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MISSOURI RIVER STUDIES: ALLUVIAL MORPHOLOGY AND QUATERNARY HISTORY.

Iowa State University of Science and Technology
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Geology

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MISSOURI RIVER STUDIES: ALLUVIAL MORPHOLOGY AND QUATERNARY HISTORY

by

Arthur Richard Dahl

A Dissertation Submitted to the

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The Requirements for the Degree of

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Major Subjects: Geology
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Signature was redacted for privacy.

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Heads of Major Departments

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Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1961

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STATEMENT OF PROBLEM

A geologic and soil engineering investigation of the Missouri River Valley and adjacent areas in Iowa and Nebraska is being conducted jointly by the Engineering Experiment Station and the Department of Geology at Iowa State University. Primary sponsorship is by the Iowa Highway Research Board of the Iowa State Highway Commission with additional aid from the Office of Naval Research and the Geological Society of America.

The primary objective of this investigation is to determine the occurrence, distribution, properties, and genetic relationships of various Quaternary deposits lying below and adjacent to the Missouri River flood plain in Iowa and Nebraska.

Other objectives are:

1. To further the scientific application of aerial photographs by correlating geomorphic features with geologic and engineering properties of materials.

2. To further an understanding of Pleistocene glaciation and its associated effects.

Preliminary reports on the alluvial morphology and engineering soil classification of the Missouri River flood plain in Iowa and Nebraska have been prepared by Glenn and Dahl (36) and by Glenn (35).

INTRODUCTION

Ten years ago a research program concerned with the geology and engineering properties of the various Quaternary deposits of Iowa was initiated at Iowa State University. The first studies were concerned with the loess deposits of western Iowa. Subsequent studies of other areas in the state have included the loess, glacial drift deposits, sands, and finally the alluvial deposits of the major flood plains. The ultimate goal of all of these studies has been to secure enough basic information so that, in the absence of readily available coarse aggregate for road building in many parts of the state, the surficial materials could be stabilized for lower-cost roads. The present study, in particular, may also help in solving some of the foundation problems which are commonly met with when structures of all kinds are founded in alluvial materials.

Some of the earlier work, both in Iowa and Alaska (19), by personnel associated with the present investigation indicated a need for detailed data on the major flood plains and the Quaternary history of their valleys if tentative or controversial interpretations involving the Quaternary of Iowa and the origin of certain deposits were to be solved. Inasmuch as a knowledge of the more basic facts concerning the Quaternary geology of the area in question is prerequisite to an appraisal of the origin and age of the materials, the data and their interpretation are presented herein.

The primary project consisted of two phases. The first was concerned with mapping the position of alluvial deposits from aerial photographs and field examination; then boring for subsurface data in distinctive deposits. Borings other than those made specifically for this investigation were also utilized.[a] Data from the first phase of the study are shown on Plates 1-24. The second phase consisted of a laboratory investigation concerned with determining some of the physical and chemical properties of the various deposits.

Subsurface investigations were also made in the Quaternary deposits lying adjacent to the alluvial valley.

Unless otherwise referenced, the radiocarbon age determinations reported in this thesis were made by the Exploration Department and Geochemical Laboratory, Humble Division, Humble Oil and Refining Company.

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[a]Borehole records furnished through the courtesy of Federal, State, and Municipal offices, private well-drilling firms, and individuals.

LOCATION AND EXTENT

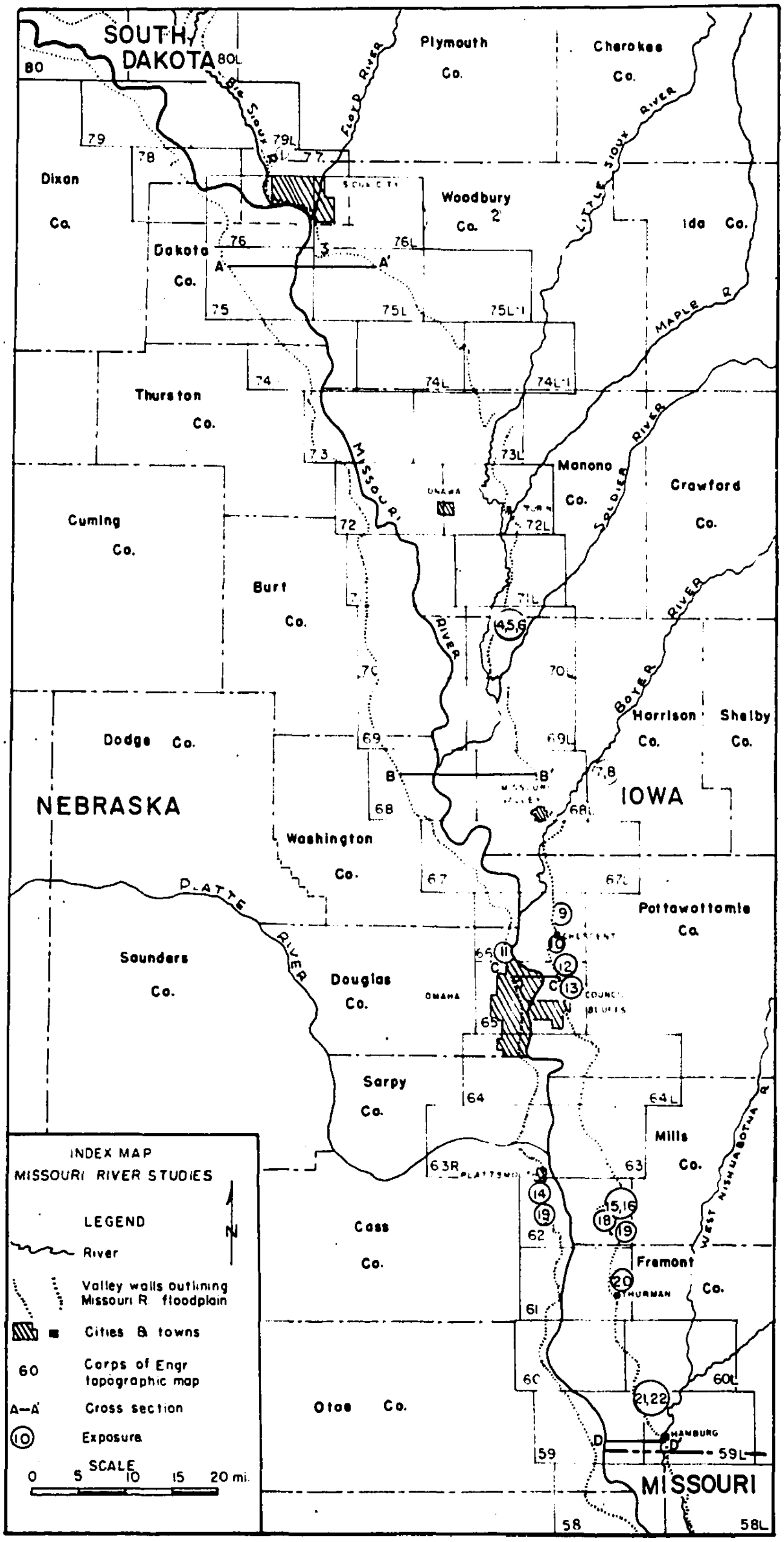
The Missouri River Valley and surrounding area under immediate consideration (Figure 1) lies between $95^{\circ}30'$ – $96^{\circ}30'$ west longitude and $40^{\circ}30'$ – $42^{\circ}30'$ north latitude. The river forms the western boundary of Iowa for an airline distance of approximately 140 miles and the flood plain width varies from about 18 miles in the northern part just south of Sioux City (Sheets 75 and 75L) to about 4 miles near Crescent, Iowa (Sheet 66). The flood plain adjacent to Iowa comprises an area of approximately 1235 square miles.

Included in the area of study are parts of Plymouth, Woodbury, Monona, Harrison, Pottawattamie, Mills and Fremont Counties, Iowa; parts of Dakota, Thurston, Burt, Washington, Douglas, Sarpy, Cass and Otoe Counties, Nebraska; and parts of Union County, South Dakota and Atchison County, Missouri.

Map sheets from the Corps of Engineers refer to Plates used in this report as follows:

Plate	Map	Plate	Map	Plate	Map
1	59 and 59L	9	67 and 67L	17	72L
2	60 and 60L	10	68	18	73
3	61	11	68L	19	73L
4	62	12	69	20	74
5	63R and 63	13	69L	21	74L and 74L-1
6	64 and 64L	14	70 and 70L	22	75
7	65	15	71 and 71L	23	75L
8	66	16	72	24	76 and 76L

Figure 1. Index map, Missouri River Valley adjacent to Iowa


SOUTH DAKOTA
NEBRASKA
IOWA
MISSOURI
Plymouth Co.
Cherokee Co.
Dixon Co.
Woodbury Co.
Ida Co.
Dakota Co.
Thurston Co.
Monona Co.
Crawford Co.
Cuming Co.
Burt Co.
Dodge Co.
Harrison Co.
Shelby Co.
Washington Co.
Pottawattomie Co.
Saunders Co.
Douglas Co.
Sarpy Co.
Mills Co.
Cass Co.
Fremont Co.
Otoe Co.
MISSOURI RIVER
PLATTE RIVER
FLOYD RIVER
LITTLE SIOUX RIVER
MAPLE R.
SOLDIER RIVER
BOYER RIVER
WEST NISHNABOTNA R.
Big Sioux R.
OMAHA
COUNCIL BLUFFS
HAMBURG
THURMAN
INDEX MAP
MISSOURI RIVER STUDIES
LEGEND
River
Valley walls outlining Missouri R. floodplain
Cities & towns
60 Corps of Engr topographic map
A—A' Cross section
10 Exposure
SCALE
0 5 10 15 20 mi.
N

LITERATURE REVIEW

Streams and Alluvial Morphology

Although major revisions have been made in the concepts concerning landform development, stream processes and sedimentation in the last few decades, only in recent years have explanations for the origin of flood plains and associated alluvial features been developed.

Early concepts of valley development and stream processes were formulated in the late 1800's in the United States by such men as Powell (63), Gilbert (33), and Dutton (23). Powell, in particular, introduced the concept of "base level," defined as the level below which streams cannot erode their valleys.

In 1894, Davis (22), utilizing the idea of these men, introduced the concept of the graded stream. He suggested that a "stream in the condition of balance between degrading and aggrading might be called a graded stream." Later, in the period 1914-1938, classic papers on stream activity were presented by Gilbert (34) Hjulstrom (41) and Rubey (66). Kesseli (47), in 1941, questioned the validity of the concept of grade but in 1948 Mackin (58) restated 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 basis. 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.

Davis (20), in 1899, also introduced the concept of the "geographical cycle" in discussing the evolution of land forms. In a series of essays published in 1909, Davis (21) outlined the evolution of a landscape through three stages termed "youth, maturity and old age." During respective stages, Davis visualized the streams and stream valleys as having features indicative of the progress in regional landscape evolution.

Origin and morphology of alluvial land forms was largely neglected in these early papers but the origin of flood plains (broad flats of low relief extending along either side of the stream and bounded by valley escarpments) in general was attributed by Gilbert (33) and Davis (21) to lateral corrasion during maturity and old age when the stream can no longer cut downward. Fenneman (25) in 1906 considered that material below the flood plain surface represented only a thin veneer on a laterally planed bedrock surface.

A new era in alluvial geology began in the late 1930's with the investigation of the valley of the lower Mississippi River. This study, under the direction of H. N. Fisk (29, 27, 26), had the evidence from thousands of borings on which to base conclusions and geologic interpretations. For the first time, the details of a large river valley could be shown in three dimensions. This study revealed that the alluvium is much thicker than the present depth of scour and that the bedrock valley floor exhibits considerable relief. The uneven floor is attributed to valley cutting during a period of lower base level accompanying the last episode of continental glaciation. Upon deglaciation and the rise of sea level, valley filling occurred to account for the volume of recent sediment in the valley. Leighton and Willman (52) would have the opposite sequence of events, i.e., alluviation during lowering sea level and valley cutting during rising sea level.

Apparently trying to rationalize differences between lower and upper Mississippi Valley geologists, Thornbury (82, p. 149) suggested

> Stream behavior in the lower Mississippi Valley may have been dominated by the effects of eustatically lowered and raised sea levels, whereas the upper Mississippi Valley was too remote from the sea to have felt the influence of sea-level changes of such short duration and hence alternated between aggradation during glacial times and erosion during interglacial times.

Contemporaneous with Fisk's work, Russell (74, 69, 70, 71 and 72) published on the Quaternary history of valleys both in the United States and abroad and also on alluvial morphology in general.

Recent Professional Papers by the U. S. Geological Survey present relationships between various controlling factors responsible for stream development. Leopold and Wolman (56) in 1957 concluded 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 (80), also in 1957, concluded that overbank deposits are relatively insignificant in the total quantity of material underlying a flood plain.

The classification of alluvial deposits by Fisk (27 and 26) is the one used in this report. The alluvial section in the lower Mississippi Valley consists of a basal graveliferous unit which grades upward into an upper fine-grained, nongraveliferous unit. The upper deposits are subdivided into those of the meander belt region and those of the back-swamp or flood basin region. Meander belt deposits are further subdivided into those of the point bar, abandoned channel fill and natural levee.

These natural subdivisions are used in this report; the methods used to map deposits are geomorphic in nature and the use of aerial photographs and large scale, small contour interval topographic maps is required.

Kolb and Shockley (48) have reported on typical engineering properties of selected environments of deposition within the lower Mississippi River alluvial valley, using Fisk's classification of alluvial deposits.

Missouri River

In this section, the literature pertaining to the Quaternary history of the Missouri River and surrounding area is briefly reviewed.

In 1887, Todd (86), discussing the terraces of the Missouri, thought the trough of the Missouri had been formed since the advent of the Ice Age, and that above Yankton the Missouri owes its present course and possibly its existence, to the influence and interference of the ice-sheet. Broadhead (2) in 1889 listed several features pertaining to the physical geography and geology of the river and in particular mentioned that downstream from Sioux City the stream bed at one time was probably filled with glacial drift, subsequently in part cleaned out. He also felt (2, p. 154) that the Missouri as well as the Mississippi was dammed at places as evidenced by the silt-like deposits in the neighboring hills termed "loess." Upham (87) in 1904 concurred with Todd and thought the present course of the Missouri to have been established since the Quaternary began.

In 1909 Shimek (76) reported on the geology of Harrison and Monona counties and mentioned the gentle slope away from the banks of the river to the flat at the base of the bluffs. He also reports (76, p. 287-292) the occurrence of benches along several tributary valleys. Shimek relates that:

> These benches have sometimes been mistaken for river terraces but they are evidently a remnant of an old drift plain, their stratigraphic structure being the same as that of all the uplands, as is shown in well-sections and exposures.

In 1914 Todd (84) published a report on the Pleistocene history of the Missouri River. He felt (84, p. 272) that the drainage channels of the past were not as deep as those of the present and that the drainage level of Kansan time was from 80 to 120 feet higher than that of the present. Todd thought that the surfaces along some of the tributary valleys were river terraces. Carman (4) in 1915 and Lees (49) in 1919 both published information on the development of the Missouri-Mississippi divide in northwestern Iowa and on the geologic history of the Boyer River, a tributary of the Missouri.

In 1935 a voluminous report in the Missouri River was compiled by the Corps of Engineers under the supervision of L. G. Straub (81). Submitted to congress as a general plan for the improvement of the Missouri River in terms of navigation, water power, flood-control and irrigation, this report contains numerous facts and figures on slope, discharge, load, etc., which will be used throughout this report. With respect to the Missouri River improvement program, Whipple (89) in 1942 discussed the effect of improvement upon the length, slope, width, shape, discharge and roughness coefficient of the natural stream between Rulo, Nebraska, and Sioux City, Iowa.

McClelland et al. (59) in 1950 reported on some flood plain soils in Monona County and concluded that the differences between them can be attributed to geological factors related to stream processes.

In 1952 Warren (88), using geomorphic and paleontologic evidence, reported that the ice that caused the White and other streams to divert and form the Missouri River near Chamberlain, South Dakota, was probably Illinoian in age. Likewise, Simpson (78) in 1954, working in the Yankton, South Dakota, area reported:

> The area about Yankton, South Dakota, was partly covered by glaciers during Nebraskan and Illinoian stages and the Iowan, Cary and Mankato substages of the Wisconsin. Each glaciation caused the abandonment of parts of the existing drainage system and the cutting of new channels. Generally these new channels were occupied temporarily, and on retreat of the glacier drainage returned to an earlier course. The most significant modification was the birth of the Missouri River during the Illinoian stage.

The terraces along streams tributary to the Missouri River were mentioned once again, this time in a report covering a soils investigation by Corliss and Ruhe (13) in 1954. They conclude (13, p. 349) that the surface along the upper Boyer and Nishnabotna rivers is neither a bench nor an alluvial terrace, but a loess-mantled outwash-alluvium complex. What they call the terrace is the buried surface of the outwash-alluvium complex, and the Iowan terrace is the present surface of this geomorphic feature. They report (13, p. 358) that, within the series, the profiles of terrace soils are similar to the adjacent upland soil profiles and that both soils are developed in Iowan-Tazewell loess.

In 1955 Flint (31) published a report on the Pleistocene geology of eastern South Dakota. He also thinks (31, p. 142) that the present Missouri River, at least in central and eastern South Dakota, probably developed in Illinoian time.

The 1959 soil survey report of Monona County (79) presents maps of the alluvial, terrace and upland soils on a scale of 1:20,000. It also reports (79, p. 1) that the loess which mantles older geological materials adjacent to the valley is thought to have been blown from the bottom lands of the Missouri River between 10,000 and 25,000 years ago. This report is the first of its kind to list engineering properties of the various soils. Another soil report, by Simonson (77) in 1960, discusses the genesis of alluvium-derived soils in a tributary valley of the Missouri River. Listed in this report (77, p, 83) are radio-carbon dates of wood found in the alluvium that range from 14,300 ± 250 Years to less than 250 years Before Present.

Recently, Jorgensen (46), working on the geology of the Missouri River Valley in southeastern South Dakota, reports that outwash deposits ranging from Illinoian to possibly Cary age underlie the alluvium in the valley.

Loess

In keeping with the previously-stated objectives of this investigation, the Quaternary deposits lying adjacent to the Missouri River Valley have been studied. In this respect, almost every major cut in the bluffs along the flood plain was investigated and many deep borings were made in the terraces, valley slopes and interfluves as well as those made in the flood plain. In all instances except one (young glacial drift plain in South Dakota), these borings adjacent to the alluvial valley penetrated varying thicknesses of silt. Since these silt (with minor clay and very minor sand and gravel) deposits are almost always discussed in the literature under the term "loess," a brief review of the literature on loess is presented.

Property studies of the loess are too numerous to mention here, but some will be cited later in this report. Regarding theories of origin and the history of loess in general, probably no one single paper presents as comprehensive a review as does Russells' (73) in 1944.

Concerning the loess deposits of southwestern Iowa, Todd (85) in 1878 found Richthofen's eolian theory (65) inadequate. In 1897 Todd (83) and in 1904 Wright (91) both favored a fluvial origin. Their observations of loess of about equal thickness on both sides of the river, the thickest deposits being closest to the river, coarsest loess closest to the river and becoming finer with distance from the river, and the existence of level-topped terraces, especially on the west side of the Missouri, led them to their conclusions. Both of these papers were apparently in objection to the combination (glacial-fluvial-eolian) theory of Chamberlin and Salisbury (6) and Chamberlin (5).

In reviewing the various works on the origin of loess as outlined by Russell (73, p. 6-8) it becomes apparent that successive authors, in effect, accepted in whole or in part the hypothesis of a previous writer and modified it to their own flavor. There were, however, always a few who completely dissented as well as those like Pumpelly (64) who completely changed their thesis. The direct line of descendents for the theory of origin widely held today is most probably Richthofen (65), Pumpelly (64), Chamberlin and Salisbury (6) and Chamberlin (5). This is a combination theory which has fine glacial debris picked up by the wind from broad flood plains and transported to sites of deposition on the adjacent bluffs, particularly along the eastern side, as the winds are thought to have been predominantly westerly.

Shimek proclaimed this relationship for the loess of western Iowa (76, p. 280, p. 284-287, p. 297). Shimek also related (76, p. 291), in regard to the Belvidere bench (the surface on Map 72L which extends along the southeast side of the Maple River at its mouth and is marked by boring No. 117), that:

> Its upper surface is quite level, and lies about 120 to 130 feet above the valley, rising toward its western extremity, however, to a height of 170 feet and then abruptly descending to the valley. This additional elevation is evidently due to the greater accumulation of loess along the edge lying nearest to the Missouri valley.

That the loess is piled up to its greatest thickness and elevation along the eastern margins of valleys and thins eastward with decreasing elevation has been proven to be unsound in the lower Mississippi Valley by Russell (73, p. 9-10).

In 1944 Russell (73) proposed that the loess of the lower Mississippi Valley developed through a process of "loessification." In this process, material, weathered from Pleistocene terrace backswamp deposits, accumulates on slopes through colluvial action and gains loessial characteristics as carbonates are added, snails are incorporated, and the particle-size becomes restricted mainly to 0.01-0.05 mm.

Leighton and Willman extended their loess studies into the lower Mississippi Valley and in 1949 initiated a two weeks field conference, during which they, along with about twenty Pleistocene specialists (52, p. 600) traversed the loess area from the latitude of Iowa City, Iowa, to Natchez, Mississippi. They reported (52, p. 619-620) that the loess deposits of the upper and lower Mississippi Valley are stratigraphically continuous, have many properties, characteristics, and relationships in common, and that the eolian theory is the best explanation for both.

Fisk (30) in 1951 discussed the origin of the loess in the light of the Quaternary geologic history of the lower Mississippi Valley and concluded that the loessification theory of Russell (73) was the only one yet proposed which is consistent with the known facts.

However, differences of opinion still exist as to the origin of loess, as evidenced by the recent publications of Leighton (51, 50). He has enough confidence in Chamberlin's combination theory (glacial-fluvial-eolian) that he can postulate the latitude to which outwash-carrying streams were overloaded because of the presence of a particular loess in the adjacent valley walls.

Engineering properties of the loess of southwestern Iowa have been reported by Davidson and Handy (17) and Davidson _et al_. (18). Holtz and Gibbs (42) and Cleavenger (9) have discussed engineering properties of the loess in areas to the west of Iowa.

In this report, the term loess will be used as a general descriptive term, without genetic significance, for the relatively thick silt deposits lying adjacent to the valley. The origin of some of the silt deposits will be considered later in this report.

FIELD STUDY

Prior to the 1958 field season, aerial photo mosaics and contact prints, as well as topographic maps of the Missouri River Valley were used to delineate gross physiographic features which were thought to be the key in outlining significant alluvial deposits.

Mapping was done on the scale of 1:24,000 using 1946-47 Corps of Engineers topographic maps as base maps. These maps have a 5-foot contour interval on the flood plains of the Missouri River and tributary streams, and up to a 25-foot contour interval on topography adjoining the flood plains. The alluvial geology was mapped from 1946-47 controlled mosaics of the valley as well as 1956 contact prints.

During the 1958 field season the mapping was detailed and modified, and 55 shallow (to depths of 28 ft.) holes were hand-augered in the previously outlined areas of the flood plain to determine the nature of the deposits. Where no readily apparent physiographic features were observed (usually in areas relatively far removed from the present channel where channel deterioration and deposition by overbank flooding has obscured surface features), bore holes were put down along a system of tranverses. Total footage for drilling during the 1958 field season was 1,195 feet.

Prior to the 1959 field season, terraces along both the Missouri River and some of the major tributaries were mapped. Here again, the previously mentioned photos as well as stereoscopic coverage for most Iowa counties adjacent to the valley were used in the mapping.

During the 1959 field season, field checking and remapping continued and intermediate-depth holes (to 60 ft.) were bored in the material below the flood plain and terrace. However, it was found that 60 ft. holes (limit of the power auger) would in most instances not penetrate the complete section of unconsolidated material. A considerable portion of the 1959 field season was also spent in examining and describing many new exposures of Quaternary materials along the Missouri River Valley in Nebraska and Iowa.

General field work was continued during the 1960 field season; however, the acquisition of a new rotary drill rig by the Office of Naval Research with a capacity of several hundred feet now permitted many deeper borings to penetrate to bedrock in holes drilled in the flood plains, terraces and uplands. Relatively undisturbed drive samples were taken with this drill and wood samples for radio-carbon dating were recovered. A total of 72 more borings were made during the 1959 and 1960 field seasons with the total footage being 5,204 ft.

The samples recovered during the field work were subjected to various laboratory tests to determine some of the physical and chemical properties. The method used in procuring the undisturbed samples from bore holes is that proposed by the American Society for Testing Materials (1). The standard penetration value (N-value) is recorded in this report in the following manner: the first number records the blows required to set the tube the first 6 inches; the second number (in parentheses) records the blows required to effect the second 6 inches of penetration; and the third number records the total blows required to effect the last foot of penetration. The standard procedure of using a 140 lb. hammer dropping 30 inches was used.

The split-tube sampler utilized in the investigation was loaded with brass liners (2.75 inches in length) when in-place samples were needed for laboratory tests. These samples were sealed against moisture loss in the field while still being securely held in the liners.

LABORATORY METHODS AND PROCEDURES

Physical Tests

Mechanical analysis

Particle-size analyses were performed on the samples by the hydrometer and sieving method (A.S.T.M. Designation: D 422-54T) (1) as modified by Chu and Davidson (7). Sodium metaphosphate was used as the dispersing agent.

The test was modified slightly in that, after the hydrometer procedure, the sediment retained on a No. 325 sieve (44 microns) was, after drying, sieved through the following nest of sieves: No. 200, No. 270 and No. 325. Since so much of the material analyzed in the investigation was dominantly silt-sized, it was thought this procedure might help in defining the grading within the silt fraction. The particle size classification used in this report is that of the American Society for Testing Materials (1) (A.S.T.M. Designation: D422-54T). It uses the following size limits: sand 0.074 to 2.0 mm. diameter, silt 0.005 to 0.074 mm. diameter, and clay less than 0.005 mm. diameter.

Unconfined compression

A portable, hand operated unconfined compression apparatus equipped with a double proving ring of 500 lb. capacity was used for this test. Specimens were loaded rapidly, the rate of strain being approximately 8 percent of the original height (h_o) of the specimen per minute. Compression was continued until a definite failure took place or until at least 20 percent strain had been reached.

The load dial was read for every 0.025 in. of strain and the axial load (P) was then read from a calibration chart for the particular proving ring.

Since it was desired to plot complete stress-strain curves, the unit stress corresponding to each reading of the strain dial was computed by use of the following equations:

1. Unit strain = Total strain/initial height (H_o)
2. Corrected area (A) = Initial area (A_o)/(1 - Σ)
3. Unit stress = P/A

Upon completion of the test, the angle of the failure plane, if distinctly visible, was measured and the field moisture of the sediment, based on its dry weight, was determined.

Ordinarily at least two, and in many cases three, samples of the same material were tested so that an average figure for $q\mu$ (unconfined compressive strength), Σ (unit strain expressed as a percent, w (field moisture expressed as a percent) and d (dry density) is presented for these values. Densities were determined by weighing the dry material which completely filled the cylinders of known volume when driven in the field.

Chemical Tests

The chemical tests were performed by laboratory personnel. These tests and methods include:

1. Calcium carbonate: leaching and titration with versenate solution
2. pH: Leeds and Northrup Co. pH meter
3. Organic matter: dichromate oxidation method (8)

Structure and Mineral Determinations

The structure and gross mineralogy of in-place samples was studied with binocular and petrographic microscopes using thin sections. The undisturbed samples were first impregnated with a cementing agent and then ground.

X-ray studies of the fine-grained material were done on a General Electric XRD-5 diffractometer using copper K alpha radiation, a nickel filter, 0.2° detector slit and 1° beam slit. Scanning rate was 2° per minute.

THE MISSOURI RIVER BASIN

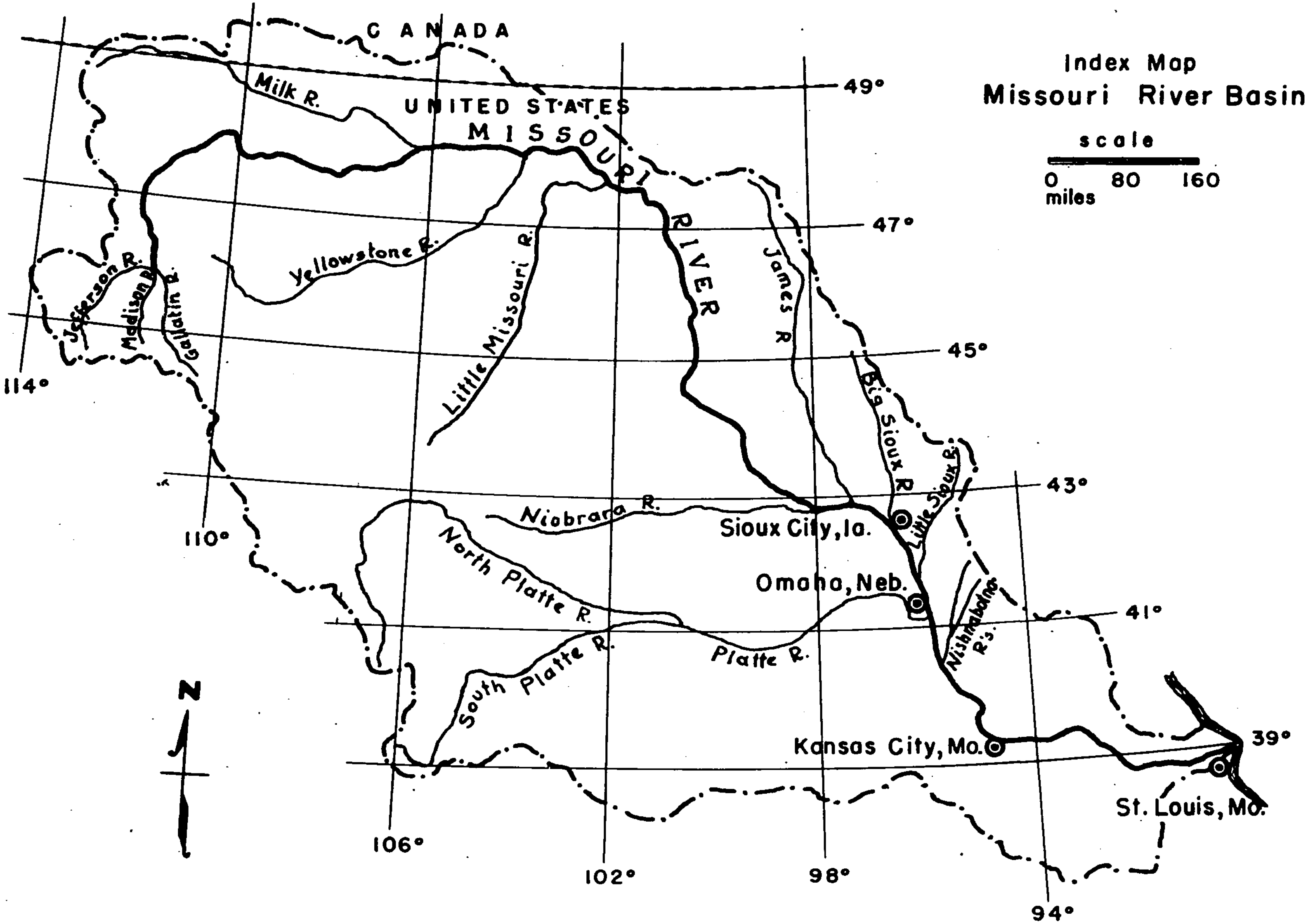
General Description

The Missouri River Basin lies between 90° and 114° west longitude and 37° to 50° north latitude. The total drainage area is approximately 529,000 square miles, and, with the exception of about 10,000 square miles lying within the southernmost part of Canada, the basin is entirely within the United States. The drainage basin (see Figure 2) is a diamond- or lens-shaped area, having a length of approximately 1,400 miles measured in a northwesterly direction from the mouth, and a maximum breadth of about 680 miles. 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 the relatively low Missouri-upper Mississippi divide, and on the south by the Ozark Uplift and an east-west ridge across central Kansas.

The Missouri River Basin consists largely of a plains area. Particularly rugged topography occurs only in the extreme west portion of the basin along the eastern slope of the Rocky Mountains, in the Black Hills of South Dakota, and the northern slope of the Ozark Mountains of Missouri. Approximately two thirds of the basin lies within the Great Plains province of the Interior Plains physiographic division.

The average rainfall over the entire basin is about 20 inches annually. Except where influenced by local circumstances in the Rocky Mountains, the average rainfall in the western portion of the basin ranges between 10 and 15 inches annually. Eastward the average annual

Figure 2. 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.
N
49°
47°
45°
43°
41°
39°
114°
110°
106°
102°
98°
94°

rainfall increases to about 18 inches in the northeastern portion and 36 inches in the southeastern portion of the basin.

Tributaries

The principal and largest tributaries enter the main stem chiefly from the right side (see Figure 2). Except for the James and Milk rivers, which flow in a direction approximately parallel to the Missouri, the streams entering from the left (looking downstream) are very short. Hence, the Missouri River system is strongly asymmetrical, with the total area of that part of the basin on the left of the river being only about one fourth of that drained by the Missouri on the right. Measured normal to the general direction of the river, the broadest section of drainage area to the left is about 160 miles as compared to a breadth of about 550 miles measured to the right of the Missouri River.

Straub (81, p. 381) calculated gradients of all the major tributaries of the Missouri. The Gallatin River has the steepest over-all slope (25.1 ft./mi.), whereas the James has the flattest (0.6 ft./mi.). For a large stream, the Platte has a relatively steep slope, averaging 7.1 ft./mi. from the headwaters to the mouth and 5.9 ft./mi. from the junction of the North and South Platte rivers to its confluence with the Missouri.

Bedrock Geology along the River

The Missouri River is formed by the junction of the Jefferson, Madison and Gallatin rivers in an area underlain by Miocene rocks (81, Map No. 32). Downstream, at a point near Helena, the Missouri enters an area of pre-Cambrian granite and other igneous rocks and the valley is cut in these rocks to the major bend in the river near Craig, Montana, in Lewis and Clark County. From this point eastward to eastern Montana, the river flows in a valley cut dominantly in Cretaceous rocks. Near Poplar, in eastern Montana, the Cretaceous rocks are succeeded in the channel by a narrow belt of early Tertiary (Eocene) rocks belonging to the Lance formation. The Lance gives way to the Fort Union formation across which the river flows for a considerable distance in North Dakota until near Stanton the river cuts through the base of the Fort Union and flows again across the Lance to a point south of Bismarck.

From Bismarck downstream for a distance of about 700 miles to the vicinity of Onawa, Iowa, the river flows across a succession of Cretaceous beds. From Onawa, southeast to the latitude of the mouth of the Grand River, the Missouri flows across Pennsylvanian strata and from there to a point south of Columbia, Missouri, the river follows a belt of Mississippian rocks. South of Columbia, the river flows through earlier Paleozoic rocks, chiefly of Ordovician age as it approaches more closely the flanks of the Ozark dome. Then, flowing somewhat more eastward of the dome, into a slightly higher stratigraphic position, the river flows for a short distance in a valley cut in Mississippian rock.

Broadly speaking then, the Missouri Basin extends across the broad synclinal structure of the Great Plains.

THE MISSOURI RIVER VALLEY

The River

The Missouri River is the longest river in the United States and the principal stream of the Missouri River Basin. From its origin at Three Forks, Montana, the Missouri flows about 2,470 miles to its confluence with the Mississippi near St. Louis, Missouri.

Except in the very uppermost reaches where the flow is generally northward, the river follows an alternating series of east to southeast treads along its course to the Mississippi (see Figure 2). At Sioux City, Iowa, the river makes a near right-angle bend and flows along a course generally 15° east of south to the latitude of Kansas City.

Slope

From the head of the river to its mouth the Missouri dropped 3,627 ft. in 1890 (81) over a distance of 2,546 miles, giving it an average slope of 1.42 ft./mi. In 1930 a survey showed the total length had decreased 28 miles by both natural and artificial processes. By 1946, total length had decreased about 75 miles, mainly by the construction of artificial cut-offs and levees, and the average gradient was 1.47 ft./mi.

A significant change in slope and river regimen occurs at the confluence of the Milk and Missouri rivers. Above its confluence with the Milk River, the Missouri has an average slope of 2.6 ft./mi., the valley is relatively narrow (a width exceeding 1.5 miles in rate), the bed is composed largely of gravel and coarse sand, and relatively little change takes place in the position of the river bed. Below the Milk River, the gradient decreases, the valley widens to about 4 miles, the river assumes a more serpentine course, and bank caving and bar shifting become more pronounced.

Straub (81, p. 734) has published the 1890 low-water slope data for 18 segments of the Missouri River, and a few slope data pertinent to the area in question are reproduced in Table 1.

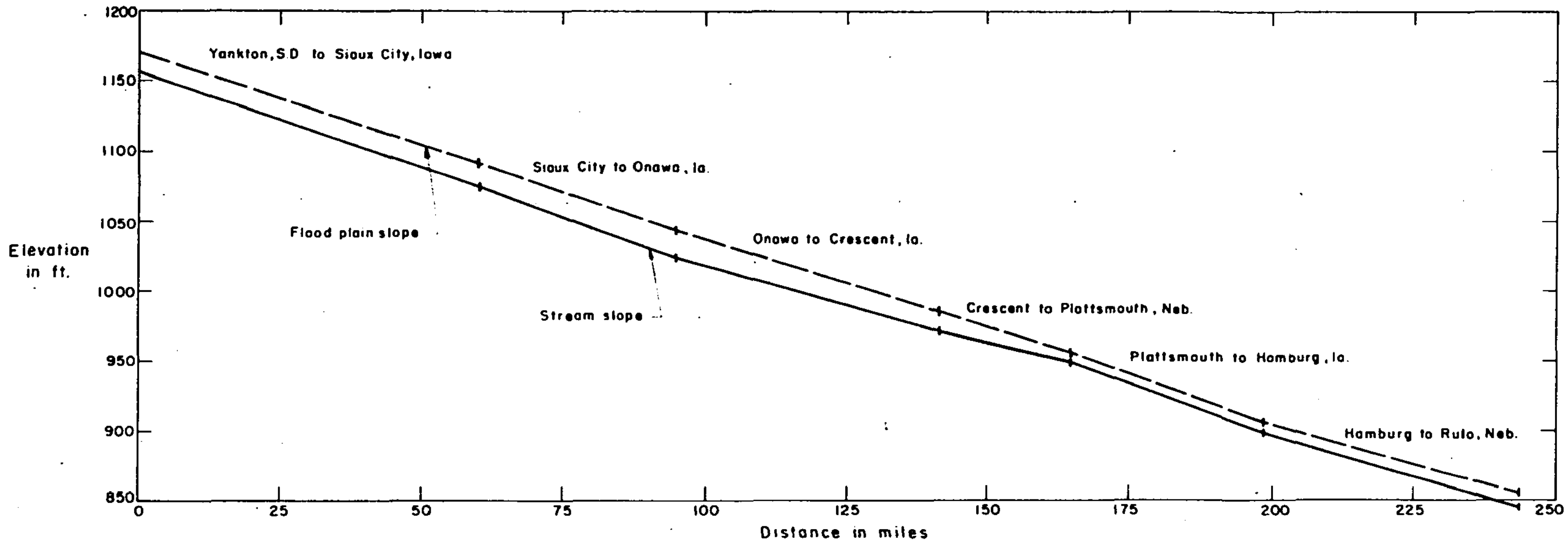
Table 1. Missouri River low-water slope data[a]

1890 miles above mouth	Locality	Elevation	Slope in feet per mile
1,067.5	Chamberlin, S. Dak.	1,324.5	
			0.94
938.1	Running Water, S. Dak.	1,202.8	
			0.94
807.5	Sioux City, Iowa	1,080.6	
			0.80
633.6	Plattsmouth, Nebr.	941.9	
			1.23
607.7	Nebraska City, Nebr.	910.0	
			0.97
537.5	Rulo, Nebr.	841.7	

[a]From Straub (81, p. 734).

Figure 3 and Table 2 contain data on water slope, flood plain gradient and sinuosity ratios for several reaches of the Missouri River between Yankton and Rulo. These data are from the 1946-47 topographic maps used as the base maps for this investigation; the 1890 and 1941

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



Elevation in ft.
1200
1150
1100
1050
1000
950
900
850
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 water slope, flood plain gradient and sinuosity ratio

Locality	Sinuosity[a] ratio 1890	Sinuosity[a] ratio 1946	Flood plain gradient feet/mile	Stream slope feet/mile
Yankton, S. Dak.				
	1.53	1.43	1.32	0.94
Sioux City, Iowa				
	1.91	1.33	1.36	0.99
Onawa, Iowa				
	1.49	1.44	1.28	0.88
Crescent City, Iowa				
	1.45	1.32	1.29	0.55
Plattsmouth, Nebr.				
	1.28	1.28	1.49	1.31
Hamburg, Iowa				
	1.48	1.31	1.12	1.02
Rulo, Nebr.				

[a]From Glenn (35, p. 26).

channels are shown and river miles above mouth are plotted. Water surface elevation as surveyed between December 13, 1944, and March 8, 1945, are used in computing the river slope.

Average figures for the stream slope of the Missouri River and the flood plain gradient adjacent to Iowa (Sioux City to Hamburg) are 0.92 ft./mi. and 1.35 ft./mi., respectively.

The increases in stream and flood plain gradients below Sioux City and Plattsmouth are explained by the entrance of the Big Sioux and Floyd rivers at Sioux City and the Platte at Plattsmouth. The sharp decrease in stream slope in the reach above Plattsmouth is attributed to channel aggradation caused by the damming influence of the Platte. Both Straub (81), in 1935, and Whipple (89), in 1942, discuss this change in slope of the Missouri caused by the entrance of the Platte with its heavy sand and gravel bed load. In discussing the graded river, Mackin (58) ascribes this phenomenon to the ability of a graded stream to adjust its slope (in this case by alluviation) in order to transport the increased load.

The sinuosity ratios shown in Table 2 help in a comparison of the river over a period of tens of years during which considerable shortening has taken place, and also in a comparison of reaches above and below the mouth of the Platte. The sinuosity of a reach is the ratio of thalweg length to valley length and is used as an index of channel type. Leopold and Wolman (56, p. 60) have designated reaches with a ratio of 1.5 or greater as meandering, those less than 1.5 as straight and reaches where flow is divided around relatively stable alluvial islands as braided.

With reference to Table 2, the sinuosity ratios of the 1890 channel are all greater than or equal to the 1946 ratios. In 1890 all reaches, except that immediately below the Platte, had a sinuosity ratio of at least 1.5 (if rounded to nearest tenth) and would be designated as meandering. The lower 1946 ratios reflect almost entirely the progress made in channel straightening by the Corps of Engineers. Indeed, with the recent completion of the DeSoto Bend cut-off east of Blair, Nebraska, the last well-developed meander in the flood plain adjacent to Iowa was abandoned. This artificial cut-off decreased river length by approximately 7 miles.

The 43 mile reach below the Platte River from Plattsmouth to Hamburg records the same sinuosity ratio for both the 1890 and 1946 channel. Note on Map 61 (Plate 3) that the 1890 thalweg closely approximates the 1946 channel. Also note that the present channel in this reach contains bars, some of which have remained relatively stable, presumably since 1890. However, it is also noted that on this same map there are pre-1890 channel scars which record a stream regimen intermediate between braiding and meandering.

Load

The gradient and nature of drainage basin, along with a velocity of flow of between 2 and 3 miles per hour during low stage, 4 to 7.5 during high stage and over 10 during flood (81, p. 193) allow the Missouri River to carry a relatively high load.

The average annual sediment load increases progressively from about 140,000,000 tons at Sioux City to about 270,000,000 tons at the mouth (14, p. 4). However, the yearly deviation from this average annual load is quite large. For example, at Omaha the largest annual load during eleven years of record from 1929 to 1931 and from 1939 to 1948 was 252,000,000 tons in 1944, and the smallest was 44,000,000 tons in 1931. Although these figures are quoted as annual load, they do not reflect the absolute total load. They do record total suspended load and that moving by relatively high saltation as sampled by depth integrated sampling devices. Less is known about the quantity of bed load, but Straub (81, p. 1149) reports that for a 2 year period from 1929 to 1931 the average ratio of suspended to bed load at Omaha was 10.7 to 1. This means that material transported along the bed of the river constituted 8.6 per cent of the total load. For this same unit of time the per cent bed load was 15.9 at Nebraska City, due to the influence of the Platte River and was down to 11.5 per cent at Kansas City as the slope continued to adjust below the mouth of the Platte.

Of the suspended load, about 80 per cent is silt and clay-size material and about 20 per cent very fine to fine sand according to the American Geophysical Union size classification (see Table 3). The median size of the sand in transport is about 0.1 mm. and the bulk of the sediment is composed of the mineral quartz (14, p. 6).

Table 3. Average mechanical composition of suspended load of Missouri River at Kansas City during the period, May 8, 1929, to June 30, 1932[a]

Classification	Per cent retained	Classification	Per cent retained
Clay (less than 1/256 mm.)	25.4	Very fine sand (1/16 to 1/8 mm.)	12.7
Silt:		Fine sand (1/8 to 1/4 mm.)	5.3
Fine and very fine (1/256 to 1/64 mm.)	28.5	Medium sand (1/4 to 1/2 mm.)	2.6
Medium and coarse (1/64 to 1/16 mm.)	23.8	Coarse sand (1/2 to 1 mm.)	1.7
		Very coarse sand (1 to 2 mm.)	Tr.
		Total	100.0

[a]From Straub (81, p. 276).

Table 4 presents the particle-size distribution of the bed sediment as averaged from 1,310 samples (81, p. 277). Approximately three fourths of this material falls within the limits of 1/8 to 1 mm. and the total gravel content is less than 10 per cent.

Table 4. Average mechanical composition of Missouri bed sediment between Kansas City and mouth during the period August to September, 1929[a]

Classification	Per cent retained	Classification	Per cent retained
Clay (less than 1/256 mm.)	0.2	Medium sand (1/4 to 1/2 mm.)	24.2
Silt:		Coarse sand (1/2 to 1 mm.)	14.2
Very fine and fine (1/256 to 1/64 mm.)	1.6	Very coarse sand (1 to 2 mm.)	6.4
Medium and coarse (1/64 to 1/16 mm.)	4.0	Gravel:	
Very fine sand (1/16 to 1/8 mm.)	6.0	Granule (2 to 4 mm.)	4.0
Fine sand (1/8 to 1/4 mm.)	34.0	Pebble (4 to 64 mm.)	5.3
		Cobble (64 to 256 mm.)	0.1
		Total	100.0

[a]From Straub (81, p. 277).

The Corps of Engineers (14, p. 7 and 8) have found, by widespread sediment and gauging stations on the main streams within the Missouri River Basin (15 and 16), that the composition and source of the sediment load varies widely during the year. During low flows of the winter months the load is small and composed almost entirely of sand. At this time when surface runoff is at a minimum the principal source of water supply is from ground water storage, and the available supply of sediment is from the sandy channel bed of the Missouri and its tributaries. The sediment load is greatest from the beginning of snow melt in March until the end of the annual summer rise in mid or late July. During this period surface runoff from melting snow and rainstorms erodes sediment from the watershed and brings it to the Missouri via the tributaries. At this time of the spring and early summer floods the portion of silt and clay in the load may be in excess of 80 per cent. In the late summer and fall months sediment production in the watershed decreases because the principal source of runoff becomes ground water augmented by some melting snow in the higher regions of the watershed. At this time the transportation of silt and clay declines and the load may include up to 70 or 80 per cent sand. During all except the winter months, bank cutting and caving makes a significant contribution to the silt and clay load of the Missouri. The relative importance of bank cutting as a contributor of sediment is greatest in the summer and fall because this may be the chief source of silt and clay between periods of surface runoff from rainstorms.

The hydrologic sequence governs the amount of sediment contributed from time to time by a given part of the watershed. Sediment is brought from the watershed into the tributary streams chiefly by the erosive action of rainfall or snowmelt runoff. A direct relationship between the amount of runoff and sediment production cannot be obtained because the rate of sediment production is strongly governed by watershed conditions before the runoff period. The soil type, antecedent moisture conditions, type of land use, and whether the ground is frozen or not, all influence sediment production. A period of drought during which vegetative cover dies out and the ground becomes dry can lead to heavy erosion at the first intense rainfall. Likewise, if rain continues and the supply of sediment has been moved into streams while the soil takes on more cohesive properties and becomes saturated with moisture, sediment production will decrease. Thus, peak sediment discharge during flood need not necessarily coincide with peak water discharge, but may either precede or follow peak water discharge depending on which part of the watershed is contributing and the characteristics of the flood wave.

The figures in Table 5 illustrate the influence of the condition of the watershed on sediment runoff. The runoff of April, 1952, which produced the largest flood of record at Omaha, is compared with the rise of May, 1942, which barely went overbank. In 1952 the runoff came from snowmelt in the Dakotas and Montana over ground which was still largely frozen. The 1942 rise was caused by rainfall on the same watershed dessicated by the drought of the 1930's (14, p. 8). Table 5 shows that over twice the water volume and over three times the peak discharge in 1952 produced only 60 per cent of the 1942 sediment runoff.

Table 5. Comparison of sediment and water discharge past Omaha during May, 1942, and April, 1952[a]

	May, 1942	April, 1952
Peak discharge, c.f.s.	114,000	396,000
Peak sediment load, tons per day	6,600,000	3,700,000
Total water runoff, acre-feet	4,933,000	11,230,000
Total sediment runoff, tons	86,000,000	52,000,000

[a]From Corps of Engineers (14, p. 8).

Discharge

The average annual water discharge increases from about 22,000,000 acre-feet (30,000 cu.ft./sec.) at Sioux City to about 52,000,000 acre-feet (72,000 cu.ft./sec.) at the mouth (14, p. 4). There are wide monthly as well as yearly variations in discharge. At Omaha the average water discharge from April through July, 1939, was 70,000 cubic feet per second (89, p. 1195).

Corresponding to its wide variation in rate of discharge, the river undergoes considerable fluctuation in stage. Table 6 presents some measured stage fluctuations on the Missouri River.

Table 6. Stage fluctuations in Missouri River[a]

Locality	River mile, 1930	Maximum fluctuation in stage during ice-free periods, ft.
Fort Benton, Mont.	2,211.8	17.0
Sioux City, Iowa	768.9	22.5
Kansas City, Mo.	380.5	38.4
St. Charles, Mo.	27.8	36.1

[a]From Straub (81, p. 1044).

Adjacent to Iowa, river width varies predominantly between 700 and 1000 feet. Thalweg depth, like river width, varies with stage and degree of artificial channel confinement, but depths of 20 to 30 feet are common in the river adjacent to Iowa, and maximum depth of scour is around 60 feet (35, p. 92).

Sources of silt

With such a high silt load being carried by the Missouri River, it is interesting to note which streams contribute the major portion of this fine-grained load (see Table 7). The Yellowstone, Kansas, and Platte rivers are unquestionably the most important silt contributors to the Missouri River, closely followed by the White, Cheyenne, and Grand (of Missouri) rivers. The Yellowstone stands out by far as the greatest silt contributor. The major portion of the drainage basins of these important silt contributors lies outside the glaciated tract (see Glacial Map of the United States East of the Rocky Mountains[a]). With reference to the amount of silt transported per unit volume of water, the Bad, White, and Cheyenne rivers of South Dakota have an unusually high silt concentration (81, p. 1080). This emphasizes the importance of these streams as silt carriers despite their relatively small drainage areas.

Major tributaries in area of study

From Yankton to Rulo, the principal left bank tributaries are the James, Big Sioux, Floyd, Little Sioux, Maple, Soldier, Boyer, and Nishnabotna rivers. The only large right bank tributary in the area of study is the Platte River.

Detailed suspended sediment records are available for all of these streams from the Corps of Engineers (15 and 16). Total quantity is

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[a]Geological Society of America, 1959.

Table 7. Contribution of tributaries to Missouri River suspended load during period July 1, 1929, to June 30, 1931[a]

Rank of river	River	Location of silt station	Silt discharge for period, tons	Per cent of amount passing Kansas City
18	Casconade	Rich Fountain, Mo.	293,000	0.11
10	Osage	Bagnell, Mo.	1,505,500	0.57
6	Grand (Mo.)	Summer, Mo.	11,500,000	4.41
2	Kansas	Bonner Springs, Kans.	28,780,000	11.00
3	Platte	Plattsmouth, Nebr.	26,140,000	9.98
16	Little Sioux	Correctionville, Iowa	447,800	0.17
17	Big Sioux	Akron, Iowa	382,700	0.15
20	James	Scotland, S. Dak.	32,970	0.01
9	Niobrara	Verdel, Nebr.	1,552,000	0.59
4	White	Oacoma, S. Dak.	20,380,000	7.78
7	Bad	Fort Pierre, S. Dak.	10,160,000	3.88
5	Cheyenne	Carlin, S. Dak.	14,100,000	5.39
11	Moreau	Promise, S. Dak.	1,093,000	0.42
13	Grand (S. Dak.)	Wakpala, S. Dak.	1,039,000	0.40
14	Cannonball	Timmer, N. Dak.	811,300	0.31
8	Little Missouri	Medora, N. Dak.	2,624,000	1.00
1	Yellowstone	Glendive, Mont.	60,700,000	23.19
12	Milk	Nashua, Mont.	1,064,600	0.41
19	Musselshell	Mosby, Mont.	281,000	0.11
15	Marias	Loma, Mont.	653,000	0.25
		Total all tributaries gauged	183,589,870	70.10

[a]From Straub (81, p. 1080).

relatively insignificant for the left bank tributaries quoted above, but the bed load of the Platte at Ashland, Nebraska, nearly equals that of the Missouri at Omaha (81, p. 1145). As measured at the above locations, the concentration of suspended load per unit volume of water is about the same for both rivers but the Missouri carries a greater quantity of suspended load. The average size of particles forming the bed of the Platte is larger as is the mean size of the suspended load.

In Iowa, the left bank tributaries below the Big Sioux exhibit a somewhat striking sub-parallelism. All flow in a general southwesterly direction with the Floyd and Little Sioux trending N25 to 30°E, the Maple, Soldier and Boyer trending approximately N40°E and the Nishnabotna trending about N20°E. With the exception of the upper reach of the East Nishnabotna, all these streams approach the NW-SE trending Wisconsin glacial boundary at about a right angle.

The Valley

Between Iowa and Nebraska the Missouri River alluvial valley is a lowland extending from Sioux City to Hamburg, Iowa. The valley is bordered by abrupt walls which rise from 200 to 300 feet above the flat upper surface of the alluvial fill, and the uplands which form the valley walls gradually decrease in elevation southward with little change in height above the flood plain.

The valley reaches a maximum width of 18 miles in the upper, relatively wide, segment extending from Sioux City to Crescent (Maps 75 to 66), decreases in width to a minimum of 4 miles between Crescent and Plattsmouth (Maps 66 to 62), and ranges from 5 to 7 miles in width in the lower part (Maps 62 to 59) below the mouth of the Platte.

Valley width can be directly correlated with bedrock stratigraphy in the area. The greater valley width starting at Crescent and extending to Sioux City occurs in the area where Cretaceous rocks (primarily Dakota sandstone) are most often found beneath the Pleistocene cover, especially on the west side of the valley.

Approximately 8 feet of Dakota underlies the unconsolidated Pleistocene material at a quarry exposure in Cen. SE 1/4 Sec. 28 T 17N, R 13E, Washington County, Nebraska. (Map No. 66.) Although thicknesses vary due to extensive pre-Pleistocene erosion, on the terrace Holes No. 94, 95, and 97 all penetrated to the Dakota sandstone as did boring No. 96 on the flood plain (Map No. 68). From Tekamah, Nebraska, north to South Sioux City occasional outcrops of Cretaceous rocks occur in the valley walls. Between North Sioux City and Yankton, Jorgensen (46, plate 2) shows the flood of the Missouri Valley as being in the Dakota, Graneros, Greenhorn and Carlisle formations of the Cretaceous system. The Dakota formation is composed primarily of a poorly cemented sandstone with minor shale partings. The slight regional dip of the Cretaceous rocks is westward.

From Crescent to Hamburg progressively younger rocks of the Upper Pennsylvanian, Missouri and Virgil series are exposed. Near Crescent where the valley is constricted the Dennis formation of the lower Missouri series is exposed in a quarry at or slightly above flood plain level. North of Thurman in Fremont County rocks of the upper Virgil series (Deer Creek and Topeka formations) outcrop slightly above flood plain elevation.

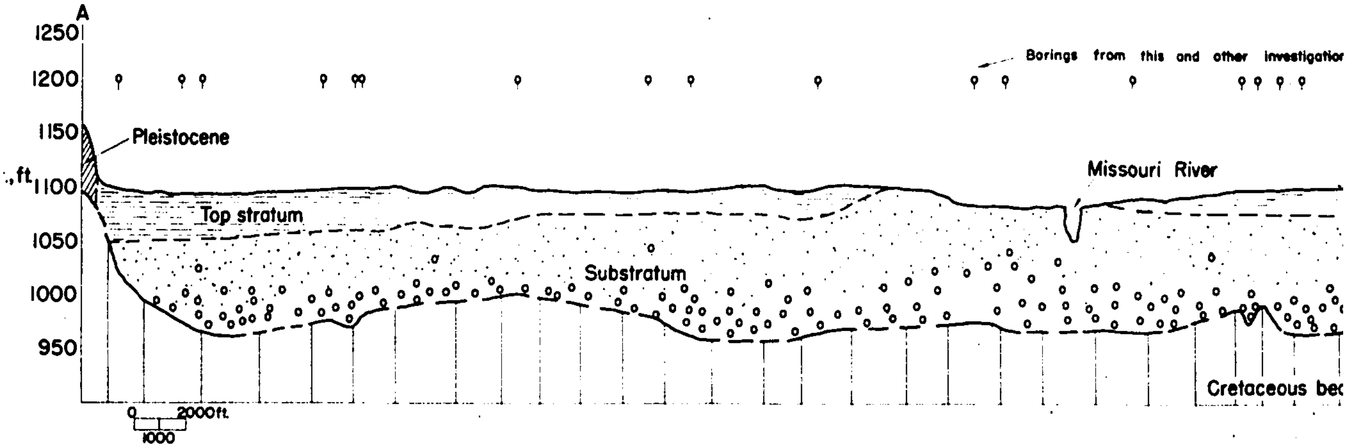
The major structural feature of the area in question, particularly in southwestern Iowa, is the Forest City Basin, a downwarped area including adjacent parts of Missouri, Nebraska and Kansas (45, Figure 17). The axis of the basin trends northeast-southwest and in Iowa it plunges southwest. Within the framework of the basin there is a structural zone consisting of a series of domes, anticlines and minor faults. These northeast-southwest trending structures cross the south-trending Missouri River Valley between Council Bluffs - Omaha and the southern Iowa line. The zone extends northeastward in Iowa through Redfield and Ames and the name Thurman-Redfield structural zone has been proposed (45, p. 35).

At the same latitude at which the Missouri flood plain becomes constricted, the Platte River makes a sharp turn to the south, and from that point to its confluence with the Missouri, its flood plain progressively decreases in width.

Figures 4, 5, 6 and 7 show the configuration of the bedrock floor of the valley as well as the general nature of the alluvial fill. The greatest relief in the valley floor and the thickest (146 ft.) fill is shown in Figure 6, a section across the narrowest part of the valley (Figure 1). It may be significant that this section has the greatest number of borings per mile of width, thus giving better control.

Sections A-A' and B-B' both in the wider segment of the valley, record a thickness of alluvium averaging greater than 100 feet, with

Figure 4. Geologic cross section along A-A'


A
1250
1200
1150
1100
1050
1000
950
ft
Borings from this and other investigatior
Pleistocene
Missouri River
Top stratum
Substratum
Cretaceous bec
0
2000ft
1000

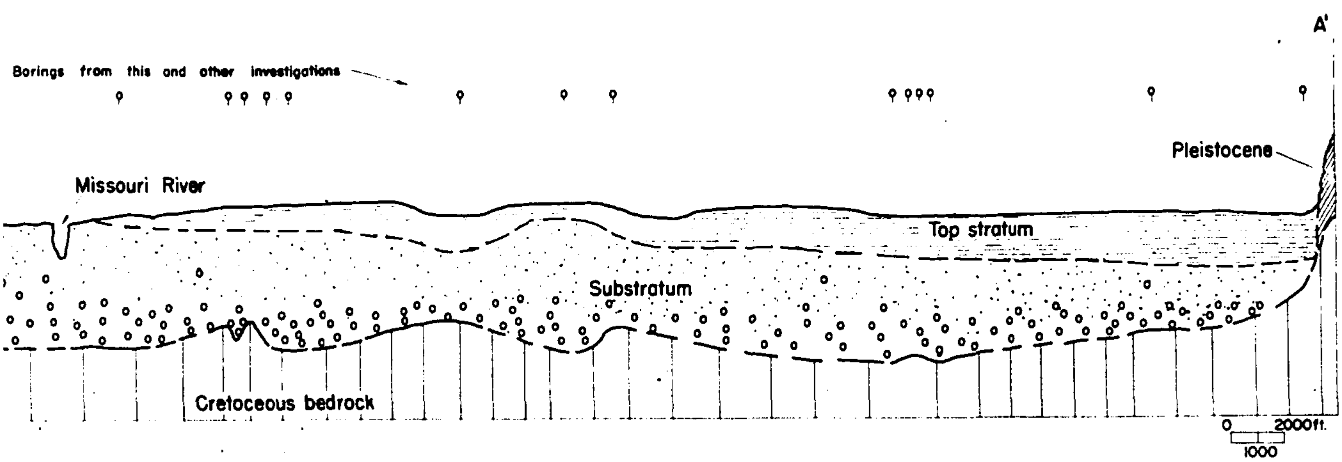
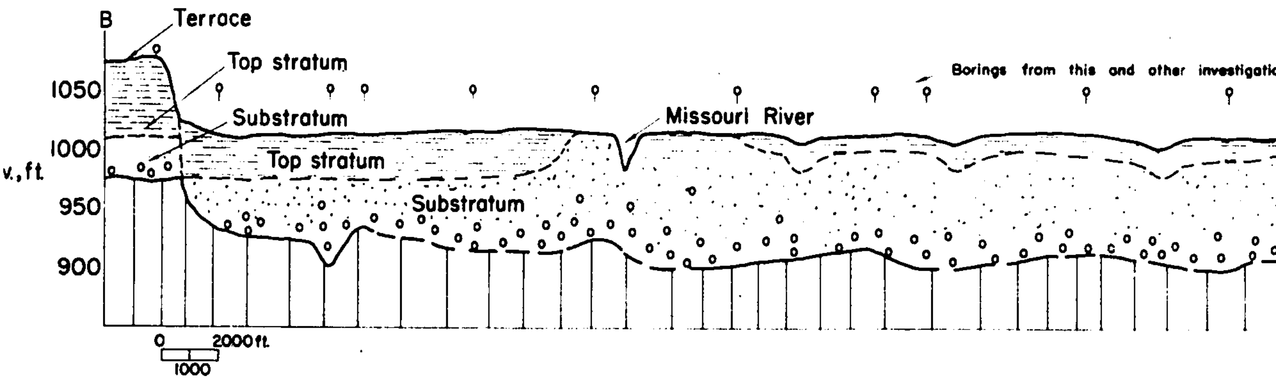
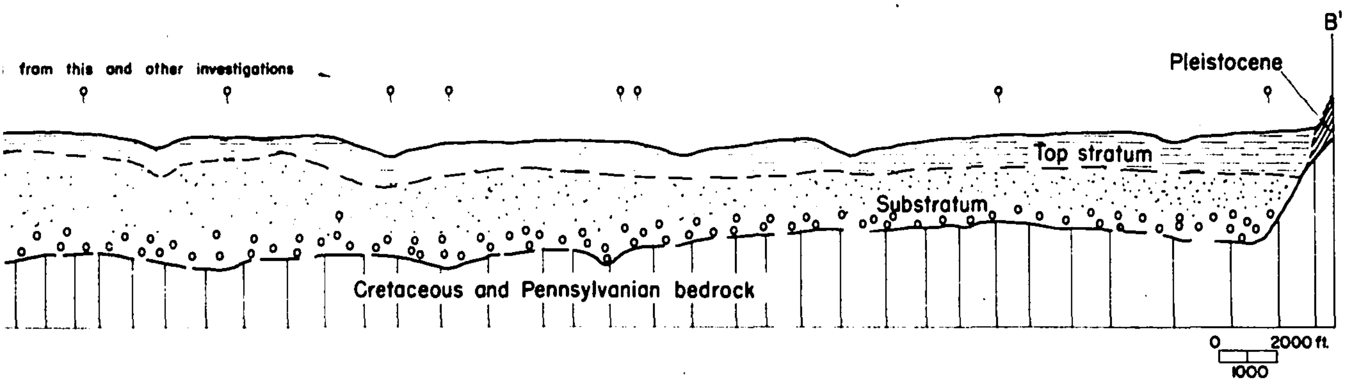

A'
Borings from this and other investigations
Pleistocene
Missouri River
Top stratum
Substratum
Cretaceous bedrock
0 2000 ft.
1000

Figure 5. Geologic cross section along B-B'

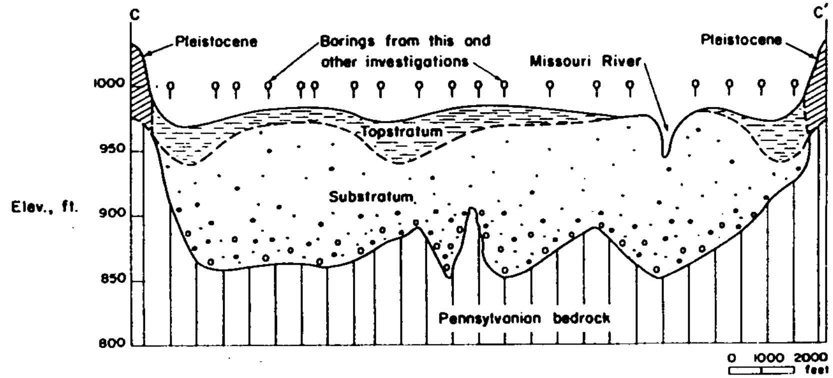

B
Terrace
Top stratum
Substratum
Borings from this and other investigatio
1050
1000
950
900
v., ft.
Missouri River
Top stratum
Substratum
0
2000 ft.
1000

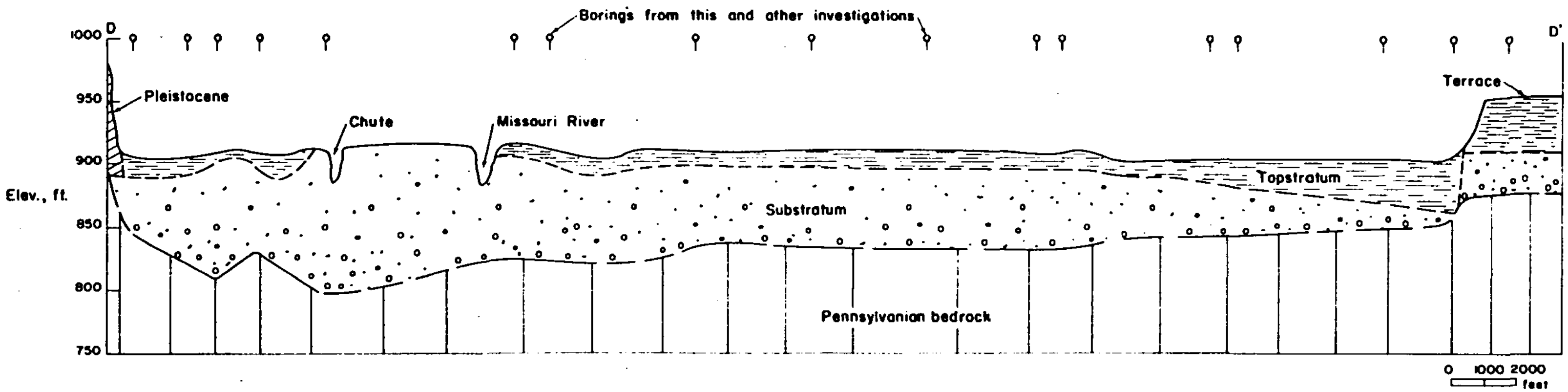


from this and other investigations
B'
Pleistocene
Top stratum
Substratum
Cretaceous and Pennsylvanian bedrock
0
2000 ft.
1000

Figure 6. Geologic cross section along C-C'

Figure 7. Geologic cross section along D-D'


C
C'
Pleistocene
Borings from this and other investigations
Missouri River
Pleistocene
1000
950
900
850
800
Elev., ft.
Topstratum
Substratum
Pennsylvanian bedrock
0 1000 2000
feet


D
D'
Borings from this and other investigations
1000
950
900
850
800
750
Elev., ft.
Pleistocene
Chute
Missouri River
Terrace
Topstratum
Substratum
Pennsylvanian bedrock
0 1000 2000
feet

the northernmost (south of Sioux City) averaging close to 120 feet. Section D-D' near Hamburg shows a thickness of alluvium averaging closer to 90 feet. However, a Corps of Engineers boring a few miles north of section D-D' penetrated 151 feet of alluvium. Jorgensen (46, Plate 2) reports thicknesses of valley fill between North Sioux City and Yankton that approximate those for section A-A'.

The stratigraphy or superposition of unconsolidated material is characterized by a sequence of deposits grading upward from gravels and coarse sand, through sands, into finer-grained silts and clays. This is shown most ideally in the flood basin, where the fine-grained topstratum reaches thicknesses of 40 feet. The gravels and sands are collectively called the substratum, the finer-grained sediments (primarily silt and clay with little sand), the topstratum. Within the area in which distinct, mappable alluvial features are present (the meander belt), the alluvial valley deposits have been reworked by river action into deposits which are quite limited in lateral and vertical distribution, but which become systematic and even predictable in terms of properties when mapped and bored in sufficient detail. The substratum sands occur closer to the surface in the meander belt whereas they are buried by 30-50 feet of topstratum in the marginal basins. The substratum comprises most of the mass of fill and the topstratum is thinner below the mouth of the Platte River.

If 100 feet is used for an average thickness of fill, the prism of alluvium in the Missouri River valley adjacent to Iowa contains 25 cubic miles of material.

Alluvial morphology

This section of the report discusses the physiographic expression of the various deposits as laid down in several environments of deposition along the river. Each type of deposit has been mapped along the Missouri River and its position, thickness and general properties are known. Aerial distribution or the alluvial geology is shown on Plates 1-24. Thickness and properties of the alluvium will be presented in the next section.

Based on valley width, the flood plain was divided into three longitudinal segments as previously mentioned. In discussing alluvial morphology, a lateral tripartite division consisting of (1) the flood basin, (2) the meander belt, and (3) the channel belt is used. Glenn (35, p. 35-84) has described in some detail the surface features of the alluvial plain; a summary is presented here. Figure 8 is a sketch map relating geomorphic areas and nature of the alluvium.

Flood basin. The flood basin is an almost featureless area of very low relief (less than 5 feet) normally lying between the meander belt and the valley wall. Occasionally it is bounded on one side by the channel belt instead of the meander belt (Plate 15). Depending on valley width, meander belt width and degree to which alluvial fans have extended themselves onto the flood plain, the flood basin area will usually lie at a lower elevation than the adjacent meander belt (Figure 9). The features which can be recognized from aerial photographs are flood distributary patterns (crevasse topography) and some channel

Figure 8. Sketch indicating stratigraphic relationships and geomorphic areas of the alluvial valley

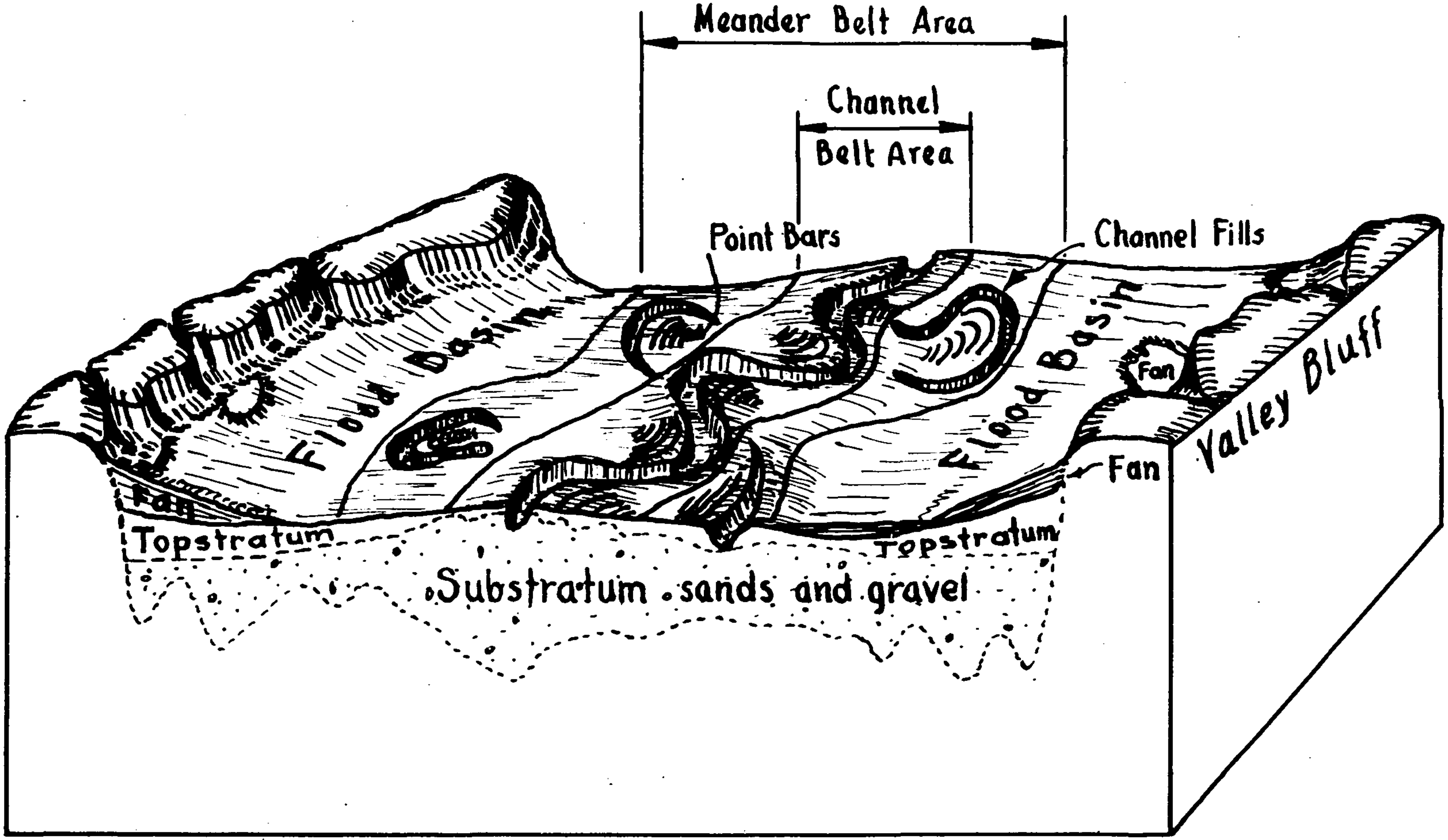
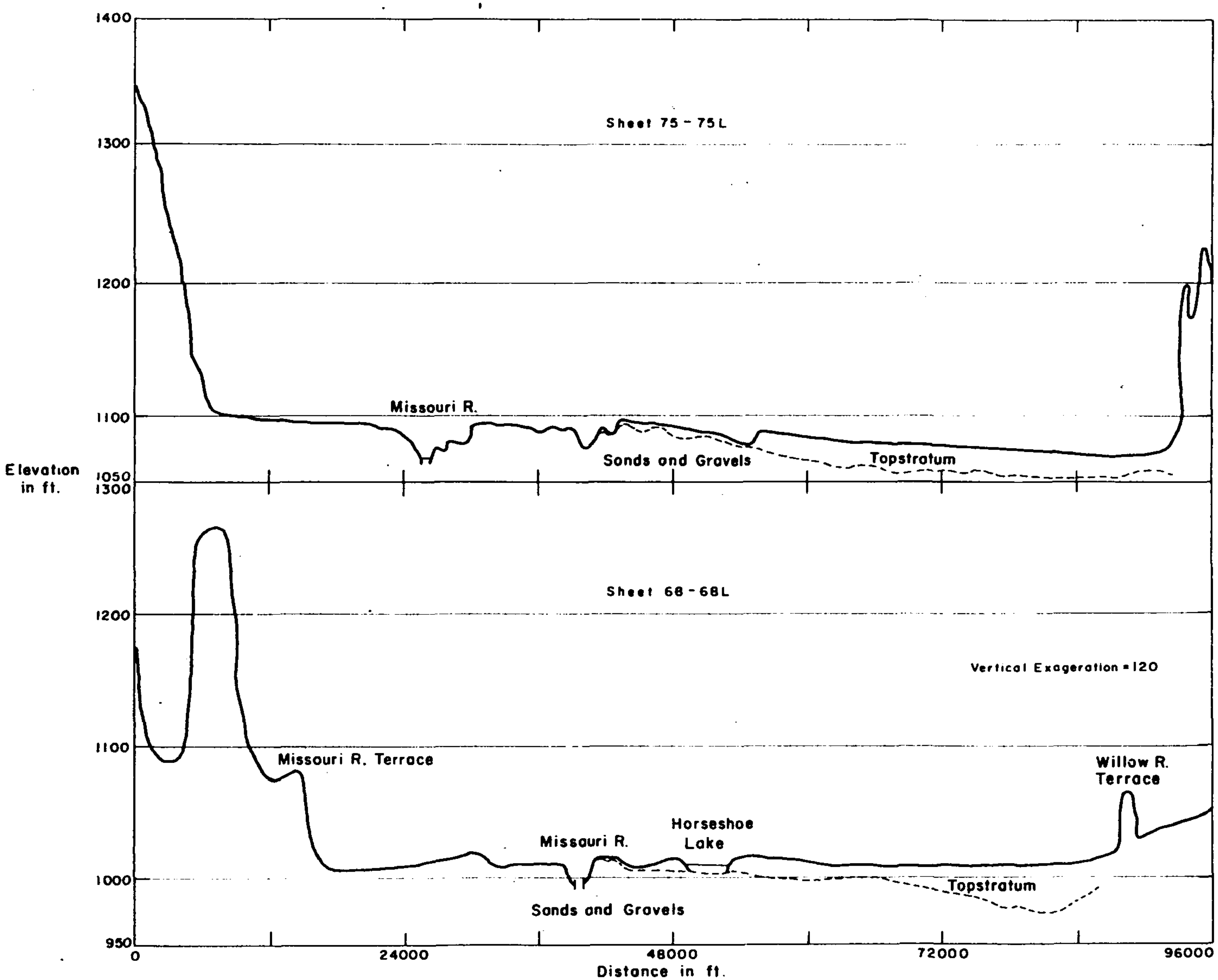

Meander Belt Area
Channel
Belt Area
Point Bars
Channel Fills
Flood Basin
Flood Basin
Fan
Valley Bluff
Fan
Fan
Topstratum
Topstratum
Substratum sands and gravel

Figure 9. Topographic profiles across the Missouri River Valley illustrating the rise in flood plain elevation from the flood basin area to the river


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

patterns of smaller tributary streams (see Figure 10). As might be expected, the flood basin comprises the greatest proportion of the alluvial valley in the upper segment.

The deposits of the flood basin constitute primarily the fine-grained sediment deposited by the river during floods. Of secondary importance are tributary stream and alluvial fan deposits. These deposits have been forming throughout the late stages of valley history as slow aggradation of the flood plain has taken place. Consequently, except where erosional activity in the channel or meander belt has redistributed material, the flood basin deposits in the marginal valley basins form the most extensive and thickest prisms of silty and clayey sediment.

A much less well-defined system of natural levees exists along the meander belt of the Missouri River than that reported along the different meander belts of the lower Mississippi by Fisk (26, p. 42). Nevertheless, aerial photos along the meander belt margin do reveal an area of lighter sediment lying concentrically around many of the older channel fills, especially in the wider part of the floodplain (see Figure 10). Almost any cross-valley profile will show a general increase in elevation toward the river; in the wider parts of the floodplain a difference in elevation approaching 20 feet is realized between the lowest part of the flood basin (usually at the toe of an alluvial fan) and the highest point in the meander belt. In this report, however, the natural levees are not mapped as separate units but are included in the flood basin.

Figure 10. Various alluvial features present in the Missouri River flood plain


SCALE
feet
0
2000

Meander belt. The meander belt area records former Missouri River activity in the form of mappable abandoned channels and their associated point bars. Downstream migration of the meander loop, especially the upstream arm, coupled with a limiting distance through which the meander develops laterally, leads to the characteristic neck cut-off. Normally the meander belt is bordered toward the river by a varying width of channel belt and bluffward by the flood basin. Relief of 10 feet is common; more recently cut-off channels may show 15 feet.

These abandoned channels and adjacent point bars subsequently become masked or modified by the depositional action of flooding, but nevertheless remain the principal geomorphic features of the meander belt. See Figure 10.

Channel fill. The surface expression of a meander scar is a dark, arcuate low area. In any single cross profile the central, low, flat portion of the now-filled channel is bordered by a slight rise onto the slip-off slope of the point bar and a sharper scarp along the concave outer margin. Longitudinally the old channel characteristically shows a series of round or oval-shaped lows or "pocks" representing irregularities in depth of the former thalweg.

Channel width at time of abandonment and type of cut-off determine the aerial distribution of each particular paleo-channel. Many of the older channels had a width greater than the present channel, and if abandoned by a chute cut-off a half-moon shape resulted rather than the oxbow shape left by a neck cut-off. The chronology of abandonment and corresponding time to which each channel was left to undergo modification is another factor. Since the Missouri River has not occupied a distinct series of different meander belts bounded by alluvial ridges, generally speaking the older channels relatively far removed from the present river are the most obscure and contain the greatest thickness of sediment. Channel fill sediment is typically a dark, very fine-grained (clays and silts) material with relatively high organic matter and moisture contents.

When a neck cut-off occurs, in contrast to a chute cut-off, quite rapid abandonment of the old channel is effected and, after the upstream and downstream arms become silted in, an oxbow lake is formed. With the eventual filling of the lake by deposition of fine-grained sediment, a clay plug is formed in the old channel. Since these deposits are hard to erode, the symmetry of a subsequent meander loop may be distorted as the channel impinges on this resistant point. Boring III on Plate 23 is located on a clay plug.

Point bar. The surface expression of a point bar appears as an alternating band of concentric ridges and lows, developed by the cyclic growth of a meander loop. Relief on the point bars of modern or quite recently cut-off meander loops shows on topographic maps having a 5-foot contour interval. A heavy growth of willow trees covers the accretion topography of the more modern point bars.

Due to periodic flooding over the meander belt, the original relief of a point bar loses its sharpness and becomes buried under a varying thickness of finer-grained sediment. Point bar relief thus generally decreases with distance from the river and age of the channel remnant.

The point bar deposits show up as lighter areas on aerial photographs surrounded by a dark accurate band marking the old channel. Better drainage, coarser material, less organic matter, and higher topographic position of the point bar account for this. Below the mouth of the Platte River, especially in the area southeast of Payne, Iowa (Plate 1), point bar and channel belt sand has been remarked by wind action.

Undifferentiated deposits. Occasionally within the meander belt area some point bar and channel fill deposits become modified by overbank flooding or tributary channel patterns to the extent that reliable mapping becomes difficult. These areas have geomorphic features characteristic of both abandoned channels and point bars but lack of continuity has lead them to be mapped as undifferentiated deposits and shown on the geologic maps as masked point bars and channel fills.

Channel belt. This area includes the portion of the alluvial valley lying adjacent to the present river and normally bounded laterally by the meander belt. The principal geomorphic features are point bars and modern channel bars of the river and they are both mapped under the designation of Missouri River bars. The point bars appear as concentric ridges and lows within a modern channel band and the channel bars are characteristically tear-shaped, flat topped features which taper downstream.

The processes of channel migration and bar building make the channel belt the area in which the most active erosion and deposition of material is taking place. Coarser-grained sediments (primarily sand) occur at the surface. A heavy growth of willows is almost always found on the point bars.

Alluvium

Surface characteristics of the various alluvial deposits, their aerial distribution on the flood plain (Plates 1 through 24) and the general nature of the alluvial fill were presented in the previous section. This section considers in more detail some of the physical and chemical properties of the alluvial deposits. Glenn (35, p. 90-114) has reported on similar properties of the alluvium as determined by 71 borings made during the 1958 and 1959 field seasons. This work is summarized and supplemented by data from the 1960 field season. Locations of all the 1960 borings (flood plain, terrace and upland) are presented in Table 8. Borings 123 through 127 were made by hand auger.

The flood plain borings made in the course of this investigation were supplemented by numerous other borings to bedrock previously mentioned and, in particular reference to the elevation of the eroded bedrock floor, a preliminary unpublished map by the United States Geological Survey[a] was helpful. Properties of the alluvium from flood plain borings made during 1960 are presented in Table 9. Basically, the alluvial fill consists of two units, the substratum sands and gravels and the finer-grained topstratum. Within the meander belt substratum sands rise closer to the alluvial plain but still are covered by some topstratum.

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[a]Miller, Robert D., United States Geological Survey, Denver, Colo. Preliminary map of eroded bedrock surface. Private communication. 1957.

Table 8. Boring locations

Boring No.	Section	Tier and range	County, state	Geologic location	Map[a] No.	Plate No.	Surf.[b] elev.	Total depth	Bedrock elev.
85	NW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 34	T79NR43W	Harrison, Iowa	Terrace. Boyer R.	68L	11	1085	90	995
86	SE$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 33	T79NR43W	Harrison, Iowa	Upland. Valley slope above Boyer R. terrace.	68L	11	1200	143	1057
87	Cen. SW$\frac{1}{4}$ sec. 33	T79NR43W	Harrison, Iowa	Upland. Interfluve between Boyer and Willow R.	68L	11	1260	166	
88	NW$\frac{1}{4}$ NW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 7	T79NR43W	Harrison, Iowa	Flood plain. Boyer R.	68L	11	1010	61	949
89	SE$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 19	T79NR43W	Harrison, Iowa	Terrace. Mouth of Willow R.	68L	11	1066	101	965
90	SE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 19	T79NR43W	Harrison, Iowa	Flood plain. Willow R.	68L	11	1032	70	---
91	SW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 28	T79NR43W	Harrison, Iowa	Upland. Valley slope above Willow R.	68L	11	1125	65	---
92	NE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 22	T79NR45W	Harrison, Iowa	Flood plain, Missouri R.	68	10	1015	40	901[c]

[a]Numbers refer to base maps from U. S. Corps of Engineer River Survey from Rulo to Yankton, 1946-1947.

[b]Elevations in feet above mean sea level.

[c]From boring other than that of this investigation.

Table 8 (continued)

Boring No.	Section	Tier and range	County, state	Geologic location	Map[a] No.	Plate No.	Surf.[b] elev.	Total depth	Bedrock elev.
93	NW¼ NE¼ SE¼ sec. 3	T19NR11E	Washington, Nebr.	Flood plain. Missouri R. Flood basin.	68	10	1012	32	914[c]
94	NE¼ NE¼ SE¼ sec. 16	T19NR11E	Washington, Nebr.	Terrace. Missouri R.	68	10	1089	126	976
95	NW¼ NW¼ SW¼ sec. 16	T19NR11E	Washington, Nebr.	Terrace. Missouri R.	68	10	1065	89	985
96	Cen. NW¼ SW¼ sec. 15	T19NR11E	Washington, Nebr.	Flood plain. Missouri R. Flood basin.	68	10	1005	80	925
97	Cen. SE¼ NW¼ sec. 17	T19NR11E	Washington, Nebr.	Terrace. Missouri R. Alluvial fan on terrace.	68	10	1100	116	984
98	SW¼ SW¼ NW¼ sec. 17	T19NR11E	Washington, Nebr.	Upland. Crest of interfluve between Missouri R. and New York Creek.	68	10	1325	108	---
99	SW¼ SE¼ SE¼ sec. 17	T19NR11E	Washington, Nebr.	Upland. Valley slope above Missouri R. terrace.	68	10	1245	154	1091
100	SE¼ SE¼ SE¼ sec. 22	T67NR42W	Fremont, Iowa	Flood plain. Mouth of Nishnabotna R.	59L	1	907	46	861
101	NW¼ NE¼ SW¼ sec. 23	T67NR42W	Fremont, Iowa	Terrace. Mouth of Nishnabotna R.	59L	1	959	90	869
102	NW¼ NE¼ sec. 29	T67NR42W	Fremont, Iowa	Flood plain. Missouri R. Channel fill.	59	1	898	78	820

Table 8 (continued)

Boring No.	Section	Tier and range	County, state	Geologic location	Map[a] No.	Plate No.	Surf.[b] elev.	Total depth	Bedrock elev.
103	NW$\frac{1}{4}$ NW$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 25	T67NR43W	Fremont, Iowa	Flood plain. Missouri R. Point bar.	59	1	902	64	830
104	SW$\frac{1}{4}$ NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 18	T68NR43W	Fremont, Iowa	Flood plain. Missouri R. Clay plug.	60	2	920	29	824[c]
105	NW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 1	T66NR42W	Atchison, Missouri	Upland.	59L	1	1025	135	829[c]
106	SE$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 12	T66NR42W	Atchison, Missouri	Upland. Crest of ridge adjacent to Missouri R. flood plain.	58L	---	1145	190	---
107	NW$\frac{1}{4}$ NE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 33	T70NR41W	Fremont, Iowa	Terrace. Nishnabotna R.	Randolph quad.	---	965	72	893
108	SW$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 27	T70NR41W	Fremont, Iowa	Upland. East of No. 107.	Randolph quad.	---	1090	48	---
109	SW$\frac{1}{4}$ SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 35	T28NR8E	Dakota, Nebr.	Flood plain. Missouri R. Channel fill.	75	22	1090	34	970[c]
110	SW$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36	T28NR8E	Dakota, Nebr.	Flood plain. Missouri R. Point bar.	75	22	1095	15	970[c]
111	NE$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$	T87NR47W	Woodbury, Iowa	Flood plain. Missouri R. Clay plug.	75L	23	1085	47	970[c]

Table 8 (continued)

Boring No.	Section	Tier and range	County, state	Geologic location	Map[a] No.	Plate No.	Surf.[b] elev.	Total depth	Bedrock elev.
112	SE¼ NE¼ sec. 29	T90NR46W	Plymouth, Iowa	Terrace. Near mouth of Floyd R.	---	---	1152	52	1100
113	SW¼ NW¼ NW¼ sec. 6	T91NR45W	Plymouth, Iowa	Terrace. Floyd R.	---	---	1172	25	1130[c]
114	SW¼ SE¼ sec. 27	T91NR46W	Plymouth, Iowa	Terrace. Floyd R.	---	---	1160	49	1111
115	SW¼ SW¼ SW¼ sec. 21	T91NR46W	Plymouth, Iowa	Upland. West of No. 114	---	---	1325	70	---
116	NW¼ SE¼ NW¼ sec. 23	T92NR50W	Union, S. Dakota	Upland. Cary drift plain.	80L	---	1210	92	---
117	Cen. NW¼ SE¼ sec. 11	T83NR44W	Monona, Iowa	Terrace. Mouth of Maple R.	72L	17	1145	142	995
118	NE¼ NE¼ NE¼ sec. 33	T85NR43W	Monona, Iowa	Terrace. Maple R.	---	---	1190	103	1077
119	NW¼ SE¼ NE¼ sec. 4	T80NR44W	Harrison, Iowa	Terrace. Mouth of Soldier R.	70L	14	1085[d]	110	970
120	NW¼ NW¼ NW¼ sec. 9	T83NR42W	Monona, Iowa	Terrace. Soldier R.	---	---	1170	83	1080
121	NW¼ NW¼ sec. 19	T20NR11E	Burt, Nebr.	Terrace. Low terrace on Missouri R.	69	12	1060	65	---
122	SE¼ NW¼ sec. 28	T17NR13E	Washington, Nebr.	Terrace. Missouri R.	66	8	1085	100	965[c]

[d]Maximum terrace elevation is 100 feet.

Table 8 (continued)

Boring No.	Section	Tier and range	County, state	Geologic location	Map[a] No.	Plate No.	Surf.[b] elev.	Total depth	Bedrock elev.
123	SW$\frac{1}{4}$ NE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ N$\frac{1}{2}$ sec. 1	T78NR44W	Harrison, Iowa	Terrace. Boyer R. Channel fill.	68L	11	1081	19	995
124	NW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ N$\frac{1}{2}$ sec. 1	T78NR44W	Harrison, Iowa	Terrace. Boyer R. Point bar.	68L	11	1085	14	995
125	Cen. NW$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ N$\frac{1}{2}$ sec. 1	T78NR44W	Harrison, Iowa	Terrace. Boyer R. Flood basin.	68L	11	1085	10	995
126	Cen. NE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ N$\frac{1}{2}$ sec. 1	T78NR44W	Harrison, Iowa	Terrace. Boyer R. Point bar.	68L	11	1084	12	995
127	NW$\frac{1}{4}$ NW$\frac{1}{4}$ SW$\frac{1}{4}$ N$\frac{1}{2}$ sec. 6	T78NR43W	Harrison, Iowa	Terrace. Boyer R. Channel fill.	68L	11	1080	18	995

Table 9. Properties of alluvium

Sample No.	Depth, feet	Particle-size, %			Carbonate, %	pH	Organic matter, %	Remarks
		Clay	Silt	Sand				
88-2	25-26.5	34.0	57.0	9.0	4.7	7.8		Fine-grained topstratum to 25 ft. substratum becomes coarser with depth to bedrock at 61 ft. Wood recovered in sand between 40-48 ft. yielded C^{14} date of 12,950±375 Y.B.P.[a] Recovered fossils.
90-3	30-31.5	13.0	55.0	32.0	16.8	8.8		Fine-grained channel fill and topstratum to 30 ft. Silt and fine sand to 43 ft. Coarse sand to gravel at 70 ft. Concretion zone at 30 ft. accounts for high carbonate. Wood from 10-13 ft. dated at 400±105 Y.B.P. Wood from 40-41 ft. dated at 13,050±375 Y.B.P. Recovered fossils.
93-1	5- 6.5	79.0	19.5	1.5	6.2	8.4		Illustrates flood basin close to meander belt. Topstratum to 27 ft. Recovered fossils, and iron and carbonate concretions.
93-2	15-16.5	72.0	26.0	2.0	9.0	8.7		
93-3	30-31.5	2.6	6.0	91.4	8.6	9.0		
96-1	5- 6.5	32.0	67.3	0.7	4.3	7.7	1.63	Illustrates flood basin close to valley wall. Fine-grained topstratum to 45 ft. Fine-medium sand to bedrock (K_d) at 80 ft. Recovered fossils.
96-2	15-16.5	25.0	74.3	0.7	5.4	8.6	0.57	
96-4	30-31.5	79.0	20.9	0.1	10.3	8.6	0.61	
96-5	45-46.5	10.0	47.1	42.9	9.3	8.7	0.93	

[a] Years before present.

Table 9 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Remarks
100-1	7-8	77.0	21.3	1.7	4.7	8.5	Illustrates flood basin close to valley wall. Fine-grained topstratum to 40 ft. Silt and fine sand to bedrock at 45.5 ft. Shallow depth to bedrock correlates with narrow, rock-defended mouth of Nishnabotna River.
102-1	5-6.5	4.0	14.2	81.8	6.3	8.8	Illustrates channel fill below mouth of Platte. Only 5 ft. of fine-grained fill. Substratum becomes coarser with depth. Gravel above bedrock at 77.5 ft.
103-1	5-6.5	3.5	12.5	84.0	7.1	8.8	Illustrates point bar below mouth of Platte. Less than 5 ft. of fine-grained material over point bar sands. 63.5 ft. to bedrock.
104-1	5- 6.5	58.0	40.8	1.2	9.2	8.5	Illustrates clay plug below mouth of Platte. Slightly more fine-grained material (14 ft.) above substratum sands than in the point bar or channel fill borings (No. 102 and 103) in the area.
104-2	15-16.5	4.0	25.1	70.9	7.9	8.6	
109-1	5- 6.5	51.0	46.7	2.3	5.0	8.1	Illustrates channel fill above mouth of Platte. 32 ft. of fill over channel bottom sands. 5 ft. of relief from lowest part of filled channel to top of outside bank. 120 ft. to bedrock.
109-2	15-16.5	58.0	41.9	0.1	10.5	8.7	
109-3	32-33.5	5.0	18.9	76.1	7.5	8.5	
110-1	5- 6.5	11.0	88.1	0.9	10.4	8.9	Point bar above mouth of Platte. 3 ft. of relief now present on this surface.
110-2	15-16.5	2.0	9.2	88.8	7.7	9.2	

Table 9 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Organic matter, %	Remarks
111-1	5- 6.5	25.0	74.6	0.4	11.4	8.1	0.87	Clay plug above mouth of Platte. Fine-grained sediment to 46 ft. This hard point has definitely distorted a subsequent meander loop which impinged upon it.
111-2	15-16.5	68.0	31.6	0.4	8.8	8.3	1.16	
111-3	25-26.5	71.0	28.9	0.1	8.4	8.2	1.16	
111-4	32-33.5	76.0	23.9	0.1	6.9	8.6	1.15	
111-5	45-46.5	31.0	68.1	0.9	7.8	8.6	1.36	

Substratum material found near the top of the unit consists of relatively clean, fine to medium sand. With depth, the substratum becomes coarser and gravel is usually found near the base of this unit, especially near the center of the valley. In the marginal basins, medium sand is likely to be the coarsest material found at depth in the substratum. Quartz, feldspar and mica dominate the mineralogy of the sand fraction. Discrete particles of carbonate usually occur throughout the mass. The gravel fraction consists of crystalline rock fragments.

The substratum ranges in thickness from less than 10 feet (Hole 100) to over 100 feet. In general it is thinnest and finest in the flood basin area closest to the valley walls and thickest and coarsest in the central part of the valley. Within the channel belt area, substratum sands occur at the surface. The distribution of topstratum and substratum in the Missouri River Valley conforms to the general relationship developed above. However, the thickness of topstratum in the meander belt area below the mouth of the Platte River is considerably less than that above the mouth of the Platte.

Flood basin deposits. The topstratum deposits of the flood basin consist dominantly of interbedded clays and silty clays with subordinate amounts of silty and clayey sands. Figure 11 shows the textural classification used in this report. Figures 12 and 13 present the range in cumulative curves and per cent of samples in each textural class for several samples from the flood basin topstratum and substratum, respectively. Substratum samples are all sands or sandy loams.

Figure 11. Textural classification chart of the U. S. Bureau of Public Roads

Textural Classification Chart

U.S. Bureau of Public Roads

Sand-Size Particles 0.074 to 2mm.

Silt-Size Particles 0.005 to 0.074mm.

Clay-Size Particles less than 0.005mm.

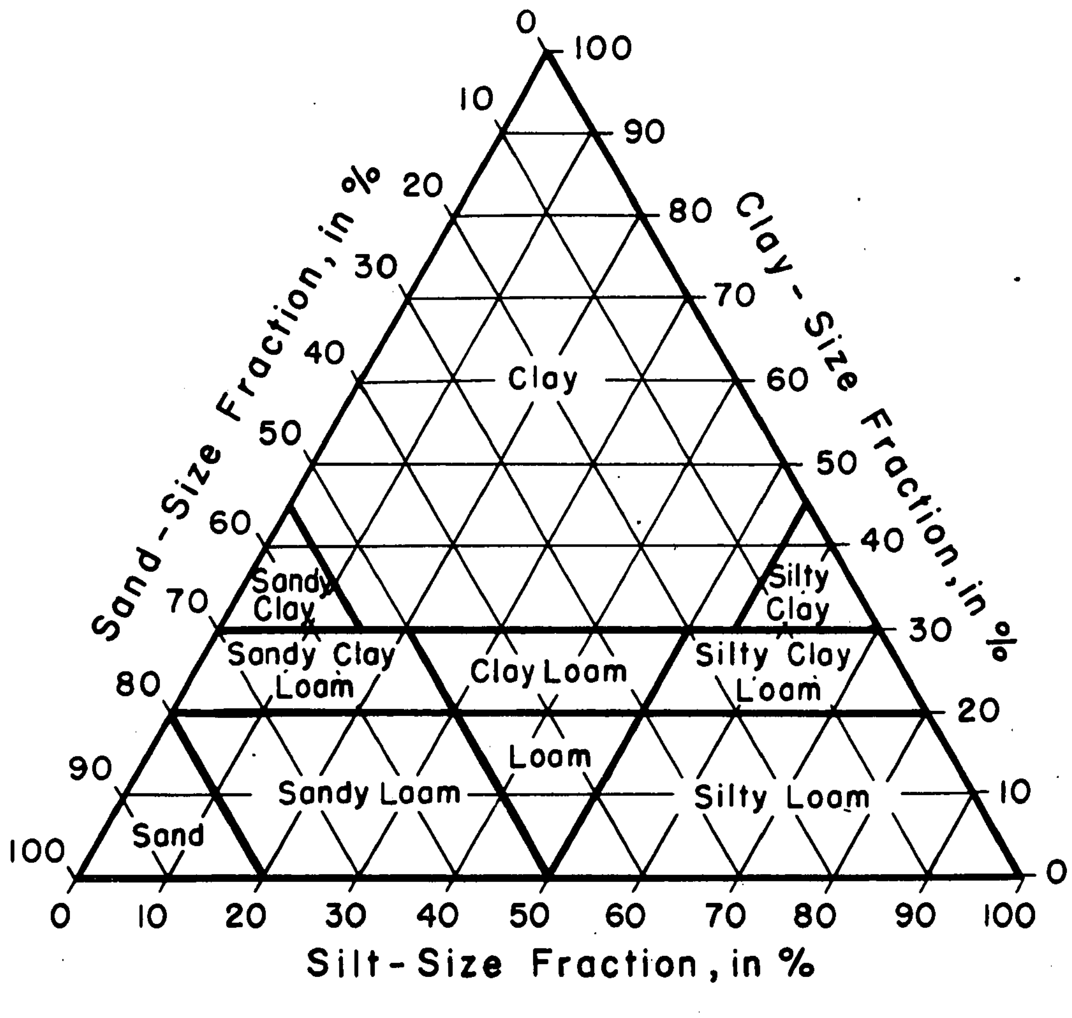
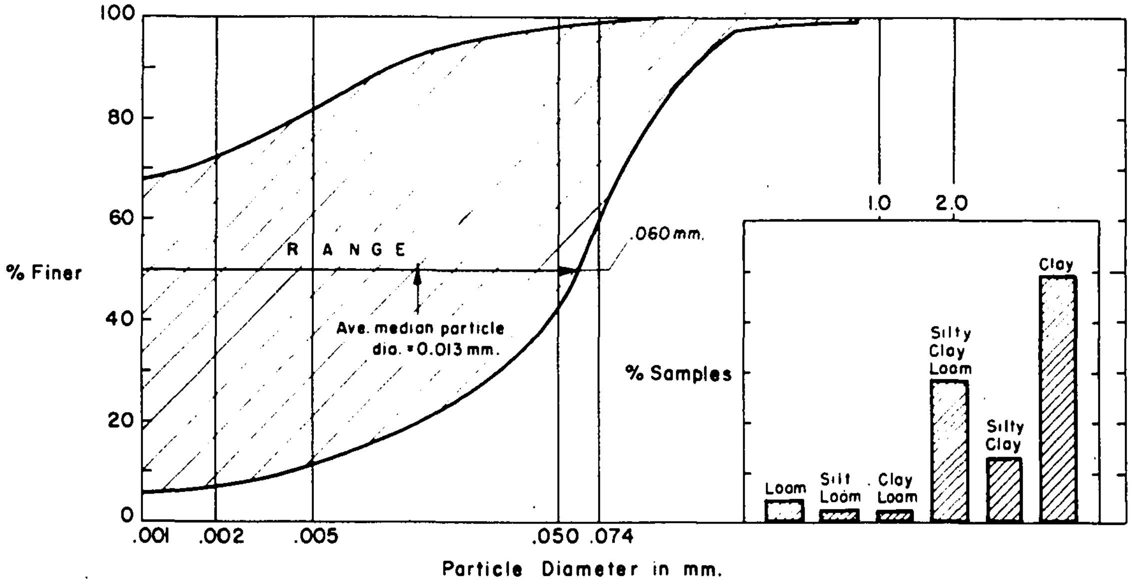
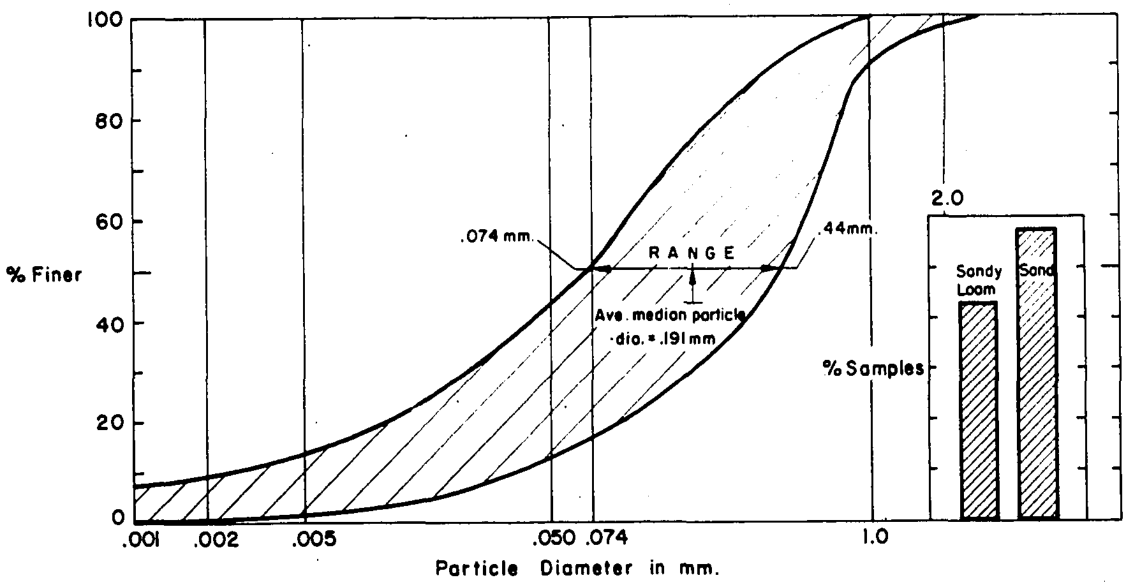


Figure 12. Range in cumulative curves for 84 flood basin topstratum samples and per cent of samples in each textural class

Figure 13. Range in cumulative curves for 17 flood basin substratum samples and per cent 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

The bimodal distribution of material in the topstratum and the relatively high percentage of samples in the silty clay loam class is attributed to the alluvial fan and natural levee samples included in the data presented in Figure 12.

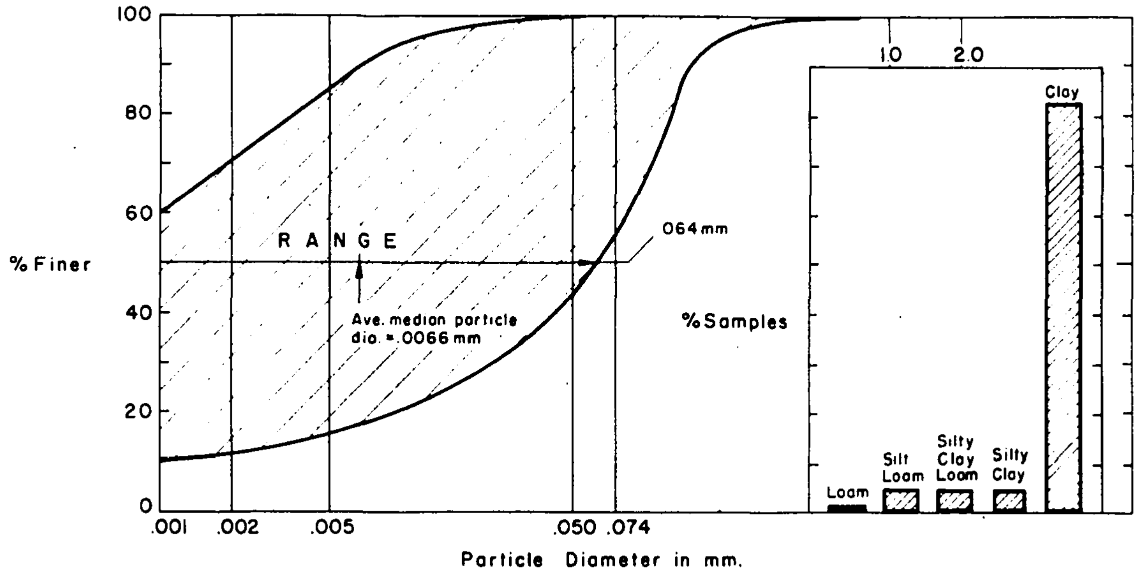
Carbonate contents in the flood basin topstratum average 7 per cent by dry weight of sediment and range between 5 and 10 per cent. Small carbonate and iron concretions are found within the deposit. The iron concretions are commonly cylindrical with a small hole along the axis whereas the carbonate concretions are both cylindrical and nodular in form. They may be found within 5 feet of the present surface.

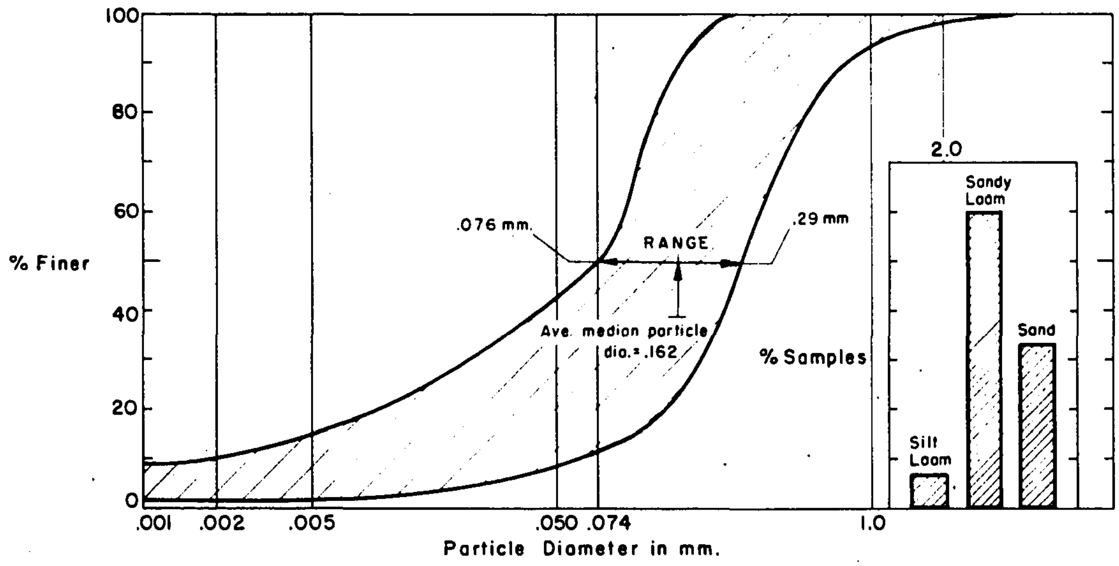
Meander belt deposits. The channel fill and point bar deposits comprise the two major subdivisions of the meander belt. Both have varying thicknesses of topstratum; channel fills have the greatest.

Channel fill deposits. Characteristically these deposits consist of interbedded blue-black clays and silts underlain by substratum sand. Apparently no more than about 1.5 per cent organic matter is needed to give the sediment a dark color (See hole 111, Table 9). Figures 14 and 15 show the range in particle-size and per cent of samples in each textural class for channel fill topstratum and substratum. Several classes are represented but the vast majority of samples (nearly 85 per cent) fall into the clay group in the topstratum. A somewhat bimodal distribution occurs in the channel fill substratum; the sandy loams near the top of the substratum represent mixing and the incorporation of finer material into the channel-bottom sand during times of higher water soon after channel abandonment. The carbonate content as

Figure 14. Range in cumulative curves for 66 channel fill topstratum samples and per cent of samples in each textural class

Figure 15. Range in cumulative curves for 18 channel fill substratum samples and per cent of samples in each textural class


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

determined from a number of channel fill and clay plug samples averages 8.2 per cent and varies between 5 and 11.4 per cent.

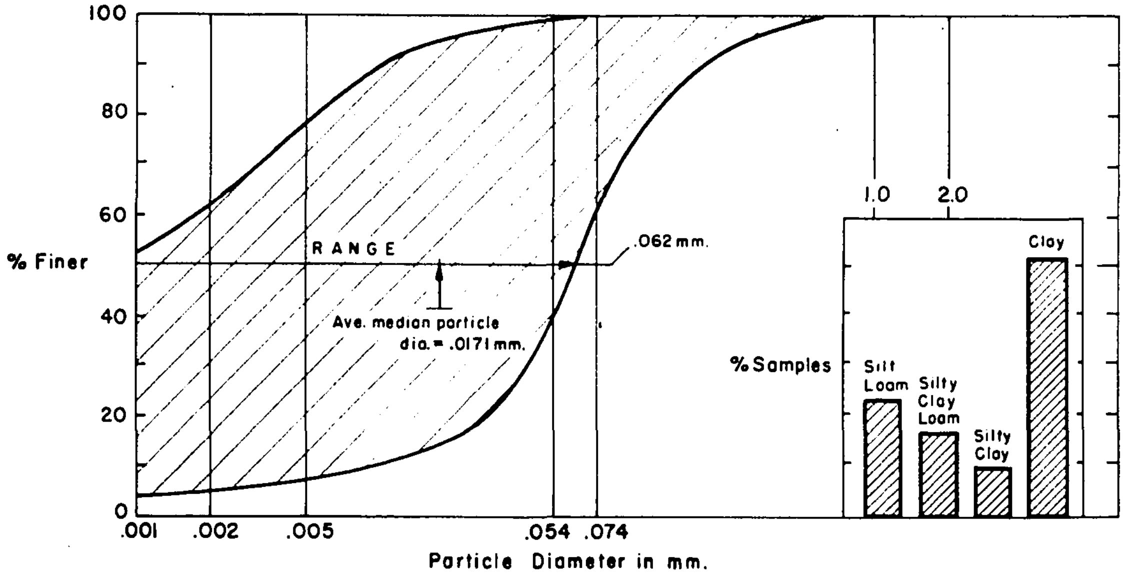
Point bar deposits. The sediments found in this environment of deposition are the silts and clays of the topstratum and the sands of the substratum. Figures 16 and 17 illustrate the range in grain-size and per cent of samples in the textural classes for point bar topstratum and substratum, respectively. The topstratum contains a predominance of samples in the clay textural class (about 50 per cent) with subordinate amounts in the slightly coarser-grained classes. The samples containing appreciable quantities of sand are found near the base of the topstratum. A comparison of the average medium particle diameters from Figures 14 and 16 illustrates the difference in the average size of sediment in the two deposits; the channel fill topstratum is finer than that of the point bar.

The transition from topstratum to substratum is somewhat sharper in the point bar environment than in the channel fill; note that nearly 70 per cent of the substratum samples from the point bar fall in the sand class. The amount of carbonate in point bar deposits varies between 7 and 10 per cent and averages 8.5 per cent.

Undifferentiated deposits. Figures 18 and 19 show the range in cumulative curves and per cent of samples in each textural class for the masked point bar and channel fill deposits. The characteristics of these deposits are similar to those previously described for the point bar and channel fill. As might be expected, the average median particle diameter of the topstratum is between that of the above-mentioned de-

Figure 16. Range in cumulative curves for 34 point bar topstratum samples and per cent of samples in each textural class

Figure 17. Range in cumulative curves for 17 point bar substratum samples and per cent 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

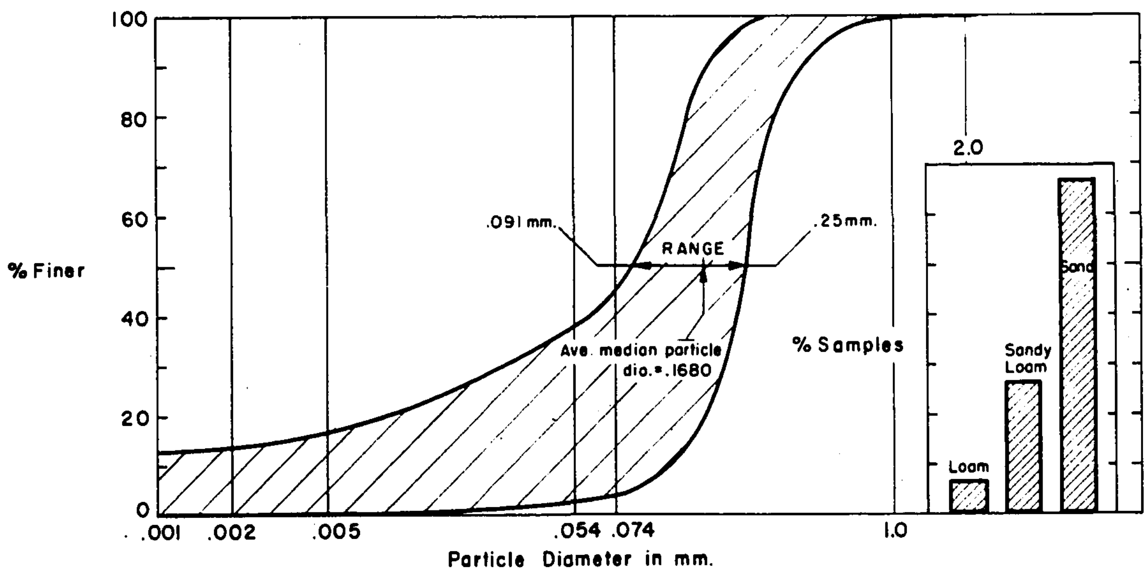
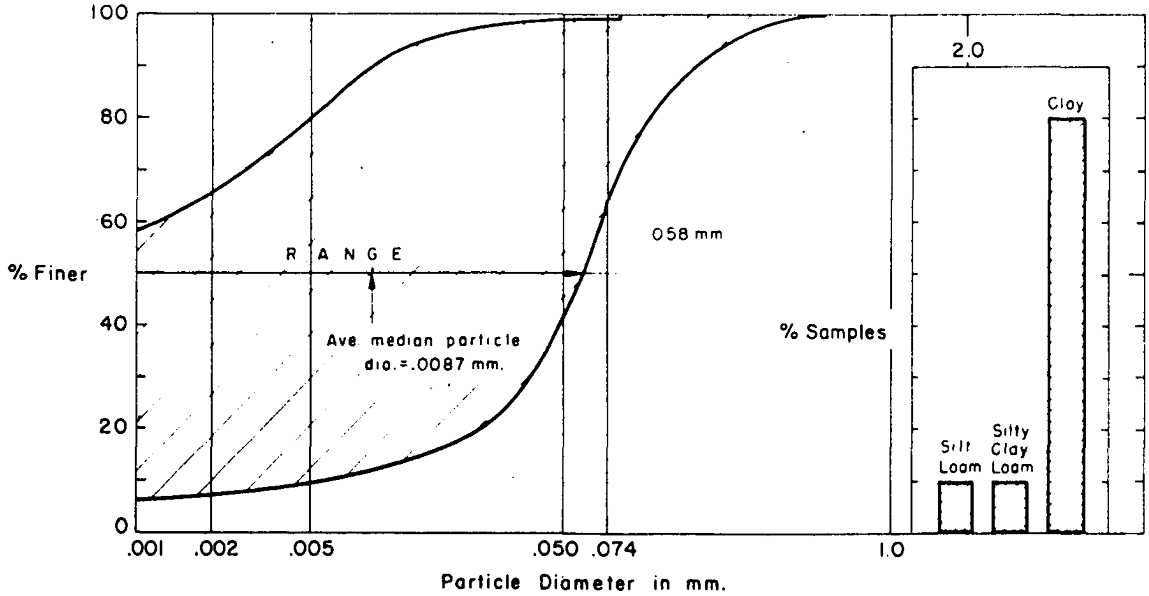
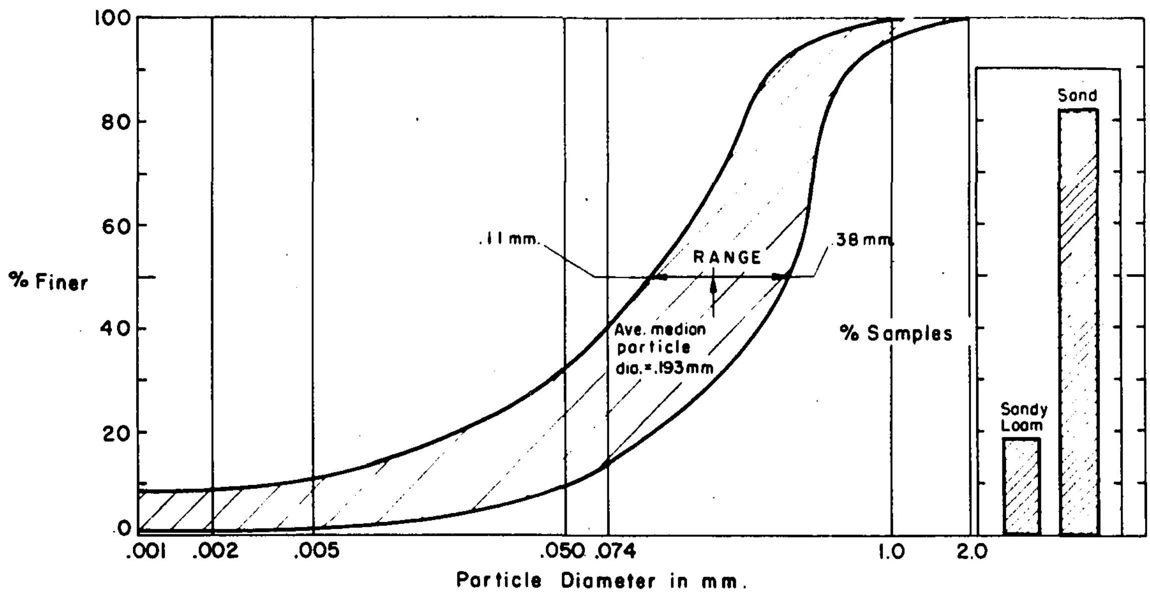

100
80
60
40
20
0
% Finer
.091 mm.
.25 mm.
RANGE
Ave. median particle dia. = .1680
.001 .002 .005 .054 .074 1.0
Particle Diameter in mm.
2.0
% Samples
Loam
Sandy Loam
Sand

Figure 18. Range in cumulative curves for 10 undifferentiated topstratum samples and per cent of samples in each textural class

Figure 19. Range in cumulative curves for 11 undifferentiated substratum samples and per cent of samples in each textural class


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


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

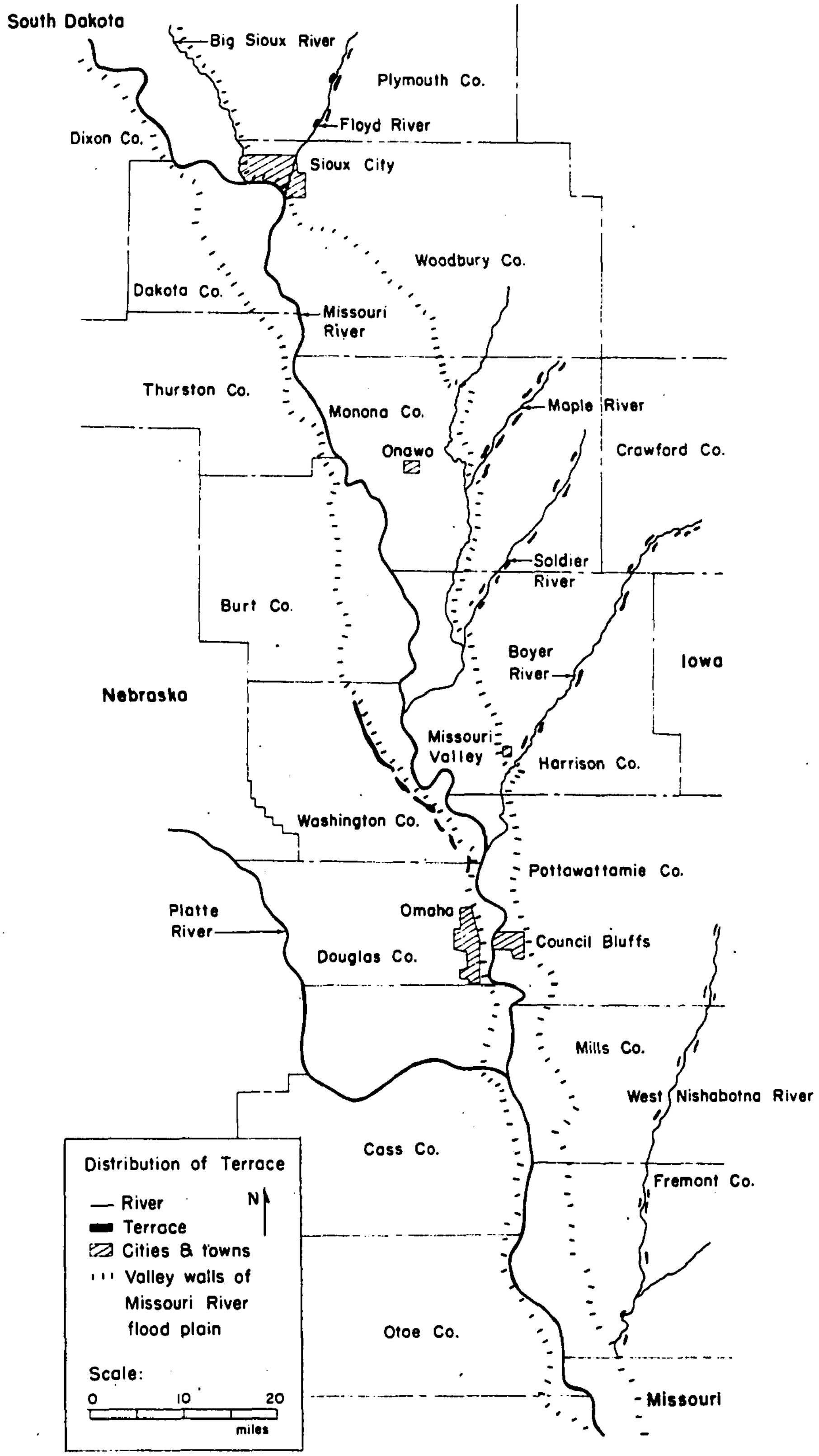
posits. Slightly over 80 per cent of the substratum samples are in the sand class.

Terraces

Remnants of one main terrace system within the area of study have been mapped along the Missouri River as well as along the valleys of the Floyd, Maple, Soldier, Boyer and Nishnabotna rivers. See Figure 20. The most continuous aerial extent of the terrace is along the right valley wall of the Missouri River north and south of Blair, Nebraska. It is fairly consistent in this area for a distance of about 20 miles. See Plates 8, 9 and 10. However, in most instances the terrace is not continuous along a valley, but consists of remnants. For this reason, as well as because only rarely can one see a cut exposing the complete stratigraphy below a terrace, many borings were made into the terrace during the 1960 field season (Table 8). It is possible that more than one terrace system exists in the area of study; a lower surface has been noted particularly along the Soldier River and north of the mouth of New York Creek along the Missouri River (Plate 12). However, care must be taken not to confuse truncated spurs of the larger, gently sloping alluvial fans with terraces. This is especially true in the more narrow tributary valleys.

Any terrace is first recognized because of its topographic discontinuity and the resulting drainage changes associated with it. These features along with the continuity and height of the surface, the lithology of the fill, and the stratigraphic relationships of the

Figure 20. Geographic distribution of the terrace mapped in this study


South Dakota
Big Sioux River
Plymouth Co.
Floyd River
Dixon Co.
Sioux City
Woodbury Co.
Dakota Co.
Missouri River
Thurston Co.
Monona Co.
Maple River
Onawa
Crawford Co.
Soldier River
Burt Co.
Boyer River
Iowa
Nebraska
Missouri Valley
Harrison Co.
Washington Co.
Pottawattamie Co.
Platte River
Omaha
Council Bluffs
Douglas Co.
Mills Co.
West Nishabotna River
Cass Co.
Fremont Co.
Distribution of Terrace
River
Terrace
Cities & towns
Valley walls of Missouri River flood plain
N
Scale:
0
10
20
miles
Otoe Co.
Missouri

sediment under the terrace to other materials laterally and to bedrock constitute the criteria for mapping and correlating this terrace. Previously mentioned authors (86, 76 and 13) have discussed these surfaces in the area of study and have reported three different modes of origin: river terraces, benches and loess-covered surfaces. Farther upstream on the Missouri River, Coogan and Irving (12) and Coogan (11) have reported terraces in the Big Bend Reservoir, South Dakota. West of the area of this study, Miller and Scott (61) have described terraces along the North and Middle Loup rivers in Valley County, Nebraska.

Surface features. The terrace stands out as a distinct topographic discontinuity on the landscape; it is readily recognized on aerial photographs, especially when stereo pairs are used. On one side it is bordered by the valley slopes of the extremely dissected upland and on the other by a scarp descending to the flood plain. In general it is a surface of low relief and does not possess an integrated drainage pattern. However, there is evidence of paleo-stream channels on the surface although in most instances these drainageways have not become integrated into the present system.

Figures 21 and 22 are aerial photographs of the terrace along the Missouri and Boyer rivers, respectively. These areas are shown on Plates 10 and 11. The dark spots (sometimes lighter in the center if standing water is present) or pocks mark the position of slightly lower areas on the terrace caused by previous stream action. On Figure 21 numerous pocks are present and from the arcuate patterns represented by some they probably record the series of lows or swales of an accretion-

Figure 21. Aerial photograph of the terrace along the west side of the Missouri River about 7 miles north of Blair, Nebraska

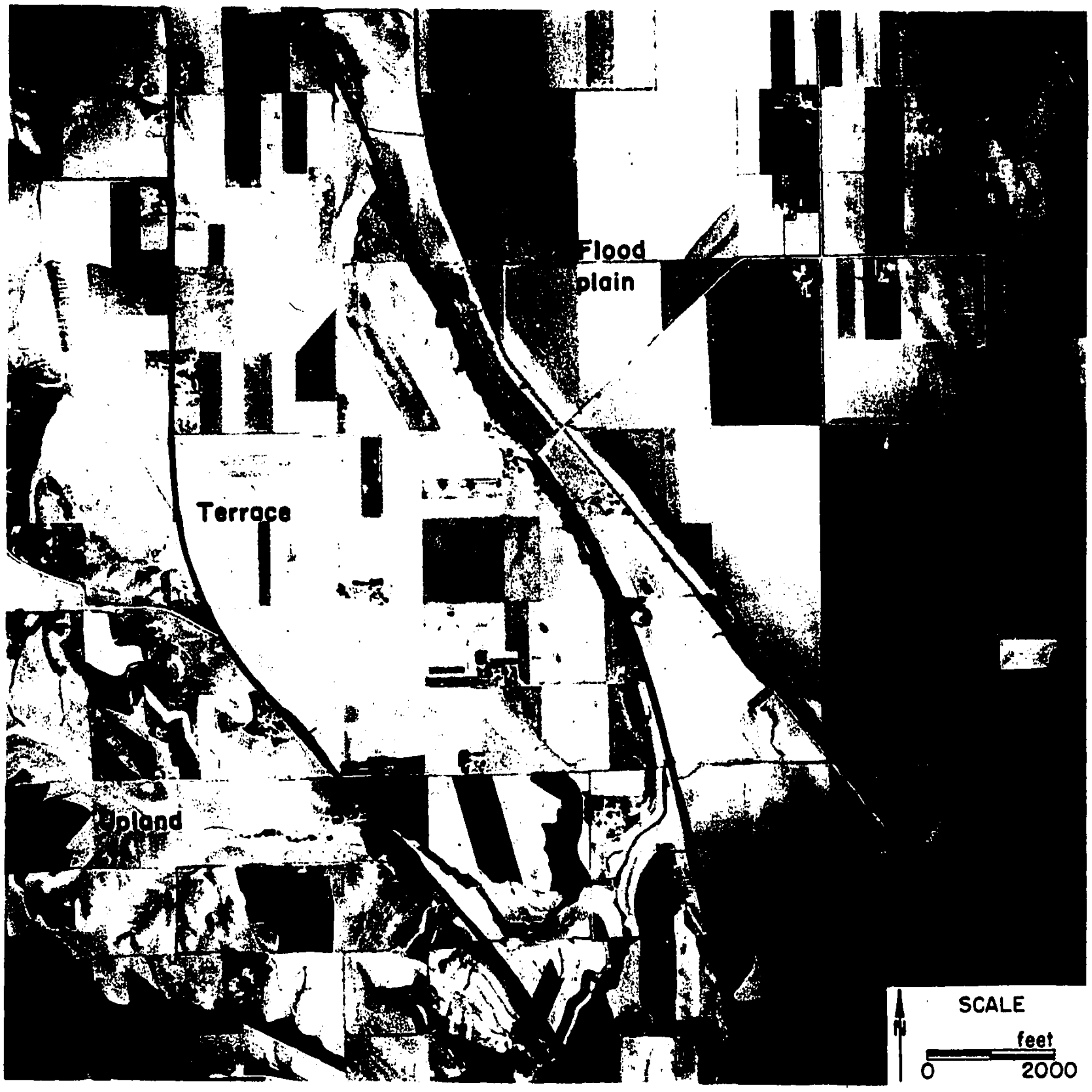
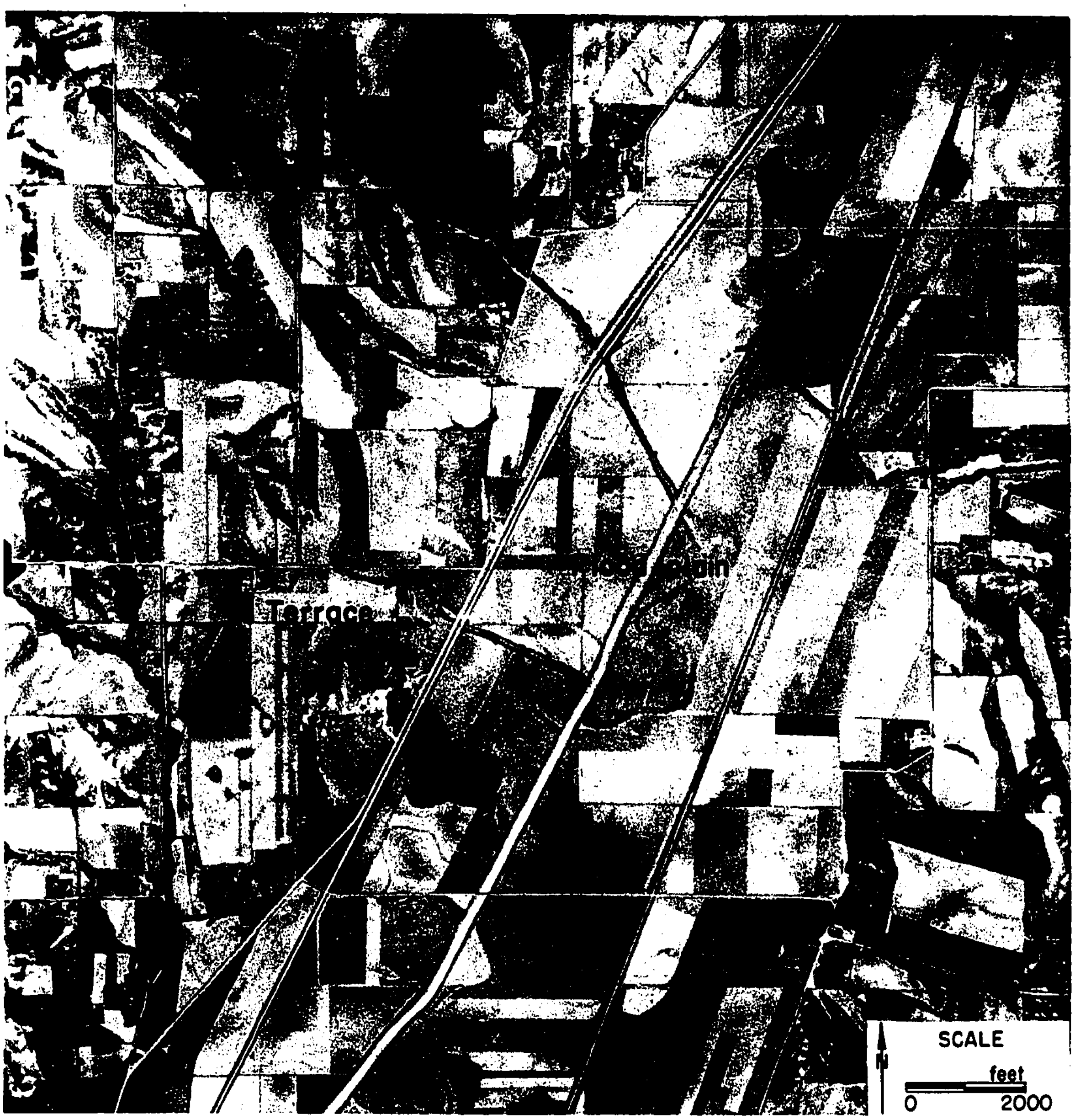

Flood
plain
Terrace
Upland
SCALE
feet
0
2000
N

Figure 22. Aerial photograph of the terrace along the northwest side of the Boyer River about 4 miles upstream from its confluence with the Missouri River

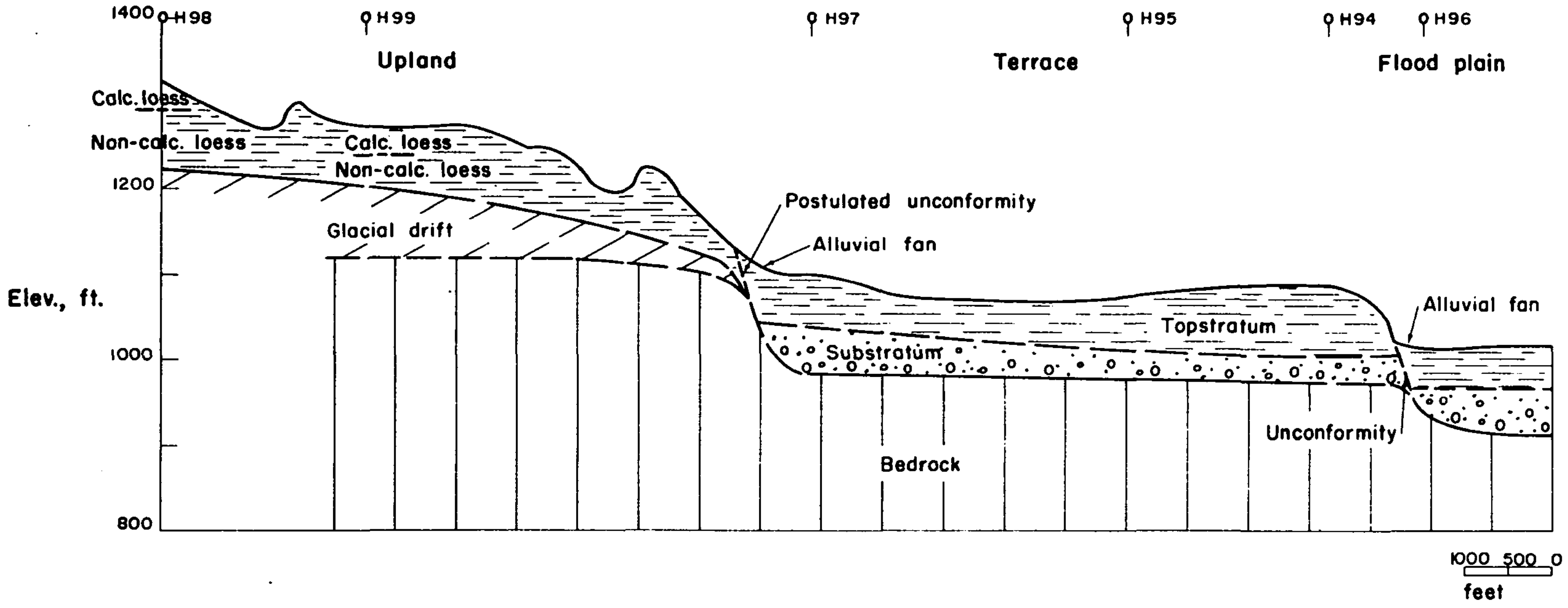

Terrace
SCALE
feet
0
2000
N

type topography. On Figure 22 the pocks representing former thalweg deeps are continuous enough so that the paleo-channel is clearly distinguishable. Fisk (28, p. 78) first proposed the name "pock" for these geomorphic features found on the Prairie Terrace of the lower Mississippi River and concludes that they represent deeper segments of old channels.

Relief as measured from the center of a pock to the level of the surrounding area varies from 4 feet on the terrace along tributary streams to 10 feet for completely undrained pocks along the Missouri River. As modern drainage progresses into the terrace fill it not uncommonly proceeds along a row of pocks. Relief is then increased rapidly because of the high gradient of these small streams working into the terrace fill from the present flood plain surface. Overall relief on the nondissected portions of the terrace is of the same magnitude as that found on adjacent flood plains; normally less than 10 feet on tributary valley terraces and 20 feet on the Missouri River terrace. Note that on Plate 10, where the terrace scarp is particularly sharp, it is difficult to differentiate the terrace from the flood plain in plan view. Yet, in this area, the two surfaces are separated by a 65 to 75 foot scarp. Small intermittent streams from the upland have built alluvial fans out onto the terrace along its inner margin.

In the wider segments of the terrace, a topographic profile perpendicular to the trend of the surface will usually show a slight increase in elevation from the toe of a fan out to the edge of the terrace. See Figure 23. This low area at the upland margin of the terrace may represent a former shallow broad drainageway that existed before

Figure 23. Geologic cross section extending from upland to flood plain on Plate 10



H98
H99
H97
H95
H94
H96
Upland
Terrace
Flood plain
1400
1200
1000
800
Elev., ft.
Calc. loess
Non-calc. loess
Calc. loess
Non-calc. loess
Glacial drift
Postulated unconformity
Alluvial fan
Alluvial fan
Topstratum
Substratum
Unconformity
Bedrock
1000 500 0
feet

appreciable alluvial fan development or it represents a more recent drainage low developed in response to fan building. In either case the topography is similar to that developed at the margins of the modern flood plain and some of the better developed drainage on the terrace exists at the upland margin of the terrace and parallel with its trend. In more narrow parts of the terrace, occasionally a fan will become extended completely across the surface. Upon reaching the descending scarp, the stream attains a new base level and incision of the fan and terrace material results. Thus, there has been some post-depositional lowering of certain areas on the terrace, but in comparison with the upland it is essentially non-dissected although the near-surface sediment underlying both landscapes is very nearly the same. The nature of both the upland and terrace material is discussed in later sections.

The relief of the terrace-flood plain scarp decreases up-valley. This feature is not demonstrated as well along the Missouri River as it is along the tributary valleys. That is, a relatively short length of terrace is available for measurement along the Missouri in the area of study in comparison to the total length of the river. Nevertheless, for a 10 mile stretch of terrace from north of Omaha (Plate 8) to north of Blair, Nebraska (Plate 10), the terrace gradient is less than that of the flood plain, being about 0.8 foot per mile. The gradients for several tributary streams and the terraces along them are presented by figures in the next section, which discusses the nature of the material underlying the terrace.

Nature of fill. This section considers the stratigraphy of the material below the terrace, its relationship to the present flood plain fill, and some of the physical and chemical properties of the sediment.

The general stratigraphy of the unconsolidated material underlying the terrace is similar to that found below the present flood plain surface in that there is a substratum of sand and gravel overlying bedrock and this in turn is overlain by a finer-grained topstratum unit. Figure 23 shows the nature of the fill as it occurs below the terrace along the Missouri River and at or near the mouths of several tributary streams. However, longitudinal profiles are needed to complete this picture and again the remnants along the Missouri occur over too small a proportion of the total stream length to illustrate completely the distribution of the topstratum and substratum with distance along the terrace. Fortunately these relationships can be demonstrated to some extent by utilizing borings made along several tributary valleys. In these, even though the terrace was not investigated along its total extent, the distance over which borings were made amounts to a much greater proportion of total stream length.

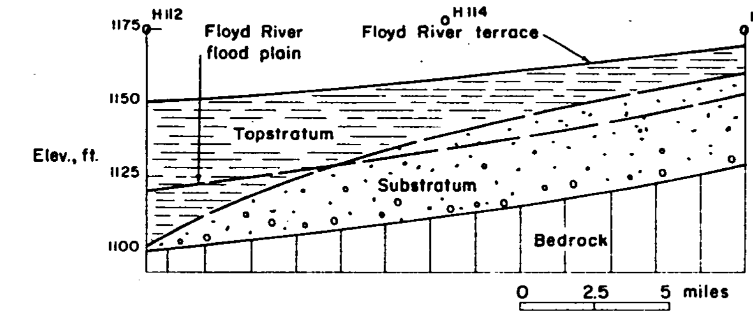
Figures 24, 25, 26 and 27 present longitudinal cross sections of the terrace along four tributary streams of the Missouri River, beginning approximately at their mouths and extending for a maximum distance of about 20 miles upstream. The bedrock surface under the terrace is shown as well as the slope of the terrace, the slope of the present flood plain and the distribution of substratum and topstratum below the terrace. Just as the flood plains of these streams are graded to the Missouri River flood plain, the terraces along these streams were at

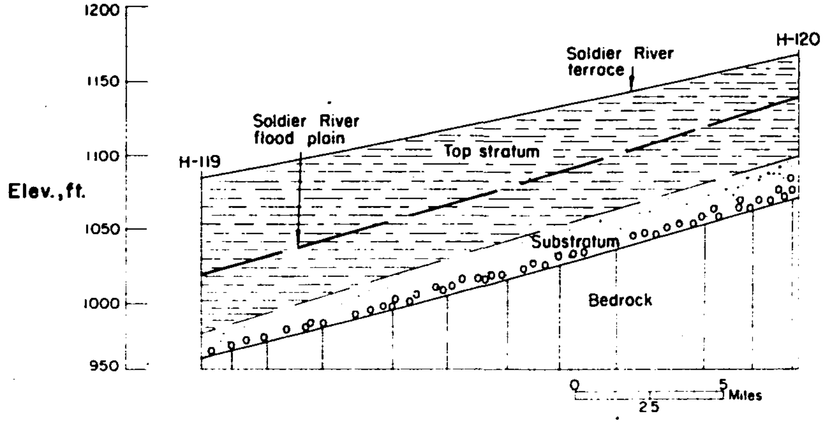
Figure 24. Longitudinal cross section of the terrace along the Floyd River

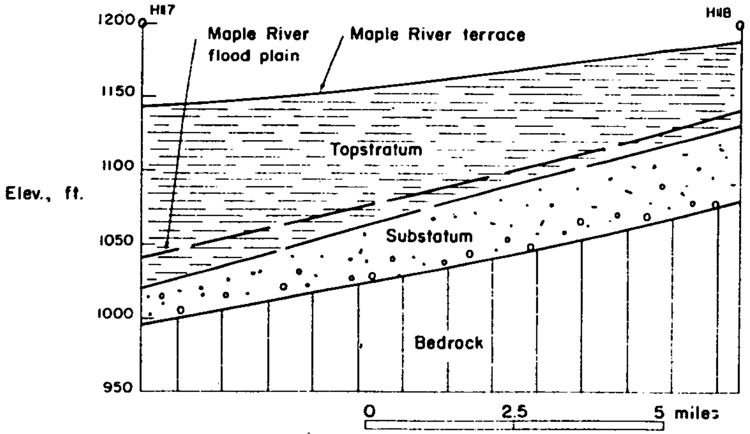
Figure 25. Longitudinal cross section of the terrace along the Soldier River

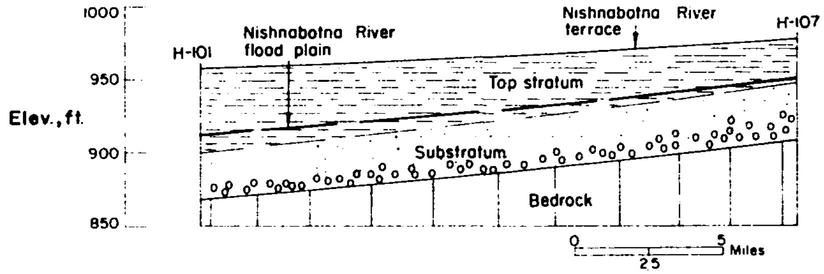
Figure 26. Longitudinal cross section of the terrace along the Maple River

Figure 27. Longitudinal cross section of the terrace along the Nishnabotna River


H112
H114
H113
1175
1150
1125
1100
Elev., ft.
Floyd River flood plain
Floyd River terrace
Topstratum
Substratum
Bedrock
0 2.5 5 miles


H120
H-119
1200
1150
1100
1050
1000
950
Elev., ft.
Soldier River terrace
Soldier River flood plain
Top stratum
Substratum
Bedrock
0 2.5 5 Miles

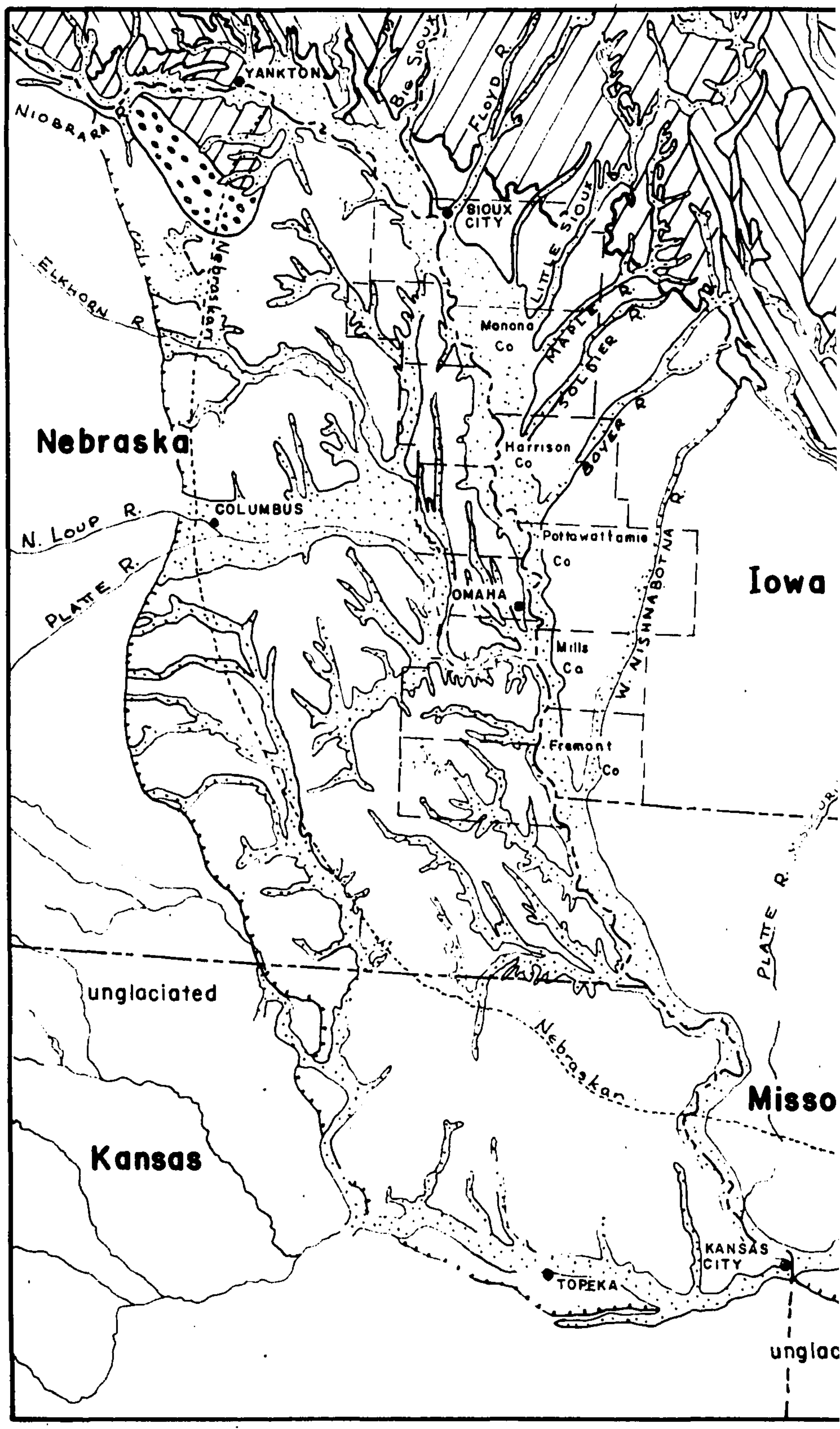

H117
H118
1200
1150
1100
1050
1000
950
Elev., ft.
Maple River flood plain
Maple River terrace
Topstratum
Substatum
Bedrock
0 2.5 5 miles

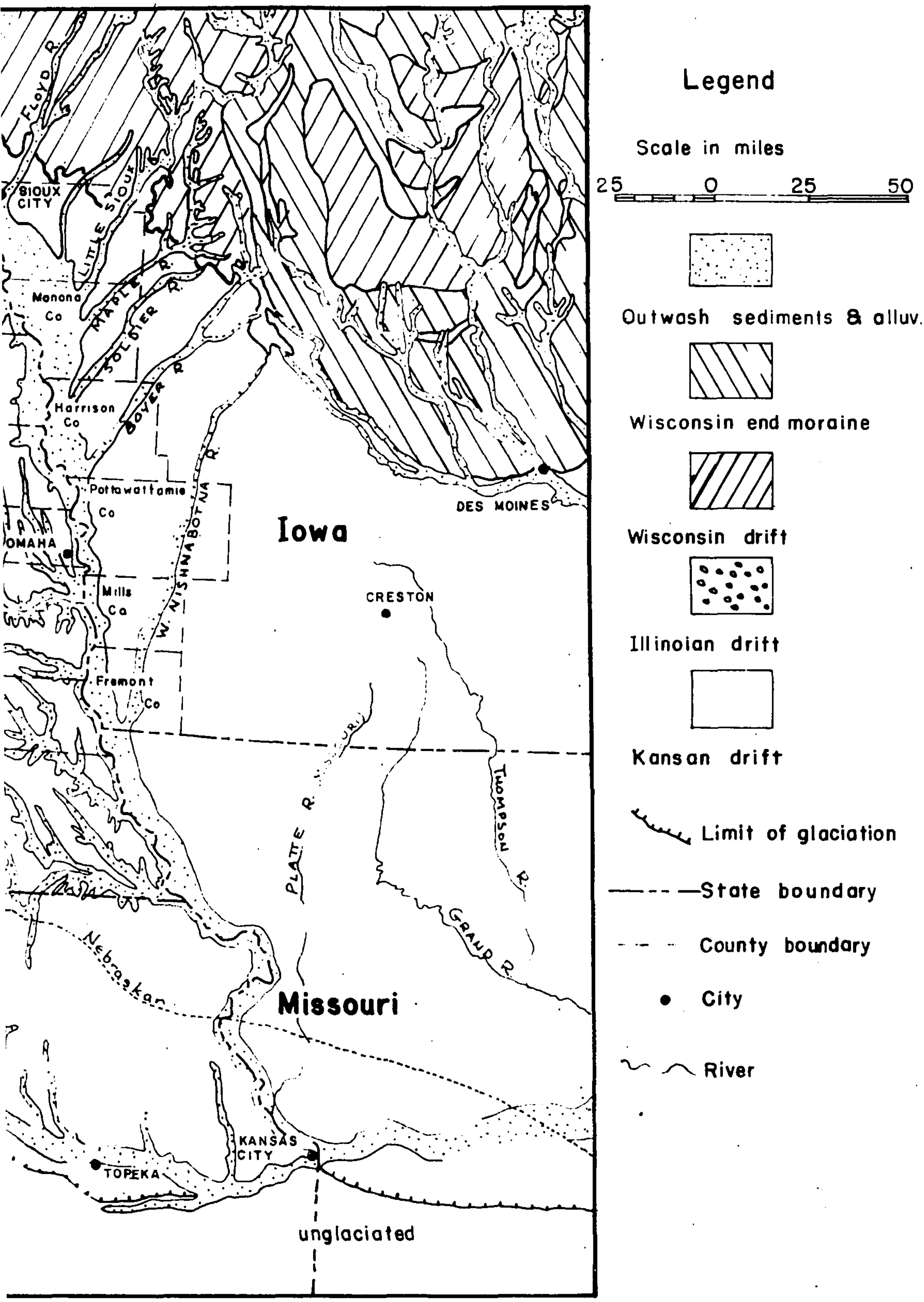

H-101
H-107
1000
950
900
850
Elev., ft.
Nishnabotna River flood plain
Nishnabotna River terrace
Top stratum
Substratum
Bedrock
0 2.5 5 Miles

one time graded to a flood plain of the Missouri River now represented by the terrace **remnants** in the main valley.

The greater thickness of topstratum occurs only near the mouths of these tributaries, where it makes up greater than 50 per cent of the mass of the fill. However, this proportion changes upstream, in some instances quite rapidly. Note particularly the change in proportion of topstratum to substratum in the Floyd River terrace as illustrated by borings made over a distance of about 20 miles. This same situation prevails, to a slightly lesser degree, in all the tributary stream terraces investigated. Considering the area investigated along these tributaries, the ratio of topstratum to substratum decreases at a rate which can be correlated with the proximity of each stream to the area glaciated during the Wisconsin glacial stage and to the amount of the watershed of each stream which lies within this most recently glaciated area. See Figure 28. That is to say, both the Floyd and Maple rivers have more than half their watershed in or close to the Iowan or early Wisconsin glaciated tract, whereas the Soldier and the Nishnabotna have only a very small portion. The two extremes, the Floyd and Nishnabotna rivers, best illustrate the point in discussion. Along the Floyd River, which traverses about 20 miles outside of the Wisconsin tract, the substratum under the terrace thickens rapidly upstream. Along the Nishnabotna, which traverses about 100 miles outside the Wisconsin limit, the rate of increase in thickness of the substratum upstream is less, but nevertheless substratum comprises at least 50 per cent of the fill below the terrace at a distance of 20 miles from

Figure 28. Map of the glacial geology in the area of study, modified from the Glacial Map of the United States East of the Rocky Mountains, Geological Society of America, 1959


YANKTON
NIOBRARA R.
Big Sioux
FLOYD R.
SIOUX CITY
LITTLE SIOUX
Nebraskan
ELKHORN R.
Monona Co
MAPLE R.
SOLDIER R.
BOYER R.
Harrison Co
Nebraska
COLUMBUS
N. LOUP R.
PLATTE R.
Pottawattamie Co
W. NISHNABOTNA R.
OMAHA
Iowa
Mills Co
Fremont Co
PLATTE R.
unglaciated
Nebraskan
Misso
Kansas
KANSAS CITY
TOPEKA
unglac


Legend
Scale in miles
25 0 25 50
Outwash sediments & alluv.
Wisconsin end moraine
Wisconsin drift
Illinoian drift
Kansan drift
Limit of glaciation
State boundary
County boundary
City
River
FLOYD R
SIOUX CITY
LITTLE SIOUX
Monona Co
MAPLE R
SOLDIER R
BOYER R
Harrison Co
Pottawattamie Co
W. NISHNABOTNA R
OMAHA
Mills Co
Fremont Co
DES MOINES
Iowa
CRESTON
PLATTE R
THOMPSON R
GRAND R
Nebraskan
Missouri
KANSAS CITY
TOPEKA
unglaciated

the mouth.

Some of the other more obvious relationships are that the terrace has a lesser slope than the present flood plain and that, especially near the mouths of the tributaries, the modern alluvial fill has been alluviated to and above the base of the topstratum in the terrace. In all instances observed during this investigation, bedrock lies at a lower elevation under the present flood plain than it does under the terrace. This is illustrated on Figure 23 and is shown in Table 8 by comparing bedrock elevations of borings made at approximately the same latitude into both terrace and flood plain.

Properties of the terrace material secured from borings made during the 1960 field season are presented in Table 10. Characteristically the topstratum is a buff or tan silty loam or silty clay loam. With depth or near its base, the topstratum may become darker in color or have a mottled appearance. The material is commonly laminated, especially at depth. Fossils, small carbonate concretions (less than 1 inch in maximum diameter), as well as some iron and manganese concretions (less than 4 mm. in diameter) were recovered from holes drilled in this material.

At or slightly above the contact of the topstratum and substratum a dark, fine-grained, organic rich unit is commonly penetrated and it is from this unit or slightly above it that the wood samples were procured. Since the organic material dated by C^{14} from below the flood plain surface was also found most readily near the contact of the substratum and topstratum, this may be the stratigraphic interval in which

Table 10. Properties of terrace material

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Remarks
85-1	0- 1.5	27.5	72.2	0.3	2.0	7.2	Fine-grained topstratum to 75 ft. Sand and gravel substratum from 75 ft. to bedrock at 90 ft. Recovered fossils from depth of 10 ft.
85-2	5- 6.5	29.0	70.6	0.3	3.0	7.2	
85-3	15-16.5	22.5	77.2	0.3	12.1	8.3	
85-4	30-31.5	21.0	78.7	0.3	12.5	8.7	
85-5	45-46.5	24.5	75.0	0.5	10.7	8.9	
89-2	15-16.5	21.0	78.0	1.0	2.5	7.6	Non-calc. topstratum to 60 ft. Calc. topstratum from 60 to 78 ft. Substratum from 78 ft. to bedrock at 101 ft.
89-4	60-61.5	21.0	78.0	1.0	9.9	8.4	
Hole No. 94							Calc. topstratum to 60 ft. Fossils at 51 ft. Non-calc. topstratum from 60 to 77 ft. Dark clay and sand from 77 to 80 ft. Substratum of fine sand increasing to gravel from 80 ft. to bedrock (K_d) at 113 ft.
95-1	60-62	28.0	69.0	3.0	3.3	8.2	Non-calc. tan to grayish-green topstratum to 62 ft. Bluish-gray clay and fine sand to 72 ft. Substratum of sand to bedrock (K_d) at 80 ft.
97-1	5- 6.5	32.0	67.0	1.0	4.0	7.0	Slightly calc. tan to grayish-green alluvial fan material and topstratum to 60 ft. Gray clay and fine from 60-65 ft. Inter bedded silts and sands to 68 ft. Substratum sands to bedrock (K_d) at 116 ft. Wood chips scattered throughout last 30 ft.
97-2	31-32.5	25.0	74.4	0.6	5.4	7.8	
97-3	46-47.5	27.0	72.4	0.6	6.7	7.5	
97-4	61-62.5	23.5	64.4	23.1	5.8	7.5	

Table 10 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Remarks
101-2	40-41.5	24.0	75.3	0.7	4.9	8.2	Calc. topstratum to 40 ft. Dark clay and fine sand with wood to 55 ft. Wood recovered from 48-50 ft. yielded C^{14} date of 21,300±850 Y.B.P. Sample above this yielded C^{14} date of 4,850±175 Y.B.P. but is thought to have been contaminated with modern wood from above. Substratum sand grading to gravel over bedrock at 90 ft.
Hole No. 107							Non-calc. topstratum to 30 ft. Substratum sands grading to gravel over bedrock at 72 ft.
112-1	15-16.5	22.0	77.2	0.8	10.7	8.9	Calcareous topstratum to 50 ft. Substratum sand to bedrock at 52 ft.
112-2	30-31.5	24.0	75.1	0.9	9.6	8.9	
112-3	45-46.5	24.0	75.4	0.6	11.7	8.8	
113-1	15-16.5	23.0	68.0	9.0	15.2	8.9	Topstratum silt and clay to 6 ft. Inter bedded silt to coarse sand to 17 ft. Substratum sands to coarse gravel over bedrock at 42 ft. -- depth of well at top of bedrock 100 yds away at same elevation on terrace surface.
114-1	16-17.5	23.0	61.4	15.6	13.0	9.0	Topstratum silts and clays with inter bedded sands to 26 ft. Substratum sand grading to gravel over bedrock at 49 ft.
114-2	31-32.5	4.5	12.3	83.2	11.5	9.1	

Table 10 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Organic matter, %	Remarks
117-1	15-16.5	21.0	78.1	0.9	14.9	8.8	0.24	Calc. topstratum to 135 ft. Almost all silt and clay to 115 ft. and then increasing amounts of sand between 115 and 135 ft. Sand and gravel from 135 to bedrock at 150 ft. Fossiliferous from 10-15 ft.
117-2	30-31.5	19.0	80.2	0.8	14.4	9.1	0.22	
117-3	45-46.5	21.0	77.7	1.3	17.1	8.9	0.21	
117-4	60-61.5	16.5	82.7	0.8	11.8	8.9	0.19	
117-5	80-81.5	17.5	81.9	0.6	13.4	8.9	0.17	
118-2	15-16.5	21.0	78.0	1.0	13.6	9.1		Topstratum of silt and clay to 65 ft. Mainly fine-grained sediment but sand stringers to 80 ft. Substratum of sand increasing in size to gravel over bedrock at 103 ft. Recovered fossils from between 5-10 ft. and 30-31.5 ft.
118-3	30-31.5	21.0	78.3	0.7	13.2	9.1		
118-5	45-46.5	25.0	74.7	0.3	11.7	8.2		
118-6	60-61.5	27.0	72.5	0.5	10.2	8.5		
119-1	15-16.5	20.0	78.9	1.1	12.4	9.1		Topstratum of silt and clay to 90 ft. Sand stringer between 50-55 ft. Substratum of fine-coarse sand to gravel over bedrock at 115 ft. Recovered fossils between 16.5 and 20 ft.
119-3	30-31.5	22.0	77.6	0.4	11.7	9.0		
119-4	45-46.5	16.0	83.7	0.3	12.2	9.1		
119-5	80-81.5	20.0	79.6	0.4	11.2	8.8		
120-2	15-16.5	21.0	78.4	0.6	12.2	8.8		Tan, calc. topstratum to 55 ft. Between 55 and 66 ft. a greenish-gray to blue non-calc. silt with clay and some sand. Substratum sand and gravel to bedrock. Recovered fossils between 5 and 15 ft.
120-3	25-26.5	23.0	76.7	0.3	11.1	8.9		
120-4	45-46.5	26.0	73.8	0.2	12.2	9.1		
120-5	60-61.5	25.0	70.6	4.4	5.3	8.0		
121-1	16-17.5	34.0	65.6	0.4	6.3	8.2	0.20	Tan to grayish-green non-calc. topstratum to 45 ft. Dark clay to 51 ft. Substratum sand to 65 ft.
121-2	31-32.5	28.0	71.9	0.1	4.4	8.2	0.49	
121-3	46-47.5	69.0	30.8	0.2	5.1	7.9	0.74	

Table 10 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH			Remarks
122-1	15-16.5	20.0	79.5	0.5	13.6	8.9			Fine-grained topstratum to 100 ft. From surface down to 60 ft. it is tan and calc. From 60 to 100 ft. it is still calc. but is mottled a tan and grayish-green color and contains abundant organic material. C^{14} date from organic matter between 75-90 ft. yielded date of 22,050±900 Y.B.P. C^{14} date from 90-100 ft. yielded date of 22,400±900 Y.B.P. Substratum to bedrock at 120 ft.
122-2	30-31.5	23.0	76.6	0.4	13.3	9.2			
122-3	45-46.5	20.0	79.6	0.4	14.4	9.2			
122-4	60-61.5	23.0	76.6	0.4	12.3	9.1			
							Org. mat., %	Fld. moist., %	
123-1	0- 2	37.0	62.2	0.8	2.0	6.6	1.36	33.2	Illustrates channel fill of paleo stream channel on terrace. From 0-9.5 represents the actual channel fill material which is very fine-grained.
123-2	2- 4	43.0	55.7	1.3	2.3	6.9	1.70	30.2	
123-3	4- 6	45.0	53.2	1.8	2.1	7.0	1.17	31.0	
123-4	6- 8	44.0	53.6	2.4	2.5	6.8	1.12	31.6	
123-5	8- 9.5	42.0	57.3	0.7	1.8	6.8	2.46	43.2	
123-6	9.5-12	23.0	76.9	0.1	1.6	6.7	0.36	24.5	
123-7	12-14	24.0	75.9	0.1	2.1	6.8	0.21	2.75	
123-8	14-16	25.0	74.9	0.1	1.6	6.5	0.23	29.9	
123-9	16-18	27.0	72.9	0.1	1.5	6.5	0.16	33.4	
123-10	18-19	27.0	72.8	0.2	1.3	6.6	0.15	29.9	
							Org. mat., %	Fld. moist., %	
124-1	0- 2	28.0	71.5	0.5	1.0	7.4	0.62	18.9	Illustrates point bar of paleo stream on terrace.
124-2	2- 4	27.0	72.7	0.3	1.4	7.4	1.00	13.7	
124-3	4- 6	25.0	74.5	0.5	1.8	7.1	0.26	11.7	
124-4	6- 8	19.0	80.7	0.7	11.6	8.4	0.19	11.8	
124-5	8-10	23.0	69.9	7.1	9.3	8.2	0.19	15.1	
124-6	10-12	21.0	78.5	0.5	8.7	8.5	0.20	14.6	
124-7	12-14	20.0	77.5	2.5	10.1	8.3	0.22	15.0	

Table 10 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Remarks
125-1	0- 2	25.0	74.3	0.7	1.8	7.4	Illustrates upper topstratum of flood basin on terrace.
125-2	2- 4	25.0	74.3	0.7	1.6	7.1	
125-3	4- 6	25.0	74.3	0.7	1.8	7.3	
125-4	6- 8	18.0	81.1	0.9	8.8	8.5	
125-5	8-10	20.0	79.1	0.9	10.8	8.7	
126-1	0- 2	25.0	74.3	0.7	1.8	7.0	Point bar of paleo stream on terrace.
126-2	2- 4	26.0	73.3	0.7	2.1	7.2	
126-3	4- 6	21.0	78.3	0.7	2.9	7.9	
126-4	6- 8	18.0	81.1	0.9	12.5	8.7	
126-5	8-10	20.0	79.1	0.9	11.4	8.9	
126-6	10-12	21.0	78.1	0.9	10.2	9.0	
127-1	0- 2	50.0	49.1	0.9	2.4	7.3	Illustrates details of channel fill material of paleo stream channel on terrace. From 0-12 ft. represents the actual channel fill sediment.
127-2	2- 4	34.0	63.0	3.0	1.7	6.4	
127-3	4- 6	43.0	54.0	3.0	2.0	6.6	
127-4	6- 8	43.0	54.7	2.3	1.9	6.5	
127-5	8-10	43.0	56.1	1.9	2.0	6.7	
127-6	10-12	41.0	57.8	1.2	1.6	6.8	
127-7	12-13	31.0	68.1	0.9	1.8	6.5	
127-8	13-14	28.0	71.3	0.7	1.5	6.5	
127-9	14-16	29.0	70.2	0.8	1.7	6.8	
127-10	16-18	25.0	74.1	0.9	1.3	6.6	

more prolific amounts of organic matter have accumulated and been preserved regardless of variations in post-depositional time and events.

Alluvial deposits on the terrace can also be subdivided in much the same way as those on the flood plain. Borings 123-127 (Table 10) were made by hand auger into the alluvial deposits present on the terrace illustrated on Figure 22. As in the flood plain prototype, the old channels have become filled with finer-grained sediment, the channel fill sediment in the terrace being in the silty clay or clay textural class. Adjacent point bar material at the same elevation is coarser. Channel depth of the former stream was about 10 feet; boring 123 penetrated 9.5 feet of channel fill and boring 127 penetrated 12 feet of similar material. At this location on the terrace, that is, near the valley mouth, the material described as the fine-grained topstratum is the only sediment in which the former stream was flowing. Its depth of scour was not great enough to reach into the coarser substratum at depth. Hence, at this latitude, the stream was working with sediment composed of only two dominant particle sizes; silt and clay. What little sand was available for transport is now segregated into small lenses located in paleo-chutes or swales of the former point bar. The only appreciable amount of sand was found between 8 and 10 feet in the point bar deposit penetrated by boring 124. However, as mentioned previously, there is a rapid thinning of the topstratum upstream so that coarse material, primarily sand with little gravel, could become incorporated into the topstratum as the stream was able to scour into the substratum material and rework some of it into the higher alluvial deposits. This is well illustrated by the borings over about a 20 mile distance on the Floyd River terrace. Note that sands occur within 6 feet of the terrace surface in boring 113 (Table 10) but that the total topstratum would be considered to be 17 feet thick. Hence, considering the sediment under the terrace as a formation, it does exhibit quite obvious facies changes. At the location of hole 113, the fill material described above is exposed in the scarp descending to the flood plain.

Generally speaking, below the upper 6 feet the carbonate content of the topstratum varies between 10 and 15 per cent. However, there are some definite exceptions to this generalization. Borings 89, 95, 107 and 121 penetrated essentially non-calcareous topstratum.

Boring 89 was on a small remnant at the mouth of the Willow River; 95 was located in a low marshy area on the Missouri; 107 upstream on the Nishnabotna and 121 on a surface lower than the main terrace along the Missouri River. Boring 97, located on an alluvial fan at the extreme inner margin of the terrace along the Missouri River, penetrated only very slightly calcareous material.

By comparing field notes with laboratory analyses, it was determined that material recovered during wet drilling in the field and logged as non-calcareous usually had a carbonate content below about 6 per cent. Between 6 and 9 per cent, it was logged as slightly or moderately calcareous. Above 9 per cent the material was logged as calcareous and effervesced freely within hydrochloric acid.

At least one possible clue to the presence or absence of carbonate in some of the terrace borings is presented by the detailed borings made into the alluvial features on the Boyer River terrace. Here, borings 123 and 127 (Table 10), in pocks, penetrated to 19 and 18 feet, respectively, but of samples taken every 2 feet, none was calcareous. However, borings 124, 125 and 126 in the same immediate area (see Plate 11 or Figure 22) revealed calcareous material below the usual upper 6 feet of non-calcareous sediment. In the pock borings, field moisture and organic matter content was greater and carbonate content lower, even below the depth of channel fill, than in the adjacent point bar or flood basin. Of all the pH measurements made, only those in borings 123 and 127 were consistently below 7. Boring 85 on this same surface but about three fourths of a mile upstream and not in a low or pock, recorded 75 feet of calcareous topstratum below the upper 7 feet.

Uplands

The area designated as upland is that landform which normally forms the valley walls and which, in the presence of the terrace, lies upslope from it and extends to higher elevations. In the usual absence of a terrace remnant, the valley slopes of the upland extend to present flood plains or to the myriad of gulleys and dry washes forming the predominantly dendritic drainage pattern. Observations and borings concerned with the upland during the course of the study were concentrated in an area close to the Missouri River flood plain. This area in question is maturely dissected and the landscape is erosional.

In keeping with the primary objectives of this study, less work has been done on the uplands than in the flood plains or terraces.

Nevertheless, the deep borings made into the uplands are the first of their kind to be made specifically for the gathering of geologic and engineering data. Heretofore, to the best knowledge of the author, artificial exposures and shallow borings (less than 60 feet) have furnished the data for interpretations found in the literature.

The purpose of this section is first to present data on the nature and properties of the upland material as determined by borings. Secondly, this section outlines observations made in artificial exposures which illustrate both the relations of the loess to underlying material and the post-depositional changes which have taken place in the area. Locations of the upland bore holes are presented in Table 8. Table 11 presents the property data on materials penetrated in these borings.

Borings. It is apparent from the data presented in Table 11 that the upland loess can be subdivided into two general units based on physical properties; an upper unit more oxidized (tan in color), calcareous, slightly coarser-grained and containing fossil shells and small carbonate concretions, and a lower unit which is less oxidized (a mottled or gray color predominates), essentially non-calcareous, slightly finer-grained, and containing few if any fossil shells or carbonate concretions. Both units contain iron and manganese concretions of less than granule size.

The relations between these properties and with depth are as follows:

1. The decrease in carbonate content with depth in the loess is the most consistent of these relationships.

Table 11. Properties of upland material

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Org. mat., %	Remarks
86-1	30 - 31.5	21.0	78.7	0.3	11.0	8.9	0.11	Calc. tan silty to silty clay loam to 52 ft. Some fossils and small carbonate concretions. Non-calc. mottled tan and gray to gray silty clay loam and silty clay to 95 ft. Non-calc. reddish-brown glacial till to 108 ft. Calc. tan glacial till to 130 ft. Calc. sand and gravel to bedrock at 143 ft.
86-2	56 - 57.5	35.0	64.4	0.6	3.9	8.2	0.47	
86-4	100.5-101.5	39.5	33.5	27.0[a]	3.8	6.9		
86-5	140 -141.5	3.0	9.0	87.0[a]	14.6	8.9		
87-1	5 - 6.5	18.0	80.9	0.1	7.5	8.5	0.17	Calc. tan silty to silty clay loam to 22 ft. Some fossils and small (less than 5 mm.) carbonate and iron concretions. Calc. mottled tan and gray silty clay loam to 56 ft. Non-calc. mottled tan and gray silty loam and silty clay to 112 ft. Non-calc. glacial till to 117 ft. Calc. yellow glacial till to 166 ft.
87-2	15.5- 17	25.5	74.0	0.5	10.0	8.4	0.23	
87-4	30 - 31.5	25.0	74.5	0.5	10.9	8.2	0.16	
87-6	45.5- 47	20.0	79.6	0.4	10.8	8.7	0.13	
87-7	60.5- 62	18.0	81.7	0.3	5.4	8.2	0.29	
87-8	75.5- 77	31.0	68.6	0.4	2.8	7.8	0.36	
87-9	105.5-107	37.0	61.2	1.8	3.9	7.9	0.08	
87-10	120.5-122	40.0	36.5	23.5[a]	14.2	8.7		
91-2	15 - 16.5	24.0	75.0	1.0	14.9	9.0	0.12	Calc. tan silty clay loam to 15 ft. Calc. mottled grayish-green and tan silty clay loam to 43 ft. Non-calc. mottled silty clay to 55 ft. Calc. glacial till to 65 ft.
91-3	40 - 41.5	22.0	77.5	0.5	10.2	8.7	0.54	
91-4	44 - 45	30.0	69.0	1.0	5.4	8.5	0.25	

[a]Sand plus gravel.

Table 11 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Org. mat., %	Remarks
98-1	15 - 16.5	33.0	65.2	1.8	8.7	8.0	0.22	Calc. to slightly calc. tan with few gray mottles, silty clay to 30 ft. Some fossils and calcareous concretions. Non-calc. tan to mottled (red and gray splotches) silty loam and silty clay to 100 ft. Heavy gray clay to 102 ft. Non-calc. till to 106 ft. Calc. glacial till to 108 ft.
98-3	30 - 31.5	30.0	69.7	0.3	6.6	7.9	1.93	
98-4	45 - 46.5	40.0	59.2	0.8	4.6	7.9	0.26	
98-5	60 - 61.5	32.0	67.4	0.6	3.4	7.8	0.32	
98-7	70 - 75	28.0	70.7	1.3	3.8	7.9	0.21	
98-8	85 - 90	22.5	74.6	2.9	3.0	7.7	0.08	
98-10	100.5-101.5	52.0	41.2	6.8[a]	3.9	7.9	0.07	
99-1	30 - 35	29.0	66.5	4.5	11.4	---		Slightly calc. to calc. tan to mottled tan and reddish-brown silty clay loam to 45 ft. Non-calc. mottled (tan, gray, reddish-brown) silty clay loam to 63 ft. Calc. silt and fine sand to 67 ft. Calc. glacial till to bedrock at 154 ft.
99-2	50 - 55	27.0	69.7	3.3	5.7	8.0		
99-3	70 - 71.5	43.0	30.5	30.5[a]	16.8	8.7		
105-1	30 - 31.5	16.5	82.1	1.4	13.1	8.5		Calc. tan silty to silty clay loam to 55 ft. Some fossils and carbonate concretions. Non-calc. mottled brown and gray silty clay loam to 135 ft. Calc. glacial till starts at 135 ft. Two local wells in the immediate vicinity at approx. the same elev. as the top of this hole went to bedrock at 195 and 197 ft. The surface at the location of this boring might represent a higher terrace.
105-3	60 - 61.5	23.0	76.2	0.8	2.6	8.0		
105-4	80 - 90	27.0	70.3	2.7	2.2	---		
105-5	120 -130	23.0	70.1	6.9	2.3	---		

Table 11 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	Carbonate, %	pH	Org. mat., %	Remarks
106-2	30 - 31.5	16.5	82.8	0.7	13.9	8.7		Tan, calc., silty loam to 73 ft. Fossils and small carbonate concretions between 10-30 ft. Mottled with gray in lower 20 ft. Non-calc. to slightly calc. mottled silty clay loam to 185 ft. Calc. glacial till to 190 ft.
106-3	60 - 61.5	16.0	83.3	0.7	11.6	8.9		
106-4	165 -170	29.0	65.7	5.3	8.9	8.9		
106-5	175 -180	24.0	59.3	16.7	7.0	8.8		
108-1	32 - 33.5	45.0	52.0	3.0	3.6	8.2	0.09	Non-calc. tan to mottled silty clay loam to 31 ft. Some wood at 22 ft. Non-calc. mottled orangish-red and gray silty clay to 36 ft. Non-calc. tan to gray sandy loam to 45 ft. Calc. glacial till to 47.5 ft.
108-2[a]	43 - 45	18.0	22.1	59.9	3.5	8.3	0.05	
108-2	46 - 47.5	32.5	39.8	27.7	16.8	8.9	0.04	
115-2	30 - 31.5	24.0	74.8	1.2	12.3	9.1	0.21	Calc. tan to mottled silty clay loam to 55 ft. Occasional sand stringer in last 20 ft. Non-calc. gray silty clay to 68 ft. Non-calc. till to 70 ft. Calc. till starting at 70 ft.
115-3	35 - 36.5	26.5	72.9	0.6	11.6	9.2	0.34	
115-4	45 - 46.5	23.0	75.9	1.1	12.1	8.9	0.21	
115-5	60 - 61.5	31.0	65.8	3.2	4.7	8.3	0.46	
116-1	12.5- 15	21.0	18.6	60.4[a]	17.9	8.6		Calc. glacial drift to 92 ft.
116-2	30 - 32	21.5	17.1	61.4[a]	20.2	7.8		

2. The change from tan to a mottled (tan and gray) or gray color with depth is always present but this change in color does not always exactly coincide with the carbonate change.

3. The upper unit, on the average, contains less clay-size material.

4. The lower unit, on the average, contains more clay-size material and locally contains more sand near the base.

5. Considering both units, the clay-size material varies between 16 and 45 per cent.

Organic matter content in the loess varies from less than 0.1 per cent to almost 2.0 per cent and shows no systematic pattern.

The above-mentioned general relationships were observed in all borings that penetrated several tens of feet of upland loess. However, the relative proportions of each unit are different, depending on topographic position. That is, from borings on or very near an interfluve site where the total thickness of loess is greatest, the lower unit comprises a greater proportion. At lower elevations on the valley slope, below an interfluve, the lower unit constitutes a smaller proportion of the total thickness.

Borings 87 and 98 serve to illustrate the stratigraphy below interfluves. Number 98 is at the crest of an interfluve whereas 87 is about 20 feet lower than the present crest in the area (Plates 10 and 11). In boring 98, two thirds or 70 feet of the total loess or upland silt deposit is made up of material more diagnostic of the lower unit. In boring 87, 56 feet or 50 per cent of the total thickness is represented by the lower unit. Valley slope borings below the interfluves (holes 86, 91 and 99) in this area show lesser proportions of the lower unit. It is also interesting to note that, within the upper calcareous unit, samples lower on the landscape had a slightly higher carbonate content. The thickest loess deposit penetrated (185 feet) was located about 4 miles south of Hamburg in Atchison County, Missouri. Here the lower unit comprises 60 per cent of the total thickness.

In all upland borings, glacial till was found to be present under the loess. In some instances (borings 86, 87 and 98) a buried weathering profile at the top of the till was penetrated. In all instances where borings on the upland penetrated to bedrock upslope from a terrace, the bedrock was at a higher elevation under the upland. This is illustrated on Figure 23 and is shown in Table 8 by comparing bedrock elevations of borings made into both upland and terrace at about the same latitude.

Exposures. The locations of exposures are shown in Figure 1 and presented in Table 12. Table 12 also lists the features in each cut which were of interest to this study and indexes photographs which are present on plates in the appendix. Exposure 8 reveals the terrace stratigraphy and is included here because of its close proximity to an upland exposure. Many new cuts have been made in recent years in response to the need for highway grade material in the flood plain.

The basic difference in the upland stratigraphy as seen in exposures and contrasted to that determined in borings, is the presence, in many instances, of sand and gravel underlying the silt instead of glacial till. In exposures 4, 5, 10, 11 and 12 the presence of ash

Table 12. Location and brief description of exposures

No.	Location	Features	Plate No.
1	NE$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 35 T90NR48W Plymouth Co., Iowa	Roadcut exposure along Highway 12 in east valley wall of Big Sioux River. Shows well laminated and slightly cross-bedded calc. silts in a paleo valley cut in cretaceous rocks. Elev. of bedrock at 1100 feet along road.	25
2	SE$\frac{1}{4}$ SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 36 T89NR44W Woodbury Co., Iowa	Roadcut exposure on north side of new Highway 20, 4 miles east of Moville and 20 miles east of the Missouri River. Base of cut at approx. 1400 ft. elev. Shows a 5 foot unit of calc. bedded sand underlain by 24 ft. of calc. silt and overlain by 6 ft. of calc. silt.	26
3	NE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 30 T88NR47W Woodbury Co., Iowa	New exposure in excavation made for military housing east of Sergeant Bluff. In west part of cut there is present a near-vertical contact of calc. drift and calc. loess. Contact is sharp with slickensided surfaces or secondary pressure laminations parallel to the contact. In center part of cut, the bedrock (K) rises to an elevation of 1165 ft. and has no drift between it and the loess, only bedded sands and gravels. At east edge of cut, slumping silt has incorporated large bedrock slabs into its base.	27
4	SE$\frac{1}{4}$ SE$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 5 T81NR44W Harrison Co., Iowa	"County line quarry" of Clark Limestone Co. (7) 1140 - top of bluff, about 1300 ft. Loess with large carbonate concretions near base. (6) 1135 - 1140. Non-calc. silt with occasional sand and gravel. (5) 1122 - 1135. Interbedded gravel, sand and silt. Possibly Crete formation. (4) 1077 - 1122. Laminated calc. silt with $CaCO_3$ concretions and ash in lower 2 feet. Upper Sappa formation. (3) 1076 - 1077. Ash with silt. Pearlette ash. (2) 1073 - 1076. Laminated silt. Lower Sappa formation.	28 29

Table 12 (continued)

No.	Location	Features	Plate No.
		(1) Elev. 1045 - 1073 ft. Graded bedding sequence from boulders to fine sand. Probably Grand Island formation. Extends deeper into pit, no elev. for top of bedrock.	
5	NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 5 T81NR44W Harrison Co., Iowa	Roadcut exposure immediately south of quarry discussed above (cut No. 4). Scattered lenses of ash between elev. 1072 - 1078 ft. Sands and gravels of unit 5 occur between 1114 - 1125 ft. and show a gradational contact with overlying loess, stringers of sand extending well up into the loess.	
6	SW$\frac{1}{4}$ SW$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 8 T81NR44W Harrison Co., Iowa	Exposure in roadcut at elev. 1165 ft. This exposure is upslope and east of cuts 4 and 5. Shows very clearly a near-vertical, sharp contact between calc. drift and calc. loess.	30
7	SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 18 T79NR42W Harrison Co., Iowa	Exposure in quarry showing complete stratigraphy of terrace fill relatively close to mouth of Boyer River. Bedrock elev. is 1026 ft.	31
		(2) 1039 - 1094. Topstratum silt that is well laminated in lower 10 ft.	
		(1) Elev. 1026 - 1039 ft. Substratum grading from gravel to an organic-rich silt.	32
8	SE$\frac{1}{4}$ NE$\frac{1}{4}$ sec. 19 T79NR42W Harrison Co., Iowa	Exposure in quarry 3/4 mile south of cut 7, illustrating upland stratigraphy. Have a sequence from bedrock through outwash sands and gravels, through glacial drift and into loess. This area is in a structural high -- are quarrying in Swope and Galesburg formations with the Hertha formation holding up Boyer River floor. This structural control is evidenced geomorphically by a marked narrowing of the Boyer River Valley and by little or no difference in bedrock elev. below terrace and upland.	

Table 12 (continued)

No.	Location	Features	Plate No.
9	NE$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 35 T77NR44W Pottawattamie Co., Iowa	New barrow pit in east valley wall. Floor of pit at 1000 ft. elev. Exposes paleo-valleys cut in glacial till and subsequently buried by loess. Both reduced and oxidized till are present and both calc. Sediment is coarser and laminated within confines of the paleo-valleys.	33 34
10	NE$\frac{1}{4}$ sec. 34 T76NR34W Pottawattamie Co., Iowa	Quarry exposure in east valley wall. Elev. top of bedrock approx. 1000 ft. (3) 1026 - 1027 ft. and up into loess. Sand with flattened $CaCO_3$ concretions at top which grades into overlying loess. (2) 1022 - 1026. Laminated silt with lenses of ash. Possibly Sappa silt and Pearlette ash. (1) Elev. 1000 - 1022 ft. cross-bedded gravel and sand. Grand Island formation.	
11	Cen. SE$\frac{1}{4}$ sec. 28 T17NR13E Washington Co., Nebr.	Quarry exposure in west valley wall. Elev. top of bedrock (K_d) is 1008 ft. (3) 1053 to top of bluff. Loess or upland silt. Gradational contact at base. (2) 1031 - 1053. Well laminated sand and silt with flattened $CaCO_3$ concretions. Possibly Sappa formation. No ash found. (1) Elev. 1008 - 1031 ft. cross-bedded sands and gravels. Possibly Grand Island formation.	35
12	NE$\frac{1}{4}$ NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 11 T75NR44W Pottawattamie Co., Iowa	Exposure in new barrow pit in east valley wall. Floor of pit is at top of coarse sand and gravel at elev. 1025 ft. Possibly top of Grand Island formation. (3) 1038.5 - about 1050. Slightly calc. sand and silt with lenses of ash which grades into overlying loess. Possibly Sappa formation. (2) 1038 - 1038.5 Calc. silty consolidated sand.	36 37

Table 12 (continued)

No.	Location	Features	Plate No.
13	SW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 24 T75NR44W Pottawattamie Co., Iowa	Exposure in sand pit in east valley wall. Lowest elev. possible in pit is about 1020 ft. Owner says there is gravel below sand. (2) 1060 - 1072. Transition zone into overlying loess. Sand lenses in a dominantly silty sediment. (1) Elev. 1020 - 1060 ft. Light gray, calc. bedded sands.	39
14	NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 20 T12NR14E Cass Co., Nebr.	Exposure in quarry south of Plattsmouth in west valley wall. Bedrock elev. is 1015 ft. Bedrock surface is glacially striated and gauged. Glacial drift overlies bedrock and a sand and gravel concentrate and stratified silts lie in small paleo-valleys cut in the drift.	40
15	SE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 10 T71NR43W Mills Co., Iowa	Exposure in east valley wall. Top of bedrock at elev. 1030 ft. (2) 1080 and 1085 on up to top of bluff. Loess above till but has scattered gravel well up into base. (1) Elev. 1030 - 1080 and 1085. Glacial till with 2 foot reddish-brown unit at top which may represent buried weathering profile. The above relationships can be traced laterally for approx. 1500 ft. along cut.	
16	NE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 16 T71NR43W Mills Co., Iowa	Exposure in east valley wall. Top of bedrock at elev. 1040 ft. (2) 1052 - up into loess. Loess above till with scattered sand and gravel in base. (1) Elev. 1040 - 1052 ft. Calc. glacial till.	
17	SW$\frac{1}{4}$ sec. 4 T11NR14E Cass Co., Nebr.	Exposure in abandoned quarry in west valley wall. Top of bedrock is at 980 ft. elev. (4) 1000 ft. - on up. Loess. (3) 992 - 1000. Unit starts out in non-calc. sand and grades upward into hard, reddish-brown silty clay. Might possibly be called Loveland.	41

Table 12 (continued)

No.	Location	Features	Plate No.
		(2) 983 - 992. Slightly calc. sand and silt which grades up from gravel below. (1) Elev. 980 - 983 ft. Semi-consolidated calcareous gravel made up of limestone slabs and crystalline rocks. Slight imbricate structure. The red band at the top of unit 3 slopes across the face of the cut, truncating units below it.	
18	NE$\frac{1}{4}$ SE$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 21 T71NR43W Mills Co., Iowa	Exposure in abandoned quarry in east valley wall. Elev. top of bedrock is 1015 ft. (4) 1021.5 - 1033.5. Poorly laminated sands and silts grading up into loess. (3) 1018.5 - 1021.5. Laminated, calc. fine sand and silt. (2) 1017.5 - 1018.5. Poorly bedded coarse sand and fine gravel. (1) Elev. 1015 - 1017.5 ft. Coarse gravel and locally derived limestone slabs. Slight imbricate structure.	42
19	SW$\frac{1}{4}$ NE$\frac{1}{4}$ SW$\frac{1}{4}$ sec. 27 T71NR43W Mills Co., Iowa	Exposure in abandoned quarry in east valley wall. Elev. bedrock top is 980 ft. (4) 1002 - on up. Calc. loess. (3) 999 - 1002. Calc. buff silty sand with a pronounced zone of large (up to 2 ft.) $CaCO_3$ concretions at top. (2) 981 - 999. Calc. semi-consolidated to unconsolidated sand and gravel becoming finer upward. Oxidized red and black. (1) Elev. 980 - 981 ft. Calc. conglomerate. Lithifield Pleistacene gravel.	43

Table 12 (continued)

No.	Location	Features	Plate No.
20	Cen. NW$\frac{1}{4}$ NW$\frac{1}{4}$ sec. 23 T70NR43W Fremont Co., Iowa	Exposure in a large quarry operation in the east valley wall. Top of bedrock at elev. 960. Several features are illustrated. (1) General superposition is bedrock, glacial drift and then loess. (2) Bedded sands and silts in paleo-valleys cut in drift. (3) Lateral truncation of sands and silts by arm of pseudoanticline. (4) Washed contact of glacial drift and loess with gravel concentrate at top of drift and with stringers of sand and fine gravel extending up into loess for several feet.	44 45
21	SW$\frac{1}{4}$ NW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 31 T68NR42W Fremont Co., Iowa	Exposure in roadcut in east valley wall. Same general section as described in cut 22, but downslope movement of loess has completely obscured lower section. However, one may dig back in from the roadway and uncover the lower units that are superimposed under the loess.	
22	SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 31 T68NR42W Fremont Co., Iowa	Exposure at base of bluffs in roadcut in east valley wall. Elev. at base of exposed material along road is 920 ft. (2) 922 - 931. Alternating 4-10 in. units of sand, silt and clay which grades into overlying loess. (1) Elev. 920-922 ft. Calc. sand and gravel.	

suggests that the basal deposits may belong to the Grand Island-Sappa-Pearlette sequence of reported (10) late Kansan age. In exposures 13, 17, 18, 19, 21 and 22 the same general basal stratigraphy (gravels and sands) as that mentioned above is present, with the exception that no ash units were noted. However, in all of these cuts no prominent unconformity or buried weathering surface was detected between the lower coarser-grained materials and the overlying finer-grained loess. The contact between the loess and the underlying coarse alluvial materials is generally transitional. Even in exposures where loess overlies glacial till there is usually an intermediate unit. For example, cut 20 clearly shows stringers of sand and fine gravel in the lower few feet of silt.

Where pre-loess erosion of the glacial drift was severe enough to produce gulleys and small V-shaped valleys, these valleys are filled with coarser sediment that commonly shows bedding or laminations. Exposures 7, 14, 15 and 20 illustrate this occurrence and cut 1 shows laminated silts in a buried bedrock valley.

Where glacial till is exposed at higher elevations in relation to the flood plain and upland elevations at that particular latitude, a weathering profile may be present at the top of the till and this in turn covered with loess. Exposure 15 illustrates this phenomenon. In this cut there are not present the horizontal stringers of sand and gravel, but yet the overlying loess does contain occasional gravels near the base.

Another type of contact present in the area of study (exposures 3, 6, 12 and 20) illustrates loess in juxtaposition with quite different materials. In exposures 3 and 6, calcareous silt is exposed adjacent to calcareous glacial drift along a near-vertical contact. These are not depositional contacts as evidenced by the freshness of material and the slickensided surfaces which show secondary laminations paralleling the contact. In cut 20, a face transverse to a spur of loess shows the limbs of a psuedoanticline (Russell 73) truncating horizontally bedded sands. A longitudinal exposure at this same quarry illustrates glacial till rising in elevation back from the transverse face. In exposure 12, one limb of a pseudoanticline has truncated a horizontal unit of semi-consolidated sand and caused the sandstone to be aligned with the attitude of the limb. A small normal fault in this same borrow pit has moved silt to a lower elevation where it truncates the underlying sands.

In several exposures, the loess has moved downslope to the extent that the underlying units are completely obscured. However, by excavating back into the cut the true nature of the superposition of materials may be determined (see cut 21).

At exposure 2, in a road cut along new Highway 20 approximately 20 miles east of Sioux City, a 5 foot unit of sand occurs well above the base of the loess at or near the highest point on the landscape in this area. Ordinarily the sand that is present in the loess is concentrated near the base but this sand occurs not only at a high elevation (greater than 1400 feet) but the bulk of the silt (loess) is below it.

PALEONTOLOGY AND PETROGRAPHY

This section presents data on fossils recovered in some of the borings and on some aspects of the petrography of the fine-grained material.

Paleontology

All fossils recovered were identified by Robert Lohnes of the Geology Department at Iowa State University, using the publications of Leonard (54 and 53) and Leonard and Frye (55) as references.

Alluvium

The following mollusca were recovered from between 5 to 45 feet below the flood plains of the Missouri River and tributary streams near their mouths.

1. Amnicola limosa parva
2. Discus cronkhitei
3. Helicodiscus parallelus
4. Helisoma antrosa
5. Lymnaea palustris
6. Physa elliptica
7. Physa anatina (?)
8. Planorbula nebraskensis (?)
9. Retinella electrina
10. Sphaerium sp.
11. Sphaerium solidulum
12. Succinea sp.
13. Succinea ovalis
14. Zonitoides arboreus

Radiocarbon dates secured in this study suggest that these fossils are less than approximately 13,000 years old. There is a slight possibility that some of them could have survived reworking and hence have been derived from older deposits.

In the Illinois Valley region, numbers 9 and 2 are reported (55, p. 17) to have common and abundant occurrence, respectively, in Woodfordian Substage materials. The Woodfordian Substage is reported (55, p. 1) to encompass the time from 22,000 to 12,500 years before present. Numbers 4 and 14 are reported as having rare occurrence in the Woodfordian in the same area.

Approximately 150 miles west of the area of the present investigation, Miller and Scott (61, p. 1437) report molluscs 2, 3, 6, 7 and 14 as indicative of a flood plain environment. They find them in alluvial silts below a terrace of possible Cary age. The same fossils, plus numbers 9 and 13 are reported (61) in a buried soil at the top of the Sappa formation lower in the same terrace fill.

Terraces

The following mollusca were recovered from between 5 and 52 feet below the main terrace in the area of this study.

1.	Discus sp.	6.	Succinea avara
2.	Discus cronkhitei	7.	Succinea grosvenori
3.	Pupilla sp.	8.	Vallonia gracilicosta
4.	Pupilla blandi	9.	Vertigo sp.
5.	Succinea sp.	10.	Vertigo modesta

Radiocarbon dates in the area suggest these fossils are less than approximately 22,000 years old and at least older than 13,000 Years Before Present. In the Illinois Valley region, numbers 2, 7 and 10 are reported (55) to have abundant occurrence in the Woodfordian. Numbers 2 and 7 are reported as having rare occurrence in the Altonian Substage (70-50,000 to 28,000 years before present) in this same area. In eastern-central Nebraska, numbers 2, 6 and 10 are reported (61) as indicative of a flood plain environment and numbers 7, 8 and possibly 5 as occurring in a fauna requiring quiet water.

Uplands

The following mollusca were recovered from between 10 and 20 feet below the upland surface in borings from interfluve and valley slope locations. All fossils are from the loess.

1. Discus cronkhitei
2. Euconulus fluvus
3. Pupilla sp.
4. Retinella electrina
5. Succinea sp.
6. Succinea avara
7. Vallonia gracilicosta

Fewer borings were made in the upland than in the valley and fewer fossils recovered. No radiocarbon dates are available from the uplands from this study, but geologic evidence strongly suggests that the upland loess is older than the silt below the terrace.

In the Illinois Valley region, fossils 1 and 2 are reported abundant in the Woodfordian (55) and number 4 as common. Molluscs 1 and 4 are reported as having rare occurrence in the Altonian in this area. In Nebraska, in terraces along the Loup River (61), numbers 1 and 6 are again reported as indicative of a flood plain environment and numbers 1, 2, 4, 7 and possibly 5 are reported in the fauna present in the gley soil (Coopers Canyon) that occurs as the upper part of the Sappa silt. It is reported (61, p. 1444) that this Coopers Canyon fauna required quiet water — lakes, ponds, swamps, slow-moving clear streams, wet grassy margins of streams, or moist woodlands.

Petrography

The relatively small amount of petrography done in this study was aimed at determining the clay minerals in the different deposits, the type of carbonate present, and the in-place structure, if any, of some of the different materials.

Clay mineralogy

In an effort to rapidly survey the clay minerals in the different sediments, 35 X-ray tests were run on samples from the alluvium, terrace sediment and upland material. Samples from holes 90, 96 and 109 in the alluvium, holes 97, 113, 117, 121 and 122 in the terrace sediment and holes 86, 87, 91, 98, 99 and 105 in the upland material were used.

The dominant clay mineral in the alluvium and terrace material is montmorillonite. Minor amounts of illite and kaolinite are present. In the uplands, however, only samples from the upper part of the loess showed clear-cut montmorillonite peaks. Lower in the section in the uplands, in material previously described as the lower unit, there were either no peaks shown in the montmorillonite range (glycolated samples) or they were very low and rather broad. For example, samples 86-2, 87-8 and 9, 98-4, 5, 7 and 8, 99-2 and 105-3 and 4 either showed no peaks for montmorillonite or broad, diffuse peaks in all instances much less sharp than those shown from samples in overlying material. Yet, the lower sediment contains as much, and in most samples, more clay-size material. All samples were prepared by the same person and packed in the same type of holder with similar technique. All were run glycolated on the same machine within a few hours' time. In many instances only a relatively small range (up to 14° 2θ) was surveyed and hence only basal spacings of clay minerals would be recorded.

Carbonates

The X-ray data from the samples analyzed in the previous section, along with calcium:magnesium ratios determined for several samples, indicate that dolomite is the principal carbonate mineral in all deposits investigated. Calcium:magnesium ratios are presented in Table 13.

From the X-rays the dolomite peak was, in all instances except one, more intense than the calcite peak. In this one sample (96-4) the peaks were of equal height. In many samples (87-7, 91-3, 97-3, 98-3, 109-3 and 122-2) there was only a dolomite peak. It has been reported to the author[a] that, if equal amounts of pure dolomite and calcite are mixed, the resulting X-ray curve will show calcite with a greater intensity. The calcium:magnesium ratios are certainly not as conclusive as X-rays simply because not all of the calcium and magnesium ions de-

[a]Diebold, Frank. Geology Department, Iowa State University, Ames, Iowa. Data on carbonate X-ray diffraction. Private communication. 1961.

Table 13. Calcium:magnesium ratios

Sample No.	Ca.:mg.	Sample No.	Ca.:mg.
Flood plain		Upland	
93-1	1.8	86-1	1.9
93-2	0.9	86-2	0.4
96-1	0.4	87-1	1.2
96-2	0.6	87-2	2.1
96-4	2.2	87-4	2.9
96-5	2.2	87-6	2.6
104-1	2.4	87-7	1.0
104-2	2.6	87-8	0.3
111-1	0.3	87-9	0.4
111-2	2.0	98-1	0.9
111-3	1.7	98-3	0.7
111-4	0.8	98-4	0.1
111-5	0.4	98-5	0.4
Terrace		98-7	0.4
119-1	1.2	98-8	0.7
119-3	1.2	105-3	0.6
119-4	1.8	105-4	2.2
119-5	0.7	106-2	0.9
121-1	0.9	106-3	1.0
121-2	0.02		
121-3	0.8		
122-1	1.5		
122-2	1.1		
122-3	1.6		
122-4	1.1		

tected in the type of test used are known to have come from carbonate minerals. In this report, ten of the X-rays detected no carbonate minerals in the sample but chemical tests had detected calcium and magnesium ions, obviously from a different source, and these were computed to calcium carbonate and reported as simply carbonate in Tables 9, 10 and 11. The highest carbonate content reported for which an X-ray showed neither calcite nor dolomite was 5.4 for sample 96-2 (Table 9).

Another factor which should be mentioned here is that in all the chemical determinations for carbonate, at least two samples were analyzed; one of the whole sample and one passing a No. 200 sieve. In all instances except one (90-3), where the screening kept out fragments of carbonate concretions, the finer fraction showed the higher carbonate content.

<u>Thin sections</u>

During the time subsurface investigations were being conducted in the terrace and upland sediment, it was noted upon inspection of the driven spoon samples that some of the deeper sediment in these deposits appears laminated. Locally these relationships can also be seen in outcrop, particularly in fresh cuts. Therefore, thin-sections were prepared from some of the in-place samples so that the structure of the material could be studied. Most of the upland loess has a massive structure, but much of the terrace sediment and some of the lower upland silt or loess exhibits a laminated character. Plates 46-52 show photographs of some of the laminated material. All of these samples except Logan-1A (Plate 47) are from material driven in a penetrometer tube and the distortion of laminations caused by skin friction is quite evident in some. Sample Logan-1A was cut out of a block of laminated silt which was removed from the outcrop (exposure 7, Table 12) and transported to the laboratory.

Ordinarily, the laminations are first noticed because of a slight alteration in color and under the microscope it can be seen that the darker laminae are along zones of slightly coarser material. Iron-stained grains (opaque to partially opaque) are concentrated along the darker laminae. To check this apparent difference in particle-size, the different-colored zones were carefully scraped from the block of laminated silt and the separated material analyzed by mechanical analysis. Although the differences are not great, the darker or reddish-brown laminae contained less clay-size material and more silt and sand than the lighter tan or gray-colored laminae. The gray sediment contained no sand. Apparently the slight increase in permeability available in the coarser-grained material allows more concentration of Fe_2O_3 and this in turn causes the laminations to be darker.

In slides 113-1 (Plate 49) and 114-1 (Plate 50), where sand grains can be traced across the slide, a darker band may occur immediately adjacent to and parallel with the sand lens.

In slide 97-4 the distorted laminations can be traced due to the iron and possibly manganese coatings on the sand grains. Pockets of darker material may also be seen.

Even though some of these slides do contain carbonate minerals, definite grain boundaries are difficult to determine because of staining.

SOIL MECHANICS PROPERTIES

This section presents data on the strength characteristics and related engineering properties of the various deposits investigated. Unconfined compressive strengths are reported as the maximum attained up to the point of failure or until 20 per cent strain had been reached in those samples that deformed plastically.

Alluvium

The particle-size of all samples recovered from flood plain borings and a condensed log of each hole have been presented in Table 9. The soil mechanics properties for the major alluvial deposits are shown in Table 14 and the particle-size is reproduced because of its important bearing on the type of laboratory strength test used.

Flood basin

Borings 93 and 96 were made in flood basin deposits close to the meander belt and valley wall, respectively. They are both at about the same latitude and in the relatively wide segment of the alluvial valley. Borings 88 and 90, near the mouths of tributaries at approximately the same latitude both have a stratigraphy similar to that of the Missouri River flood basin and may be included here.

The tested samples from borings 88, 90 and 93 all had comparable strengths and essentially the same N-value. Samples 93-1 and 2 have much greater clay contents but lower densities and higher moisture

Table 14. Soil mechanics properties of alluvium

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
88-2	25-26.5	34.0	57.0	9.0	1344	20	94	30	5(6)10	60	Flood plain of Boyer River near mouth.
90-3	30-31.5	13.0	55.0	32.0	1300	8	104	22	6(5)10	65	Flood plain of Willow River near mouth.
93-1	5- 6.5	79.0	19.5	1.5	1153	6	86	43	3(4)9	60	Flood basin close to meander belt. Sample 93-3 in loose, saturated fine sand.
93-2	15-16.5	72.0	26.0	2.0	1448	16	84	40	4(4)10	55	
93-3	30-31.5	2.6	6.0	91.4	---[a]	--	--	--	2(3)7	--	
96-1	5- 6.5	32.0	67.3	0.7	582	20	83	35	1(1)2	--	Flood basin close to valley wall.
96-2	15-16.5	25.0	74.3	0.7	577	20	89	33	1(2)5	58	
96-4	30-31.5	79.0	20.9	0.1	814	17	70	51	2(2)5	60	
96-5	45-46.5	10.0	47.1	42.9	926	7	86	31	3(4)10	70	
102-1	5- 6.5	4.0	14.2	81.8	294[a]	3	98	20	2(4)13	60	Channel fill below mouth of Platte R.
103-1	5- 6.5	3.5	12.5	84.0	528[a]	3	96	26	9(11)34	63	Point bar below mouth of Platte R.
104-1	5- 6.5	58.0	40.8	1.2	2053	18	89	33	3(3)6	53	Clay plug below mouth of Platte R.
104-2	15-16.5	4.0	25.1	70.9	677[a]	3	98	25	6(11)21	58	

[a]Samples contain too much sand for valid unconfined compression test. They were tested only for the cohesive strength present. The N-value is diagnostic of total strength.

Table 14 (continued)

Sample No.	Depth, feet	Particle-size, % Clay	Silt	Sand	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
109-1	5- 6.5	51.0	46.7	2.3	1433	18	83	38	2(3)6	50	Channel fill above
109-2	15-16.5	58.0	41.9	0.1	785	19	72	50	1(2)5	56	mouth of Platte R.
109-3	32-33.5	5.0	18.9	76.1	388[a]	3	101	23	4(9)19	60	
110-1	5- 6.5	11.0	88.1	0.9	685	2	95	11	7(7)13	--	Point bar above
110-2	15-16.5	2.0	9.2	88.8	328[a]	5	106	18	13(24)50	63	mouth of Platte R.
111-1	5- 6.5	25.0	74.6	0.4	1239	12	87	33	2(3)8	60	Clay plug above
111-2	15-16.5	68.0	31.6	0.4	1352	9	77	44	2(3)9	46	mouth of Platte R.
111-3	25-26.5	71.0	28.9	0.1	2120	13	83	40	3(4)8	50	
111-4	32-33.5	76.0	23.9	0.1	584	12	64	59	2(2)4	54	
111-5	45-46.5	31.0	68.1	0.9	724	20	82	38	1(1)3	55	

contents. Samples 96-1 and 2 at the same depths as 93-1 and 2 have less than half the strength and N value but comparable densities and moisture contents. However, 96-1 and 2 contain only a third as much clay-size material. Sample 96-4 has 79 per cent clay but density is low and moisture high. Judging from the N-value, density, moisture and relatively high sand content, sample 96-5 would probably exhibit greater shearing strength if tested in confined compression.

Meander belt

Within this area borings were made into the major alluvial deposits both above and below the mouth of the Platte River. In all borings the fine-grained material above the substratum sand was found to be thinner in the Missouri River deposits below the confluence of the Platte River.

Channel fill. Borings 102 and 109 were made into channel fill deposits below and above the mouth of the Platte River, respectively. Even at a depth of 5-6.5 feet, sample 102-1 contained 82 per cent sand and hence the strength shown is not diagnostic of total strength. Samples 109-1 and 2 have essentially the same mechanical composition but the strength of 109-1 is twice that of 109-2. This fact illustrates an important phenomenon that was recognized in several channel fill borings. That is, the upper few feet of the very fine-grained channel fill sediment will harden with drying and a crust is developed near the surface. In some of the earlier hand-auger borings it was difficult to penetrate the upper 4-7 feet of crust, but once penetrated the auger would slip by its own weight through the next 10 feet or so. The lower strength of sample 109-2 may be correlated with lower density and higher moisture content. Sample 109-3 contains too much sand for a valid unconfined compression test but its N-value is relatively high.

Point bar. Borings 103 and 110 penetrated the upper substratum of point bar deposits below and above the mouth of the Platte River, respectively. Sample 110-1 is the only one on which a valid strength test could be performed in the laboratory. However, it is interesting to note that all the samples from these borings, especially 103-1 and 110-2, had high N-values. In contrast to substratum materials driven in other deposits which were sometimes much deeper, the substratum in the point bars has much more strength. The reworking of these sands during the process of meander development coupled with better drainage and resulting low moisture contents and high densities, have produced the greater strength evidenced by the high N-values.

Clay plug. Borings 104 and 111 were made into clay plug sediments below and above the mouth of the Platte River, respectively. Both borings penetrated thicker fine-grained deposits than other channel fills in the respective areas. Sample 104-1 records the highest near-surface unconfined compressive strength but the N-value is relatively low. Boring 111 records an increase in strength to a depth of 25 feet and then a marked decrease even though all the material has valid mechanical properties for an unconfined test. The low strength of sample 111-4 may be correlated again with low density and high moisture content but sample 111-5 defies any reasonable correlation with other samples above it considering the different parameters that are known.

The four graphs shown in Figure 29 relate the strength, density, moisture content and N-value for all samples of alluvium judged suitable for a valid unconfined compression test. In considering all samples regardless of depth, the only good correlation that can be made is that relating density and moisture.

Glenn (35) has reported the elevation of the water table below the flood plain for all borings made during the 1958 and 1959 field seasons.

Terraces

The particle-size of terrace samples and a condensed log of each boring have been presented in Table 10. The soil mechanics properties are recorded in Table 15. The particle-sizes are not reproduced in Table 15 because all the samples tested in unconfined compression had a valid mechanical composition for this type of test. That is, the strength of these samples came dominantly from the cohesion of the material, not from intergranular friction. Table 15 also contains data, mainly for purposes of comparison, from several borings in terraces where the N-value is known for drive samples taken at various depths but on which laboratory strength tests were not performed.

Borings 85, 89, 97 and 119 can be grouped together to illustrate strength properties of the terrace material in central latitudes of the valley where the fine-grained topstratum is at least 50 feet thick. Sample 97-1 underwent artificial compaction under the wheel loads of equipment used in the construction of a small earth dam nearby. Its strength is shown for comparison.

Figure 29. Graphs relating strength, density, moisture content and N-value for in-place samples from below the flood plain

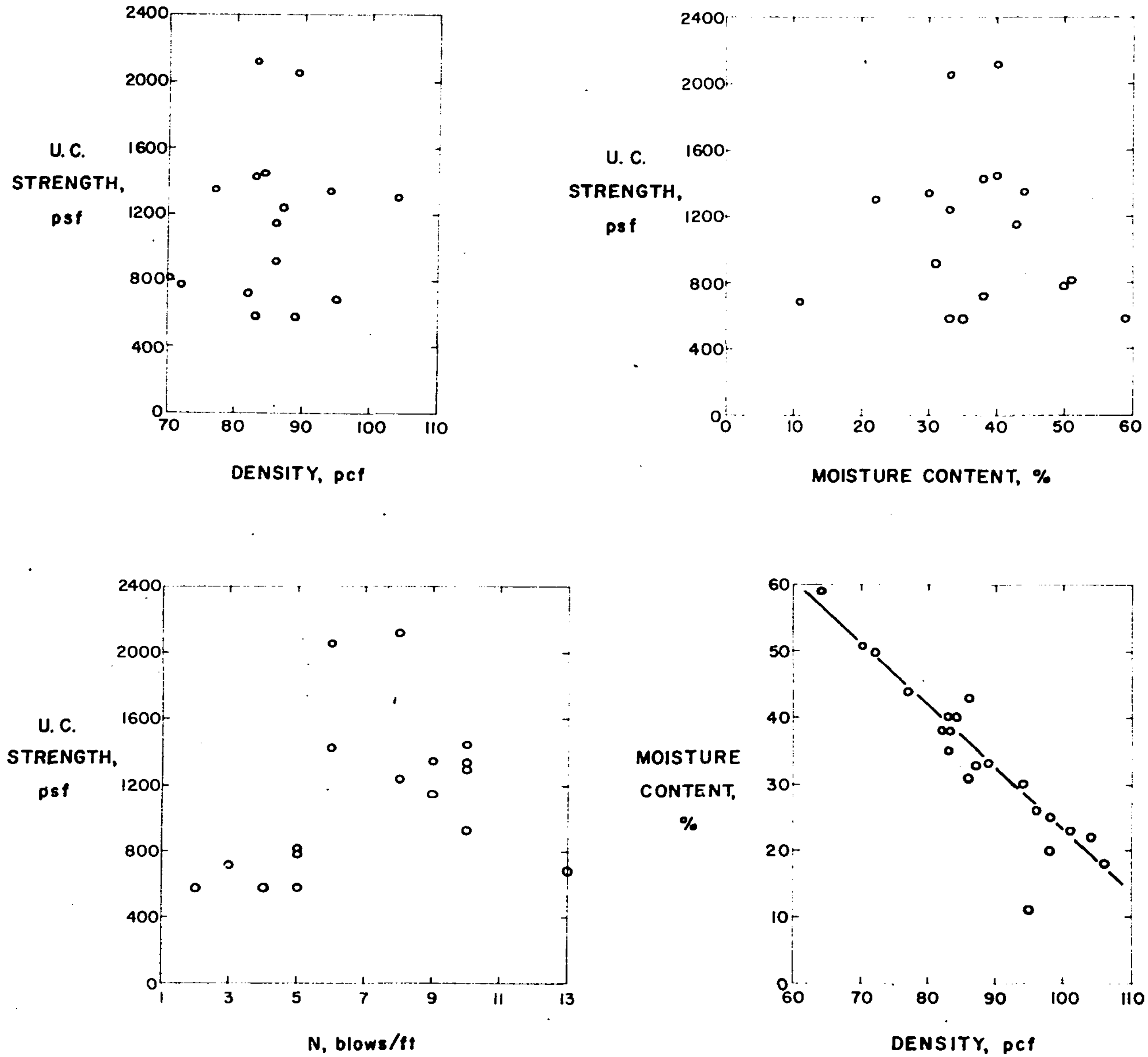

U. C. STRENGTH, psf
DENSITY, pcf
U. C. STRENGTH, psf
MOISTURE CONTENT, %
U. C. STRENGTH, psf
N, blows/ft
MOISTURE CONTENT, %
DENSITY, pcf

Table 15. Soil mechanics properties of terrace material

Sample No.	Depth, feet	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
85-1	0- 1.5	---	--	--	--	2(2)4	--	Boyer River valley near mouth.
85-2	5- 6.5	341	20	83	34	1(1)3	55	
85-3	15-16.5	1430	9	94	26	1(3)7	--	
85-4	30-31.5	2107	8	97	20	5(5)17	65	
85-5	45-46.5	817	20	89	28	8(9)19	--	
89-2	15-16.5	357	20	81	33	2(2)3	63	Willow River valley at mouth.
89-4	60-61.5	902	20	93	29	5(5)10	60	
97-1	5- 6.5	5160[a]	18	94	26	20(-)-	--	Missouri River valley north of Blair, Nebr. Upper 15 ft. of material in alluvial fan.
97-2	31-32.5	1205	20	92	30	3(3)7	55	
97-3	46-47.5	955	20	91	31	4(5)11	57	
97-4	61-62.5	1286	20	97	26	4(5)10	--	
101-2	40-41.5	551	20	86	34	3(4)8	63	Nishnabotna River valley at mouth.
112-1	15-16.5	4520	3	101	15	6(7)13	--	Floyd River valley near mouth. All samples were laminated.
112-2	30-31.5	5870	5	104	15	5(7)16	--	
112-3	45-46.5	2080[b]	9	92	22	5(4)9	--	
113-1	15-16.5	---	--	--	--	3(3)8	--	Floyd River valley about 20 miles upstream from No. 112.

[a]Sample was artificially compacted.

[b]Poor extrusion.

Table 15 (continued)

Sample No.	Depth, feet	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
114-1	16-17.5	---	--	--	--	6(7)16	--	Floyd River valley about 10
114-2	31-32.5	---	--	--	--	12(18)44	--	miles upstream from No. 112.
117-1	15-16.5	---	--	--	--	1(3)7	--	Maple River valley at mouth.
117-2	30-31.5	---	--	--	--	6(8)19	--	
117-3	45-46.5	---	--	--	--	7(10)24	--	
117-4	60-61.5	---	--	--	--	7(11)24	--	
117-5	80-81.5	---	--	--	--	12(19)39	--	
118-2	15-16.5	---	--	--	--	3(4)9	--	Maple River valley about 10
118-3	30-31.5	---	--	--	--	6(6)14	--	miles upstream from No. 117.
118-5	45-46.5	5670	3	102	13	7(11)24	--	Sample 118-5 was laminated.
118-6	60-61.5	---	--	--	--	9(14)28	--	
119-1	15-16.5	---	--	--	--	4(5)11	--	Soldier River valley at mouth.
119-3	30-31.5	---	--	--	--	5(8)17	--	
119-4	45-46.5	1190[b]	6	97	18	7(8)17	--	
119-5	80-81.5	2425	10	90	26	5(10)20	--	
120-2	15-16.5	---	--	--	--	3(4)9	--	Soldier River valley about
120-3	25-26.5	4800	4	104	16	5(10)19	--	20 miles upstream from No. 119.
120-4	45-46.5	4200	6	103	16	7(11)24	--	Samples were laminated.
120-5	60-61.5	2181	20	95	25	4(6)13	--	
121-1	16-17.5	---	--	--	--	1(2)4	--	Low terrace along Missouri
121-2	31-32.5	---	--	--	--	3(3)6	--	River valley.
121-3	46-47.5	---	--	--	--	4(5)9	--	
122-1	15-16.5	---	--	--	--	5(8)18	--	Missouri River valley north of
122-2	30-31.5	---	--	--	--	8(12)26	--	Omaha.
122-3	45-46.5	---	--	--	--	6(6)12	--	
122-4	60-61.5	---	--	--	--	5(8)16	--	

In general, the trend shown from these borings is one of increasing strength with depth to about 45 feet. Then there is a decrease at 45 feet followed by an increase. However, the strengths at the same depth from different locations show a wide variance and the correlation with N-value, particularly in samples 85-5 and 97-3, is poor. The correlation of higher strength with higher density and lower moisture is much better than comparing strength with N-value.

There is, however, a good correlation in all respects for boring 112. It also shows a zone of lesser strength with depth as does boring 120. Borings 112, 118 and 120 in tributary valleys all produced samples with relatively high strength and these samples all showed some of the best laminations observed in the terrace borings. Hence, samples which exhibit some of the highest strengths have directional properties perpendicular to the applied (deviator) stress. The highest N-value recorded is shown by 114-2, which drive was in the coarse sands and fine gravel which approach the terrace surface upstream.

The four graphs shown in Figure 30 relate the soil mechanics properties for all samples from the terrace fill tested for strength in the laboratory. Reasonable correlations can be made for strength, moisture and density, but not for strength and N-value.

Uplands

The particle-size of upland samples and a condensed log of each boring have been presented in Table 11. The soil mechanics properties are shown in Table 16. All materials tested were relatively fine-

Figure 30. Graphs relating strength, density, moisture content and N-value for in-place samples from below the terrace.

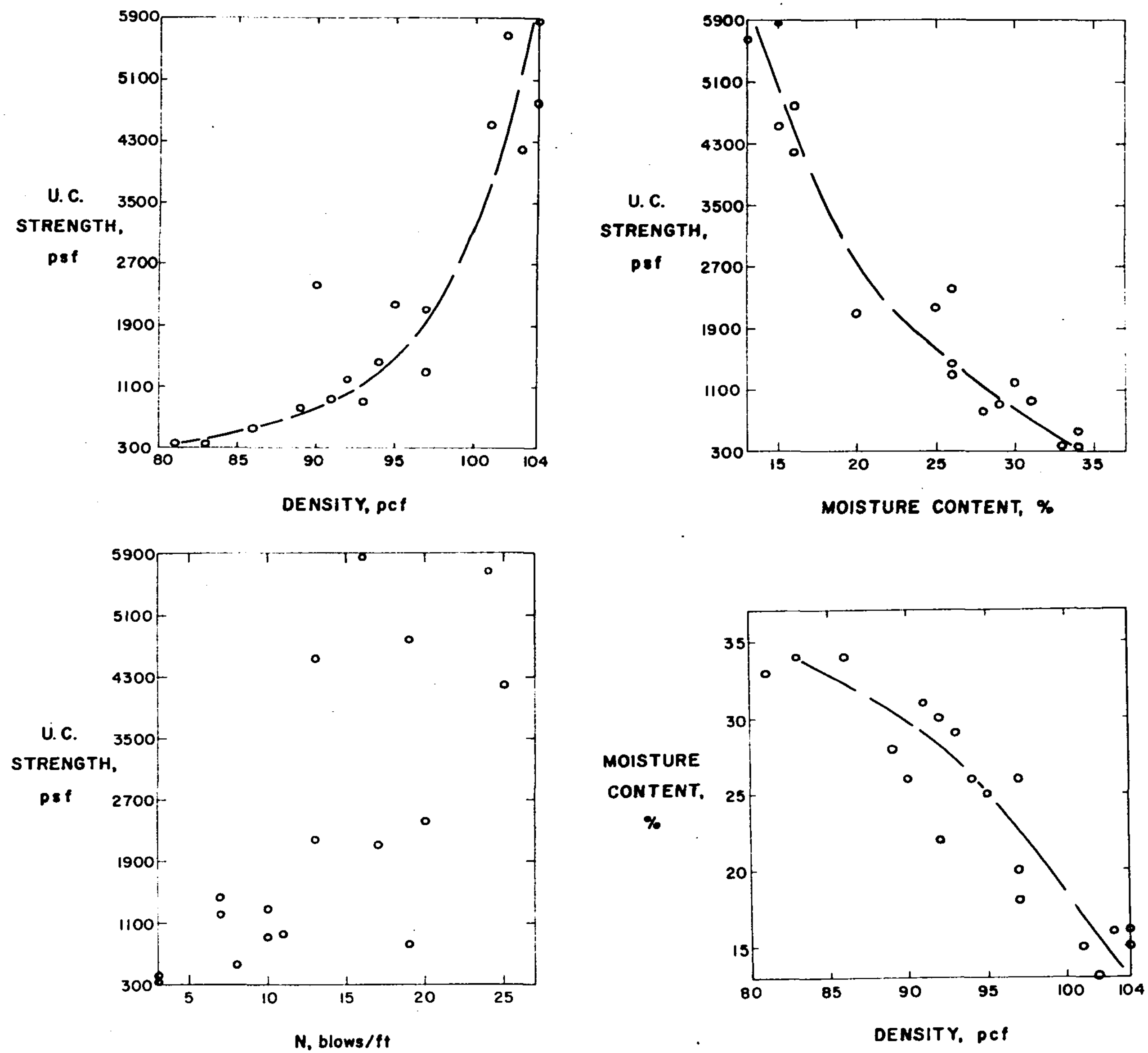

U. C. STRENGTH, psf
5900
5100
4300
3500
2700
1900
1100
300
80
85
90
95
100
104
DENSITY, pcf
U. C. STRENGTH, psf
5900
5100
4300
3500
2700
1900
1100
300
15
20
25
30
35
MOISTURE CONTENT, %
U. C. STRENGTH, psf
5900
5100
4300
3500
2700
1900
1100
300
5
10
15
20
25
N, blows/ft
MOISTURE CONTENT, %
35
30
25
20
15
80
85
90
95
100
104
DENSITY, pcf

Table 16. Soil mechanics properties of upland material

Sample No.	Depth, feet	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
86-1	30 - 31.5	1313	20	91	32	4(5)12	61	Valley slope above Boyer
86-2	56 - 57.5	2572	20	99	26	4(6)15	55	River terrace. Sample 86-4
86-4	100.5-101.5	4320	20	108	19	8(10)23	--	in glacial till, 86-5 in
86-5	140 -141.5	---	--	--	--	82(-)-	--	outwash.
87-1	5 - 6.5	254	20	81	43	4(6)13	65	Boring located about 20 feet
87-2	15.5- 17	889	12	84	31	4(6)15	55	below crest of interfluve
87-4	30 - 31.5	1682	11	94	26	6(7)17	65	between Boyer and Willow
87-6	45.5- 47	1950	9	97	25	9(11)23	--	river valleys. Sample 87-10
87-7	60.5- 62	1402	20	90	31	5(5)12	63	in glacial till.
87-8	75.5- 77	2754	20	100	26	5(8)18	65	
87-9	105.5-107	3440	20	102	25	8(10)21	65	
87-10	120.5-122	12420	13	114	17	13(20)48	60	
91-2	15 - 16.5	868	20	91	32	4(4)8	58	Valley slope below 87.
91-3	40 - 41.5	1523	20	94	28	5(6)12	60	
98-1	15 - 16.5	---	--	--	--	8(9)20	--	Crest of interfluve between
98-3	30 - 31.5	6460	6	104	20	7(11)25	--	Missouri River and New York
98-4	45 - 46.5	5030	17	102	22	6(9)22	65	creek. Samples 98-9 and
98-5	60 - 61.5	6595	12	102	20	8(12)29	--	98-10 were recovered in the
98-9	100 -100.5	1390	18	93	31	9(10)23	65	same drive. 98-9 is base of
98-10	100.5-101.5	6700	15	102	25		44	silt, 98-10 top of till.
99-3	70 - 71.5	3938	20	102	25	12(14)30	48	Valley slope above Missouri River terrace. Sample 99-3 is till.

Table 16 (continued)

Sample No.	Depth, feet	qu, psf.	Strain, %	Fld. den., pcf.	Field moist., %	Std. pene., N	θ, deg.	Remarks
105-1	30-31.5	---	--	--	--	8(11)25	--	Upland flat.
105-3	60-61.5	3750	20	96	25	3(4)9	--	
106-2	30-31.5	---	--	--	--	6(9)20	--	Crest of ridge adjacent to
106-3	60-61.5	---	--	--	--	13(19)43	--	Missouri River flood plain.
108-1	32-33.5	6800	20	108	24	9(11)25	--	Low divide east of Nishna-
108-2	46-47.5	5905	20	119	17	10(13)30	--	botna River terrace about
								20 miles upstream. Sample
								108-2 is till.
115-2	30-31.5	---	--	--	--	10(15)32	--	Upland west of Floyd River
115-3	35-36.5	---	--	--	--	6(15)31	--	terrace about 10 miles
115-4	45-46.5	---	--	--	--	6(11)24	--	upstream from mouth.
115-5	60-61.5	---	--	--	--	7(8)18	--	

grained and only the glacial till or drift below the loess would show appreciable gains in strength due to intergranular friction.

Borings 87 and 98, near or at the crests of interfluves, record the greatest detail in strength characteristics of relatively thick loess. Boring 98 is located on an interfluve crest and samples at comparable depths with hole 87 record two to four times the strength. Boring 87 is slightly downslope from the crest of an interfluve and is on the Iowa side of the river. Boring 98 is on the Nebraska side and at a slightly higher latitude and hence greater elevation due to the regional slope of the upland. Both borings show an increase in strength with depth except for the first drive taken in the lower unit of the upland loess (87-6 and 98-4). Unconfined compressive strengths show a good correlation with moisture content and density. As shown in boring 87, moisture contents decrease in depth to an elevation near the top of the lower unit where they increase and then once more decrease with depth. The moisture change is reflected in density, strength and strain; those samples having a higher moisture content failing in more plastic deformation and having a higher strain value. Throughout this report, the failure plane (θ) when reported for samples with 20 per cent strain, was measured after this strain had been reached or was measured along incipient failure planes in the sample. Thus, the measured θ in these instances does not correspond to the strength reported at 20 per cent strain, but for practical engineering purposes it was deemed best not to report strengths at strains greater than 20 per cent.

Samples from borings downslope (holes 86, 91 and 99) from interfluve borings show less strength than that in the latter. Several samples of glacial till were tested and strengths were consistently high.

Figure 31 presents four graphs relating the soil mechanics properties for all samples from the uplands, regardless of depth. Reasonably good correlations are present in all but the strength and N-value graph.

Engineering Classification

Glenn (35, p. 96-114) has reported in some detail on the engineering classification of the different deposits lying below the Missouri River flood plain. This work is briefly summarized here.

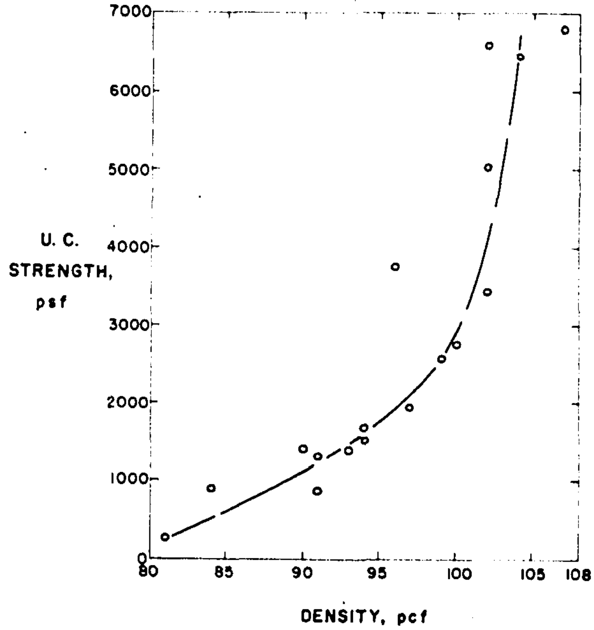
The topstratum in the flood basin is typically an A-7 material with an A-3 substratum. Alluvial fan material varies between an A-4 and A-6 engineering soil classification.

Within the meander belt area, the channel fill sediment is always an A-7 as is the topstratum in point bars when at least a few feet of overbank sediment masks the point bar sands. Both point bar and channel fill substratum classifies as A-3 and occasionally a transition zone will classify as an A-4. A-3 material predominates in the channel belt and in very modern point bars.

Undifferentiated material (masked point bar and channel fill) has an A-7 topstratum and A-3 substratum. Natural levee deposits vary between A-4 and A-6, being slightly coarser-grained.

The loess adjacent to the Missouri River in western Iowa is reported (40) to classify as an A-4 engineering material.

Figure 31. Graphs relating strength, density, moisture content and N-value for in-place samples from below the upland surface


U. C. STRENGTH, psf
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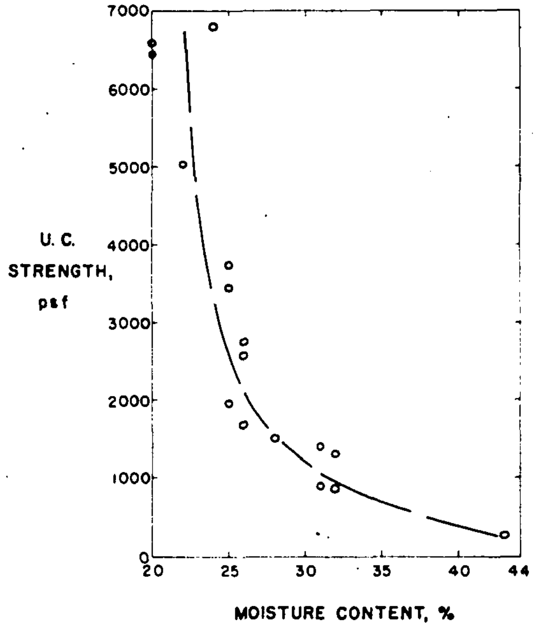
5000
4000
3000
2000
1000
0
80
85
90
95
100
105
108
DENSITY, pcf


U. C. STRENGTH, psf
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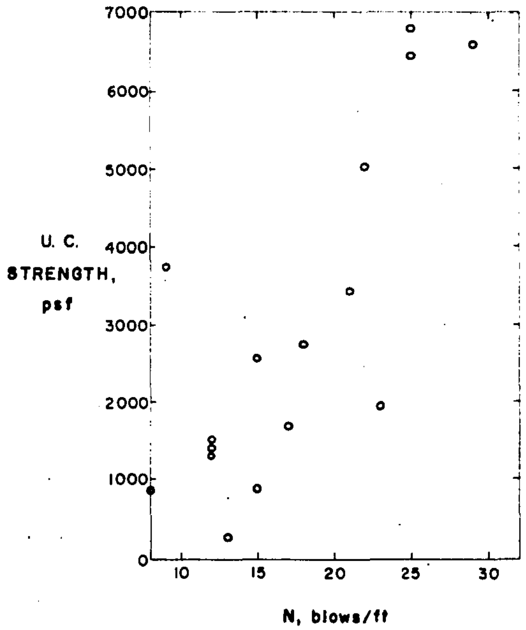
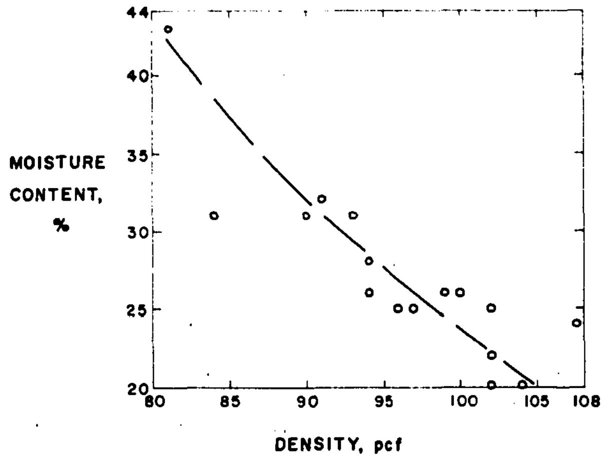
6000
5000
4000
3000
2000
1000
0
20
25
30
35
40
44
MOISTURE CONTENT, %


U. C. STRENGTH, psf
7000
6000
5000
4000
3000
2000
1000
0
10
15
20
25
30
N, blows/ft


MOISTURE CONTENT, %
44
40
35
30
25
20
80
85
90
95
100
105
108
DENSITY, pcf

SUMMARY AND CONCLUSIONS

This study is the first of its kind to present data on the alluvial morphology and properties of alluvium of a large river valley within the glaciated tract. It is also the first attempt to correlate river history and valley development with surrounding Quaternary deposits whose history has been interpreted by other workers. The primary goal of the study has been reasonably well achieved; some problems have arisen in the correlation of the Quaternary history.

Alluvial Morphology

The alluvial morphology and nature of alluvium along the Missouri River follow closely the works of Fisk (27) and Russell (69).

The present alluvial plain is a product of the deposition of 40-50 feet of alluvium in approximately the last 13,000 years. The surface is not controlled by the shape of the underlying bedrock floor and the flood plain exists as a distinct topographic discontinuity on the landscape.

The mappable alluvial features present on the Missouri River flood plain, particularly above the mouth of the Platte River, are due to the meandering character of a large stream working predominantly in the fine-grained topstratum but having the ability, especially during flood stage, to scour into the coarser-grained substratum as well as overflow its banks. The almost featureless area of the flood plain is the flood basin marginal to the meander belt where overbank deposits are least disturbed by more recent stream action.

It is within the meander belt, where distinct alluvial features are present, that the recent geologic history of the Missouri River is best illustrated. The abandoned meander loops with their associated features (channel fill, point bar, clay plugs and natural levees) can be readily mapped from air photos and by field reconnaissance using relatively small scale topographic maps as base maps. Some of these alluvial features may be quite limited in lateral and vertical extent, but they become systematic with detailed mapping over a relatively large area and hence record the systematic behavior of the river that formed them. Within the mappable history of the Missouri River adjacent to Iowa, it has been predominantly a meandering river; meander loops grew and were periodically abandoned, the stream overflowed its banks, inundated its flood plain, and clay plugs and natural levees were formed in the process.

The river has one recognizable main meander belt, and the clay plugs and low natural levees have helped to contain the stream within this area. The only likely place for the river to completely abandon its present meander belt is in the upper, wider segment. In this area there is a relatively wide expanse of flood basin on the Iowa side at a slightly lower elevation than that adjacent to the river.

Alluvium

The nature of all the major alluvial deposits previously mapped by their characteristic surface morphology was revealed by numerous borings.

There is a definite correlation between alluvial morphology as displayed on aerial photographs and the nature of the sediment. Thus, one of the prime objectives of this study was achieved.

The alluvial fill consists of two basic units; the coarser-grained substratum gravels and sands, and the finer-grained topstratum of mainly silts and clay-size material. Thus, there is an increase in particle-size with depth in the alluvium. The coarsest substratum is present in the deeper parts of the bedrock trench usually near the center of the valley. The substratum rises closer to the alluvial plain below the confluence of the Platte River. Substratum sands are usually present on the surface within the channel belt.

The topstratum is most ideally developed in the flood basin where it attains its greatest thickness over the largest aerial extent. Within the meander belt the topstratum is thickest in paleo-channels. The alluvium in the meander belt has a distribution determined by the meandering habit of the main channel coupled with periodic overbank flooding. Below the confluence of the Platte River the relationship is not as systematic as it is above the confluence.

Radiocarbon dates from wood samples recovered from well within the substratum and near the top of the substratum in borings slightly upstream in tributary valleys suggest that at least 40 to 50 feet of alluvium has been deposited in the last 13,000 years. Within the meander belts of the Missouri River and a tributary stream near its mouth, radiocarbon dates of less than 400 years before present were determined from wood samples. If alluviation progressed upstream then it is likely that the basal substratum in the Missouri River Valley was deposited no longer than about 15,000 years ago.

Considering the general graded character of the alluvium (progressively finer upward), the depth of fill over the uneven bedrock floor and the abrupt topographic discontinuity (escarpment) between the flood plain and the valley walls, the term "alluvial drowning" introduced by Russell and Howe (75) seems appropriate to describe these relationships. Possible causes of this alluviation will be discussed in the section on Quaternary History.

Missouri River

Discounting the recent artificial controls imposed upon it, the Missouri River since attaining its present characteristics has adjusted its slope to provide the velocity necessary to transport the debris supplied to it, and fits Mackin's (58) definition of a graded stream. The change in characteristics due to the entrance of the Platte River demonstrates that the river has responded to a displacement in equilibrium by tending to absorb the effect of the change. Leopold and Wolman's (56) conclusion that a continuum of natural stream channels may have different characteristics but be in quasi-equilibrium is appropriate for the Missouri River above and below the confluence with the Platte.

At least in its meandering state above the mouth of the Platte, the river is in a poised state if this term is used to denote a condition whereby a stream shows no tendency to aggrade or degrade its channel. A favorable comparison exists between present channel depth and depth of fill in abandoned meanders. Even though this condition exists, the flood plain surface is slowly being aggraded by periodic overbank deposition during flood.

Quaternary History

Before presenting a brief summary of the Quaternary events in the area of study, it is appropriate to list a few of the perennial problems of Pleistocene geology.

1. There is lack of complete understanding as to the origin and development of ice caps.

2. There is lack of agreement concerning the sequence of events in Pleistocene chronology. The disagreements are most numerous regarding detailed chronology of the Wisconsin Stage.

Most of the evidence for glacial chronology is found in a narrow marginal portion of the total glaciated tract. It remains uncertain whether all recognizable events in the marginal areas of Wisconsin glaciation were of equal duration or significance. Some of the minor events of the Wisconsin Stage appear to be of special significance in the geologic history of the Missouri Valley but are only incidental in both time, and area affected, to the whole of the Stage.

3. The actual chronology (in years) of Pleistocene events remains, for the most part, almost wholly unknown. The recent development of C^{14} dating has contributed greatly to the actual dating of events during the last 35,000 years. This interval includes only part of the Wisconsin

Stage but there is lack of agreement on the total length of this Stage and therefore the portion of the whole which falls in the range of the C^{14} technique. The validity of C^{14} dates, especially in more humid areas, has been questioned, Hunt (44). The overall duration of the Pleistocene has recently become even less certain than before (24). The traditional interpretation of gumbotil as being a product of intense weathering, and thus a qualitative measure of the actual ages of the original materials is being questioned by competent authorities (38, 32 and 37). Formerly it was generally believed that the total duration of the Pleistocene was about 1,000,000 years. Recent developments suggest that the total duration may be no more than half this long.

A general subdivision of the Pleistocene is shown in Table 17. The following sequence of events (the pre-terrace geology being most tentative) is suggested for the area of study.

1. In preglacial time the topography and drainage as depicted by Horberg and Anderson (43) probably existed in the area.

2. Nebraskan and Kansan ice sheets transgressed the area and moved to a position where bedrock elevation on the High Plains surface is approximately 1500 feet. The Kansan moved to a position outboard of the Nebraskan (Figure 28), and High Plains drainage was extensively modified at the margin of the glaciated tract. In the course of this study no evidence was found for a Nebraskan drift sheet and the uppermost drift in the area is presumed to be Kansan.

3. In post-Kansan time, possibly before Illinoian, enough drainage had been developed so that the gravels, sands, silts and ash which may

Table 17. Subdivision of Pleistocene epoch

Glacial age	Stadial	Interglacial age
Wisconsin	Mankato Cary Tazewell Iowan	
		Sangamon
Illinoian		
		Yarmouth
Kansan		
		Aftonian
Nebraskan		

represent the Grand Island-Sappa-Pearlette sequence were deposited. The drainage may have developed in a sag reflecting a bedrock low. Whether the present course of the Missouri River had been developed at that time or not, the distribution of the above-mentioned sediment, sometimes without the ash, is along the trend of the present valley and in paleo-valleys extending away from the present valley.

4. The information contained in a number of previously mentioned papers from South Dakota suggests the opinion that the present course of the Missouri River developed in Illinoian time. No direct evidence from this study is available to substantiate or refute the above. In this area all that can be said is that the Missouri is younger than the uppermost drift, assumed to be Kansan. However, the bedrock stratigraphy is essentially the same under the river in northwestern Iowa and southeastern South Dakota but the valley is much wider in Iowa than in South Dakota. There is thus a suggestion that the valley in Iowa may be older than the Illinoian age postulated in South Dakota.

5. The next major event in the area was deposition of the silt which now exists as the upland loess. Borings made in this study suggest that the bedrock floors of the Missouri Valley and of tributary valleys near their mouths were probably on the order of 100 feet higher in elevation than they are at present. The silt was deposited rapidly as evidenced by the lack of significant buried erosion surfaces (unconformities) or vegetational horizons. The gradational contact with underlying alluvial materials (number 3 in this sequence), at least in exposures relatively low in elevation along the bluffs, makes it difficult to ascertain the exact age of these deposits. However, this interpretation does mean that the upland loess adjacent to the Missouri River Valley is more than 22,000 years old.

6. A major erosion cycle was initiated after deposition of the loess (geologic age) or sometime considerably more than 22,000 years ago (actual age). During this time streams cut downward and eroded glacial drift (and any overlying sediment) as well as at least 40 feet of bedrock locally under what is now the terrace. Dissection of the loess was taking place during this time.

7. A change from erosion to deposition occurred about 22,000 years ago as the sediment now underlying the terrace began to be deposited. This alluviation took place rapidly, probably within 3,000 years or less and the streams remained on the former alluvial surface for only a brief period.

8. A cycle of downcutting and erosion followed deposition of the material now underlying the terrace. The bedrock floor under the

present flood plain was again lowered by several tens of feet. The actual age of the start of the downcutting is not known. It lies somewhere between 13,000 and 22,000 years ago. If the time span suggested above of 3,000 years for deposition of the terrace fill is used, then the actual age at commencement of downcutting is about 19,000 years ago. It lasted no longer than 6,000 years and probably closer to 4,000 or 5,000 years.

9. Commencing at least 13,000 years ago and probably no longer than 15,000 years ago, the most recent event, deposition of alluvium, in the modern valley, began.

Two reasons may be postulated for the most recent valley fill; one is that the fill was deposited in response to the last rise in sea level. In the valley of the Lower Mississippi River, Fisk (27) has shown that the rise in sea level during deglaciation caused that river to alluviate. Recently McFarlan (60) has supplemented the geologic evidence for that rise in base level and subsequent valley filling by the use of over 100 radiocarbon dates from the late Quaternary deposits of southern and offshore Louisiana. He proposes a two-stage rise, the last being in the order of 250 feet and commencing about 18,500 years ago. Broecker (3) suggests a drop in sea level between 25,000 and 18,000 years ago followed by a rise which was particularly rapid about 11,000 years ago when an abrupt warming in climate is postulated.

The other possible cause of alluviation is centered closer to the area of study. This is the glacial drift plain (Cary?)[a] which extends to the flood plain of the Missouri River a few miles upstream from Sioux City. The Radiocarbon dates of 12,000 Years Before Present places this drift sheet in a chronologic position to supply alluvial debris.

Engineering

Engineering and geologic properties of materials have been correlated with geomorphic features as displayed on aerial photographs. An interpretation of soil variations can be made by the study of photos. This is of value in selecting terrain elements which will be underlain by finer or coarser materials and in the selection of samples to verify conclusions.

Soil mechanics properties and a discussion of drive samples taken at depth below the flood plain, terrace and upland surfaces have been presented. The following conclusions may be drawn from the data secured in this investigation:

1. Moisture content is the single most important factor affecting the strength of fine-grained material. As a consequence of moisture changes there are corresponding density changes and a resulting variation in strength. Low moisture content correlates with greater density and greater strength.

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[a]Tipton, M. J. South Dakota Geological Survey, Vermillion, South Dakota. Radiocarbon dates in young drift plain around Vermillion. Sample Y-452 dated at 12,330±180 B.P. years from Parker, South Dakota, and sample W-801 dated at 12,200±400 B.P. years from Rosewell, South Dakota. Both dates from the laboratory of the U. S. Geological Survey. Written communication. 1960.

2. Overburden thickness may not be used as a guide to strength with depth unless moisture contents remain very nearly the same.

3. The reliability of correlating penetration resistance (N-value) with soil properties probably increases as the particle-size of the material being investigated increases. This is essentially the same idea advocated by Peck et al. (62, p. 109).

In the deposits with the highest clay contents (present flood plain deposits), the correlations are the poorest. In the terrace and upland silts (with some clay-size material but little sand) the correlations are better but the graphs plotting strength against N-value still show little correlations.

4. The highest unconfined compressive strengths (not including glacial drift) were determined from upland samples, the lowest from flood plain samples. However, moisture content and density must be borne in mind.

5. Two zones of lesser shear strength are present in the upland loess, one in or near the transition zone between the upper and lower units and another at or near the contact with the underlying glacial drift.

6. Comparing in-place density at the outcrop of a thick loess section as reported by Davidson et al. (18) with the density determined from drive samples taken in this investigation, there is a difference of at least 10 per cent. The drive samples show greater density. This difference is in part due to compaction when driving samples (increases density) and unloading at the outcrop (decreases density).

Materials

Several sources of coarse (sand-size and larger) aggregate for road building are possible within the area of study. The local geology and economics will govern profitable exploitation.

1. The most readily available aggregate is that occurring at the surface in the area mapped as channel belt. Above the mouth of the Platte River this material will be dominantly sand, with little gravel. Below the Platte it is slightly coarser, and closer to the surface if used from areas outside the channel belt.

Probably the best use for this aggregate is in granular stabilization in conjunction with the many county roads founded on the fine-grained material in the area mapped as flood basin. An inexpensive sand-clay mix would thus be locally available. The aggregate might also be used to give granular strength to the silt-clay roads in the adjacent loess bluffs.

2. Sand and gravel is present along the base of the bluffs where it is buried by loess of varying thickness.

3. The sand and gravel present under flood plain and terrace surfaces in tributary valleys presents a possible new source for coarse aggregate.

4. Stabilization techniques, outside of granular stabilization, should be concerned primarily with maintaining and improving the inherent cohesive strength of the fine-grained soils which are predominant over the flood plain.

SUGGESTIONS FOR FURTHER STUDY

As mentioned previously, some problems have arisen in attempting to rationalize or correlate the findings of this investigation with other Quaternary events in the area. Very likely this is simply a consequence of past authors relating other events in the area to the history of rivers and their valleys without understanding river and valley history. Up to this time little work has been done on major streams and valleys within the glaciated tract -- their history was assumed when being related to other events. Considering the present state of knowledge on Pleistocene geology, it certainly is likely that as more parameters are investigated some of the relationships and concepts concerning the geology will have to be modified or discarded.

Silt

The silt deposits adjacent to the alluvial valley will be discussed in the light of information gathered during this investigation.

Origin of deposits

1. The silt deposits below the terrace and upland surfaces in the area of study, as in most of central United States, are described as being of a wind-deposited origin. It is common practice to state, or imply, that the silt was derived from "the flood plains of braided streams" (80, p. 442).

In the mapping of the present flood plain of the Missouri, one of the widest within the glaciated tract, there is no evidence to suggest that a braided stream ever occupied the valley. Indeed, the present thickness of alluvium below the flood plain is not great enough to accommodate a braided stream. Leopold and Wolman (56, p. 59) have plotted channel slope against discharge for a variety of natural channels; using conservative figures the slope of the Missouri River would be at least three times the present slope if in a braided condition. Using the present flood plain elevation at Hamburg, such a slope would put the channel elevation above the loess bluffs at Sioux City. If the braided channel were flowing on bedrock at Hamburg, the channel at Sioux City would be 140 feet above the modern flood plain.

2. Several specific problems have arisen concerning the origin and age of the terrace silts as contrasted to the upland silt or loess.

(a) The nature and degree of dissection has been in the past, a valuable and diagnostic geomorphic tool in determining the geologic or relative age of landscapes. The degree and type of dissection has in fact been used to differentiate the relative age of the different Pleistocene drift sheets. Logically, the older landscape shows a greater dissection and a better integrated drainage system. This geomorphic approach has been used as one line of evidence to show that the terrace silt is younger than the upland silt. Yet, previous workers have said (13) that the silt under both landscapes is the same age and the modern soils are similar. The alternative is to assume that recent dissection (at least as seen in the upland loess) has not developed the landscape as it appears today, but that the silt mantles an underlying much-dissected topography. Then, why was not the landscape under the terrace silt also eroded along with the landscape underlying the upland silt or loess? If the gravel and sand under the terrace silt is younger than the pre-loess dissection assumed in the uplands, where is the topstratum or fine material that would have been deposited above the substratum sand and gravels?

The similarity of soils on both landscapes might be explained simply by the amount of dissection each landscape has undergone since deposition of the respective materials. Less erosion on the younger terrace surface might, in effect, let that soil attain profile development similar to the soil on the steeper, continuously eroded, upland slopes.

(b) The material underlying the terrace and upland silt is different except locally where gravel and sand underly upland loess in some exposures in the valley walls. The upland loess is usually underlain by glacial till, whereas no till was penetrated in any terrace boring.

(c) A consideration of the thickness of silt under the different geomorphic surfaces raises serious doubt that the two deposits could be the same age. For example, approximately 50 feet of fine-grained topstratum that might be considered loess underlies the terrace at the mouth of the Nishnabotna River. This surface is relatively flat and has undergone little erosion or lowering since deposition ceased. Its surface features are still primarily those of a depositional surface. Less than 3 miles south of this terrace a boring in the upland on a ridge bordered by extremely dissected terrain penetrated over 180 feet of loess. Both these landscapes are immediately adjacent to the Missouri River flood plain. This same relationship is present, although not to the same degree, in other borings which penetrated topstratum under the terrace and upland loess at about the same latitude. It is unlikely that these relationships could prevail if both deposits are of eolian origin and the bulk of the material the same age.

(d) The buried bedrock scarps descending from beneath the upland, terrace and flood plain surfaces coupled with the upstream slope of the terrace and the paleo-stream features on its surface all suggest a younger age for the terrace silt. However, further study could delineate the unconformity which must exist at the outer margin of the terrace where topstratum below the terrace lies adjacent to upland loess. Bore holes would have to be closely spaced and even then the similarity of material plus the complications caused by alluvial fans and post-depositional movement will make this task difficult.

3. Very serious problems arise in attempting to work out a logical sequence of events if one attempts to correlate the geologic evidence and radiocarbon dates presented in this report with the chronology developed by other workers.

For example, Ruhe and Scholtes (67, p. 269) state that the upper

60 to 65 per cent of the Wisconsin loess in southwestern Iowa must be of Tazewell age and that the Missouri River Valley was a source for this wind-blown silt. Ruhe et al. (68) suggest that Tazewell loess deposition took place about 15,000 to 17,000 years ago. Using this interpretation, eolian silt of the same age would underlie both the upland and terrace surfaces. If silt is being blown from the flood plain of the Missouri River, then how can the 75 foot scarp between the level-topped terrace and flood plain be explained? Data from this report indicate that the terrace is a former alluvial surface and that the relief between terrace and flood plain was produced by erosion as the river down-cut sometime prior to 15,000 years ago but not more than 22,000 years ago.

From this study it has been shown that at least 50 to 75 feet of topstratum underneath the terrace surface was deposited after 22,000 years ago and that about 50 feet of recent alluvium has been deposited since 13,000 years ago. Furthermore, the present surface of the alluvial plain has been alluviated up to and above the base of the silt under the terrace surface.

The finer-grained topstratum that could conceivably have been a source for wind-blown silts was not being actively deposited by the river until at least 13,000 years ago. Between 13,000 and 15,000 years ago the alluvial plain was several tens of feet lower than it is today and the river, although it may have just begun to actively alluviate the coarser-grained substratum, was certainly transporting the finer-grained sediments. If silt were being removed from a substratum source, where are the sand dunes that would be expected to occur along the valley walls?

Furthermore, the terrace, which would make a fine source for wind-blown silt, has not been deflated by wind erosion since it was abandoned as a flood plain. That is, depositional lows are still present on the surface, and certainly if winds were removing great quantities of silt from this surface, silt would be at least drifted into the lows or pocks. The topographic low which exists on the upland margin of the terrace along the Missouri River on the west side would not be expected if there had been any predominant silt-carrying winds from the west.

Ruhe and Scholtes (67, p. 269) likewise state that the thinning of the loess (wind-blown) in northwest Iowa can be accounted for by generally westerly winds removing sediment from a major source, the west-east trending Missouri River Valley between Nebraska and South Dakota, and distributing the sediment in a broad fan-shaped pattern to the east. Borings in the Floyd River terrace in northwest Iowa show the terrace silt existing as a wedge rapidly thinning upstream and underlying a surface controlled by the level of a former stream. It is also difficult to presume that the sand unit present in the upland loess high on the landscape 20 miles east of Sioux City was blown there from the Missouri River flood plain.

4. The cause of some of the problems in correlation may lie in the fact that there has been a lot of silt deposited in Iowa and it is not all of the same age nor is it all related to the Missouri River. This fact may help in future studies. Two examples of the above are cited herein:

(a) In central Iowa ($NW\frac{1}{4}$, $NW\frac{1}{4}$, $NW\frac{1}{4}$, Sec. 32, T84N, R24W, Story County) a spruce log procured from near the top of a silt deposit at least 60 feet thick[a] exposed in the east valley wall of Onion Creek and overlain by glacial drift, yielded a radiocarbon date of 10, 175 ± 250 Years Before Present.

(b) West of the above-mentioned locality but still within the mapped late Wisconsin drift area, a wood sample from near the top of a laminated silt section in the east valley wall of the Raccoon River yielded a date of $14{,}500\pm375$ Years Before Present. This silt deposit (approximately 17 feet thick) is located in $SW\frac{1}{4}$, Sec. 33, T84N, R31W, Greene County, Iowa, and is underlain and overlain by glacial drift. The above date is in excellent agreement with a date ($14{,}470\pm400$ Years Before Present) reported from the alluvial silt at this location by Ruhe et al. (68, p. 681).

5. Another problem in correlation concerns the time during which the present bedrock gorge was cut. Investigations in South Dakota suggest that the valley was developed to its present dimensions in Illinoian and Sangamon time. Jorgenson (46, p. 9) states that possibly Illinoian as well as Iowan, Tazewell and Cary outwash underlie the alluvium in the Missouri River Valley above Sioux City. Evidence from this study suggests that the floor was cut during at least two stages and that most of the dissection took place after deposition of the upland loess. It

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[a]Roy, C. J. Data on silt deposits as determined by borings along Onion Creek, Story County, Iowa. Private communication. 1961.

is likely that the debris described (46) as outwash in South Dakota is the substratum of this investigation.

6. Some aspects of the upland loess to be borne in mind by future investigations are as follows:

(a) Width of the present Missouri River flood plain apparently *has no relationship to the thickness* of the loess in the upland; the thickest loess penetrated was adjacent to a relatively narrow portion of the flood plain below the mouth of the Platte River.

(b) The bedrock floor under the present flood plain may have been on the order of 100 feet higher when the upland loess was deposited.

(c) Regionally the gross aspects of the loess raises problems. Its nearly equal distribution on both sides of the Missouri River Valley, the fact that its surface is at about the same elevation on both sides of the valley and the existence of an undissected terrace underlain by silt, especially along the west side of the valley, must be clearly recognized and explained in any theory on the genesis of the material.

In regard to the regional slope in western Iowa, topographic profiles (two are shown on Plate 53) show that elevations are highest along the divide adjacent to the Wisconsin glacial tract and that the slope is southwestward, toward the Missouri River. Using loess thickness contours from the Pleistocene Eolian Map of the United States[a] (they are also available from a number of

[a]Geological Society of America. 1952.

other sources), it is found that the thickest loess deposits lie adjacent to the Missouri River Valley, in highly dissected topography, and with sub-accordant ridges at or below the elevations eastward from the valley. Thus, the time-honored idea that the loess deposits adjacent to the Missouri River attain their greatest thickness and highest elevation near the bluff line and then thin as the surface decreases in elevation away from the valley must be dispelled.

In fact, the regional slope of the loess surface is slightly upward away from the river, and the thickness of this upland silt decreases as the underlying material increases in elevation away from the river. Locally the thickness and slopes vary due to erosion.

7. The exact cause for the alluviation which emplaced the material under the terrace is not known. Quite possibly it is related to the advance of a mid-continent ice sheet between 25,000 and 18,000 years ago. Close to the area of study (NW$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 25, T92N, R40W, Cherokee County, Iowa) date of 20,000$\pm$800 Years Before Present (Tazewell ?) from a wood sample removed from glacial till exposed in the east valley wall of the Little Sioux River may record this advance.

Whatever the ultimate controlling force, certainly the concept of alluvial drowning fits the known relationships. That is, a rapid rise of base level in the area either by eustatic change in sea level or some local phenomena related to glacial wastage would cause a decrease in stream gradient and deposition of coarse material first and then that of the fine-grained sediment. Longitudinal profiles in several tributary valleys show that the topstratum exists as a wedge decreasing in thickness upstream, suggesting that the alluviation began near the valley mouth and progressed upstream. As the Missouri aggraded so did the tributary streams and the gradients were reduced first near the confluence and then upstream. When silt was being deposited near the mouth, sand and gravel was being deposited upstream.

It is well to remember here that the contact between the substratum and topstratum in the sediment under the terrace is considered to be fairly sharp or transitional through only a few feet. As in the recent alluvium, once sands are penetrated in a boring it is likely that the remainder of the material penetrated will become coarser with depth. The wood samples recovered from the terrace borings also occurred at about the same stratigraphic interval as that retrieved from the flood plain borings. No significant amounts of wood were recovered in the upper portion of the topstratum.

8. Basal relationships of the loess as observed in exposures adjacent to the Missouri River flood plain suggest that either the loess is an upper unit of the alluvial deposits below it or that, if these basal units are appreciably older, that there has been an alluvial reworking of this material along with deposition of at least the lower loess or silt. Considering the history since deposition of the loess and the regional aspects of this deposit, it seems likely that at least 100 feet of silt could have been deposited in the area by alluviation. With a source of silt available, other areas could be

covered by varying thicknesses of eolian silt. The eolian hypothesis for covering large areas with a relatively thin cover of silt has merit only if there is a source. If future work in the area can determine the amount of possible regional tilting due to isostatic adjustment and rebound from glacial loading as well as details of possible topographic inversion, the overall picture will undoubtedly become much clearer.

One of the bigger problems will be to determine exactly when and why the bulk of the loess was deposited. Iowan glaciation may be intimately related to this problem.

9. Last, but not least, the commonly accepted definition of the word "loess" leads to confusion. As with other rock names, the word loess should be used to designate a material with particular physical characteristics. Certainly as long as controversy exists as to the origin of the material, the name should not have a genetic connotation.

Diagenesis

Observations concerning large scale physical changes and some analytical data suggesting possible chemical changes since deposition indicate a need for additional work, particularly on the upland loess.

Structure. Observations made in recent artificial exposures and in the drive samples taken at depth show that there is a primary structure (laminae) in the silt. It is more clearly shown in the terrace silt. Considering the positive evidence for post-depositional movement, particularly of the upland loess, it is suggested that most of the silt was laminated at one time but that some of the structure has been destroyed by downslope movement as well as by downward movement of water through the permeable silts. Downslope movement may also help to explain why the loess appears to blanket the underlying topography. Where the lower silt contains only occasional sand and gravel particles not arranged in definite lenses or layers, it is likely that these were incorporated during downslope movement.

Carbonate. The low carbonate content at depth in the loess suggests that either the loess was deposited without carbonate or that there has been a movement and recrystallization of carbonate material toward a surface. In either case, a type of caliche phenomenon is suspected. Certainly the decrease in carbonate with depth rules out any major leaching and reprecipitation at depth. Handy and Davidson (39, p. 475) may have been the first to recognize the quantitative difficulties in the hypothesis for downward movement of carbonate and precipitation above an underlying clay zone. They suggest the possibility of general upward and/or downward carbonate movement. Recently Lohnes (57) has reported the occurrence of large carbonate concretions lying in horizontal zones sometimes above sand units near the base of the thick loess adjacent to the Missouri River flood plain in western Iowa. He suggests a penecontemporaneous origin and a mechanism of ion migration without appreciable water movement.

Clays. The petrography of clay-size material retrieved from the loess suggests that authigenic montmorillonite or at least a more well-ordered montmorillonite nearer the surface is being made from less-ordered material at greater depth.

The above-mentioned problems at least suggest that the loess may be quite different from the way it was originally deposited. Nearly 20 years ago Russell (73) grouped similar diagenetic alterations under the term of loessification.

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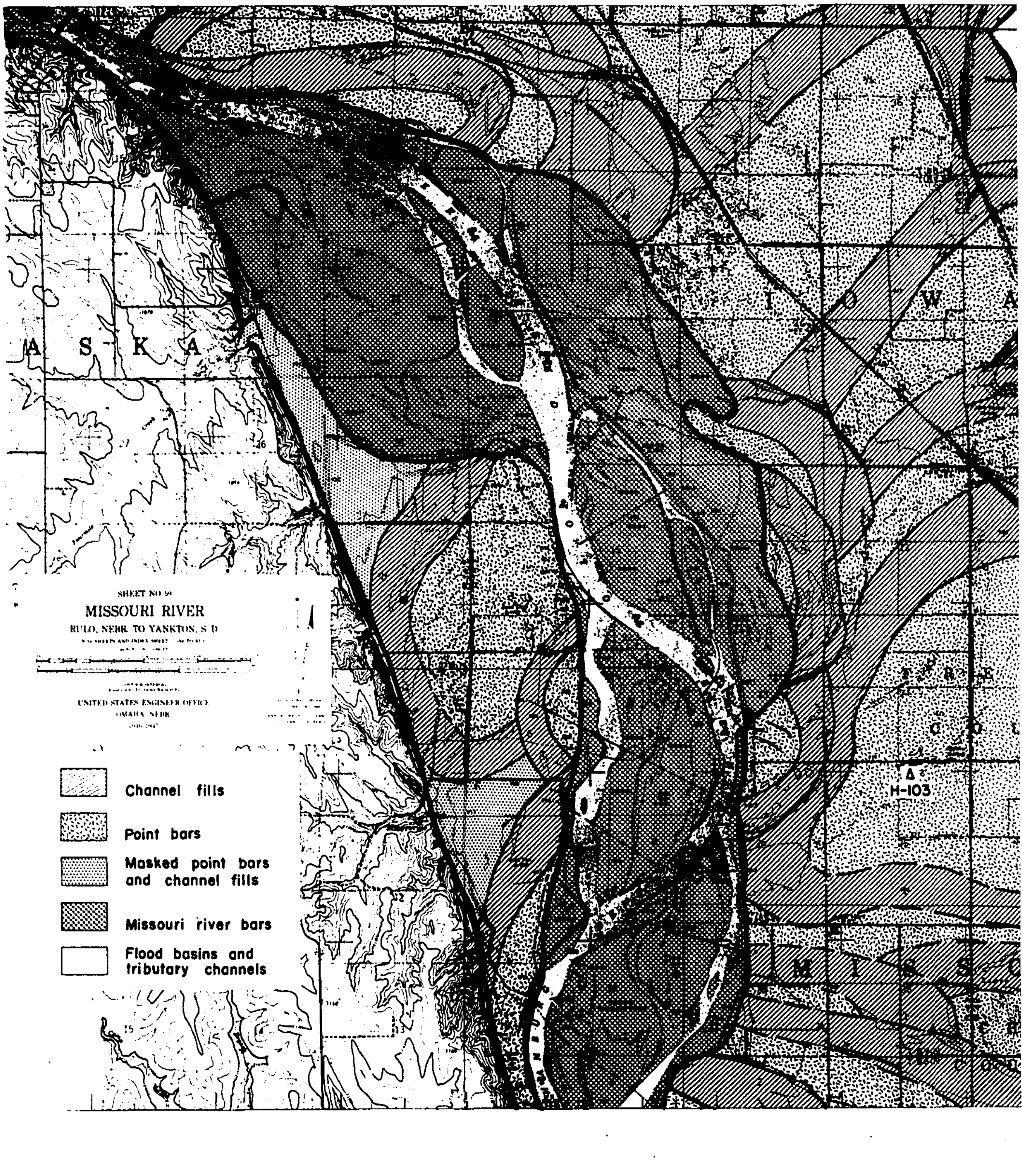
Sincere appreciation is given to all members of the Geology Department and Engineering Experiment Station staff for their help throughout the course of this study.

APPENDIX

Plate 1. Alluvial geology, Maps 59 and 59L


A S K A
I O W A
SHEET NO. 50
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
H-103
M I S S O

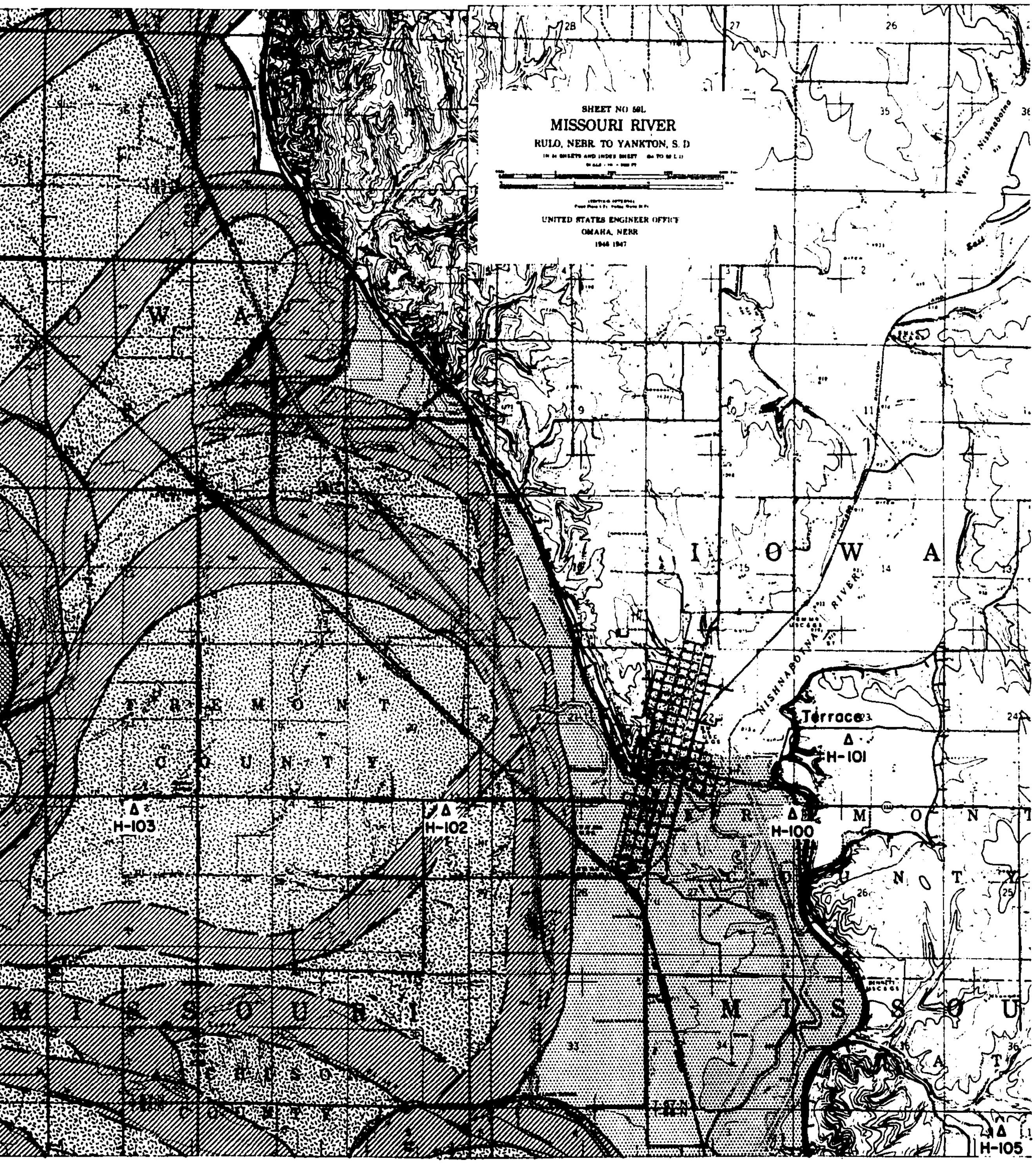
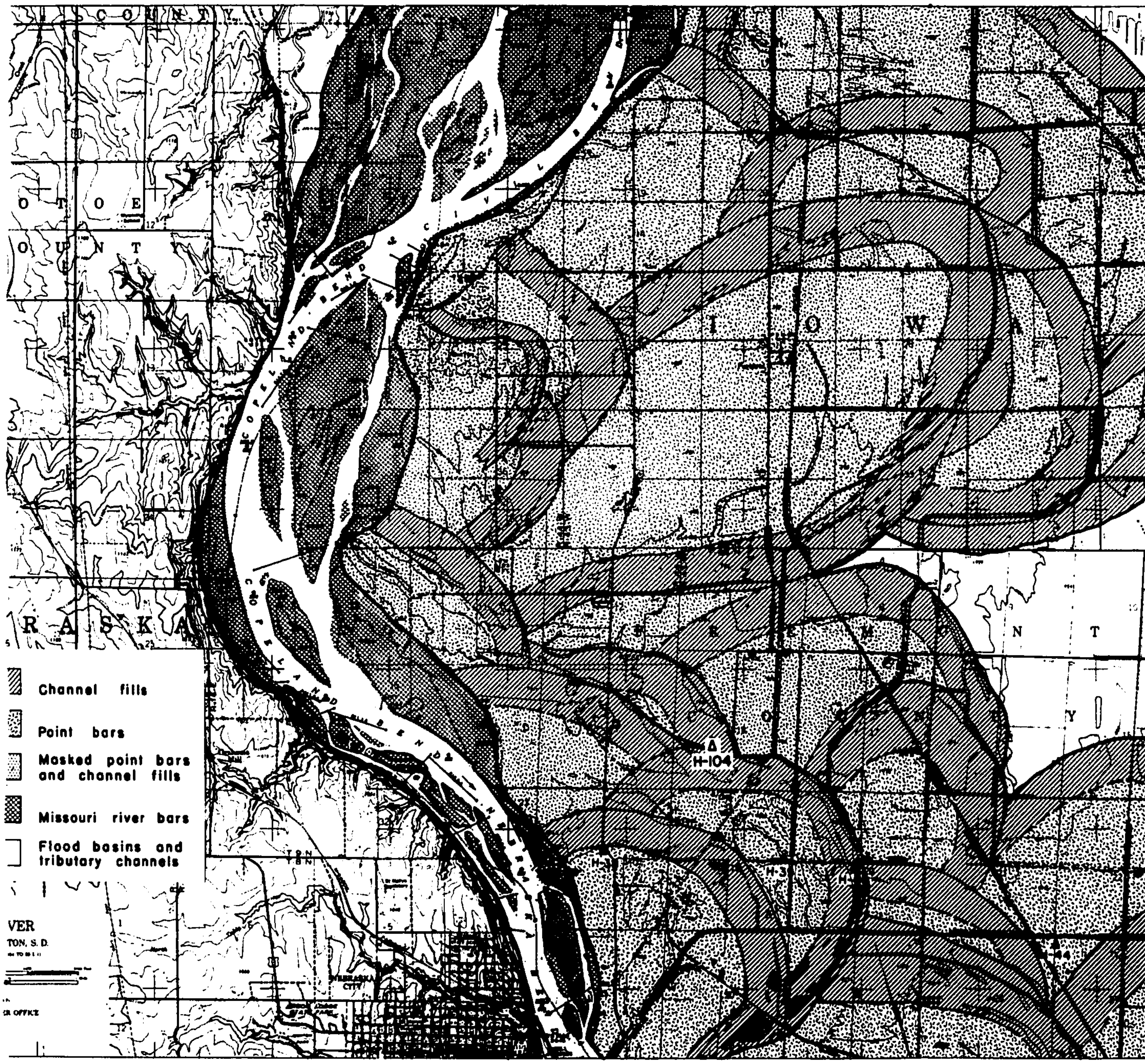
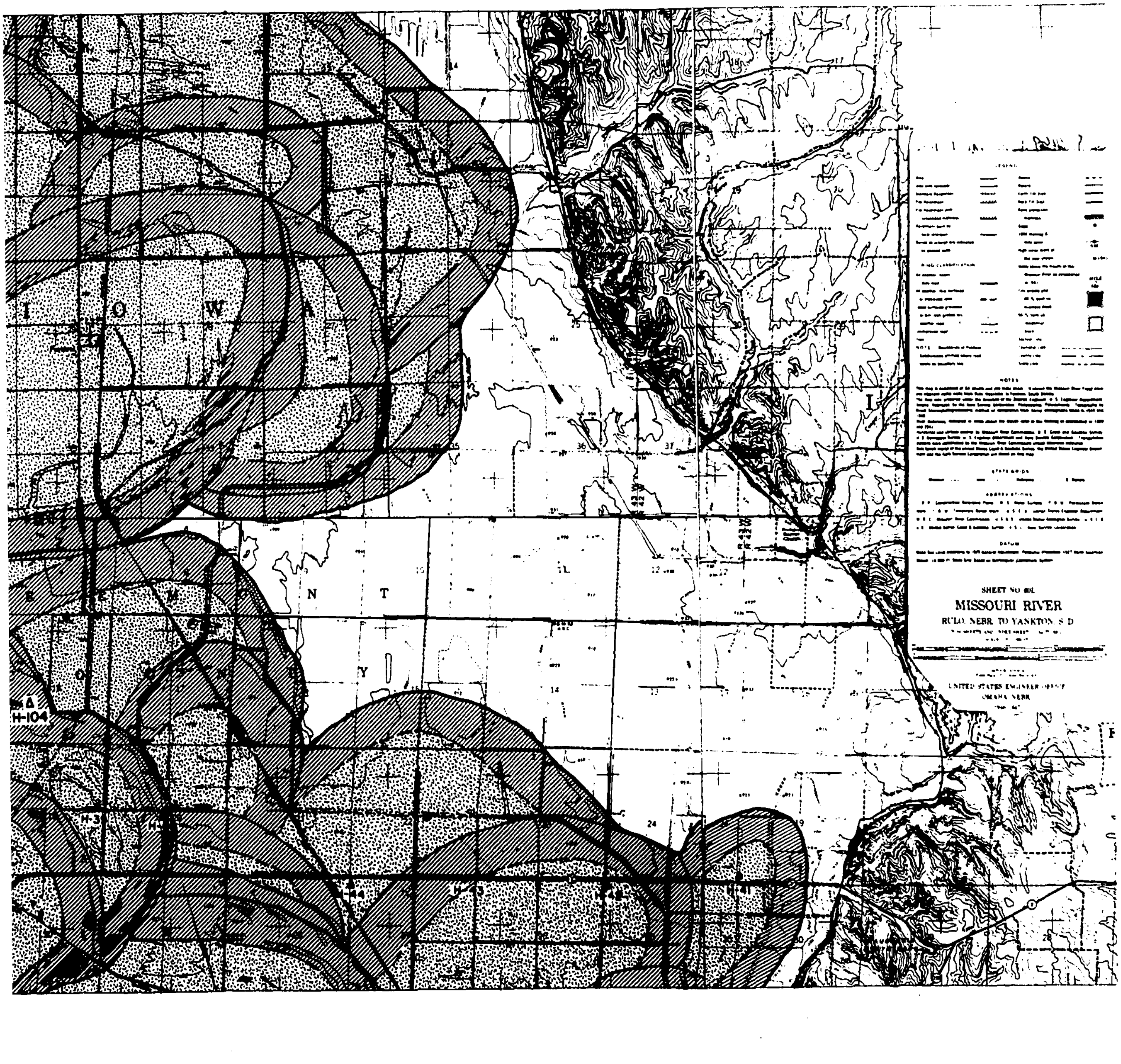

SHEET NO 59L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR
1946 1947
IOWA
FREMONT COUNTY
MISSOURI
NISHNABOTNA RIVER
Terrace
H-100
H-101
H-102
H-103
H-105

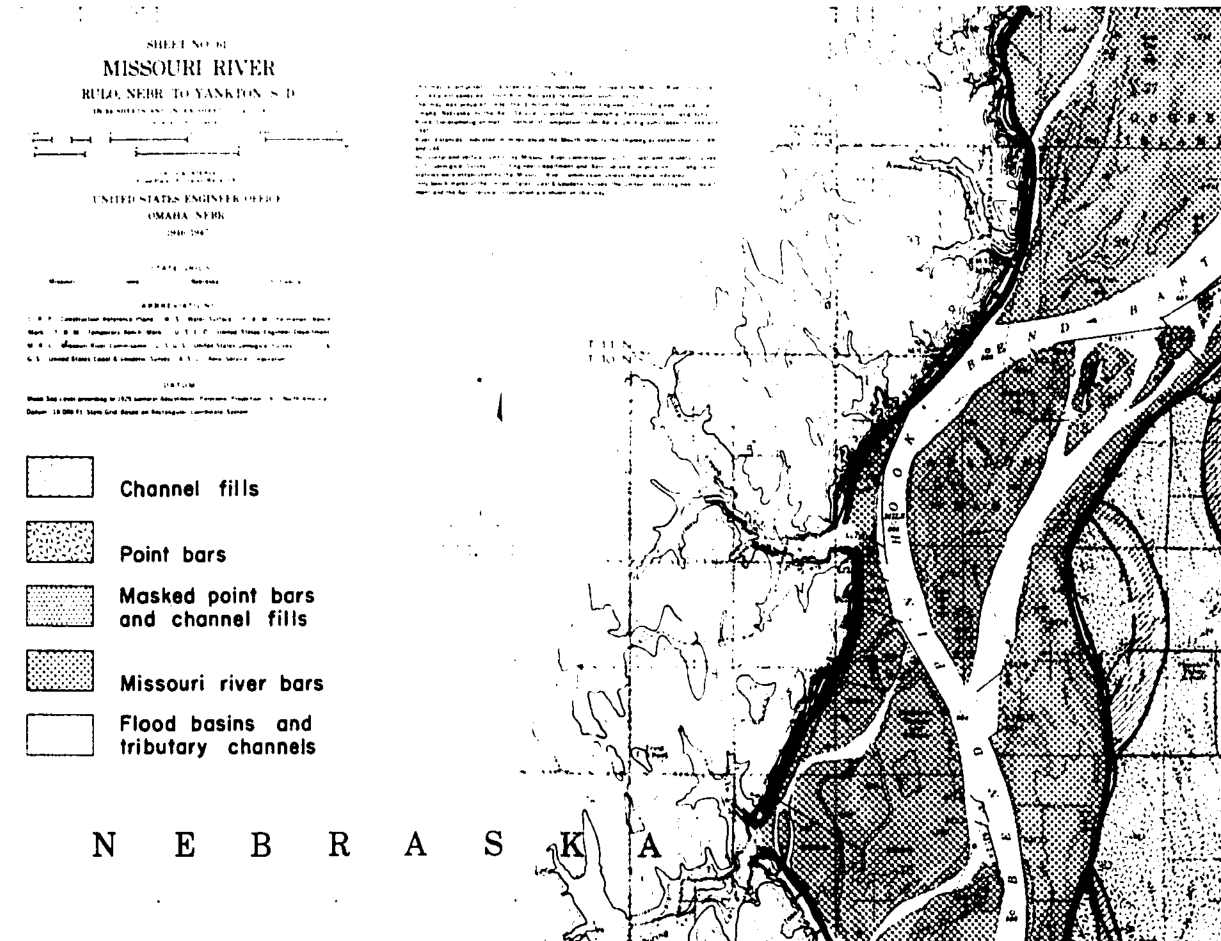
Plate 2. Alluvial geology, Maps 60 and 60L

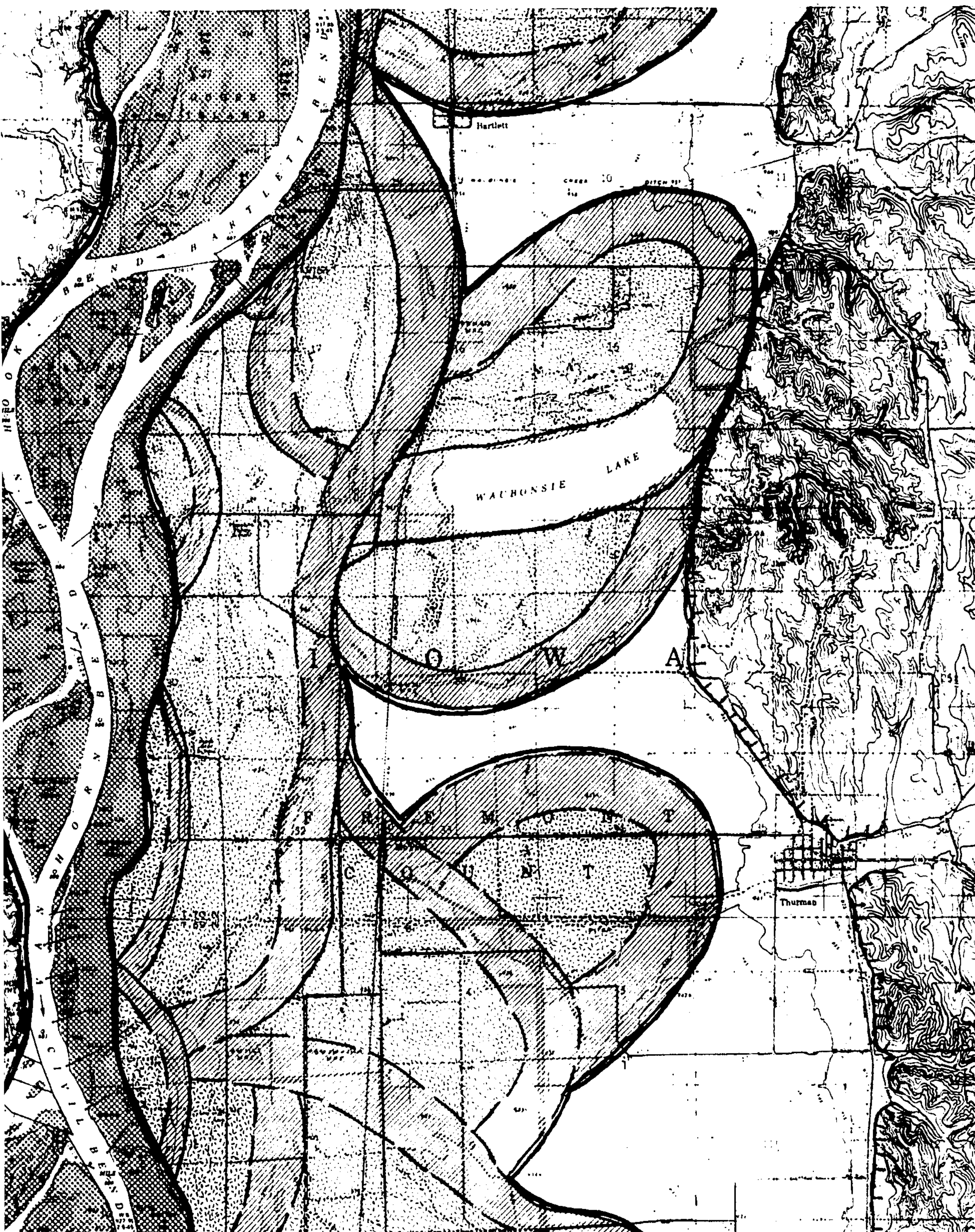

Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
O T O E
C O U N T Y
R A S K A
I O W
N T
H-104
COPELAND BEND
NEBRASKA CITY



SHEET NO. 60L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S.D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
IOWA
H-104

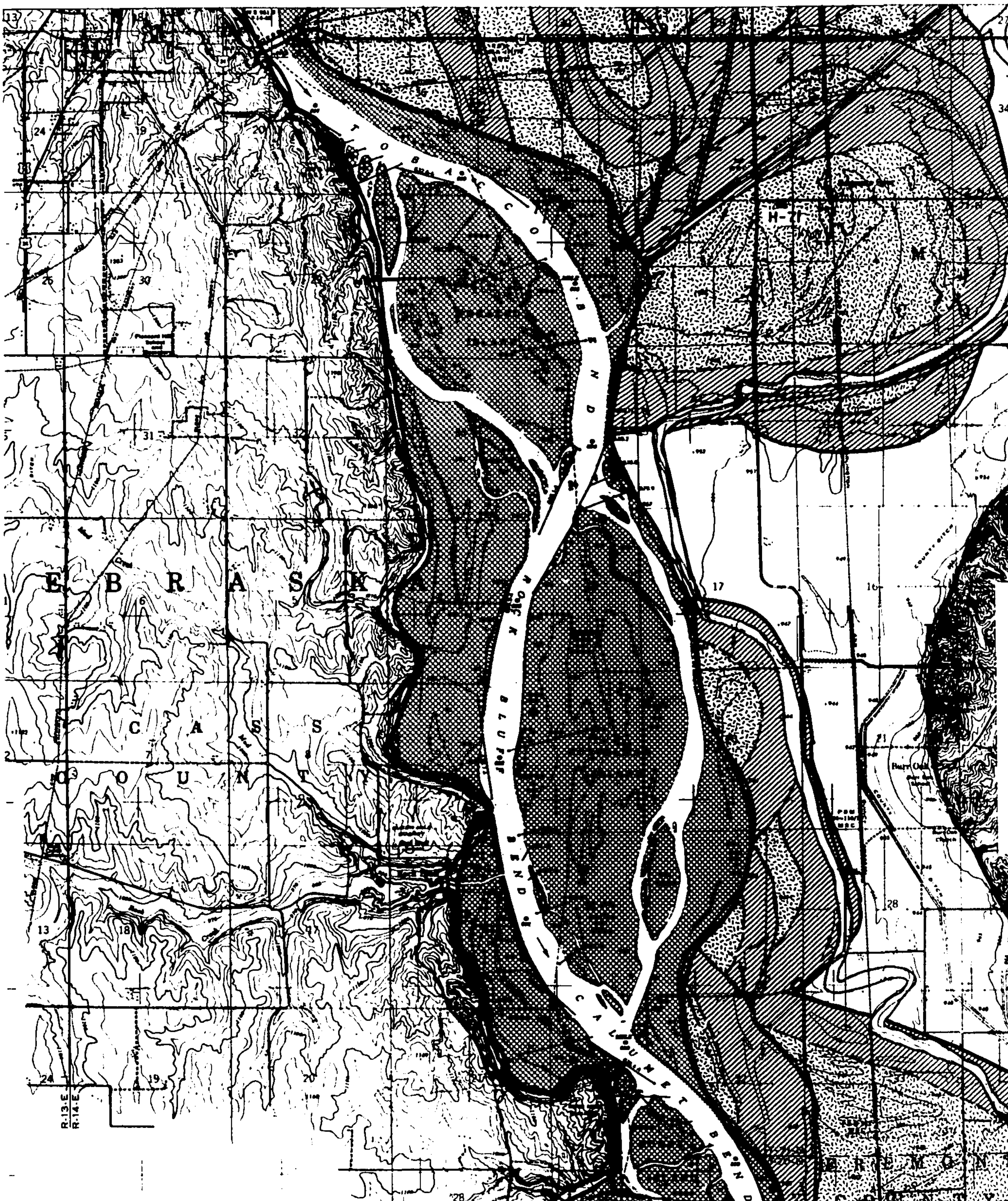
Plate 3. Alluvial geology, Map 61

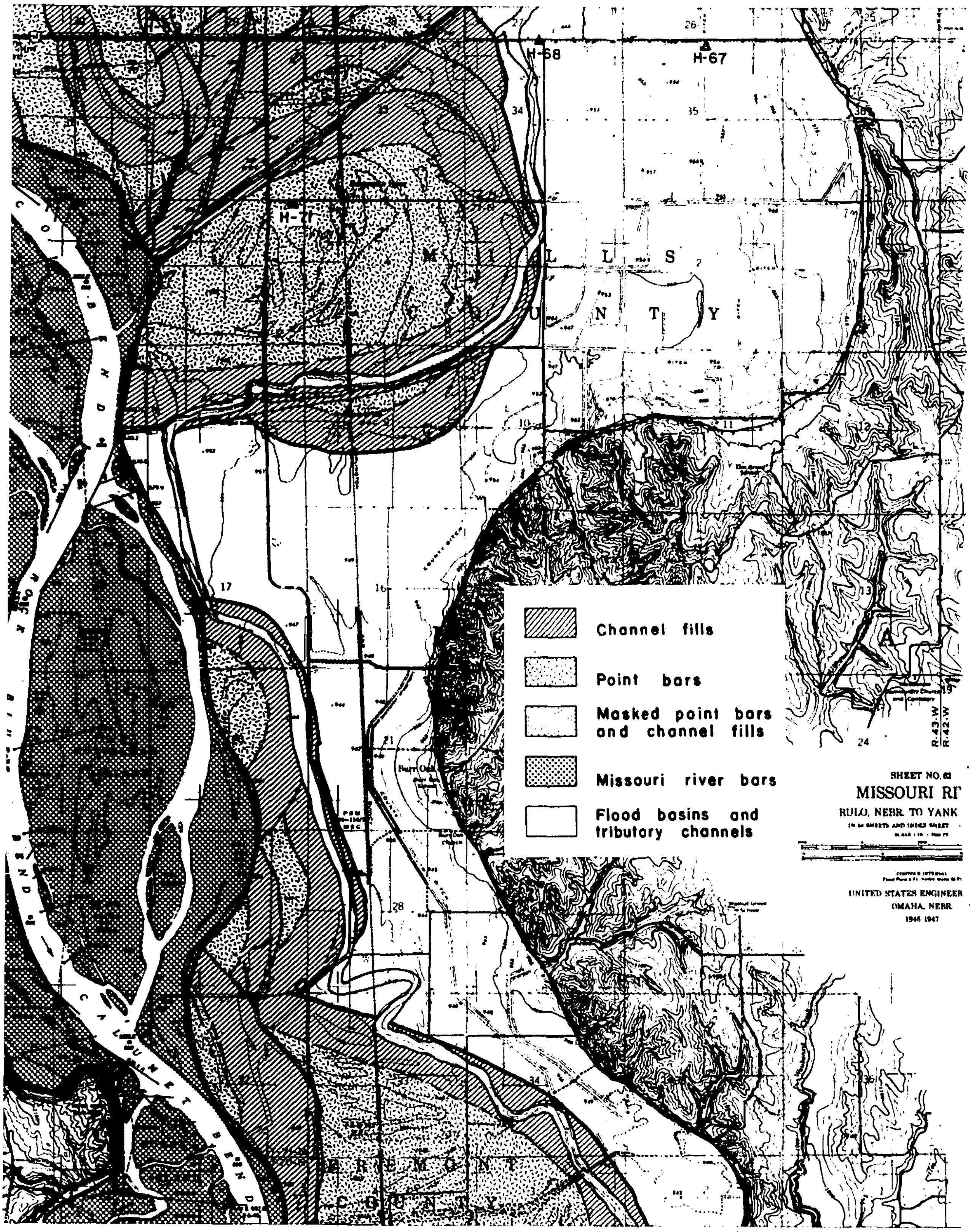

MISSOURI RIVER
UNITED STATES ENGINEER OFFICE
OMAHA NEBR
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
N E B R A S K A
C A S S
C O U N T Y
Union
W E E P I N G W A T E R
B O T T O M



Bartlett
WAUBONSIE LAKE
I O W A
FREMONT
COUNTY
Thurman

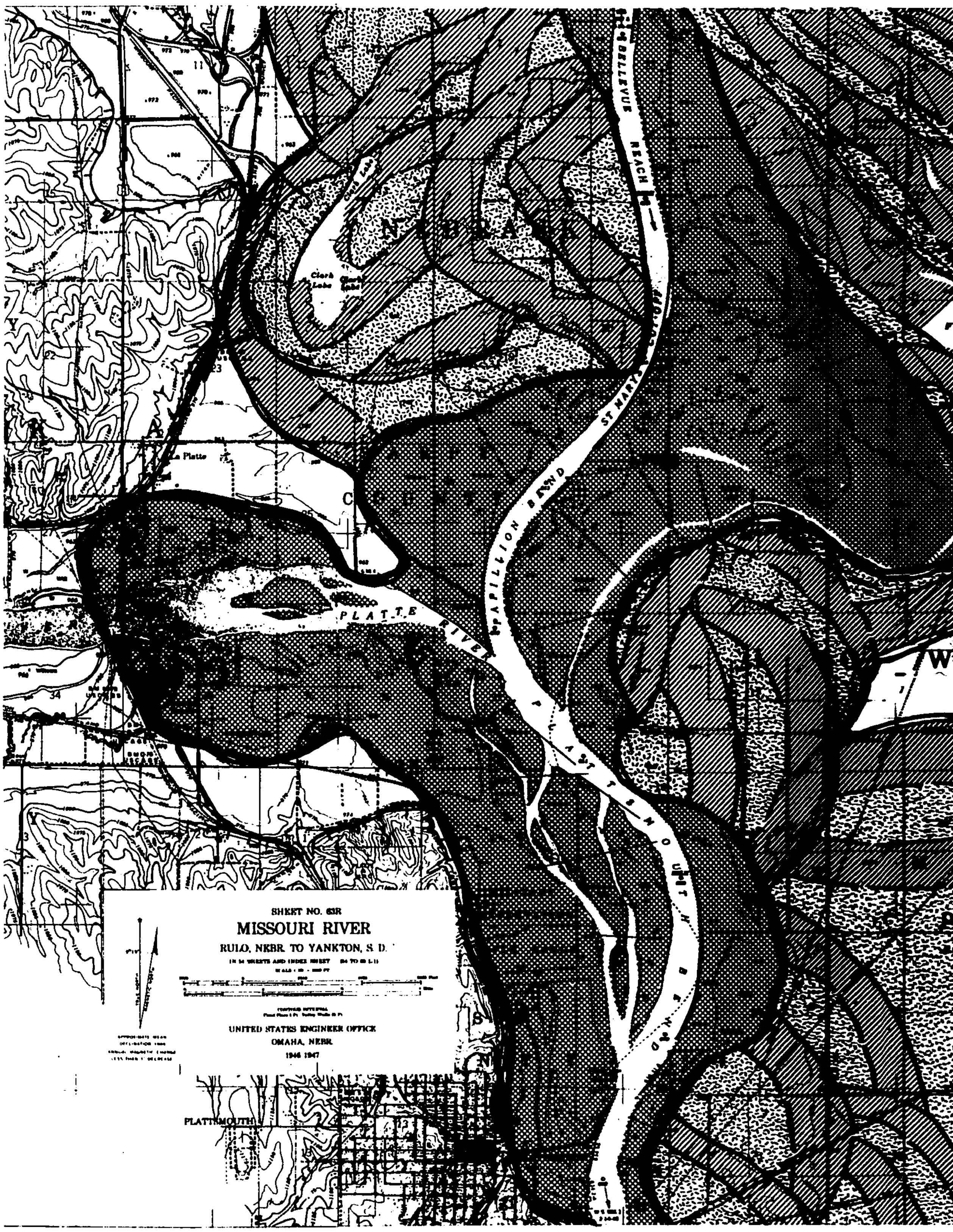
Plate 4. Alluvial geology, Map 62


E B R A S K
C A S S
C O U N T
ROCK BLUFF BEND
R.13.E
R.14.E



Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributory channels
SHEET NO. 62
MISSOURI RI
RULO, NEBR. TO YANK
UNITED STATES ENGINEER
OMAHA, NEBR.
1946 1947
H-68
H-67
H-71
M I L L S
C O U N T Y
F R E M O N T
C O U N T Y
R-43-W
R-42-W

Plate 5. Alluvial geology, Maps 63R and 63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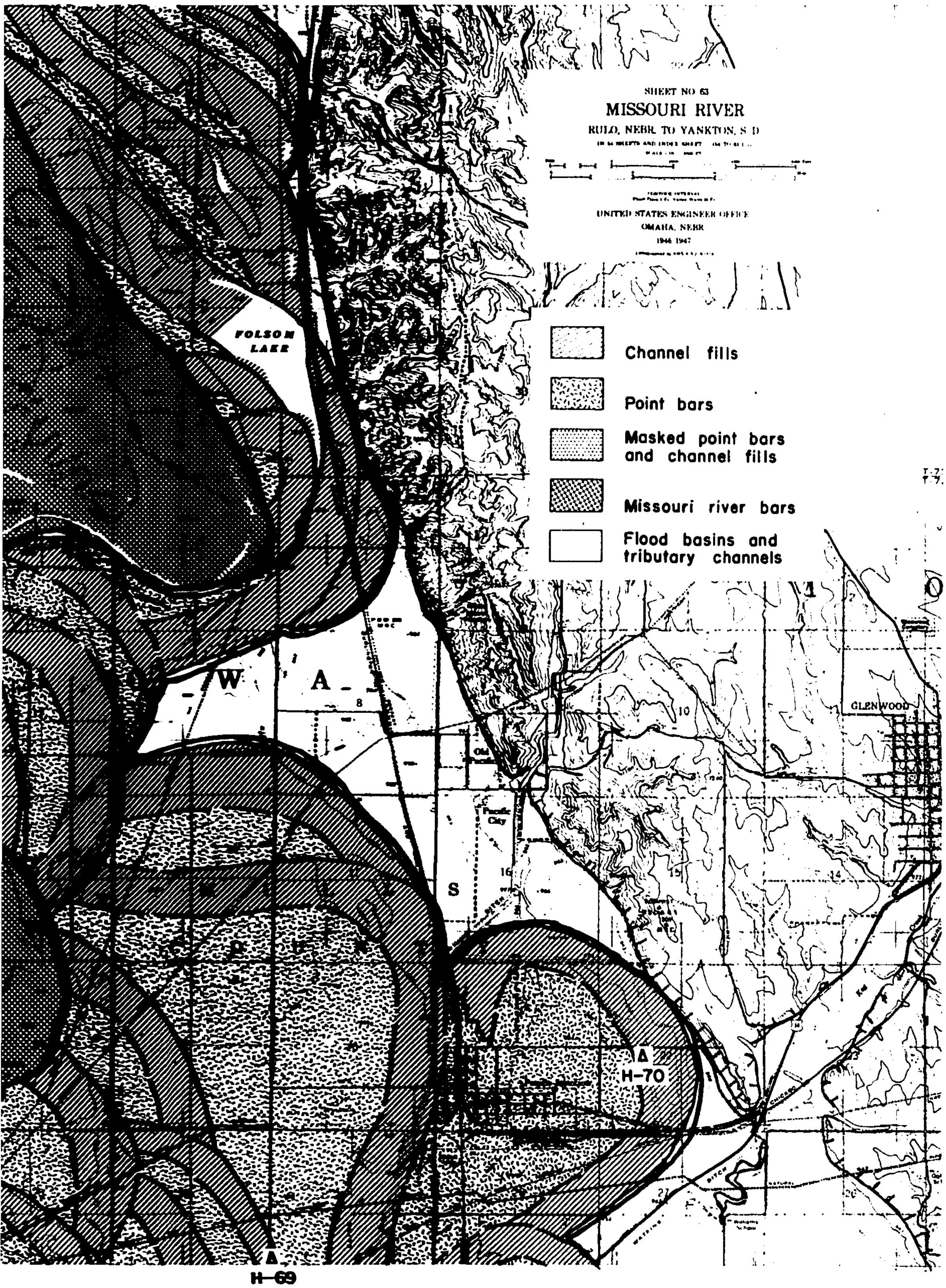
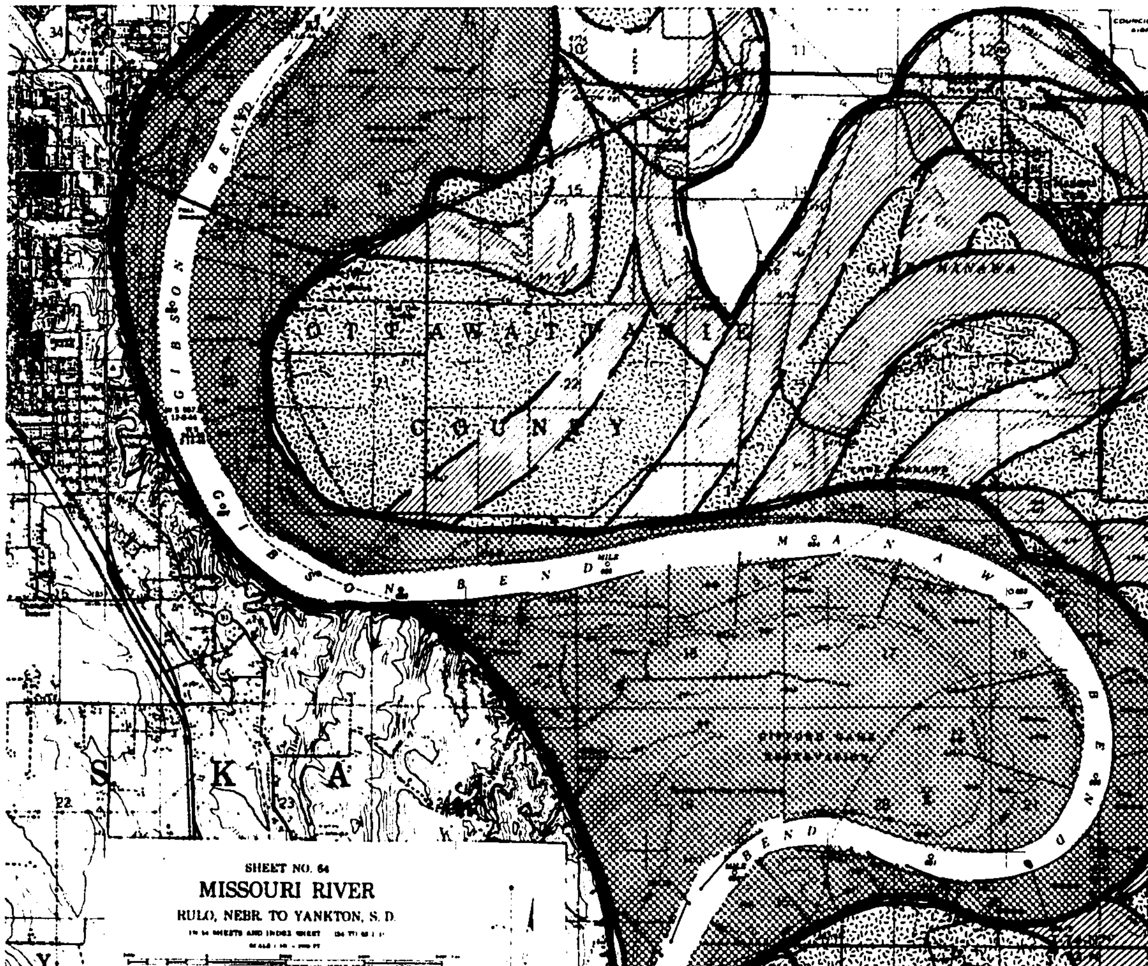
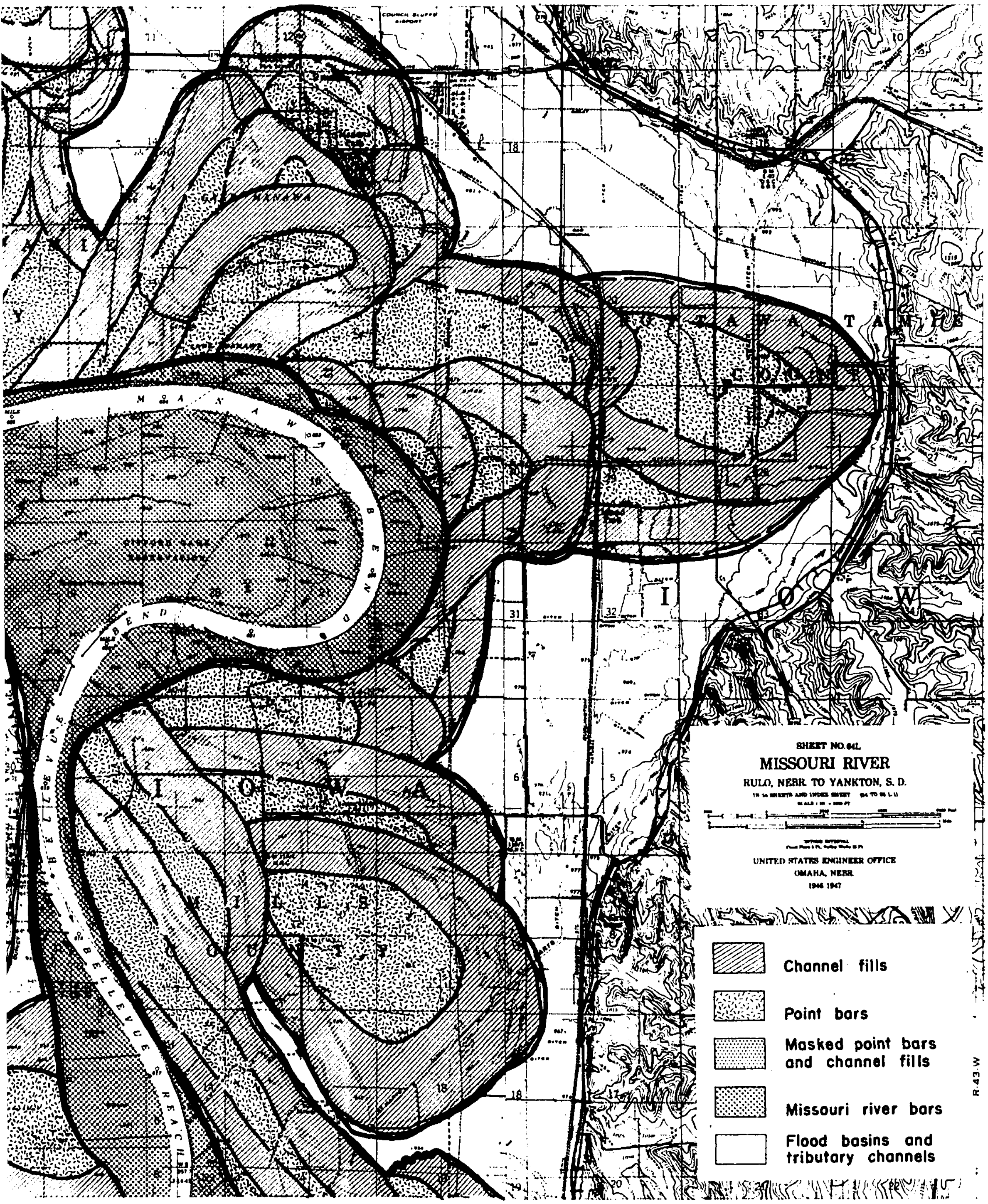
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
PLATTSMOUTH
PLATTE RIVER
PAPILLION BEND
ST. MARYS
BELLEVUE REACH
PLATTSMOUTH BEND
Clark Lake



SHEET NO 63
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
FOLSOM LAKE
W A
S
GLENWOOD
Pacific City
H-70
H-69

Plate 6. Alluvial geology, Maps 64 and 64L

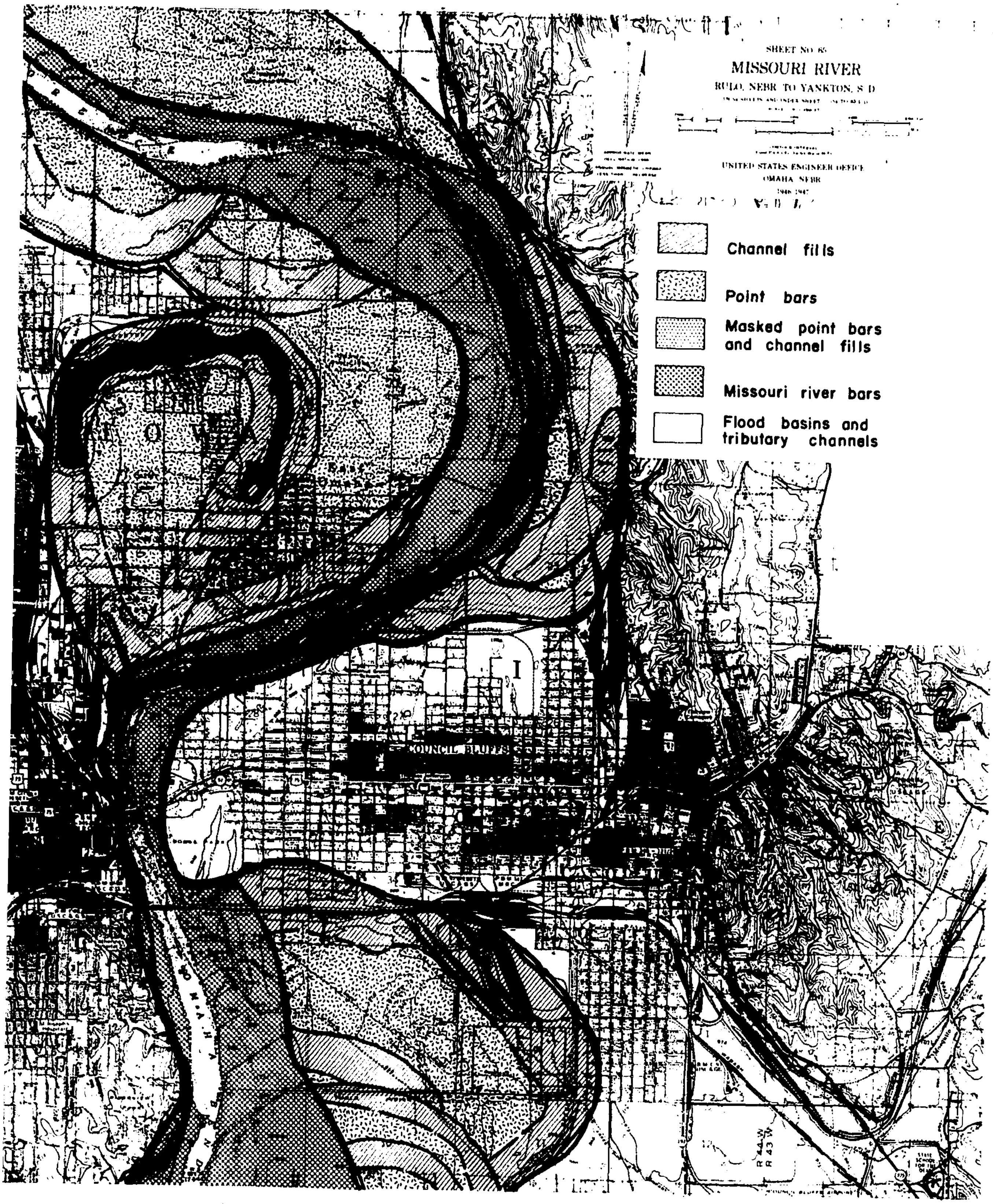

SHEET NO. 64
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
Low Terrace
Bellevue
OFFUTT FIELD
Junction
GIBSON BEND
MANAWA BEND
BELLEVUE REACH
BELLEVUE BEND
POTTAWATTAMIE
COUNTY
MILLS
COUNTY
IOWA



SHEET NO. 64L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
I O W A
M O N A W A
BELLEVUE BEND
BELLEVUE REACH
R. 43 W.

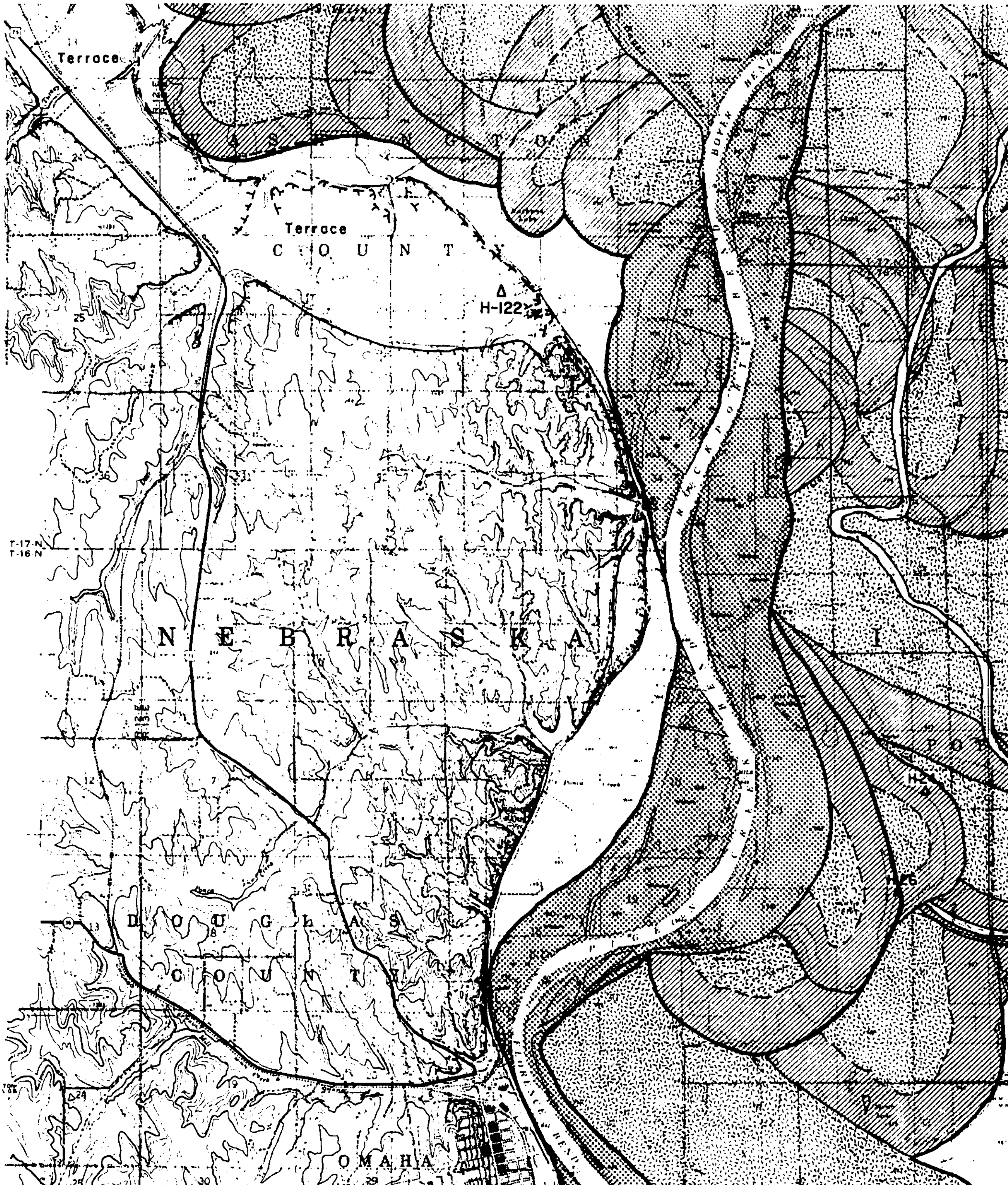
Plate 7. Alluvial geology, Map 65


OMAHA



SHEET NO. 65
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
COUNCIL BLUFFS

Plate 8. Alluvial geology, Map 66


Terrace
Terrace
C O U N T Y
H-122
T-17-N
T-16-N
N E B R A S K A
D O U G L A S
C O U N T Y
O M A H A

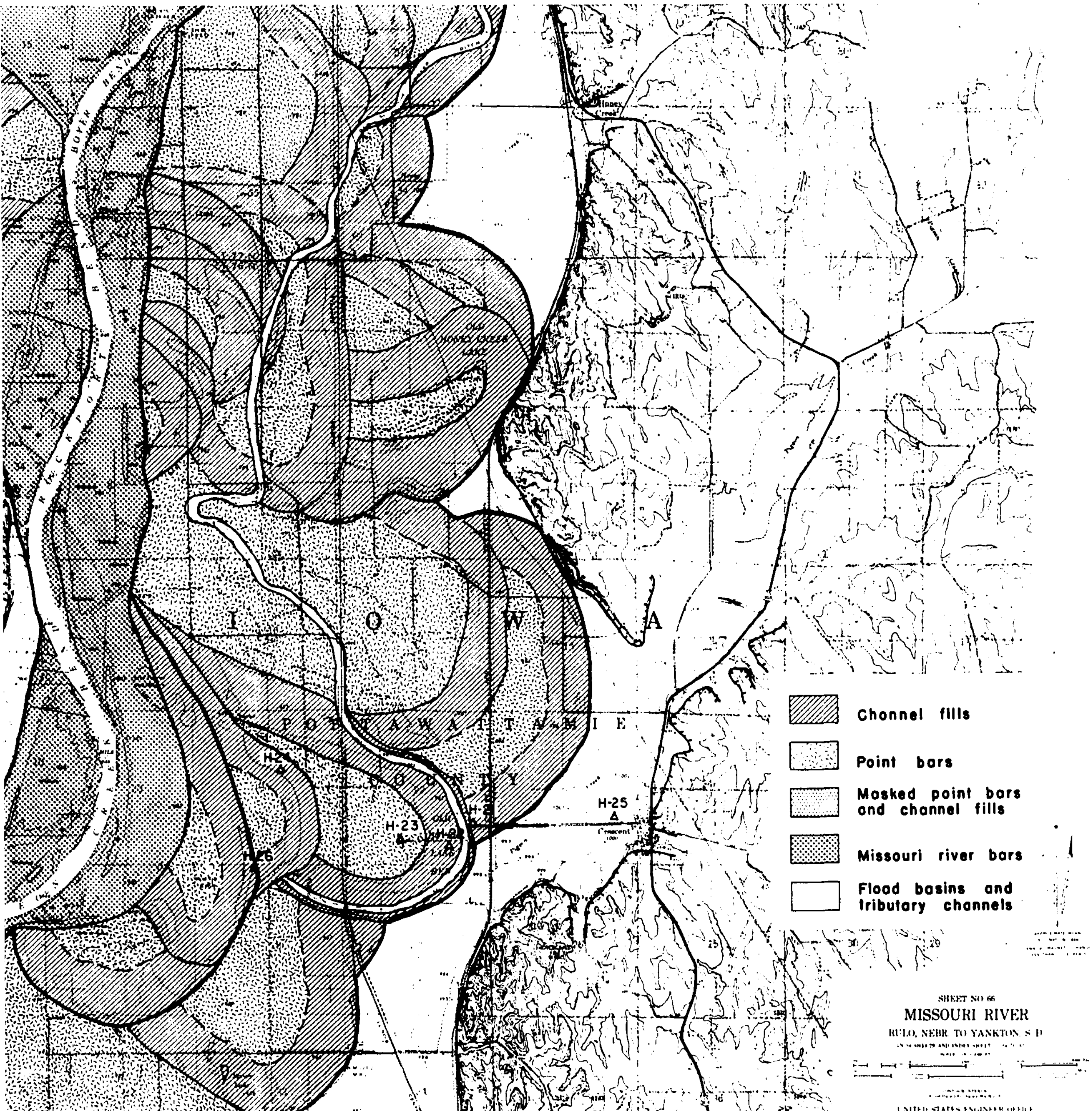
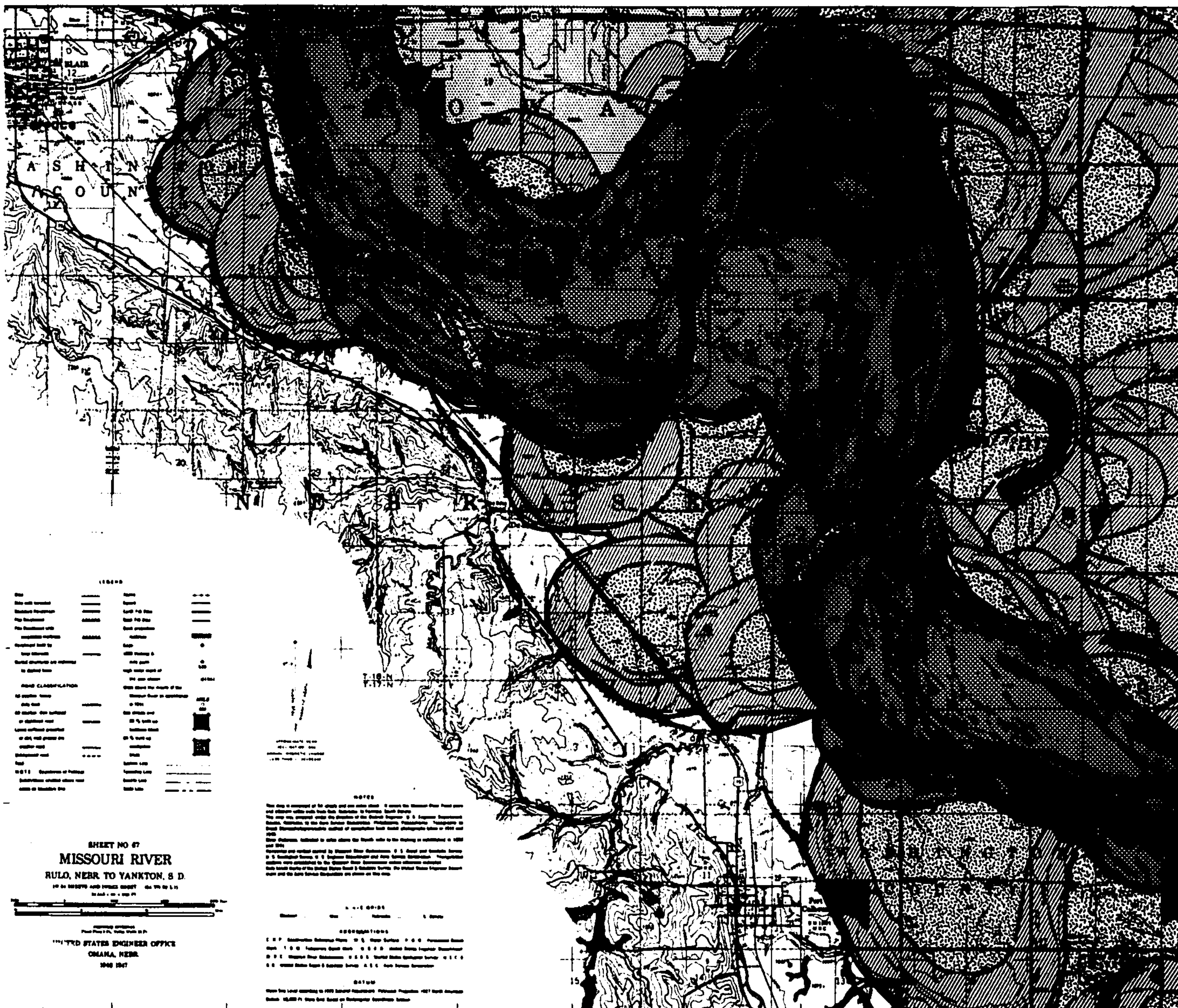
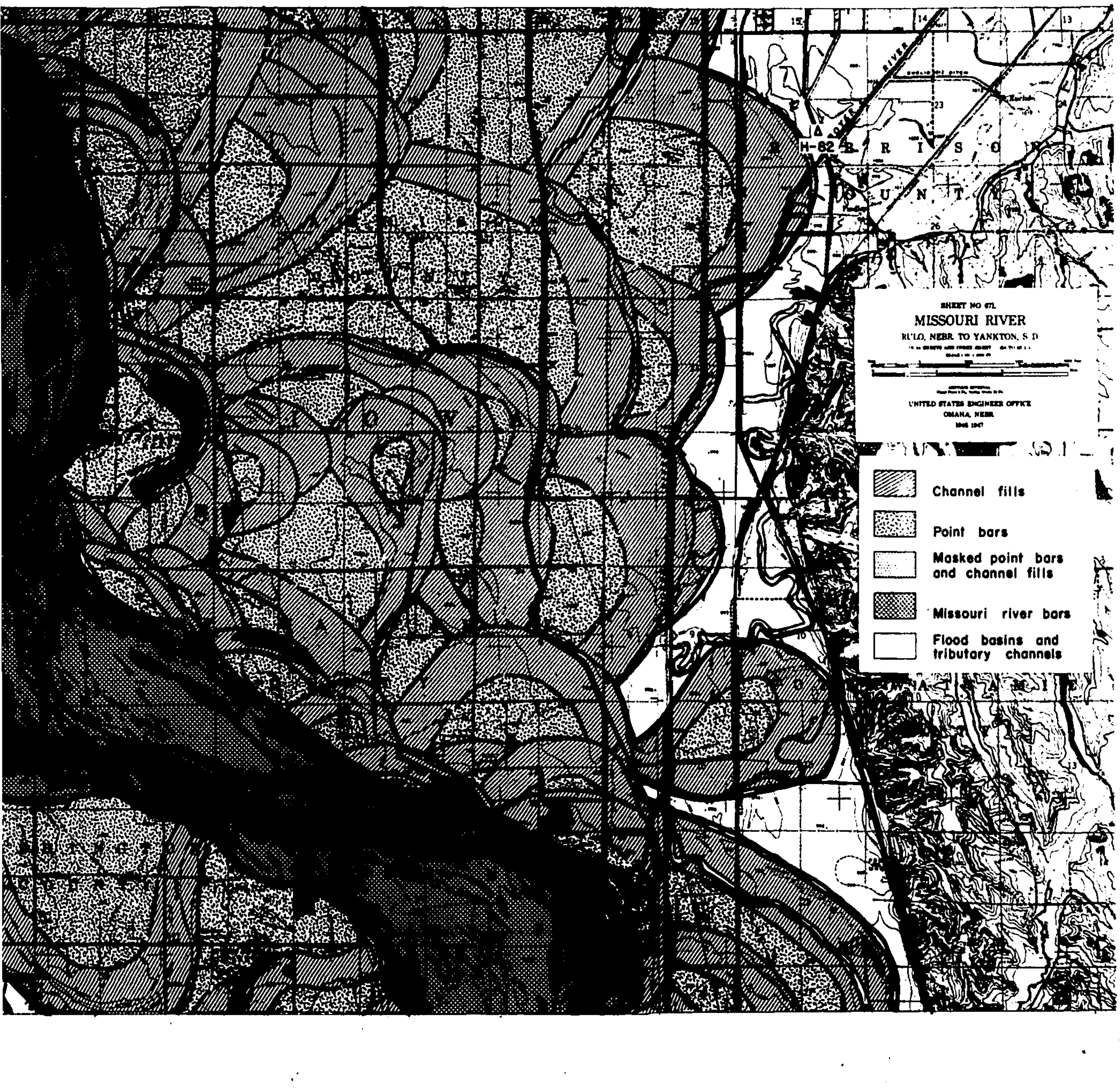

Chonnel fills
Point bars
Masked point bars and chonnel fills
Missouri river bars
Flood basins and tributary channels
I O W A
POTTAWATTAMIE COUNTY
H-25
H-23
H-26
SHEET NO 66
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.

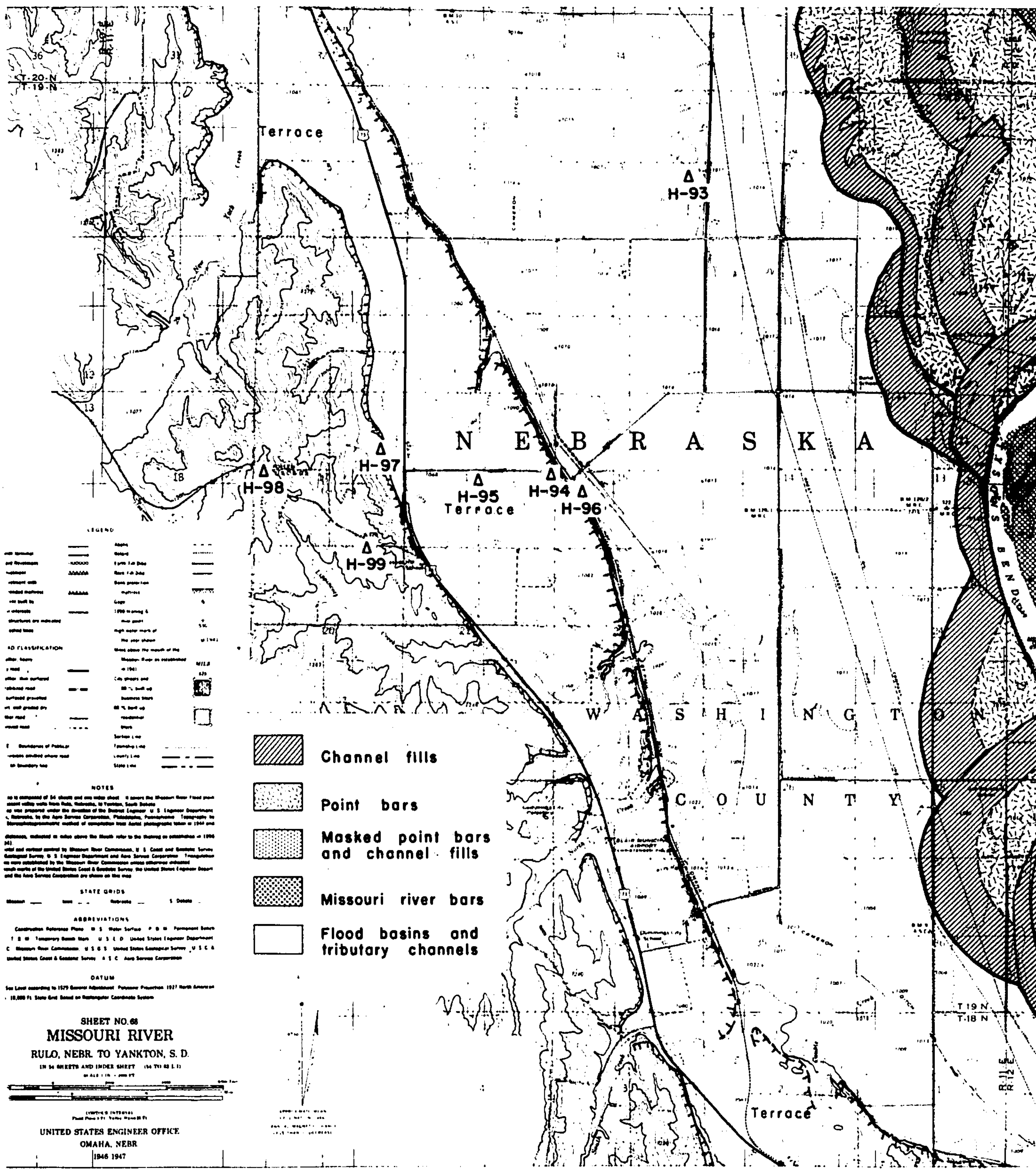
Plate 9. Alluvial geology, Maps 67 and 67L


NEBRASKA
SHEET NO 67
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
''''TRD STATES ENGINEER OFFICE
OMAHA, NEBR.



H-82
MISSOURI RIVER
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

Plate 10. Alluvial geology, Map 68


Terrace
H-93
H-97
H-98
H-95
Terrace
H-94
H-96
H-99
N E B R A S K A
W A S H I N G T O N
C O U N T Y
T-20-N
T-19-N
T 19 N
T 18 N
Terrace
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
LEGEND
NOTES
STATE GRIDS
ABBREVIATIONS
DATUM
SHEET NO. 68
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947

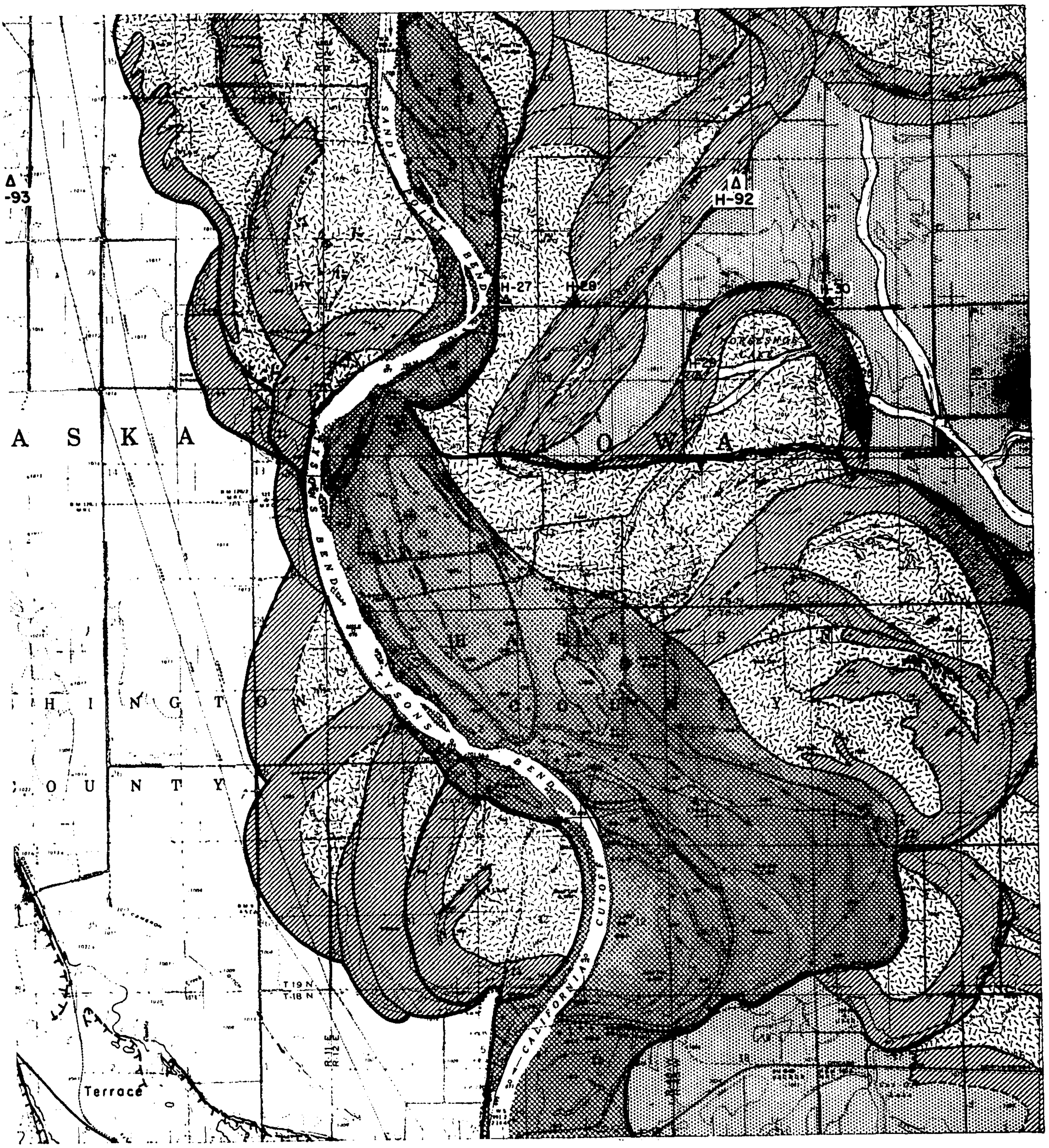
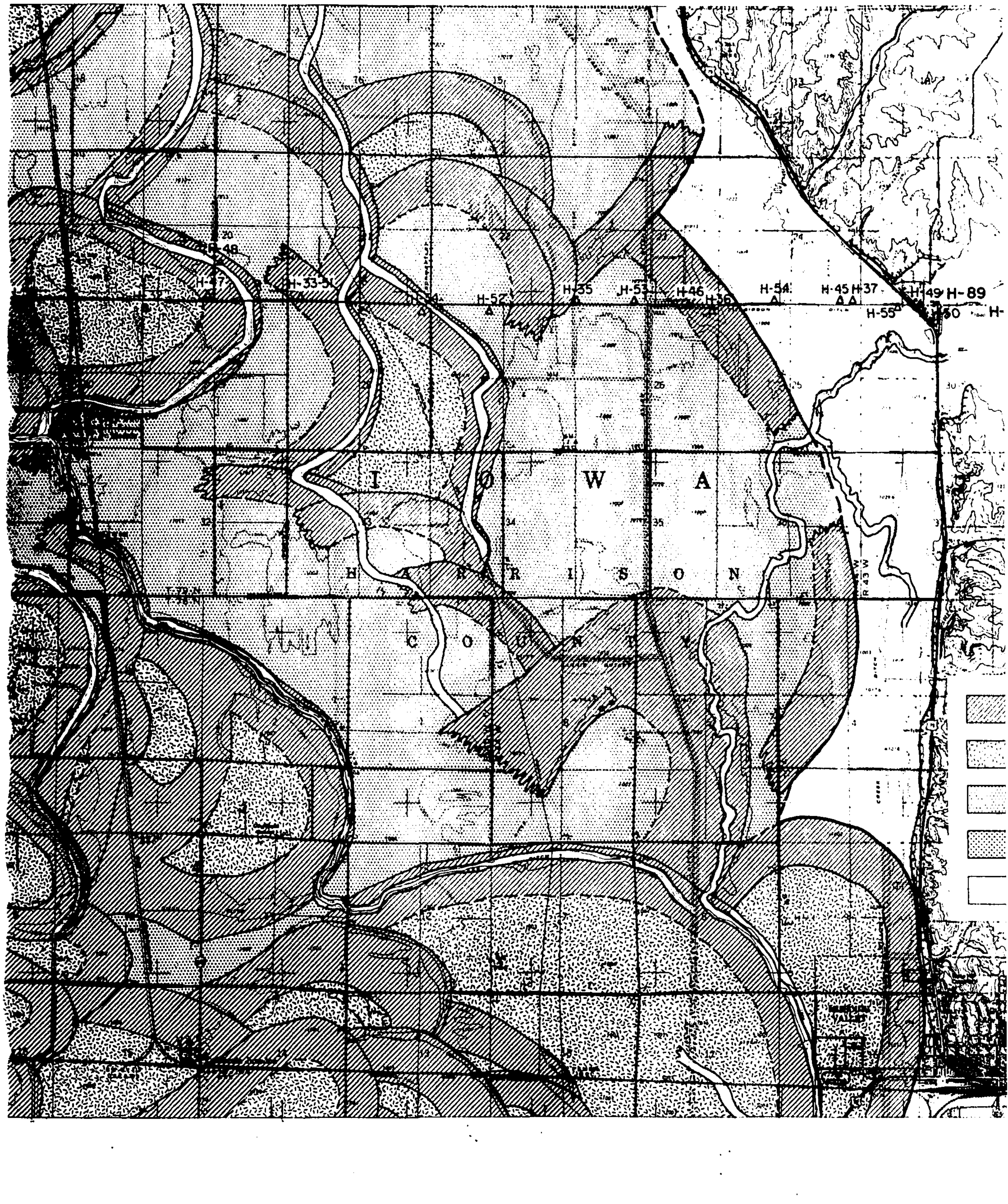

SANDY POINT BEND
TYSONS BEND
TYSONS BEND
CALIFORNIA CUT-OFF
HORSESHOE LAKE
H-27
H-28
H-30
H-92
-93
A S K A
I O W A
H I N G T O N
C O U N T Y
H A R R I S O N
C O U N T Y
T 19 N
T 18 N
R 11 E
R 12 E
Terrace

Plate 11. Alluvial geology, Map 68L


I O W A
H A R R I S O N
C O U N T Y
H-48
H-47
H-53-51
H-52
H-35
H-53
H-46
H-36
H-54
H-45
H-37
H-49
H-89
H-55
H-50

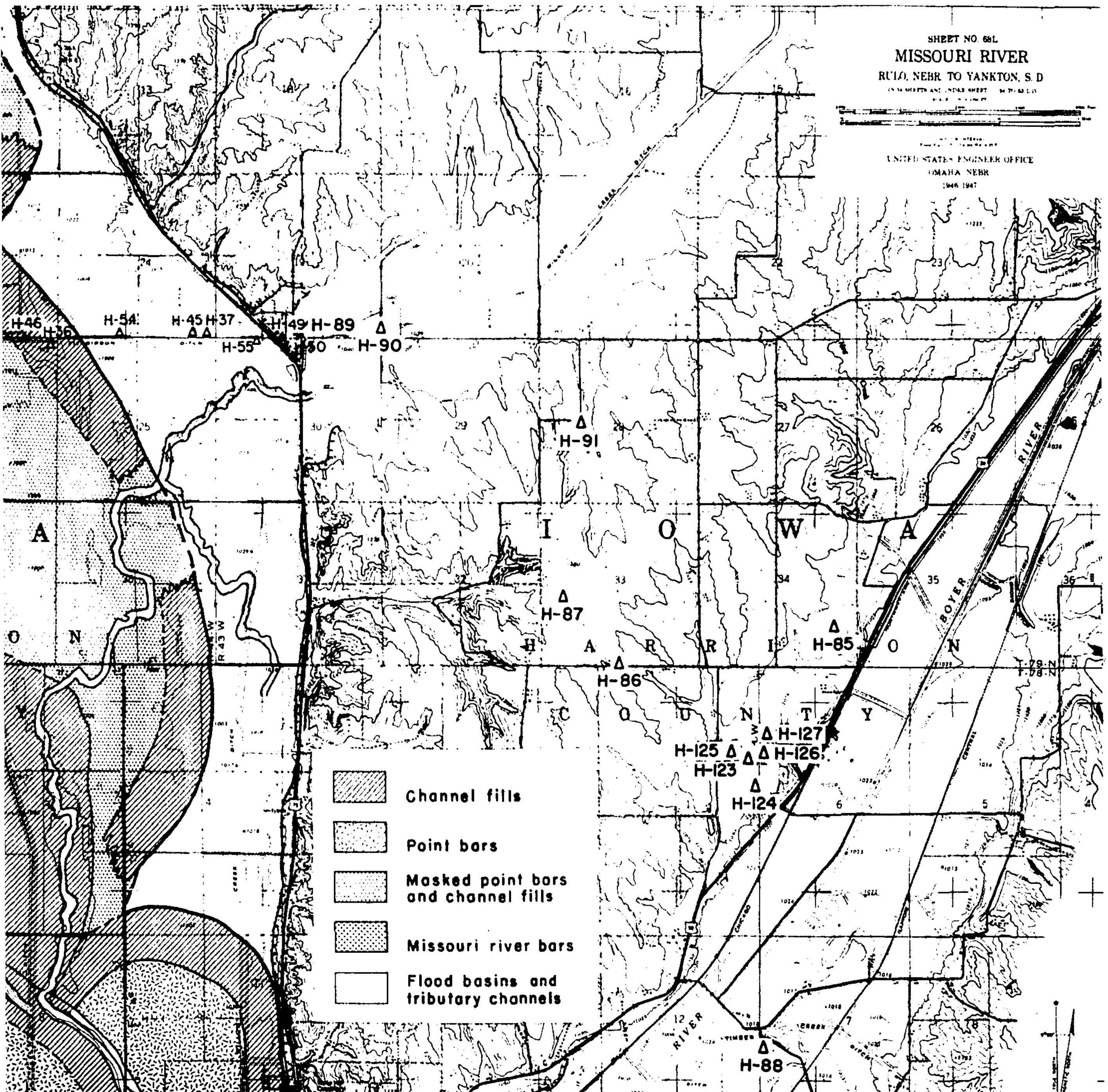
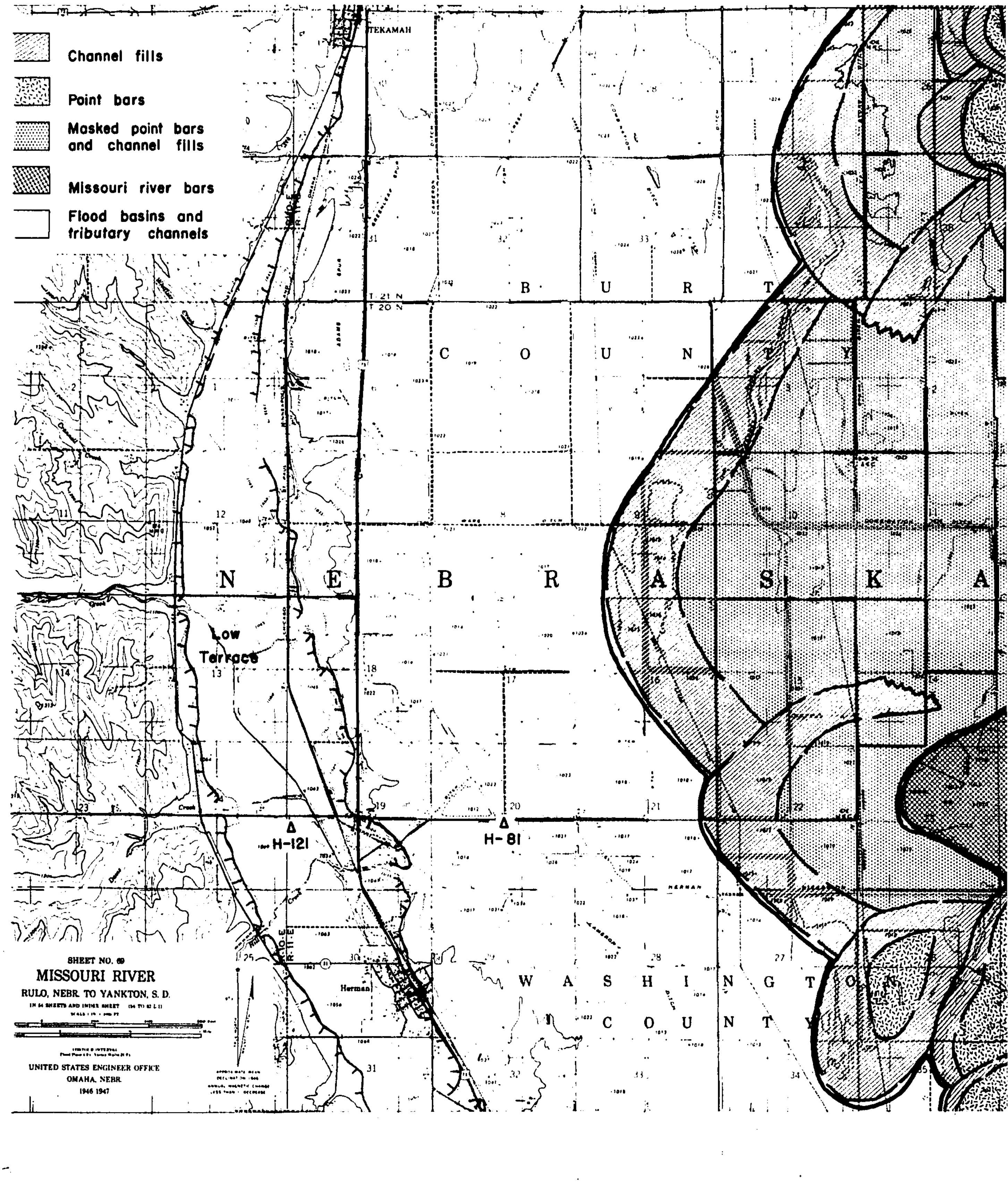

SHEET NO. 68L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
I O W A
H A R R I S O N
C O U N T Y
BOYER RIVER
BOYER
RIVER
H-46
H-36
H-54
H-45
H-37
H-49
H-55
H-50
H-89
H-90
H-91
H-87
H-86
H-85
H-127
H-126
H-125
H-123
H-124
H-88
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
T.79 N
T.78 N

Plate 12. Alluvial geology, Map 69


Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
TEKAMAH
B U R T
C O U N T Y
N E B R A S K A
Low Terrace
H-121
H-81
Herman
W A S H I N G T O N
C O U N T Y
SHEET NO. 69
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947

R T
N T Y
A S K A
LITTLE SIOUX BEND
I O W A
H A R R I S O N
C O U N T Y
H I N G T O N
O U N T Y

Plate 13. Alluvial geology, Map 69L

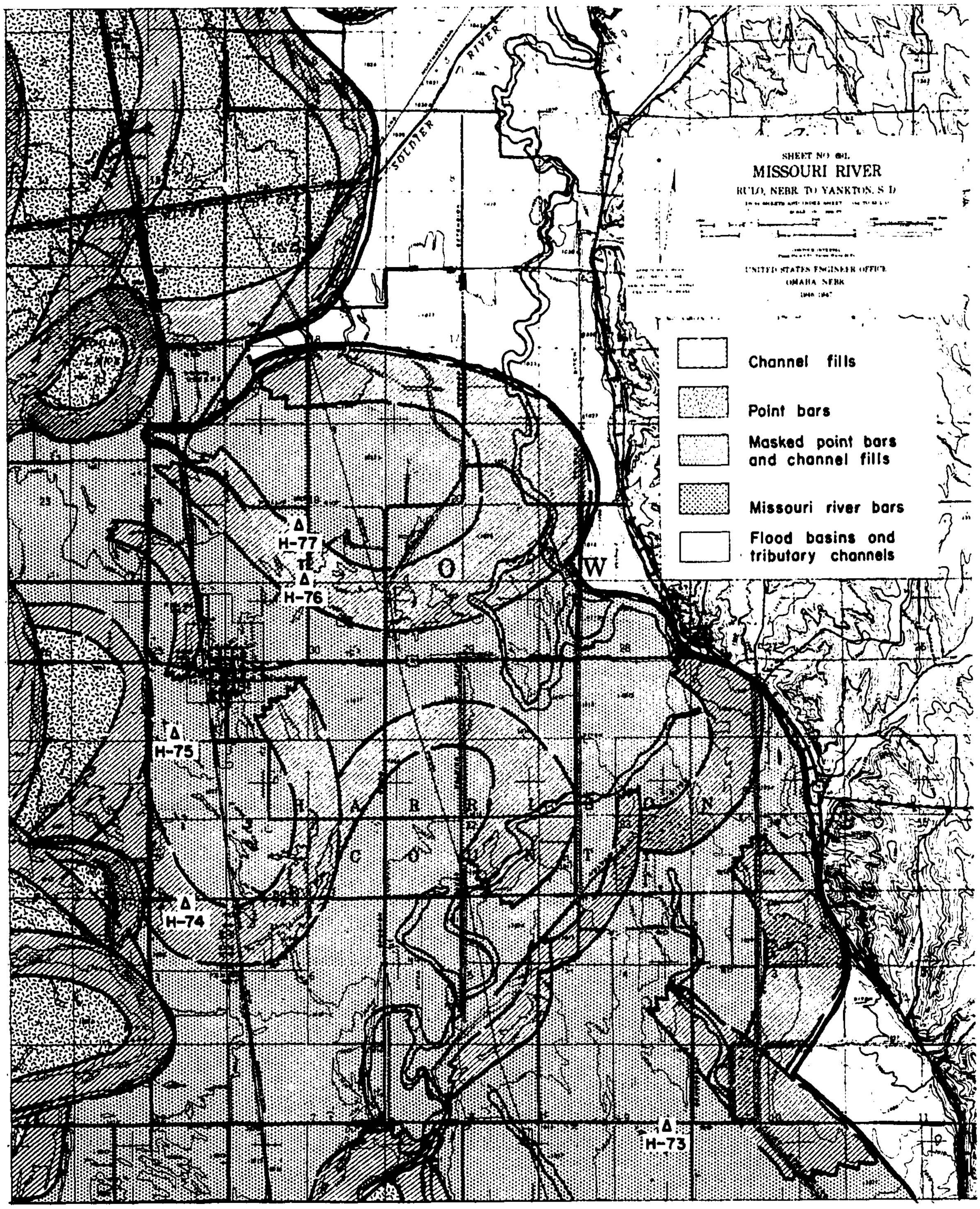
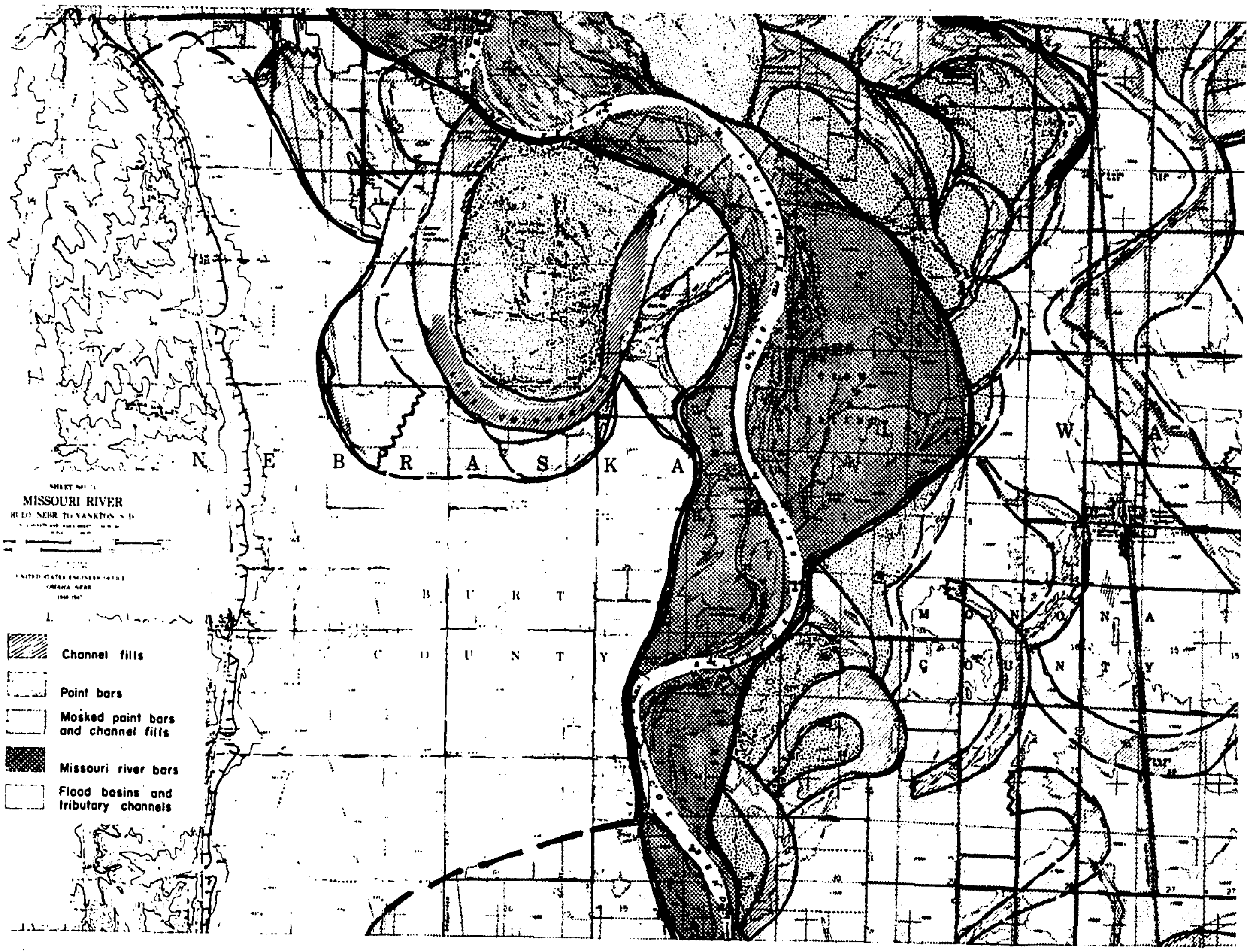

MISSOURI RIVER
RULO, NEBR TO YANKTON, S D
UNITED STATES ENGINEER OFFICE
OMAHA NEBR
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SOLDIER RIVER
H-77
H-76
H-75
H-74
H-73

Plate 14. Alluvial geology, Maps 70 and 70L


MISSOURI RIVER
UNITED STATES ENGINEER OFFICE
N E B R A S
B U R T


MISSOURI RIVER
RULO, NEBR. TO YANKTON, S D
UNITED STATES ENGINEER OFFICE
OMAHA NEBR
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
H-78
H-79
H-119

Plate 15. Alluvial geology, Maps 71 and 71L


MISSOURI RIVER
N E B R A S K A
B U R T
C O U N T Y
M O N O N A
C O U N T Y
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

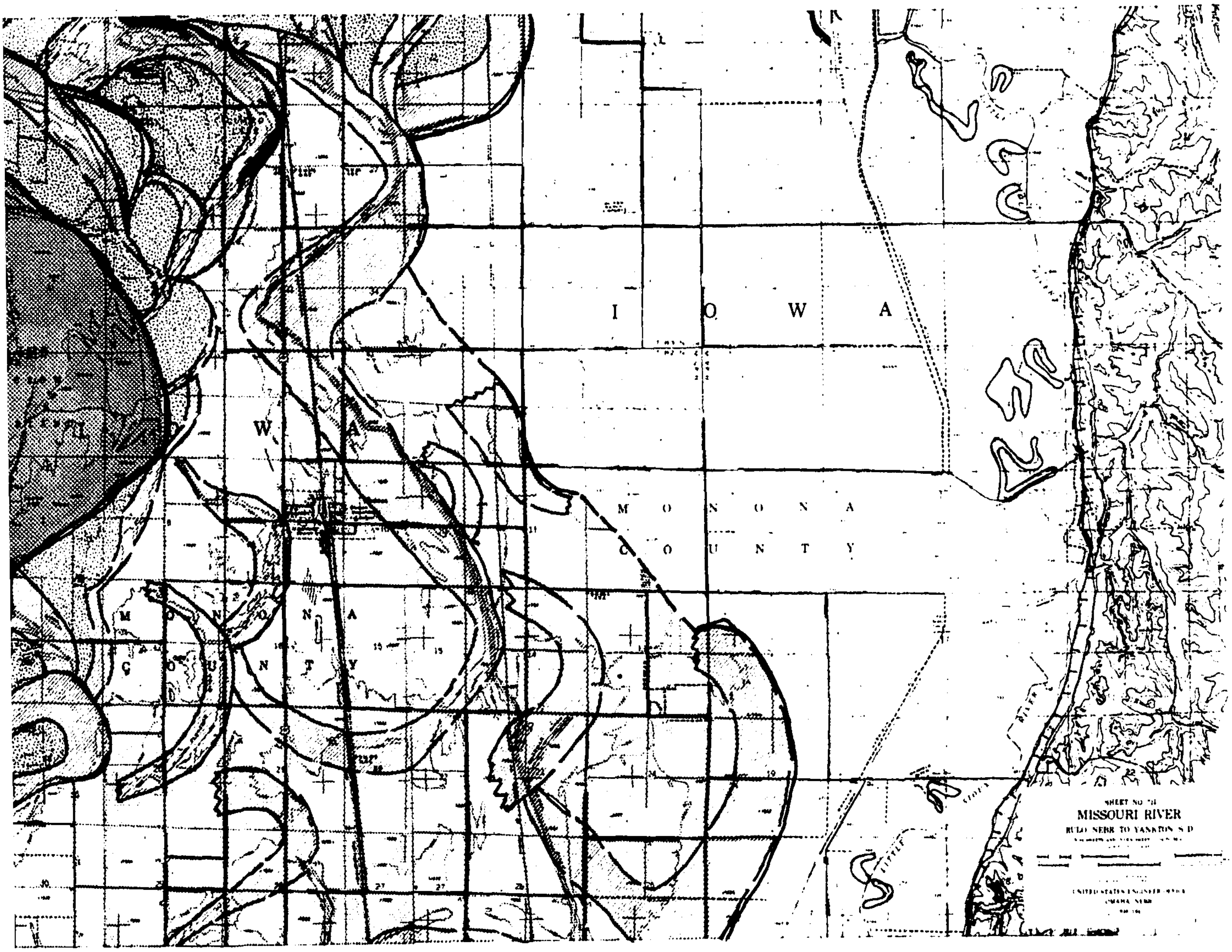
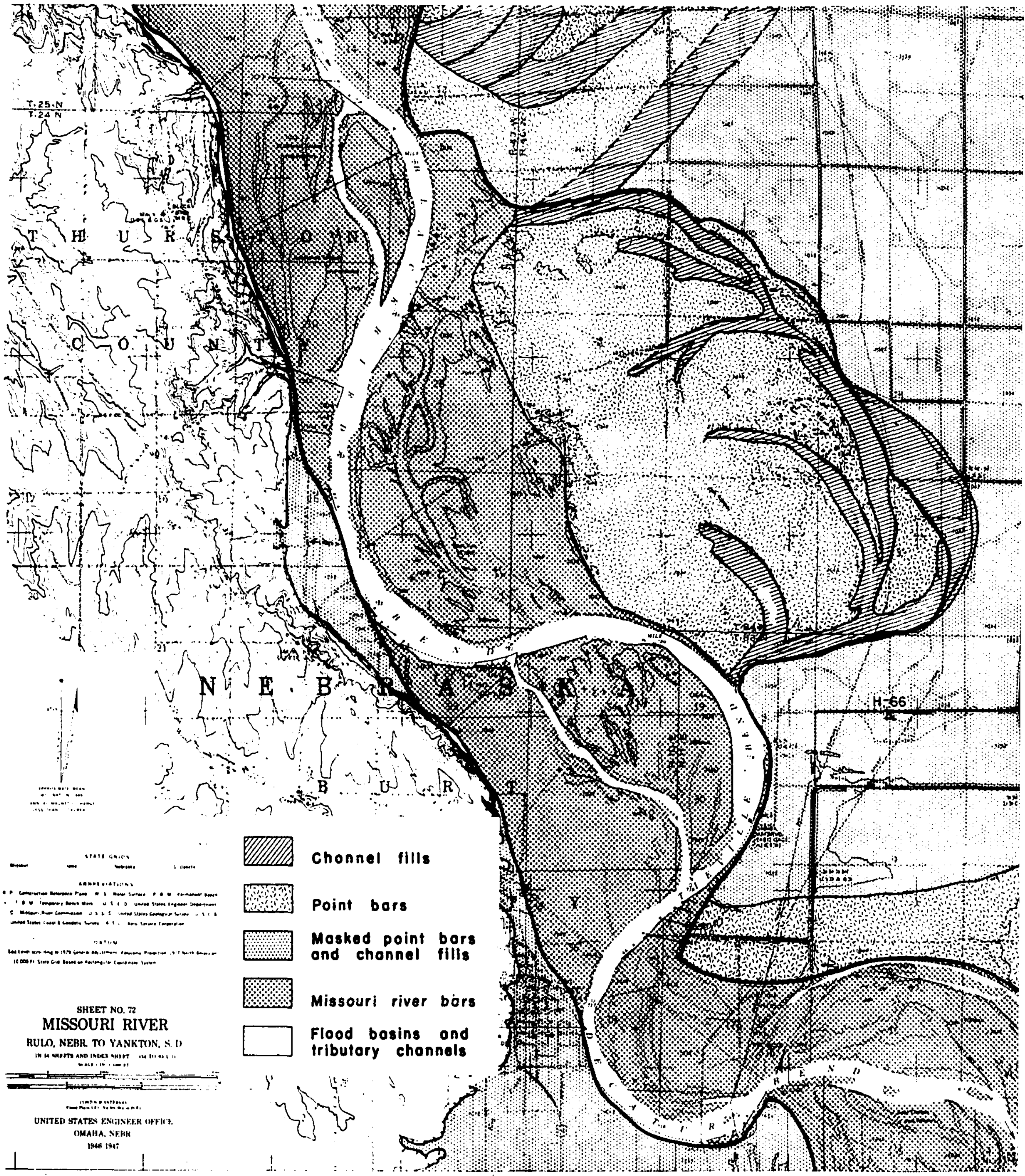
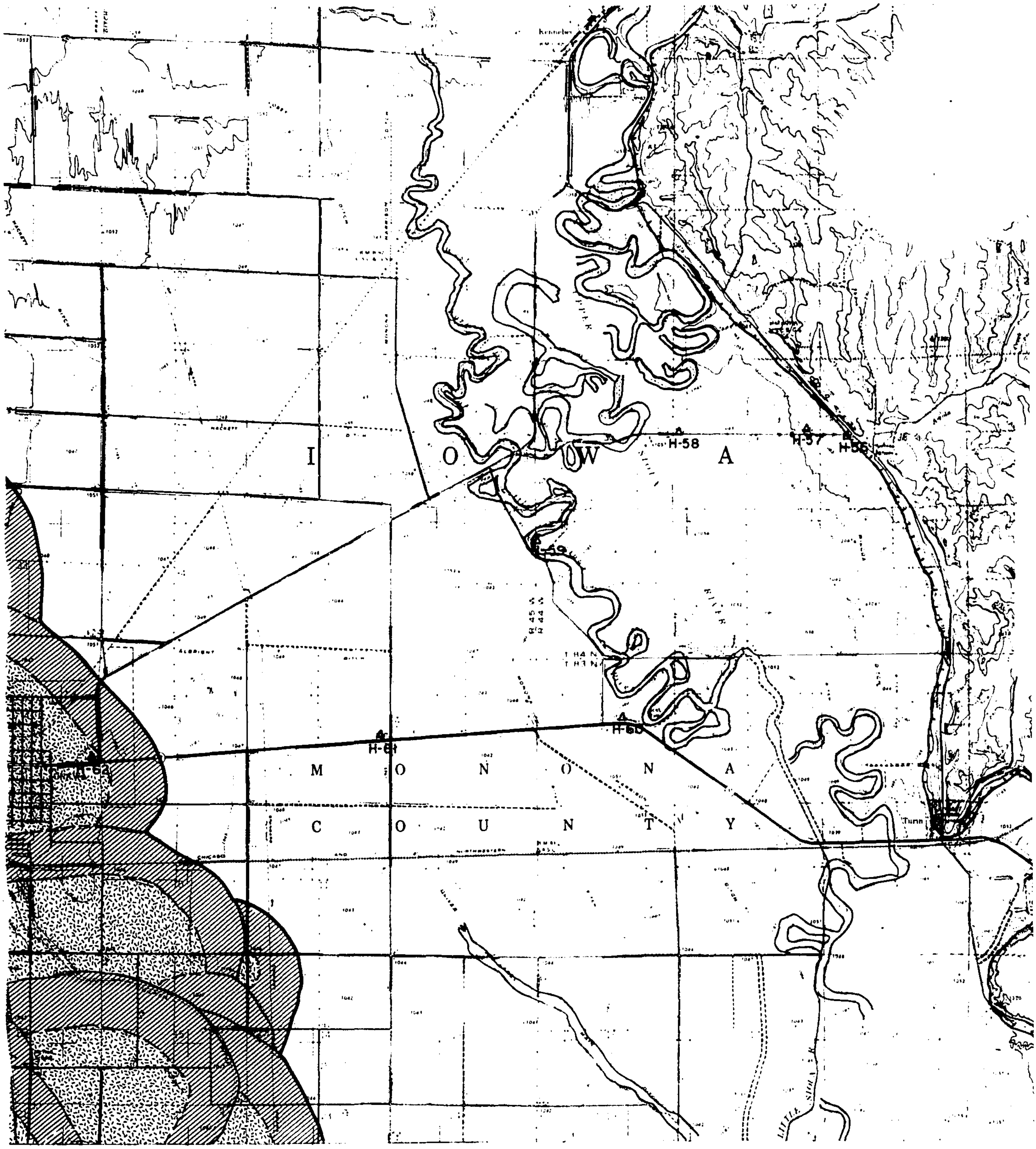

I O W A
M O N O N A
C O U N T Y
MISSOURI RIVER
RULO NEBR TO YANKTON S D
UNITED STATES ENGINEER OFFICE
OMAHA NEBR

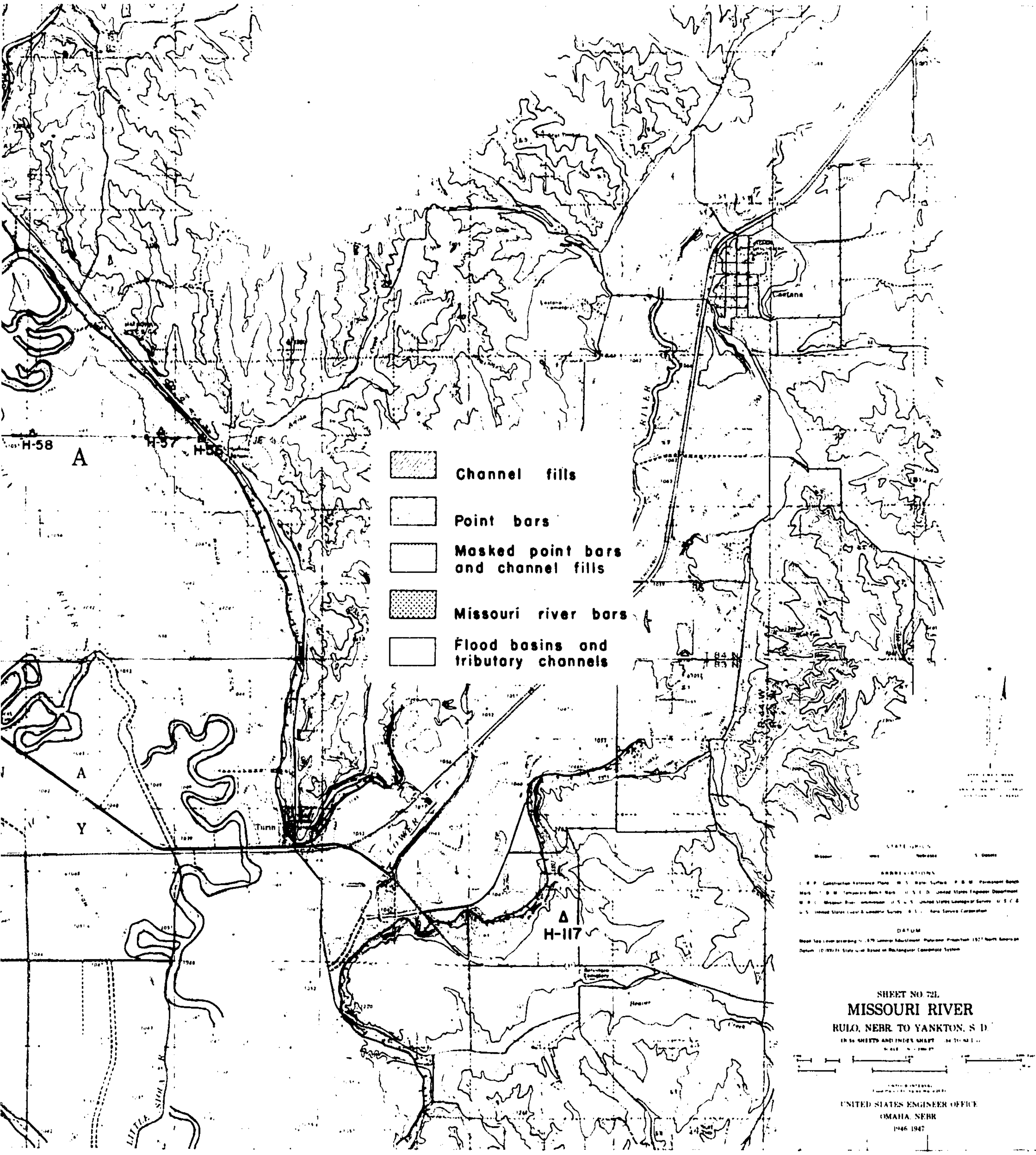
Plate 16. Alluvial geology, Map 72


T. 25 N
T. 24 N
T H U R S T O N
C O U N T Y
N E B R A S K A
B U R
H-66
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO. 72
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947


I O W A
H-63
H-64
H-65
H-66

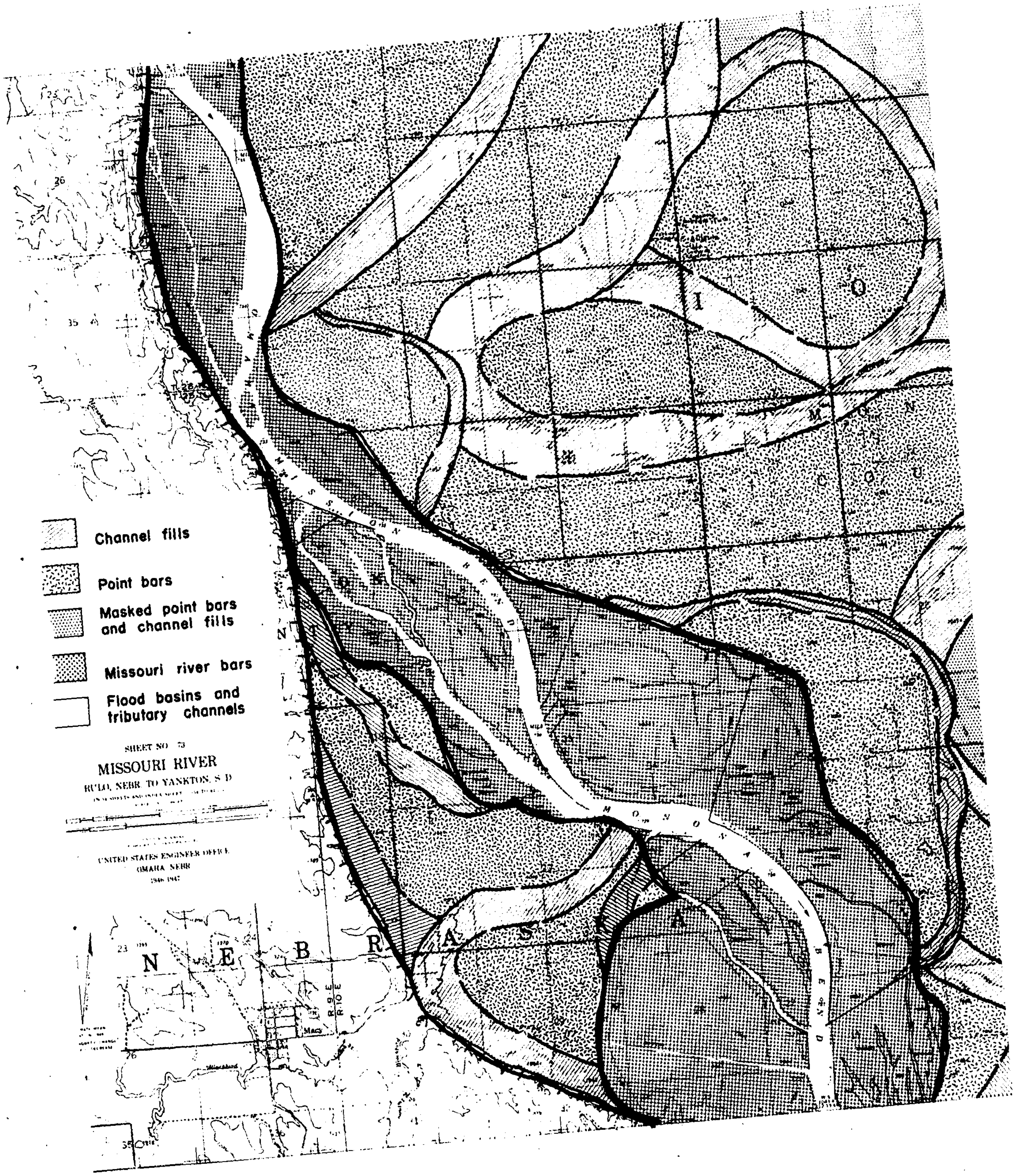
Plate 17. Alluvial geology, Map 72L


I O W A
M O N O N A
C O U N T Y
H-56
H-57
H-58
H-60
H-61
H-62
Turin



H-58
H-57
H-56
A
A
Y
Turin
H-117
LITTLE
RIVER
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO. 72L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947

Plate 18. Alluvial geology, Map 73


Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
SHEET NO 73
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S D
UNITED STATES ENGINEER OFFICE
OMAHA NEBR
1946 1947
N E B R A S K A
I O W A
MONONA BEND
MISSOURI BEND
Macy

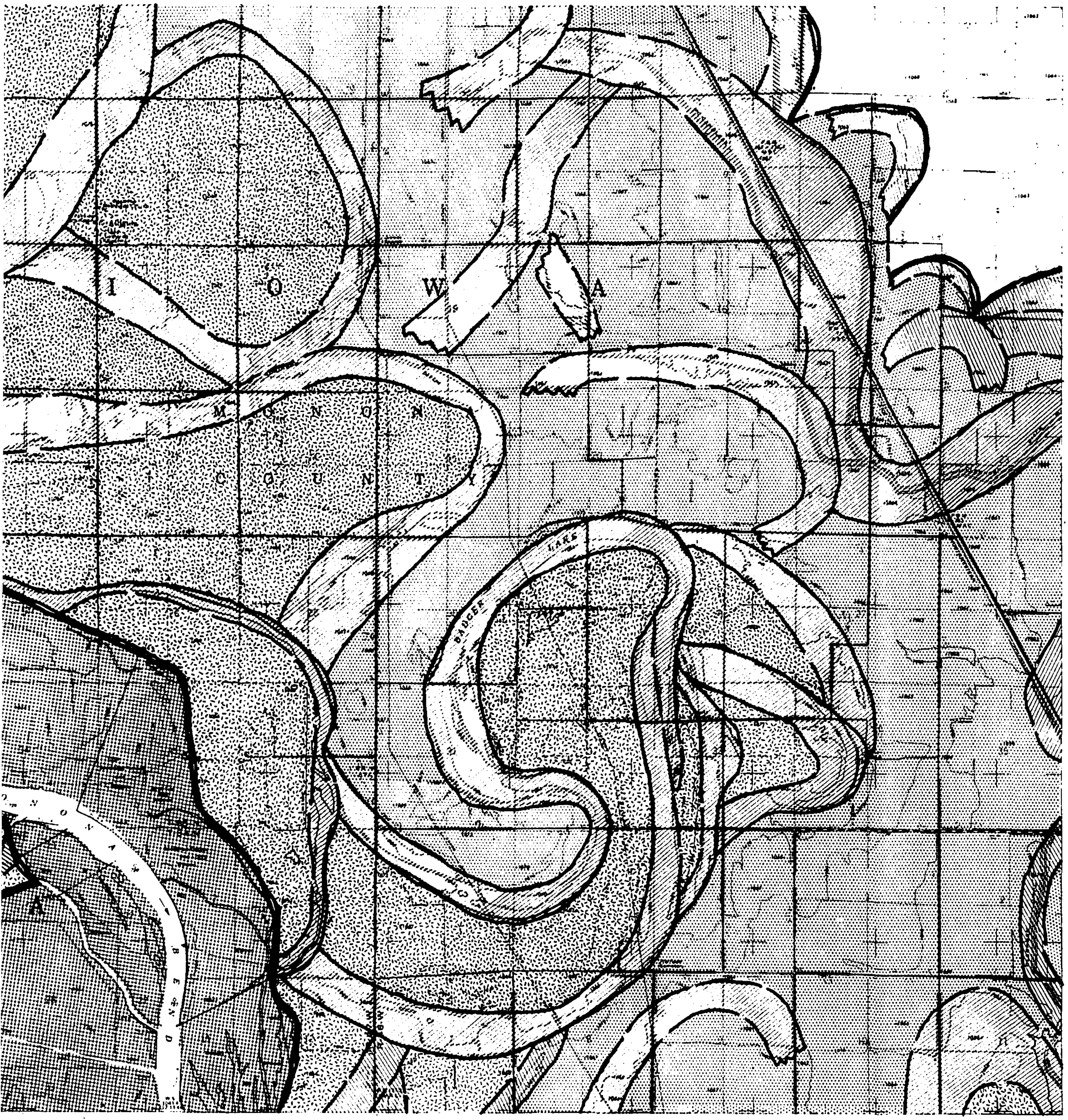

I O W A
M O N O N A
C O U N T Y
BADGER LAKE

Plate 19. Alluvial geology, Map 73L

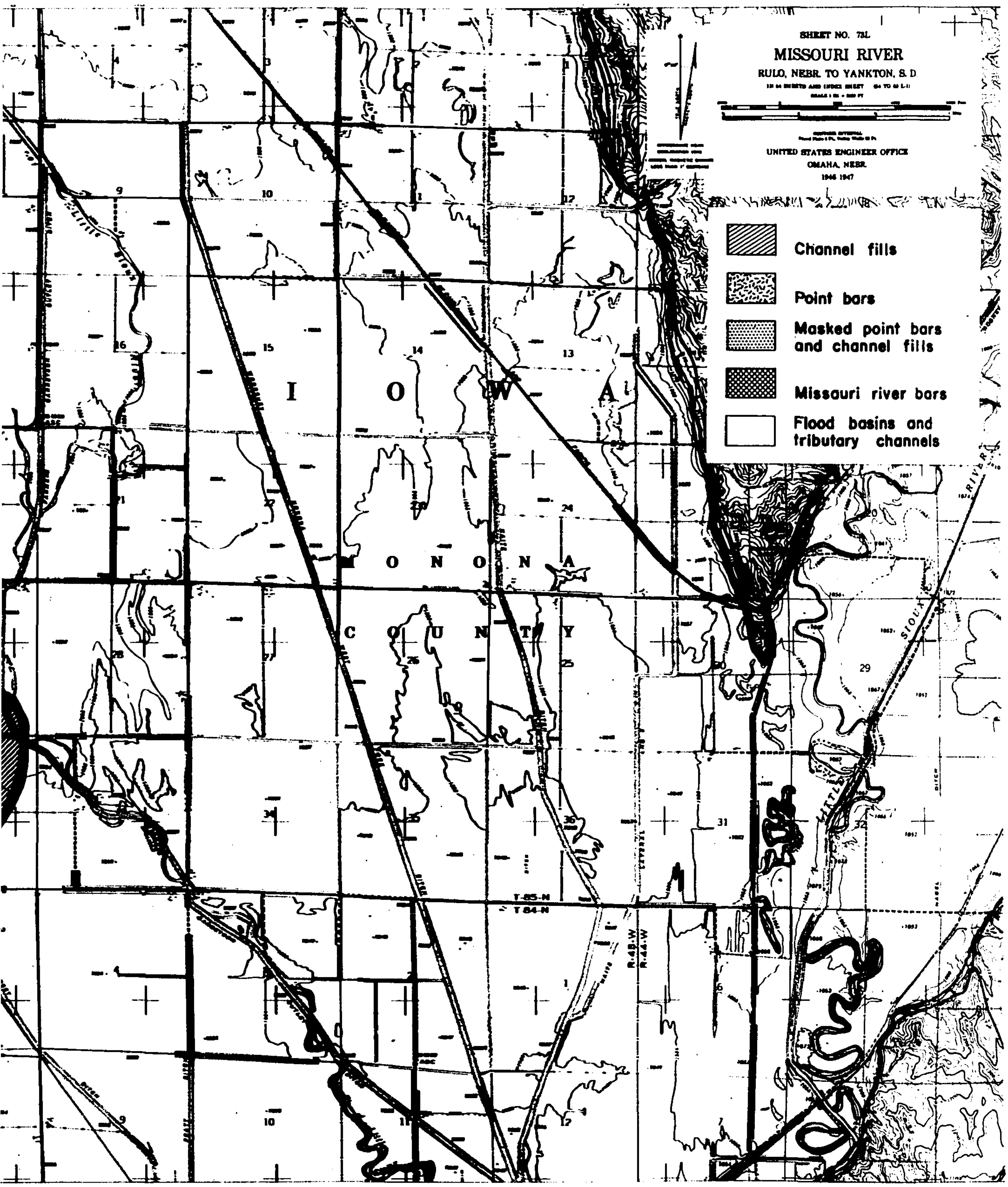
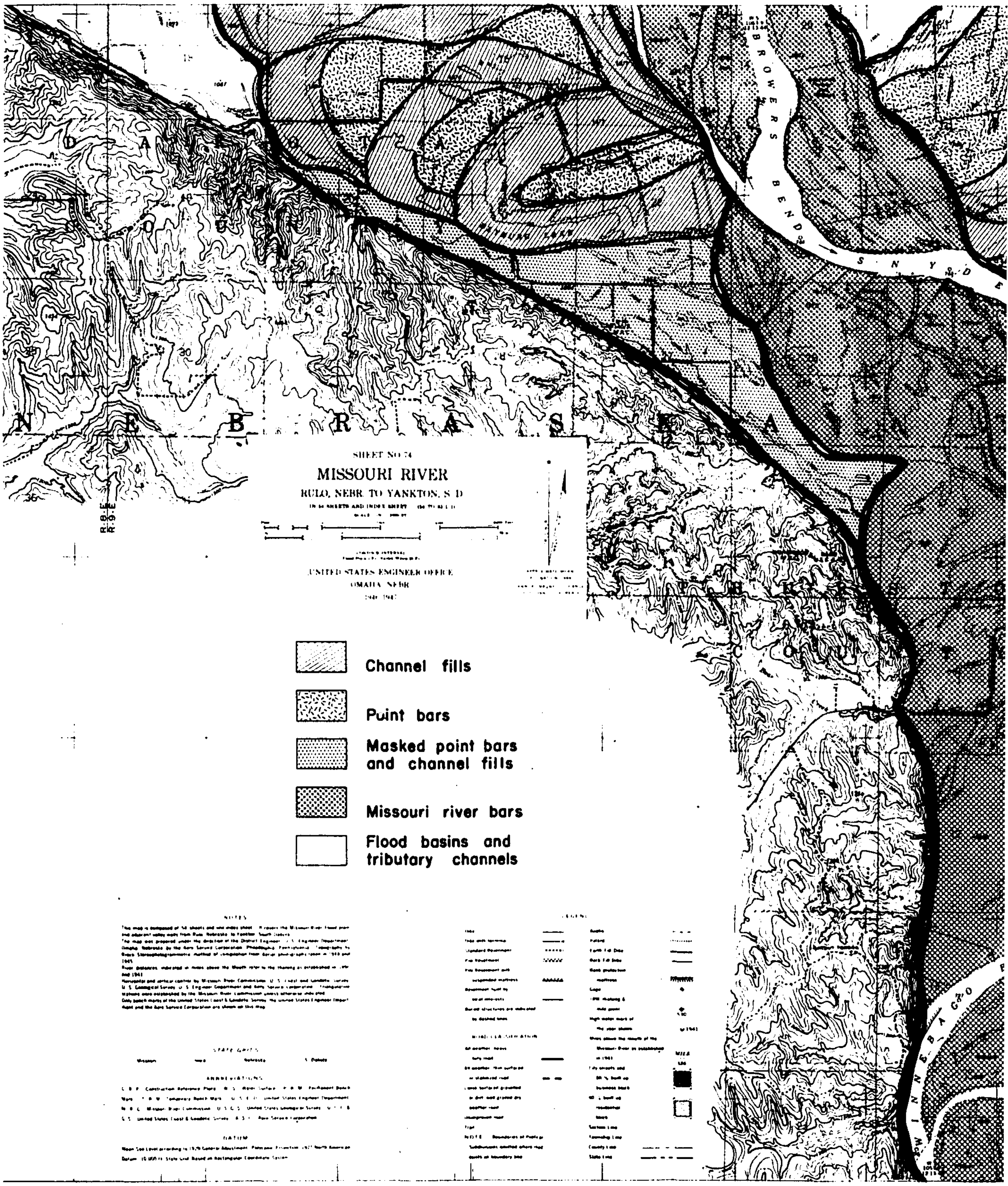

SHEET NO. 73L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
I O W A
M O N O N A
C O U N T Y
Little Sioux
SIOUX RIVER
LITTLE
T-85-N
T-84-N
R-45-W
R-44-W

Plate 20. Alluvial geology, Map 74


NEBRASKA
SHEET NO. 74
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
BROWERS BEND

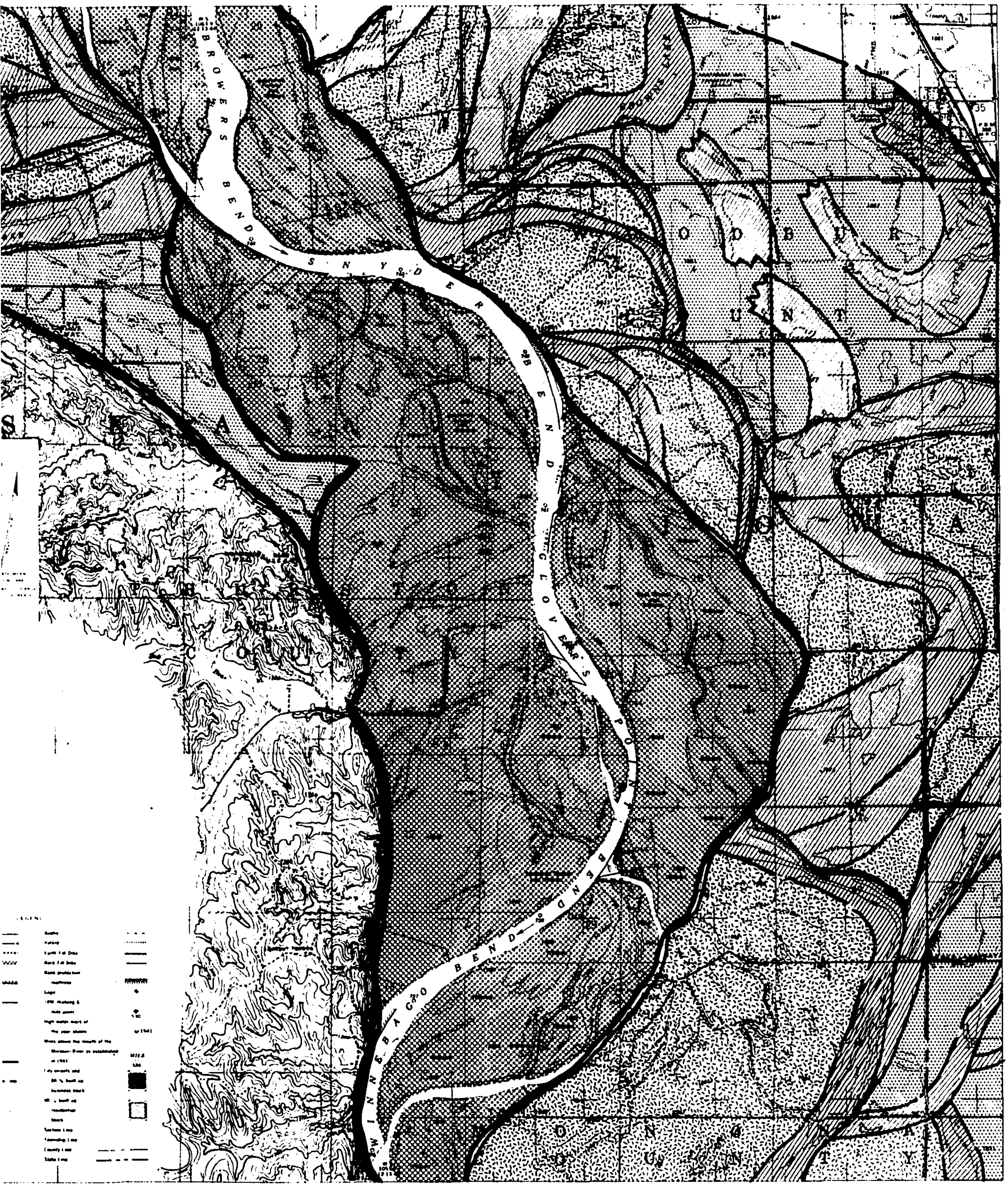
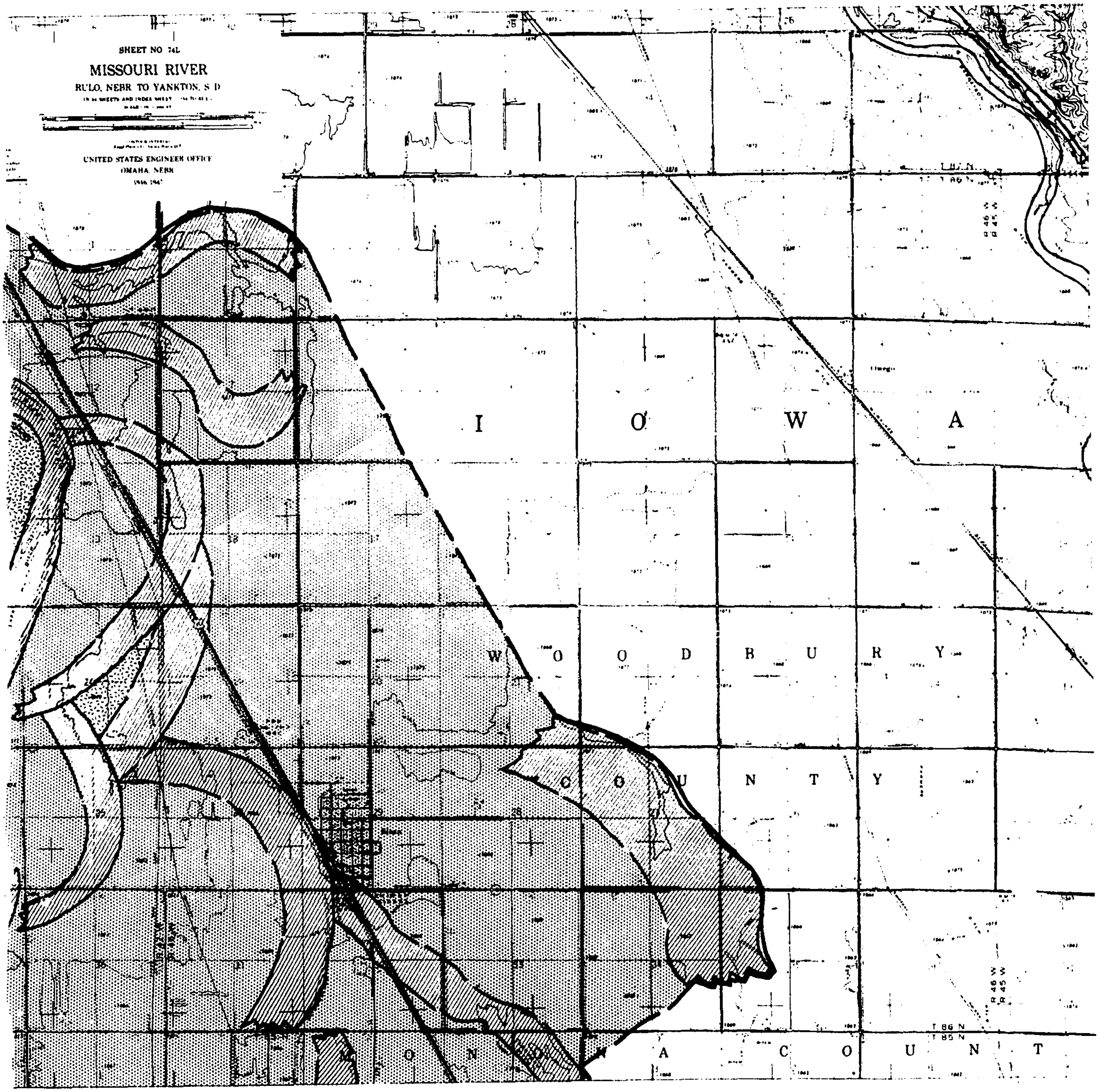
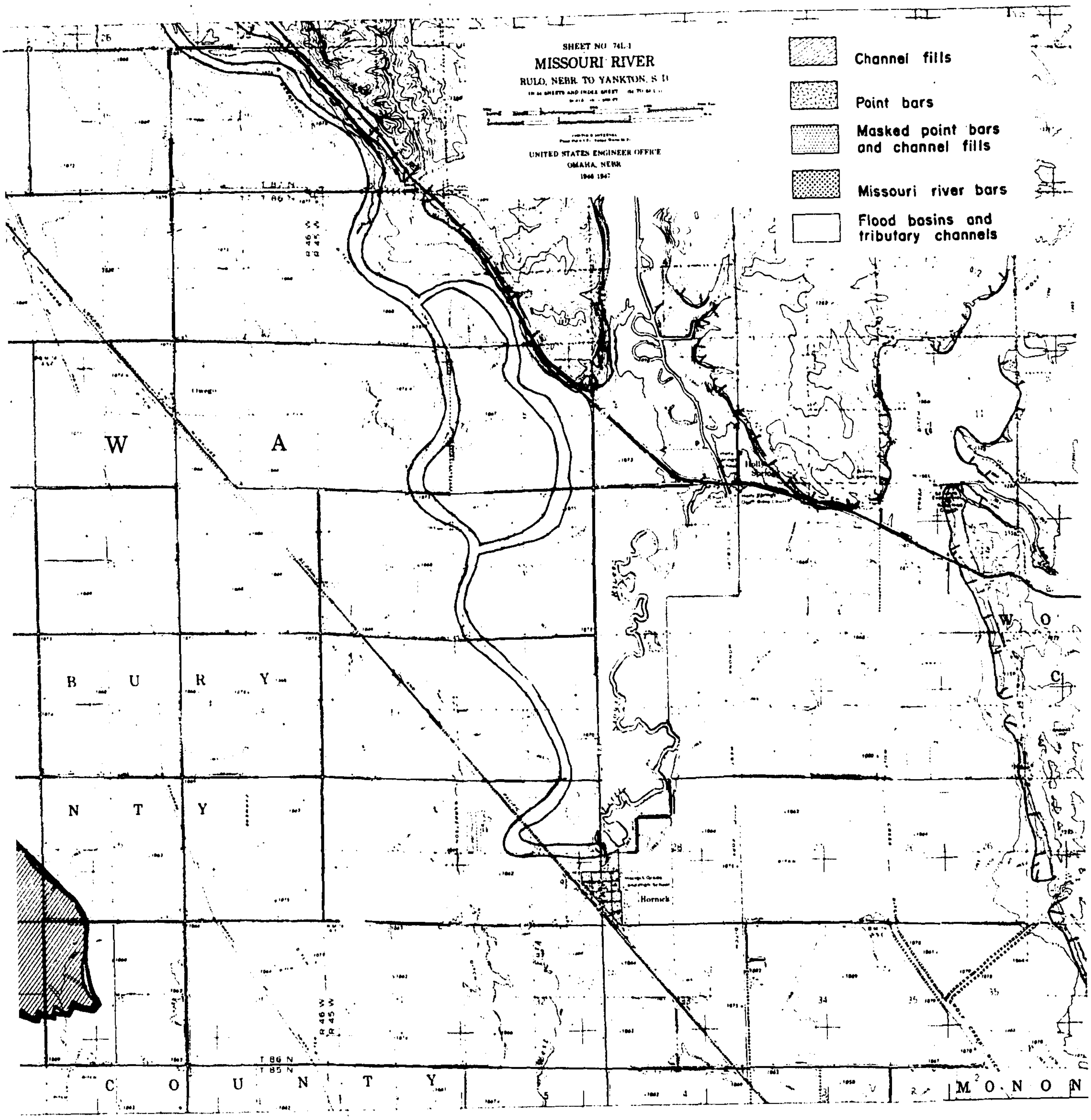

BROWERS BEND
SNYDER BEND
GLOVERS POINT BEND
WINNEBAGO BEND

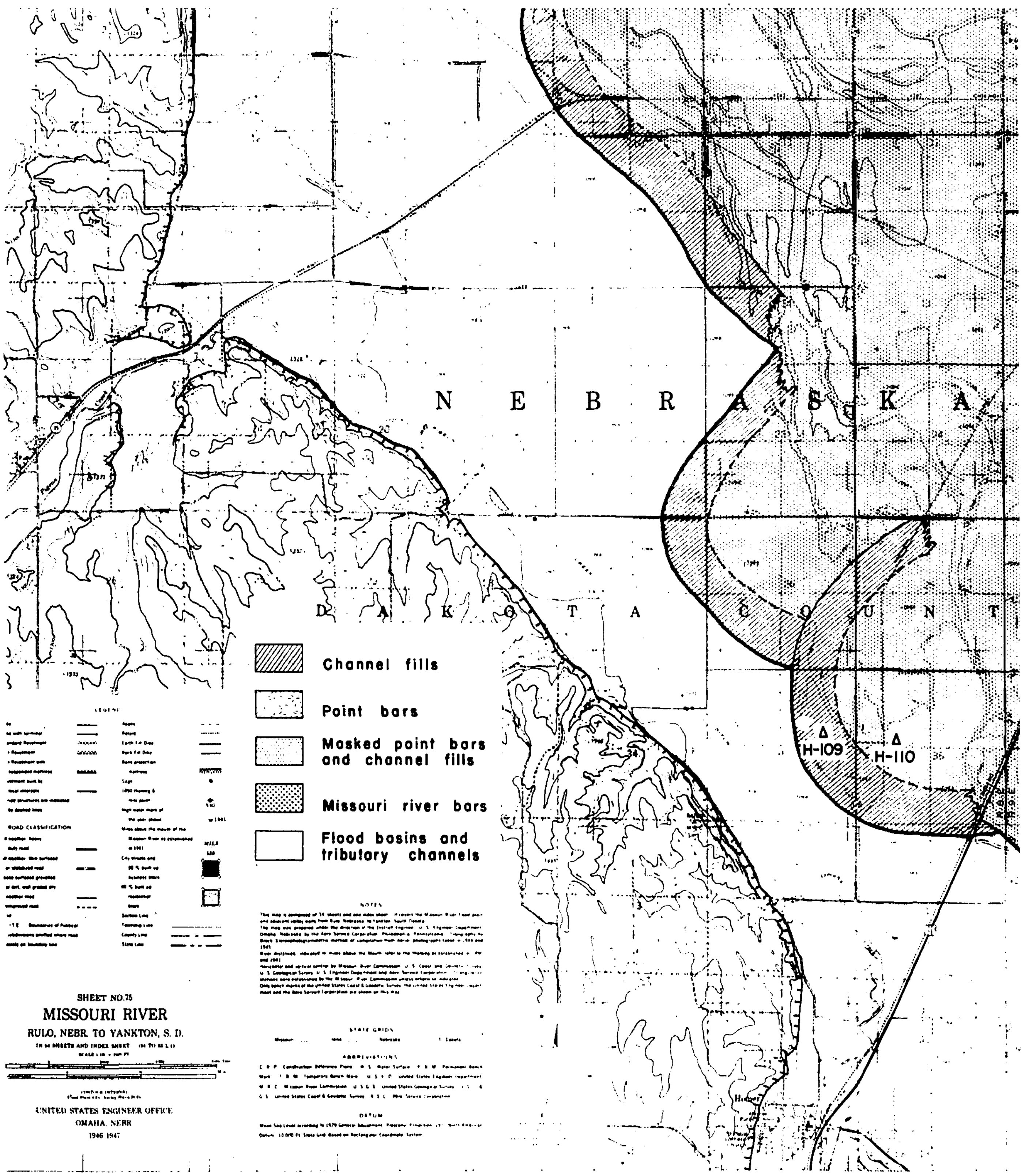
Plate 21. Alluvial geology, Maps 74L and 74L-1

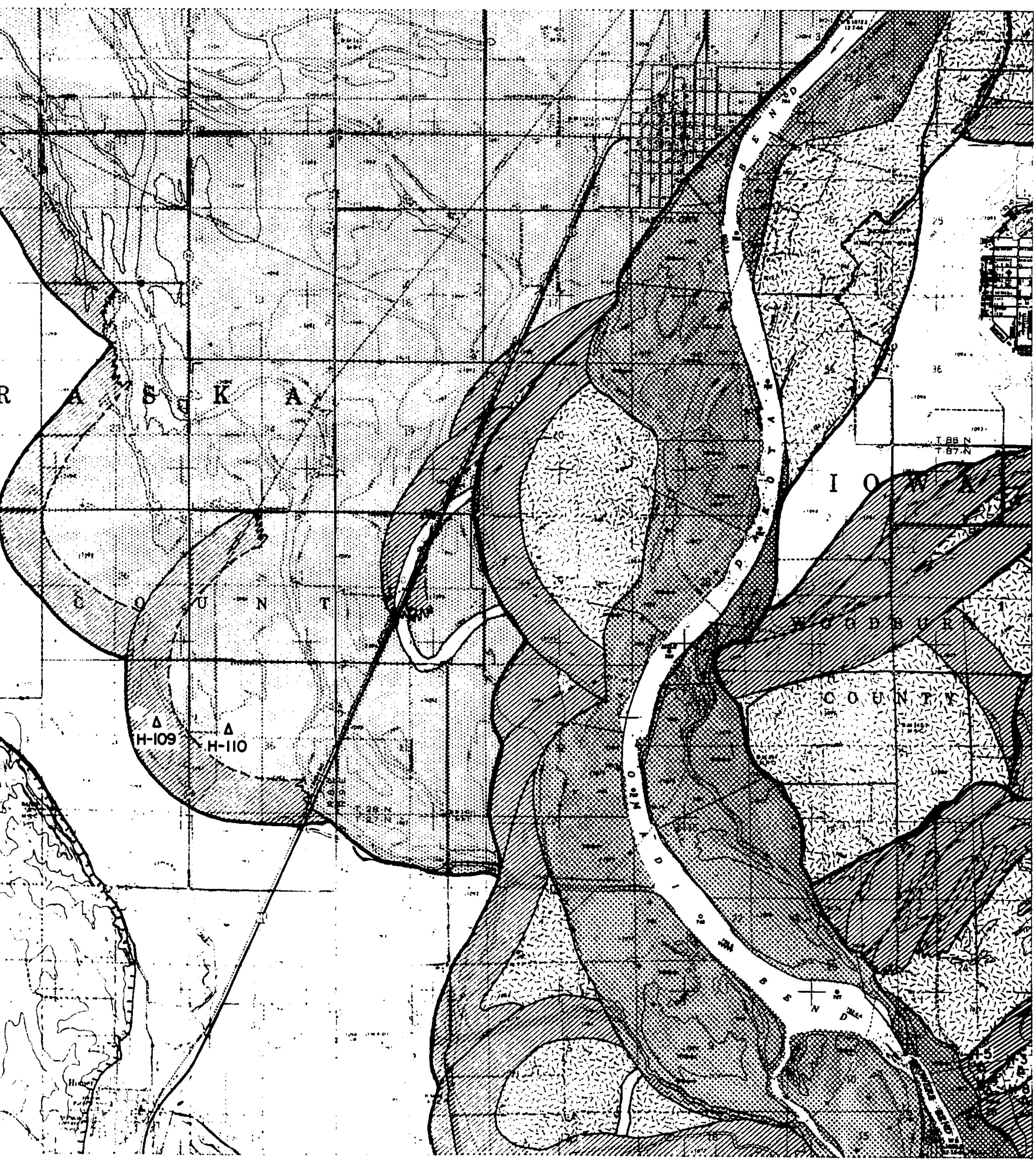

SHEET NO. 74L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
I O W A
W O O D B U R Y
C O U N T Y
M O N
A C O U N T
T 86 N
T 85 N
R 46 W
R 45 W



SHEET NO. 74L-1
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
W A
B U R Y
N T Y
C O U N T Y
W O
C
M O N O N
Hornick
T 86 N
T 85 N
R 46 W
R 45 W

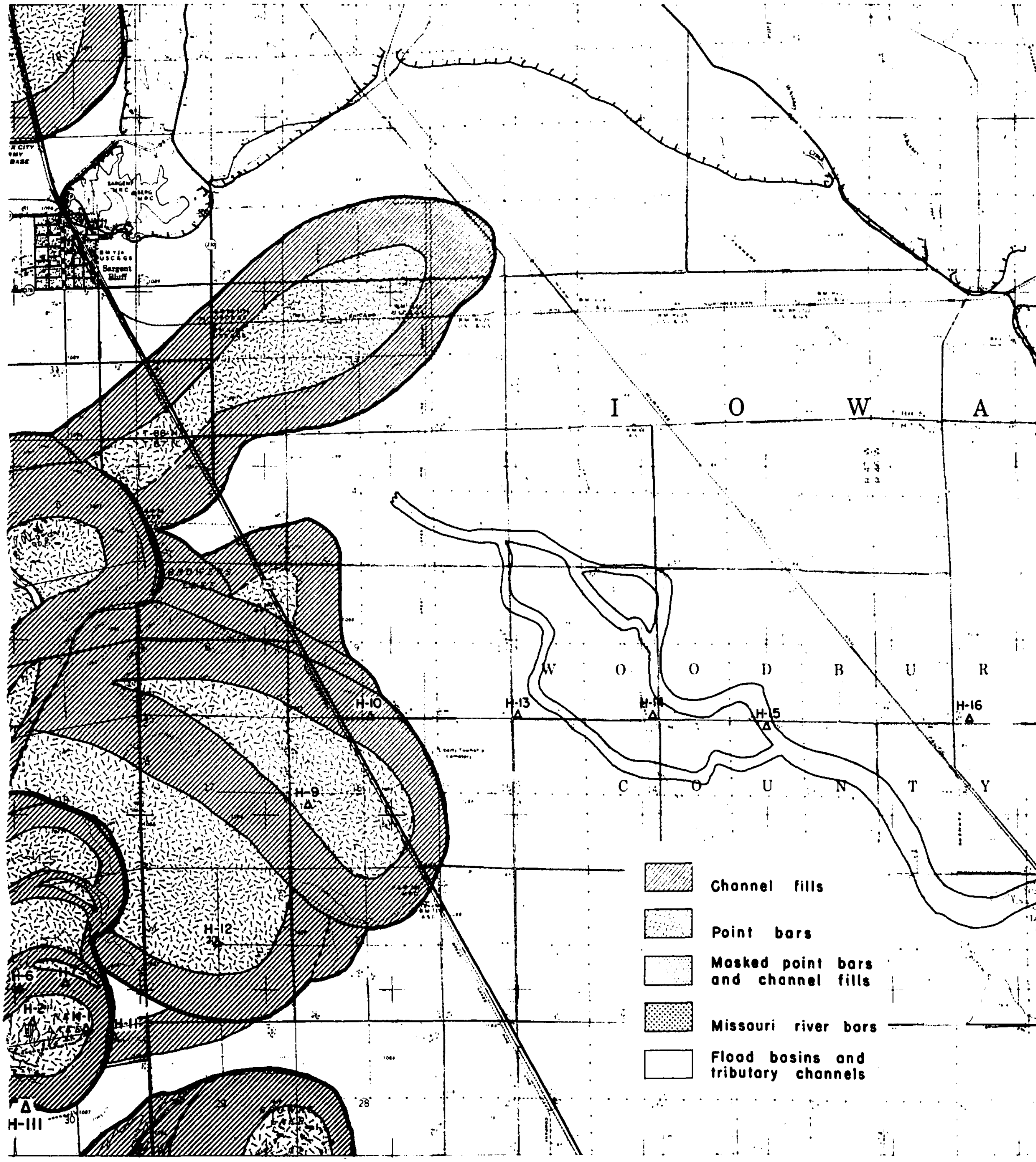
Plate 22. Alluvial geology, Map 75


N E B R A S K A
D A K O T A C O U N T
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
H-109
H-110
SHEET NO.75
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR
1946 1947



R A S K A
C O U N T
H-109
H-110
I O W A
W O O D B U R
C O U N T Y
T.88 N
T.87 N
T.28 N
T.27 N

Plate 23. Alluvial geology, Map 75L


Sargent Bluff
I O W A
W O O D B U R Y
C O U N T Y
H-10
H-13
H-14
H-15
H-16
H-9
H-12
H-6
H-2
H-11
H-111
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

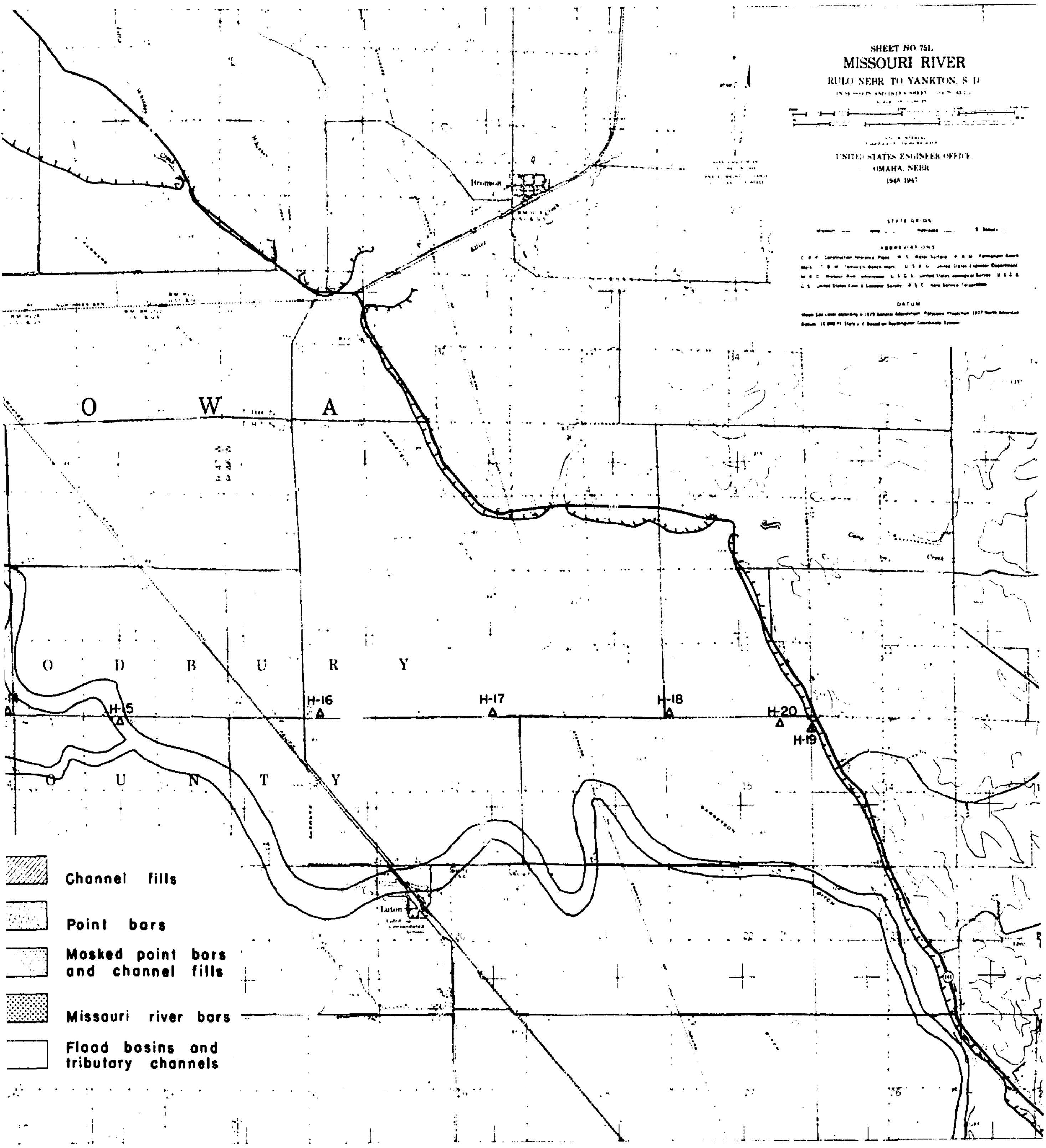
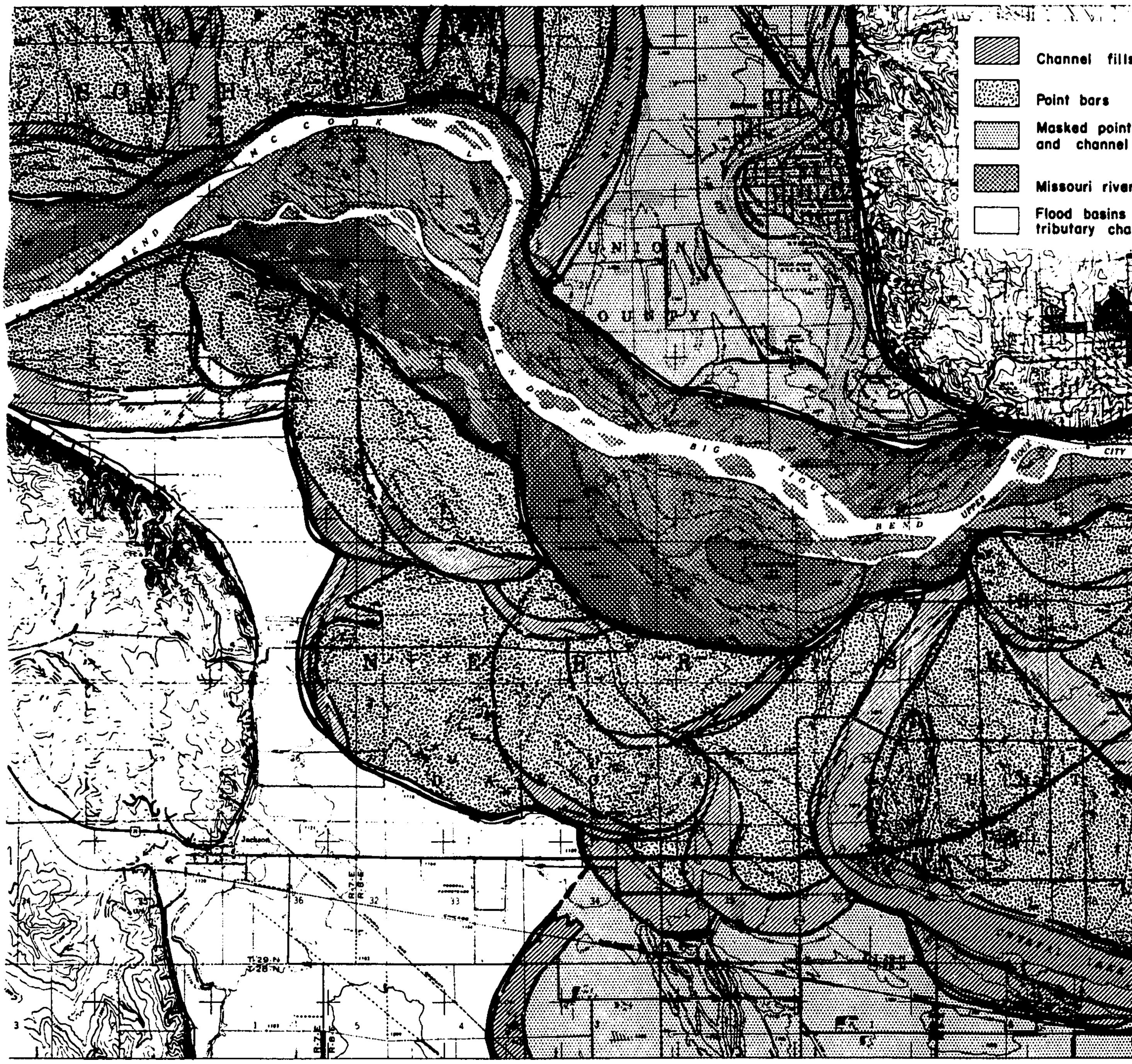

SHEET NO. 751.
MISSOURI RIVER
RULO NEBR. TO YANKTON, S. D.
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946-1947
Bronson
I O W A
W O O D B U R Y
C O U N T Y
H-14
H-15
H-16
H-17
H-18
H-20
H-19
Luton
Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels

Plate 24. Alluvial geology, Maps 76 and 76L


Channel fills
Point bars
Masked point
and channel
Missouri river
Flood basins
tributary cha
BIG SIOUX BEND
UNION
COUNTY
Jackson

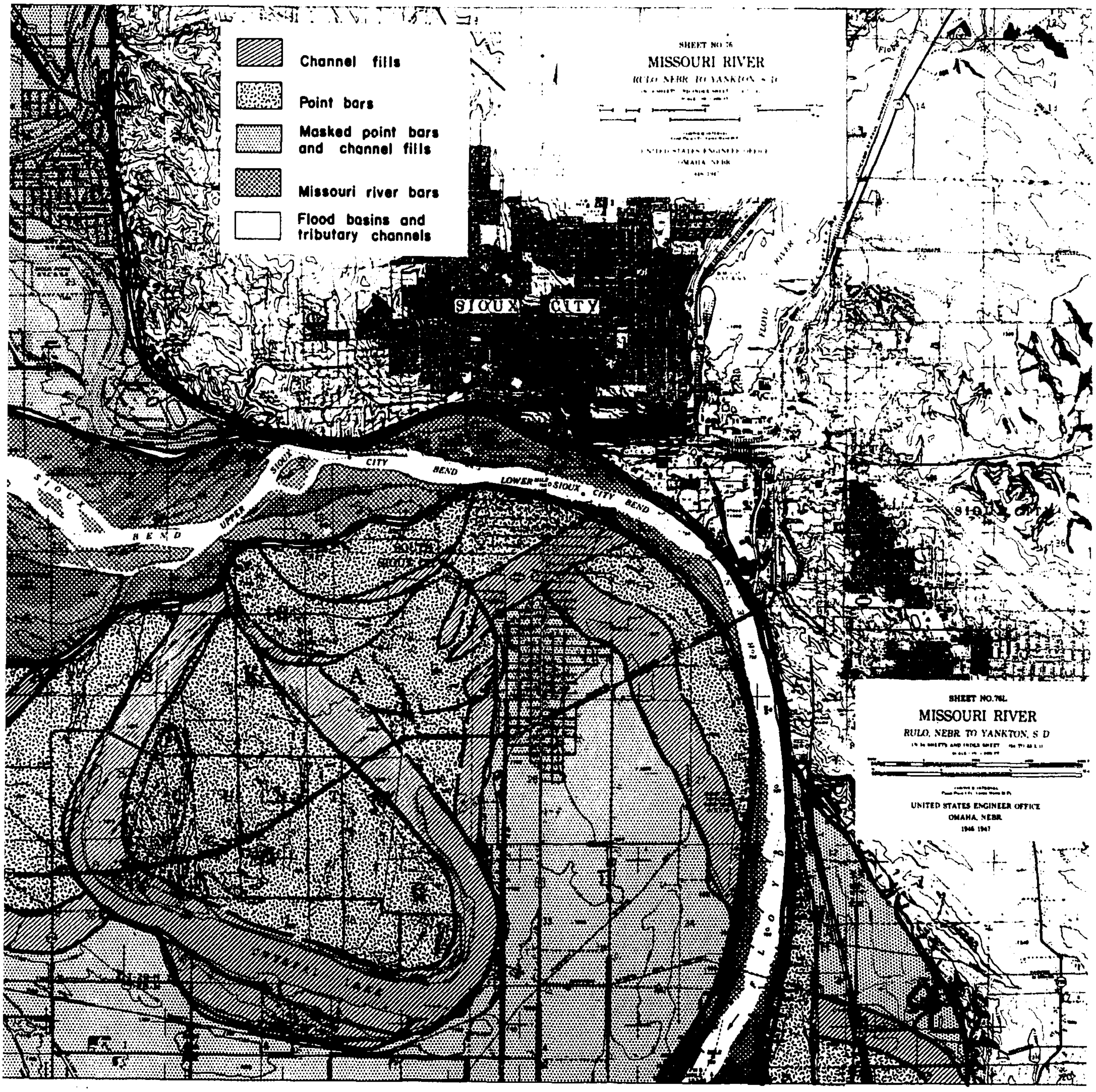

Channel fills
Point bars
Masked point bars and channel fills
Missouri river bars
Flood basins and tributary channels
MISSOURI RIVER
SIOUX CITY
SHEET NO.76L
MISSOURI RIVER
RULO, NEBR. TO YANKTON, S. D
UNITED STATES ENGINEER OFFICE
OMAHA, NEBR.
1946 1947

Plate 25. Laminated silt, exposure 1

Plate 26. Laminated silt and sand lens, exposure 2. Spade in sand for scale

Plate 27. Contact of loess and drift, exposure 3

Plate 28. Top of unit 1, exposure 4

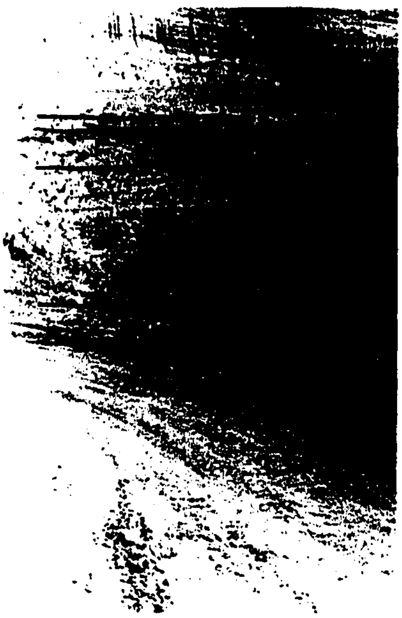

Drift
Loess

Plate 29. Units 2-7, exposure 4. Range pole in unit 5 for scale

Plate 30. Contact of loess and drift, exposure 6

Plate 31. Block of laminated silt removed from lower top-stratum, exposure 7

Plate 32. Terrace along Boyer River about 12 miles upstream from exposure 7



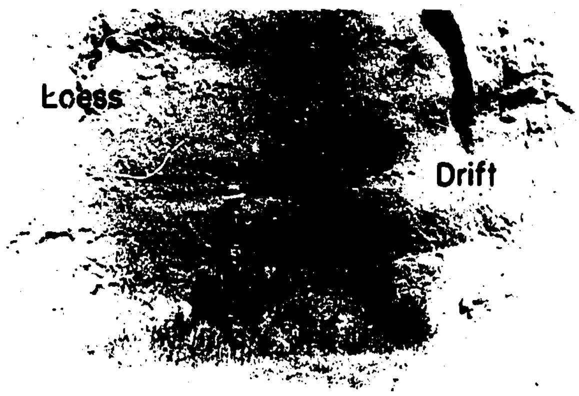

Loess
Drift

Plate 33. Loess overlying till, exposure 9

Plate 34. Close-up of laminated silt and sand in base of loess within confines of paleo-valley, exposure 9

Plate 35. Units 1-3, exposure 11

Plate 36. Psuedoanticline, exposure 12

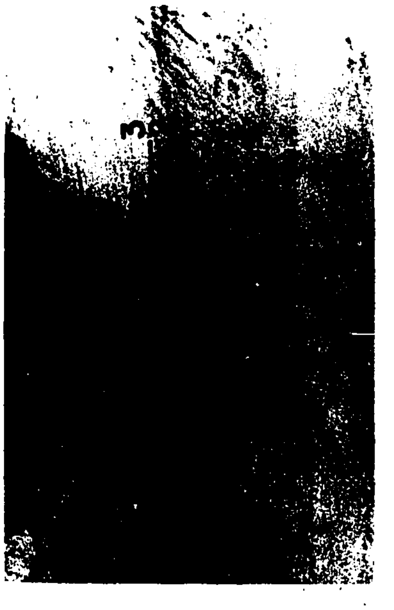


Plate 37. Blocks of semi-consolidated sandstone aligned along limb of pseudoanticline, exposure 12

Plate 38. Fault, exposure 12

Plate 39. Unit 1, exposure 13

Plate 40. Close-up of stratified silts within confines of paleo-valley cut in glacial drift, exposure 14

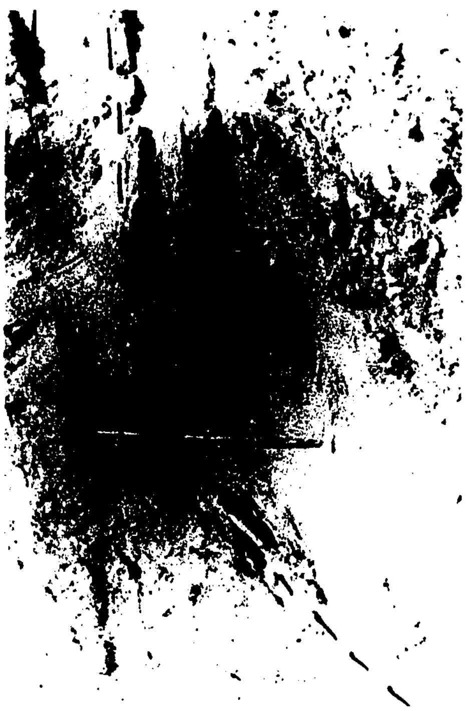


Plate 41. Stratigraphy, exposure 17. Man standing in unit 3 for scale

Plate 42. Stratigraphy 1, exposure 18. Pick in unit 3 and shovel in unit 4 for scale

Plate 43. Stratigraphy, exposure 19. Man in unit 3 for scale

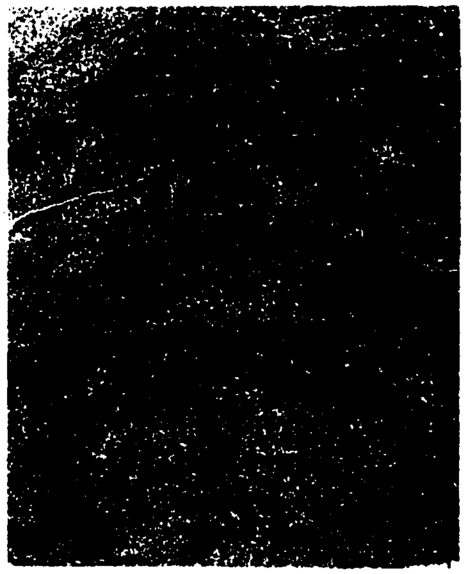
Plate 44. Pseudoanticline, exposure 20

Plate 45. Close-up of truncation along limb of pseudoanticline, exposure 20

Plate 46. Photograph of thin-section from in-place sample 91-3, X15

Plate 47. Photograph of thin-section from block of laminated silt (Logan - 1A) removed from lower topstratum, exposure 7, X15

Plate 48. Photograph of thin-section from in-place sample 97-4, X15



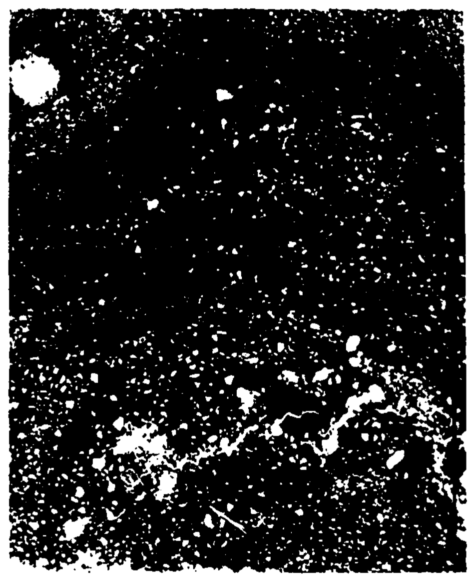


Plate 49. Photograph of thin-section from in-place sample 113-1, X15

Plate 50. Photograph of thin-section from in-place sample 114-1, X15

Plate 51. Photograph of thin-section from in-place sample 117-1, X15

Plate 52. Photograph of thin-section from in-place sample 117-4, X15

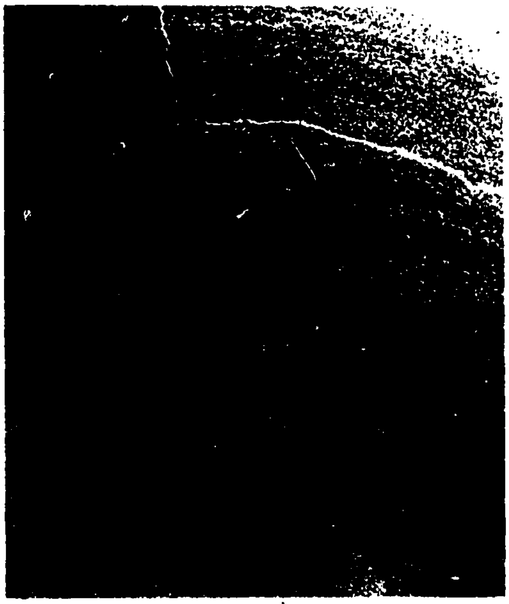
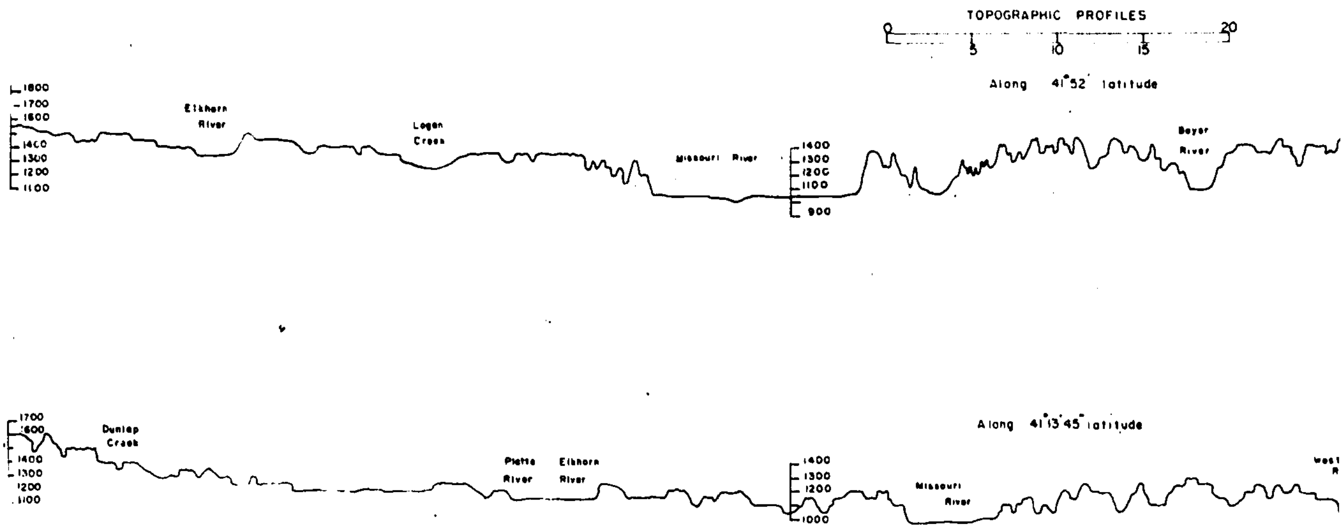


Plate 53. Topographic profiles across the Missouri River Valley in Iowa and Nebraska


TOPOGRAPHIC PROFILES
0
5
10
15
20
Along 41°52' latitude
1800
1700
1600
1400
1300
1200
1100
Elkhorn River
Logan Creek
Missouri River
1400
1300
1200
1100
900
Boyer River
Along 41°13'45" latitude
1700
1600
1400
1300
1200
1100
Dunlap Creek
Platte River
Elkhorn River
1400
1300
1200
1000
Missouri River

TOPOGRAPHIC PROFILES