CORPS OF ENGINEERS, U. S. ARMY

GEOLOGICAL INVESTIGATION OF THE ATCHAFALAYA BASIN AND THE PROBLEM OF MISSISSIPPI RIVER DIVERSION

PREPARED FOR

THE PRESIDENT, MISSISSIPPI RIVER COMMISSION

BY THE

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

UNDER THE GENERAL SUPERVISION OF

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PREFACE

The geological investigation of the Atchafalaya Basin was authorized 29 September 1950 by the Office of the Chief of Engineers as a part of a complete engineering study of the Atchafalaya River. General P. A. Feringa, President, Mississippi River Commission, on 20 October 1950 reviewed the purpose of the study and assigned responsibilities for its engineering and geological phases. Mr. R. A. Latimer, Chief Engineering Assistant, Mississippi River Commission, was designated coordinator of the entire project and was asked to prepare the final engineering report. Dr. Harold N. Fisk, Chief, Geological Research Section, Humble Oil & Refining Co., and Geological Consultant, was charged with the responsibility for the development of the complete geological study within the Atchafalaya Basin. Mr. W. J. Turnbull, Chief, Soils Division, Waterways Experiment Station, CE, was authorized to coordinate and supervise the layout of borings and the collection of soil and geological data needed for both the engineering and geological studies. The New Orleans District through Col. C. G. Holle, District Engineer, was to develop the factual data for the engineering report.

The geological investigation was carried out largely by Mr. Charles R. Kolb, geologist, Geology Branch, Waterways Experiment Station, and by Dr. L. J. Wilbert, Assoc. Professor of Geology, Louisiana State University, Geological Consultant. Assembly of the data gathered for the report, direction of field work, and preparation of the plates were the responsibility of Mr. Kolb. Dr. Wilbert assisted in those phases of the work and, together with Mr. Kolb, wrote the major part of the report. Dr. Fisk conceived and outlined the geological approach to the problem, generally supervised the program, and is responsible for the organization and conclusions reached in the report.

Mr. C. W. Schweizer, Special Engineering Assistant, Mississippi River Commission, assisted in all aspects of the report requiring coordination of engineering and geological data. Members of the staff of the Geology Branch, Waterways Experiment Station, who assisted in field investigations, the gathering of library data, or preparation of plates were Dr. J. R. Schultz, Chief of the Branch, Mr. P. R. Mabrey, Mr. W. B. Steinreide, and Mr. J. W. Cagle, geologists. In addition, the Waterways Experiment Station furnished drill crews and equipment, and the facilities of its soils laboratory and Reproduction Branch. The New Orleans District supplied drill crews and equipment for a portion of the drilling program. Mr. Edward McFarlan, Jr., geologist, Humble Oil & Refining Co., assisted in the interpretation of geological information on the Mississippi delta region.

Many organizations, including oil companies, geophysical and engineering companies, and the Louisiana State Highway Department, contributed logs of borings made in the Atchafalaya Basin region. Particular mention is due Mr. Paul H. Jones, District Geologist, Groundwater Division, U. S. Geological Survey, Baton Rouge, Louisiana, and Mr. L. W. Hough, State Geologist, Louisiana Geological Survey, for granting free access to their files and use of their equipment.

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Volume I

GEOLOGICAL INVESTIGATION OF THE ATCHAFALAYA BASIN AND THE PROBLEM OF MISSISSIPPI RIVER DIVERSION

PART I: INTRODUCTION

The Problem

1. One of the most significant problems posed the Corps of Engineers since the Mississippi River Commission was established as the guiding agency for flood control and navigation improvement on the Lower Mississippi River is the distribution and control of flood-flow south of Old River. Here a portion of the Mississippi River flow is diverted through Old River into the Atchafalaya River distributary (see frontispiece), and here the attention of the present study is focused. For the past fifty years a steadily increasing volume of water has been diverted from the Mississippi River into the Atchafalaya distributary, and there are justifiable fears that this tendency will continue or increase until eventually the Mississippi River takes this new and shorter path to the sea.

2. A discussion of the Mississippi River Commission plan for distribution of floodwaters south of the latitude of Old River is essential to an adequate statement of the problem. A hypothetical flood, called the "project flood," of 3,000,000 cfs -- a discharge approached but never actually carried by the river during the years of record -- is the basis of the plan. The levees at New Orleans are designed for only 1,250,000 cfs of this project flood; an additional 250,000 cfs can be diverted through the Bonnet Carre floodway just above New Orleans. The

remaining 1,500,000 cfs must be diverted from the Mississippi at the latitude of Old River and carried either through the channel of the Atchafalaya, or through the Morganza and West Atchafalaya floodways which flank the channel. The Atchafalaya River and its basin are, therefore, a most important part of the flood-control plan. Dredging operations were conducted in 1932-1940 to improve flow capacity of the Lower Atchafalaya Basin. These operations provided one major low-water channel from the head of the Atchafalaya to its mouth and the river has subsequently become increasingly important as an artery of navigation.

3. In contrast to the plan which utilizes the Atchafalaya as an important navigation and flood-flow route is the consideration that a steadily enlarging Atchafalaya River may eventually capture the entire Mississippi River flow. The Atchafalaya has long been recognized as an alternate and shorter route to the Gulf for Mississippi River waters. Whereas water passing the latitude of Old River must travel over 300 miles to reach sea level via the Mississippi River, water diverted through the Atchafalaya reaches sea level in slightly more than 100 miles. This sizeable advantage in gradient is thought to be one of the principal reasons for the increase in diversion of flow from the Mississippi noted during the past several decades. The trend of diversion (fig. 1) not only shows an increase in the amount of yearly discharge through Old River and the Atchafalaya, but also indicates a steadily increasing rate of diversion. By projecting the curve it can be seen that at the present rate 40 per cent or more of the Mississippi River water will be diverted into the Atchafalaya River by 1971.

4. The present geological investigation was authorized, therefore,

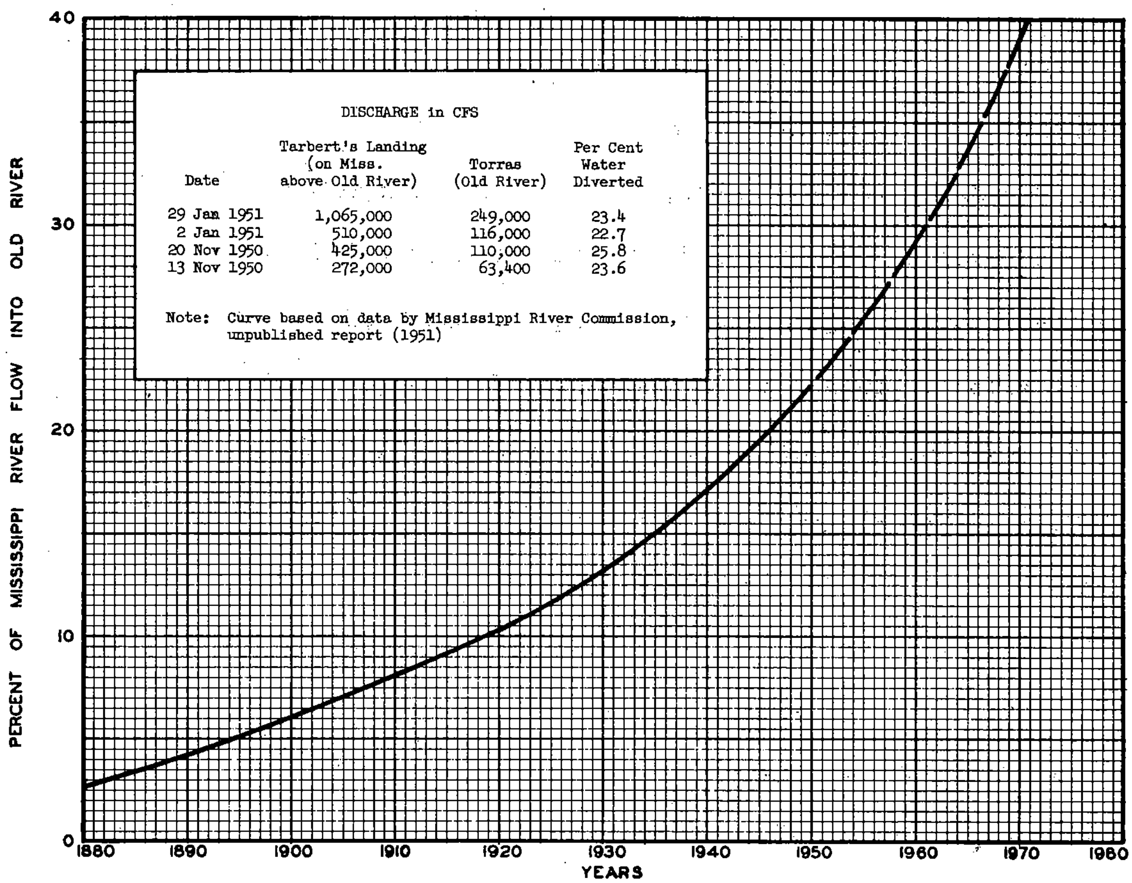


Fig. 1. Flow through Old River in per cent of total annual flow in Mississippi River

for the purpose of assembling all geologic information that might bear on the problem of Mississippi-Atchafalaya diversion. Its specific aim was to determine whether the Atchafalaya River, if left alone, would eventually capture the entire flow of the Mississippi, and if so, when.

Geological Approach to the Problem

5. The prospect of the Mississippi River being diverted into a shorter channel to the sea is not unique. In fact, geological evidence shows that this is the normal process by which the Mississippi has shifted its course during the past several thousand years. Drainage

patterns and alluvial scars on the valley surface show the positions of former courses of the Mississippi, and the arrangement of these features permits interpretation of the events which led to each river diversion. Through use of logs of thousands of borings, field observations and detailed examination of aerial photographs, it is possible to reconstruct accurately the history of Mississippi Valley alluviation and to establish the basic similarity between alluvial processes active in the past and those active today. The geologic record demonstrates that there are definite limits to which the Mississippi can extend its channel seaward. Beyond such limits, stream gradients become too low, the channel becomes untenable, a diversion arm develops, and a new and shorter route to the sea is established. The geological approach to the problem has been to determine the factors causing past Mississippi diversions and to use these factors to assess the diversion potential of the Atchafalaya River.

Sources of information and study methods

6. Aerial photographs were used in the reconstruction of the geologic history of the Atchafalaya Basin and in the delineation of its physiographic features. Photographs were available of most of the Atchafalaya Basin for the years between 1931-50. Earliest photographs (Fairchild, 1931) were found to be especially useful. They show relict drainage and old meander scars much more clearly than do those taken after cultural developments in the basin began to obscure former drainage patterns. Wherever possible, details of alluviation were checked by data available from earlier borings and borings made especially for the project. Aerial photographs were of considerable help in planning the most effective spacing of project borings. In addition, photographs of areas

in which former Mississippi River diversions occurred and of abandoned main channels were studied carefully for evidence of the causes and effects of diversions.

7. Two hundred borings were made for this study. Their purposes were to determine: (a) the nature of the Atchafalaya bed and bank materials; (b) the character of the deposits in the Atchafalaya delta; (c) the configuration of ancient and modern distributary channels and the nature of the materials filling them; (d) the over-all thickness of topstratum and substratum deposits in the Atchafalaya Basin; and (e) the nature of the deposits forming the marshes and the bay bottom along the present coast line south of the Atchafalaya Basin. A large number of logs of borings was also available from other sources. The source, type, and approximate number of borings referred to, other than the 200 project borings, are listed below.

Class A Borings (deep and carefully logged)	
New Orleans District and Waterways Experiment Station	550
Louisiana State Highway Department	150
Railroad and pipeline companies, water-well drillers, etc.	50
	750
Class B Borings (shallow and/or poorly logged)	
New Orleans District	1000
Seismic shot points (made for geophysical exploration)	8000
	9000

8. A comprehensive survey was made of published literature and of unpublished reports and documents in the files of the Mississippi River Commission. The latest and most accurate sets of maps, graphs, and charts were those prepared by the New Orleans District and the Mississippi River Commission as appendices B and C to the unpublished

"Atchafalaya River Study." Much use is made of these data in the present report. A large number of earlier maps, graphs, and charts was also examined in order to determine changes in Atchafalaya banklines and channel cross sections and growth of the Atchafalaya delta. The effects of cultural developments such as dredging, levee building, and railroad and highway construction were carefully studied.

9. Suspended-load and bed-load samples were taken by the New Orleans District at selected stations along the Mississippi River above and below Old River, within the Old River channel, and in the channels of the Red and Atchafalaya Rivers, in order to determine the distribution of sediment load at the present point of diversion and downstream from it. These samples were compared and correlated with samples taken at similar stations in the early 1930's.

10. Detailed studies were made of the processes active in the rapid growth of the Atchafalaya delta. Type, source, and thickness of the deltaic deposits were tested to aid in determining the rate of lengthening of the Atchafalaya River and the time of ultimate establishment of a single channel to the sea. Deposits which will eventually form the bed and banks of the Atchafalaya, i.e., the coastal marsh and bay bottom deposits south of the basin, were also studied to determine their effect on the enlargement of the Atchafalaya River.

11. Distributary channels of the modern Mississippi and ancient Lafourche-Mississippi and Teche-Mississippi deltas were examined to establish the processes by which these deltas were built, the character of distributary channels as related to the deposits across which they advanced seaward, and the nature of the sediments filling the

channels. The ultimate purpose of this portion of the investigation was to determine the rate and method by which the Atchafalaya River will advance its delta following the establishment of a single channel.

12. Past Mississippi diversions were critically examined to determine the factors which influenced their occurrence. Aerial photographs of points of former diversions and areas in the former main channel downstream from these points were studied to determine the method and rate of deterioration of a former main channel after abandonment by the main flow. The most recent diversion of the Mississippi, that which brought about abandonment of its Lafourche course below Donaldsonville, was the subject of a special study. Borings, aerial photographs, and field observations were used to reconstruct the history of this latest change in Mississippi River flow.

PART II: THE ATCHAFALAYA RIVER AND ITS BASIN

13. The Atchafalaya River is the principal distributary of the Mississippi River, and for the past decade has carried a discharge exceeded by few other rivers in the United States. Virtually all of this discharge is derived from the Mississippi River, through the short connecting channel known as Old River, and from the Red River which joins the Atchafalaya near its head (see frontispiece). Under certain conditions (that is simultaneous flood stage in Red River and average stage in Mississippi River) flow in Old River is toward the Mississippi, but such occurrences have become increasingly rare in the last few years. Records show an average annual increase in Atchafalaya flow (fig. 1), caused entirely by the progressively greater volume of Mississippi water being diverted into this distributary. Discharge at the present time averages about one-fourth that of the Mississippi above the point of diversion. The river is 143 miles in length from its junction with the Mississippi to Atchafalaya Bay, an inlet of the Gulf of Mexico; however, during most of the year, it reaches sea level, in approximately 100 miles at the point where it empties into Grand Lake. A single, deep channel exists in the upper 52 miles of the river. Moderate to very shallow depths characterize the lower channel.

Physical Features

The Atchafalaya River

14. The Atchafalaya River is a complex stream which flows partly in its own channel, partly in a channel inherited from other streams;

which possesses a single channel for only part of its length; which builds a delta into a lake system along its course; and which finally conducts the water from the lake system into an arm of the sea by means of several channels. Because of the complex nature of the stream and the distinctive features of its several component parts, the Atchafalaya River is divided into five segments for purposes of description (fig. 2).

15. Old River. Old River, which marks the lower arm of a cutoff meander loop of the Mississippi, extends for six miles from its junction with the Mississippi to a point five miles above Simmesport, where it joins the Red River to form the head of the Atchafalaya River proper. Channel depths vary from 60 to 130 ft.

16. Leveed Atchafalaya River. This segment extends from the junction of Red and Old Rivers to the end of the artificial levees bordering the channel on both sides to river mile 52. The west bank levee extends an additional 16 miles downstream, and is not present from the head of the Atchafalaya to Simmesport. Throughout this segment the river follows a single, well-defined channel varying in depth from 80 to 180 ft. The river is comparatively straight and has few

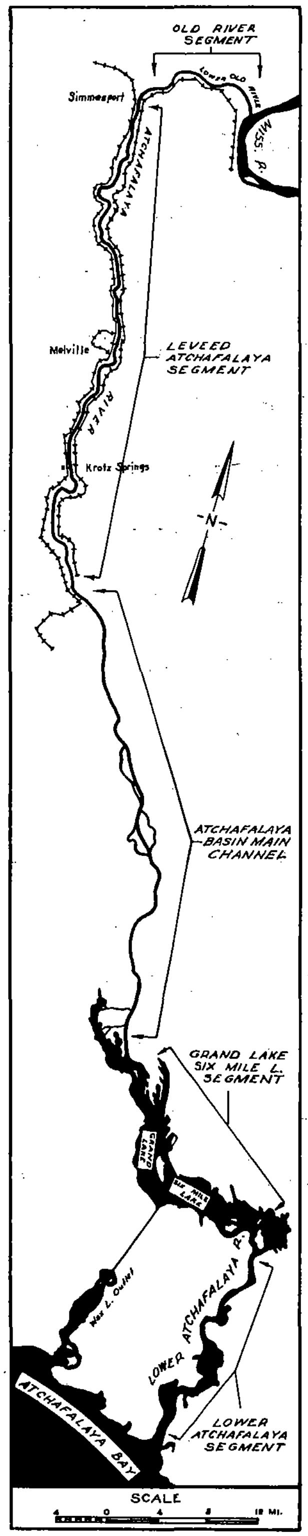


Fig. 2.
The Atchafalaya River

meander loops such as characterize most streams in the Mississippi alluvial valley.

17. Atchafalaya Basin main channel. South of the leveed segment, the Atchafalaya channel under natural conditions separated into numerous small, shallow streams which emptied in a typical deltaic pattern into Grand Lake, approximately 50 miles downstream. Dredging and other improvements since 1932 have resulted in the development of a channel which carries the main flow across the accumulation of Atchafalaya River deltaic deposits that have been gradually filling Grand Lake. During flood and high-water stages, considerable amounts of water are carried along subsidiary channels to the head of Grand Lake; for example, the Bayou L'Embarras-Lake Rond channel carries as much as 60 per cent of the total discharge. The Atchafalaya Basin main channel is approximately 44 miles long and varies in depth from 40 to 80 ft.

18. Grand Lake-Six Mile Lake. These two inter-connecting lakes form a stilling basin for water draining into the low southern end of the Atchafalaya Basin. Both are being rapidly alluviated by the growth of the Atchafalaya delta and have been much reduced in size during historic time. Underwater channels averaging eight or more feet in depth, apparently extensions of the Atchafalaya Basin main channel, are developing across this lake area. The length of this segment of the river is approximately 18 miles.

19. Lower Atchafalaya River. The natural outlet for the Atchafalaya Basin system is Lower Atchafalaya River. The main flow from the basin enters it by way of Berwick Bay from Six Mile Lake through Stouts Pass and from Flat Lake through Drews Pass, and flows across approximately 20 miles of coastal lowlands into Atchafalaya Bay and the Gulf of Mexico. A channel

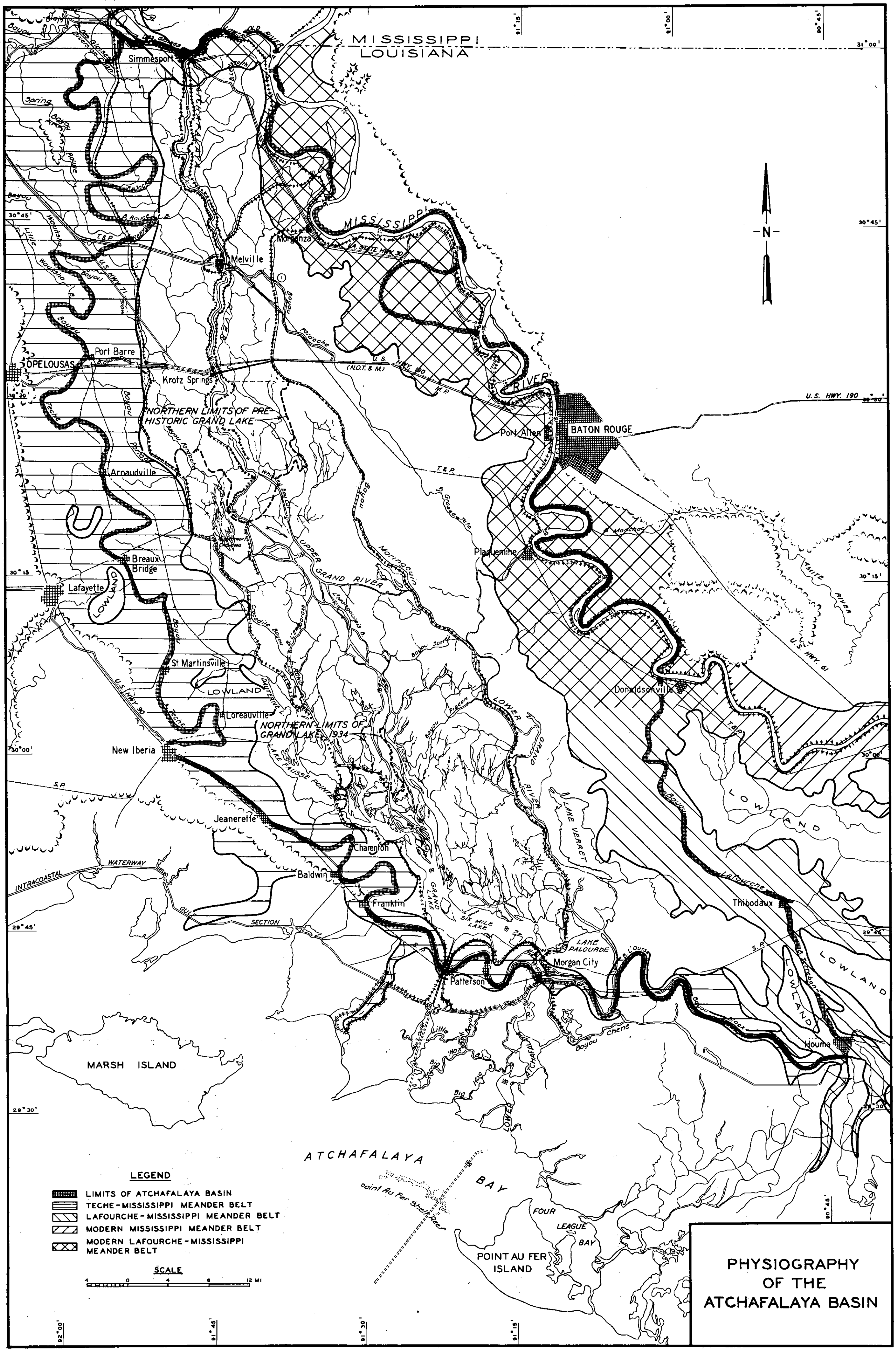
varying from 50 to 140 ft in depth characterizes most of its length, but shallows to a 6-8-ft depth entering Atchafalaya Bay.

The Atchafalaya Basin

20. The Atchafalaya River flows through a low, well-drained basin within the Mississippi Alluvial Valley covering an area of about 3,000 square miles (fig. 3). The basin extends in a general southerly direction for more than 100 miles from the latitude of Lower Old River and Bayou des Glaises to the southern end of Six Mile Lake near Morgan City, and eastward from the Mississippi River and Bayou Lafourche to the vicinity of Bayou Teche (an average distance of 30 miles). The basin surface slopes gently seaward from an elevation of approximately 40 ft msl near its northern limits to an average elevation of 10 ft msl in the latitude of Krotz Springs, Louisiana. South of Krotz Springs, the basin surface gradually slopes to sea level and is under water for much of the year. Permanently dry land areas in this southern portion are mostly restricted to narrow natural levees which have developed along major stream channels.

21. The Atchafalaya Basin is bounded by alluvial ridges which mark the positions of the meander belts of ancient Mississippi River courses. These ridges are formed mainly of bar accretions laid down within stream meanders and are capped by the broad natural levees of the Mississippi and by narrow natural levees along minor streams which flowed in the abandoned Mississippi channel. Secondary ridges, consisting mainly of natural levees, mark the position of minor active drainage lines within the basin.

22. Principal alluvial ridges. The most prominent ridges are those



PHYSIOGRAPHY OF THE ATCHAFALAYA BASIN
LEGEND
LIMITS OF ATCHAFALAYA BASIN
TECHE-MISSISSIPPI MEANDER BELT
LAFOURCHE-MISSISSIPPI MEANDER BELT
MODERN MISSISSIPPI MEANDER BELT
MODERN LAFOURCHE-MISSISSIPPI MEANDER BELT
SCALE
4 0 4 8 12 MI
MISSISSIPPI
LOUISIANA
MISSISSIPPI RIVER
OLD RIVER
Simmesport
Morganza
Melville
Port Barre
OPELOUSAS
Krotz Springs
NORTHERN LIMITS OF PRE-HISTORIC GRAND LAKE
BATON ROUGE
Port Allen
Arnaudville
Breaux Bridge
Lafayette
LOWLAND
UPPER GRAND RIVER
Plaquemine
St. Martinsville
Loreauville
NORTHERN LIMITS OF GRAND LAKE, 1934
New Iberia
Donaldsonville
LOWER RIVER
LAKE VERRET
LAKE FAUSSE POINTE
Jeanerette
Charenton
Baldwin
Franklin
GRAND LAKE
SIX MILE LAKE
LAKE PALOURDE
Morgan City
Patterson
Thibodaux
Houma
INTRACOASTAL WATERWAY
GULF SECTION
MARSH ISLAND
ATCHAFALAYA BAY
Point Au Fer Shell Reef
FOUR LEAGUE BAY
POINT AU FER ISLAND
U.S. HWY. 190
U.S. HWY. 61
U.S. HWY. 90
U.S. HWY. 71
AMITE RIVER
N
31°00'
30°45'
30°30'
30°15'
30°00'
29°45'
29°30'
92°00'
91°45'
91°30'
91°15'
91°00'
90°45'

Fig. 3.

which delimit the basin. The Teche ridge (labeled "Teche-Mississippi Meander Belt" on fig. 3) forms the western and southern basin boundaries. The channel is occupied by several streams (parts of Bayous Jack, Rouge, Negro Foot, Wauksha, and Courtableau; all of Bayou Teche; and part of Lower Atchafalaya River, Berwick Bay, Bayous Boeuf, L'Ourse and Black) the longest of which is Bayou Teche. Alluvial ridges along Bayou des Glaises, Atchafalaya River (from its head to Simmesport), and Lower Old River limit the basin on the north. The eastern boundary is formed by ridges along the Mississippi River extending from the head of Old River to Donaldsonville and by those flanking Bayou Lafourche from Donaldsonville to Houma, La. At Houma, the Lafourche ridge is built over the Teche ridge, completely enclosing the basin. Near their distal ends the Teche and Lafourche ridges break up into a number of minor ridges, resembling the pattern of distributaries in a delta. The ridge along which the Atchafalaya River flows extends down the center of the basin from Simmesport to Krotz Springs. Farther south, it gradually diminishes in height until it virtually disappears a few miles north of Grand Lake. These features are illustrated in figure 3. Ridges which flank Bayous Maringouin and Grosse Tete are roughly parallel to the Atchafalaya River from Morganza to the latitude of Plaquemine, and these also gradually disappear southward.

23. Between ridges the basin surface has little relief. A few low arcuate features having the dimensions of the Red and Mississippi Rivers meander loops are discernible from aerial photographs but cannot be followed as uninterrupted ridges. These are remnants of very ancient alluvial ridges now largely buried beneath more recent deposits of the

Atchafalaya Basin.

24. Drainage. The Atchafalaya River does not drain the northern portion of the basin. Streams in the inner ridge areas are not integrated into an efficient system but wander freely in complex drainage networks over the area and empty eventually into lakes in the southern part of the basin. A few of the larger streams, such as Bayou Courtableau, were under natural conditions tributaries of the Atchafalaya River, and a few, such as Alabama Bayou, served as distributaries. Their connections with the river have been severed by the construction of artificial levees along the Atchafalaya.

25. Construction of railroad or highway embankments across Atchafalaya Basin in the latitudes of Simmesport, Melville, Krotz Springs, and Atchafalaya, building of artificial levees along the Atchafalaya River, and erection of guide levees of the West Atchafalaya and Morganza floodways from the northern to the southern basin boundaries (plate 1), completely altered natural drainage. Normal drainage into the Atchafalaya River was interrupted, and water was channeled into the lake system in the southern portion of the basin where it passes through openings in the transbasin railroad and highway embankments built between the artificial river levees and the floodway guide levees. South of the leveed portion of the Atchafalaya River where the Morganza and West Atchafalaya floodways merge into a single floodway, a sheet of water from 15 to 20 miles wide flows seaward during flood stages.

26. Lake areas. The low southern part of the Atchafalaya Basin contains a system of shallow lakes covering approximately 150 square miles. They are the centrally located Grand Lake-Six Mile Lake water

body, Lake Fausse Pointe on the west, Flat Lake and Lake Palourde on the east, and Lake Verret which lies north of Lake Palourde.

27. Drainage between the modern, separate, smaller lakes of the basin is accomplished either by direct connection or by a network of swamp streams. Natural drainage from Flat Lake into Lake Palourde has been prevented by the artificial levees of the Morganza floodway. Waters from the lakes leave the basin by means of outlets across Teche ridge. Most of the outlets eventually enter the Lower Atchafalaya River.

28. South of the latitude of Krotz Springs most of the land surface of the basin has been built by deposits that accumulated in a much larger ancestral Grand Lake. Distribution of Indian mounds that appear to have been located on the shores of this ancient lake, and the distribution of deposits built out into it by the Atchafalaya River in recent years, indicate that the several lakes now separated by miles of low swampy land were once a single water body. Heaps of shells of fresh and brackish water clams on which Indians subsisted mark former occupation sites. Detailed examination of aerial photographs and information obtained from borings strongly suggest that pre-historic Grand Lake extended as far north as the latitude of Krotz Springs (fig. 3).

29. Lowlands south of the Atchafalaya Basin. On the southern side of Teche ridge is a strip of marshlands 15 to 25 miles wide (approximately 1300 square miles in area) which forms part of the extensive Louisiana coastal marshes. The Lower Atchafalaya River crosses these marshes and carries the drainage of the Atchafalaya Basin into Atchafalaya Bay. The marshlands contain many lakes, including Bateman Lake, Sweet Bay Lake, Lake Decade, Four League Bay, and a large number of smaller water bodies

and shallow, sluggish streams. Water from most of the lakes finds its way into the Lower Atchafalaya River, joining drainage from the Atchafalaya Basin proper. Some drainage water is also added to the Lower Atchafalaya from marshlands and lakes to the east and west, and some water flows into Lake Decade and Four League Bay and thence directly into Atchafalaya Bay (fig. 3). Wax Lake, west of Lower Atchafalaya River, is connected to Six Mile Lake within the Atchafalaya Basin by an artificially constructed channel across Teche ridge. Bayou Chene, which drains Lake Palourde through Bayou Black, is a minor outlet for the basin.

History of Atchafalaya River Development

Early history

30. Reconstructions based on geologic evidence(9)* show that conditions for the formation of the Atchafalaya distributary were established about the year 1500 (plate 2). According to Elliott(4), a map dated 1578 drawn by Monk Ptolemy, who accompanied DeSoto's expedition in 1542, shows conclusively that the Atchafalaya then, as now, served as an outlet for the Mississippi.

31. Accounts of later visitors to the Atchafalaya Basin reflect its impassability. Highly cultivated and well-populated communities quickly developed on the alluvial ridges of the Teche and Lafourche which flanked the region, but no overland trails of any consequence crossed the basin; only water transportation was feasible. The most

* Numbers in parentheses refer to sources listed in selected bibliography at the end of this report.

traveled route across the basin was by way of Bayou Plaquemine, through Upper Grand River and Bayou Courtableau to the Teche at Opelousas. The Atchafalaya River itself was a minor stream, choked by a raft of logs at the upper end. It was joined near the present end of its leveed segment by Bayou Courtableau and flowed diagonally across the basin along the modern Upper Grand River. At its junction with the Plaquemine, the Atchafalaya flowed south along what is now Lower Grand River and emptied into the lake area north of Berwick Bay. Darby's map of Louisiana (1816) shows this relationship (see fig. 4). He refers to the entire stream as the Atchafalaya. South of the cross-basin portion now represented by Upper Grand River, Darby shows only minor dendritic drainage into a very large Grand Lake, which he calls Lake Chetimaches. The over-all accuracy of this map is too great to suspect the cartographer of very serious error, and it can be stated with some degree of certainty that only since Darby's time has a channel of any considerable size been developed which carries water to the head of Grand Lake.

Raft of logs

32. As could be expected, cultural development of the region progressed from the higher, better-drained northern part of the basin southward toward Grand Lake and its adjacent swamplands. A raft of logs blocked the Atchafalaya from its head for a distance of perhaps 20 miles downstream. Darby(1) describes the raft as follows:

> "The mass of timber rises and falls with the water in the river, and at all seasons maintains an equal elevation above the surface. The tales that have been narrated respecting this phenomenon, its having timber of large size, and in many places being compact enough for horses to pass, are entirely void of truth. The recent formation [Darby states elsewhere that the raft began to form about 1778]

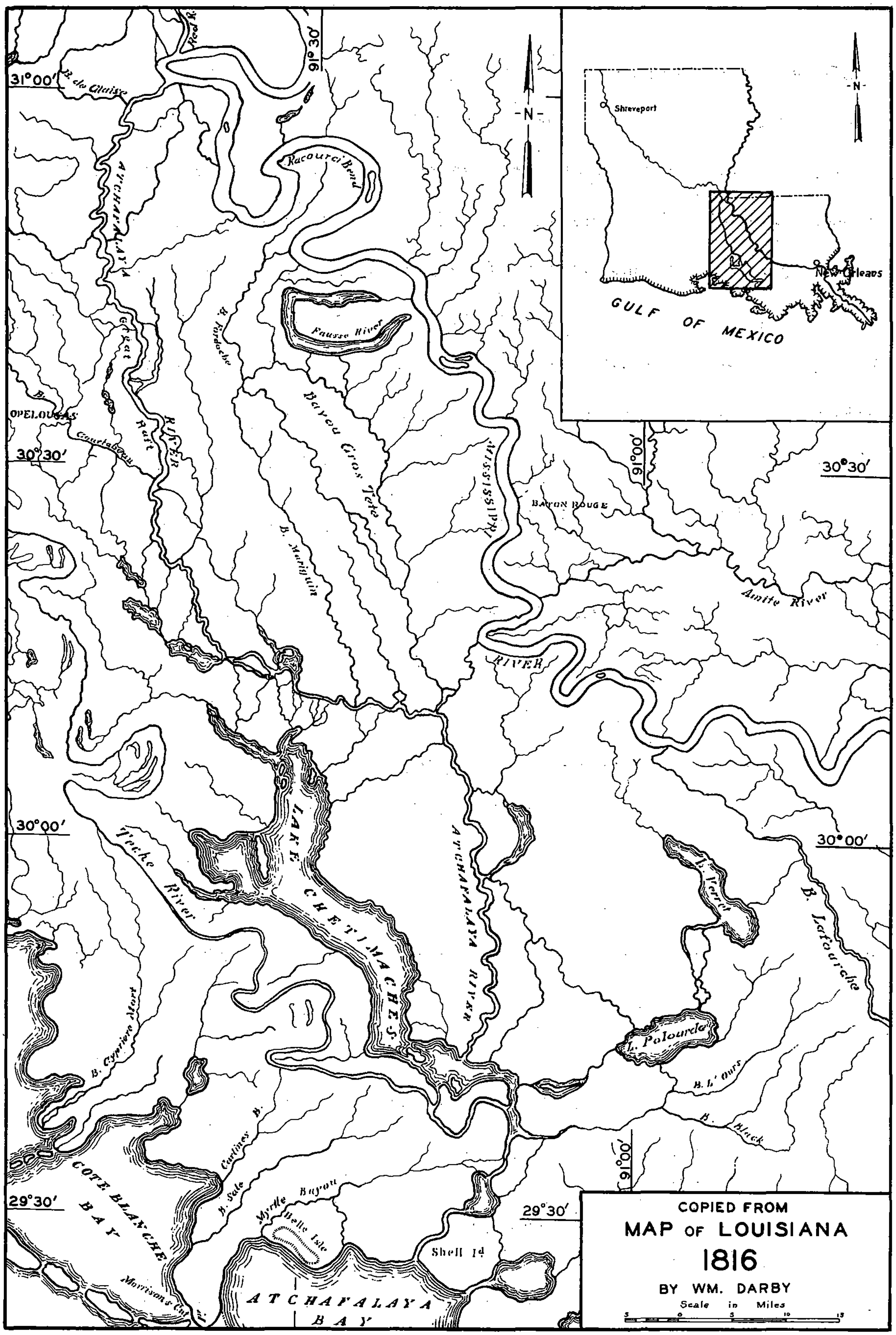

COPIED FROM
MAP OF LOUISIANA
1816
BY WM. DARBY
Scale in Miles
31°00'
30°30'
30°00'
29°30'
91°30'
91°00'
Shreveport
New Orleans
GULF OF MEXICO
Racourci Bend
Fausse River
Bayou Gros Tete
MISSISSIPPI
RIVER
BATON ROUGE
Amite River
ATCHAFALAYA
RIVER
OPELOUSAS
Teche River
LAKE CHETIMACHES
ATCHAFALAYA RIVER
L. Verret
L. Palourde
B. Lafourche
B. L'Ours
B. Black
COTE BLANCHE BAY
ATCHAFALAYA BAY
Belle Isle
Myrtle Bayou
Shell Id
Morrison's Cut
B. Sale
Red R.

Fig. 4.

renders either the solidity of its structure, or the growth of large timber impossible. Some small willows and other aquatic bushes are frequently seen amongst the trees, but are too often destroyed by the shifting of the mass to acquire any considerable size."

33. The Atchafalaya at that time was connected directly with the Mississippi (see plate 2) and trapped much of the floating debris from the parent stream. In 1831 Shreve's cutoff isolated this bend and the Atchafalaya raft ceased to grow. As described in the "Atchafalaya River Study"(21):

"The first effort toward removing [the raft] was made in 1839 by citizens who resided on the river. Constant appeals to the State for aid, without success, induced a few citizens of the Atchafalaya, under the direction of Captain Laird, to take the remedy in their own hands, and availing themselves of one of the seasons of greatest drought, they set fire to the raft. The water in 1839 was so low that foot passengers, by means of a plank 15 feet long, could walk across the river. The fire swept over the raft, some twenty miles in extent, destroying thousands of alligators and burning off the immense mass of timber to the water's edge, but it did not remove the raft below the water. The State of Louisiana, in 1840, undertook the removal of the raft, using snagboats, and the raft was cleared to the extent needed for steamboat travel, in April, 1842. This cleared channel was not permanent, however, as the State Engineer of Louisiana reported in 1847 that the Atchafalaya was filled with raft and floating drift from a point two miles above Pigeon Bayou to within seven miles of its head. These rafts were broken up from year to year and evidently they were all removed before 1855."

34. The Mississippi River Commission report of 1881(22) stated:

"......Immediately upon the removal of the obstruction from the upper part of the stream, its rapid enlargement commenced. Portions of the raft that had been left, as not endangering navigation, were washed out piecemeal, the bed was deepened, and heavy caving was started in the bends and on both sides of narrow reaches. Lands previously exempt from overflow were annually submerged by the increasing volume from above and the nonextension of proportional relief through the lower reaches of the stream........"

"First the profits and then the capital of the owners was absorbed in building and raising levees to restrain the augmenting floods from above, for which no adequate discharge below was provided ...."

"Then followed general abandonment of this naturally favored region to the hunter and the raftsman."

Development of Old River

35. The stages in development of Old River segment of the Atchafalaya distributary are shown on plate 2. A map made in 1838, seven years following Shreve's cutoff, depicts rapid silting of the lower arm near its junction with the Mississippi. Some narrowing of the abandoned channel and a great deal of shoaling were no doubt also taking place. By 1854-55 sizeable bars had formed at the Red River's junction with the upper arm, but the arm was essentially open its entire distance to the Mississippi. The lower arm, on the other hand, was closed at the point of cutoff, and a canal through the silted area was proposed by the Louisiana State Engineer. In addition, the Mississippi River had meandered considerably to the south from the original point of cutoff, so that the oxbow lake formed by Old River was almost isolated and a sharp entrance angle existed between the waters of the Red flowing through Upper Old River and the Mississippi.

36. Lower Old River is described in the Mississippi River Commission report of January, 1881(22) as:

"......a wide, shallow, slack-water basin, receiving sediment alternately from the Mississippi and Red Rivers..... By 1875 this process had nearly closed low-water connection; and the waterway near the lower end of Turnbull's Island was only about 100 feet wide and 20 inches deep, with a fall of about 2 feet in a quarter of a mile towards the Atchafalaya."

The report continues that it was only through extensive dredging by the

State of Louisiana of a bar which formed yearly at the head of Old River that a channel between the Atchafalaya and the Mississippi could be maintained.

37. As the Atchafalaya channel increased in size (undoubtedly due to raft clearance) additional amounts of Red River water were diverted down the Atchafalaya distributary, and by 1883 considerable silting was in evidence in both the upper and lower arms of Old River. Had no dredging been done the Red, using the Atchafalaya channel, and the Mississippi would have probably flowed in separate channels to the sea.

38. In 1891, a sill and dam were built across the Atchafalaya River just south of the former junction of the Red with the Mississippi. The purpose of the dam was to force the Red River, when below a certain low stage, to discharge its flow through Upper Old River into the Mississippi. The dam was sporadically maintained and finally abandoned in 1896, after which the upper arm of Old River silted up entirely. Only a series of elongate lowlands now marks its former course.

39. In the meantime, the lower arm of Old River became the principal navigation route.

> "The Louisiana Railway and Navigation Company used the Lower Old River channel for transporting railroad equipment and cargoes from their incline at Angola on the east bank of the Mississippi to their incline on the Red River at Naples. With the exception of a few years, maintenance of this channel required annual dredging in the Mississippi River at the mouth of Old River until 1937. Ferry transportation service over this route was discontinued after the combination railroad and highway bridge was erected at Simmesport in 1927-28"(21).

40. By 1940 dredging for maintenance of a channel through Lower Old River was a thing of the past. Rapid enlargement began. Where

formerly water flowed from Old River into the Mississippi an average of fifty days out of every year, between 1942 and 1950 there were only nine days on which this reversal of flow was recorded.

41. Carr Point cutoff was made in 1944 providing a shorter path for Mississippi River water diverted into Old and Atchafalaya Rivers. Shortly after this cutoff was made, the northern span of an abandoned railroad bridge, which crosses Old River about two miles west of its entrance into the Mississippi, fell into a rapidly enlarging river. In 1949 and 1950 revetments were placed on the banks upstream and downstream from the junction of Old River with the Mississippi as the latter stream began a rapid westward migration in the area.

Levee construction

42. By 1881 levees had been built by private interests from Simmesport downstream 26 miles on the west bank and to approximately half that distance on the east bank. In that year levees were also built on the south side of Bayou des Glaises and Old River, channeling floodwaters down the river rather than through the lowlands flanking the river. These levees were subject to general crevassing during the 1882 high water when a discharge of 281,000 cfs is reputed to have gone down the Atchafalaya. Between 1882 and 1900 levees were enlarged and extended downstream, and by 1900 they flanked both sides of the stream as far south as Melville, and by 1910 had been extended to Krotz Springs. Plate 1 shows approximate positions of the ends of the levees along the Atchafalaya at the time of completion of these extensions.

Sill dams

43. By 1882 enlargement of the Atchafalaya had reached the point

where attempts were made to control its flow with brush and stone sill dams. The dams were to be built up to just below low water in order to permit the passage down the Atchafalaya River of a volume of flow equal to the flood discharge of Red River. Two such sill dams were built. One was completed in 1888 at the general location of the present highway and railroad bridge at Simmesport and was built up to six feet below low water; the other was completed in 1889 approximately one-half mile downstream. These dams were maintained until 1920, after which partial maintenance was carried out by the Louisiana Railway and Navigation Company in connection with building their bridge across the river in this locality. Maintenance by the L. & R. ceased after 1934. Remnants of the sills which obstructed the channel were removed in 1939-40 during the dredging operations described below.

Dredging

44. A program of dredging was begun in 1932 in order to improve the discharge capacity of the Atchafalaya River (see plate 1). One of the principal deterrents to enlargement was believed to be the tortuous maze of deltaic channels into which the river branched south of its leveed segment. Between 1932-40 a single channel was dredged through this area with an over-all 250-ft bottom width and a depth of 40 ft below mean Gulf level. More than 100,000,000 cu yd of earth were dredged in this portion of the river.

45. In 1938 dredging began in the upper, leveed segment of the Atchafalaya. The entrance angle at the junction of the Old, Red, and Atchafalaya Rivers was improved. The channel was enlarged at the railroad bridges which crossed the river at Simmesport, Melville, and Krotz

Springs, and to a minor extent in other parts of the leveed channel. Carr Point cutoff was dredged at the Old-Mississippi junction in 1944-45. About 22,000,000 cu yd were dredged in the leveed channel. Wax Lake Outlet, 15 miles in length, with a channel 300 ft wide and 45 ft below sea level, was completed in 1941 and provided an additional outlet for waters through the marshes south of the basin.

Characteristics of the Modern Atchafalaya River

46. During the fifty years in which the Atchafalaya has developed from a minor distributary into one which threatens capture of the Mississippi, the Corps of Engineers has kept nearly continuous records which document its enlargement. The Mississippi River Commission's "Atchafalaya River Study"(21) presents these data in tabular and graphic form. Published reports and articles which contain portions of these data include references 22, 23, 26, and 30 in the bibliography. The paragraphs below are intended only as a summary of the principal hydraulic data on the Atchafalaya River.

Length

47. The Atchafalaya distributary from its head, at the junction of the Old River segment with the Mississippi River, to Atchafalaya Bay is 143.8 miles in length. It reaches approximate Gulf level at Grand Lake 105 miles below its head. In contrast, the length of the Mississippi below Old River is 332.0 miles to the mouth of Southwest Pass and 301.8 miles to Head of Passes (approximate Gulf level).

Slope

48. The average slope of the water surface of the Atchafalaya,

though steeper than that of the Mississippi, is relatively flat in the leveed segment of the river, steepens markedly as the water passes from this confined segment into the area below the levees, and flattens again approximately 20 miles downstream (see plate A). The slope of mean stage flow averages one foot in three miles. Slopes are becoming progressively flatter. The "Atchafalaya River Study"(21) cites the following example:

> "For a discharge of 350,000 in 1929 at Simmesport, the water surface was 49 feet msl, and for the same discharge at Atchafalaya, La., 54 miles downstream the water surface was 22.5 ft msl with a head differential of 26.5 ft. In 1950, the water surface elevation for a similar discharge was 39.5 ft. at Simmesport, and at Atchafalaya was 26 ft. msl giving a head differential of 13.5 feet. These comparisons indicate a lowering of 9.5 feet in water elevation at Simmesport and an increase in elevation of 3.5 feet at Atchafalaya, La."

Discharge

49. A maximum discharge of 660,000 cfs was recorded in the leveed segment of the Atchafalaya at Simmesport in 1945; 703,000 cfs was recorded passing Morgan City in 1927. Discharge through the distributary has increased, since 1900, from 5 per cent to 25 per cent of the total annual flow of the Mississippi (fig. 1) and from 15 to 30 per cent of the total annual flow past the latitude of Old River (fig. 5).

Channel width and depth

50. The increase in discharge through the Atchafalaya River is coupled with a corresponding increase in channel widths and depths. The thalweg profile on plate 17 shows the channel to be deepest in its leveed segment where depths as great as 180 ft are encountered. It shoals abruptly at the ends of the levees and is even more shallow in the Grand

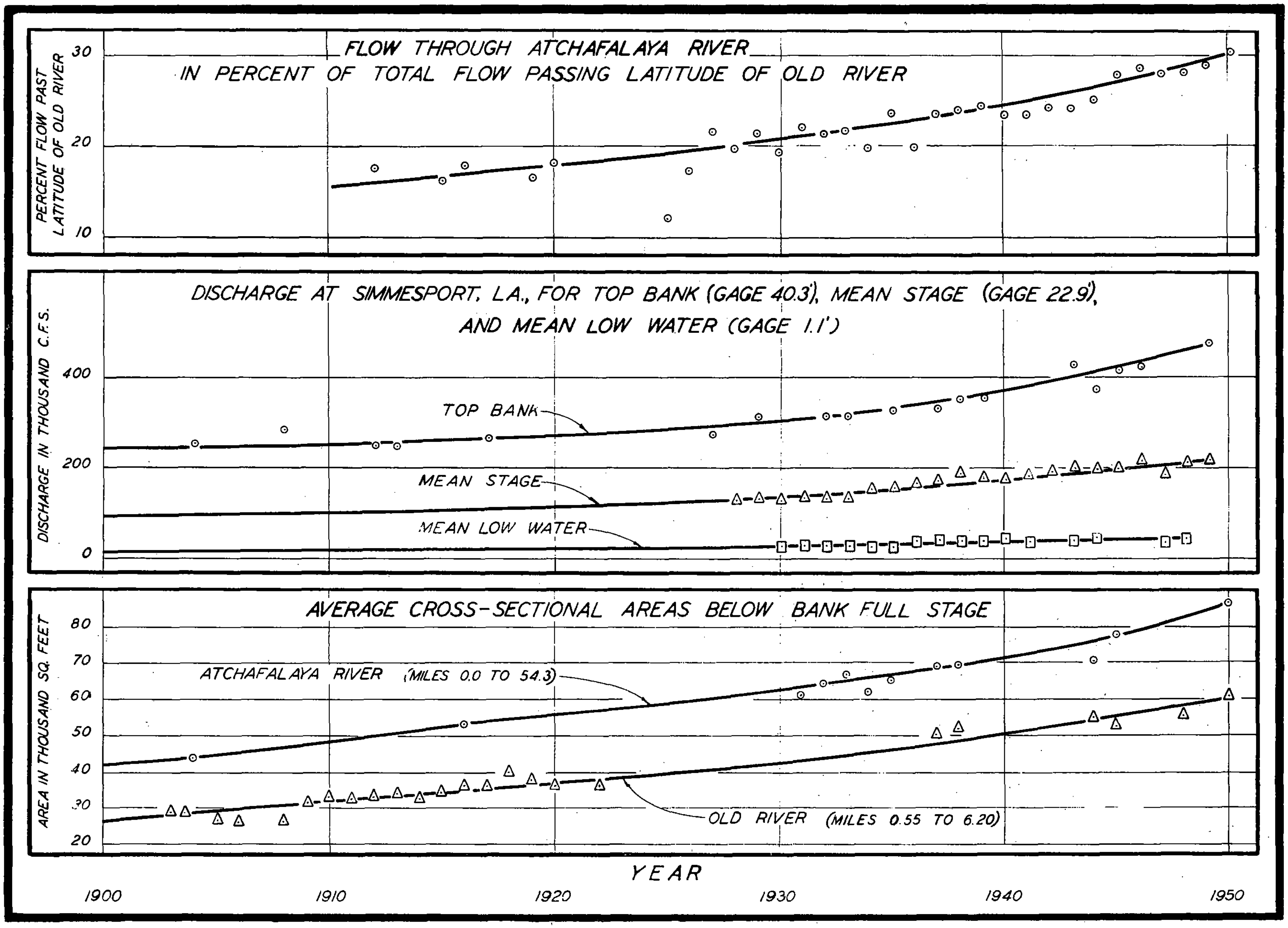


Fig. 5.

Trends in Atchafalaya River enlargement

Lake-Six Mile Lake segment. South of Six Mile Lake, depths increase to as much as 140 ft and become shallower as the river enters Bateman Lake and Atchafalaya Bay.

51. Data collected show a gradual increase in depth through the years together with a smoothing out of some of the major irregularities in the channel bottom. Channel widths have also increased so that some areas show a channel width double that of 50 years ago. This trend of enlargement manifests itself along many reaches of the river by caving of opposite banks, a condition not observed on the Mississippi River where caving along an individual reach is usually confined to a single bank (see fig. 21). Graphs of channel enlargement in Old River and in the leveed segment of the Atchafalaya River are shown in figure 5.

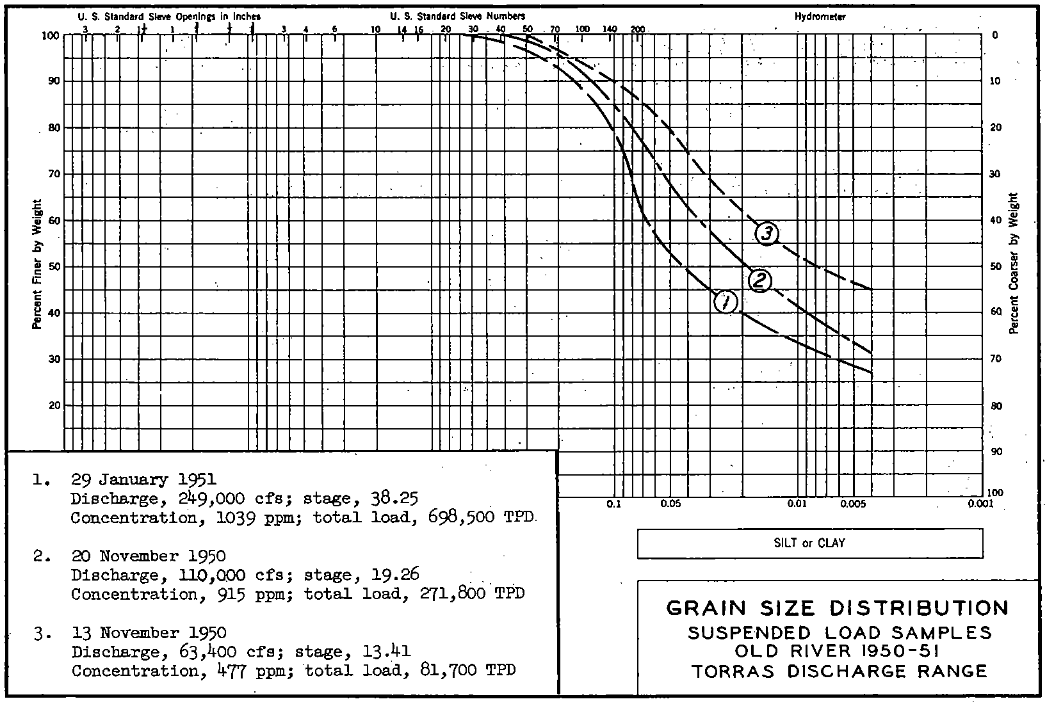
Load

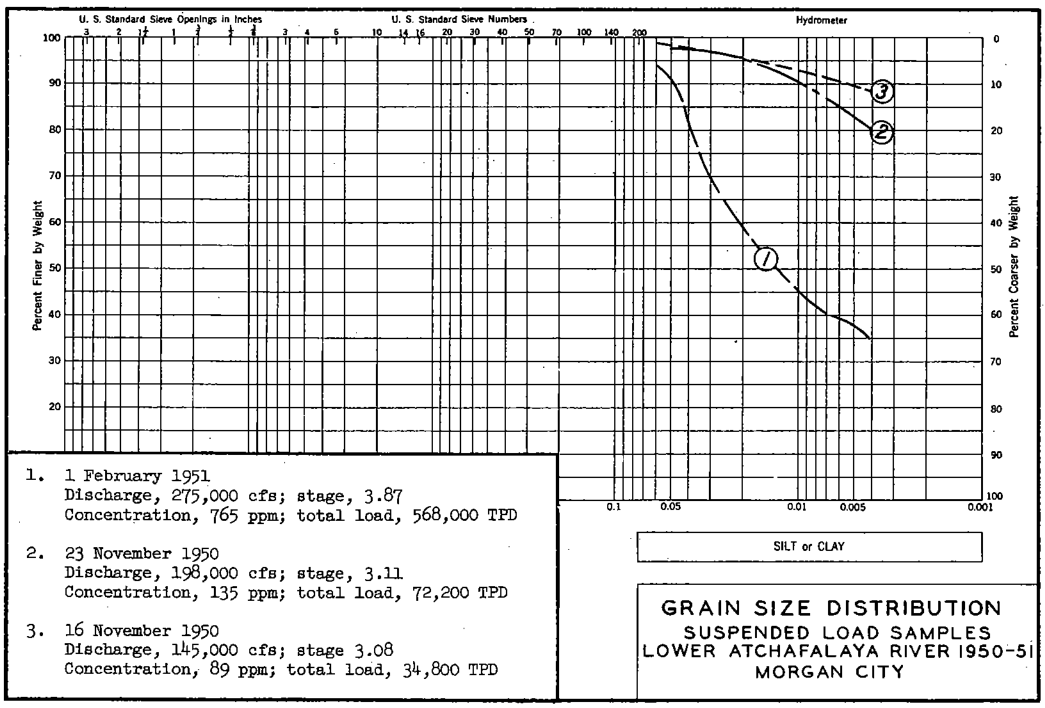
52. The results of suspended-load and bed-load measurements made on the Mississippi and Atchafalaya Rivers in 1932 are published in Waterways Experiment Station Paper 17(30). Similar measurements made in 1950 are contained in appendix B to the Mississippi River Commission's "Atchafalaya River Study"(21). Table 1 summarizes the suspended load carried by the Mississippi, Red, Old, and Atchafalaya Rivers at three representative stages and the amount of suspended load discharged through the Atchafalaya Basin outlets, Lower Atchafalaya River and Wax Lake Outlet. Figures 6 and 7 show grain-size distribution curves of suspended-load and bed-load samples taken along Old and Atchafalaya Rivers.

Table 1

Discharge Measurements		Suspended-load Measurements		
Date	Discharge (cfs)	Date	Concentration (ppm)	Suspended Load (TPD)
Mississippi River, Tarberts Landing (above Old River)				
13 Nov 50	272,000	13 Nov 50	358	263,000
20 Nov 50	425,000	20 Nov 50	770	883,600
29 Jan 51	1,065,000	29 Jan 51	871	2,505,000
Mississippi River, Red River Landing (below Old River)				
14 Nov 50	221,000	14 Nov 50	366	218,400
21 Nov 50	399,000	21 Nov 50	736	654,000
30 Jan 51	766,000	30 Jan 51	766	1,584,000
Red River (Acme, La.)				
13 Nov 50	19,300	13 Nov 50	96	5,000
20 Nov 50	15,200	20 Nov 50	66	2,700
29 Jan 51	73,000	29 Jan 51	93	18,300
Old River (Torras)				
13 Nov 50	63,400	13 Nov 50	477	81,700
20 Nov 50	110,000	20 Nov 50	915	271,800
29 Jan 51	249,000	29 Jan 51	1039	698,500
Atchafalaya River (Simmesport)				
14 Nov 50	87,000	14 Nov 50	340	79,900
21 Nov 50	126,000	21 Nov 50	696	236,800
30 Jan 51	333,000	30 Jan 51	992	891,900
Lower Atchafalaya River (Morgan City)				
17 Nov 50	145,000	16 Nov 50	89	34,800
24 Nov 50	198,000	23 Nov 50	135	72,200
1 Feb 51	275,000	1 Feb 51	765	568,000
Wax Lake Outlet (Calumet)				
16 Nov 50	32,600	16 Nov 50	80	7,040
23 Nov 50	39,100	23 Nov 50	200	21,100
2 Feb 51	80,000	1 Feb 51	770	166,300

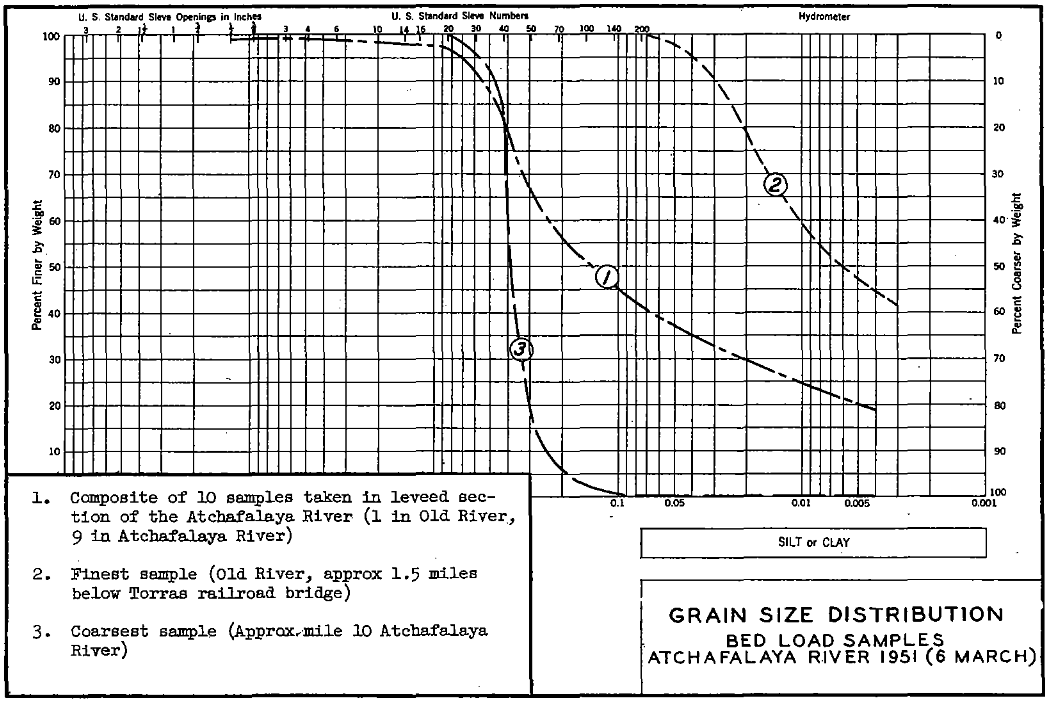
Note: Based on mean velocity measurements the Atchafalaya averages 50 miles per day. In two and one-half days water introduced at Simmesport should be discharged at Morgan City and Calumet.

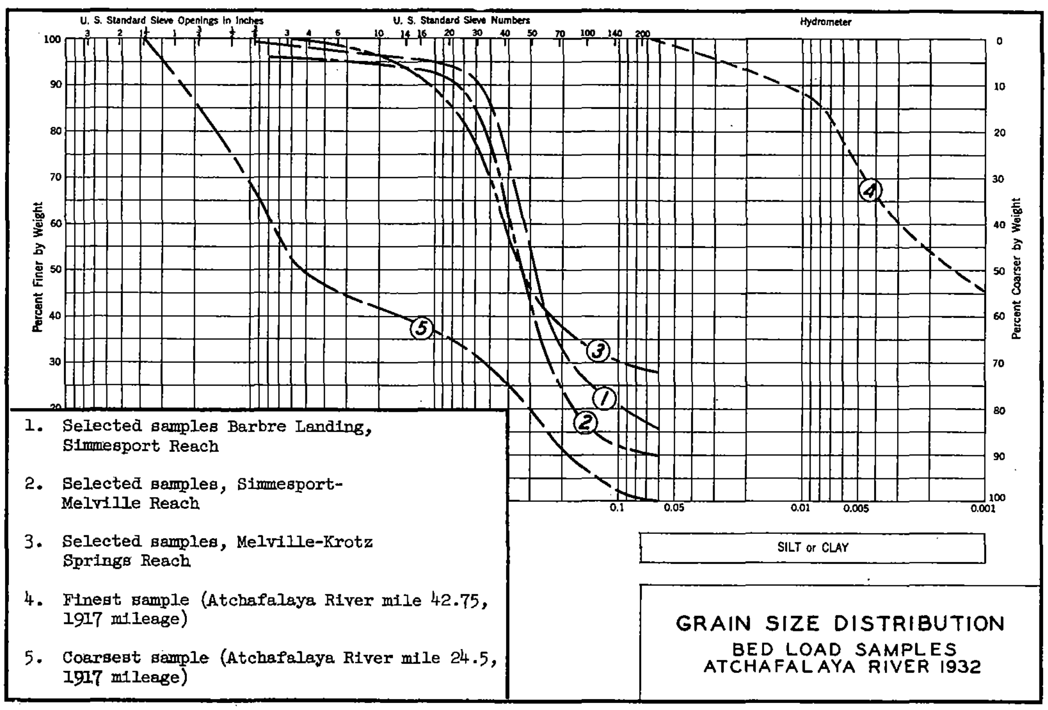




SUSPENDED LOAD MEASUREMENTS OLD AND ATCHAFALAYA RIVERS

Fig. 6.





BED LOAD MEASUREMENTS OLD AND ATCHAFALAYA RIVERS

Fig. 7.

PART III: GEOLOGICAL SETTING OF THE ATCHAFALAYA BASIN

53. The Atchafalaya Basin is a heritage of Mississippi River activity. The basin is enclosed by alluvial ridges laid down along Mississippi River courses. It has developed on the surface of alluvial material which fills a trench excavated by the Mississippi, and a preponderance of the deposits found within its boundaries are in one way or another related to the Mississippi River. A resume of the geological history of the Mississippi River, therefore, is a necessary introduction to the geology of the basin. The basin was isolated from the rest of the Mississippi Alluvial Valley at a comparatively late stage in the evolution of the present landscape. An even more recent occurrence was the introduction of the Atchafalaya River into the basin, and the subsequent development of that small initial stream into the major river it is today. The following paragraphs are devoted to a chronicle of the principal events leading to the present condition of the Atchafalaya Basin and River, and are designed to provide a background for the discussion of the effect of basin deposits on the enlarging Atchafalaya River treated in part IV.

Geological History of the Mississippi River

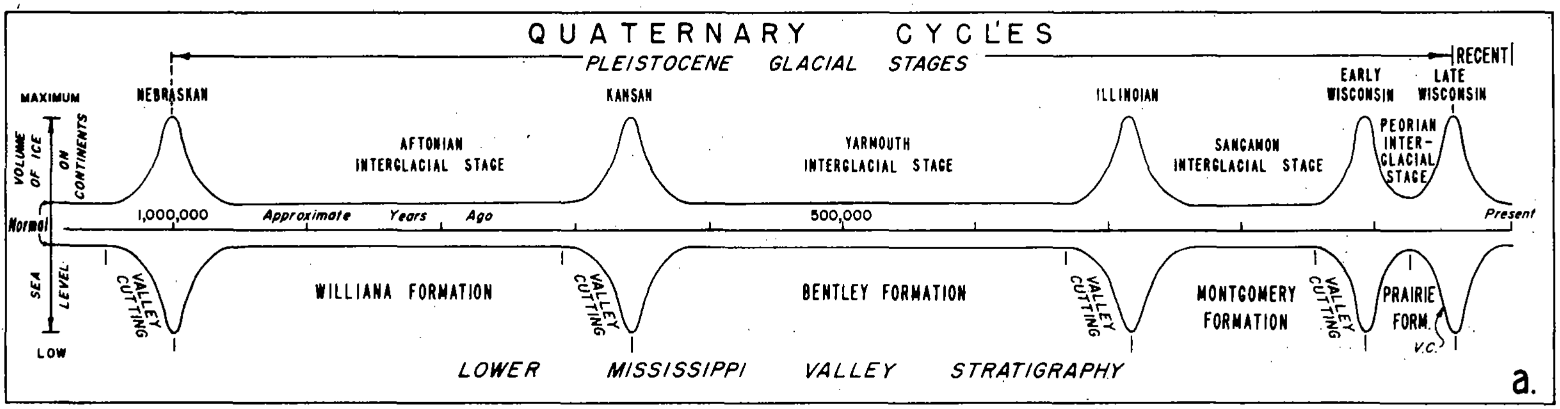
Quaternary events

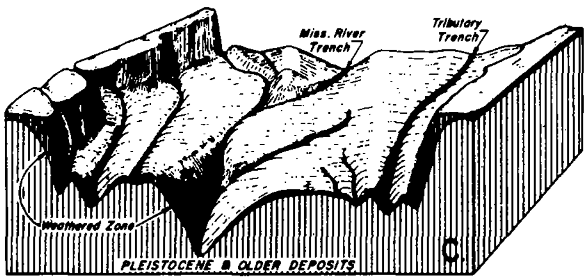
54. The Mississippi drainage system was integrated as a result of the first of a series of climatic abnormalities. During the last 1,000,000 years of geologic time, the Quaternary period, glacial ice periodically accumulated and spread outward from local centers in Canada until it blanketed

eastern Canada and northern United States and dammed most northward-flowing streams of that region. The Mississippi River originated during the first glacial advance as many of the natural drainage lines were turned towards the south and collected into a great river flowing down the center of the low interior part of the continent into the Gulf of Mexico.

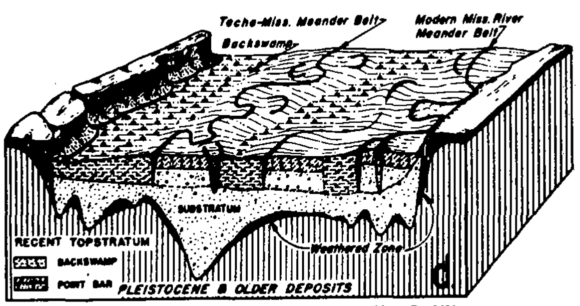
55. The ice accumulation caused a drop of several hundred feet in sea level. The newly formed river system, in its efforts to adjust itself to the lowered base level thereby imposed on it, began to entrench itself forming a deep valley. Somewhat later, as the ice sheets retreated, their meltwater was returned to the oceans causing sea level to rise to about its former position. The entrenched valley was alluviated by the same streams that cut it, as the Mississippi River and tributaries built up their beds as part of the process of adjustment to the higher base level. As the adjustment was attained, the river developed a meandering course on the wide, flat surface of the alluvial materials it had deposited.

56. Evidence is available in the alluvial deposits of the Lower Mississippi Alluvial Valley and adjacent areas that sea level was lowered and later restored to near its present stand five separate times. Each oscillation of sea level can be correlated with an advance and retreat of the glacial ice, and the intervening period of stationary sea level can be correlated with an interglacial stage. The relationship between chronology developed in glaciated parts of the continent and Lower Mississippi Valley stratigraphic units is shown by figure 8a. A typical glacial cycle is shown by figure 8b.





MISSISSIPPI RIVER ENTRENCHED VALLEY SYSTEM DURING LATE WISCONSIN GLACIAL STAGE



FEATURES OF MODERN MISSISSIPPI ALLUVIAL PLAIN AND RECENT DEPOSITS FILLING LATE WISCONSIN ENTRENCHED VALLEY

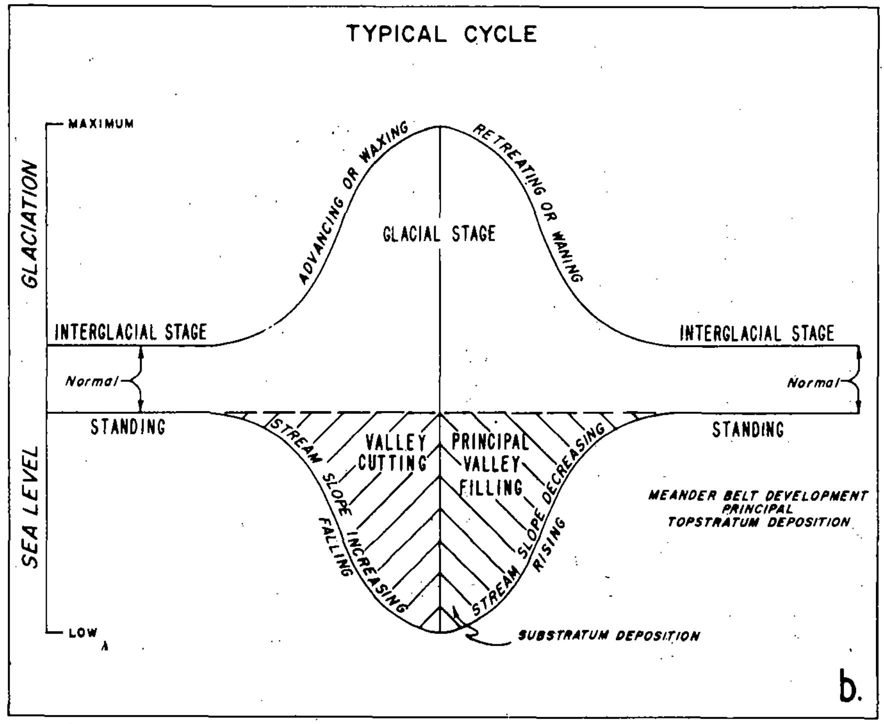


Fig. 8.

Quaternary events in Lower Mississippi alluvial valley

57. The latest (Late Wisconsin) entrenched valley of the Mississippi River system, produced during the last drop in sea level, is shown diagrammatically on figure 8c. The weathered zone indicated on the figure developed owing to subaerial exposure. The subsequent rise of sea level resulted in rapid decrease in stream slopes and a regular sequence of alluvial materials was deposited. Coarse sand and gravels which first accumulated in the trough were gradually covered by finer and finer materials as the sea returned nearer to its normal position. These pervious sands and gravels which constitute the lower part of the sequence are known as the substratum. The relatively impervious silty clay and clay that accumulated during the interglacial interval of more nearly stationary sea level is called topstratum. Figure 8d shows substratum and topstratum materials of the alluvial sequence that fills the Late Wisconsin entrenched valley and forms the modern Mississippi Alluvial Plain. Figure 9a shows this relationship in longitudinal profile.

58. A complication to the regular cyclical pattern of valley entrenchment, valley filling, and alluvial plain development is found in the structural activity that affected the Louisiana coast throughout the Quaternary period. Each alluvial plain was downwarped in its deltaic portion and uplifted throughout most of the remainder of its length. The uplifted portion became an alluvial terrace and formed the walls of the next later entrenched valley (fig. 9b). Along the present Mississippi Valley, four terraces have been recognized above the present floodplain, representing four former floodplains, each with its characteristic sequence of alluvial deposits, now uplifted successively to their present positions. The oldest floodplain surface forms the highest terrace.

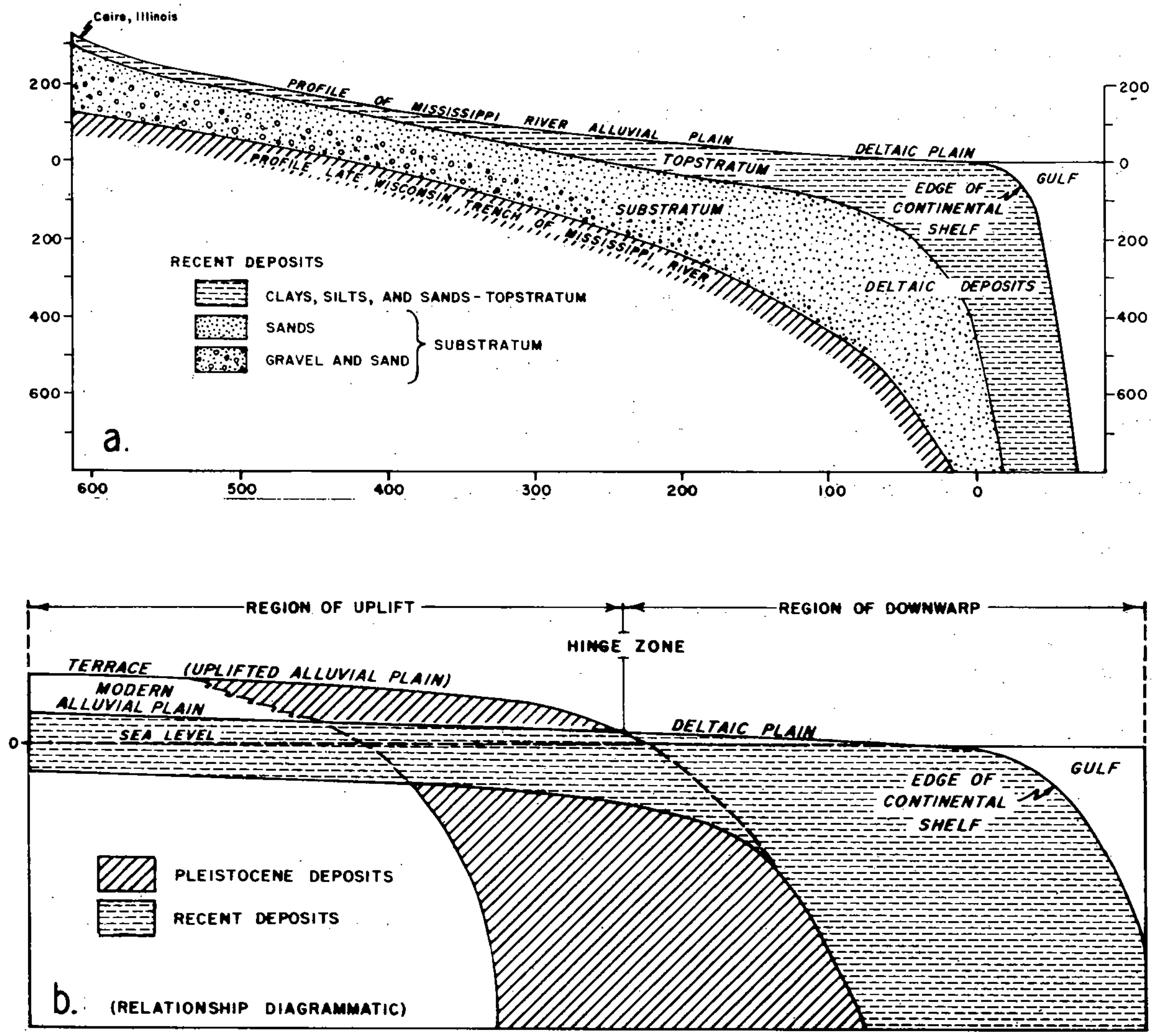


Fig. 9. Longitudinal profiles, Mississippi Alluvial Valley

Deltaic sequences corresponding to the terraces are present below the modern deltaic plain, but here the oldest sequence is the most deeply buried one. Each upwarped terrace dips beneath the next lower surface at a place near its downstream end called the hinge zone. Downstream from this hinge zone, downwarping has occurred. Hinge zones of successively younger alluvial sequences are progressively farther downstream. The youngest terrace dips beneath the present floodplain at Donaldsonville on the east side of the valley and at Franklin on the west side.

Sea level and river activity

59. Falling sea level. The last alluvial cycle in the Mississippi Valley began with the drop in sea level that marked the Late Wisconsin glacial advance. The Mississippi River which cut the resulting entrenched valley was a fairly straight stream fed by relatively straight tributaries in the manner shown in figure 8c. The river flowed down a steep slope and entered the Gulf of Mexico possibly near or beyond the site of the submarine canyon indicated on figure 17, about 60 miles southwest of the present river delta. The Mississippi was not adjusted to the steep slope of the trench bottom, and its tributary streams had gradients that were even steeper. Quantities of coarse gravel and sands were supplied to the master stream by the tributaries; the coarse materials were in turn swept into the sea.

60. Rising sea level. During the period of falling sea level the Mississippi River was never in adjustment with its slope, because it could not cut down as fast as sea level dropped. The rate of gradient reduction during the rise of sea level was likewise too rapid to permit adjustments. As a consequence, the river became a braided stream and began rapidly to fill the valley. Tributaries built alluvial cones of gravel and sands into the deep main trench, because the material they supplied could no longer be swept out to sea by the numerous shallow channels of the braided Mississippi. The coarse alluvium which accumulated in the trench in this manner makes up the substratum.

61. As the sea approached its present stand and the thickness of substratum deposited within the trench increased, stream gradients were progressively reduced; the grain size of detritus supplied to the river

was diminished, and alluvial deposits in the valley became finer and finer, until their principal constituent was silt. This decrease in grain size is also a measure of the degree of adjustment, gradually attained by the river system, to a gradient which by this time was nearing stability. As the adjustment became more and more complete, the braided character of the river became less and less pronounced.

62. Standing sea level. A meandering stream replaced the braided stream as sea level became stationary. The sediments brought into the Mississippi by tributaries were of such fine grain size that, for the most part, they could be carried in suspension. A balanced relationship between gradient and load was attained for the first time since sea level was last stationary and meandering began. The meandering habit was attained initially in the downstream portion of the river where adjustments could be made most easily and later came to prevail throughout the entire alluvial valley. The change from a braided to a meandering stream brought about a concentration of the flow into a single channel, which in turn resulted in deeper scouring action, periodic flooding, and more rapid channel migration.

Deposits of the meandering river

63. Topstratum deposits are the characteristic products of a meandering stream. They are more heterogeneous, more variable in thickness than the underlying substratum and reflect the diversity of depositional environments created in the alluvial valley by the meandering stream.

64. Within the belt of migration of meander loops, sediments with characteristic properties are deposited. Natural levee deposits form

thin widespread belts of comparatively coarse deposits flanking stream channels. Point-bar deposits of minor thickness form behind growing meander loops and are fairly coarse-grained. Deposits filling abandoned cutoff channels in contrast are normally deep and fine-grained. Part IV describes these deposits in more detail.

65. The extensive low-lying floodbasins marginal to meander belts receive all water spilled over the riverbanks during flood. This is the site of backswamp deposits, the very fine, predominantly silt and clay detritus which is slowly dropped by the floodwater impounded there.

66. Downvalley, where river deposits mingle with sediments of the various marginal-marine environments, fine-grained alluvial materials of a different type accumulate. These consist of complexly interfingered natural levee deposits, shells, backswamp sediments, organic oozes, marsh and lake deposits, and silts and sands from rivers which debouch in the vicinity. This area is known as the deltaic plain and the deposits as deltaic plain deposits.

67. The recognition of these various types of deposits permits more accurate interpretation of boring information, and makes possible reconstruction of the geology of areas within the Mississippi Alluvial Valley from a fewer number of borings than would otherwise be necessary. The presence of these distinctive products of floodplain environments marks the river which deposited them as a meandering poised stream, and makes it possible to trace in detail the activity of that stream.

The poised river

68. The Mississippi River has been described as a "poised" stream, a description indicating that it shows no over-all tendency either to

aggrade or to degrade its channel, and implying that a balance is maintained between stream velocity, volume, load, and the materials forming its bed and banks. Poised streams are characterized by meanders, the mark of local adjustment. The equilibrium attained among these important factors of stream behavior, signified by the maintenance of a poised condition over a long period of time, furnishes perhaps the best key to an understanding of the factors involved in Mississippi River diversion. Accordingly certain activities of the river in its present poised condition are described below in some detail.

69. General stream activity. Adjustments are preserved within a poised stream for all natural circumstances. Variation in load and channel cross section matches variation in stream volume with stage. Preservation of adjustments during flood stages requires that riverbanks be topped, building up natural levees so that greater volumes can be accommodated during the next flood. Natural levees become a reflection of the graded profile of the stream; they are higher upstream where there is greater stage variation in the river. As natural levees increase in height and channel capacity is increased, more rapid migration of meander loops is promoted because the responsible scour-and-fill processes are more effective owing to concentration of a greater volume of water. As time goes by the river improves progressively as a drainage and sediment transporting agent.

70. One of the main obstacles to increased channel efficiency is the bar which forms at the mouth of the river where the coarser fraction of stream-borne sediment is dropped. The growth of this bar causes the river to branch into distributaries, and thus to form a delta. As the

river-mouth bar grows and advances seaward the river may be lengthened, causing adjustments to be made upstream.

71. The river in these ways reduces its gradient to a minimum, and in such an extended condition it is only necessary for one of the migrating meander loops to intersect a small alluvial valley stream flowing independently into the Gulf of Mexico to establish all conditions necessary for diversion of the Mississippi into a new course. The channel of the smaller stream enlarges owing to progressive increase in flow, derived initially from water from the river introduced during high stage only, and eventually from medium and low stage discharge. The diversion arm then becomes the main channel. The old river channel deteriorates rapidly as decreased water volume causes reduction in velocity and load, and the sand and silt carried into the channel are dropped, restricting its cross-sectional area. The new main channel is able to accept full Mississippi flow when its slope and channel are adjusted to volume of water, and the poised condition is established. Diversion of large segments of the Mississippi River from one part of the alluvial valley to another has been a frequent occurrence since the poised condition was attained shortly after sea level became stabilized. The above explanation of the steps in the diversion process is consistent with all data available from the study of several of the ancient Mississippi River courses as well as the modern course.

72. Channel migration. Channel migration in the Mississippi River is accomplished principally by enlargement, shifting, and abandonment of meander loops. Figure 10 shows the details of a typical Mississippi River bend. The thalweg impinges against the concave bank and scours deeply in the river bendway; a shoal area in the channel occurs at the crossings

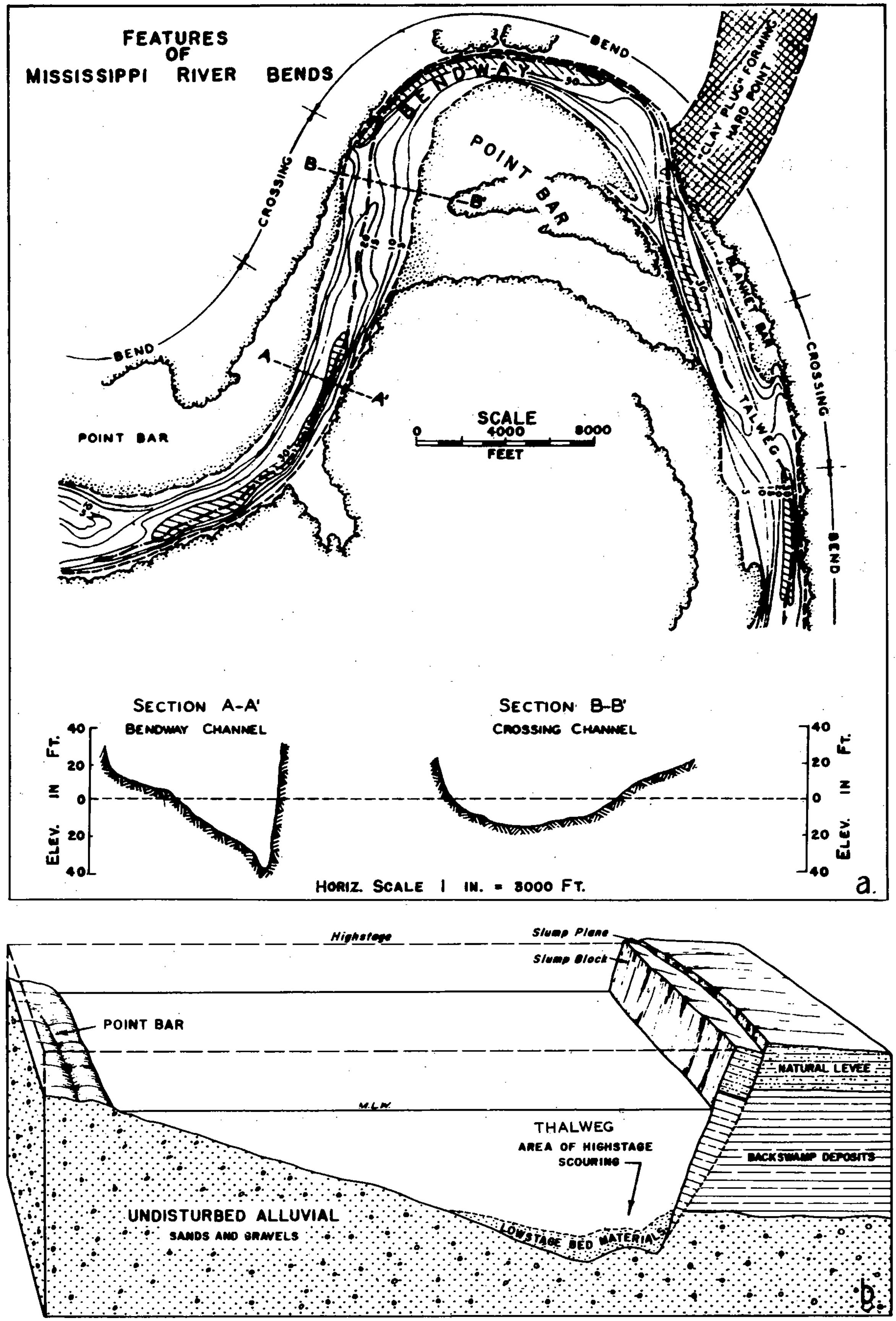


Fig. 10. Features of Mississippi River bends

where the thalweg shifts to the opposite side of the river. The bend enlarges as the maximum erosive force of the current is applied against the concave stream bank, causing it to retreat and the convex bank is extended in the same direction by point-bar accretions. The two processes, concave bank retreat and convex bank accretion, are contemporaneous and interrelated. The rate at which bends enlarge is controlled to a great degree by the bed and bank materials through which the river flows.

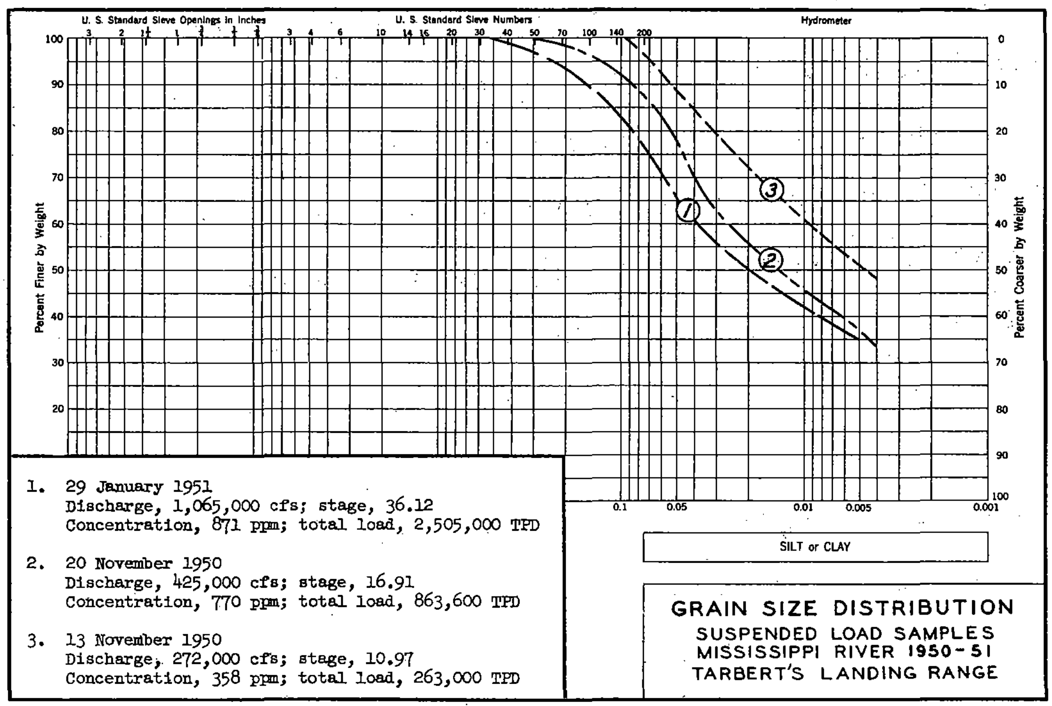
73. In the southern portion of the valley where fine-grained topstratum deposits are thick, the river is relatively straight, the channel is somewhat narrower and deeper than upstream, and channel migration is a relatively slow process. These observations are explained by the fact that fine-grained topstratum deposits are a more cohesive mass, not readily eroded by the river. On the other hand, where the substratum is nearer the valley surface, bank-caving and associated activity are speeded up, because the coarse sand and gravel particles are less tenacious and are more easily moved by the river. Even where sand forms only a minor portion of the bank, bend enlargement is relatively rapid due to slumping (fig. 10). Pleistocene bank materials of similar grain size have a similar influence on bend migration, except where greater cohesion has been produced by cementation.

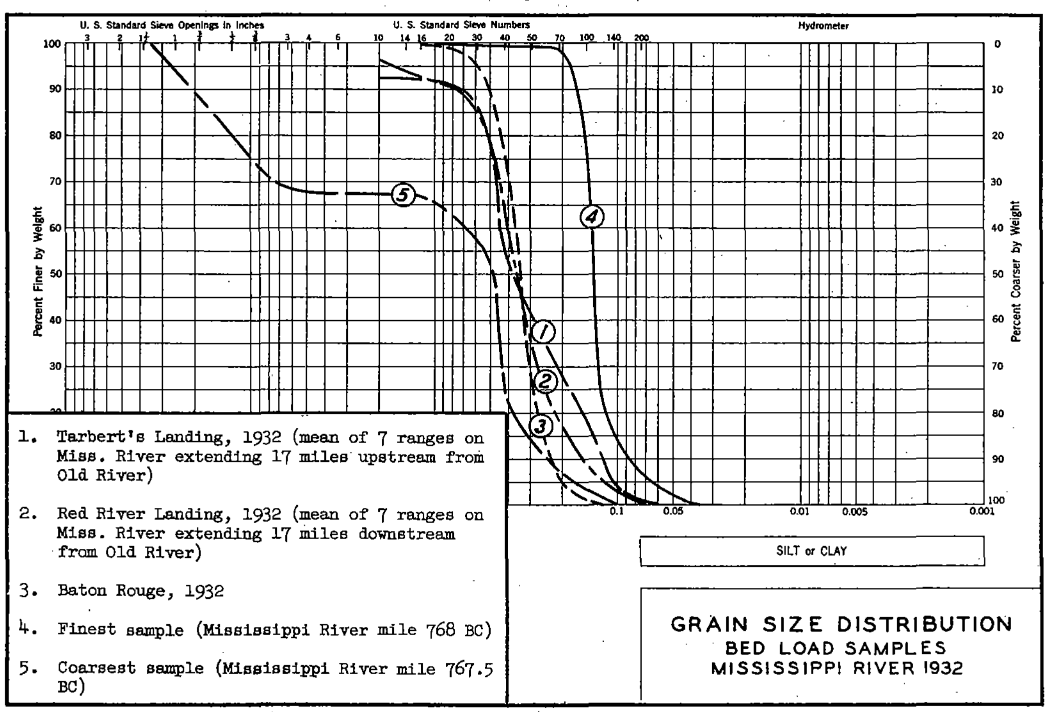
74. Load. A poised stream is identified by the way it manipulates its load and maintains equilibrium with no over-all tendency either to aggrade or degrade. Locally, however, both aggradation and degradation are noted, as at enlarging bends, and are necessary in order to produce the characteristic meandering course of the Mississippi. The poised

condition implies that relatively little coarse load is introduced by tributary streams. Most of the sediment transported by the Mississippi is the very fine sand, silt, and clay materials which make up the suspended load that the river is able to carry in continuous transit to its mouth. The quantity and size of the suspended load vary with river stage, being greatest when the river is at high stages. On figure 11 average values for typical suspended-load samples taken at different river stages are plotted to show this variation.

75. Coarser particles are transported by the river as bed load. Some of the bed load becomes suspended during high-water stages when carrying capacity of the river is increased; and some settles to the bottom of the stream becoming bed material during low stages (fig. 10). Figure 11 shows the variation in grain-size distribution in typical samples of bed load taken at different places along the Mississippi River. Most bed load, however, moves by a discontinuous process called "trading." It is mainly derived by erosion of coarse substratum material which forms the bed and banks, or from a few tributary streams that have steep gradients. The river can carry these sediments from the place where they are introduced only a short distance to the next point bar downstream.

76. Not all authorities agree that bed load in poised streams moves in the manner described above. However, strong support for the trading process may be cited: (a) virtually no sediment is found near the mouth of the river which is coarser than the river may carry in suspension a short distance upstream from its mouth (plates 34 and 34a); (b) although an over-all downstream reduction in grain size of bed load samples is noted (caused by finer particles available to the river downstream) local





MISSISSIPPI RIVER SEDIMENT LOAD MEASUREMENTS

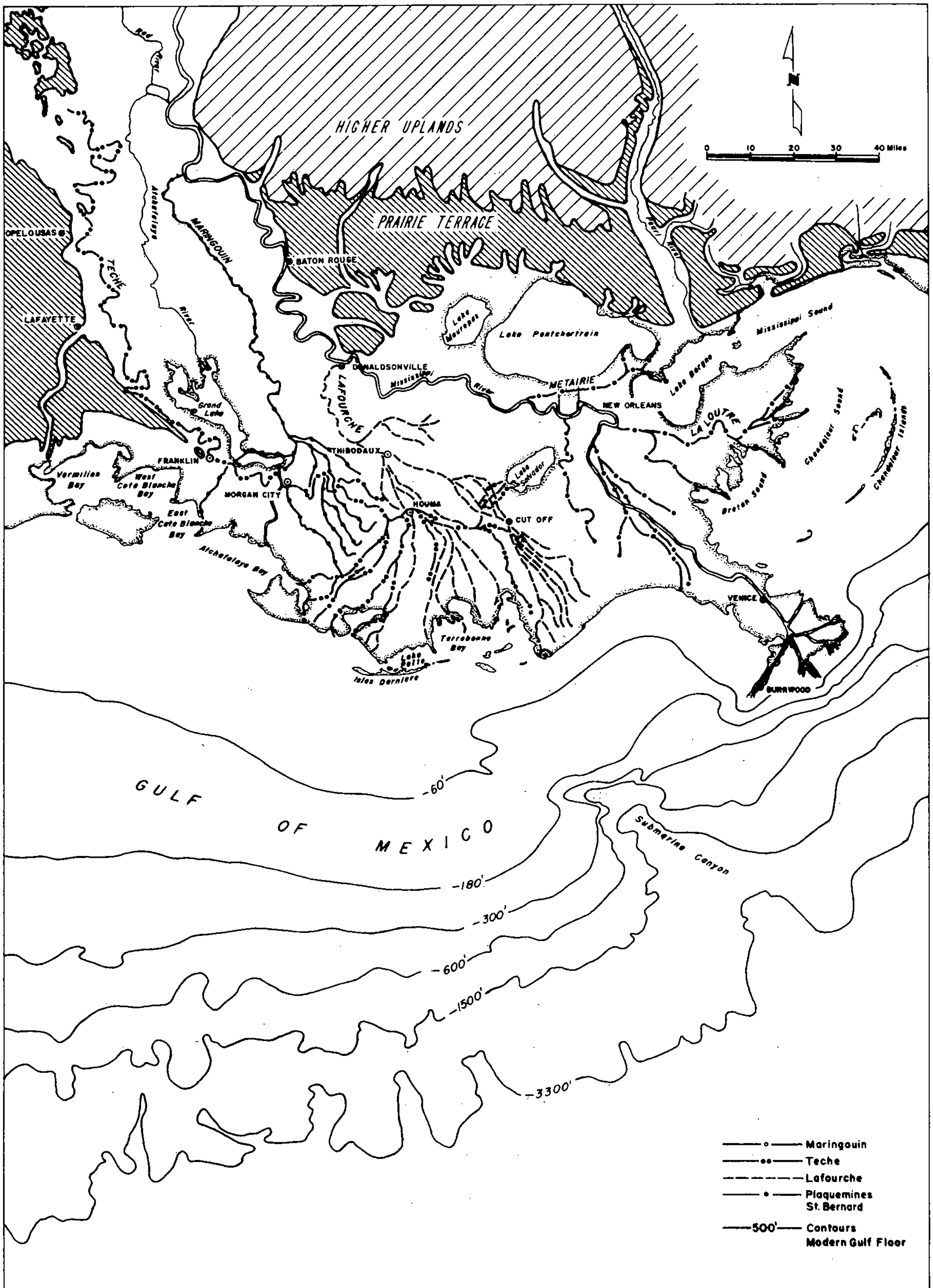
Fig. 11.

exceptions are numerous where coarse material is available to the stream; and (c) as far downstream as they are available to the river, coarse gravel particles are moved for short distances. These facts seem to preclude explanations calling for continuous downstream movement of bed load.

Courses

77. Since the Mississippi River became a meandering stream it has shifted its meander belt several times. Each shift was accomplished by the gradual diversion of Mississippi discharge into the channel of a smaller stream in the alluvial valley, seemingly as a normal activity of the river. The abandoned Mississippi meander belts have been mapped in considerable detail by Fisk(9). He concludes that the major shifts in the position of the river began shortly after the sea reached its present level and have continued into the present.

78. The portions of the abandoned Mississippi River courses which are of importance to the present study are shown in figure 12. The oldest course that can be detected in the region is the Maringouin-Mississippi, marked by Bayou Maringouin and other small streams in the center of the modern alluvial valley. Bayou Teche and other bayous along the western alluvial valley wall follow the Teche-Mississippi course, the next younger position of the river. The delta built by the Teche-Mississippi southeast of Houma may be recognized easily by the pattern of the small streams in that vicinity. Following a series of shifts involving different segments of the river, the Mississippi became established in its Lafourche course along the eastern alluvial valley wall. This course is marked by the modern Mississippi channel as far south as



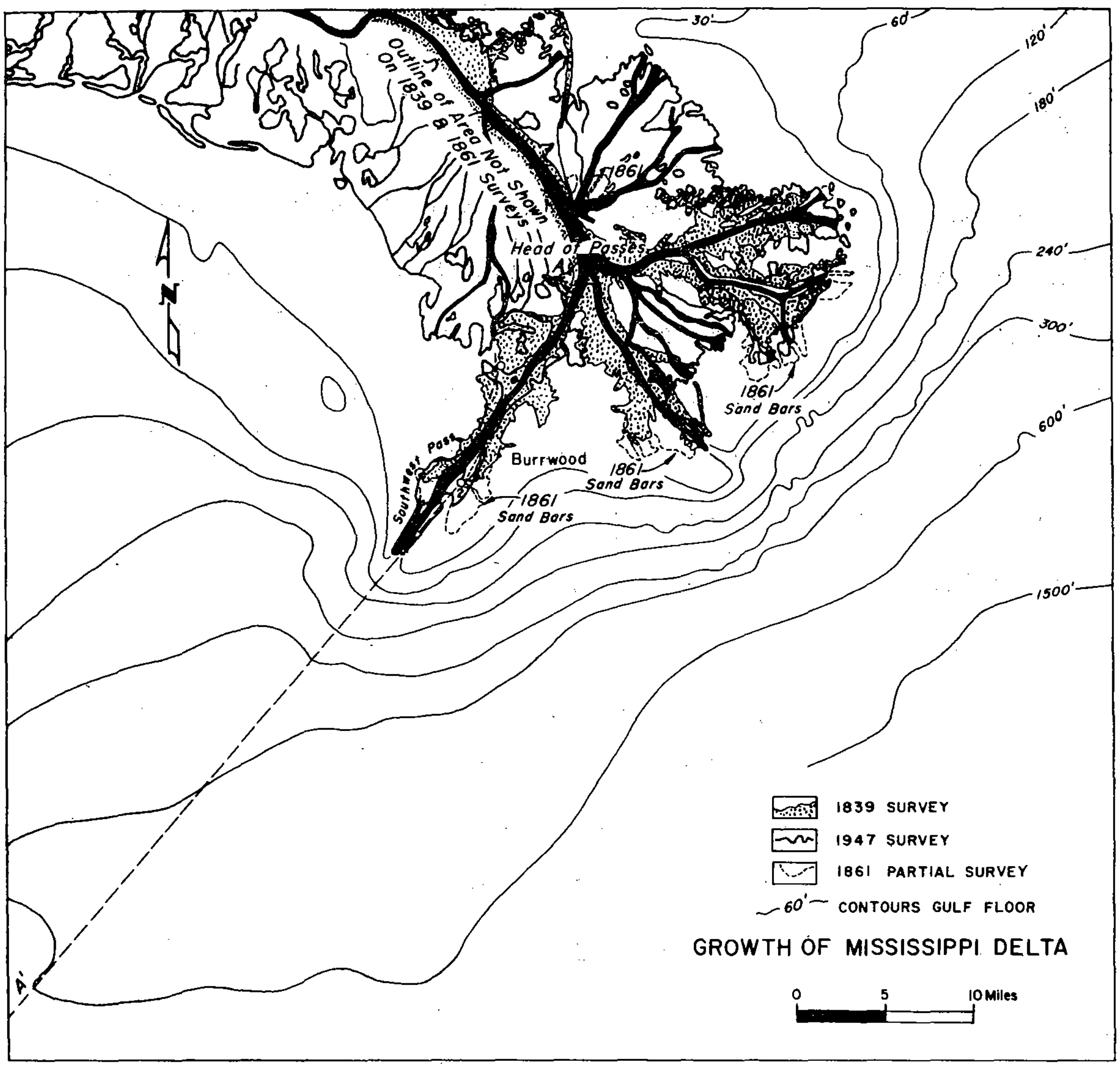
ANCIENT AND MODERN MISSISSIPPI RIVER COURSES AND THEIR DISTRIBUTARY SYSTEMS (GENERALIZED)

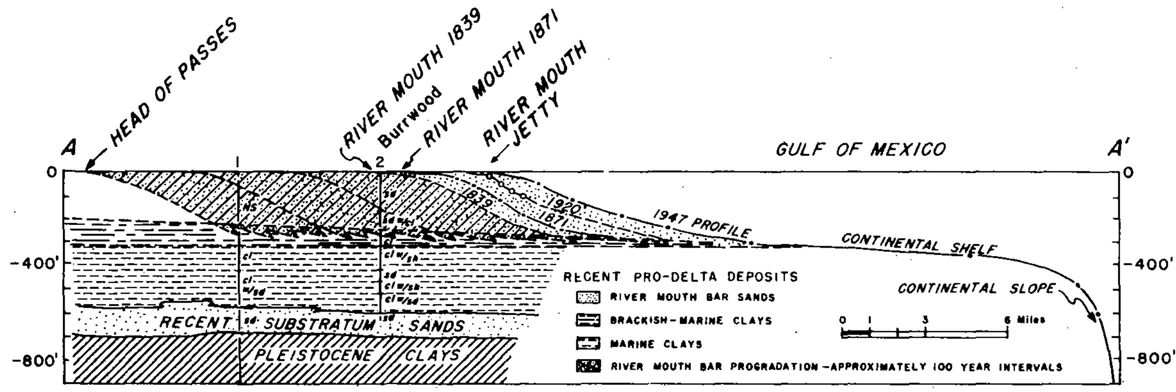
Fig. 12.

Donaldsonville, La., from which point the river flowed down a channel now occupied by Bayou Lafourche and built a delta south of Thibodaux. Later a diversion occurred at Donaldsonville, and the river came to flow in its present channel past New Orleans, constructing in succession several deltas (subdeltas of Russell(24); Fisk(9)) south and east of the city (Metairie delta, Barataria delta, etc.), and finally forming its present delta (Balize) a short time prior to European settlement of Louisiana in 1699.

79. Early courses compared with modern course. The earlier Mississippi courses give every indication that they were produced by a stream of the same size and characteristics as the modern one. All of the characteristics of the poised Mississippi enumerated above are duplicated in the abandoned channels in virtually every measurable particular. For example, meander belts, bends, and natural levees of the ancient courses are the size of the equivalent modern Mississippi features; natural levee slopes are comparable; and all of the courses, ancient and modern have channels of the same width and depth. The only significant difference lies in the nature of the deltas.

80. Modern Mississippi delta. The delta of the present Mississippi is formed by a few shallow channels or passes which spread at rather large angles from the distal end of the main stream (fig. 13). The division of the main channel into the shallow deltaic distributaries is caused by the construction and growth of a sand bar (C-C', fig. 14) in the channel where some of the coarser elements of the river's load are dropped, splitting the flow. The passes extend themselves beyond the division point by the process of progradation, gradually building up the





ADVANCE OF MOUTH OF SOUTHWEST PASS

Fig. 13.

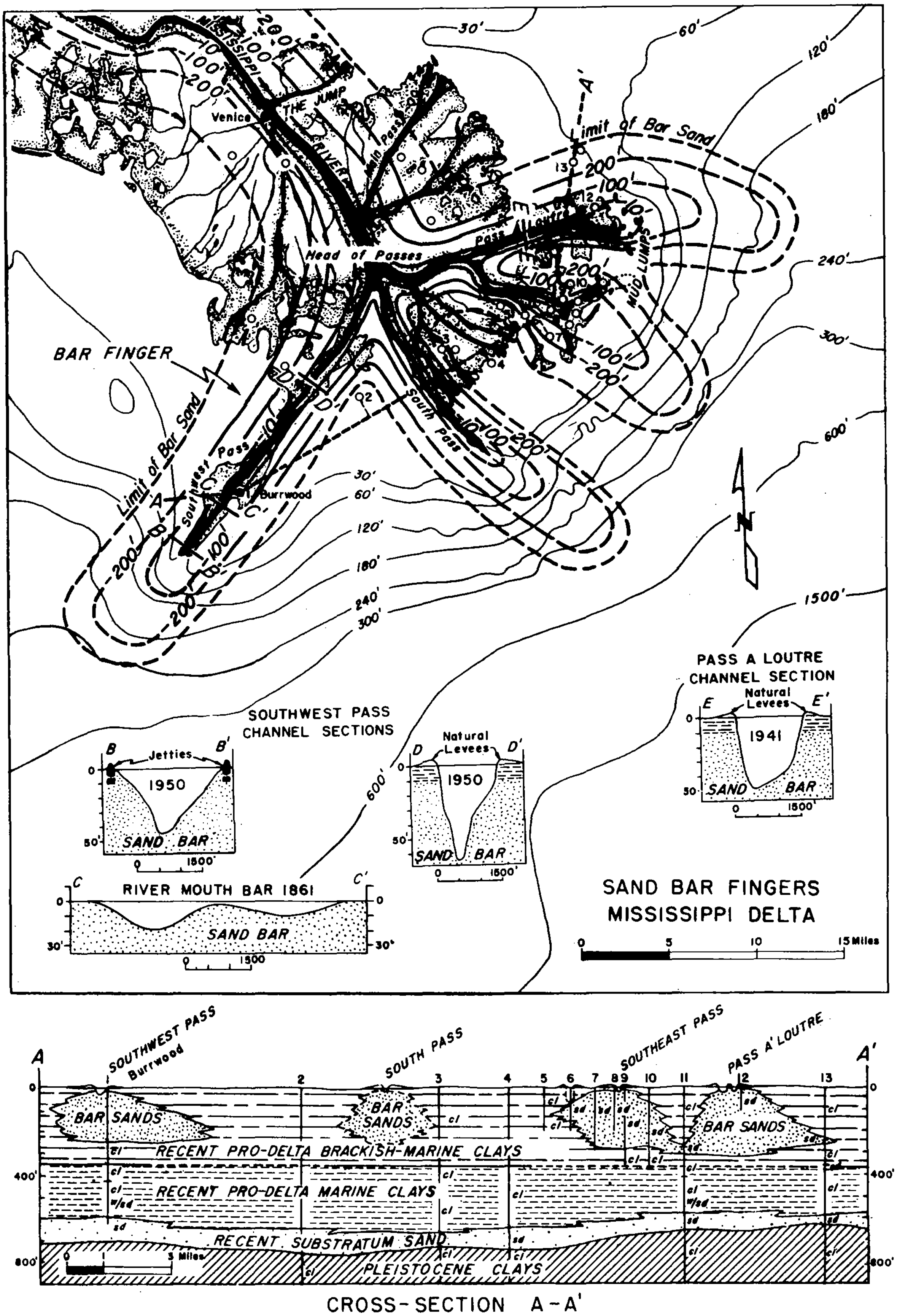

SAND BAR FINGERS
MISSISSIPPI DELTA
BAR FINGER
Limit of Bar Sand
Venice
THE JUMP
MISSISSIPPI
RIVER
Head of Passes
South Pass
Southwest Pass
Burrwood
MUD LUMPS
PASS A LOUTRE
CHANNEL SECTION
SOUTHWEST PASS
CHANNEL SECTIONS
Jetties
Natural Levees
SAND BAR
RIVER MOUTH BAR 1861
RECENT PRO-DELTA BRACKISH-MARINE CLAYS
RECENT PRO-DELTA MARINE CLAYS
RECENT SUBSTRATUM SAND
PLEISTOCENE CLAYS
BAR SANDS
SOUTHEAST PASS
PASS A'LOUTRE
SOUTH PASS
CROSS-SECTION A-A'

Fig. 14.

bottom of the Gulf, channeling the flow beyond their ends, developing natural levees beneath the water surface and finally above it. The cross-section A-A', figure 13 shows the progradation of Southwest Pass. Characteristic deltaic deposits result from this growth of the passes. The bar sand across which the passes extend themselves is deposited above fine clay laid down in front of the growing delta (pro-delta clays). Similar clay sediments accumulate in the wedge-shaped areas between the active passes. The pattern of deltaic deposition which results is shown on figure 14. Great finger-shaped masses of sand representing the growth of the river-mouth bar surround each of the passes; pro-delta clays surround the sand fingers on all sides. The shallow, wide channels characteristic of the modern Mississippi passes are thought to be caused by their being built across sand (B-B', D-D', E-E', fig. 14).

81. Earlier Mississippi deltas. Old deltaic distributaries are unlike those of the present delta. Deltas built southeast of Houma by the Teche-Mississippi and south of Thibodaux by the Lafourche-Mississippi have easily recognized channels and are regarded as typical of ancient Mississippi deltas (plate 35). The distributary channels of both of these deltas are numerous and have many branches with small angles of divergence between passes. In contrast to the wide shallow modern distributary channels, the ancient ones investigated proved to be narrow and deep (B-B', C-C', fig. 15). No wide sand fingers are encountered in these deposits, but instead passes are built across pro-delta clays. Sand deposits in these older features are restricted to a rather thin, widespread layer, or occur as the filling for abandoned distributary channels.

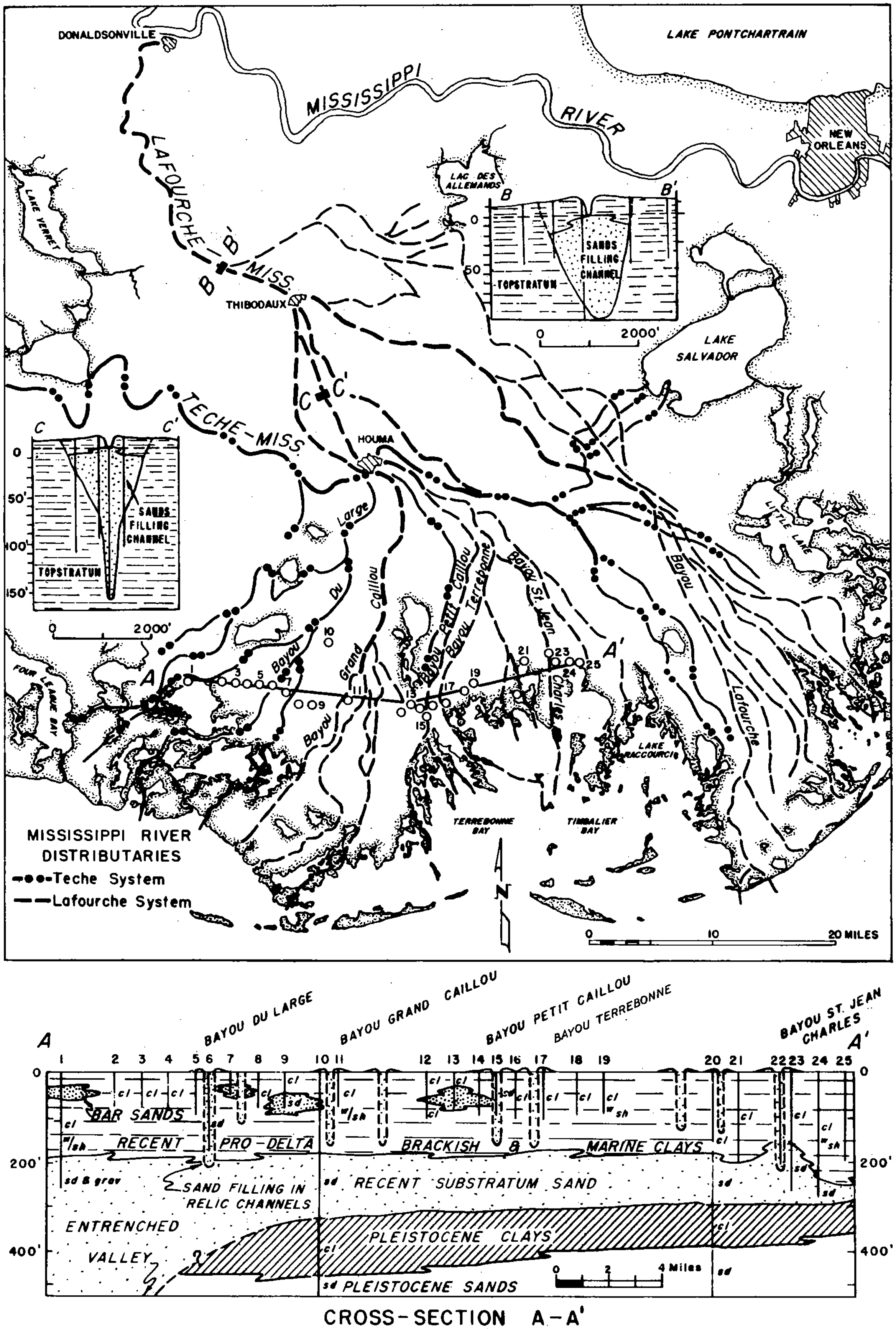


Fig. 15. Mississippi River distributaries

82. Reason for differences. The explanation for the dissimilarity noted between the deltas is explained by the depth of water into which each was built. The modern Mississippi course has developed a deep-water delta; the older courses did not. The distribution of sand as a thin sheet is indicative of shallow conditions, whereas sand fingers only develop in fairly deep water. The deep, narrow, numerous channels are the kind of distributaries to be expected in a shallow near-shore environment where clay forms the Gulf bottom. Undoubtedly shallow-water deltas grew seaward at a much faster rate than does the modern deep-water delta because the same load was being introduced into the Gulf in each case.

Summary of geological history

83. The following observations regarding the Mississippi River seem most significant to an understanding of the development of the Atchafalaya Basin.

a. The river first entered the region through which it now flows at the time of the first Quaternary glacial stage.

b. Glacial advance and retreat affected sea level, and the variations in sea level in turn caused the successive cycles of entrenchment, valley filling with coarse alluvium, and alluvial plain development with fine topstratum deposits.

c. Distinctive topstratum deposits permit the activities of the stream which produced them to be traced in detail.

d. Study of the modern Mississippi in its present poised condition furnishes basic information on the relationship between its present activities and the resulting sedimentary record.

e. Deposits of the Mississippi Alluvial Valley indicate that the river has successively occupied several courses since sea level became stabilized, and that when it occupied each of these courses the Mississippi was poised and exactly like the modern river, except in the deltaic portion.

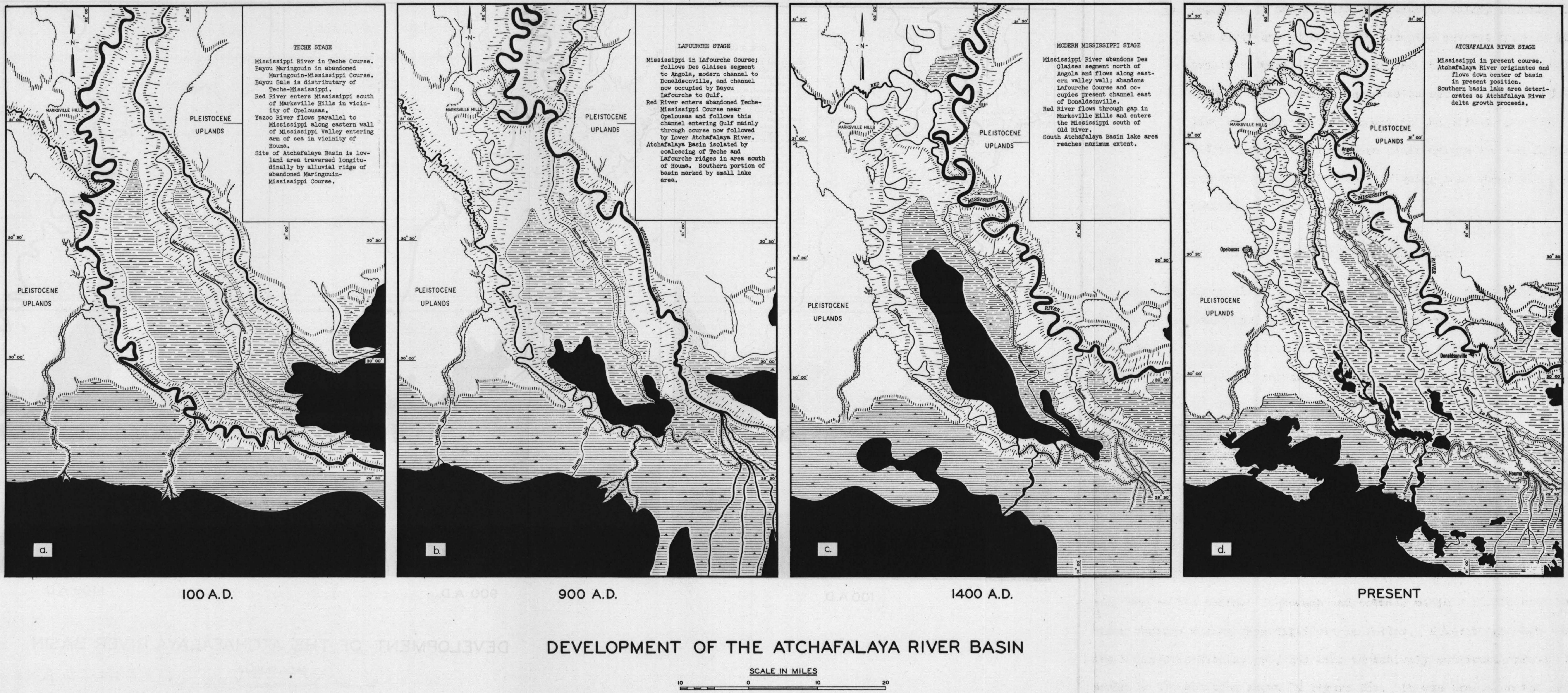
f. Differences evident between older deltas and the modern one are explained by the depth of water into which the stream emptied.

Creation of the Atchafalaya Basin

84. The Atchafalaya Basin was formed when the low central portion of the Lower Mississippi Alluvial Valley became completely surrounded by the alluvial ridges built by various Mississippi River courses. This occurred in comparatively recent times and was one of the latest steps in the evolution of the alluvial valley.

Pre-Teche stage

85. Details are lacking concerning the earliest of the abandoned Mississippi River courses in the area now occupied by the Atchafalaya Basin. Despite very incomplete evidence, it is nonetheless certain that the river traversed this region, possibly several times, before it occupied the Teche course, for pre-Teche courses can be traced to the northern edge of the basin. Backswamp and deltaic plain deposits have buried these courses making them difficult to follow. However one such course, the Maringouin-Mississippi, has been tentatively continued through the basin in the position shown in figure 16a. It was traced on the basis of scattered, partially buried, meander scars, distinctive Mississippi River



DEVELOPMENT OF THE ATCHAFALAYA RIVER BASIN

Fig. 16.

point-bar deposits encountered in borings, and the alluvial ridge followed by Bayou Maringouin and Lower Grand River which seems to have been built by a larger stream. The Mississippi River at this stage flowed longitudinally down the central part of the basin and probably built a delta in the vicinity of Morgan City.

Teche stage

86. The earliest of the Mississippi River courses in this region which may be easily traced is that of the Teche-Mississippi course. While in this position the river built the Teche ridge which forms the western and southern boundaries of the basin. The old partially filled Mississippi channel is now followed by a number of small bayous (paragraph 22). Figure 16a is an attempt to reconstruct the physiography of the basin during this stage (approximately 100 A. D.). The Teche-Mississippi follows closely the western wall of the alluvial valley for much of its length. South of Franklin this valley wall is buried beneath coastal lowlands, but borings indicate that it continues in a southeast direction. This buried valley wall undoubtedly controlled the Teche-Mississippi course beyond Franklin, where the river swung eastward and built an extensive delta south and east of Houma.

87. The alluvial valley east of the Teche-Mississippi was a lowland area bisected by an alluvial ridge of the Maringouin-Mississippi course. It is probable that at this time the Yazoo River flowed along the eastern wall of the Mississippi Valley. Seemingly, the hydrographic and topographic situation during the Teche stage of Atchafalaya Basin development was such that marine waters never extended very far into this lowland, for no marine fossils have been found in any of the borings made in the basin

proper. Some brackish-marine shells were recovered from samples taken from material below the surface along small streams south of Houma and Thibodaux. A small marine embayment into which the Yazoo River flowed may have occupied the southeastern portion of the present alluvial valley.

Lafourche stage

88. The Mississippi River abandoned the Teche course on the western side of the alluvial valley in favor of a new course (Lafourche-Mississippi) adjacent to its eastern valley wall. This stage is represented on figure 16b. The new course extended from Marksville to Angola along what is now Bayou des Glaises, a portion of the Atchafalaya River and a section that has been reworked by the present Mississippi and is now occupied by Lower Old River (Des Glaises segment), and southward from Angola along the eastern valley wall. Alluvial ridges built along the Des Glaises segment of this course form the northern boundary of the Atchafalaya Basin. This segment was later abandoned in favor of the present channel from Vicksburg, Miss., to Angola (see fig. 16c). South of Angola the river occupied its present course to Donaldsonville. South of Donaldsonville, the river flowed in a channel now partially used by Bayou Lafourche and established a delta in Lafourche and Terrebonne Parishes south of Thibodaux. The building of the delta produced small diverging distributary ridges which extended out into coastal marshlands and overlapped similar ridges of the Teche-Mississippi course, crossing them at nearly right angles.

89. The Lafourche-Mississippi course from Angola to the Lafourche delta was determined by the course of the Yazoo River. The Mississippi simply occupied and enlarged the Yazoo channel because the latter had a

gradient advantage over the Teche-Mississippi course. The Red River remained in the Teche-Mississippi channel for some time after that channel was vacated by the larger river.

90. When the Lafourche-Mississippi delta was built out to join parts of the Teche-Mississippi delta, the Atchafalaya Basin was surrounded by alluvial ridges and isolated from the rest of the Mississippi Valley. Subsidence and paucity of sediment deposited in the area caused the basin to remain a lowland. A lake was formed as drainage was ponded in the southern portion of the basin by the alluvial ridges. The natural outlet for the basin, then as now, was the Lower Atchafalaya River.

Modern Mississippi stage

91. The Mississippi River abandoned its Lafourche course at Donaldsonville and occupied its present course from there past New Orleans at about 1400 A. D. The only subsequent changes which occurred in the Mississippi involved a shifting of the river delta as the position of the river mouth was changed.

92. The geography of the basin at this stage is shown on figure 16c. The Red River had abandoned the old Teche-Mississippi channel and now entered the Mississippi at the meander loop just south of Old River. The whole of the basin was a very low-lying part of the alluvial valley, and the entire southern basin area as far north as the latitude of Baton Rouge was one large lake. The water in this lake was somewhat brackish (as revealed by fossils encountered in borings) owing to the periodic influx of sea water via the Lower Atchafalaya River, which continued to act as the principal basin outlet. The basin surface remained low and the lake area became extensive because no large stream contributed the

sediment necessary to build it up.

Atchafalaya River stage

93. The Atchafalaya River was introduced into the basin about 1500 A. D. as the last step in basin development. The present Atchafalaya Basin is being alluviated at an ever-increasing rate by the Atchafalaya River. The lake area in the southern part of the basin is being rapidly reduced as the Atchafalaya delta continues to enlarge.

Origin and Development of the Atchafalaya River

94. Results of the present investigation support some of the earlier published views concerning the origin of the Atchafalaya River (see references 3, 4, and 8). However, many details are yet to be documented. There is little doubt that the Atchafalaya River originated before the coming of the white man to the area, but the absence of Indian mounds along its course indicates that the river is younger than most other large streams in this portion of the Mississippi Alluvial Valley. Studies made by Fisk(9) suggest that the conditions necessary for the formation of the river were established about 1500 A. D. These conditions involve the activity of the Red River prior to that time and the growth of Turnbull Bend in the Mississippi River.

95. The Red River prior to 1500 A. D. entered the Mississippi south of Old River along a course now marked by Bayou Lettsworth (see plate 2). Near its present junction with the Atchafalaya it intersected the relict drainage of the abandoned Bayou des Glaises segment of the Mississippi (present Atchafalaya channel north of Simmesport) and in all probability used it as a distributary. Westward migration of the Turnbull Island

loop of the Mississippi eventually captured the Red and further enlarged the former Red distributary. The development of the distributary south of Simmesport was aided to a large extent by its location. The alluvial ridge forming the northern boundary of the Atchafalaya Basin also acted as an effective dam across the valley, and Red River backwater that accumulated behind this ridge had only the Mississippi River as a major outlet before the Atchafalaya was developed.

PART IV: INFLUENCE OF BASIN DEPOSITS ON ATCHAFALAYA RIVER BEHAVIOR

96. The influence of alluvial deposits on meandering characteristics, channel shape and size, and the over-all regimen of alluvial valley streams has been discussed in part III. Inasmuch as the Atchafalaya is an enlarging stream, the nature of the deposits forming its bed and banks has added significance, for it controls to some extent the rate at which the channel will enlarge to accept the flow of the Mississippi. A knowledge of the alluvial deposits of the Atchafalaya Basin is therefore essential to an understanding of the development of the river. Description of the basin alluvium involves a delineation of the site of deposition, a general discussion of the character of substratum deposits, and a more detailed discussion of the topstratum deposits, especially of those materials forming the bed and banks of the Atchafalaya River. Such a description, together with an account of the influence of deposits on past and present development of the Atchafalaya River, is the subject of the following paragraphs.

Entrenched Valley

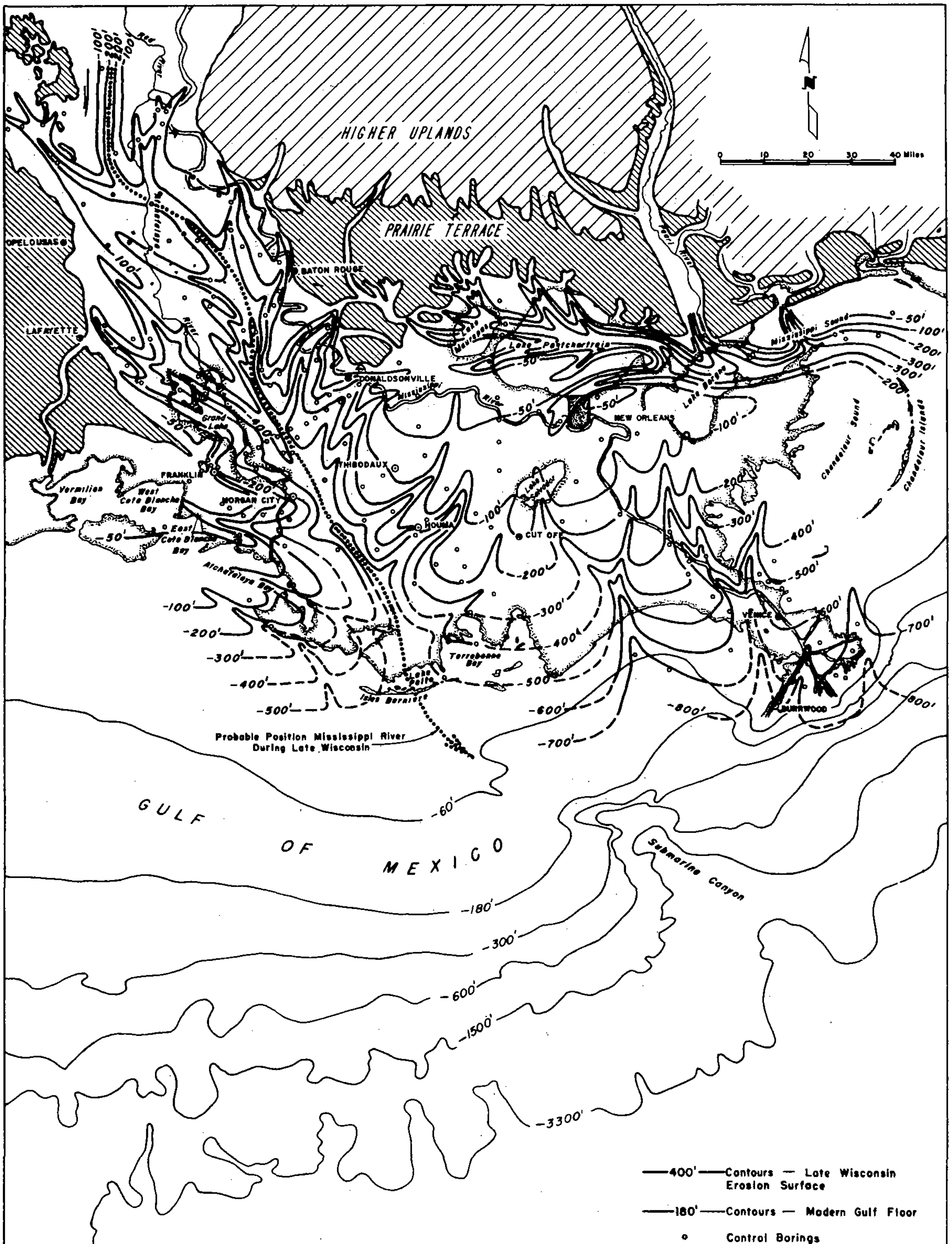
97. The entrenched valley of the Mississippi River has been the site of alluvial deposition by streams of the Mississippi River System since sea level began to rise in response to the waning of the Late Wisconsin ice sheet. The valley has been filled to its present level with substratum and topstratum deposits during the last 25,000 to 30,000 years. A contour map published by Fisk(9) first showed the over-all configuration of the entrenched valley. Additional information based on deep borings

made for the present study and on borings and electrical logs collected from other sources has made it possible to trace with more accuracy that portion of the entrenched valley lying beneath the Atchafalaya Basin. Figure 17 is a generalized contour map, showing the major irregularities of this buried feature.

98. The deepest part of the entrenched valley, or valley axis, lies approximately beneath the central portion of the Atchafalaya Basin throughout much of its length, diverging from this position to pass east of Morgan City, through Lake Pelto, possibly to connect with the Mississippi Submarine Canyon, a well-known notch in the continental shelf (fig. 17).

99. The most accurate information regarding the position of the valley axis, base of Recent alluvium, nature of substratum, and general relationships between the Atchafalaya Basin surface and the underlying deposits, is available along a trans-valley line of project borings made between Donaldsonville and Franklin. This line was located within the hinge zone of the Prairie terrace where neither downwarping nor uplift has been operative since the beginning of Recent time. Excellent subsurface information was also available in the northern part of the Atchafalaya Basin along a line between Baton Rouge and Opelousas. Plate 3 is a block diagram designed to show the detail available along these lines and the relationship between the surface and the subsurface.

100. Neither of the two subsurface profiles shows abnormalities indicative of structural deformation during Recent time. The base of the Recent shows no irregularities which cannot be attributed to the erosional activity which shaped it. The contact between topstratum and substratum



SOUTHERN PORTION
ENTRENCHED MISSISSIPPI VALLEY SYSTEM
LATE WISCONSIN GLACIAL STAGE

Fig. 17.

shows no excessive thickening which might have been caused by differential subsidence along these transvalley profiles. It is concluded, therefore, that the location and past and present development of the Atchafalaya River have not been affected by structural movements and that active subsidence, which might significantly affect future Atchafalaya River development, is not to be expected.

Recognition of base of the Recent alluvium

101. At most places within the alluvial valley the base of the Recent alluvium is easily determined by locating the base of the gravel-bearing substratum deposits. Alluvial activity consistently caused coarse clastic constituents to be laid down as the initial deposit in the entrenched valley. Where no gravel beds appear in the alluvial sequence or where, for any reason, the gravel base is not a distinctive horizon, evidence* of subaerial exposure normally marks the base. Both types of criteria were useful in identifying the entrenched valley surface in borings made in the Atchafalaya Basin. However, in the portion of the basin south of the hinge zone, near the entrenched valley axis, Recent gravels and sands overlie similar deposits of previous alluvial cycles, and the effects of subaerial exposure, if any, are not recognizable. Here it was necessary to determine, from regional data available, the position

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* Examples of such evidence are: red-stained or brown-stained zones encountered in borings, indicating oxidation of ferruginous constituents under subaerial conditions. Somewhat less conclusive criteria, but still quite useful are: concentration of concretions at a particular level, abrupt increase in degree of compaction or decrease in water content of sediments, and the degree of preservation of fossil shells. Red deposits of a different kind are laid down by the Red River, so red-stained material must be carefully examined to correctly determine its significance.

of the next older alluvial succession; to project this position to the site of critical Atchafalaya Basin borings; and, using the combined information, to locate the base of the Recent alluvial sequence. Plate 4 is an east-west extension of the Donaldsonville-Franklin line of borings and shows the regional relationships between Recent and older alluvial deposits in the southern part of the Atchafalaya Basin. Successively older sequences of gravel, sand, and topstratum deposits are seen to underlie the Recent section. Other information regarding the position of both Prairie and Recent sections north and south of this line was also used in locating the boundaries of these alluvial sequences. The detailed information regarding the succession of deposits in these project borings permitted more intelligent interpretation of the near-surface portion of electrical and drillers logs of many oil and water wells drilled in the basin.

Substratum

102. Substratum deposits are the coarse basal fraction of the alluvial sequence laid down in the entrenched valley and consist principally of sand and gravel. Within the Atchafalaya Basin thickness of the substratum increases in a downvalley direction. Borings penetrate 160 ft of substratum near Old River at the northern end of the basin, whereas about 350 ft of pervious sediments are encountered a few miles southeast of Morgan City. The substratum is thickest along the axis of the entrenched valley; it is virtually absent in places near the Mississippi alluvial valley wall and locally south of the Atchafalaya Basin. For example, no substratum is encountered in borings which reach the

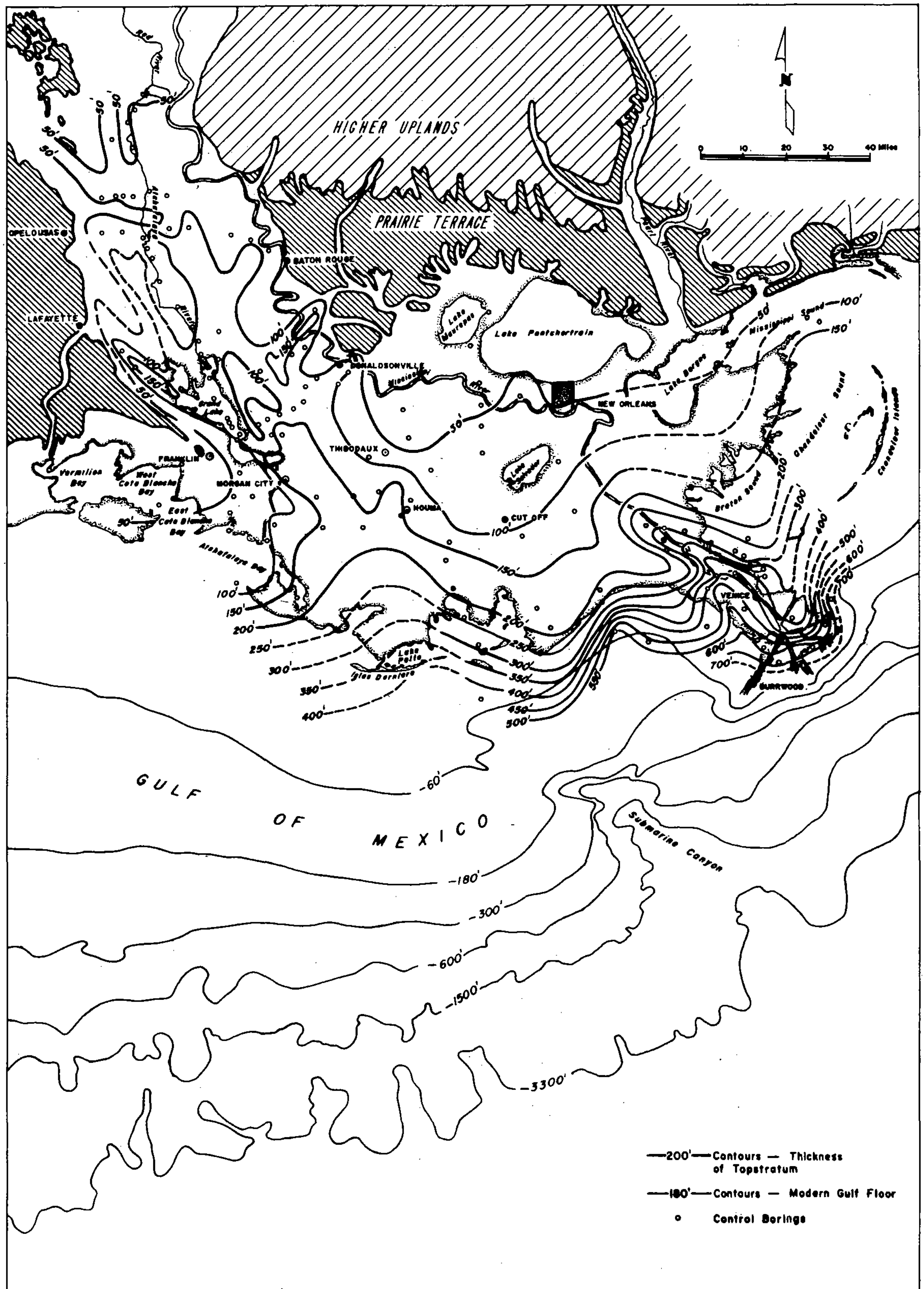
Prairie formation at shallow depths south of Bateman Lake.

103. The nature of the substratum is best shown by the deep project borings made along the Donaldsonville-Franklin line (see plate 5). In most of these borings coarse substratum sands and gravels rest directly upon the upper clay portion of the Prairie alluvial sequence. On either side of the entrenched valley axis near the center of the basin, the substratum lies on gravel-bearing deposits of the Prairie formation and the contact between the two units is not so easily determined.

104. The boundary between the substratum and the overlying topstratum is an irregular one. Figure 18 shows the general thickness of the topstratum clays and silts and illustrates this irregularity. Substratum deposits are brought near the surface in meander belts. These are relatively common in the northern portion of the basin along the leveed Atchafalaya segment. A belt of abnormally high substratum is also found immediately south of the leveed segment, now marked by Bayou Courtableu and Upper Grand River; another is found at the southern limit of the basin, marked by Bayou Teche.

Topstratum

105. Topstratum deposits include all materials overlying the substratum from which they are distinguished chiefly on the basis of grain size, topstratum being composed of finer-grained impervious constituents, such as silty clay or clay. In general, the topstratum forms a wedge-like body, the average thickness of which increases from 80 ft in the northern portion of the basin to more than 150 ft in the southern part. The deepest portions of the topstratum represent former thalweg positions



THICKNESS OF RECENT TOPSTRATUM DEPOSITS
MISSISSIPPI DELTAIC PLAIN

Fig. 18.

of cutoff channels, which are sometimes filled with clays to a depth of 180 ft. The thinnest topstratum deposits are found in areas of point-bar deposition where as little as 25 ft of topstratum is not uncommon.

106. Most types of alluvial valley environments are represented by deposits in the Atchafalaya Basin. Topstratum deposits characteristic of meander belts (natural-levee, point-bar, and channel-fill deposits) occur principally in the northern portion of the basin. Backswamp deposits are more widespread. Deltaic deposits, together with the marsh deposits which extend seaward south of the Atchafalaya Basin, can be classified with the deltaic plain environment of deposition.

107. Of a different nature, but added for completeness, are the Pleistocene terrace deposits which form the Mississippi River Alluvial Valley walls on either side of the Atchafalaya Basin, and which underlie the marsh deposits south of the Teche ridge at comparatively shallow depths.

108. The surface distribution of alluvial deposits in the Atchafalaya Basin has been mapped and is shown in color on plates 7-14. Symbols designate areas where shallow backswamp or natural levee deposition masks underlying point-bar and channel-fill deposits. Surface deposits shown on plate 12 are almost exclusively deltaic. The usual color scheme is disregarded and colors are used to differentiate growth of the delta into Grand Lake since 1917.

Natural levee deposits

109. Natural levee deposits consist principally of silts and fine sands laid down by floodwaters when the river tops its banks and spreads out over the above-bank surface. They accumulate in the form of ridges

flanking stream channels. Coarser materials are laid down nearest the banks while progressively finer materials predominate with increasing distance from the river.

110. The most extensive natural levee deposits in the Atchafalaya Basin are not those along the Atchafalaya River, but those along minor streams which mark former courses of the Mississippi or Red Rivers. For example, the natural levees flanking Bayous des Glaises, Teche, and Grosse Tete are of greater areal extent than those which flank the Atchafalaya (plates 7, 8, and 9). Although the discharge through the Atchafalaya is considerably greater than that of the Red or the Ouachita, the natural levee deposits along the Atchafalaya are insignificant in comparison. This is a reflection of two things: the recency of Atchafalaya River development as a major stream, and the construction of artificial levees before and during this development preventing normal formation of a natural levee system in the upper reaches of the river. Natural levees are forming at a rapid rate along the lower unleveed section of the river, and it is conceivable that they will eventually become larger in areal extent than those along the upper segment of the river where artificial levees prevent their continued formation. Natural levee deposits are representative of the coarsest material carried in suspension during overbank flow. Along the Atchafalaya, silty sand and fine sand predominate as constituent materials.

Point-bar deposits

111. Point bars consist of predominantly sandy deposits laid down within enlarging meander loops. During the process of local river migration a series of arcuate ridges is formed on the bar bordering the concave

bank of the stream. The ridges are separated by intervening troughs, or swales, in which silts and clays are deposited during falling river stages. The aggregate is referred to as point bar, which may be further subdivided into swale fillings and sandy ridge deposits. Topstratum is thinnest above point-bar accretion ridges, and is thickest over swales. The curvature and alignment of the ridges and swales reflect closely the size and shape of the meander loops in which they were laid down. Inasmuch as the radii of meander loops are proportional to the size of the stream, it is possible to distinguish point bars laid down by the Mississippi River from those formed by smaller streams such as the Atchafalaya and Red Rivers.

112. The surface distribution of point-bar materials is shown on plates 7-14; those buried under cover of backswamp or natural levee deposits are designated with appropriate symbols. Point-bar deposits of the Atchafalaya River are irregularly distributed along the stream course. Many are extremely narrow since there has been only slight migration of the channel during enlargement of the river, and are not mappable at the scales used in the plates. Only the areas of major point-bar deposition are shown. Broad belts of point-bar materials of Mississippi or Red River origin cross the Atchafalaya River in the Simmesport sector (plate 7), near Cypress Bend (plate 8), and in the area south of Krotz Springs (plates 9, 10, 11). A band of point-bar deposits of Teche-Mississippi origin forms the bed and banks of the Atchafalaya at Morgan City where the river leaves the confines of the basin (plate 14).

Channel-fill deposits

113. The abandoned channel of a meander loop which has been

separated from the main channel by a natural or artificial cutoff gradually fills with deposits of sands, silts, and clays. The slack-water area of the upper arm receives coarser sediments from the main channel and rapidly seals itself off. The lower arm seals more slowly and normally with finer materials. The finest materials are laid down in the resultant ox-bow lake which gradually fills with sediments carried in by floodwaters. This thick clay deposit is commonly called a "clay plug."

114. Abandoned channel fillings in the vicinity of Simmesport and Cypress Point are shown on plate 7. Figure 19 illustrates to some extent the nature of the tight clay which fills the lower arm of the abandoned channel at Cypress Point. The cypress knees indicate the water in the old ox-bow lake prior to its becoming entirely filled with sediment.

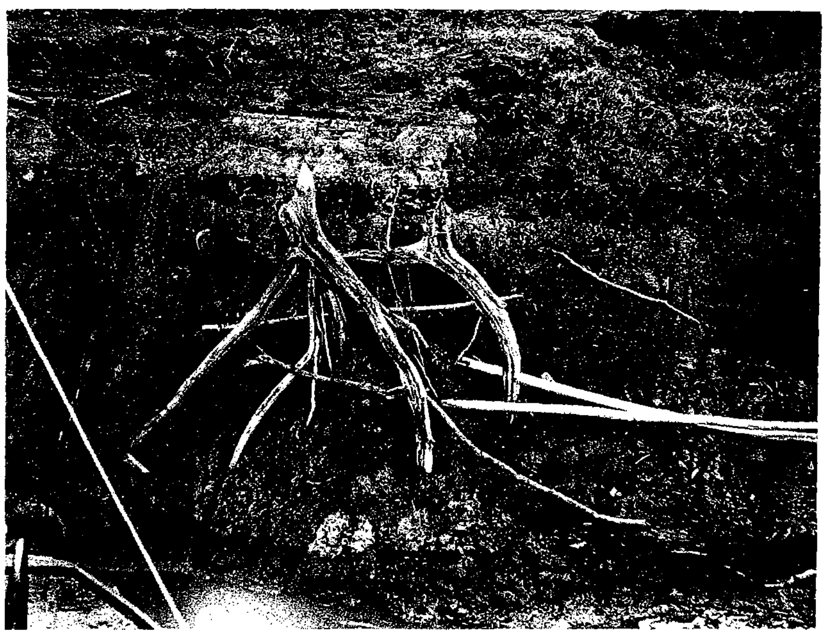


Fig. 19. Tight clays in the lower arm of an abandoned channel fill at river mile 14. Note cypress "knees" which indicate water level in the old ox-bow lake prior to its becoming entirely filled with sediment. Top of riverbank at this point is an estimated 12 to 15 ft above these cypress "knees."

The top of the riverbank at this point is estimated 12 to 15 ft above these cypress knees.

Backswamp deposits

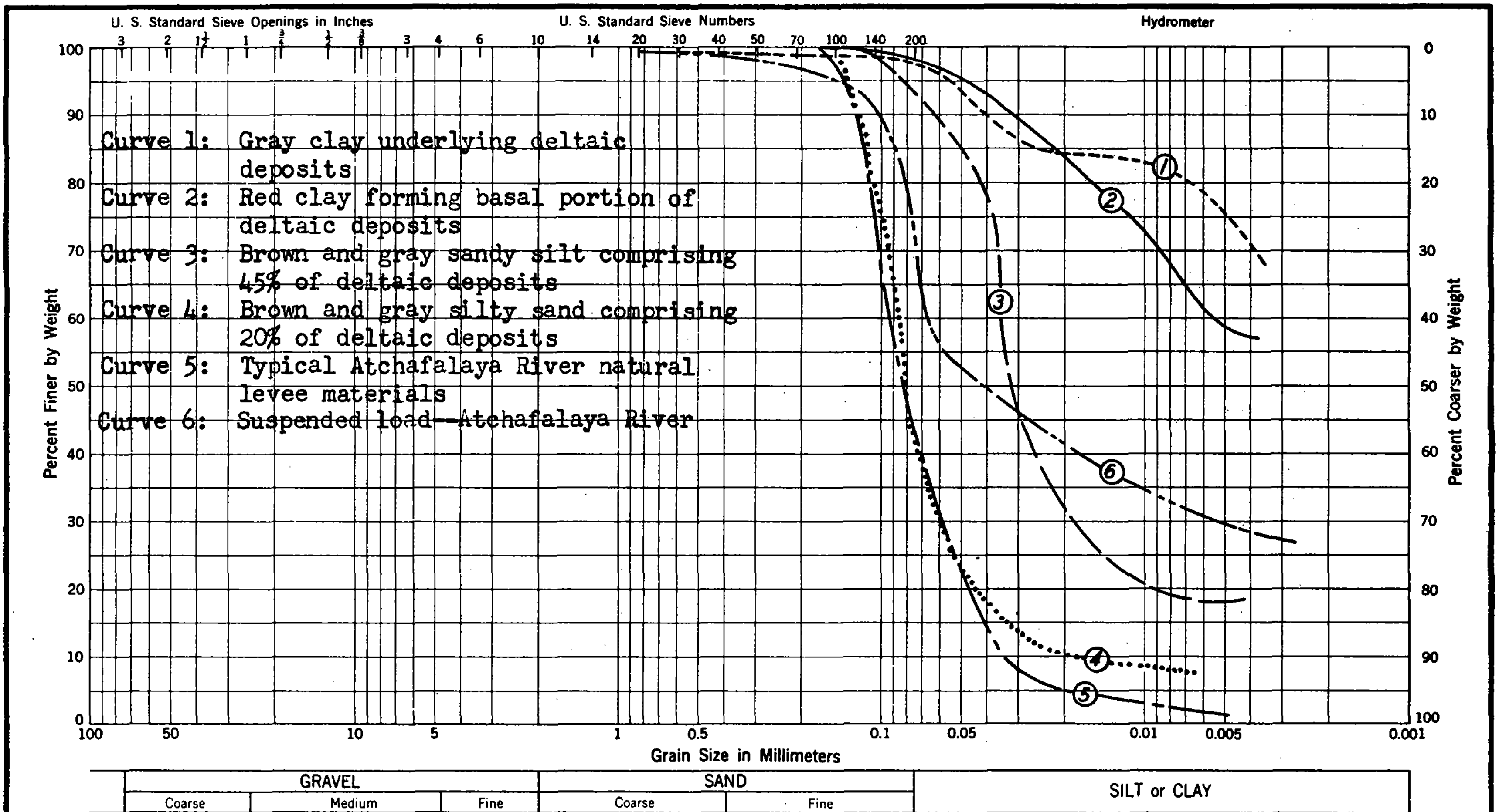
115. Backswamp deposits are the most extensive of the materials forming the bed and banks of the Atchafalaya River. They represent principally the long-continued accumulation of deposits in the low-lying areas which flank meander belts, and consist of clayey material which is not dropped at natural levee sites but remains in suspension until the waters are impounded in flood basins. The Atchafalaya Basin, situated between the Mississippi-Teche meander belt and the meander belts of the modern and Lafourche-Mississippi courses, is ideally located for the entrapment of floodwaters and the formation of backswamp deposits. Their thickness and lithologic character are remarkably uniform. Backswamp thicknesses in the northern end of the basin average 90 ft, gradually increasing to about 140 ft in the Grand Lake area, where they are overlain by thin Atchafalaya deltaic deposits.

Deltaic deposits

116. Most of the Atchafalaya Basin south of the leveed segment of the Atchafalaya River is covered with a blanket of deltaic deposits laid down by the river in a large ancestral Grand Lake, now rapidly being filled. Remains of this lake are the Grand Lake-Six Mile Lake water bodies in the extreme southern end of the basin. Although natural levees, shell beds, and lacustrine and backswamp clays occur locally, the complex is mapped principally as deltaic deposits. Maps have been prepared showing the rate at which the lower basin is being alluviated (plates 15 and 15a) and the phenomenal growth of the delta into Grand

Lake in recent years (plate 12). Since 1930 more than 60 square miles of additional land surface has been formed in the lake area. Detailed shallow borings made in Grand Lake demonstrate the extent of this deposit in profile as well as in plan (plates 12a and 12b). The deltaic deposits are built outward over heavy organic clays which represent the old lake bed and backswamp deposits formed before active Atchafalaya River delta-building began. The maximum thickness of the deltaic deposits is about 25 ft, the average approximately 15 ft.

117. The deltaic deposits can be divided on a color basis into two units (plates 12, 12a, 12b); a lower unit, distinctly red in color, overlain by a brown and gray-brown unit. In north-south section, the units tend to thin toward the south. The lower unit overlies thick gray and blue-gray lacustrine and backswamp clays. The contact between the thick clays and the deltaic deposits is marked by shell and wood accumulations. The red color of the lower unit reflects that stage of deltaic growth when only Red River sediments were carried by the Atchafalaya. The overlying brown and gray-brown unit reflects the gradual increase in diversion of Mississippi River water. Exclusively Red River deposits form approximately 30 per cent of the deltaic deposits in Grand Lake. Mixed Red River and Mississippi River deposits form the remaining 70 per cent. Red River deposits consist of about 85 per cent clay and 15 per cent silty clay. Mixed Red and Mississippi River deposits consist of approximately 10 per cent fine sand, 20 per cent silty sand, 45 per cent sandy silt, 15 per cent silty clay, and 10 per cent clay. Figure 20 contrasts the grain-size distribution of three samples selected from the deltaic deposits with that of the gray backswamp clay which they overlie,



Number	Natural % Moisture	L. L.	P. L.	P. I.	Classification

ATCHAFALAYA RIVER

COMPARATIVE GRAIN-SIZE DISTRIBUTION CURVES

Fig. 20.

and with suspended load and natural levee samples characteristic of the Atchafalaya River.

Marsh deposits

118. South of the Atchafalaya Basin the well-drained natural levees of the Teche ridge give way to the complex of brackish and salt-water marsh, shell beds and organic oozes mapped on plates 13 and 14 as marsh deposits. The chief constituents of the marsh deposits are highly organic clays and silts with minor amounts of sand and shell deposits. The marsh deposits normally possess very high water contents at the surface but develop into firmer strata at depth. None, however, are as consistently firm as the clays which characterize abandoned channel or backswamp environments of deposition in the Atchafalaya Basin to the north.

Pleistocene Deposits

119. Underlying the marsh deposits at fairly shallow depths south of the Teche ridge are tough, oxidized clays of the Prairie (Pleistocene) formation. Plates 13, 13a, 14 and 14a show the depth at which oxidized Pleistocene clays are encountered below the marsh deposits. Contours on the Pleistocene show that the old erosion surface gradually slopes beneath the marshes from its outcrop near Franklin to a depth of approximately 100 ft beneath the Atchafalaya Bay area. On a line extending from Calumet through Deer Island, there is an abrupt steepening of the contours where the Pleistocene has been eroded to a depth of from 200-250 ft below present sea level. Eastward, approaching the entrenched valley axis, the eroded surface is encountered at even greater depths.

Effect of Bed and Banks on Atchafalaya River Development

120. The effect of the bed and bank materials on Atchafalaya channel enlargement can be best described in terms of the thickness of the topstratum along its channel and the relative erodibility of the types of alluvial deposits through which it flows.

121. Bank recession along the Atchafalaya is dependent not so much on the cohesiveness or relative erodibility of the topstratum materials into which the channel is cut, as on their thickness. It is the position of the substratum materials relative to the channel bottom which greatly influences bank recession in an individual reach. Once the channel has cut through the topstratum and into the underlying comparatively loose substratum sands, rapid scouring of the sands causes unstable slopes to develop by removing support from beneath the topstratum. Bank caving results.

122. Channel fill and backswamp clays, and to some extent the marsh deposits, form the least erodible of the alluvial deposits. Studies of the Lower Mississippi River(10) have shown that the thick deposits of rather uniform clay laid down in abandoned channels often possess considerable resistance to erosion and act as "hard points" which tend greatly to retard the rate of bank recession and channel enlargement. Backswamp clays possess a resistance to river scour comparable to that of channel-fill deposits. Their depth in the leveed reaches of the river is ordinarily not as great, however; consequently, they are subject to more rapid undercutting as the channel enlarges and the river cuts through them into the substratum. Figure 21 illustrates the serrated

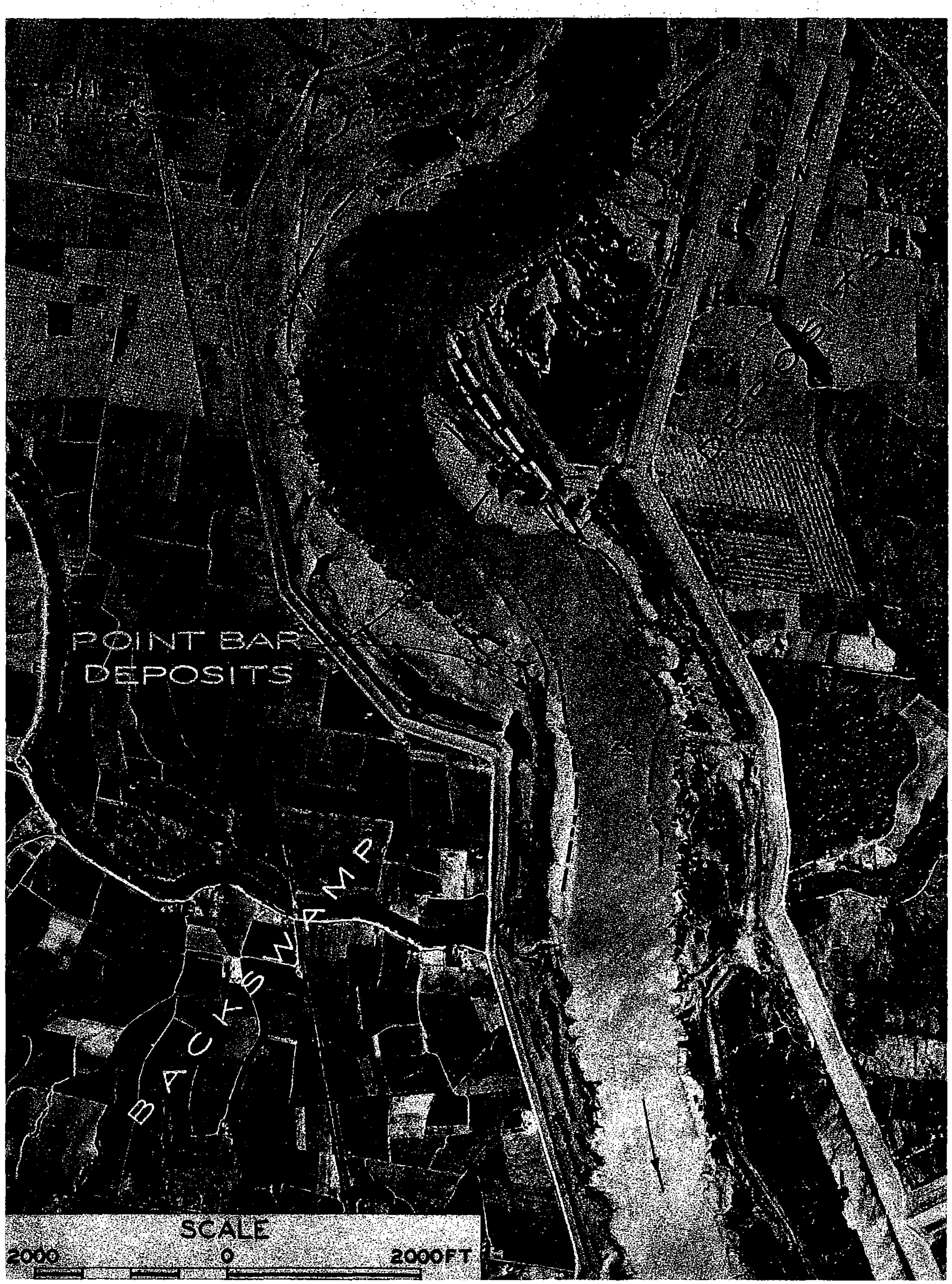


Fig. 21. Reach along Atchafalaya River where bed and banks are composed principally of backswamp deposits. Note active slumping of banks on both sides of stream. Numbers 25 and 26 indicate Atchafalaya River miles

pattern characteristic of banks composed of cohesive backswamp and channel-fill deposits. Large arcuate segments of the bank slump into the river and act as natural revetments for some time until they in turn are removed by scour as deterrents to channel enlargement.

123. The coarser alluvial materials, point-bar, natural-levee, and deltaic deposits, retreat fairly rapidly as the river enlarges. Point-bar deposits generally possess only slight cohesion. However, in instances where clay-filled swales are wide and extend to below the low-water level, they may exert a minor control on the rate of channel migration or enlargement. Banks along the Atchafalaya composed of point-bar material retreat rapidly and evenly, and relatively smooth banklines are characteristic of such reaches (see figure 22). Natural levee and deltaic deposits possess some cohesion but are comparatively thin. The principle effect of the natural levee is that of confining water in a single channel, hastening scour, especially in the lower reaches of the river.

124. For descriptive purposes the river has been divided into reaches based principally on types of deposits forming the bed and banks. Plates 18-33 show the distribution of these deposits in plan and profile along Old River and from the head of the Atchafalaya River to its mouth in Atchafalaya Bay. Plate 17 is a generalized subsurface profile along the entire length of the Atchafalaya distributary system.

Old River reach

125. This reach strikingly demonstrates the control exercised by an abandoned channel on subsequent drainage alignment. Old River follows the thalweg position of the Mississippi River prior to Shreve's cutoff

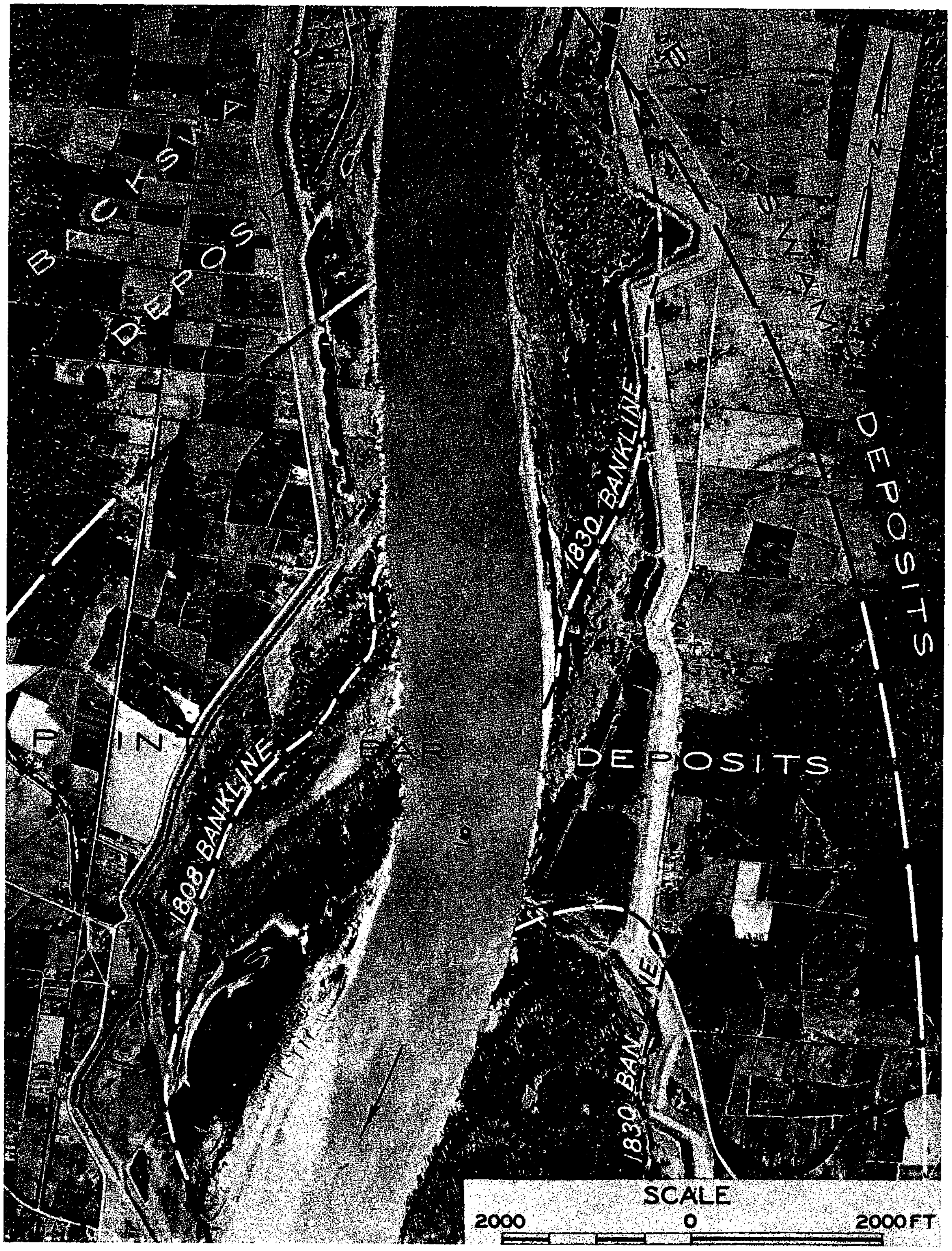


Fig. 22. Reach along Atchafalaya River where bed and banks are composed principally of point bar deposits. Note relatively smooth banklines. Numbers 8 and 9 indicate Atchafalaya River miles

in 1831. Throughout a complicated history of enlargement (see paragraphs 35 to 41) the river has closely followed the position of the former Mississippi thalweg. In so doing, the present channel is flanked by abandoned channel deposits on its south bank for the first two miles of the reach, on both banks at the location of the old Mississippi River crossing, and on its north bank for the remaining two miles before its junction with the Atchafalaya.

126. As illustrated in various sections which cross the river in this reach (sections B-B', C-C', D-D', E-E', and F-F', plates 18a and 18b) there is a tendency for the river to increase its cross-sectional area at the expense of the shallow point-bar deposits bordering the abandoned channel position first on its northern and then on its southern side. The most stable sections of this reach are considered to be at the former crossing, or between river miles 3.5-4.5, where the present channel is flanked on both sides by channel-fill deposits, and between 4.5-5.0 where an old channel-fill deposit forms the bank of an enlarging bend. Slumping characteristic of this area is shown in figure 23. Another area of significance in this reach is at the junction of the Old and Mississippi Rivers where the channel is scouring into deep, but fairly coarse-grained channel-fill deposits. The coarse nature of this fill at the junction and its gradual increase in clay content west from the former point of cutoff is shown in section A-A' (plate 18). A recent development (Nov-Dec 1951) in this area has been the placing of revetment along the south bank of Old River downstream as far as river mile 0.6 This revetment, if held in place, will increase the control exercised by the point of diversion in over-all channel enlargement.

Fig. 23. Slump block of channel-fill materials at Old River mile 4. Note arcuate slump and angle which surface of block makes with horizontal. Photograph taken 30 November 1950 during comparatively low stage of the river

Reach 0.0-5.0

127. Sections illustrative of this reach are H-H' and I-I', plate 19a. The materials composing the bed and banks are almost exclusively point-bar deposits and as such offer little resistance to channel enlargement. Sand substratum lies at depths as shallow as 25 ft and is sometimes exposed along the banks during low-water stages of the river.

Reach 5.0-7.5

128. Immediately south of the entrance of Bayou des Glaises into the Atchafalaya River is one arm of a "clay plug" traced in its entirety on plate 7 (see section J-J', plate 19a for detail). Clay in this area extends to a depth of 60 or more feet below the deepest portion of the Atchafalaya channel. Southward from the clay body is a continuation of fairly deep, tenacious clays of backswamp origin (section K-K' plate 19b).

129. The tight nature of the material composing this reach makes it one of primary importance from the standpoint of material type control on channel enlargement. In addition, flow through the Atchafalaya distributary is confined for the first time between artificial levees and flood flows can be fully effective in enlarging the channel.

Reach 7.5-13.0

130. The most conspicuous meandering along the Atchafalaya River occurs in the point-bar deposits which comprise this reach. Maps comparing historic banklines show that the extent of change in channel alignment has been considerable. Bankline surveys show a lateral migration of the channel at this point of nearly 4,000 ft since 1904, and of more than two miles, judging by the extent of deposition of Atchafalaya River point-bar deposits, since it began to meander (section L-L', plate 19b). This lateral migration into what must have been tough backswamp clays, similar to those in the previous reach, seems to have been the result of the controlling influence of the clay plug just downstream from this reach described in subsequent paragraphs. This reach is considered to have little control on over-all enlargement of the Atchafalaya.

Cypress Point reach, river miles 13.0-20.0

131. It is necessary to divide this reach into three segments, river miles 13.0-15.0, 15.0-18.5, and 18.5-20.0, in order to evaluate the effect of the bed and banks on channel enlargement. For purposes of description, however, the three are described as a single unit, a unit controlled entirely by two arms of a clay plug which lie across the course of the Atchafalaya. What appears to be an abnormally large river meander at Cypress Point is actually caused by the upper arm of this clay

plug, which controls the direction of flow of the Atchafalaya. Bankline surveys dating as far back as 1810 show that the bend has remained essentially stable and that the Atchafalaya River has had little success in wearing away the clays which compose it. Plate 20 shows the position of this clay plug as determined by borings and scars left on the alluvial surface. Plates 20a and 20b show details of the bed and bank deposits within the reach. The stability of the Cypress Point segment from river mile 13.0-15.0 is in direct contrast to the intermediate segment from river mile 15.0-18.5 where the Atchafalaya has meandered extensively in the shallow point-bar materials lying between the two arms of the clay plug. Less prominent meandering has occurred in the materials forming the lower arm, possibly initiated by the meanders in the intermediate segment.

132. The confining effect of the plug in the upstream arm, by resisting passage of river waters, probably flattened the gradient above that point, and was the cause of the extensive meandering in the reach immediately upstream. The river in this upper reach has straightened materially in recent years resulting in a shortening of 0.8 mile in this reach (miles 7.5-13.0) since 1917 and 2.2 miles since 1881. A similar tendency for the river to cease meandering and shorten its path is noted between miles 15.0 and 18.5.

Reach 20.0-46.0

133. The bed and banks of this extensive reach are mostly backswamp clays which reach depths of -60 to -70 ft msl, or a thickness of from 90 to 100 ft. The type of material forming the bed and banks is so very much alike that it is considered as a unit.

134. Sections Q-Q' through X-X' (plates 21 through 22a) show subsurface conditions in this reach. These sections are immediately adjacent to the river and indicate a rather consistent depth of the backswamp clays, with a slight thickening southward. Plates 8a and 9a show sections which extend for several miles to the east and west of the river in this area and illustrate the homogeneity of the backswamp clays in transverse as well as longitudinal profile. The pattern is interrupted slightly by point-bar deposits from old Mississippi meander courses and distributaries, but the continuity of the clays, especially adjacent to the river, is well illustrated.

135. Generally speaking, the reach is remarkably stable. Bankline surveys show almost no change in channel alignment since the early 1800's. Less than one mile of shortening has occurred in this 26-mile length since 1917, and only about 1.5 miles since 1881. Small meanders at miles 25, 31 and 34 are migrating downstream at a very uniform rate, attesting to the homogeneity of the bed and banks in the area.

136. Although the thalweg of the present river is at such a depth that it is scouring into the sandy substratum in a number of places and hastening channel enlargement, the length and over-all stability of this reach is such that it is regarded as the principal control, from the standpoint of material type, to channel enlargement of the Atchafalaya River.

<u>Reach 46.0-67.0</u>

137. This reach is characterized by a fairly shallow topstratum composed of comparatively fine-grained and cohesive point-bar deposits of possible Mississippi River origin. Details are shown on sections

Y-Y', Z-Z' and AA-AA' (plates 23, 24a, and 25). The river throughout the upper half of this reach has been leveed and is scouring into substratum sands which average 60 ft below top of bank. The lower portion of the channel, between miles 54-67 has penetrated the substratum sands in only a few places but evidence of active enlargement caused by substratum scour is shown by slump blocks which occur along this portion of the reach at infrequent intervals (fig. 24).

138. Comparatively little control of channel enlargement is exerted by the bed and bank materials in this reach. However, further channel deepening will result in more extensive scouring of the substratum sands. This in turn should cause more widespread meandering to develop within and immediately downstream from the reach.

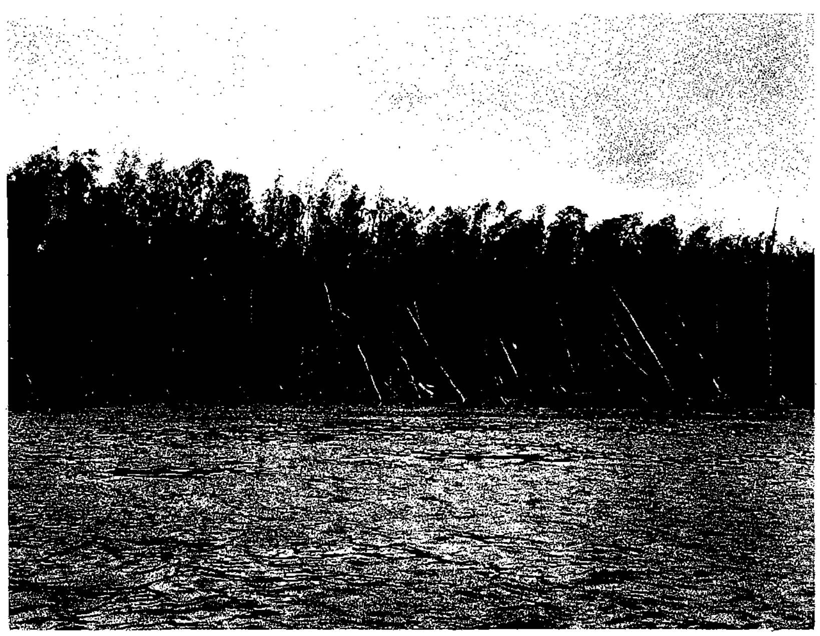


Fig. 24. Slumping of backswamp materials at river mile 66. The slump block has subsided beneath the water, but the trees which grew upon it and the angle which they make with the vertical indicate its extent and the relative position. Photograph taken 1 December 1950

Reach 67-112

139. Plates 26-29 illustrate the type of deposits encountered south of mile 67. Generally speaking, a heavy clay stratum reaching an average depth of -120 ft below sea level lies below relatively thin deltaic deposits of the Atchafalaya River. The deltaic deposits are in most instances composed of silts, silty clays, and silty sands, and, as such, offer little resistance to channel enlargement. Plates 12a and 12b show the detailed lithology of the deltaic deposits and the underlying backswamp clays.

140. The materials composing the bed and banks in this reach are not an important factor, at the present time, in channel enlargement. Rather than scouring its channel, the river takes the path of less resistance and tops its banks. As natural levees are built up, however, and as volume of discharge continued to increase, heavier scour will result in the river channel and the deposits forming the bed and banks of this reach will become of greater importance. A deep, narrow, nearly straight channel, comparable to the present Mississippi south of Donaldsonville, will probably develop in the thick backswamp clays which compose this reach.

Lower Atchafalaya River-Wax Lake Outlet

141. Plates 30-33 show the type of material in which these outlets to the Atchafalaya Basin are developed. Wax Lake Outlet was dredged almost entirely through marsh deposits composed of highly organic clays. Tough, oxidized Pleistocene clays lie only 10 ft below the present 50-ft channel throughout most of its length.

142. The Lower Atchafalaya River is a natural outlet for waters in

the basin. A deep wide channel is already in existence. Silty and sandy deposits filling the abandoned Teche-Mississippi channel, marsh deposits, and bay bottom clays form its bed and banks. The channel has penetrated substratum sands only in its upper end where channel depths reach 140 ft; southward the channel shoals gradually to a 6-8 ft depth as it enters Atchafalaya Bay. Pleistocene clays underlie the dredged channel in Atchafalaya Bay at a depth of 80 ft.

143. The most significant alluvial deposits along these reaches are the high sands of the abandoned Teche-Mississippi channel and the tight Pleistocene clays into which the future channel must develop. The sands will promote stream meandering. The tight Pleistocene clays will control, to a large extent, the future rate of enlargement of these two outlets to the basin.

Summary

144. Evidence based on topstratum-substratum relationships in the Atchafalaya Basin show that past development of the Atchafalaya Basin has not been affected by structural movements. There is no reason to believe that active subsidence or structural movement will affect future Atchafalaya River development.

145. Reaches considered most important from the standpoint of bed and bank control on over-all channel enlargement are those along Old River from river miles 0.0-1.0 and 3.0-5.0, and along the leveed Atchafalaya channel between river miles 4.5-7.5, 13.5-15.0, and 20.0-46.0. These reaches consist largely of channel fill and backswamp clays which offer most resistance to scour and cross-sectional enlargement.

The fact that the thalweg along most of the leveed segment is in substratum sands should speed up channel enlargement and cause more extensive channel migration in the future.

146. The lower unleveed segment of the Atchafalaya is composed principally of thick backswamp clays with two major exceptions: the high substratum sand area which crosses the river near the end of the levees and extends downstream to mile 67, and the sandy materials brought near the surface at the Teche ridge, miles 113-117. Other than some meandering initiated by these high sands, the Atchafalaya south of the leveed segment should develop a deep, comparatively straight channel.

147. Eventual development of the channel through Atchafalaya Bay will be largely controlled by tough Pleistocene clays which lie at depths of -80 ft msl.

PART V: MISSISSIPPI RIVER DIVERSION

Introduction

148. No literature is known to exist which attempts to analyze the factors that control diversion. A general idea of some of the more obvious factors in stream diversion can be obtained from an interpretation of recorded diversions of other rivers. However, vital aspects of the diversion problem peculiar to the Mississippi must be obtained from geological studies of previous Mississippi diversions. Each former shift in the course of the river seems to have been accomplished in a manner similar to that now in progress. Therefore, a study of past Mississippi diversions is the best source of information bearing on prediction of future behavior of the Atchafalaya River.

149. Distinction must be made between diversions which occur near the river mouth as the delta grows, and those which take place far upstream where water is deviated from long-occupied full-flow channels. In almost all deltas, the development of river mouth bars divides a channel into several minor courses. As minor channels develop, changes in alignment or other factors cause them to be abandoned. Some of the old channels may be reoccupied, especially during floods. These river mouth diversions are not the subject of the following discussion.

Diversion in large alluvial rivers

150. Diversions which result in complete abandonment of

long-occupied courses and the establishment of the river in a new position are phenomena associated only with alluvial streams like the Mississippi. They are not known to occur along swift-flowing, actively eroding rivers such as the Columbia. Judging from mapped stream patterns, it is probable that diversions resulting in significant changes in stream courses have occurred along most of the world's alluvial rivers in the recent past, but records of historical occurrences are available for relatively few. These include the Rhone(25), which in Roman times occupied a course far to the west of its present channel; the Po which abandoned its old course, the Po Morto(19), in 1390; and the Ganges and Brahmaputra which have several times shifted the position of main channels in their common delta(5). Probably the most spectacular diversions for which published accounts are available are those of the Yellow River(29) which, in 1851 and again in 1938, caused the river mouth position to be shifted several hundred miles. In the United States, the Colorado River(28) diversion of 1905-07 provides a well-documented example.

151. Almost without exception, these streams are heavily silt-laden or otherwise overloaded, and diversion is accomplished in a very short period of time, in some documented examples of the Yellow and Po Rivers during a single flood. The high sediment concentration is related to the extremely rapid diversion of these streams. Normal stage variation and natural levee construction cause them to build up their channels to an elevation at which the stream bed is actually above the level of the surrounding land surface. During abnormally large floods when they overflow their high banks, these

rivers may so silt up their channels that with decrease in stage water they cannot continue to follow the old courses.* The observed rapid diversions result. Observers report numerous and correspondingly rapid changes in the deltaic distributaries of such sediment-laden rivers.

152. No diversion of the Mississippi River has occurred since European colonization of the area. However, a satisfactory knowledge of the history of the river's diversion is provided by the deposits of the Mississippi Alluvial Valley which record most of the essential details regarding the courses successively occupied by the river. This sedimentary record shows conclusively that Mississippi courses are not abandoned rapidly, as is the case in the other large rivers mentioned. No indication has been found that a permanent diversion of the Mississippi River has ever been brought about by crevassing or overtopping banks during flood. Instead, abandonment of each of the Mississippi courses seems to have been accomplished in a gradual and progressive manner by stream action similar to that now active in the enlargement of the Atchafalaya.

153. The course changes of the Mississippi are methodical and fundamentally different from the rapid diversions described in other large rivers because: (1) the Mississippi channel is deep throughout its length; and (2) the Mississippi is able to transport

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* This is well shown by the 1938 diversion of the Yellow River, where below the point of diversion, the old main course was plugged with silt for 15 to 20 miles, beyond which the old channel retained its normal character(29).

its load* without difficulty on the slopes of the alluvial valley. As a result, unlike most alluvial rivers, the Mississippi meanders in a predictable manner, and the migration of the meander loops of the course is confined within well-defined belts. The Mississippi keeps its deep meandering channel in over-all adjustment with the materials comprising its bed and banks, load, discharge, slope, velocity, etc. It is a poised stream which neither aggrades or degrades its channel, maintaining equilibrium among its various activities. This characteristic poised condition is not disturbed even when the stream is diverted from one course to another.

154. The unique nature of Mississippi diversions diminishes the value to this particular problem of analogies with other major rivers, and increases proportionately the importance of a careful study of all possible characteristics of former Mississippi diversions.

Typical Mississippi Diversion

Former Mississippi diversions

155. A number of separate courses of the Mississippi River have been recognized and traced the length of the alluvial valley to deltas which mark the downstream terminus of each. The most recent of

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* Compared to other major rivers of the world the Mississippi load is small. Sediment concentration in the Colorado River is about 5,000 ppm most of the year. Silt load in the Yellow River reaches 40 per cent by weight at times, but 10 per cent is a more average figure for discharge of 200,000 cfs ((29) pp 374-378). Using these figures and a specific gravity of 2.0 for the silt, Yellow River sediment concentration is 50,000 ppm. As observed on January 29, 1951, Mississippi discharge of 1,065,000 cfs contained a measured sediment concentration of 871 ppm.

the series of course changes occurred in the southern part of the valley, beginning with the abandonment of the Teche-Mississippi channel. These courses have furnished much of the information on which the present study is based.

156. Figure 25 shows the location of the most recent diversions of the Mississippi. The river left the Teche course for the Lafourche course at a point near the Marksville Hills where it probably occupied and enlarged the channel of a tributary of the Yazoo River as far as Angola, from which point it flowed down the Yazoo channel, building a delta across the older Teche delta. The next point of diversion was near Vicksburg, the Mississippi taking a more direct course to Angola along the eastern valley wall occupying and enlarging the old Yazoo channel above Angola. The river then shifted near Donaldsonville and flowed past the site of New Orleans along what had been the Amite River channel, to debouch in the vicinity of St. Bernard Parish. Thereafter, the only major change involved the transfer of the downstream end of the river to the present delta site by enlargement of one of its own distributary channels.

Progressive development

157. One of the most significant discoveries resulting from a study of former Mississippi River courses is that river activity in the meander belt upstream from the point of diversion was unaffected by the diversionary process. From this finding it is concluded that each diversion developed gradually. It seems reasonable to assume that if diversion had been accomplished rapidly, the resultant steeper gradient of the new course would have been reflected upstream by causing the river to

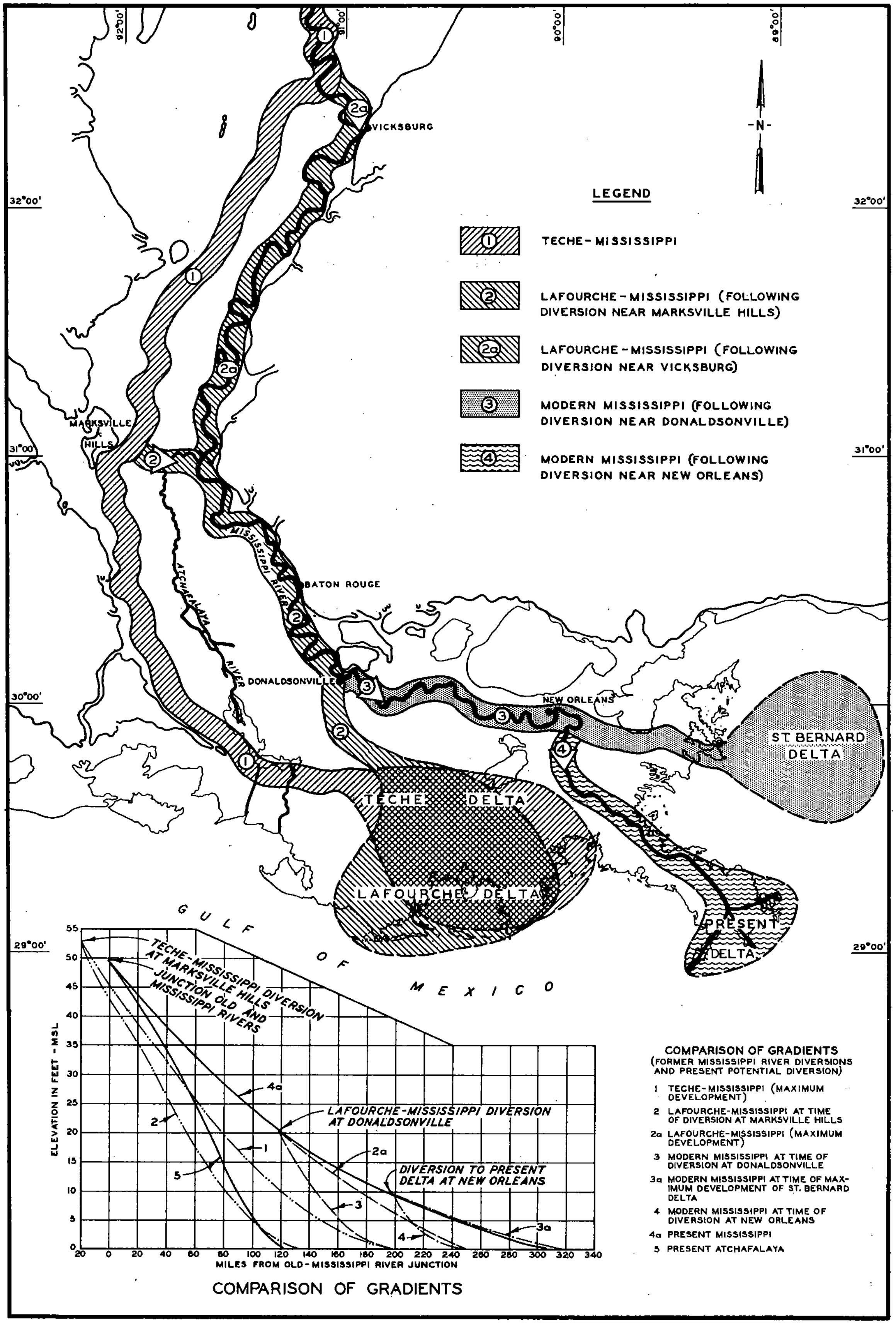

Fig. 25. Mississippi River diversions since Teche time

scour below normal meander belt level. No traces of such down-cutting are found in the local topography, in changes in natural levee slope, or in channel alignment.

158. Such a progressive development of the diversion arm permits it to attain an equilibrium between valley slope, bed and bank materials, load, and other variables before it can completely capture the old stream. The new channel must be able to carry the full flow of the river away from the point of diversion and to transport sediment load to the sea. If this transporting ability cannot be achieved, the new channel becomes plugged with its own load. All Mississippi valley diversions have been accomplished only after development of a diversion arm having a single channel and only after diversion arm deposits have alluviated the lowlands across which it flows, lengthened the channel, constructed natural levees, and aggraded its floodbasin. These processes continue until a valley slope has been developed which reflects the adjustments between volume, gradient, and load. The stream adjustments which permit an increase in flow through the diversion arm take place progressively and keep pace with valley alluviation.* As the course lengthens, the slope decreases and the channel enlarges by widening and deepening until it can take full Mississippi flow.

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* In discussing the Yellow River, Van der Veen(29) refers to valley aggradation as "plainbuilding" and states: "...a process which continues on and on until eventually a certain equilibrium is reached, whereby the slope of the plain has become sufficiently steep to enable the river to develop a gradient that is capable of imparting to the current the energy that is required to carry all the silt as far as the sea."

Stages in diversion development

159. In each of the former Mississippi diversions, it seems that the new course taken by the river was determined by a smaller stream which flowed in a lowland near the Mississippi, and became a distributary of the river when a migrating meander loop intersected it. Thereafter this distributary enlarged until it became the new Mississippi course, and in so doing passed through initial, intermediate, critical and final stages of development.

160. Initial stage. In the early part of its existence, the new channel is too small and probably too crooked to carry all of the Mississippi water offered at the upper end. Low-stage Mississippi flow may follow it and enlarge the channel, but during higher stages water tops its banks and flows down the relatively steep slopes of the valley surface to the sea, following any convenient route. This flooding and runoff produces numerous small shallow channels along the diversion arm.

161. Intermediate stage. Continued flooding causes natural levees along the diversion arm to be built higher near the main stream and beyond. This concentrates the flow, permits progressively more scouring and widening of the channel with successive flood stages, and, in general, increases the capacity of the distributary. Natural levee building plugs minor lowland channels downstream, unifying and concentrating the flow into a single channel having the most advantageous alignment. Sediment load becomes increasingly important. The coarser fraction of the load is deposited in bars along the channel and helps to cause meandering; the finer particles are swept downstream and are deposited at

the delta. A greater and greater portion of Mississippi water comes to flow down the diversion arm.

162. Critical stage. This stage of development is reached when there is essential balance between the main stream and the diversion arm. Bankfull flow in both the old and the new courses is sufficient to sweep sediment load downstream without plugging either channel. However, owing to its gradient advantage the distributary channel is able to continue to enlarge, whereas the main channel cannot. A slight decrease in flow through the main channel is sufficient to cause part of the load to be dropped, restricting the channel, reducing flow still more and necessitating deposition of more sediment.

163. Final stage. During this stage balance is broken, the old main channel is plugged with sediment, and the diversion arm becomes the new main channel. The old main channel is plugged because with the reduction of flow the velocity is greatly diminished, and load can no longer be transported. This is accomplished rapidly, and the old main channel is cut off from low water flow. The new main channel experiences a correspondingly rapid enlargement. The sediment load along with the water flow can be adequately handled by the new poised Mississippi River. The abandoned channel fills with sediment swept in during flood stages.

Analysis of the Diversion Process

Principal causes of diversion

164. A fundamental reason for diversion is gradient advantage. Many paths through the Mississippi Alluvial Valley have such an

advantage over the present long meandering Mississippi course. Much more complex but no less important to diversion is the question, "What are the prerequisite conditions for Mississippi water to flow along one of these shorter paths available and to reach the Gulf by more expeditious means than is possible through its existing channel?" This can be answered "Development of a distributary that is advantageously situated so that it can be enlarged to accept the full flow of the Mississippi River." This is the crux of the diversion problem. The origin of such a distributary and the more complicated and involved factors which influence its enlargement are discussed below.

Origin of the diversionary distributary

165. The process of diversion begins when the river rather fortuitously intersects a minor alluvial valley stream. Most streams within the valley are tributary to the Mississippi, eventually adding their water to the river at some point along its length. Owing to the great width of the valley, some few, usually small streams have developed a course to the Gulf independent of the Mississippi. These streams flow in lowland portions of the valley between Mississippi meander belt ridges, where the alluvial surface has a relatively steep slope. Meander loops of the Mississippi are constantly migrating and enlarging, and from time to time have intersected these independent alluvial valley streams. Being intersected by an enlarging meander loop places this stream in an excellent position to be maintained as a distributary, inasmuch as it is then situated on the convex side of a bend where it is least likely to be plugged with Mississippi sediment. Also it has an established channel which though small may still be deep enough to

carry Mississippi water away from the river during low stages as well as concentrate the high-water flow down its channel and thus enlarge into a new Mississippi course.

166. Alternative possibilities for distributary origin do not meet the test of careful examination. Major floods may breach high natural levees of the river locally, and resultant crevassing may provide a temporary avenue for diversion of water into the adjacent lowland, but Mississippi crevasses are healed when the river stage drops, and do not carry the low-water flow necessary for the development of permanent distributaries. The sudden decrease in velocities experienced as floodwaters escape through crevasses results in the release of the greater part of the sediment load. Dispersal of the crevasse water into many branching channels rather than integrating it into a single channel capable of carrying the load further aids in sealing the breach. This is conclusively shown in Bonnet Carre spillway 20 miles upstream from New Orleans where floodwaters diverted from the river to Lake Ponchartrain have deposited quantities of sand and silt over the broad floodway and show no tendency to scour a channel. Only when a distributary has been developed which can maintain a channel during the entire year, including low water stages, does flow during higher stages enlarge the channel for eventual use as a diversion arm.

167. Each time diversion of the Mississippi takes place such a distributary appears to have acted as the diversion arm. The position of various tributary streams within the alluvial valley and the tracing of their history and that of the larger river have made it possible to identify which independent drainage channel was intersected and used by

the Mississippi for each of its last several diversions. These are indicated earlier (paragraph 155).

Development of the diversion arm

168. The factors involved in enlargement of a distributary channel that originated in the manner described above are important to consideration of the rate at which diversion of the river occurs. This process is complicated by the many interrelated features in simultaneous operation. Of particular importance to successful diversion of the Mississippi is the handling of sediment load both by the developing distributary and the old main channel downstream from the diversion point. Deductions made in the paragraphs below are predicated on the contention that the poised stream condition was maintained by the Mississippi throughout the diversion.

169. Area near diversion point. Data bearing on the manner of enlargement of the distributary channel are not usually found by studying surface features or aerial photographs of the area near diversion point. The immediate position of the diversion is invariably destroyed by shifting of the river and migration of meander loops. Accordingly it is impossible to draw from study of former Mississippi course relationships any conclusions regarding the angle between old and new channels except those which can be inferred from the position of successive courses. The angle of diversion, however, apparently is important to the development of the distributary if there is resemblance between it and deltaic distributaries. Speaking of the latter, Russell(24) states that distributaries (which in the Mississippi delta often originate from crevasses) continue to widen and deepen their channels for a much

longer time if they diverge from the main channel at angles which are acute downstream.

170. The importance of angular relationship between main and subsidiary channels to the process of diversion is intimately related to the division of sediment load between the two streams. Apparently the success with which a distributary channel is maintained and enlarged is dependent upon the success with which it can handle the sediment load introduced into it. As long as there is sufficient water volume and velocity to sweep the load down the channel to the delta the distributary is kept open. A small angle of diversion is most advantageous for the maintenance of maximum water volume and velocity.

171. Deterioration in abandoned courses. The sediment which fills abandoned Mississippi channels affords evidence of the nature of the diversion. The information supplied by borings made for this project along Bayou Lafourche have permitted the construction of the longitudinal profile of the Lafourche-Mississippi channel south of Donaldsonville shown on figure 26. The feature of most interest on this figure is the sand wedge which has filled the channel. The wedge is thickest at the Mississippi River end of the profile, the point of diversion, and thins in a downstream direction. The head of the Lafourche delta at Thibodaux is indicated on the figure by disappearance of the sand wedge and abrupt decrease in the depth of the channel.* (See inset drawings

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* Inasmuch as other distributaries of the Lafourche-Mississippi have much deeper channels (see section across Bayou Terrebonne, fig. 15), it is probable that Bayou Lafourche south of Thibodaux follows a drainage line which did not function until after the Mississippi had abandoned its Lafourche course.

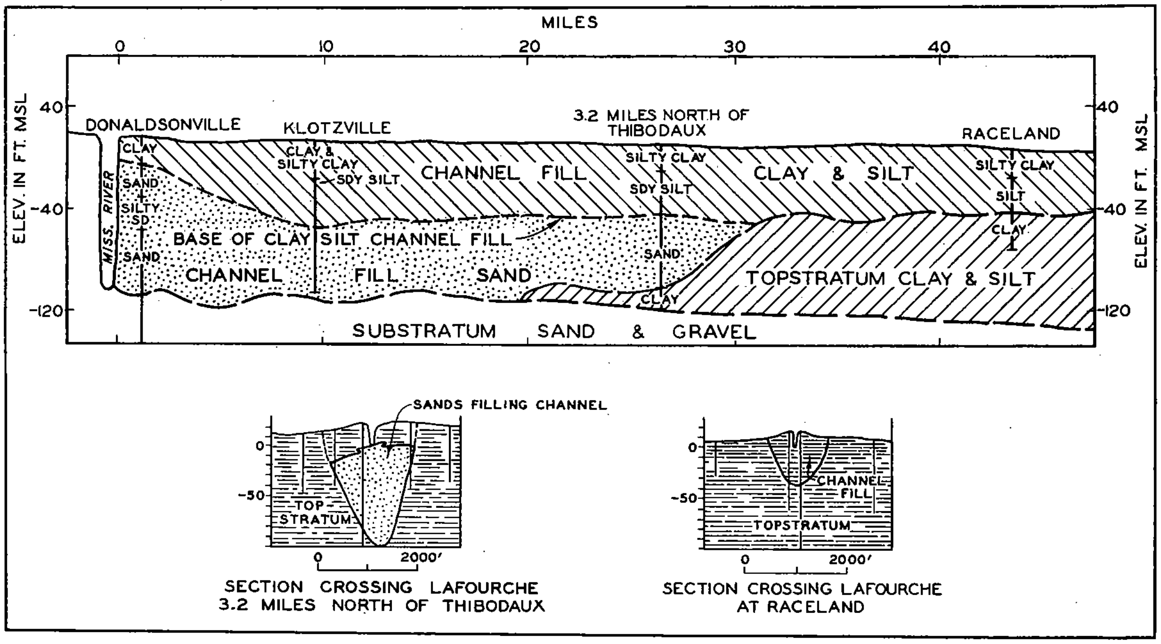

Fig. 26. Longitudinal profile, Bayou Lafourche

of cross section of old Mississippi channel above and below Thibodaux.) Above the sand wedge the Lafourche-Mississippi channel is filled with clay and silt.

172. This type of filling in the Lafourche-Mississippi channel strongly indicates that in the course of the diversion, a stage was reached in which the old main channel was rapidly plugged by sand after which it was isolated from effective low Mississippi flow, and thereafter the channel was slowly filled with fine sediment from the river during high stages.

173. Evidence of a similar kind is seen in features of abandoned Mississippi channels discernible from aerial photographs. Figure 27 was prepared to illustrate this type of evidence. Shown here is the Tensas River, a minor stream following part of the Teche-Mississippi channel which was abandoned when the river was diverted into its

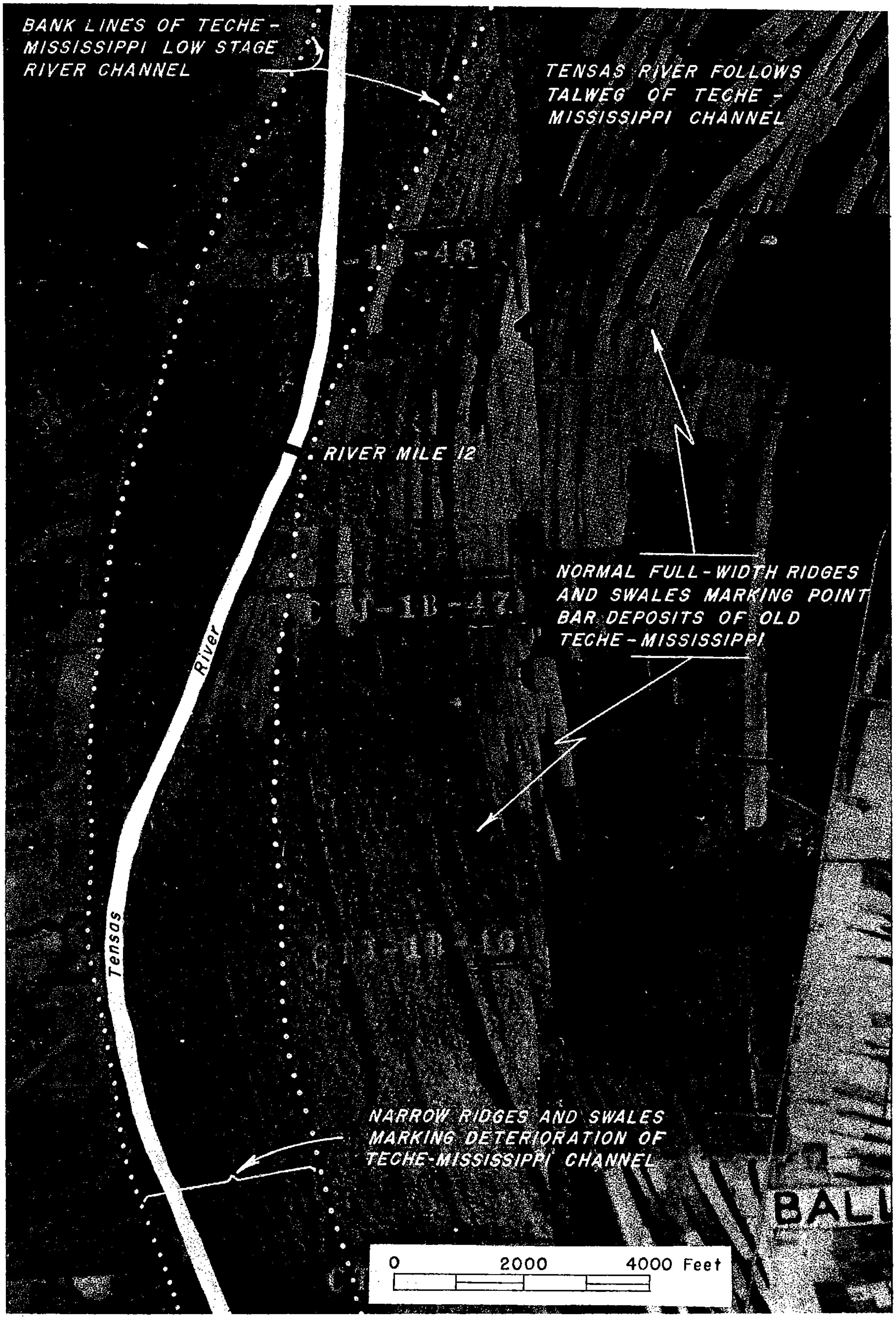

Fig. 27. Features of abandoned Walnut Bayou, Mississippi Channel

Lafourche course. Large point-bar ridges and swales constructed during the occupancy of the channel by the full-flow Mississippi may be seen on the right side of the photograph. The position of the low-stage Mississippi channel just prior to the diversion may be located beyond the end of the coarse accretion scars. Within this final low-stage channel are much narrower ridges and swales conspicuously smaller than those of the Mississippi, which mark deposition caused by the deterioration of the old Teche channel during the diversion of the river into the enlarging Yazoo River diversion arm. The Tensas River follows the thalweg of the last low-water Teche-Mississippi channel.

174. The example of the Tensas River used here to illustrate these features is only one of a number of such streams which might have been chosen. All of the other abandoned Mississippi River courses show the same type of deterioration effects. None of the minor streams which occupy abandoned Mississippi channels have migrated and developed meanders of their own, but simply follow the old Mississippi thalweg.

175. The facts available from study of abandoned channels indicate that a critical stage is reached in the orderly development of Mississippi courses when the old channel is swiftly vacated by the river. Reduction of Mississippi flow until only enough remained to maintain such a minor stream as the Tensas River now in the channel would, if accomplished gradually, inevitably have produced meanders of smaller size within the larger channel. None are found. Instead the thalweg of the low-water stage of the Mississippi is followed closely by the remaining minor stream. Narrow accretion scars which are seen on the bar side of the thalweg position are produced by deposition of sediment added after the

main Mississippi flow had been shunted into the diversion arm. Such deterioration effects are precisely the type to be expected if the old main Mississippi channel at a particular critical stage in the diversion process were quickly plugged with the sand it carried, producing a sand wedge such as has been delineated in the Lafourche-Mississippi channel south of Donaldsonville.

176. Again it is the handling of load which is important. The critical stage is reached when there is essential balance between flow, velocity, and load through both diversion arm and main channel. When the diversion arm takes more flow because of its steeper gradient, the balance is disturbed and in the old main channel flow slackens, velocity lags and the load can no longer be swept downstream and is dropped at the entrance. This causes more reduction in flow, loss of velocity and additional deposition. The rapid plugging of the channel entrance results, producing the above-cited effects noted in old abandoned Mississippi courses.

177. On a smaller scale, the same effects of rapid abandonment are noted in cutoff meander loops. The loop is normally plugged with a sand wedge at its upstream end turning the river into the cutoff channel and sealing off the loop. The ox-bow lake which occupies the channel behind the entrance plug is slowly filled with fine detritus introduced during high or flood stage, until all that remains is a small stream which follows the thalweg of the Mississippi channel around the loop.

178. The analogy between cutoff loops (particularly chute cutoffs*)

* Chute cutoffs occur when the river establishes a new and shorter course across the point bar on the inside of an enlarging meander loop, and are distinguished from neck cutoffs which form owing to the coalescing of upstream and downstream arms of the enlarging loop.

and abandoned courses also furnishes the only quantitative data available regarding stage in the diversion development at which rapid plugging of the old main channel greatly accelerates the process. A study of Brandywine chute south of Memphis on the Mississippi River was made by the Mississippi River Commission(21) to determine the rate at which the loop channel deteriorated in terms of the amount of water diverted through the chute. It was found that when 30 per cent of the water was flowing through Brandywine chute, the main channel entrance began to silt up rapidly, and the old channel soon became isolated from low-stage Mississippi flow.

179. Although it is probable that variable conditions at the point of diversion control the exact relationship between the percentage of total flow being taken off by a diversion arm and rapid silting of the old main channel, the 30 per cent figure observed in the study of Brandywine chute provides data which seem to be of the right order of magnitude. If the critical stage in the diversion process is reached when there is essential balance between the old main channel and the developing diversion arm, certainly when 50 per cent of the flow is passing down the newer channel with its superior gradient advantage, this balance has already been disturbed. The fact that abandoned courses of the Mississippi show no signs of meandering by a stream which became progressively and gradually smaller, but preserve only minor accretions between a relict channel nearly as wide as the present Mississippi, is additional evidence that rapid deterioration began while the old channel was taking a major portion of the flow.

Progression of distributary development

180. The discussion of stages in the development of a typical diversion of the Mississippi River in paragraphs 159-162 above was based on information gathered from examination of old Mississippi courses and observation of behavior of the modern river. Data and deductions for the phase of the diversion reconstruction concerned with enlargement of the distributary channel involve the most diverse and complex considerations of the whole process. This in part is due to the fact that the enlarging channel destroys much evidence of the progression of its enlargement. The factors seemingly involved are reviewed below.

181. Evidence is available to indicate that the diversion arm was initially an overloaded distributary channel. In the downstream portion of each of the former Mississippi courses studied networks of abandoned deltaic-type distributary channels are encountered. These furnish testimony of an early stage in the history of the course when the channel was a diversion arm still too small to take all of the flow offered it by the master stream. Water was forced to spill over the low banks at the downstream end and to flow toward the Gulf by means of numerous small shallow channels. As the course gradually and successively extended itself by enlarging one of the network streams that happened to be advantageously aligned, the network drainage became integrated through concentrating all of the flow in this favored channel and sealing off the others. A deepening of the channel accompanies this lengthening of the distributary, because the flow is not dispersed. That shallowing and dispersal of flow are correlative is demonstrated by hydrographic surveys of the Mississippi River which show an abrupt reduction of

channel depth at Head of Passes. Diversionary channel enlargement is also promoted by the gradual increase in the height of natural levees, and the downstream extension of these features progresses with the lengthening and deepening of the stream. The net effect of these activities is to increase cross-sectional area of the distributary, permitting it to handle more and more water from the Mississippi.

182. The high stage of the Mississippi River is the most effective in promoting general over-all enlargement of the distributary, for at this stage the maximum possible flow is shunted into the distributary channel and the slope of its water surface is steepest. On the low valley slopes near the coast, stream velocities and scouring activity may lessen somewhat during flood as water level in the floodbasin is raised. It is during these flood stages, however, that the load dropped by the developing stream along its channel margin raises the level of the natural levees. In this manner the enlarging channel increases its cross section during each flood and becomes increasingly capable of accommodating greater discharge.

183. Falling stage in the master stream may greatly reduce stream velocity in the diversion arm, particularly during the early stages in its development. Deposition in the low-water channel of the distributary might so reduce the high stage cross section that a considerable portion of the high-water energy is expended in removing low-water deposits. The diversion progress may in this way be reduced by excessive stage variation in the Mississippi.

184. The nature of the materials which form its bed and banks is important to the development of every stream. Rapid enlargement of the

Mississippi diversion arm where it flows through part of the alluvial valley in which substratum sands are near the surface in contrast to the much slower process in areas where thick clays must be scoured is discussed in part IV of this report.

185. As all of these mechanisms for improving the ability of the channel to take more flow continue their operation, the diversionary channel is able more and more successfully to compete with the main stream below the diversion point for the entire Mississippi flow. The newer stream must yet increase its length until it can empty directly into the Gulf of Mexico. Any shoal water discharge basin along the path of the distributary channel acts as a barrier to concentration of flow, causes dissipation of stream velocity and deposition of load. The stream overcomes this difficulty as it lengthens until it finally has reached deeper water into which it can discharge its flow and where its load may be shifted about by currents and swept away from the immediate vicinity of its mouth. The stream has then achieved some stability at its downstream end, and its over-all gradient becomes more nearly constant.

Summary

186. Diversions of major rivers which have been described appear to have been accomplished rapidly, and are basically unlike those of the Mississippi River. The most pertinent data regarding Mississippi River diversion have been collected from study of modern river activity and characteristics of abandoned Mississippi courses. These studies indicate that all Mississippi diversions have been accomplished in a gradual,

progressive manner, the river having maintained its poised condition with load, stream velocity, flow, gradient and other variables in adjustment throughout the process. After slow, progressive initial and intermediate stages a critical stage is reached when there is essential balance between flow down the main channel and down the diversionary channel, after which diversionary activity is greatly accelerated until a new course is occupied. No definite data are available to indicate what percentage of the total Mississippi flow must be diverted into the diversionary channel before this critical stage is reached, but 40 per cent is considered a conservative maximum figure.

187. Each Mississippi diversion has occurred because a migrating meander loop intersected a stream with gradient advantage flowing within the alluvial valley by a separate course to the Gulf. The stream became a distributary to the Mississippi and in time took full Mississippi flow. The important factors in determining the rate at which such a distributary will become the main stream are complexly interrelated and difficult to define. However, the most important of these appear to be:

a. Angle of diversion.

b. Diversion of load.

c. Deterioration of old main channel below point of diversion.

d. Nature of bed and bank materials.

e. Stage variation.

f. Freedom of stream to discharge flow and load at mouth.

PART VI: THE MISSISSIPPI-ATCHAFALAYA DIVERSION

188. In the following discussion each of the factors known to have an important effect on diversion or on the rate of diversion is applied to the relationship now existing between the Atchafalaya and Mississippi Rivers. Hydraulic data collected during the past half century show the tendency toward eventual capture of the full Mississippi flow by the Atchafalaya. The trends established furnish the quantitative information on which must be based any estimate of the approximate date when this diversion might occur. Geological examination of the situation has as its partial objective qualification of these quantitative estimates, where acceleration, deceleration, or possible reversal of present trends may be indicated.

Factors Controlling Diversion

Gradient advantage

189. The fact that the Atchafalaya River has a steeper gradient than the Mississippi River is the basic reason for the present threatened diversion of the larger stream. Water must travel three times as far along the Mississippi channel (approximately 300 miles) as along the Atchafalaya (100 miles) to reach sea level from the point where the rivers diverge. On figure 25 the gradient advantage of the Atchafalaya is compared with the gradient advantages* enjoyed by diversion arms

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* Gradients of former courses and former diversion arms shown on figure 25 were computed from comparisons of the heights of the ancient natural levees with those of the modern Mississippi, and from the best available information regarding the location of the upstream limits of relict deltas.

of former Mississippi River courses immediately before each became the new main channel. Comparison of these curves shows gradient advantages of former diversions to have been 3:2, 2:1, and 2:1 at the time of diversion at Marksville Hills, Donaldsonville, and New Orleans, respectively. The gradient advantage of the Atchafalaya over the Mississippi from the present point of diversion is 3:1.

Establishment of low-water flow

190. The stage was set for potential diversion of the Mississippi through the Atchafalaya at the time when the westward migration of Turnbull Island Bend intersected a relict channel of the abandoned Bayou des Glaises segment of the Mississippi (marked by present Atchafalaya channel north of Simmesport). A well-integrated channel began developing south of Simmesport, principally because this portion of the Atchafalaya course lay along the natural outlet for Red River backwater ponded behind the alluvial ridge which bounds the Atchafalaya Basin on the north. The period following Shreve's cutoff in 1831 was marked by a gradual shoaling of the upper arm of the cutoff; while the lower, which served as a connection between the Atchafalaya and the Mississippi, showed signs of sealing off completely (see plate 2). Had the situation developed naturally, the two arms would undoubtedly have sealed, in which event the Mississippi and the Red, the latter using the channel of the Atchafalaya, would have flowed in separate channels to the sea. However, dredging for maintenance of navigation through Lower Old River prevented such an occurrence. Even following the natural closure of the upper arm and the establishment of Lower Old River as the sole connecting link between the Red-Atchafalaya system and the Mississippi, the Atchafalaya

served primarily as a distributary of the Red, rather than as a distributary of the Mississippi, and normally flow was toward the Mississippi. As the Atchafalaya began to take more and more Red River discharge, flow toward the Mississippi was progressively reduced, and again Lower Old River began to shoal. Once more every effort was made to keep the channel open by dredging. Perhaps the most critical period in Atchafalaya diversionary development was in the late 1930's when the Old River channel became largely self-maintaining and flow through Old River toward the Mississippi occurred in only exceptional cases. With the establishment of distributary flow from the Mississippi down this course during low-water stages the remaining requirement was satisfied for eventual capture of the Mississippi by the Atchafalaya. From that time on, it became only a question of how soon the diversion would take place.

Factors Affecting Rate of Diversion

Angle of diversion

191. The angle of diversion at the junction of Old River and the Mississippi, or more accurately the angle between the thalwegs of the respective streams, has become successively smaller since Carr Point cutoff in 1944. Prior to 1944, water was diverted around a bend, leaving the main stream at a fairly acute angle. Following the cutoff, the entrance was more or less at right angles to the main flow of the Mississippi. Westward migration of the Mississippi and bar building on the north bank of Old River, however, are forcing the diversion current against the opposite bank, deepening the thalweg, rebuilding the bend at the entrance, and generally developing a more favorable angle of diversion.

Distribution of sediment load

192. Suspended load. A number of suspended load observations on the Mississippi River and in the channel of Old River* indicate a disproportionate amount of suspended load diverted through Old River when compared with the volume of water. The table below shows this relationship.

Date	Discharge at Tarbert Landing in Cfs	Discharge at Torras in Cfs	Per Cent Water Diverted at Old River	Per Cent Suspended Load Diverted at Old River
29 Jan 1951	1,065,000	249,000	23.4	27.8
29 Nov 1950	425,000	110,000	25.8	30.7
13 Nov 1950	272,000	63,400	23.6	30.8

Sediment concentrations at each of the above ranges have been contoured and the results are presented in figure 28. It may be seen that the amount of material above a grain size of 0.074 mm is consistently greater in Old River than in the Mississippi. During the low stage of 13 November 1950 no material as large as 0.074 mm was in suspension at Tarbert Landing range. Yet, measurements at Torras range showed considerable suspended material of this size and larger. This indicates that material carried along the bed at Tarbert Landing is carried in suspension at Torras, thus increasing the sediment concentration and accounting for the increase in suspended load diverted through Old River. It also implies that the sediment-carrying capacity of Old River is more than sufficient to keep the channel clear of sediment diverted from the parent stream.

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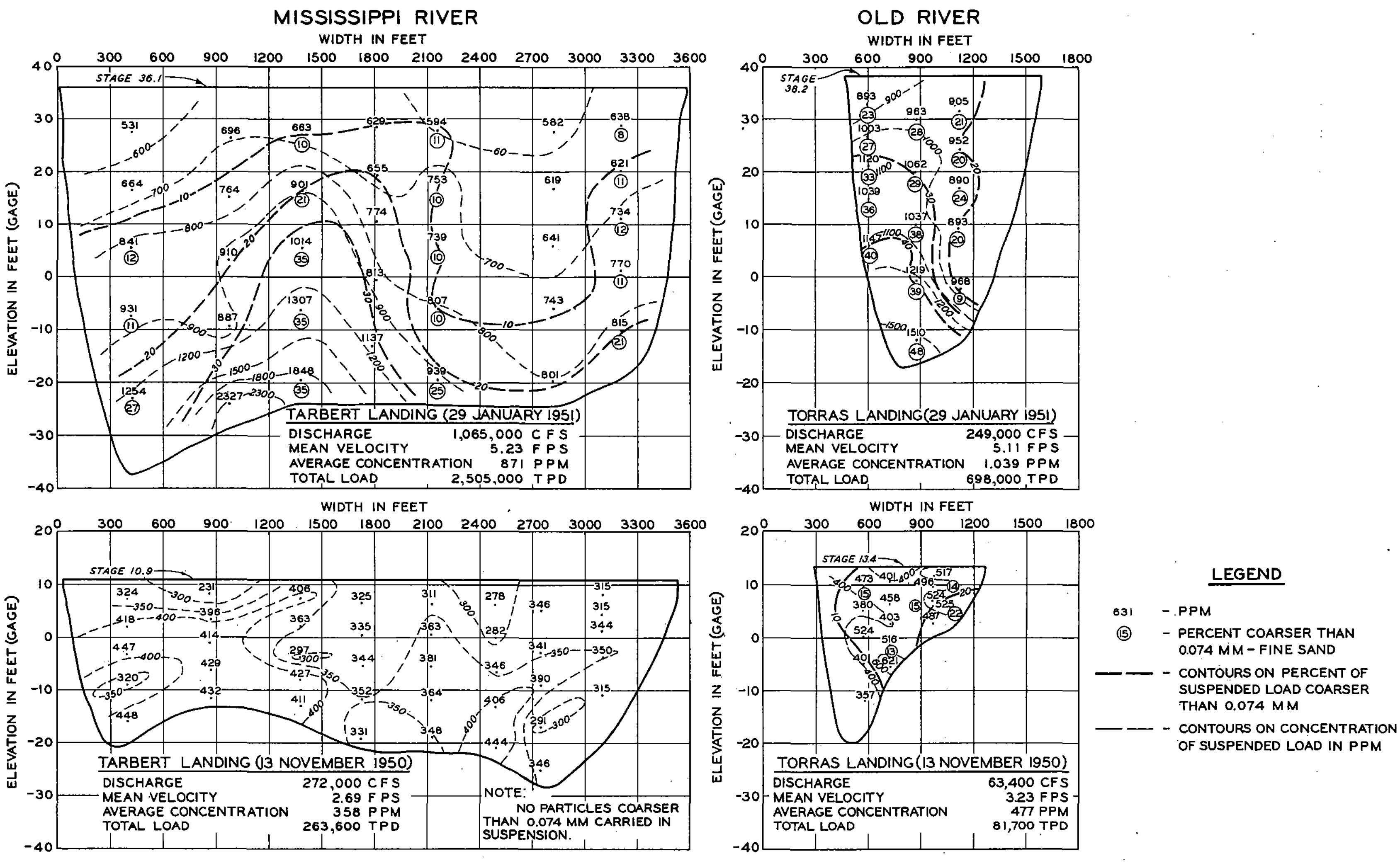
* Tarbert Landing range is on the Mississippi approximately 2.5 miles above Old River, Torras range is on Old River a short distance downstream from the point of diversion. Table 1, page 28 shows suspended load in tons per day measured at these ranges.



DISTRIBUTION OF SUSPENDED LOAD IN MISSISSIPPI AND OLD RIVER CHANNELS
(TARBERT AND TORRAS LANDINGS)

Fig. 28.

193. Bed load. Laboratory experiments(23) which show a very high percentage of bed-load diversion in comparison with water diverted into side channels seem to have little application to the Atchafalaya. Bed-load samples collected in the leveed channel of the Atchafalaya River show variations in grain size ranging from material coarser than those in the Mississippi River to those which are distinctly finer (figs. 7 and 11). Comparison of averages indicates that Atchafalaya River bed load is composed of a larger proportion of fines, and, therefore, coarser bed load moves from the Mississippi into the Atchafalaya in only minor quantities. This assumes the validity of the concept that bed-load transit is a more or less continuous process and that samples taken from the bed of the Atchafalaya would have been derived from the Mississippi.

194. Opposed to the above assumption is the theory that bed load moves from bar to bar, a concept more in keeping with the results of observations along the Mississippi and one which has been borne out in laboratory experiments(6). Under this concept considerably more channel migration should have occurred along the Atchafalaya if coarse, Mississippi River bed load were introduced into the Atchafalaya in abnormally large quantities. The little migration that has occurred along the Atchafalaya River can be readily attributed to the coarse material which the river has picked up in enlarging its own channel cross section. It is concluded, therefore, that the measure of coarse bed-load movement into the Atchafalaya from the Mississippi is the growth of the bar on the north side of the Old River entrance, and that the little swept farther downstream probably lodges on the next bend below. There are indications that the growth of the bar at the Old River entrance is accelerating

(see plate 36).

195. Downstream from this point on Old and Atchafalaya Rivers, several normal bends and crossings have developed which attest to bed-load movement similar to that on the Mississippi. That coarse bed load is not being carried as far south as the present Atchafalaya delta is shown by the fineness of the deposits forming the most recent portions of the delta (see paragraph 116 and plates 12a and 12b).

Deterioration of Mississippi channel

196. As has been shown in part V, deterioration of the old main channel below the point of diversion is rapid following a certain critical stage in diversion development. At this stage the main channel becomes less and less capable of carrying its load, a bar begins to choke the main channel downstream from the point of diversion and forces more flow into the diversion arm hastening its development. The channel south of Old River was examined for any signs of deterioration in an attempt to determine if such a process is taking place on the Mississippi River. The Atchafalaya River Study(21) describes the results as follows:

> ".... a fairly straight reach was selected in an area or crossing in the river where change in flow conditions would normally cause sediment to deposit and create a deterioration in the channel. Cross-section areas of the main Mississippi River were plotted at a point about 6 miles below Old River at miles 296.3 to 295.0, 296.3 to 292.5 and 293.8 to 292.5 AHP for bankfull stage, using 1881 to 1950 survey data. These sections have deteriorated from an average area of 184,000 sq ft in 1920 to 168,000 sq ft in 1949, while the flow into Old increased from about 7 per cent of the total flow to 23 per cent for the same periods. This reduction in cross section occurred notwithstanding this stretch of river has been dredged for navigation purposes and there has been no appreciable reduction in the discharge for a given gage height and river stage condition at Red River Landing discharge range. Cross sections at the discharge range at Red River Landing from 1882 to 1950 show a deterioration in the 1950 cross section when compared with previous years."

197. It is evident from the above discussion that rapid deterioration has not begun and that a critical stage in Atchafalaya diversion has not been reached. When this will occur is problematical, but present studies have shown that 40 per cent diversion is a conservative maximum estimate of the time when rapid closure of the old main channel will occur. It should be remembered, however, that the critical stage could occur at a time when a smaller percentage of water is diverted and that the present trend of deterioration, though slight, may be a forceful portent of a rapidly increasing rate of deterioration in the not too distant future.

Nature of bed and banks

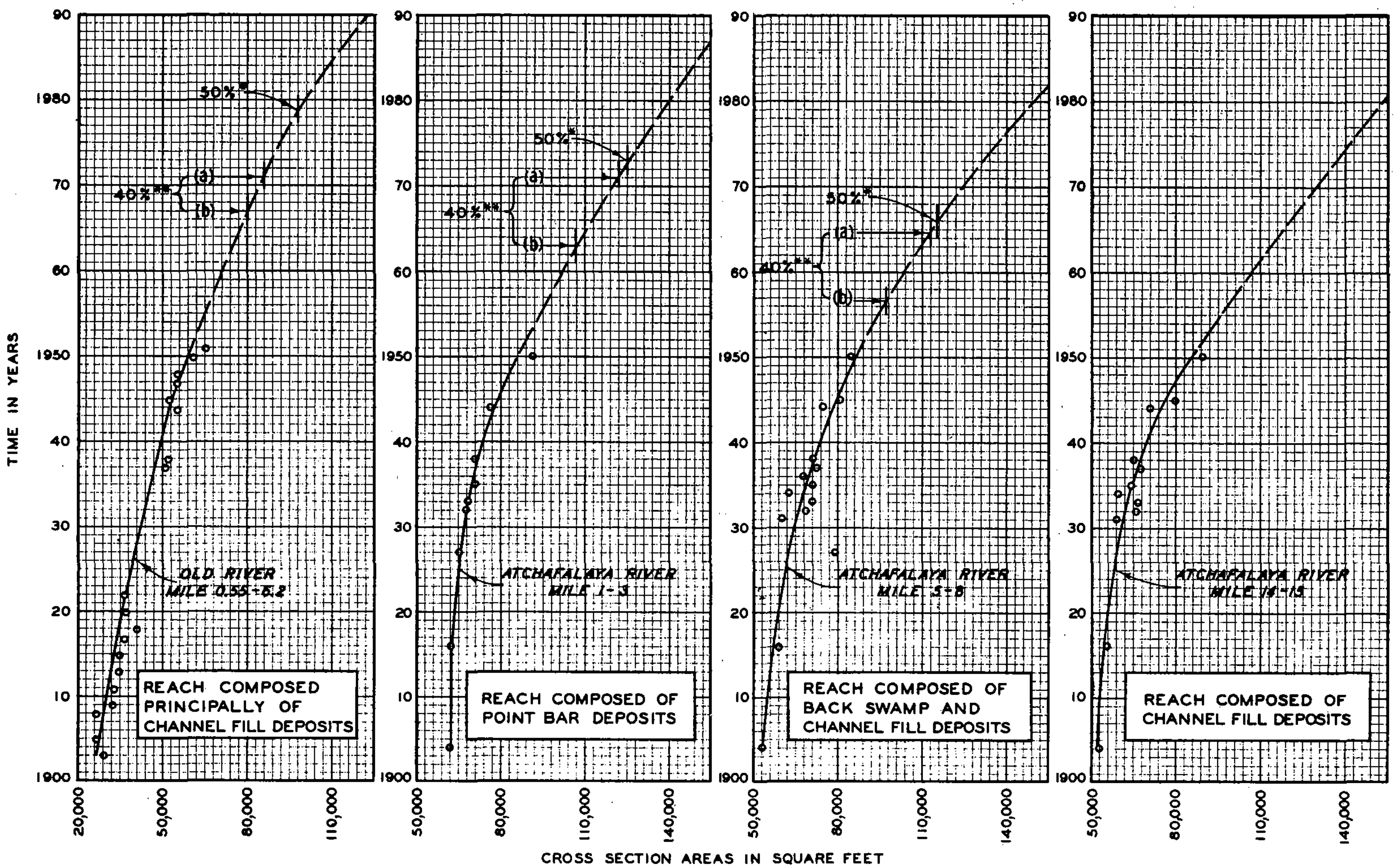
198. In assembling data to determine the influence of the bed and bank materials on the rate of diversion, it was found that the channel south of the leveed segment could be largely disregarded. The Atchafalaya Basin main channel has been in existence only since 1940, and without the confining influence of levees, increased flows spread overbank rather than scour the channel. Enlargement of this unleveed portion of the river is taking place, but cannot be correlated with the rate of diversion. Similarly, it was found that rapid channel enlargement closely followed extension of artificial levees along the channel. Therefore, analysis of data on cross-sectional enlargement has been largely limited to the upper leveed segment of the river where levees have been in existence for more than 50 years.

199. Summarizing the discussion on the bed and banks of the leveed segment of the Atchafalaya River in part IV, the most important reaches from the standpoint of material type control are river miles 0.0-1.0 and

3.0-5.0 in Old River and the reaches along the leveed Atchafalaya channel between river miles 4.5-7.5, 13.5-15.0, and 18.0-44.0. In each instance, the bed and banks of the reaches are composed of channel fill or backswamp clays which often extend to depths greater than present river scour. It is safe to assume that whatever control is exerted on over-all channel enlargement by the bed and banks of the Atchafalaya distributary is caused by these reaches; that they act somewhat like faucets, which gradually open to allow more water to flow from the Mississippi into the Atchafalaya.

200. If the only factor influencing channel enlargement were the composition of the bed and banks, there would be little reason to believe that future channel enlargement would proceed less rapidly than it has in the past. In fact, bank caving and consequent channel enlargement should be accelerated as the channel continues to deepen and cuts more and more into substratum sands. In short, the controlling effect of cohesive materials in the bed and banks is diminishing as discharge increases.

201. Figure 29 shows the increase in cross-sectional area since 1900 of four reaches chosen on the basis of the type of material which forms the bed and banks; one on Old River, and the other three in the upper leveed segment of the Atchafalaya. Based on the trend established by this increase in channel enlargement, predictions can be made as to when the channel in each of these reaches will have developed the capacity to carry 40 per cent and 50 per cent of the flow passing the latitude of Old River. Cross-sectional areas required to carry these flows were based on figures prepared by E. A. Graves, Mississippi River Commission(11)



* Sufficient area to enable Atchafalaya to carry 50% flow past latitude of Old River assuming Mississippi deteriorates as rapidly as Old-Atchafalaya system improves.

** Sufficient area to enable Atchafalaya to carry 40% of latitude flow assuming:
(a) No deterioration of Mississippi.
(b) Mississippi River deteriorates as rapidly as Old-Atchafalaya system improves.

Note: Data on channel areas required for 40% and 50% diversion of flow through Old-Atchafalaya system taken from unpublished report of E. A. Graves (Mississippi River Commission) 1949.

Fig. 29.

Changes in cross-section areas of selected Atchafalaya River reaches with time assuming that (a) there is no deterioration of the Mississippi, and (b) the Mississippi deteriorates as rapidly as the Old-Atchafalaya system improves. These curves indicate that enlargement of the Old River reach lags behind those selected farther downstream and that the more conservative estimates based on the enlargement of Old River channel are the most reliable in predicting the time when the channel of the Atchafalaya distributary will have enlarged sufficiently to accept the flow of the Mississippi. Certainly, whatever factors influence increased diversion of flow from the Mississippi must enlarge the channel of this connecting link between the Mississippi and the Atchafalaya Rivers.* Assuming that some slight deterioration is occurring and will continue to take place in the Mississippi River below Old River, the trend of enlargement of the Old River channel as shown in figure 29 indicates that the time of 40 per cent diversion can be bracketed between 1965-75.

Stage variation

202. Cross-sectional area along the leveed Atchafalaya channel can be closely correlated with annual discharge. The trend is toward gradual channel enlargement; however, years of low discharge and consequent channel deterioration are followed by years of high discharge during which the products of deterioration are removed and over-all

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* During 1951, a year of fairly low discharge on the Red River, the channel of Old River increased 2 per cent in cross section and the Atchafalaya channel at Simmesport decreased 2 per cent. Had the channel of the Atchafalaya been the factor controlling enlargement, it would have maintained its cross-sectional area and its discharge by diverting more water from the Mississippi. This indicates that during 1951, the channel of Old River acted as a control to diversion of flow from the Mississippi.

channel enlargement occurs. The effect of two successive flood years, or two or three consecutive years of high discharge, on the rates of channel enlargement would be significant in rapid diversion of the Mississippi into the Atchafalaya.

203. Natural levee growth, which affects to a large extent the rate of development of the Atchafalaya channel from the end of the leveed segment to Lower Atchafalaya River, is also dependent on the variation in stage. The larger flows, with their higher stages and greater capacity for carrying load, contribute most to natural levee construction. Under normal conditions natural levees develop most quickly in the upper portions of the unleveed reach where stage variation is highest. Progressively higher levees result in more rapid channel enlargement and downstream extension of a single channel.

Freedom of diversion arm to discharge flow and load at mouth

204. One of the factors influencing the development of a diversion arm is its ability to move its load successively greater distances, and thereby integrate and lengthen its channel. In the normal development of a diversion arm, the initial delta may be formed quite close to the point of diversion. As time goes on, a single channel is built seaward through a maze of minor distributaries and deltaic deposits. The delta represents that portion of the channel where the stream is no longer able to carry the major portion of its load. The resulting shoaling forms a barrier to stream development in much the same way that the load dropped at the distal ends of a crevasse tends to seal the crevasse.

205. The network of drainage channels below the leveed segment of the Atchafalaya acted as such a barrier prior to extensive dredging

operations in 1932-40. Under normal conditions, an individual distributary in the network of deltaic distributaries would seal itself only when it no longer had a water area into which to dump its load. More favorably aligned channels, normally those debouching into deeper water, were maintained and a single channel gradually developed across a deltaic mass which completely filled the former lake area. Dredging in the lower basin has greatly accelerated a rather slow, orderly natural process. The deltaic barrier has now been shifted downstream to the head of the Grand Lake-Six Mile Lake segment.

206. An interesting example of the effect of dredging in the lower basin on over-all hydraulic efficiency of the river was cited by Kramer in 1945.* He noted the fact that on 28 April 1945, the Atchafalaya River at Simmesport discharged approximately 650,000 cfs at a peak stage of 51.4 ft. Straight line projection of stage-discharge relations for the peak conditions of 1937, 1939, 1943, and 1944 had indicated that at a stage of 51.4 ft the Atchafalaya could only accommodate 475,000 to 500,000 cfs. He states:

> "..... If the Atchafalaya River had behaved itself in accordance with previously established stage-discharge relations, it should have registered a peak discharge in substantial agreement with the design hypotheses of former years, or about 500,000 cfs. But the 1945 flow was actually measured at approximately 650,000 cfs -- an unexpected jump of 150,000 cfs!
>
> "My explanation for this jump is that it is entirely logical for the projection of the stage-discharge relation curve to 'flatten out' in reflection of the general increase in

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* A memorandum in the files of the Mississippi River Commission from Brig. Gen. Hans Kramer to Brig. Gen. M. C. Tyler, President, MRC, subject, "Minority Report" on Proposed Control Structures at Old River and Morganza, dated 24 July 1945.

> hydraulic efficiency produced by improvement dredging in the Atchafalaya Basin in recent years, and specifically because of the beneficial effect of opening Wax Lake Outlet..."

207. Another obstacle to enlargement of the Atchafalaya is the present inability of the Atchafalaya to discharge its flow directly into the Gulf. Water now introduced at the head of Grand Lake is impounded behind the Teche Ridge, raising the level of the lake during high stages and exerting a backwater effect on the lower reaches of the river. Once the river ceases to dissipate its discharge at the head of Grand Lake and can concentrate its flow in a single channel and carry its load directly to the Gulf, the full advantage of a direct gradient from the head to the mouth can be realized. Such a channel is believed essential before the Atchafalaya can become the main Mississippi channel.

208. The time when a single channel capable of carrying the greater share of its load to the Gulf will be established depends to a large extent on the rate at which deltaic deposits fill the lake areas. A channel capable of enlarging itself has already been established to the head of Grand Lake. Several principal underwater channels now exist through the Grand Lake-Six Mile segment. Rapid alluviation of the area between these channels and build-up of natural levees flanking them below the water surface confine flow, promote scouring, and are hastening the formation of an enlarging channel along this segment of the river (see plate 15). An estimate of the effect of confinement of flow by natural levees is afforded by the considerably greater depth of the channel where the water passes from Grand to Six Mile Lake at Cypress Pass (river mile 103). Eventually a single channel will be built through the lake areas,

flanked by remnant lakes. The time when this channel can carry its load to the head of the Lower Atchafalaya River, where a deep-water channel is already established, will be critical in the diversion process.

209. Based on the present rate of filling, and the fact that a single channel will develop without the necessity of filling in the entire lake area, it is estimated that a single, efficient channel should be established from the head of the Atchafalaya distributary to Atchafalaya Bay by 1970-75.

Future Development of the Atchafalaya River

Development of the point of diversion

210. Changes in banklines near the junction of Old and Mississippi Rivers are shown on figure 30. Prior to the placing of revetment on the west bank of the Mississippi above and below Old River, the bar on the east bank was building westward at a rate averaging 100 ft per year between the years 1914-44. Assuming that the revetments can be held in place and that natural development of the Atchafalaya diversion will follow the pattern set by former Mississippi River diversion, estimates of future development can be based on several interrelated factors: the rate of migration of the Mississippi upstream from, and near the point of diversion; the rate of growth of the bar on the north bank of Old River; and the rate at which the channel enlarges and the thalweg deepens in Old River.

211. Plate 36 shows the development of the point of diversion since 1943 and probable future development if flow is not controlled artificially. The Atchafalaya is now in its intermediate stage of

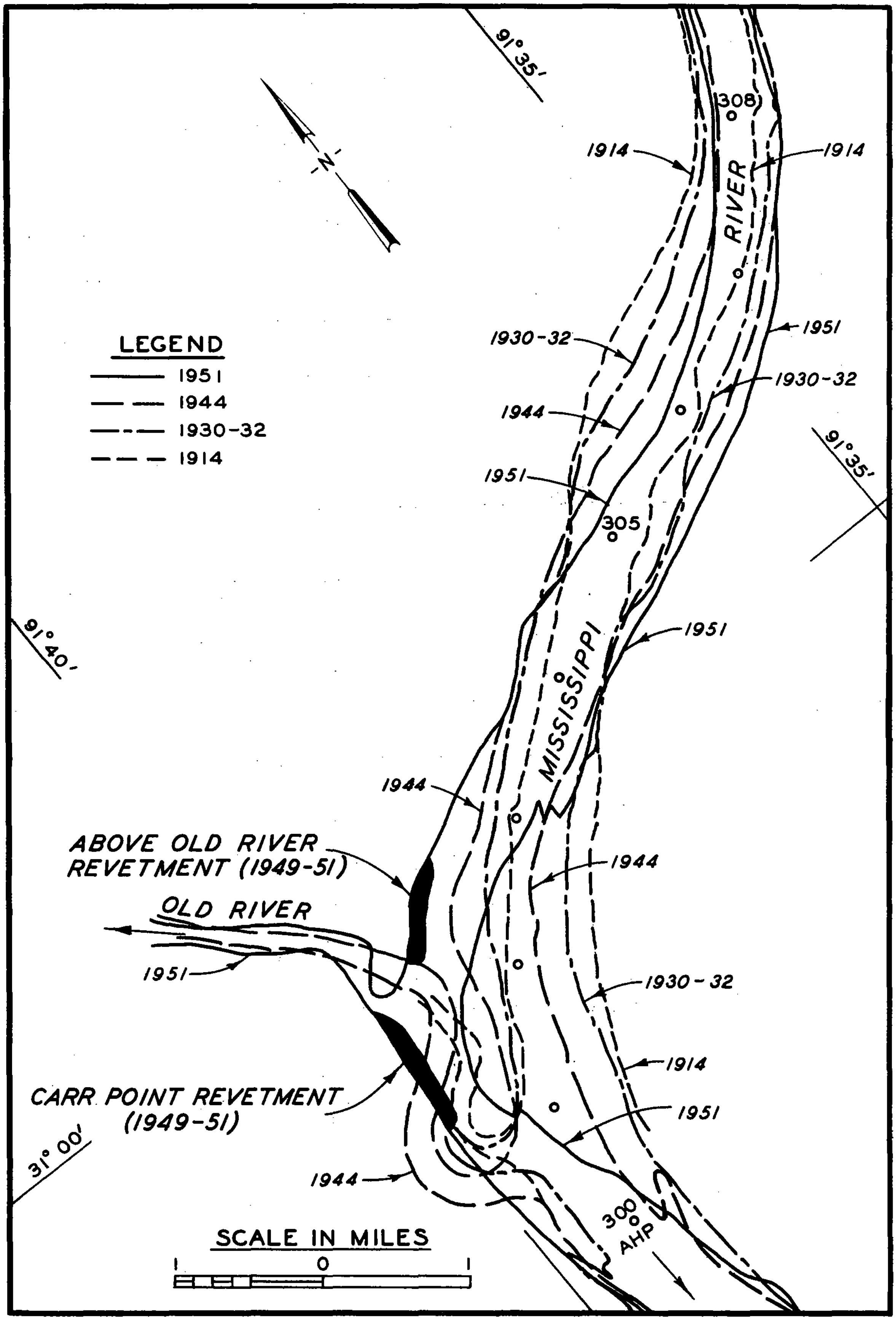

Fig. 30. Changes of banklines at point of diversion

diversion receiving approximately 25 per cent of its discharge from the parent stream. As the bar on the north bank of Old River grows and the channel shifts toward the south, the angle of diversion will become increasingly favorable and a more normal bend will develop at the entrance with a continuous deep thalweg along the south bank of Old River. The Mississippi River thalweg, at the present time, is close to the west bank north of the entrance, and scouring at the toe of the "above Old River revetment" (fig. 30) is contributing much of the coarse material which forms the bar on the north bank of Old River. The thalweg is beginning to shift toward the east, however, and a blanket bar is gradually developing along the northern part of the revetment. As the thalweg continues to shift eastward, loose, coarse material which forms the bar along the east bank will be subject to scour and will be entrained as bed load into the Mississippi River channel below Old River. By 1970 it is estimated that 40 per cent of the Mississippi River flow should be entering the diversion arm. As its discharge and capacity for load transport lessen, the Mississippi will began to deteriorate and the rapid closure characteristic of the critical stage of diversion will result. The old Mississippi channel in its final stage will receive principally bankfull and flood flows as the new main channel develops the cross-sectional area to carry the entire flow of the Mississippi.

Development of the main channel

212. Main channel development should be orderly throughout the intermediate stage of diversion. As cross-sectional areas of the leveed segment gradually enlarge, the Atchafalaya Basin main channel will build up natural levees and develop greater capacity. A channel capable of

carrying load to Atchafalaya Bay will develop through the lake areas and Lower Atchafalaya River. The regular movement of bed load from bar to bar, the development of scour pools and crossings, in short, the attainment of a normal meandering habit, will not become a reality until the Atchafalaya ceases to be an enlarging stream. It is believed that the Atchafalaya will, under normal conditions, reach its maximum enlargement before meandering has affected the stream farther downstream than the Bayou Courtableau-Upper Grand River high sands (river mile 67). The river south of this point should develop similarly to the deep, comparatively straight Mississippi River channel now present south of Donaldsonville.

Development of the Atchafalaya delta

213. At some time before the establishment of a single channel through Grand and Six Mile Lakes and before the Atchafalaya has reached a critical stage in diversion, delta building should be evident in Atchafalaya Bay. At the present time approximately one-quarter of the suspended load of the Atchafalaya is carried through Lower Atchafalaya River into the Gulf. No estimates are available on the rate of filling of Atchafalaya Bay with these fine sediments but mudflats are beginning to blanket many of the sand beaches along the Louisiana coast west of Atchafalaya Bay. Oyster reefs along the coast have been buried by this wave of fine alluviation. Beaches at a former resort area at Cheniere au Tigre just west of Marsh Island, are now isolated from the Gulf by extensive mudflats. (See fig. 31.)

214. This phenomenon will be accentuated as the capacity of the Atchafalaya channel to carry load develops. During the critical and

Fig. 31. Mudflats blanketing beach sands along southwest Louisiana coast. Photograph courtesy of J.P. Morgan, Louisiana State University faculty

final stages of diversion, coarse load should be introduced for the first time into Atchafalaya Bay. A delta similar to that of the Lafourche-Mississippi delta, with many deep, narrow distributaries fanning out in all directions, should be built into the shallow, marsh deposits of the bay and the tougher Pleistocene clays which underlie the marsh deposits. The shallow depths which characterize Atchafalaya Bay and the Gulf south of Atchafalaya Bay, suggest a fairly rapid extension of the delta seaward, especially if dredging for navigation purposes becomes necessary. The slow natural process of selection of one distributary for development and orderly seaward extension of the delta would then be accelerated. Rates of Atchafalaya delta growth in the Gulf would be slower than its present growth in Grand Lake but much faster than the present rate of Mississippi delta growth. Rates of

Mississippi delta growth (see fig. 13) have averaged less than 1 mile in 25 years since 1839. At the present time the depth of water into which the Mississippi is discharging and longshore currents make delta growth almost negligible. The Mississippi River is discharging into water 300 ft deep a few miles off Southwest Pass. The Atchafalaya must build its delta seaward nearly fifty miles before it can deposit its load in water as deep.

PART VII: SUMMARY AND CONCLUSIONS

215. The Atchafalaya distributary is following a developmental pattern characteristic of former Mississippi River diversions which eventually took the entire flow of the master stream. Now that a channel capable of carrying low-water flow has been established and enlargement has begun, no natural processes are known which in the case of the Atchafalaya might prevent further enlargement and eventual diversion of the entire Mississippi flow.

216. The Atchafalaya at the present time is in its intermediate stage of diversion. Engineering studies show that approximately 25 per cent of the water of the Mississippi is being diverted. The present study has shown that a critical stage is to be expected at some time before 50 per cent of the flow is diverted. Following this critical stage, closure of the Mississippi River below Old River will be rapid and diversion will be uncontrollable. A conservative maximum estimate as to when the critical stage will occur is based on the time of 40 per cent diversion. Trends established by present measurable rates of Atchafalaya development are as follows:

a. The trend established by the percentage of total annual flow diverted from the Mississippi through Old River shows that 40 per cent of the Mississippi flow will be diverted by 1971.

b. Trends based on the time when the channel of Old River and the upper Atchafalaya River will have sufficient cross-sectional area to accept 40 per cent of the flow of the Mississippi, bracket the time between 1965-75.

c. Trends based on the rate of filling of Grand Lake and the establishment of a channel from the head of the Atchafalaya distributary to its mouth in Atchafalaya Bay, show that this condition can be expected between 1970-75.

d. Trends based on the rate of bank migration and channel enlargement at the point of diversion indicate that a critical stage of diversion will be reached in 1970.

217. It is concluded, therefore, that under normal conditions of development the diversion will have reached a critical stage between the years 1965-75.

218. Factors which will accelerate the diversionary process are the frequency of floods or sustained high-water flows through the distributary, continued dredging in the lower Atchafalaya Basin, and a critical stage of development occurring before the time of 40 per cent diversion. In connection with this last factor, any sudden increase in deterioration of the Mississippi channel immediately below the point of diversion should be interpreted as marking the beginning of the critical stage.

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