratigraphy and structure of the basin, concludes that it is generally of synclinal nature.

Glacial drift, loess, or bedrock may be found forming the valley walls along the reach of the Missouri River adjacent to Iowa. Where drift or loess forms the bluffs, the valley is conspicuously wider than where bedrock is present. In the northern part of the valley, Sargent Bluff (Plate ~~2~~ 3, Sheet 75L) is a prominent salient underlain by bedrock. From Sargent Bluff southward to Loveland, Iowa (Sheet 67L), the valley widens and glacial drift or loess forms the adjacent bluffs. The marked narrowing of the alluvial valley from Loveland to near Thurman, Iowa (Sheet 61), is accompanied by a gradual rise in bedrock from near flood plain level to a maximum of 90 feet above flood plain level (elevations determined by hand leveling and aneroid) near Plattsmouth, Nebraska (Plate 9, Sheet 62). South of Plattsmouth bedrock elevation decreases, until south of Thurman, Iowa, glacial drift or loess forms the bluffs; and the valley widens.

The width of the valley and general configuration of the valley walls are apparently controlled primarily by regional or local structural trends modified by stream activity. As a general rule, it would seem that extreme valley width is correlated with the existence of drift or loess bluffs. Whether the drift or loess deposition was controlled by structure or pre-depositional topography is not known. The general narrowness of the valley and straightness of the bluff line except for very sharp reentrants from Loveland, Iowa, to Thurman, Iowa, may be related to the reported existence of subdued structural trends of which the Thruman-Wilson anticline is an example (3).

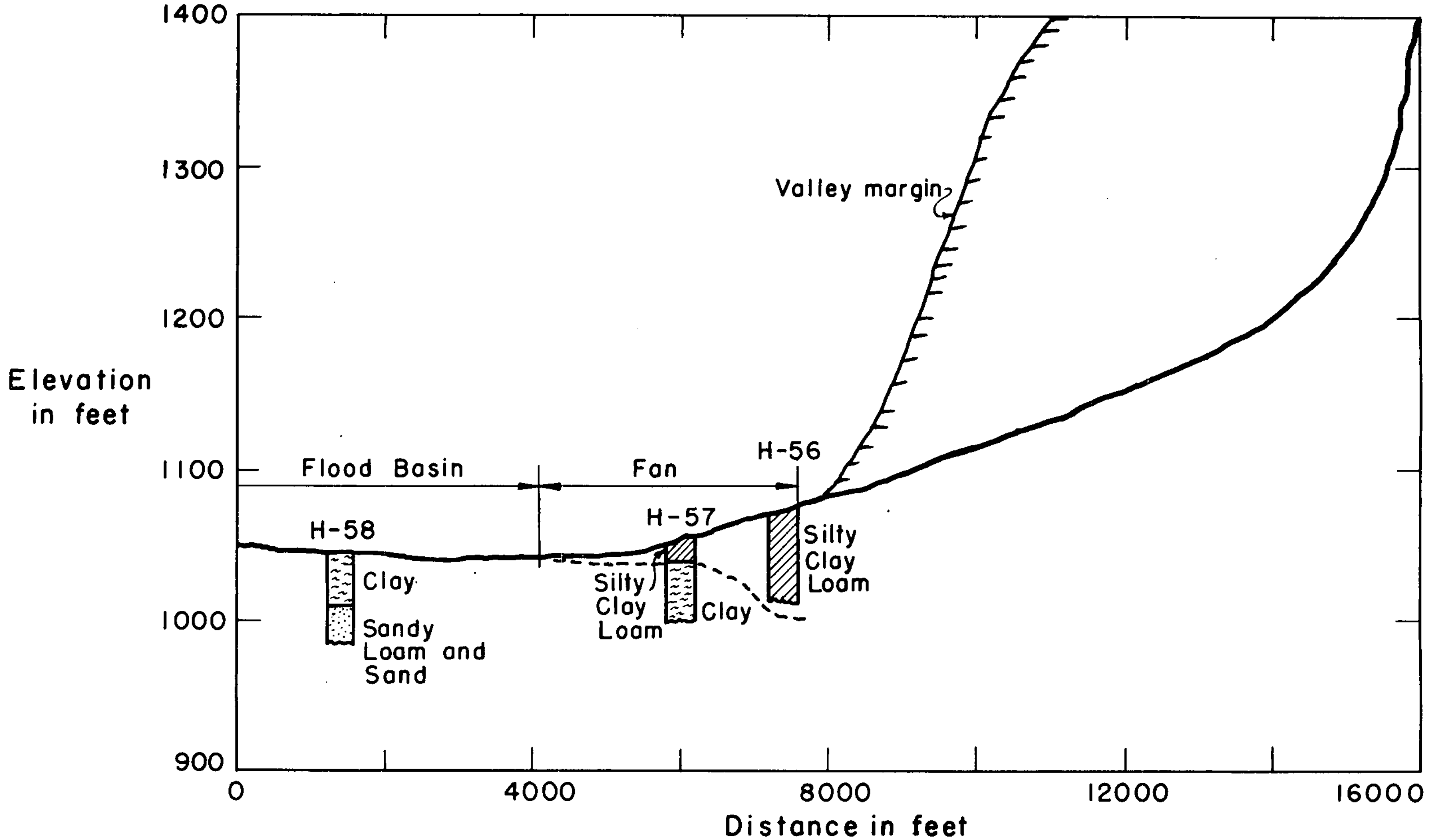
Evidence that the Missouri River modified the bluff outline can be seen on Plate 10, Sheet 60, where the present course of the river has impinged against the west bluff. Similar reentrants may be found all up and down the length of the alluvial valley. Many of these reentrants have a radius of curvature similar to that of the modern river but are many miles from it. This and the large number of faceted spurs indicates that the Missouri River has flowed, at one time or another, over the entire flood plain.

Tributary streams may also modify the bluff line by cutting reentrants on a much smaller scale. This is well illustrated on Plate 5, Sheet 72L, where both the Little Sioux and Maple Rivers have cut into the bluffs.

Another factor in modifying the bluff outline is the building of alluvial fans by the miriad of small tributaries issuing from the adjacent, badly disected, easily eroded uplands. Figure 2 is a longitudinal cross-section of the valley and fan of Arcola Creek (Plate 5, Sheet 72L). The slope of the fan was calculated to be about 70 feet per mile, and an arcuate area with a radius of approximately one-half mile is covered by fan deposit. Holes 56, 57, and 58 were bored into the fan, did not penetrate the maximum thickness of fan deposit; but in Hole 57, farther down the slope of the fan, material identified as being of flood plain origin was penetrated at the elevation of the surrounding flood plain. Hole 58 was bored off the margin of the fan and was in flood plain material.

The segment of the Missouri Valley from Yankton, South Dakota (Sheet 83), to Rulo, Nebraska (Sheet 54), includes the area studied during the present investigation. The river in this segment and between here and the mouth flows on an alluvial fill calculated by Suter to vary from 70 feet to over 100 feet thick. In no place does the river touch bedrock except where it has cut against valley walls.

Figure 2. Longitudinal cross-section of Arcola Creek fan.



1400
1300
1200
1100
1000
900
Elevation in feet
0
4000
8000
12000
16000
Distance in feet
Valley margin
Flood Basin
Fan
H-58
H-57
H-56
Clay
Sandy Loam and Sand
Silty Clay Loam
Clay
Silty Clay Loam

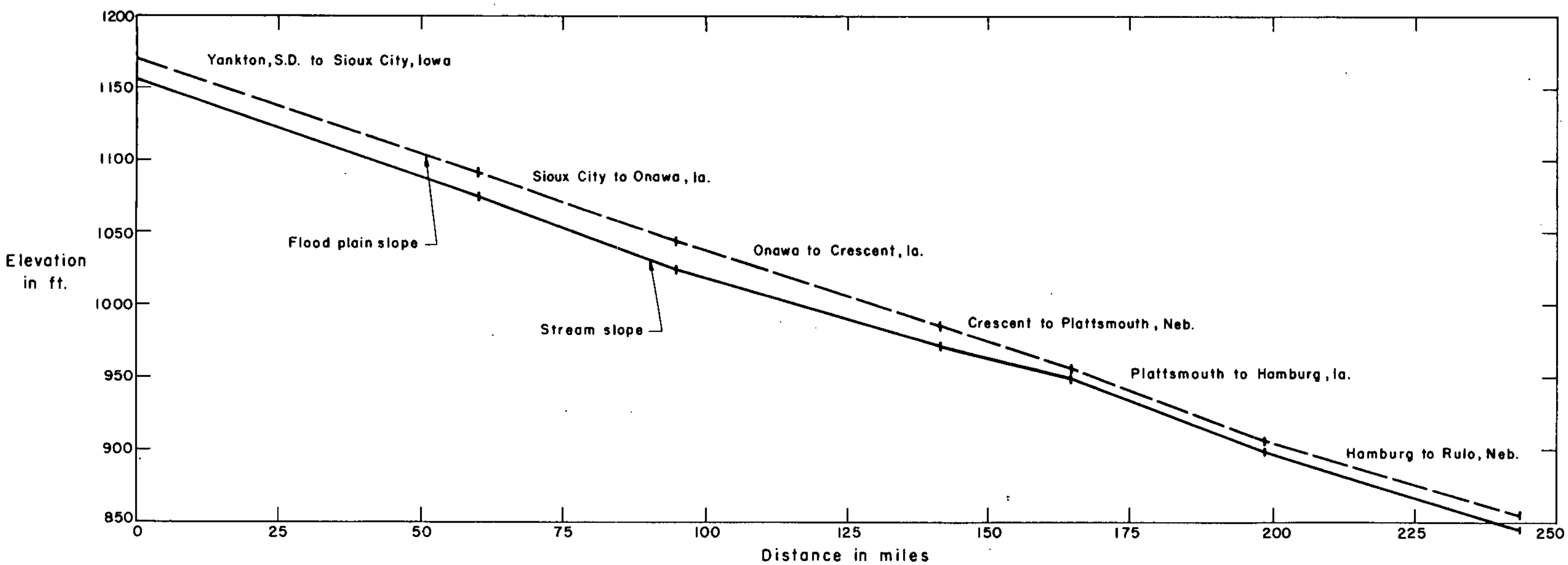
Table 2 and Figure 3 contain data on the low water slope, flood plain gradient and sinuosity ratio for seven reaches of the Missouri River between Yankton and Rulo. These data are significant in portraying the general nature the modern Missouri River and changes in it since 1890.

During this interval of time, the Missouri has decreased in length by a little over 63 miles. This has resulted from a combination of natural processes and artifical cut-offs to improve navigation. A stream may shorten its length by either a chute-type or neck-type cut-off. In the first, the stream enlarges a swale of its point bar during flood and remains in this swale during lower stages because of the gradient advantage gained. In the second or neck-type cut-off, the downstream arm of a meander loop is prevented from migrating as fast as the upstream arm, and the intervening neck becomes breached. The neck-type appears to be the more common cut-off in older river courses whereas modern cut-offs are more commonly of the chute type. Hole 10, Plate 3, Sheet 75L, is bored into the channel fill associated with a neck-type cut-off whereas Blue Lake, Plate 4, Sheet 72, is an example of the chute type cut-off.

The sinuosity of a reach is the ratio of thalweg length to valley length and is used as an index indicating the type of channel pattern associated with a particular reach of a stream. Reaches with a sinuosity greater than or equal to 1.5 are designated as meandering, less than 1.5, straight, and braided when the flow is divided around relatively stable islands.

Comparison of 1890 and 1946 sinuosities reveals some important differences between the present stream and the unmodified one. In all

Figure 3. Slope profiles of the Missouri Valley between Yankton and Rulo



1200
1150
1100
1050
1000
950
900
850
Elevation in ft.
0
25
50
75
100
125
150
175
200
225
250
Distance in miles
Yankton, S.D. to Sioux City, Iowa
Sioux City to Onawa, Ia.
Onawa to Crescent, Ia.
Crescent to Plattsmouth, Neb.
Plattsmouth to Hamburg, Ia.
Hamburg to Rulo, Neb.
Flood plain slope
Stream slope

Table 2. Missouri River low water slope, flood plain gradient and sinuosity ration

Location		River miles		Sinuosity ratio		Floodpplain gradient feet per mile	Stream slope 1946 mileage elevation feet per mile
From	To	1890	1946	1890	1946		
Yankton, S. D.	Sioux City, Ia.	92.0	85.9	1.53	1.43	1.31	.94
Sioux City, Ia.	Onawa, Ia.	66.0	45.8	1.91	1.33	1.36	.98
Sioux City, Ia.	Crescent City, Ia.	135.0	116.8	1.61	1.42	1.30	.88
Onawa, Ia.	Crescent City, Ia.	71.0	71.0	1.49	1.44	1.26	.82
Crescent City, Ia.	Plattsmouth, Neb.	32.0	29.0	1.45	1.32	1.27	.58
Plattsmouth, Neb.	Hamburg, Ia.	43.0	43.0	1.28	1.28	1.49	1.24
Hamburg, Ia.	Rulo, Neb.	66.0	60.0	1.48	1.31	1.12	1.03
		515.0 total	451.5 total	1.56 avg.	1.39 avg.	1.35 avg.	.82 avg.

instances, the 1890 sinuosity ratio is greater than or equal to the 1946 ratio. In 1890 all reaches, with the exception of the one immediately below the Platte River, had a sinuosity greater than or equal to 1.5 and so could be called meandering. The most sinuous reach in 1890 was between Sioux City and Onawa, Iowa, whereas in 1946, it was between Onawa and Crescent City, Iowa. The apparent anomaly can probably be explained by the degree to which both reaches were altered to improve navigation.

Mileages and elevations of 1946 were used in calculating flood plain gradients and water surface slopes. The increase in both flood plain gradient and stream slope below Sioux City and Plattsmouth can be attributed to the entrance of the Big Sioux and Floyd Rivers at Sioux City and of the Platte at Plattsmouth. In general, there is a direct relationship between flood plain gradient and stream gradient. In the segment above Plattsmouth, however, the general relationship is reversed. The flood plain gradient increases slightly whereas the stream gradient continues to decrease. This relationship may be attributed to sedimentation in the channel of the Missouri due to the "damming" influence of the Platte.

The important tributaries of the Missouri River from Yankton,to Rulo are the James, Big Sioux, Floyd, Little Sioux Maple, Soldier, Boyer and Nishnabotna Rivers from the left bank and the Platte River from the right. The James River, which is one of the longest left bank tributaries of the Missouri, has a very low average gradient (0.6 feet per mile) and adds little to the total load of the Missouri. The Big Sioux River, with an average gradient of 1.6 feet per mile, adds a significant quantity of sand as well as silt and clay to the Missouri. The remaining left bank tributaries have average gradients ranging from 1.6 feet per mile for the Little Sioux to 4.5 feet per mile for the Nishnabotna. The load of these streams consists principally of silt and clay derived from the surrounding loess covered hills. The total overall effect of the left bank tributaries does not significantly alter the Missouri.

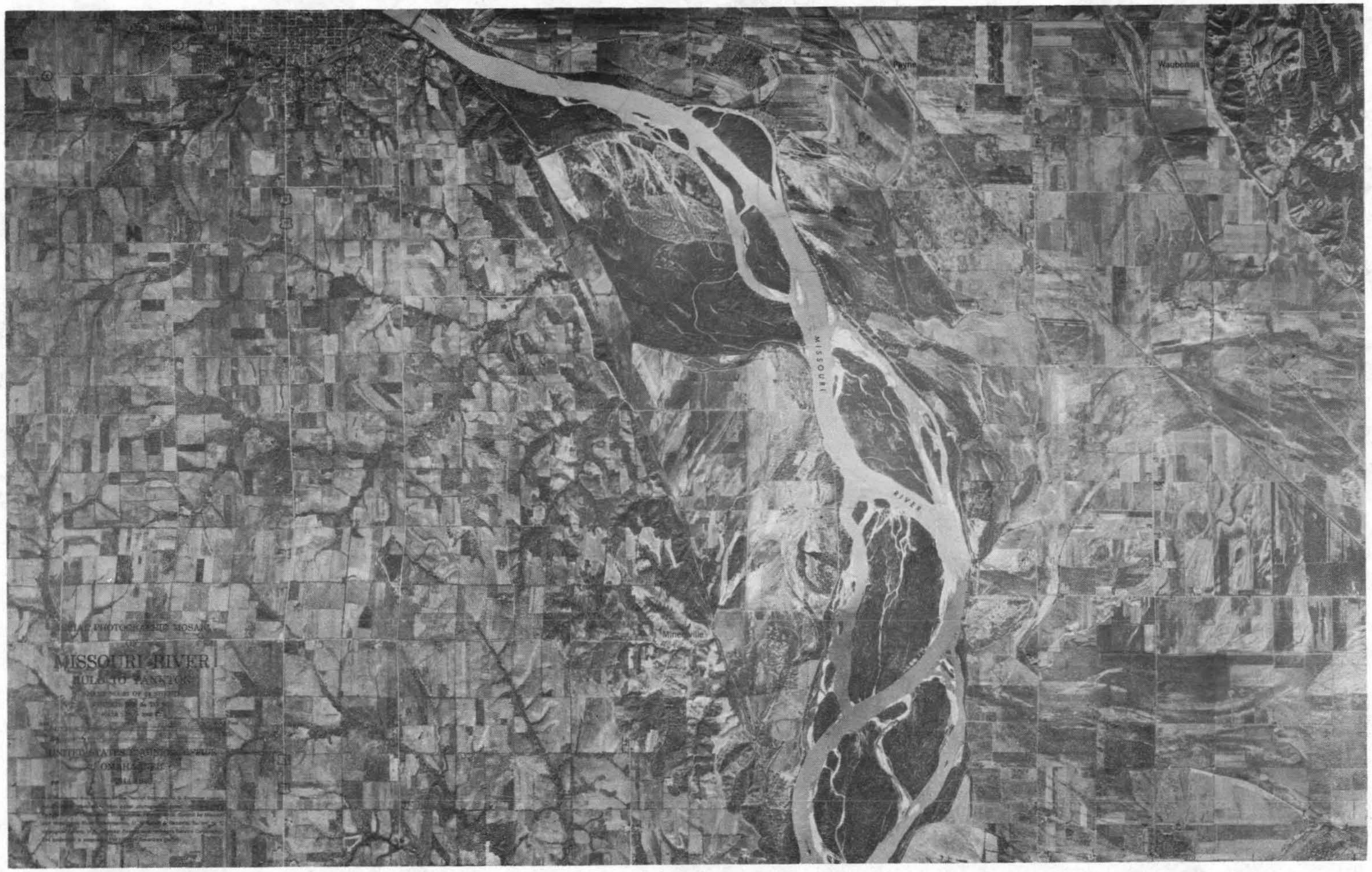
One unique feature of the tributaries south of the Big Sioux is their parallelism. All flow in a general southwesterly direction and enter the Missouri Valley at an angle 25 to 30 degrees east of north. The prevalence of this particular trend might indicate bedrock control of these streams.

The Platte River, with a drainage basin over 900 miles long and an average gradient of 7.1 feet per mile, enters the Missouri River about 25 miles south of Omaha, Nebraska. The bed load of the Platte and concentration (per unit volume of water) of the suspended load are near or equal to that of the Missouri at Omaha. The influences of the heavy load of the Platte is twofold. The increase in slope of the Missouri has already been discussed. The second prominent change is in the regimen of the Missouri. Above the mouth of the Platte, the Missouri is a typical meandering stream with many bends and flow confined to one channel. The Missouri below Plattsmouth has a broad, irregular, sandy channel obstructed by many bars and relatively fewer bends. These features, including the steeper slope, indicate a regimen intermediate between meandering and braided for the river. Figures 4 and 5 illustrate reaches of the river above and below the mouth of the Platte.

Figure 4. Aerial mosiac of the Missouri River and flood plain area above the mouth of the Platte River.


AERIAL PHOTOGRAPHIC MOSAIC
MISSOURI RIVER
RULO TO YANKTON
UNITED STATES ENGINEER OFFICE
OMAHA, NEB.
1944-1945
MISSOURI
RIVER
Decatur

Figure 5. Aerial mosiac of the Missouri River and flood plain area below the mouth of the Platte River.


MISSOURI RIVER
MISSOURI
RIVER

Missouri River Valley in Iowa

The valley of the Missouri River parallels the western boundary of Iowa for an airline distance of approximately 139 miles. The valley trends in a general south-southeast direction and is composed of an upper wide segment, a middle narrow segment, and a lower segment intermediate in width. The maximum width of the valley is 18 miles in the northern segment, and the minimum width is 4 miles in the middle segment. The valley width ranges from 5 to 7 miles in the lower segment.

The bedrock floor of the Missouri Valley trench lies at varying depths below the level of the surrounding uplands. A thickness of alluvium ranging from 70 to 156 feet fills the lower portion of the trench. The upland area rises from 200 to 300 feet above the flat upper surface of the alluvial fill. The maximum known depth of the Missouri trench below the surrounding upland is approximately 450 feet.

Alluvial Morphology

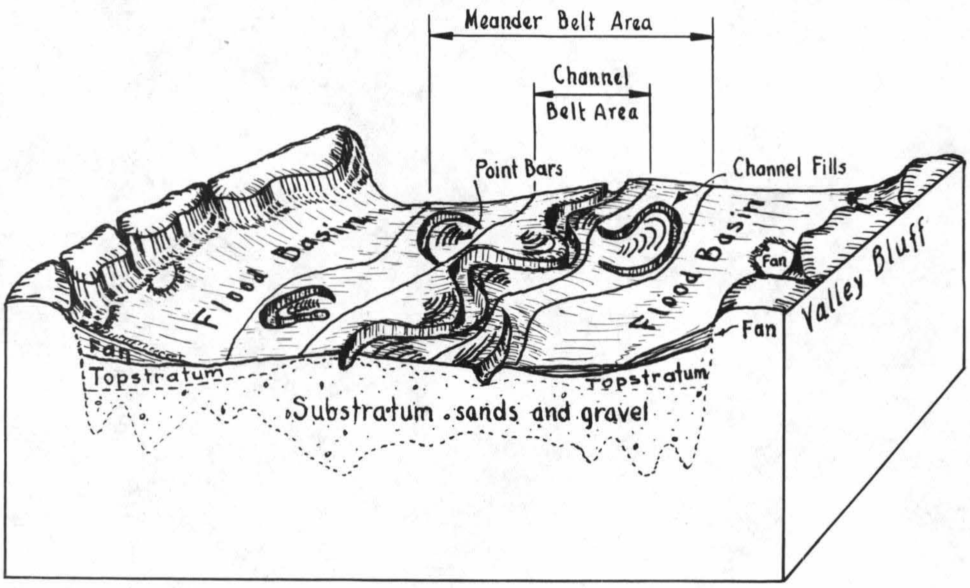
For convenience, a three-fold division of the Missouri River can be made, an upper segment including the valley between Sioux City and Crescent, Iowa; a middle segment, between Crescent and Plattsmouth, Nebraska; and a lower segment, between Plattsmouth and the southern Iowa border. These subdivisions have geomorphic significance in that their boundaries correspond to those of the valley subdivisions based on valley width.

To facilitate discussion, the flood plain area of the Missouri Valley may be considered to consist of three distinctive geomorphic areas. These areas are 1) channel belt, 2) meander belt, and 3) flood basin. Figure 7 is a sketch indicating the geomorphic areas and

Figure 6. Surface characteristic attributed to wind reworking of sand near Payne, Iowa

Figure 7. Sketch indicating stratigraphic relationships and geomorphic areas of the alluvial valley.

C B & Q RR
Payne
CHICAGO
BURLINGTON
AND



Meander Belt Area
Channel
Belt Area
Point Bars
Channel Fills
Flood Basin
Flood Basin
Fan
Valley Bluff
Fan
Fan
Topstratum
Topstratum
Substratum sands and gravel

general stratigraphic relationships across the Missouri Valley.

Each of the three longitudinal subdivisions of the Missouri Valley has varying amounts of channel belt, meander belt, and flood basin in them. The margins of these areas are indicated by heavy black lines on the base maps.

Sioux City To Crescent

With the exception of the Sargent Bluff salient (Plate 3, Sheet 75L), glacial drift or loess forms the adjacent bluffs along this segment of the alluvial valley. The surrounding uplands rise to concordant highs 200 to 250 feet above the general flood plain level. A terrace-like feature occurs below the uplands and forms the right valley escarpment of the modern river from Tekamah, Nebraska (Sheet 69), to Omaha, Nebraska.

Traverses A-A', B-B', and C-C' cross the Missouri Valley in the upper, middle and lower parts of the Sioux City to Crescent segment. Plates 2 and 3, 4 and 5, and 6 and 7 are maps of the alluvial deposits in this segment; and Figures 8, 9, and 10 show the mechanical composition of all samples along each traverse.

The alluvial deposits of the Missouri Valley are the modern Missouri River bars of the channel belt area, the point bars, filled channels and undifferentiated deposits of the meander belt area, and the flood basin area deposits.

The following discussion treats in more detail the geomorphic distinction between channel belt, meander belt and flood basin areas and the geomorphic expression characteristic of each type of alluvial deposit.

Plate 2. Alluvial geology, Sheet 75.

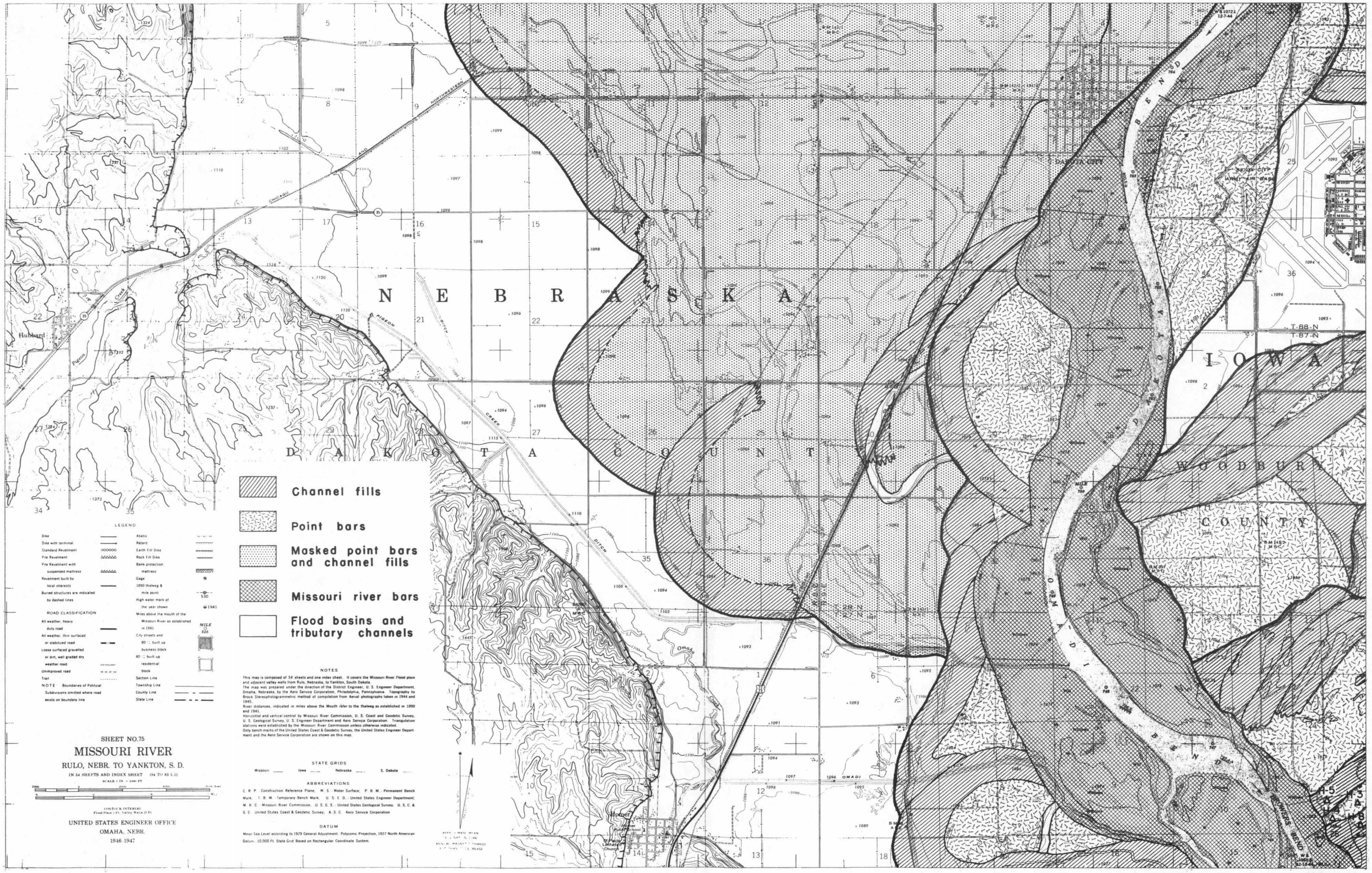
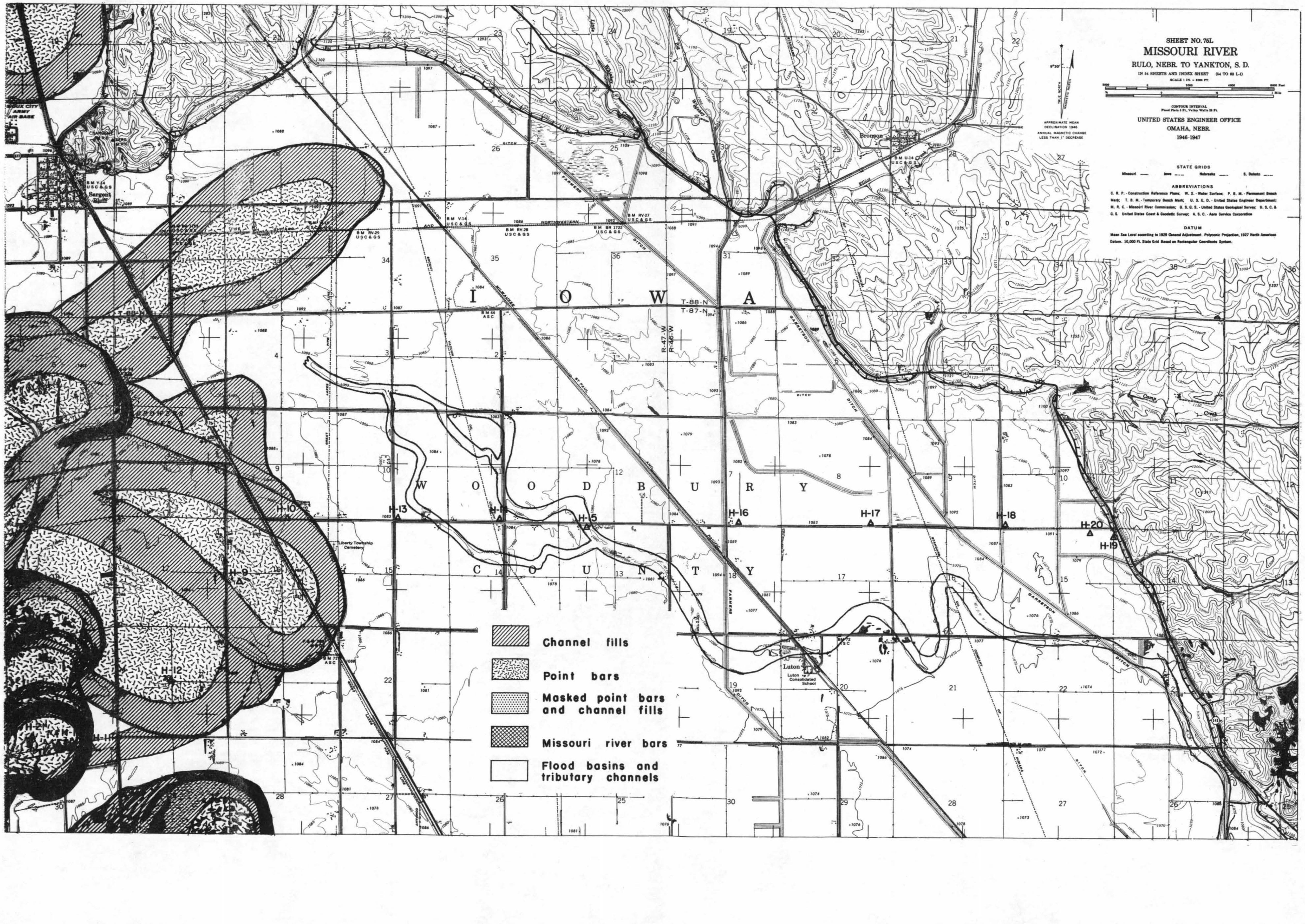

NEBRASKA
DAKOTA COUNTY
IOWA
WOODBURY COUNTY
DAKOTA CITY
Hubbard
Homer
OMADI BEND
DAKOTA BEND
PIGEON CREEK
PIGEON DITCH
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
LEGEND
Dike
Dike with terminal
Standard Revetment
Pile Revetment
Pile Revetment with suspended mattress
Revetment built by local interests
Buried structures are indicated by dashed lines
ROAD CLASSIFICATION
All weather, heavy duty road
All weather, thin surfaced or stabilized road
Loose surfaced gravelled or dirt, well graded dry weather road
Unimproved road
Trail
NOTE Boundaries of Political Subdivisions omitted where road exists on boundary line
Abatis
Retard
Earth Fill Dike
Rock Fill Dike
Bank protection mattress
Gage
1890 thalweg & mile point
530
High water mark of the year shown
1941
Miles above the mouth of the Missouri River as established in 1941
MILE 528
City streets and 80% built up business block
80% built up residential block
Section Line
Township Line
County Line
State Line
SHEET NO.75
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET
CONTOUR INTERVAL
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
NOTES
This map is composed of 54 sheets and one index sheet. It covers the Missouri River Flood plain and adjacent valley walls from Rulo, Nebraska, to Yankton, South Dakota.
The map was prepared under the direction of the District Engineer, U. S. Engineer Department, Omaha, Nebraska, by the Aero Service Corporation, Philadelphia, Pennsylvania. Topography by Brock Stereophotogrammetric method of compilation from Aerial photographs taken in 1944 and 1945.
River distances, indicated in miles above the Mouth refer to the thalweg as established in 1890 and 1941.
Horizontal and vertical control by Missouri River Commission, U. S. Coast and Geodetic Survey, U. S. Geological Survey, U. S. Engineer Department and Aero Service Corporation. Triangulation stations were established by the Missouri River Commission unless otherwise indicated.
Only bench marks of the United States Coast & Geodetic Survey, the United States Engineer Department and the Aero Service Corporation are shown on this map.
STATE GRIDS
Missouri
Iowa
Nebraska
S. Dakota
ABBREVIATIONS
C. R. P. - Construction Reference Plane; W. S. - Water Surface; P. B. M. - Permanent Bench Mark; T. B. M. - Temporary Bench Mark; U. S. E. D. - United States Engineer Department; M. R. C. - Missouri River Commission; U. S. G. S. - United States Geological Survey; U. S. C. & G. S. - United States Coast & Geodetic Survey; A. S. C. - Aero Service Corporation
DATUM
Mean Sea Level according to 1929 General Adjustment. Polyconic Projection, 1927 North American Datum. 10,000 Ft. State Grid Based on Rectangular Coordinate System.
T-88-N
T-87-N

Plate 3. Alluvial geology, Sheet 75L.



SHEET NO. 75L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-1)
SCALE 1 IN. = 2000 FT.
CONTOUR INTERVAL
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
STATE GRIDS
Missouri
Iowa
Nebraska
S. Dakota
ABBREVIATIONS
C. R. P. - Construction Reference Plane; W. S. - Water Surface; P. B. M. - Permanent Bench Mark; T. B. M. - Temporary Bench Mark; U. S. E. D. - United States Engineer Department; M. R. C. - Missouri River Commission; U. S. G. S. - United States Geological Survey; U. S. C. & G. S. United States Coast & Geodetic Survey; A. S. C. - Aero Service Corporation
DATUM
Mean Sea Level according to 1929 General Adjustment. Polyconic Projection, 1927 North American Datum. 10,000 Ft. State Grid Based on Rectangular Coordinate System.
APPROXIMATE MEAN DECLINATION 1946
TRUE NORTH
MAGNETIC NORTH
I O W A
W O O D B U R Y
C O U N T Y
T-88-N
T-87-N
R-47-W
R-46-W
Sergeant Bluff
Bronson
Luton
Luton Consolidated School
Liberty Township Cemetery
H-5
H-9
H-10
H-12
H-13
H-16
H-17
H-18
H-19
H-20
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

Figure 8. Columnar sections showing mechanical composition with depth, traverse A-A'.

TRAVERSE A—A'

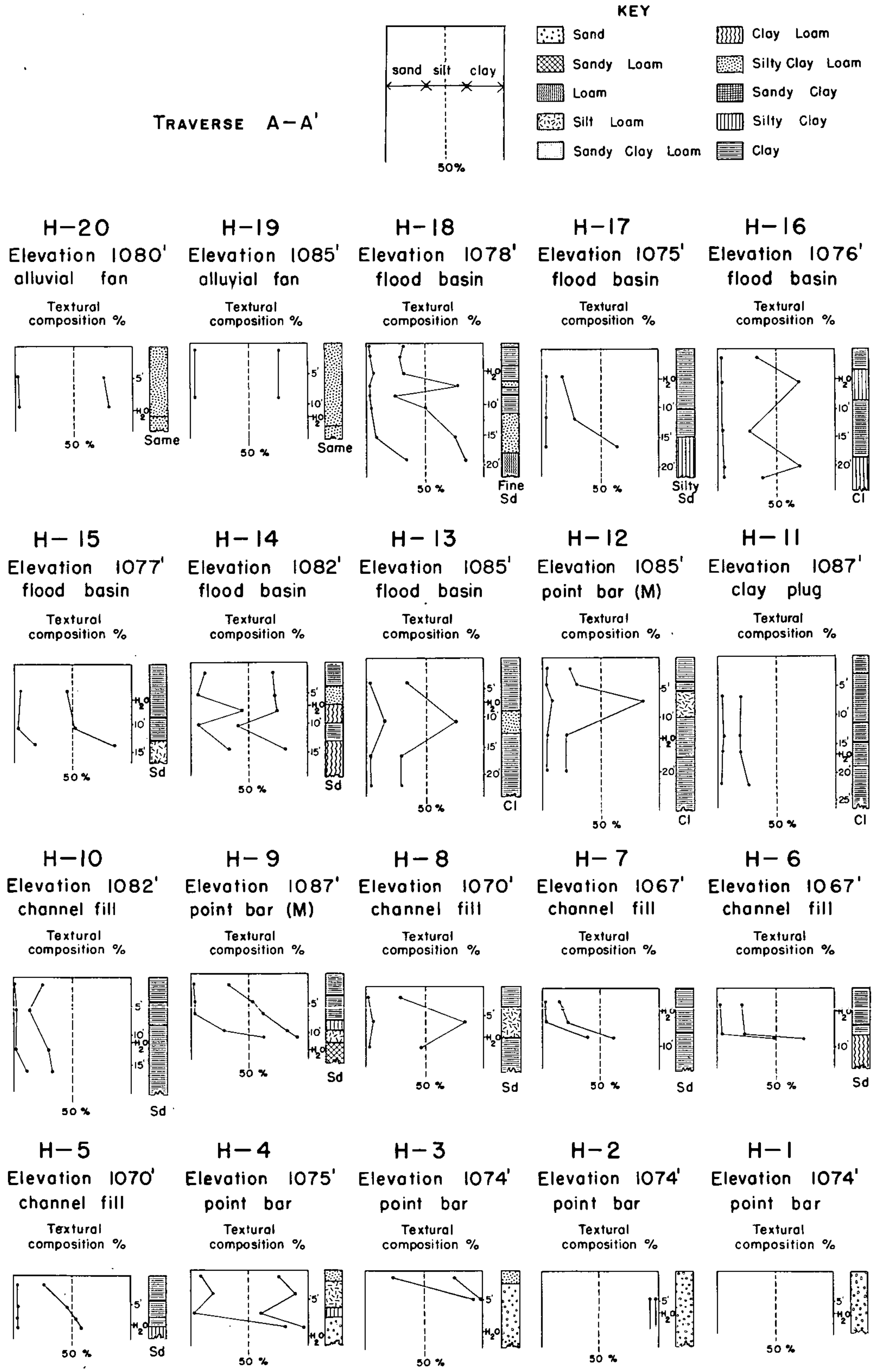
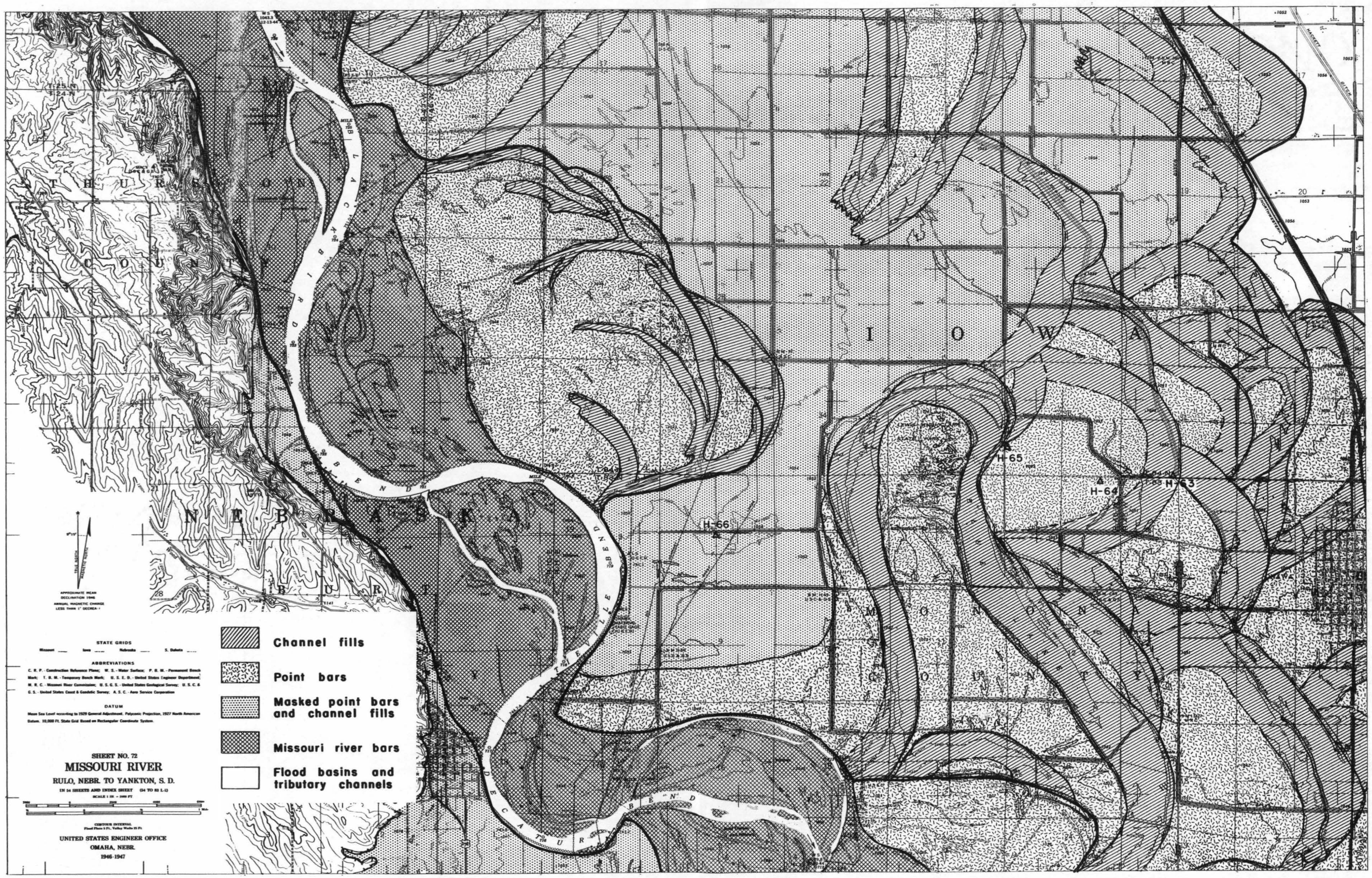
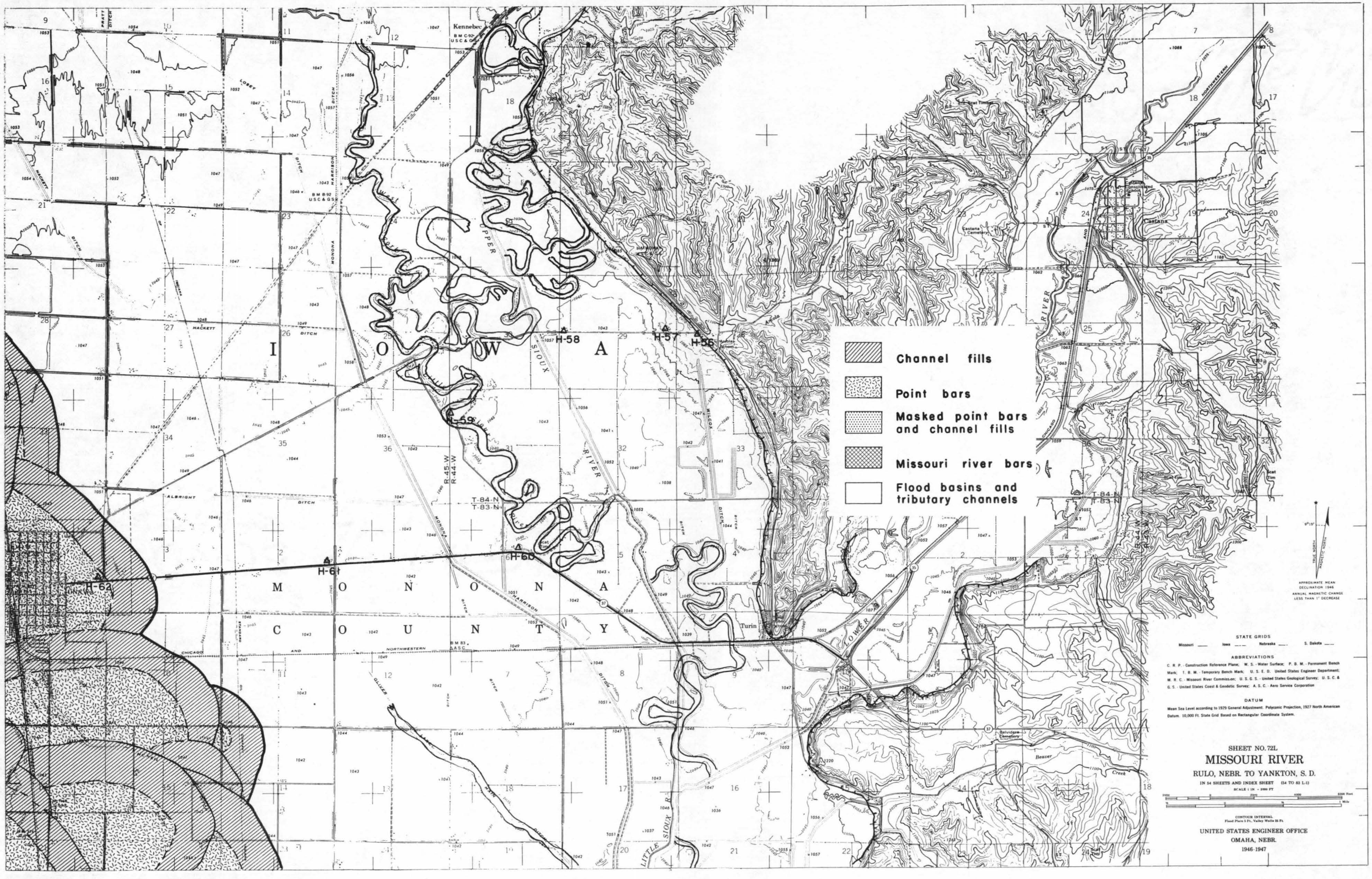

KEY
sand silt clay
50%
Sand
Sandy Loam
Loam
Silt Loam
Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay
H-20
Elevation 1080'
alluvial fan
Textural composition %
Same
H-19
Elevation 1085'
alluyial fan
Textural composition %
Same
H-18
Elevation 1078'
flood basin
Textural composition %
Fine Sd
H-17
Elevation 1075'
flood basin
Textural composition %
Silty Sd
H-16
Elevation 1076'
flood basin
Textural composition %
Cl
H-15
Elevation 1077'
flood basin
Textural composition %
Sd
H-14
Elevation 1082'
flood basin
Textural composition %
Sd
H-13
Elevation 1085'
flood basin
Textural composition %
Cl
H-12
Elevation 1085'
point bar (M)
Textural composition %
Cl
H-11
Elevation 1087'
clay plug
Textural composition %
Cl
H-10
Elevation 1082'
channel fill
Textural composition %
Sd
H-9
Elevation 1087'
point bar (M)
Textural composition %
Sd
H-8
Elevation 1070'
channel fill
Textural composition %
Sd
H-7
Elevation 1067'
channel fill
Textural composition %
Sd
H-6
Elevation 1067'
channel fill
Textural composition %
Sd
H-5
Elevation 1070'
channel fill
Textural composition %
Sd
H-4
Elevation 1075'
point bar
Textural composition %
H-3
Elevation 1074'
point bar
Textural composition %
H-2
Elevation 1074'
point bar
Textural composition %
H-1
Elevation 1074'
point bar
Textural composition %

Plate 4. Alluvial geology, Sheet 72.



Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
THURSTON COUNTY
NEBRASKA
BURT
IOWA
MONONA COUNTY
BLACKBIRD BEND
DECATUR BEND
H-63
H-64
H-65
H-66
APPROXIMATE MEAN DECLINATION 1946
ANNUAL MAGNETIC CHANGE LESS THAN 1° DECREA-
STATE GRIDS
Missouri Iowa Nebraska S. Dakota
ABBREVIATIONS
C. R. P. - Construction Reference Plane; W. S. - Water Surface; P. B. M. - Permanent Bench Mark; T. B. M. - Temporary Bench Mark; U. S. E. D. - United States Engineer Department; M. R. C. - Missouri River Commission; U. S. G. S. - United States Geological Survey; U. S. C. & G. S. - United States Coast & Geodetic Survey; A. S. C. - Aero Service Corporation
DATUM
Mean Sea Level according to 1929 General Adjustment. Polyconic Projection, 1927 North American Datum. 10,000 Ft. State Grid Based on Rectangular Coordinate System.
SHEET NO. 72
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-1)
CONTOUR INTERVAL
Flood Plain 5 Ft., Valley Walls 25 Ft.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947

Plate 5. Alluvial geology, Sheet 72L.



IOWA
MONONA COUNTY
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
APPROXIMATE MEAN DECLINATION 1946
ANNUAL MAGNETIC CHANGE LESS THAN 1' DECREASE
STATE GRIDS
Missouri Iowa Nebraska S. Dakota
ABBREVIATIONS
C. R. P. - Construction Reference Plane; W. S. - Water Surface; P. B. M. - Permanent Bench Mark; T. B. M. - Temporary Bench Mark; U. S. E. D. United States Engineer Department; M. R. C. - Missouri River Commission; U. S. G. S. - United States Geological Survey; U. S. C. & G. S. - United States Coast & Geodetic Survey; A. S. C. - Aero Service Corporation
DATUM
Mean Sea Level according to 1929 General Adjustment. Polyconic Projection, 1927 North American Datum. 10,000 Ft. State Grid Based on Rectangular Coordinate System.
SHEET NO. 72L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-1)
SCALE 1 IN. = 2000 FT
CONTOUR INTERVAL
Flood Plain 5 Ft., Valley Walls 25 Ft.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947

Figure 9. Columnar sections showing mechanical composition with depth, traverse B-B'.

TRAVERSE B—B'

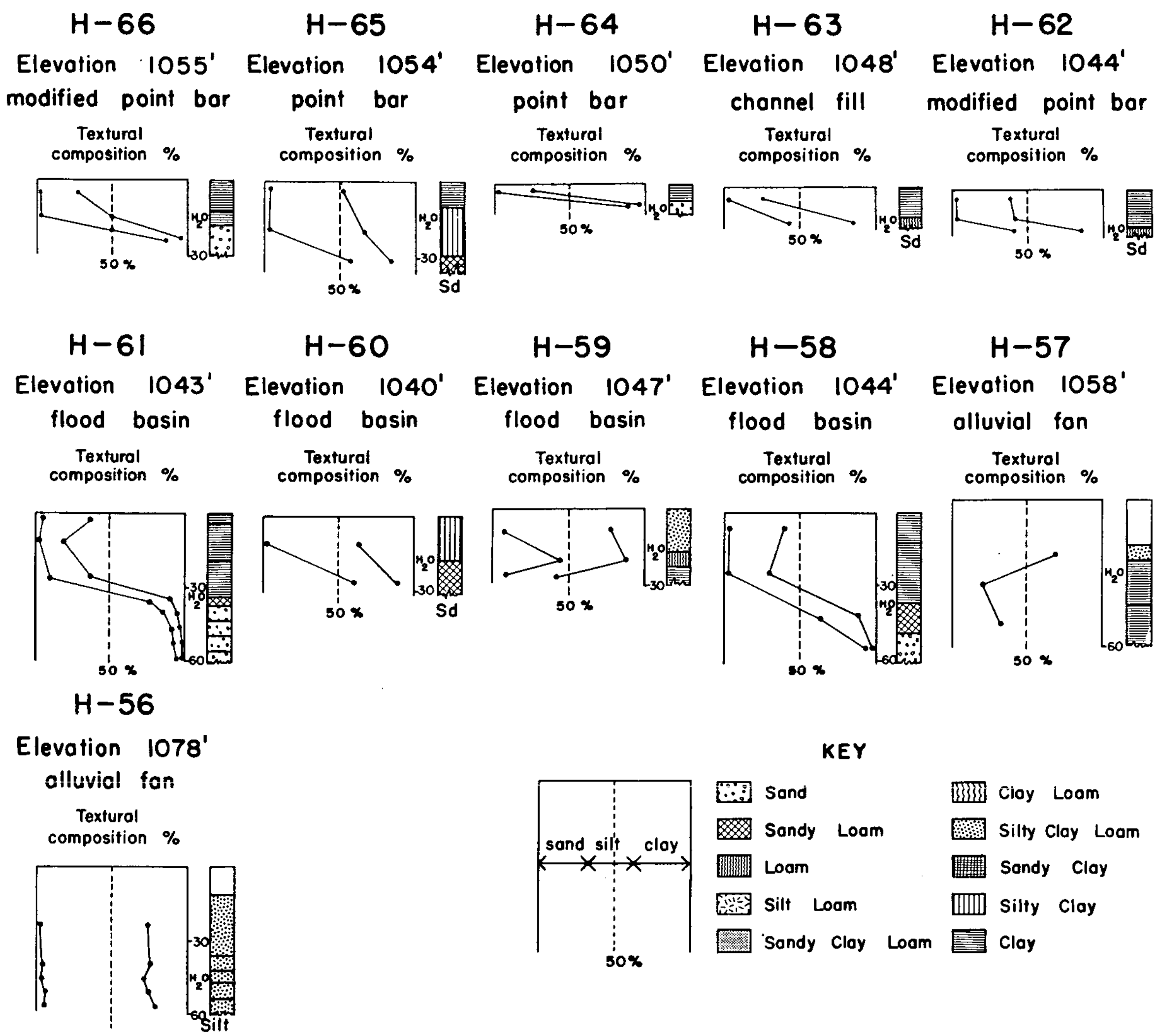

H-66
Elevation 1055'
modified point bar
Textural composition %
H-65
Elevation 1054'
point bar
Textural composition %
Sd
H-64
Elevation 1050'
point bar
Textural composition %
H-63
Elevation 1048'
channel fill
Textural composition %
Sd
H-62
Elevation 1044'
modified point bar
Textural composition %
Sd
H-61
Elevation 1043'
flood basin
Textural composition %
H-60
Elevation 1040'
flood basin
Textural composition %
Sd
H-59
Elevation 1047'
flood basin
Textural composition %
H-58
Elevation 1044'
flood basin
Textural composition %
H-57
Elevation 1058'
alluvial fan
Textural composition %
H-56
Elevation 1078'
alluvial fan
Textural composition %
Silt
50 %
30
60
H_2O
KEY
sand silt clay
Sand
Sandy Loam
Loam
Silt Loam
Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay

Plate 6. Alluvial geology, Sheet 68.

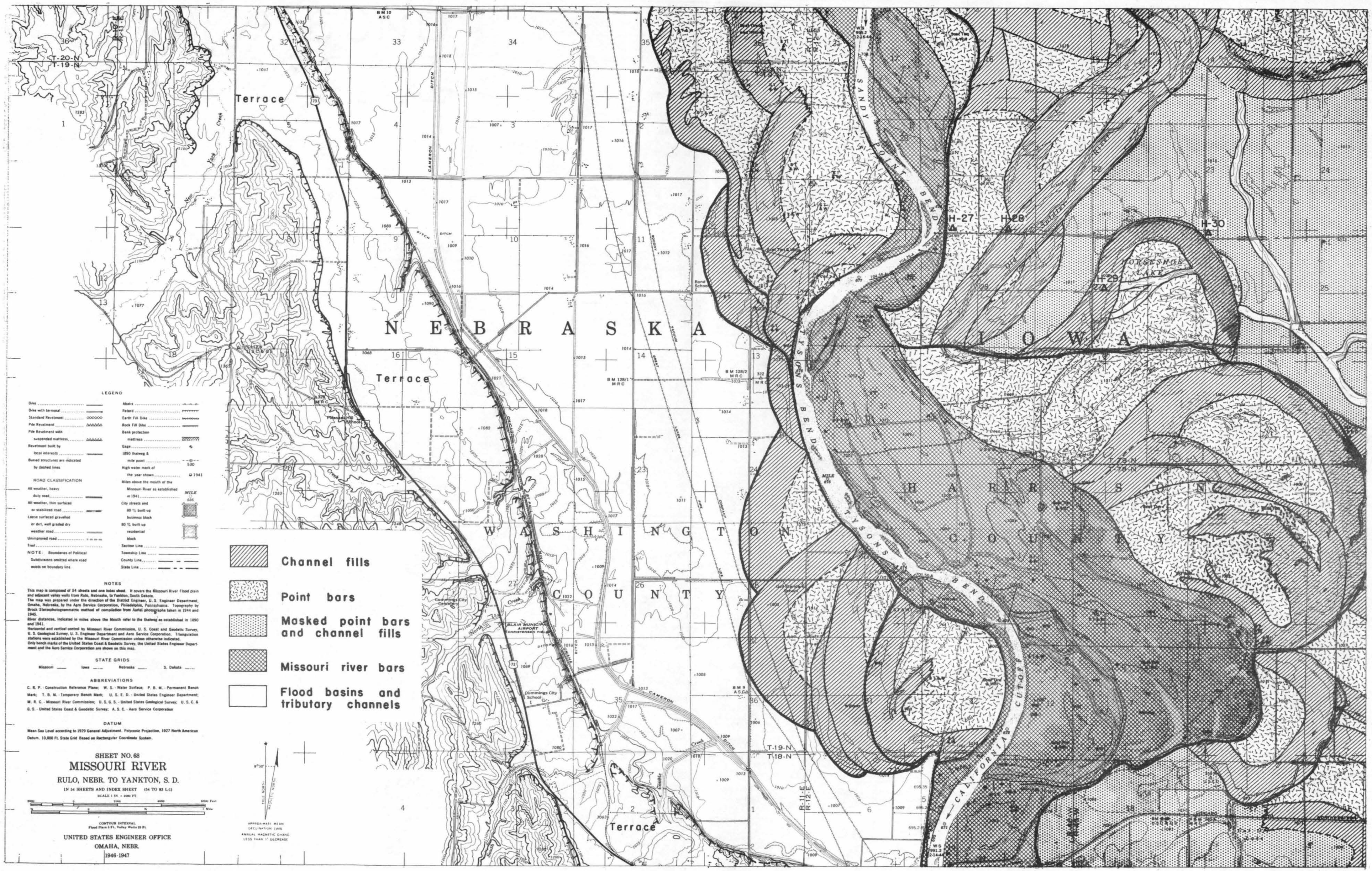
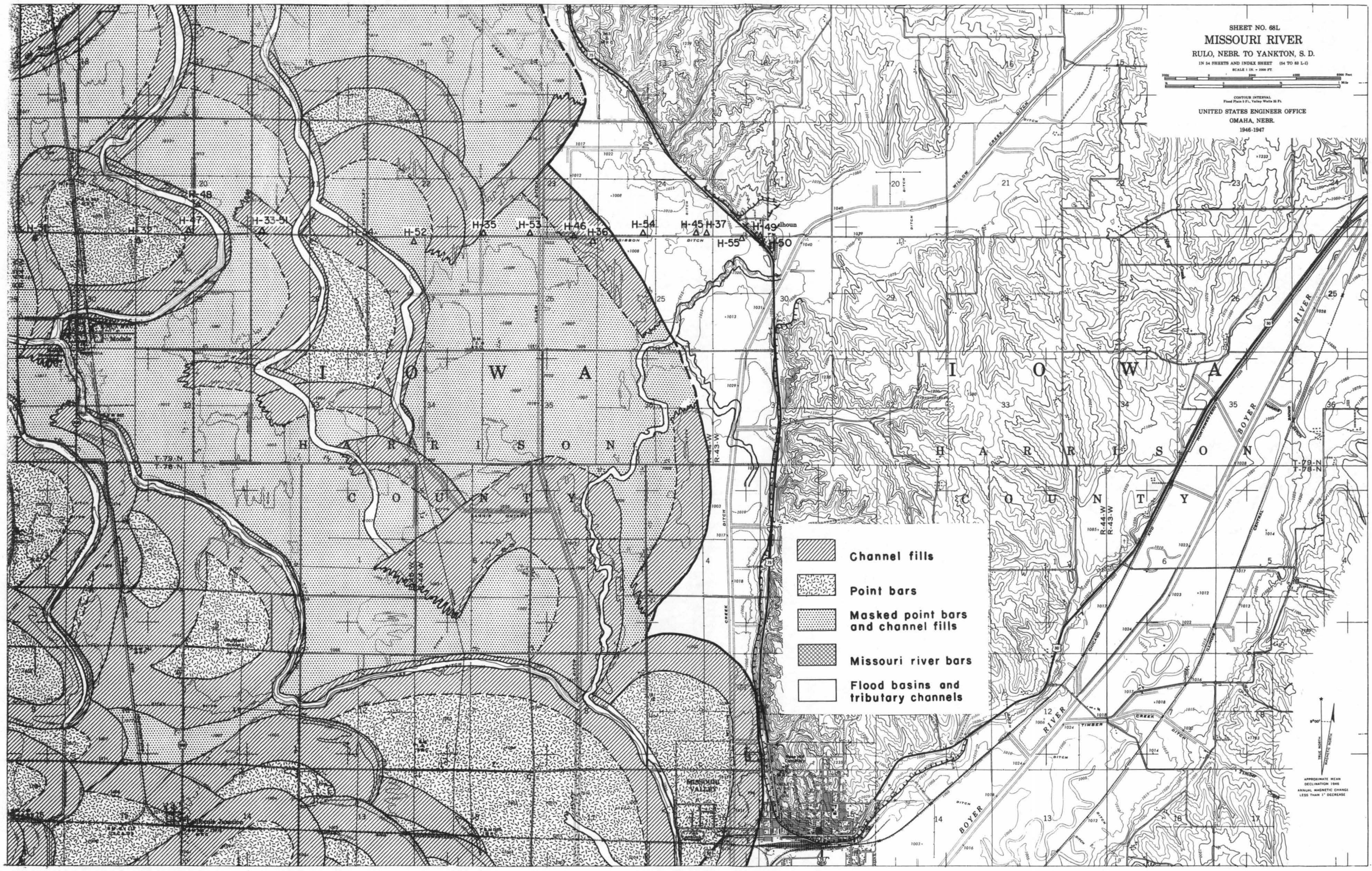

NEBRASKA
IOWA
WASHINGTON COUNTY
HARRISON COUNTY
Terrace
Terrace
Terrace
SANDY POINT BEND
TYSONS BEND
TYSONS BEND
CALIFORNIA CUTOFF
HORSESHOE LAKE
H-27
H-28
H-29
H-30
T-20-N
T-19-N
T-19-N
T-18-N
R-11-E
R-12-E
CAMERON DITCH
BLAIR MUNICIPAL AIRPORT
Cummings City School
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
LEGEND
ROAD CLASSIFICATION
Loose surfaced gravelled or dirt, well graded dry weather road
Unimproved road
Trail
NOTE: Boundaries of Political Subdivisions omitted where road exists on boundary line
80 % built up business block
80 % built up residential block
Section Line
Township Line
County Line
State Line
NOTES
This map is composed of 54 sheets and one index sheet. It covers the Missouri River Flood plain and adjacent valley walls from Rulo, Nebraska, to Yankton, South Dakota.
The map was prepared under the direction of the District Engineer, U. S. Engineer Department, Omaha, Nebraska, by the Aero Service Corporation, Philadelphia, Pennsylvania. Topography by Brock Stereophotogrammetric method of compilation from Aerial photographs taken in 1944 and 1945.
River distances, indicated in miles above the Mouth refer to the thalweg as established in 1890 and 1941.
Horizontal and vertical control by Missouri River Commission, U. S. Coast and Geodetic Survey, U. S. Geological Survey, U. S. Engineer Department and Aero Service Corporation. Triangulation stations were established by the Missouri River Commission unless otherwise indicated.
Only bench marks of the United States Coast & Geodetic Survey, the United States Engineer Department and the Aero Service Corporation are shown on this map.
STATE GRIDS
Missouri
Iowa
Nebraska
S. Dakota
ABBREVIATIONS
C. R. P. - Construction Reference Plane; W. S. - Water Surface; P. B. M. - Permanent Bench Mark; T. B. M. - Temporary Bench Mark; U. S. E. D. - United States Engineer Department; M. R. C. - Missouri River Commission; U. S. G. S. - United States Geological Survey; U. S. C. & G. S. - United States Coast & Geodetic Survey; A. S. C. - Aero Service Corporation
DATUM
Mean Sea Level according to 1929 General Adjustment. Polyconic Projection, 1927 North American Datum. 10,000 Ft. State Grid Based on Rectangular Coordinate System.
SHEET NO. 68
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-1)
SCALE 1 IN. = 2000 FT
CONTOUR INTERVAL
Flood Plain 5 Ft. Valley Walls 25 Ft.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947

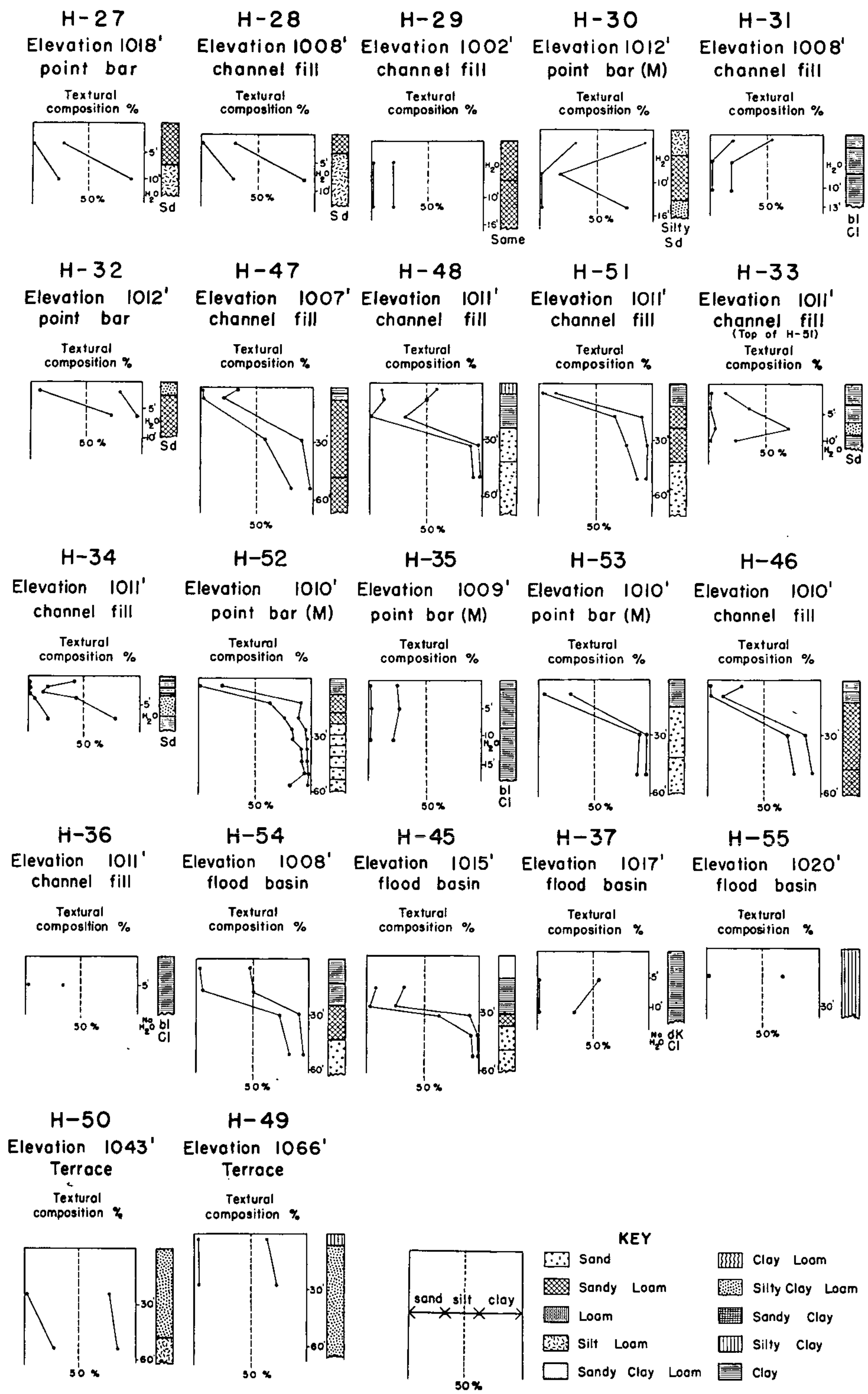
Plate 7. Alluvial geology, Sheet 68L.



SHEET NO. 68L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-I)
SCALE 1 IN. = 2000 FT.
CONTOUR INTERVAL
Flood Plain 5 Ft., Valley Walls 25 Ft.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
I O W A
H A R R I S O N
C O U N T Y
BOYER RIVER
R-43-W
R-44-W
T-79-N
T-78-N
H-48
H-47
H-32
H-33-51
H-34
H-52
H-35
H-53
H-46
H-36
H-54
H-45
H-37
H-49
H-55
H-50
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

Figure 10. Columnar sections showing mechanical composition with depth, traverse C-C'.

TRAVERSE C–C'


H-27
Elevation 1018'
point bar
H-28
Elevation 1008'
channel fill
H-29
Elevation 1002'
channel fill
H-30
Elevation 1012'
point bar (M)
H-31
Elevation 1008'
channel fill
H-32
Elevation 1012'
point bar
H-47
Elevation 1007'
channel fill
H-48
Elevation 1011'
channel fill
H-51
Elevation 1011'
channel fill
H-33
Elevation 1011'
channel fill
(Top of H-51)
H-34
Elevation 1011'
channel fill
H-52
Elevation 1010'
point bar (M)
H-35
Elevation 1009'
point bar (M)
H-53
Elevation 1010'
point bar (M)
H-46
Elevation 1010'
channel fill
H-36
Elevation 1011'
channel fill
H-54
Elevation 1008'
flood basin
H-45
Elevation 1015'
flood basin
H-37
Elevation 1017'
flood basin
H-55
Elevation 1020'
flood basin
H-50
Elevation 1043'
Terrace
H-49
Elevation 1066'
Terrace
Textural composition %
50%
Sd
Some
Silty Sd
bl Cl
dK Cl
No H_2O
sand silt clay
KEY
Sand
Sandy Loam
Loam
Silt Loam
Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay

Channel belt area. The channel belt area is that portion of the alluvial valley adjacent to the modern river. It includes all the area traversed by the river since the 1890 course was surveyed and the point bars and river bars of the modern river. This is the area of the most rapid erosion and deposition and also of the most uniform type of material.

The most important processes active in the channel belt are channel migration and bar building. Channel migration is accomplished by undercutting the stream bank on the outside or concave side of a bend. Contemporaneous with or causing the cutting is bar building on the inside or convex bank. The rate of bank recession and thus of bar building depends primarily on the nature of the bank and bed materials, the river stage, and the channel alignment.

In the upper segment of the valley, the channel belt area ranges from 1 to 3 miles wide. This is generally about evenly bisected by the present course of the river but may occur with the river nearer one margin than the other. The general nature of the channel belt area and its relationship to the meander belt and flood basin areas are well illustrated on Plate 2, Sheet 75.

Missouri River bars. The principal geomorphic features of the channel belt area are point bars and modern channel bars of the Missouri River. These are collectively mapped under the designation of Missouri River bars. On topographic maps, these geomorphic features commonly appear as areas of irregular relief mapped as being sandy and covered with a dense growth of willows. The point bars appear as concentric ridges and swales within modern channel bends. The channel bars appear as tear-shaped, flat topped areas which gradually taper downstream. A chute or low swale may lie in back of the channel bar and between it and the bank line. If this chute contains water during low stages and the bar is stabilized by a growth of willows, it may be considered to be an island.

On aerial photos, the point bars may be identified by concentric bands of light colored material composing the ridges separated by darker colored materials filling the swales or chutes. Channel bars or islands commonly appear as light colored areas if not covered by vegetation and dark areas if growth of willows has occurred. Figure 11 shows the geomorphic expression of typical Missouri River bar deposits.

The principal type of material in the channel belt area is sand. Scattered, irregular patches of gravel may be present where local sorting has taken place. Where willows have acted as obstructions to the flow of water, varying thicknesses of fine-grained topstratum may occur. The fine-grained materials are principally silty sands and silty clays. This same material may also be in the swales or chutes and as a thin blanket deposit over the ridges.

Meander belt area. The meander belt is an area where the record of past Missouri River activity is indicated by abandoned channels and associated point bars. Continued migration of the channel has lead to the abandonment of former courses by chute or neck type cut-offs. These abandoned channels and associated point bars then become partially filled or masked by fine-grained topstratum deposited during flood and are the principal geomorphic features of the meander belt area.

The width of the meander belt including the channel belt varies from 5 to 13 miles in the upper segment. Near the lower boundary of the upper segment (Plate 8, Sheet 66), the meander belt area occupies almost the entire flood plain.

The boundaries of the meander belt are the outermost recognizable meander scar or point bar and the channel belt. Most commonly meander belt features lie between the channel belt and flood basin areas. South of the Sioux City Municipal Airport (Plate 2, Sheet 75), however, the river has cut into the flood basin area; and the channel belt is marginal to the flood basin area.

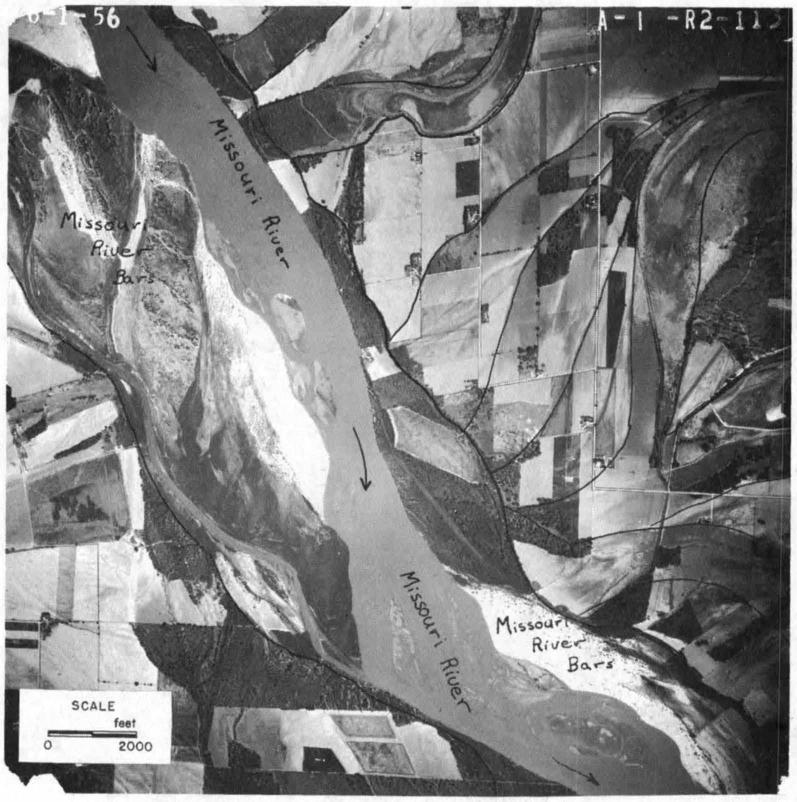
Point bars. The point bars of the meander belt area are different from those of the channel belt area with respect to both geomorphology and sediment. In point of origin, however, they are exactly the same and represent the accretion deposits of a migrating meander.

Most point bars of the meander belt have been masked by varying thicknesses of interbedded silty sands and clays. Irregularities in the accretion topography have been smoothed by deposition. In general, meander belt relief decreases with distance from the river and age of the channel remnants. Older channels near the outer margin of the meander belt are indicated only by a low swell marking the concave bank of a former meander.

Point bars inside modern meander loops commonly reach elevations comparable to the highest elevation of the surrounding flood plain but never exceed this elevation. From the center of a buried point bar the fine-grained topstratum increases in thickness toward the channel proper.

Figure 11. Geomorphic expression of Missouri River bars.

Figure 12. Typical point bar and channel fill, traverse A-A'


6-1-56
A-1 -R2-115
Missouri River
Missouri River Bars
Missouri River
Missouri River Bars
SCALE
feet
0
2000


6-1-56
A-1 -R2-110
Channel Fill
Point Bar
SCALE
feet
0
2000

Point bar deposits appear on aerial photographs as areas of lighter colored material surrounded by an arcuate band of darker material marking the old channel. Figure 12 shows the typical geomorphic expression of a point bar and associated channel fill. Organic matter and topographic position apparently determine this relationship. The point bars are topographically higher than the old channel floor which, being lower, tends to act as a container for runoff water during heavy rains. The permeability of most channel fill deposits is relatively low, and water may stand in the old channel for a long time. Channel fill deposits commonly accumulate in a reducing environment whereas, at best, point bars are only intermittently exposed to the same environment.

Channel fills. The geomorphic expression and nature of the deposits in abandoned channels are controlled by the type of stream which occupied the channel and the type of cut-off responsible for abandonment. Missouri River abandoned channel patterns are essentially those of a meandering stream. The average radius of meander loops turning through an angle greater than 180° in 1890 between Sioux City and Crescent was approximately 5500 feet, and the range in radius was from 4000 to 6000 feet. Well developed meander features were concentrated in the upper two segments. Abandoned meander loops have a radius averaging slightly less than those of the 1890 channel. Modern (1946) meander loops which pass through an angle greater than 180° are exceedingly rare due to artificial cut-offs and other forms of channel improvement. The average radius of those present ranges from 4000 to 7000 feet. As much as five to eight miles of a former river course have been abandoned due to a single natural or artificial cut-off.

The average width of abandoned channel ranges from 1500 to 3000 feet. The 1946 channel had an average width of approximately 1000 feet. Whipple (34) states that the 1930 channel width between Rulo and Sioux City had narrows considerably less than 1000 feet and a mean usable width of 3,650 feet.

Chute cut-offs, which form as the result of enlargement of a point bar swale or chute, develop slowly and result in the gradual abandonment of the meander loop. Because of the small angle of divergence between the old channel and the new one, reduction in flow through the old loop is slow and results in deposition of the coarser fraction of the stream load. The upper arm gradually becomes narrowed and eventually choked by deposition of sand, and the old course is completely abandoned. Neck cut-offs, in direct contrast to chute cut-offs, result in rapid abandonment of the old course. Relatively rapid silting of the upstream and downstream arms takes place, and an ox-bow or cut-off lake is formed. Deposition in the upper and lower extremities of neck cut-offs may form "clay plugs" whereas generally only the lower arm is filled with fine-grained material in chute out-offs.

Channel fill deposits occupy arcuate areas with width and radius of curvature comparable to those of the modern river prior to 1930. Modern channel fills generally have topographic expression characterized by a relatively flat area between the gentle slip off slope of the point bar and the steeper slope of the concave outer margin. The only relief along most filled channels is a gradual rise toward the upper and lower extremities as a result of greater deposition there. This is also indicated by the position and shape of most ox-bow lakes. They generally occur near the point of maximum curvature and are about evenly distributed around it.

Individual channels fill and lose their identity by a process called "channel deterioration." This results from sedimentation during floods and by slope wash during rainstorms. Agricultural activities have also obscured old channel boundaries. During floods the old channel acts as a settling basin for materials carried by the river. Fine-grained materials are deposited in the channel as a result of the checked velocity of flood waters when they enter the basin and from suspension when quiet water prevails after withdrawal of flood waters. The distribution of fine-grained material in a channel fill depends on the position of the former thalweg in the channel. In general, the thickest portion of the fill will also correspond to this thalweg position.

Undifferentiated deposits. Within the meander belt area, some point bar and channel fill deposits become masked by overbank materials deposited during flood, or by tributary channel patterns. Plates 2, 4 and 5, Sheets 75, 72 and 72L contain extensive areas of undifferentiated deposits.

Areas mapped as including undifferentiated deposits have some of the geomorphic characteristics of abandoned channels and some of point bars. These areas commonly appear on topographic maps as areas of irregular relief of a smaller scale than that characterizing channel fills or point bars. The relief commonly consists of low swells or swales which coalesce and divide and eventually die out. On aerial photos these areas are represented by lighter colored materials with interfingering channels of dark material.

<u>Flood basin area</u>. The flood basin area is that portion of the flood plain between the outer boundary of the meander belt or channel belt and the valley wall. In general, this is an almost featureless lowland between two areas of distinctive relief.

The width of the flood basin area ranges from approximately 12 miles south of Sargent Bluff (Plate 3, Sheet 75L) to a maximum of 1 mile near the lower part of the upper segment where the meander belt occupies most of the flood plain area.

The flood basin is largely devoid of distinctive relief features. The only features present are those due to flood distributary patterns or associated with channel patterns of smaller tributary streams. Until the area along the Missouri River was ditched and tiled, the land was largely unsuitable for agriculture because of its swampy nature.

Flood distributary patterns generally do not develop sufficient relief to be indicated on topographic maps. On aerial photographs they are indicated by a series of alternating light and dark linear trends of which the area shown in Figure 13 is an example. The darker areas represent low swales which coalesce and divide and generally become broader in a down valley direction. The lighter areas are low, broad swells which may rise as high as one to two feet above the floors of intervening swales. In this particular linear trend, the transverse distance between swales ranges from 50 to 250 feet. The entire pattern is concentric around the channel fill penetrated in Hole 10, Plate 3, Sheet 75L.

The flood basin area comprises a greater portion of the alluvial valley in the upper segment than in the middle or lower. To be strictly

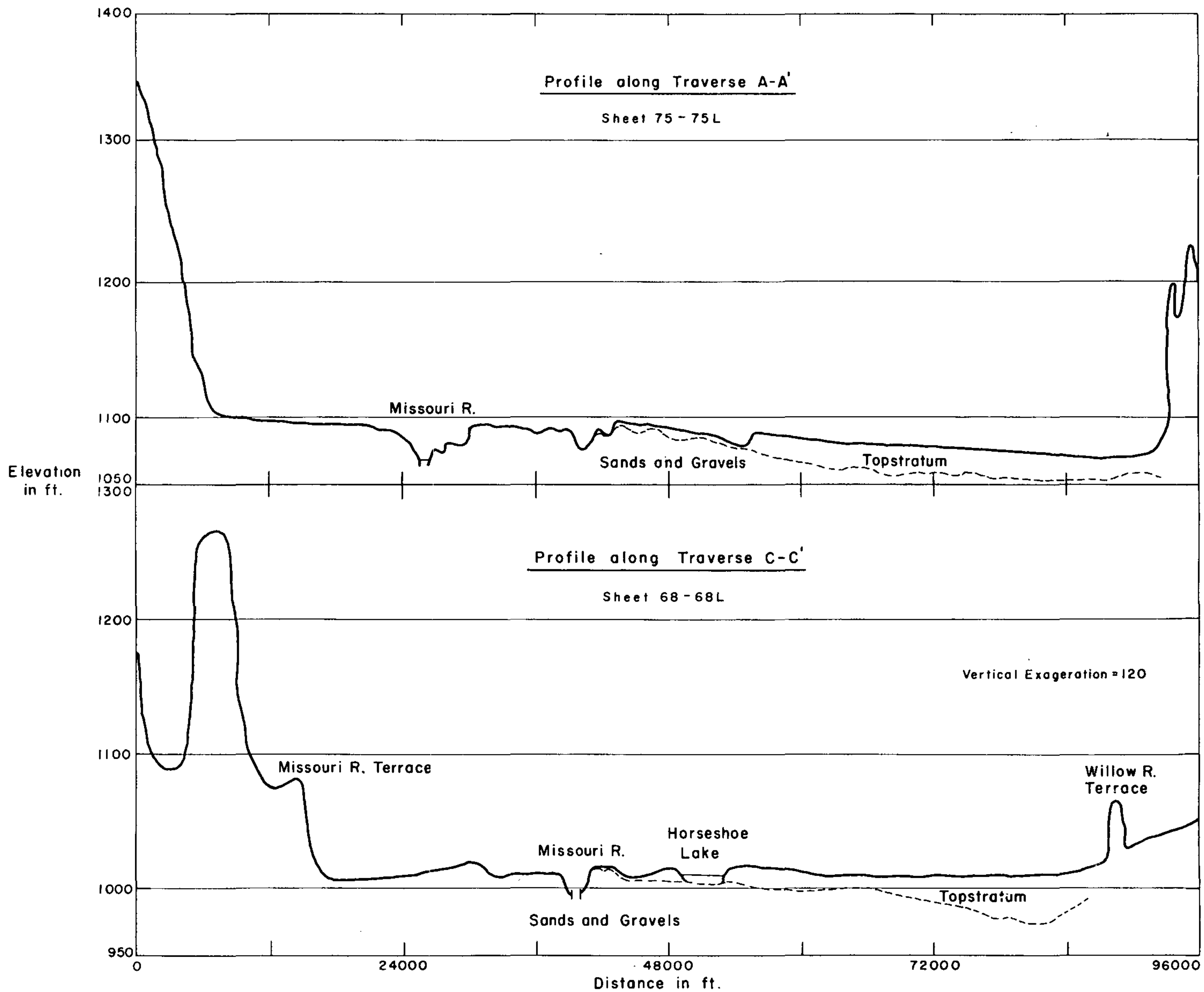
Figure 13. Surface features on natural levee and flood distributary areas, traverse A-A'.

6-1-56
A-1 -R2-94
6-1-56
A-1 -R2-54
Channel fill
Point bar
Natural Levee
"Clay Plug"
Big Sioux-Floyd
Channel
Linear trends - Flood distributary Channels
SCALE
feet
0
2000

analogous to the flood basins in the Lower Mississippi Valley, this area should be bounded by the natural levees of the meander belt area and the valley wall. The five foot contour interval of available topographic maps reveals little direct evidence of pronounced natural levees associated with many reaches of the Missouri River. In general, however, cross-valley profiles do rise toward the river; and aerial photographs along the meander belt margin reveal an area of lighter sediments lying in a concentric band around some older channel fills. Figure 14 shows the general nature of cross-valley profiles, and Figure 13 shows the surface expression of a natural leavee deposit along traverse A-A'. As a mappable unit, however, natural levees are not differentiated and are included in the flood basin deposits.

Some of the more important tributaries of the Missouri River adjacent to Iowa enter the alluvial valley in this upper segment. These may flow for long distances down valley before reaching their confluence with the Missouri. The tributary pattern outlined on Plate 3, Sheet 75L, can be continuously traced on southward to the vicinity of Hornick, Iowa (Sheet 74L). At Hornick it becomes dissected by the tributary pattern of the West Fork of the Little Sioux River, but discontinuous remnants of it may be followed as far south as Little Sioux, Iowa (Sheet 70L). This tribuaary channel pattern is one of the older geomorphic features in the alluvial valley. It apparently represents a former course of the combined Big Sioux and Floyd Rivers which was abandoned when the Missouri occupied the channel which truncates it at its upper end. At one time, the entire flow of the upper reach tributaries with the exception of the Boyer River may have been carried to the Missouri by this Big Sioux-Floyd channel.

Figure 14. Topographic profiles across the Missouri Valley illustrating the gradual rise in flood plain elevation from the bluffs to the river.


Profile along Traverse A-A'
Sheet 75 - 75L
Missouri R.
Sands and Gravels
Topstratum
Elevation in ft.
1400
1300
1200
1100
1050
1300
Profile along Traverse C-C'
Sheet 68 - 68L
Vertical Exageration = 120
1200
1100
1000
950
Missouri R. Terrace
Missouri R.
Horseshoe Lake
Willow R. Terrace
Topstratum
Sands and Gravels
0
24000
48000
72000
96000
Distance in ft.

Tributary stream patterns are highly individualistic and have characteristic dimensions determined by the combination of hydraulic variables found in each stream. The combined Big Sioux-Floyd channel, previously discussed, has a width of approximately 300 feet, a depth of about 8 feet, and a channel pattern characterized by relatively long straight reaches separated by sharp irregular bends. Little Sioux and Maple River channels (Plate 5, Sheet 72L) are 30 to 50 feet wide and 10 to 15 feet deep. Their channel patterns, however, are exceedingly crooked with very sharp bends and few straight reaches.

Flood basin deposits. The deposits of the flood basin area include the material deposited by the Missouri during floods, tributary channel deposits, and alluvial fans. Missouri flood deposits are the most abundant and widespread whereas tributary channel and alluvial fan deposits are only locally important.

Tiibutary channel and alluvial fan geomorphic expression have already been discussed. The remaining flood basin deposits show either natural levee surface expression or are characterized by being largely devoid of significant differences in relief. Natural levee deposits occur as low ridges around the outside margin of an abandoned channel. They occur only in the Sioux City to Crescent segment, and in many places cannot be identified as such even in this area. Thus the surface expression of flood basin area deposits is that of a flat, featureless, plain.

Crescent to Plattsmouth

The middle segment of the Missouri Valley is the narrowest part of the valley adjacent to Iowa. The flood plain is from 4 to 5 miles in width and the average stream gradient is 0.58 feet per mile.

Bedrock begins to rise from near flood plain level at Crescent and forms the lower section of the valley wall along the length of this segment. The higher glacial drift or loess mantled uplands rise to concordant highs 250 to 300 feet above the general flood plain level.

Meandering in the middle segment of the Missouri Valley is restricted by the narrowness of the alluvial valley despite the lower average gradient. This is indicated by the 1890 sinuosity ratio which decreases from 1.61 in the upper segment to 1.45.

The Missouri River maintains most of the characteristics described in the upper segment of the alluvial valley. It generally flows along the right valley wall and makes several sharp meander bends. The average radius of these bends is 5000 feet and the average channel width is approximately 1750 feet.

Alluvial morphology and flood plain deposits. The alluvial morphologh and geomorphic expression of flood plain deposits in this segment are similar to those of the upper segment. Tr verses D-D' and E-E' cross the alluvial valley near the upper and lower boundaries of the Crescent to Plattsmouth segment. Plates 8 and 9 are maps of the flood plain deposits along these traverses and Figure 15 shows the mechanical composition of samples from each flood plain deposit.

The channel belt in this segment ranges from 0.5 to 1.5 miles in width. Modern Missouri River point bars are the most common channel belt feature as the river is almost free of channel bars or islands. The meander belt ranges from 3 to 4 miles in width and may extend from bluff to bluff. The flood basin area is notably narrow along most of this segment. Alluvial fans extending out from the bluffs form a greater portion of flood basin deposits along this segment than along the upper segment.

Plattsmouth to south Iowa boundary

The lower segment of the alluvial valley of the Missouri River adjacent to Iowa ranges from 5 to 7 miles in width. In the upper part of the lower segment, bedrock overlain by glacial drift and/or loess forms the adjacent bluffs. In the middle and lower parts of this segment glacial drift or loess forms the entire bluff section. The surrounding upland hills rise to concordant highs 225 to 275 feet above the general flood plain level.

The Platte River exerts a controlling influence on the character of the Missouri River in this segment. Both the suspended load and bed load af the Platte are coarser than those of the Missouri and are equal in amount to those of the Missouri at Omaha (31). The sinuosity of the Missouri River decreases and its flood plain and stream gradients increase in response to the heavy load of the Platte. The average width of the stream channel increases and the average depth decreases as flow becomes divided around channel islands.

The alluvial morphology and deposits of this segment of the alluvial valley also reflect the influence of the Platte on the regimen of the Missouri. The average width of abandoned channels increases to approximately 2500 feet and they occupy arcuate areas with a radius of curvature ranging from 6000 to 8000 feet. Partially filled abandoned channels show distinct relief as in-channel bars stand 2 to 3 feet above the average

Plate 8. Alluvial geology, Sheet 66.

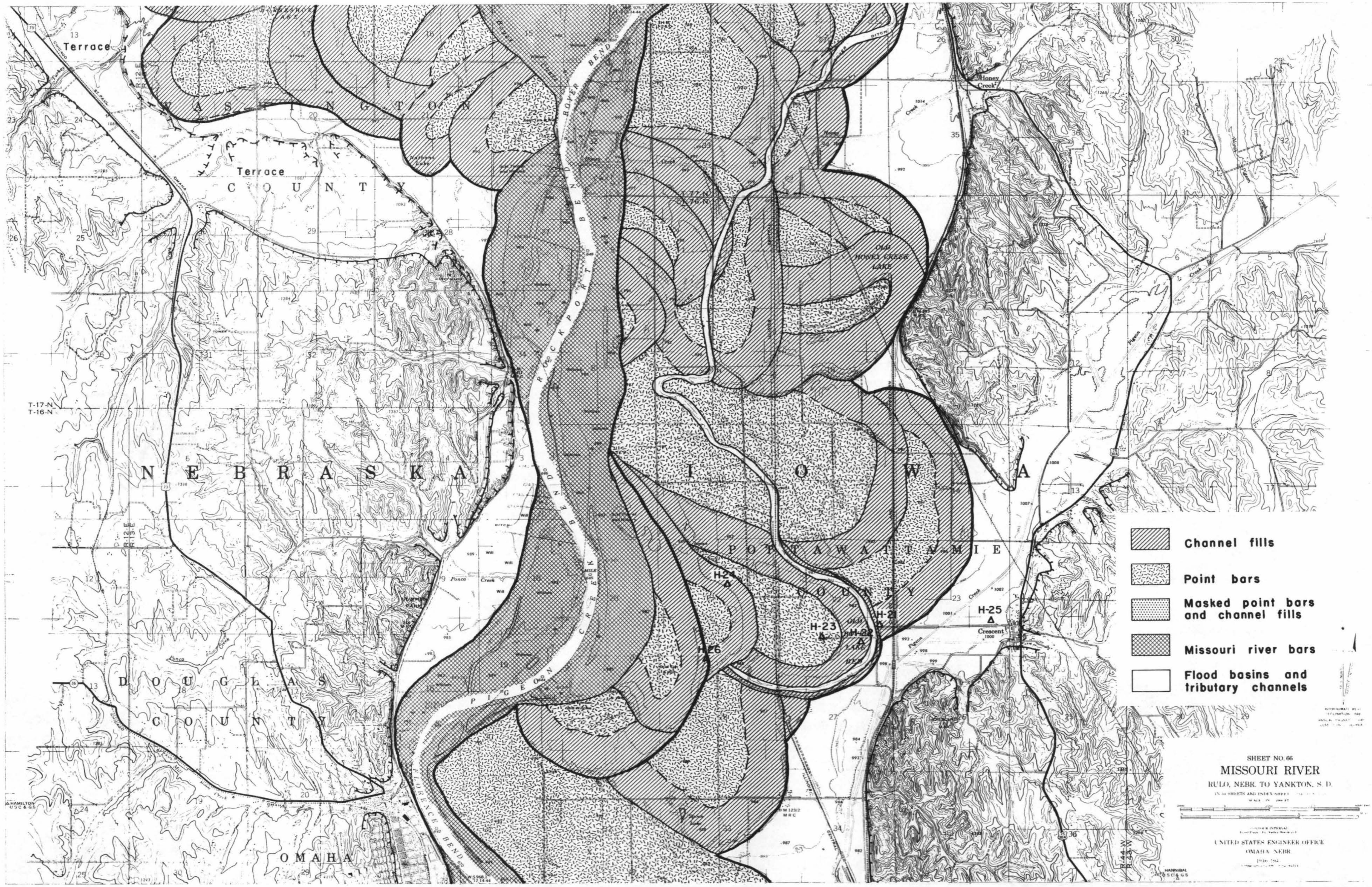
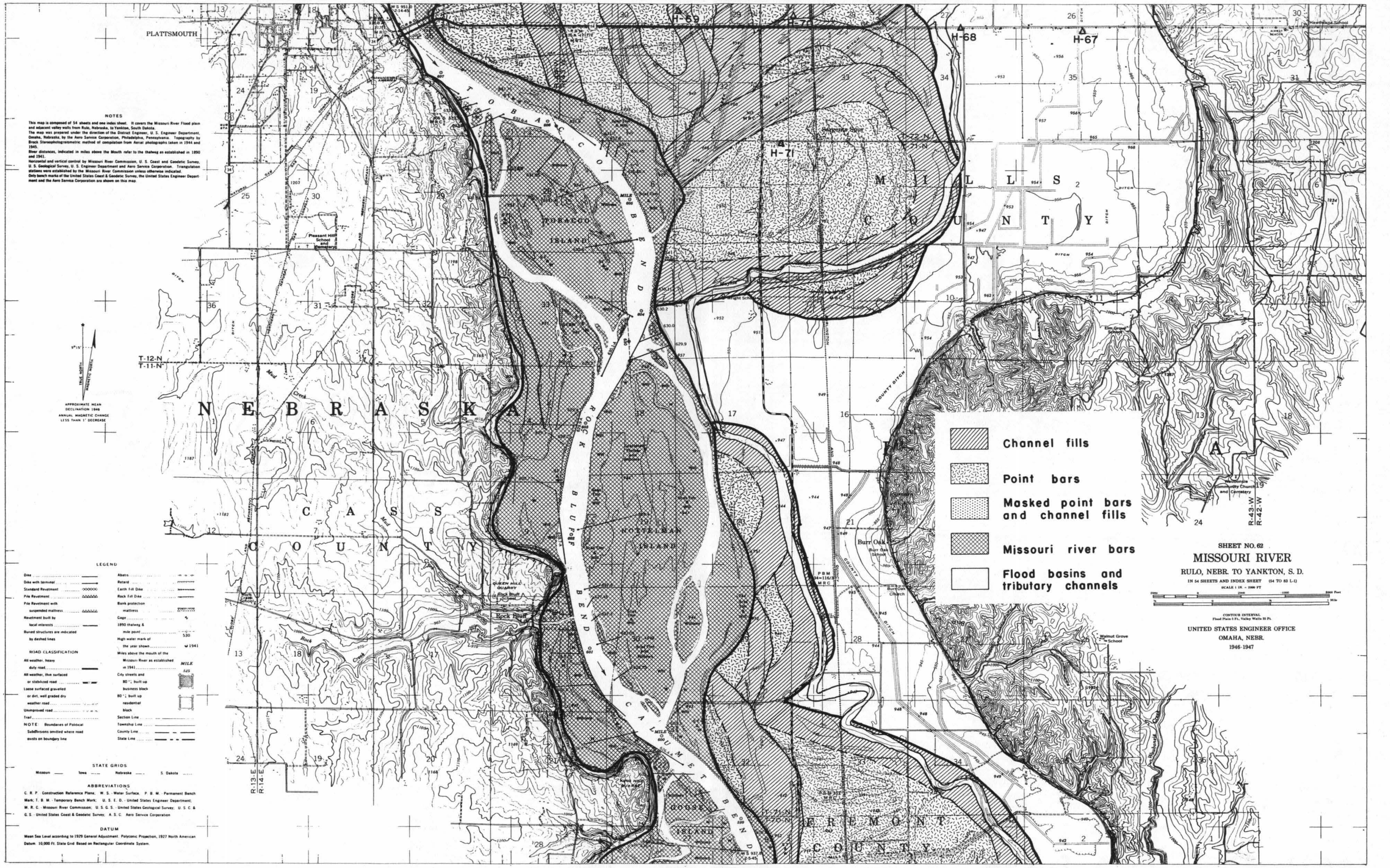
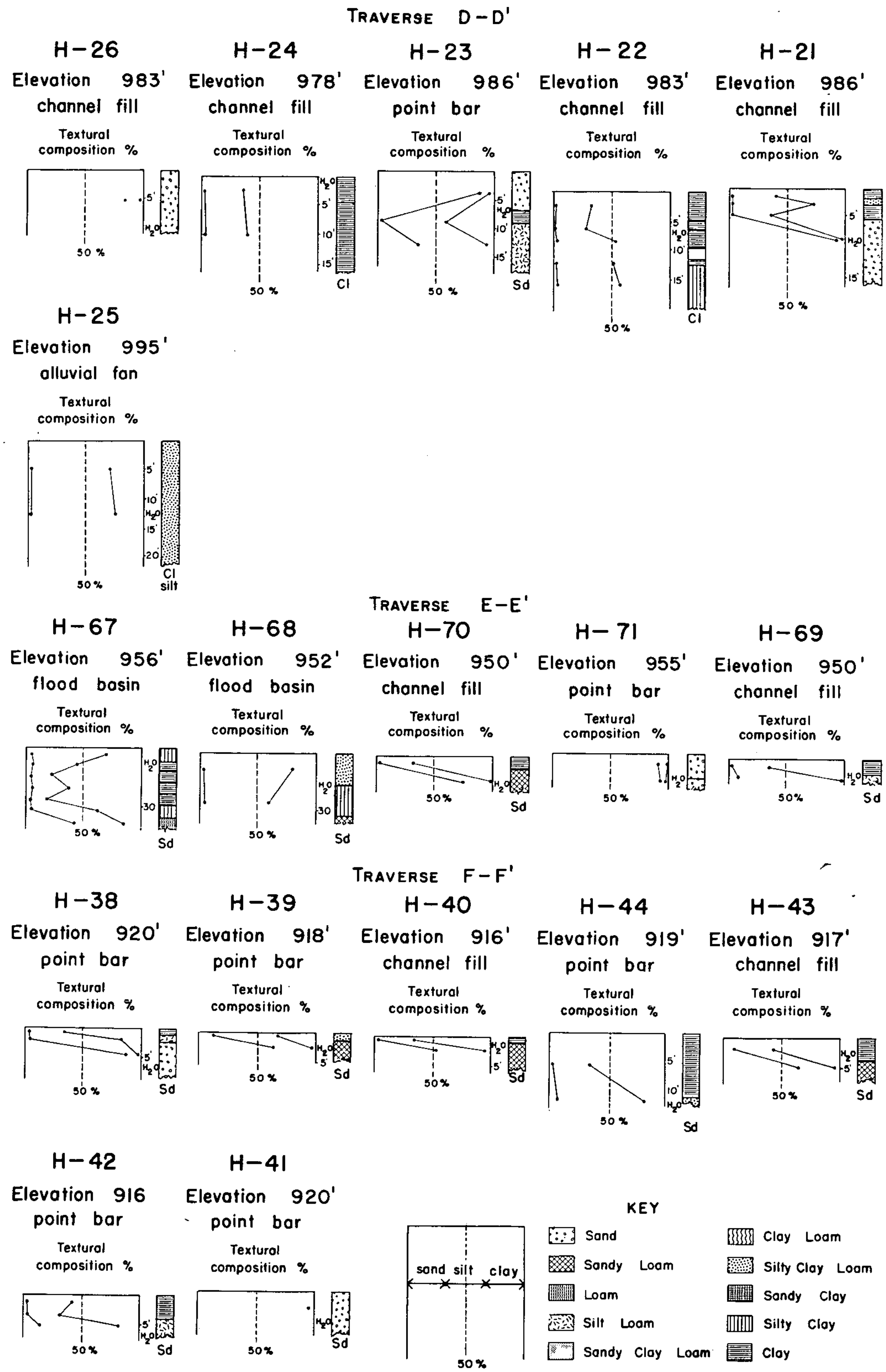

Terrace
W A S H I N G T O N
Terrace
C O U N T Y
OLD HONEY CREEK LAKE
Honey Creek
N E B R A S K A
I O W A
P O T T A W A T T A M I E
C O U N T Y
D O U G L A S
C O U N T Y
OMAHA
Crescent
ROCKPORT BEND
BOYER BEND
PIGEON CREEK BEND
FLORENCE BEND
H-21
H-22
H-23
H-24
H-25
H-26
T-17-N
T-16-N
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO. 66
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA NEBR.
HANNIBAL USC&GS

Plate 9. Alluvial geology, Sheet 62.



NOTES
This map is composed of 54 sheets and one index sheet. It covers the Missouri River Flood plain and adjacent valley walls from Rulo, Nebraska, to Yankton, South Dakota.
The map was prepared under the direction of the District Engineer, U. S. Engineer Department, Omaha, Nebraska, by the Aero Service Corporation, Philadelphia, Pennsylvania. Topography by Brock Stereophotogrammetric method of compilation from Aerial photographs taken in 1944 and 1945.
River distances, indicated in miles above the Mouth refer to the thalweg as established in 1890 and 1941.
Horizontal and vertical control by Missouri River Commission, U. S. Coast and Geodetic Survey, U. S. Geological Survey, U. S. Engineer Department and Aero Service Corporation. Triangulation stations were established by the Missouri River Commission unless otherwise indicated.
Only bench marks of the United States Coast & Geodetic Survey, the United States Engineer Department and the Aero Service Corporation are shown on this map.
PLATTSMOUTH
NEBRASKA
CASS COUNTY
MILLS COUNTY
FREMONT COUNTY
TOBACCO ISLAND
NOTTLEMAN ISLAND
GOOSE ISLAND
TOBACCO BEND
ROCK BLUFF BEND
CALUMET BEND
Rock Bluff
T-12-N
T-11-N
R-13-E
R-14-E
R-43-W
R-42-W
H-69
H-68
H-67
H-71
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO. 62
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
IN 54 SHEETS AND INDEX SHEET (54 TO 83 L-1)
SCALE 1 IN. = 2000 FT
CONTOUR INTERVAL
Flood Plain 5 Ft., Valley Walls 25 Ft.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
LEGEND
ROAD CLASSIFICATION
STATE GRIDS
ABBREVIATIONS
DATUM

Figure 15. Columnar sections showing mechanical compositions with depth, traverses D-D', E-E' and F-F'.



TRAVERSE D-D'
H-26
Elevation 983'
channel fill
Textural composition %
H-24
Elevation 978'
channel fill
Textural composition %
H-23
Elevation 986'
point bar
Textural composition %
H-22
Elevation 983'
channel fill
Textural composition %
H-21
Elevation 986'
channel fill
Textural composition %
H-25
Elevation 995'
alluvial fan
Textural composition %
Cl silt
TRAVERSE E-E'
H-67
Elevation 956'
flood basin
Textural composition %
H-68
Elevation 952'
flood basin
Textural composition %
H-70
Elevation 950'
channel fill
Textural composition %
H-71
Elevation 955'
point bar
Textural composition %
H-69
Elevation 950'
channel fill
Textural composition %
TRAVERSE F-F'
H-38
Elevation 920'
point bar
Textural composition %
H-39
Elevation 918'
point bar
Textural composition %
H-40
Elevation 916'
channel fill
Textural composition %
H-44
Elevation 919'
point bar
Textural composition %
H-43
Elevation 917'
channel fill
Textural composition %
H-42
Elevation 916
point bar
Textural composition %
H-41
Elevation 920'
point bar
Textural composition %
KEY
sand silt clay
50 %
Sand
Sandy Loam
Loam
Silt Loam
Sandy Clay Loam
Clay Loam
Silty Clay Loam
Sandy Clay
Silty Clay
Clay

elevation of the channel floor. Cut banks along the outside of bends are commonly from 4 to 8 feet high and point bars rise to an elevation 3 to 5 feet higher than that of the channel fill.

Alluvial morphology and flood plain deposits. Traverses E-E' and F-F' cross the alluvial valley near the upper and lower boundaries of the lower segment. Plates 9, 10 and 11 are maps of the alluvial deposits along these traverses and Figure 15 shows the mechanical composition for samples along each traverse.

The channel belt along this segment ranges from 1 to 2 miles in width. A large number of Missouri River bars and islands characterize the geomorphic expression of the channel belt area. The meander belt ranges from 5 to 7 miles in width and, in many places, occupies almost the entire flood plain area. The flood basin area is characteristically lacking in relief features with the exception of alluvial fans and is generally less than a mile in width and may be entirely absent.

The alluvial deposits also reflect the change in the regimen of the Missouri. Sand occurs closer to or on the surface in channels and fine-grained topstratum is thinner both on point bars and in the flood basin. This is reflected both in bore holes, many of which penetrated the fine-grained material, and in the relatively smoothness of stream bends which indicates that the stream had little difficulty cutting its channel.

The sand on the surface in both the channel belt and the meander belt areas may be reworked by wind. Figure 6 is a view of an extensive area of the flood plain near Nebraska City, Nebraska (Sheet 59), in which the distinctive surface features are the result of wind erosion

Plates 10-11. Alluvial geology, Sheets 60 and 60L.

CASS COUNTY
OTOE COUNTY
NEBRASKA
IOWA
FREMONT COUNTY
NEBRASKA CITY
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO. 60
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
LEGEND
NOTES
STATE GRIDS
ABBREVIATIONS
DATUM
SHEET NO. 60L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947

and deposition. These areas can be recognized by their irregular topographic expression and show up on aerial photos as mottled light and dark areas.

SAMPLING METHODS AND PROCEDURES

Field Phase

Prior to the first field season, topographic maps and aerial photographs of the Missouri River adjacent to Iowa were secured from the Omaha District of the Corps of Engineers. Using the air photos, the alluvial deposits were identified and outlined on the topographic maps according to the techniques employed by Fisk (11). The topographic maps will serve as base maps for this and subsequent reports.

The first phase of the field investigation involved checking the validity of the mapping techniques and selection of traverse areas for detailed sampling. Six areas, about equally spaced along the length of the valley, were selected primarily because they exhibited well defined alluvial deposits. The index map of the alluvial valley (Plate 1) shows the general location of these traverse areas.

With the selection of the traverse areas completed, the next step was to determine bore-hole locations. In the meander belt area where the greatest variation in deposits occurs, bore holes were so placed as to sample as many of the different deposits as extensively as possible. Bore holes were spaced at one mile intervals across the flood basin except where deposits of minor tributaries were investigated.

Laboratory Phase

The laboratory tests performed on these samples are those necessary to determine the engineering classification of the alluvial deposits.

Mechanical analyses were performed on all samples to determine the size frequency distribution of the constituent particles by the hydrometer and sieving method (A.S.T.M. Designation: D 422-54T) as the dispersing agent. The fraction retained on the No. 200 sieve was then dry sieved through the following nest of sieves: No. 20, No. 40, No. 60, No. 100, or No. 140, and No. 200.

The textural classification of each sample was then determined according to the textural classes of the U. S. Bureau of Public Roads (30) (Figure 16).

Determination of the soil-water consistency and engineering classification was done on selected samples by laboratory personnel according to the following procedures:

1) Liquid limit (A.S.T.M. Designation: D 423-54T) (2).

2) Plastic limit (A.S.T.M. Designation: D 424-54T) (2).

3) Plasticity index (A.S.T.M. Designation: D 424-54T) (2).

4) Engineering classification: Bureau of Public Roads (30).

During the course of this investigation, 71 holes were bored and 227 samples taken. Borings were done by hand auger to a depth of thirty feet and by continuous flite power auger to a depth of sixty feet. A general description of the material found as to particle size, color, texture, and oxidation state was kept and the depth of the water table recorded. Point samples or composite samples were taken whenever significant changes in these properties were observed. The samples were then

Figure 16. Textural classification chart for U. S. Bureau of Public Roads.

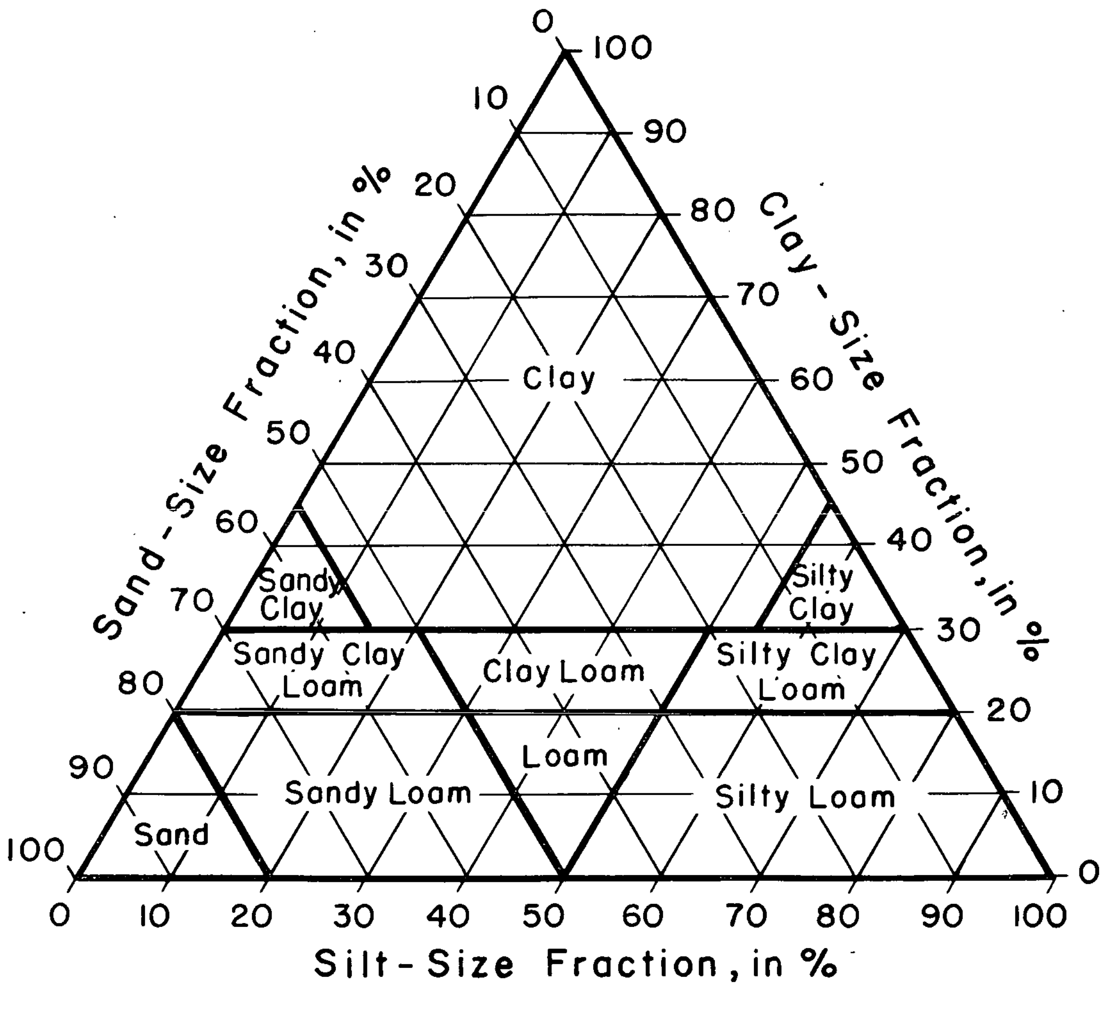
Textural Classification Chart

U.S. Bureau of Public Roads

Sand-Size Particles 0.074 to 2 mm.

Silt-Size Particles 0.005 to 0.074 mm.

Clay-Size Particles less than 0.005 mm.



placed in cloth bags and transported back to the laboratory for further analysis.

PRESENTATION OF DATA

The data to be presented in this report consists primarily of those necessary to determine the engineering classification of the different alluvial deposits. These have been discussed with respect to their geomorphic expression and mechanical composition so far as this composition was important in determining the surface expression of some deposits. The following discussion treats in more detail the specific characteristics and engineering behavior of each type of alluvial deposit.

Alluvial Sequence and Engineering Classification

Briefly, the alluvial fill consists of two major units, a substratum of sands and gravels and a topstratum of fine-grained material. The physical characteristics of the upper fine-grained unit permis a further subdivision of this portion of the alluvial fill into deposits of the point bar, channel fill and backswamp environments. In the meander belt area, some deposits could not definitely be delineated as channel fills or point bars and have been mapped as masked or undifferentiated channel fill and point bar material. Within the flood basin area natural levee, tributary stream and alluvial fan deposits may be important locally.

<u>Substratum sands and gravels</u>.

The sands and gravels of the substratum unit compose the major portion of the alluvial fill, Deep borings in the valley reveal that this unit ranges from 70 to over 100 feet in thickness and grades from gravels and boulders near the base to predominantly sand near the top. Samples from 60 foot holes bored during the course of this investigation show increasing median particle diameters with increasing depth.

Generally the substratum materials found near the top of the unit consist of a relatively clean, fine to medium sand. Above the water table, the material is commonly oxidized to a red-brown color and contains discrete particles of $CaCO_3$ disseminated throughout. Below the water table and particularly below channel fill topstratum, the sand is in a reducing environment and is a black to gray color.

Quartz is the most abundant mineral found in substratum sand samples. It is generally poorly rounded to angular, the difference apparently correlated with grain size, the finer sand grains being better rounded than the medium and coarser grains. Other minerals occurring in a significant amount are feldspars and a dark mica. Scattered lenses of gravel occur and commonly consist of fragments of crystalline rocks.

The boundary between substratum and topstratum is commonly marked by a transition zone indicating some mixing of the two units during deposition or during sampling. However, this boundary is easily recognized during borings by the transition from fine to coarse-grained material. Mechanical analyses of all samples reveal that topstratum samples invariably have a median particle diameter less than or equal to 0.074 mm. whereas substratum samples have larger median particle diameters.

Materials of the substratum unit occur at varying depths with respect to the surface of the fill throughout the alluvial valley. Within the channel belt area, substratum sands occur at or near the surface. The most modern point bars within the meander belt also have sand exposed at the surface. Twenty-five feet o fine-grained topstratum have been found overlying substratum sands in some channel fills, and this figure is probably exceeded in others. In the modern river, depths of scour to a maximum of 60 feet* have been recorded, and depths to 30 feet are common. Channel fill topstratum thus could accumulate to this thickness. Point bars, because of their higher topographic position, commonly have less topstratum over substratum than may be found in channel fills. The thickness of topstratum over point bars increases with distance from the river and a maximum of 20 feet was penetrated in one point bar hole near the meander belt margin. The top of the substratum under point bars generally reflects the original swell and swale relief. The swales, being topographically lower, may be expected to have greater thicknesses of topstratum in them. Deposition in the swales gradually results in reduction of the surface relief of a point bar until, as the margins of the meander belt are approached, they may be essentially flat. In the flood basin area, depths to substratum reach the maximum observed during this investigation. Several holes reached the substratum at depths from 36 to 42 feet.

The preceding discussion of the general nature of the substratum distribution and depth below the surface of the fill will apply to the entire valley. As has been discussed, however, thickness of topstratum over substratum below the Platte River are generally less than the above

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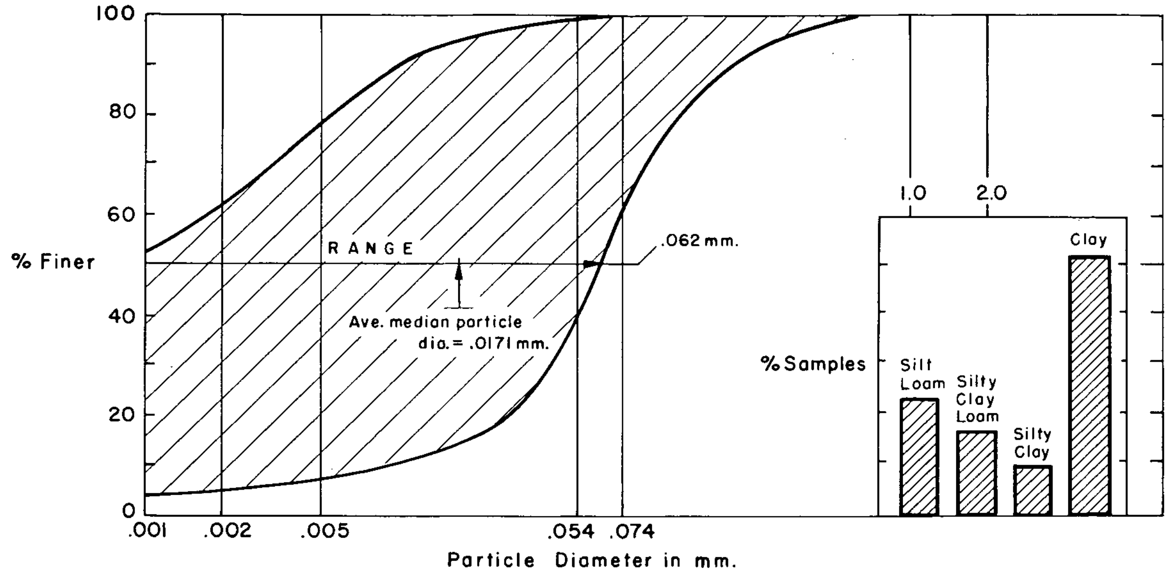
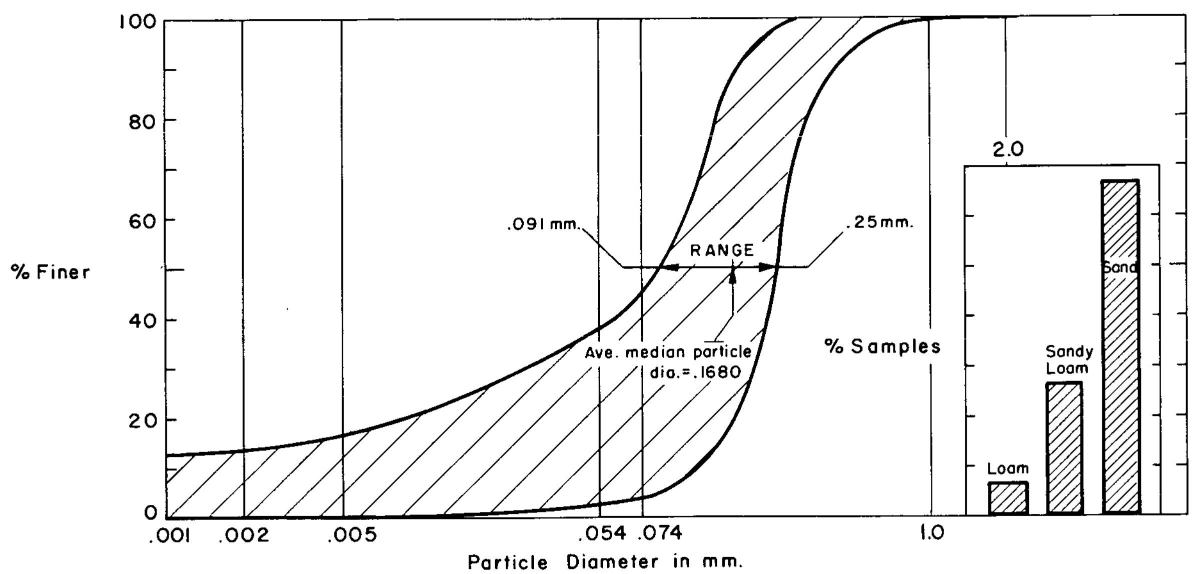
*Huber, R. L., Corps of Engineers, Omaha, Nebraska. Data on depths of scour. Private communication. 1959.

Figure 17. Range in cumulative curves for 31 point bar topstratum samples and percent of samples in each textural class.

Figure 18. Range in cumulative curves for 15 point bar substratum samples and percent of samples in each textural class.


100
80
60
40
20
0
% Finer
RANGE
.062 mm.
Ave. median particle
dia. = .0171 mm.
.001
.002
.005
.054
.074
Particle Diameter in mm.
1.0
2.0
% Samples
Silt Loam
Silty Clay Loam
Silty Clay
Clay


100
80
60
40
20
0
% Finer
.091 mm.
RANGE
.25mm.
Ave. median particle
dia. = .1680
.001
.002
.005
.054
.074
1.0
Particle Diameter in mm.
2.0
% Samples
Loam
Sandy Loam
Sand

figures. The distribution of topstratum below the Platte does conform to the general relationships developed above.

Point bar deposits

The deposits of the point bar environment include the silts and clays of the topstratum, and the sands of the substratum. Figures 17 and 18 show the range in cumulative curves and percent of samples in each textural class for point bar topstratum and substratum samples. The greatest concentration of samples is in the clay and silty clay textural groups. Invariably, samples containing significant percentages of sand occur near the base of the topstratum.

Topstratum samples are generally gray to black to red in color, the difference being correlated with organic matter content and oxidation state. Organic matter is usually concentrated in the upper few feet of fill. Locally this is also the zone of oxidation. The water content of most point bar topstratum deposits is relatively low, and the position of the water table is usually below or near the boundary between topstratum and substratum.

Point bar substratum samples are usually gray to red and exhibit crossbedding. Thin lenses of gravel occur throughout the deposit, and silt or clay lenses are found in the upper few feet of the substratum. Approximately 67 percent of substratum samples fall into the sand textural class. The Trask sorting coefficient indicates that these are usually well sorted.

Table 3 shows the engineering classification of selected point bar samples. Where considerable thickness of topstratum overlies a point

Table 3. Point bars

Sample Number	Sample Depth	Liquid Limit	Plastic Limit	Plasticity Index	Percent Clay-Sand	Engineering Soil Classification	Remarks
H1-S1	0-7.5'	Non-Plastic			2-98	A-3(0)	substratum
H3-S1	0-2'	28.4	26.4	2	25-25	A-4(8)	topstratum
H4-S1	0-1'	23.0	19.5	3.5	23-08	A-4(8)	topstratum
H4-S2	2-6'	30.5	29.4	1.1	14-22	A-4(8)	topstratum
H9-S1	0-3.5'	68.5	28.6	39.9	68-00.4	A-7-5(20)	topstratum
H12-S1	0-4'	76.2	29.2	47.0	77-00.4	A-7-6(20)	topstratum
H23-S1	0-7.5'	Non-Plastic			1-91	A-3(0)	substratum
H27-S1	0-7.5'	76.2	27.2	49.0	72-00.4	A-7-6(20)	topstratum
H32-S1	0-2.5'	32.7	22.3	10.4	21-20	A-4(8)	topstratum
H38-S1	0.1.0'	66.4	26.1	40.3	69-00.3	A-7-6(20)	topstratum
H39-S2	1-4'	Non-Plastic			2-65	A-2-4(0)	topstratum substratum
H41-S1	0-6'	Non-Plastic			0.5-96	A-3(0)	substratum
H42-S1	0-3'	72.8	26.3	46.5	61-03	A-7-6(20)	topstratum
H44-S1	0-11'	71.0	25.2	45.8	70-01	A-7-6(20)	topstratum

bar, the upper portion generally classifies A-7. The typical material of this group is a plastic clay soil which exhibits high volume change between wet and dry states and is generally elastic in nature. The A-7-5 sub-group materials are especially subject to elastic deformation whereas the A-7-6 sub-group is generally subject to extremely high volume changes. The group index of A-7 soils ranges from 1 to 20. Higher values indicate the combined effect of high liquid limits and plasticity indices and increased percent of fines. The percentage of clay in point bar topstratum ranges from 12 to 80 percent and the average for all point bar topstratum samples is 44 percent.

The lower few feet of point bar topstratum is usually a transition zone where mixing of topstratum and substratum has taken place. Missouri River bars and modern point bars in the meander belt with thin topstratum over them have this zone of mixed materials at the surface. Generally this material may be classed in the A-4 engineering soil group. The typical material of this group is a moderately plastic silty soil. The percent of silt in point bar topstratum of this group ranges from 50 to 69 percent, and the average of point bar transition zone samples is 60 percent.

The substratum sand which underlies the alluvial valley surface and occurs at the surface in the channel belt area and in some modern point bars commonly is an A-3 engineering soil. The typical material of this group is a fine to medium sand with limited amounts of coarse sand and gravel. The percent of sand in substratum samples ranges from 58 to 98 percent, and the average of all substratum samples is 84 percent.

Small quantities of silt generally comprise the remainder of substratum samples.

Channel fill deposits

Channel fill deposits consist of varying thicknesses of interbedded clays and silts underlain by substratum sand. The topstratum of channel fills is usually blue to black in color and contains abundant organic matter. Modern channel fill material accumulates in ox-bow lakes which eventually become filled above the level of the water table. Fluctuation of the water table then results in the upper portion of a fill developing a mottled color because of alternating oxidizing and reducing conditions. The lower few feet of fill may become compacted into a very tenacious blue clay because of the weight of the overlying material.

Figures 19 and 20 show the range in cumulative curves and percent of samples in each textural class of channel fill topstratum and substratum samples. A number of textural classeas are represented in channel fill topstratum, but almost 84 percent of samples fall into the clay textrual class. The difference in the amount of clay sized material in point bar topstratum and channel fill topstratum is illustrated by the difference in average of the median particle diameters of the two deposits. The average of the median particle diameter of point bar topstratum samples is well within the silt range whereas channel fill topstratum samples have median particle diameter near the lower boundary of the silt range. Because of the high water content of channel fill deposits, samples of topstratum and substratum material may become mixed because of flowage into bore holes. This probably explains, in part, the concentration of substratum samples in the sandy loam textural class and the variety of textural classes in topstratum samples.

Table 4 shows the engineering classification of selected channel fill samples. Because substratum samples are generally non-plastic A-3 materials and can easily be recognized as such, very few samples of them have been run for purposes of engineering classification. Channel fill topstratum samples generally classify A-7. The percent of clay in these samples ranges from 27 to 82, and the average percent of clay in all samples is 62 percent. This represents an increase of 18 percent over the average percent of clay in point bar topstratum samples.

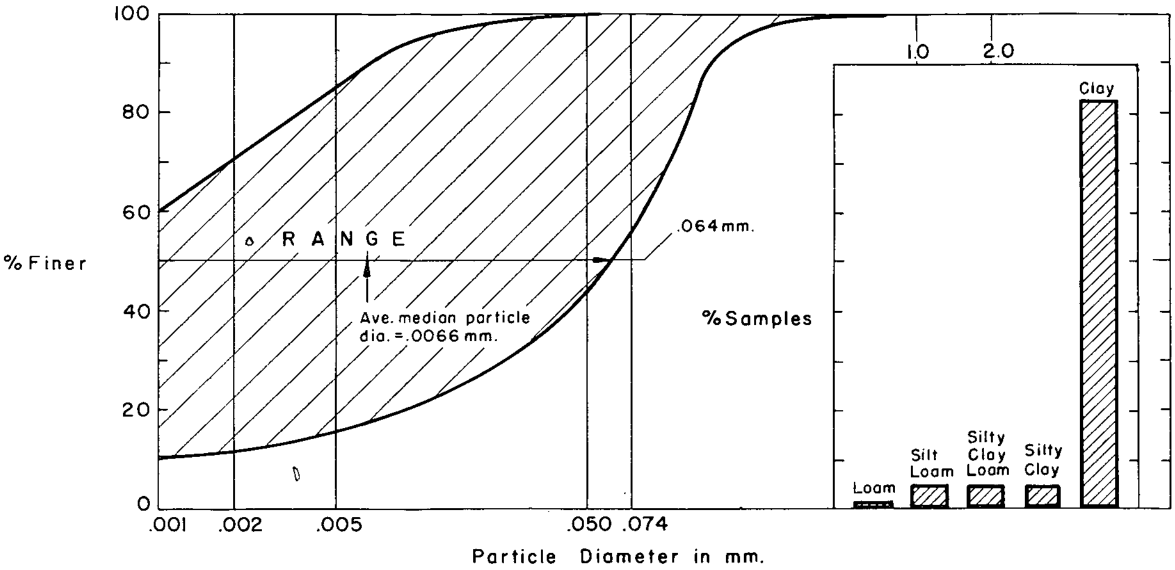
Undifferentiated deposits

Within the meander belt area, some point bar and channel fill deposits have been masked by materials deposited during floods. These point bar and channel fill deposits are extensive in some areas and have been mapped under the designation of masked channel fills and point bars. The characteristics of the deposits found in these areas are similar to those of the previously described channel fills and point bars. Figures 21 and 22 show the range in cumulative curves and percent of samples in each textural class for masked channel fill and point bar deposits. The average median particle diameter of topstratum samples is between that of channel fill and point bar topstratum. Substratum sands have an average median particle diameter slightly larger than that of surrounding substratum material.

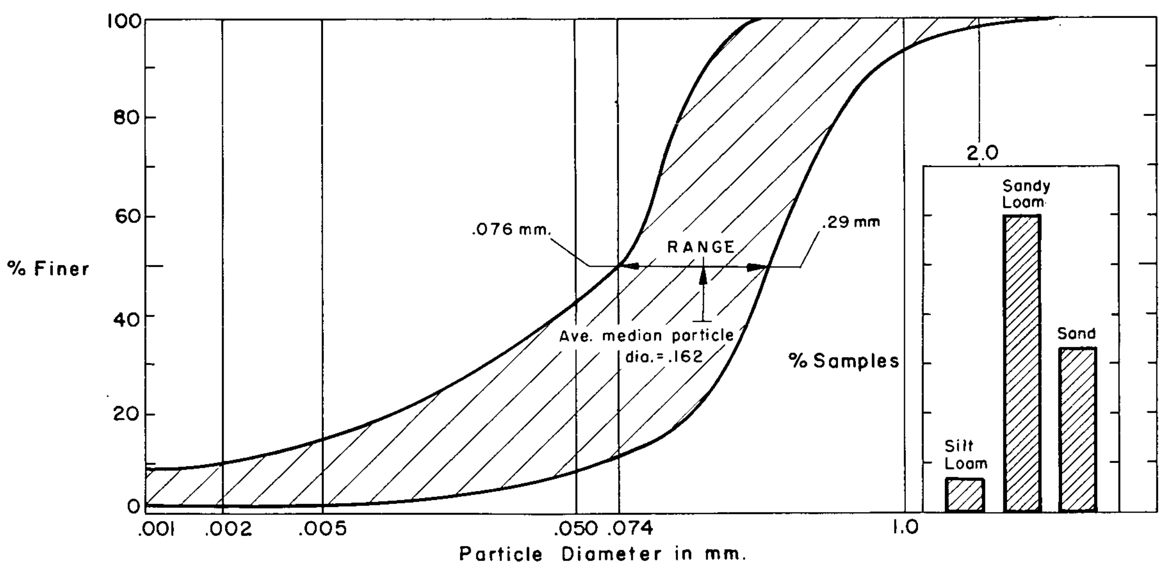
Table 5 gives the engineering classification of selected undifferentiated samples. As in channel fill and point bar samples, most

Figure 19. Range in cumulative curves for 60 channel fill topstratum samples and percent of samples in each textural class.

Figure 20. Range in cumulative curves for 15 channel fill substratum samples and percent of samples in each textural class.



100
80
60
40
20
0
% Finer
RANGE
Ave. median particle
dia. = .0066 mm.
.064 mm.
.001
.002
.005
.050
.074
Particle Diameter in mm.
1.0
2.0
% Samples
Clay
Loam
Silt
Loam
Silty
Clay
Loam
Silty
Clay



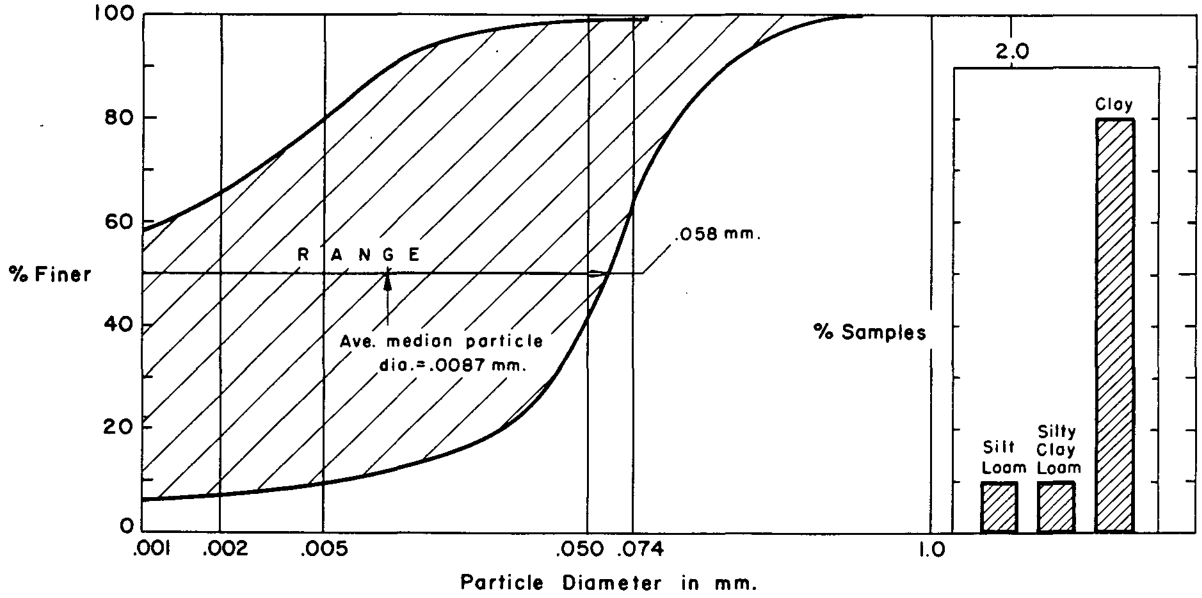
100
80
60
40
20
0
% Finer
.076 mm.
RANGE
.29 mm
Ave. median particle
dia. = .162
.001
.002
.005
.050
.074
1.0
Particle Diameter in mm.
2.0
% Samples
Sandy
Loam
Sand
Silt
Loam

Table 4. Channel fills.

Sample number	Sample depth	Liquid limit	Plastic limit	Plasticity index	Percent clay-sand	Engineering soil classification	Remarks
H5-S1	0-4'	70.7	22.3	48.4	72-00.2	A-7-6(20)	topstratum
H5-S4	8-9'	41.1	23.0	18.1	42-01	A-7-6(11)	topstratum
H6-S1	0-6.5'	75.0	30.0	45.0	81-00.2	A-7-5(20)	topstratum
H8-S1	0-3.5'	80.6	29.8	50.8	72-00.2	A-7-6(20)	topstratum
H10-S1	0-3.5'	76.2	29.4	46.8	79-01	A-7-5(20)	topstratum
H11-S1	3-12'	75.3	30.5	44.8	81-00.5	A-7-5(20)	topstratum "clayplug"
H11-S4	20-25'	79.6	27.2	52.4	75-00.8	A-7-6(20)	topstratum "clayplug"
H21-S1	0-2'	63.2	23.0	40.2	62-01	A-7-6(20)	topstratum
H22-S1	0-5.5'	73.3	24.9	48.4	72-00.4	A-7-6(20)	topstratum
H24-S1	0-4'	76.6	25.9	50.7	68-00.4	A-7-6(20)	topstratum
H26-S1	0-11'	Non-Plastic			1-87	A-1(0)	substratum
H28-S1	0-3.5'	84.5	29.5	55.0	72-00.1	A-7-6(20)	topstratum
H29-S1	0-7'	73.8	26.5	47.3	76-00.2	A-7-6(20)	topstratum
H31-S2	2.0-7'	80.4	31.7	48.7	82-02	A-7-5(20)	topstratum
H33-S1	3.8-6.8'	91.3	31.7	59.6	36-20	A-7-6(20)	topstratum
H34-S2	1.0-1.7'	90.2	31.5	58.7	83-02	A-7-6(20)	topstratum
H34-S5	3-7'	33.0	21.9	11.1	27-17	A-7-5(9)	topstratum
H36-S1	.5-10'	80.3	27.2	53.1	71-03	A-7-6(20)	topstratum
H40-S1	0-1.0'	74.6	30.4	44.2	66-02	A-7-5(20)	topstratum
H43-S1	0-4'	66.8	23.5	43.3	57-10	A-7-6(20)	topstratum
H46-S1	5-12'	77.4	38.9	38.5	65-03	A-7-5(20)	topstratum
H47-S1	0-7'	69.2	26.5	42.7	65-02	A-7-6(20)	topstratum
H48-S1	0-5'	48.2	20.7	27.5	42-11	A-7-6(18)	topstratum

Figure 21. Range in cumulative curves for 10 undifferentiated top-stratum samples and percent of samples in each textural class.

Figure 22. Range in cumulative curves for 11 undifferentiated substratum samples and percent of samples in each textural class.


100
80
60
40
20
0
% Finer
.001
.002
.005
.050
.074
1.0
Particle Diameter in mm.
R A N G E
.058 mm.
Ave. median particle
dia.=.0087 mm.
% Samples
2.0
Clay
Silt
Loam
Silty
Clay
Loam

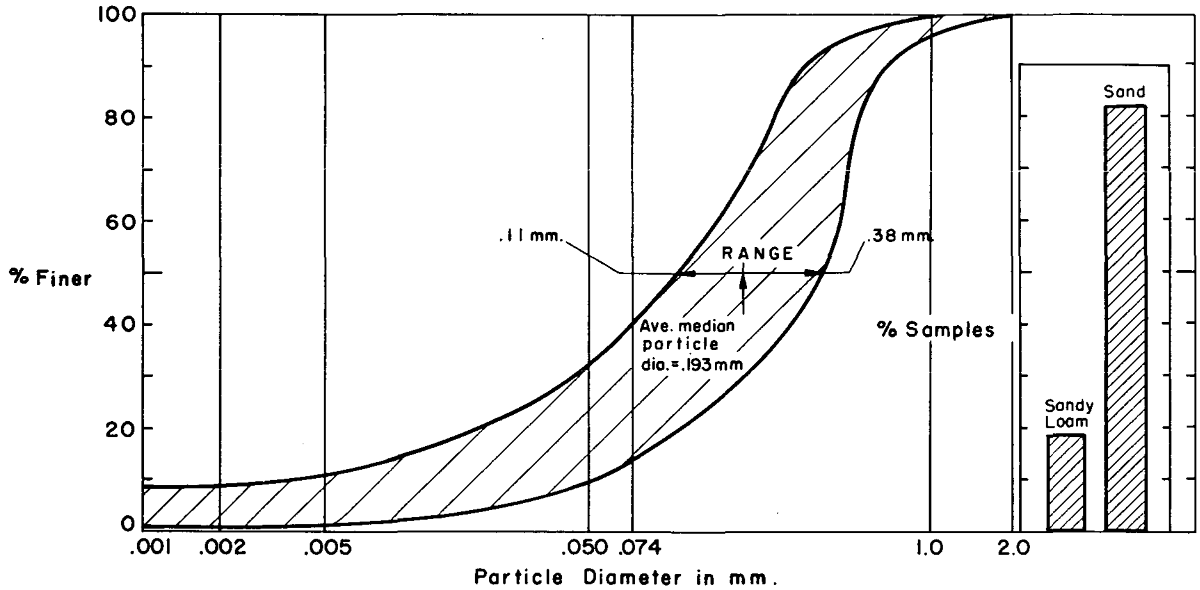

100
80
60
40
20
0
% Finer
.001
.002
.005
.050
.074
1.0
2.0
Particle Diameter in mm.
.11 mm.
RANGE
.38 mm
Ave. median
particle
dia.=.193mm
% Samples
Sand
Sandy
Loam

Table 5. Undifferentiated.

Sample number	Sample depth	Liquid limit	Plastic limit	Plasticity index	Percent clay-sand	Engineering soil classification	Remarks
H30-S1	.5-4.5'				8-30	A-4(8)	topstratum natural levee?
H35-S2	1.2-7.0'	81.0	27.2	53.8	74-02	A-7-6(20)	topstratum
H52-S1	4"-8'	87.0	29.6	57.4	81-02	A-7-6(20)	topstratum
H53-S1	0-14'	83.3	26.4	56.9	72-06	A-7-6(20	topstratum

undifferentiated samples classify A-7. Hole 30 is located near the cutbank of an abandoned channel and the material sampled probably represents a natural levee deposit associated with the Horseshoe Lake channel. This material is similar to the overbank topstratum on the surface of some Missouri River bars and modern point bars with thin topstratum in that it is predominantly silt and classifies as A-4.

Flood basin deposits

The deposits of the flood basin area are most extensive in the upper and wider segment of the alluvial valley. These deposits mask older strata and consist of interbedded laminated clays and silty clays and minor amounts of silty and clayey sands.

Flood basin deposits represent the slow accumulation of flood water sediments in low basins marginal to the meander belt area. They commonly have organic matter contents as large or larger than that of most channel fills. Characteristically, these deposits have a reddish-brown to gray color and are commonly mottled. The mottled appearance is attributed to fluctuations of the water table and alternation of reducing and oxidizing conditions. Flood basin topstratum will generally contain less water than channel fill topstratum but more than point bar topstratum.

Small calcium carbonate and iron concretions resembling "pipe stems" are commonly scattered within the deposit. The distribution of the carbonate concretions is apparently related to texture and permeability. Some clay lenses or bands within a more permeable material have a zone of concretions near the upper boundary. Iron oxide concretions are commonly cylindrical with a small hole along the axis and may be scattered throughout the backswamp material.

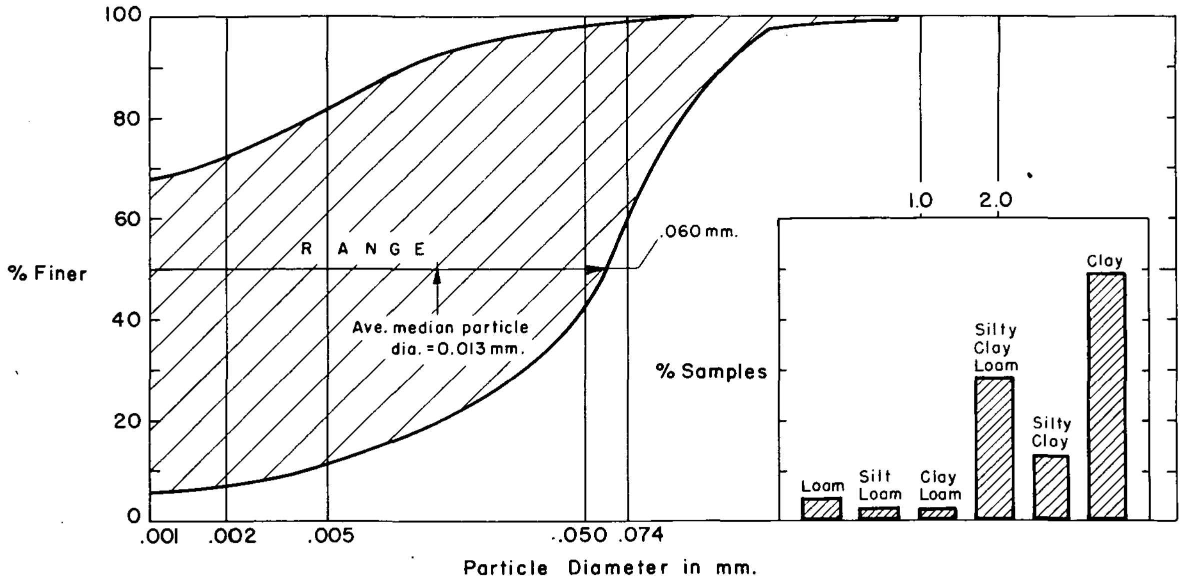
Figures 23 and 24 show the range in cumulative curves and percent of samples in each textural class for selected flood basin topstratum samples. The substratum of the flood basin area is similar to that previously discussed.

Flood basin topstratum samples are represented in more textural classes than any other major deposit. The biomodal distribution of samples is attributed to the inclusion of alluvial fan and natural levee deposits in the flood basin sample data. All silty clay loam samples are from locations near the valley margins or on natural levees. The greatest concentration of flood basin samples, as in other major deposits, are in the clay textrual class. Silty clays and combinations of clay and sand comprise the remainder of the samples. As in the point bar and channel fill deposits, samples containing significant percentages of sand generally occur just above the substratum boundary in the lower few feet of topstratum material. The amount of clay in flood basin topstratum samples ranges from 16 to 90 percent. The average clay content is approximately 46 percent. The average of the median particle diameters places the median particle size well within the silt range but smaller than that of point bar topstratum samples. Excluding the silty clay loam samples, the average of the median particle diameters decreases to .0090 mm., coarser than channel fill topstratum samples but finer than point bar topstratum samples.

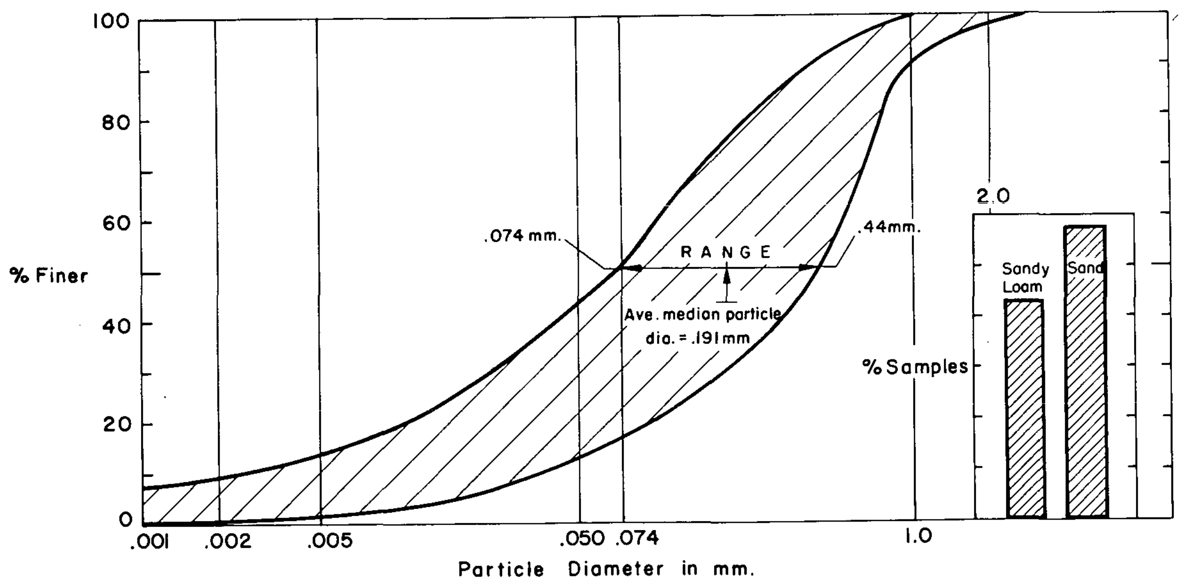
The substratum which underlies flood basin topstratum is similar to that of adjacent areas. The majority of samples again fall in the sand and sandy loam testural classes. The average of the median

Figure 23. Range in cumulative curves for 71 flood basin topstratum samples and percent of samples in each textural class.

Figure 24. Range in cumulative curves for 14 flood basin topstratum samples and percent of samples in each textural class.



100
80
60
40
20
0
% Finer
R A N G E
.060 mm.
Ave. median particle
dia. = 0.013 mm.
.001
.002
.005
.050
.074
Particle Diameter in mm.
1.0
2.0
% Samples
Loam
Silt Loam
Clay Loam
Silty Clay Loam
Silty Clay
Clay



100
80
60
40
20
0
% Finer
.074 mm.
R A N G E
.44mm.
Ave. median particle
dia. = .191 mm
.001
.002
.005
.050
.074
1.0
Particle Diameter in mm.
2.0
% Samples
Sandy Loam
Sand

particle diameters is comparable to that of undifferentiated deposits and greater than that of channel fill or point bar substratum. The median particle diameter of modern river sands is closer to that of the point bar and channel fill substratum materials. Two possible explanations exist for this observation. Either the river was capable of carrying coarser material during the time when it occupied the flood basin area or more samples from deeper depth intervals were used in computing the average of the median particle diameters in the flood basin and undifferentiated areas.

Table 6 contains the engineering classification data for selected flood basin samples. As in other deposits, the A-7 engineering soil group contains the majority of topstratum samples.

Natural levee, tributary channel and alluvial fan depssits. In the upper and middle divisions of the alluvial valley natural levee deposits are locally important and can be recognized. These consist of a ridge-like mass of clays, silty clays and sands deposited by overbank flow along stream channels. They may be recognized in the alluvial valley by their position marginal to an old channel and by their characteristic slope away from the river or abandoned channel. The natural levee shown in Figure 13 rises to approximately seven feet above the surrounding flood basin area and slopes away from the associated channel fill with a gradient of approximately 1.6 feet per mile.

Natural levee deposits will generally be graded, with the coarsest material occurring near the crest and finer materials found at greater distances from the crest. Most natural levee samples have enough clay in them to fall in the clay textural class. However, enough silt and

Table 6. Flood basin.

Sample number	Sample depth	Liquid limit	Plastic limit	Plasticity index	Percent clay-sand	Engineering soil classification	Remarks
H13-S1	0-9'	69.6	21.5	44.5	65-01.4	A-7-6(20)	topstratum-natural levee
H14-S1	2-4'	37.6	22.4	15.2	31-11.6	A-6(10)	topstratum
H15-S1	0-8.5'	58.6	22.0	36.6	55-04.3	A-7-6(20)	topstratum-tributary channel
H16-S1	0-3.5'	74.9	25.9	49.0	67-02.4	A-7-6(20)	topstratum
H17-S1	0-9.5'	91.0	30.0	61.0	83-01.1	A-7-5(20)	topstratum
H18-S1	0-0.5'	76.9	36.6	40.3	72-02	A-7-5(20)	topstratum
H19-S1	.5-3'	40.9	25.7	15.2	26-01	A-7-6(11)	topstratum-fan
H20-S1	.5-10'	36.7	25.9	10.8	25-02.4	A-6(8)	topstratum-fan
H25-S1	2-7.5'	44.3	26.4	17.9	27-01.1	A-7-5(12)	topstratum-fan
H37-S1	0-10'	63.3	25.3	38.0	54-01.3	A-7-6(20)	topstratum
H45-S1	12-30'	65.0	25.3	29.7	66-09.3	A-7-6(20)	topstratum
H54-S1	0-12'	67.1	25.0	42.1	55-01.2	A-7-6(20)	topstratum
H55-S1	0-24'	46.3	25.4	20.9	32-01.3	A-7-6(13)	topstratum

sand may be found in some samples to affect the engineering classification. Hole 14 of Table 6 is an example where the common A-7 engineering soil of most deposits has been replaced by an A-6 soil in a natural levee deposit.

The deposits of tributary streams may be important locally in the upper and middle divisions of the valley. The engineering classifications of these samples will usually place them in the same soil group as surrounding topstratum materials. However, the percent of clay sized material is usually less; and the percent of water may be higher, especially in tributary channel fills.

Alluvial fan deposits may be significant in the flood basin areas of the entire alluvial valley. These generally have topographic expression and can be recognized by such and by their distribution around the mouths of small tributaries. The material of fans is always a silty clay loam and can be differentiated from topstratum Missouri Valley deposits by its oxidized red-brown color. This material also generally fits into the A-7 engineering soil group. However, enough silt may be present to change the engineering class to an A-6. Hole 20, Table 6 is an example. Enough coarse material may be present to lower the group index. Hole 19 and Hole 25, Table 6 illustrate this observation.

DISCUSSION

Alluvial Morphology and Valley Fill Development

With the discussion of alluvial morphology and deposits completed, we are now in a position to give certain interpretation to the available data.

In retrospect, the alluvial valley of the Missouri River consists of a wide flat alluvial plain underlain by a thick deposit of clays, silts and sands and separated from the adjoining uplands by abrupt valley escarpments. The overall characteristics of the valley of the Missouri River when viewed in two dimensions are such that the descriptive term "old age" as defined by Davis may be applied. The connotation denoted by "old age" is flat-floored valleys with slowly moving streams in them surrounded by low hills. The uplands adjacent to the Missouri Valley, however, are distinctively different from this picture; and instead of exhibiting "old age" characteristics, might better be placed in the "late youth" or "early maturity" stage of landscape evolution. The Missouri Valley thus represents an "old age" feature in the midst of a "late youth" to "early maturity" landscape. Logically now, one might ask why and how such dissimilar relationshpss chance to occur.

The first and most obvious clue indicating at least the nature of the deviation from the traditionally Davisian concepts is the boundary separating valley from uplands. In all cases, this is topographic unconformity represented by abrupt escarpments leading directly to concordant upland highs. The second clue is furnished by the nature of the alluvial valley and fill itself. From deep borings by the Corps of Engineers, the bedrock surface has been found to lie at a maximum depth of 156 feet below the flat alluvial plain and to exhibit as much as 55 feet of local relief. The thickness of alluvium far exceeds the maximum depth of scour of the modern river and so precludes the formation of a flat valley floor by this stream. The thickness and coarsemess of the substratum sands and gravels require that they be deposited by an aggrading stream carrying an excess amount of coarse-grained material.

Since it has been indicated that the alluvial fill resulted from valley aggradation (i.e., alluviation), the next question is why the Missouri alluviated. Two contrasting ideas have been introduced in the literature review. From the data available at the present time, it appears that the concept of alluvial drowning due to rising base level, as introduced by Fisk and Russell, better fits the observed facts. That the most recent event in the alluvial valley history has been or is alluviation is indicated by the stratigraphic relationship observed during borings along the longitudinal profile of the Arcola Creek fan (Figure 2). Here material identified as being of fan origin occurs at depths below the average elevation of surrounding alluvial valley material. The chronology suggested by Leighton and Willman and applied by Thornbury to inland glaciated regions seems completely untenable. That streams should down cut during rising base level accompanying deglaciation seems to have two processes, both of which should result in alluviation, accomplishing exactly the opposite. If the present time can be counted as part of a period characterized by deglaciation, then the Missouri River should presently, or in the most recent geologic time, have left a record indicating a degradational episode. Such is not the case.

Alluvial Geology and Engineering Behavior

The deposits of the Missouri Alluvial Valley may be characteristically described as consisting of an upper A-7 unit underlain by a transitional A-4 unit and a basal A-3 unit. Although the majority of near-surface deposits have the characteristics of an A-7 engineering group soil, differences in other properties affecting engineering behavior require subdivision of this material. As these properties vary directly with alluvial environments of deposition, delineating these environments becomes extremely important if maps of alluvial geologic deposits are to have engineering significance. Kolb and Shockley (18) discuss at some length the engineering characteristics of Mississippi Valley deposits which require that they be mapped as being significantly different for engineering purposes. Many of these same characteristics have been noted in similar deposits of the Missouri Valley and will be discussed here.

For most engineering projects, the thickness and distribution of fine-grained topstratum will materially affect construction practices and procedures. The thickness and distribution of these materials has been shown to vary within the alluvial valley and within different deposits. Fine-grained material is thinner and has less aerial distribution near the river than in the meander belt and flood basin areas. Point bars will commonly have less topstratum over them than will occur in associated channel fills, and flood basin deposits will commonly be composed of a thicker fine-grained topstratum unit than either point bars or channel fills.

Several properties of topstratum material may affect its suitability for stabilization or as a foundation unit. These are water content, organic matter content, and oxidation state. Point bar topstratum would generally be better material for most engineering purposes than channel fill or flood basin topstratum because of its low organic matter content, relatively less saturated condition, and generally coarser nature. Channel fills would generally be the least desirable as an engineering material because of the high water and clay content characteristic of most of these deposits. The upper few feet are also relatively high in organic matter. Flood basin area deposits are relatively high in clay content and also contain the highest percentage of organic matter. These deposits tend to be better compacted and to have lower water content than do channel fill deposits.

Stabilization of Alluvial Deposits

It might be said that within or adjacent to the alluvial valley varying types of material and conditions warrant attempts at stabilization using a variety of techniques. Granular or mechanical stabilization might well be tried in the upper and lower segments of the valley where extensive deposits of gravel have been noted in the adjacent bluffs and Platte River Valley. If necessary, deposits of gravel may be located at depth below the valley surface and may be used. Within the valley proper, extensive sand, silt, and clay deposits occur at the surface and stabilization using combinations of these easily available materials is feasible. For higher class roads, cement or bituminous stabilization might be tried using available sand.

Stabilization of in-place clay sized material using lime might be attempted in almost any segment of the valley.

A number of different environments and types of material may occur in close proximity within the alluvial valley. An opportunity thus exists to test the applicability of stabilization methods under naturally occurring conditions ranging from oxidizing to reducing environments, high to low organic matter, and high to low percentagesof fines.

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