DISTRIBUTION OF SOILS BORDERING THE MISSISSIPPI RIVER FROM DONALDSONVILLE TO HEAD OF PASSES

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This report maps the distribution of soils which border the Mississippi between river mile 189 and Head of Passes in southeast Louisiana with special regard to their engineering significance. The subsurface disposition of depositional environments and their associated soil types are shown on 34 subsurface profiles. The text describes the physiographic and geologic development of the area studied, summarizes physical and engineering characteristics of the engineering soil types mapped, and discusses some of the effects of geologic factors on river migration.
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PREFACE

This study was authorized by letter dated 22 April 1958, subject, "Geology Study - Mississippi River - Donaldsonville to Gulf," from the District Engineer, U. S. Army Engineer District, New Orleans, through the Division Engineer, Lower Mississippi Valley Division, to the Director, U. S. Army Engineer Waterways Experiment Station, and first endorsement thereto from the Division Engineer, LMVD, dated 25 April 1958. Subsurface exploration and field work began in late 1958. The project was essentially completed by September 1960, but final plates and figures were destroyed in a fire at WES on 3 October 1960. Plates and figures were reprepared and redrafted, and the text was completed during 1961.

This report was written by Dr. Charles R. Kolb, Geology Branch, Soils Division, WES. Plates accompanying the report were prepared by Dr. Kolb, assisted by Messrs. Harry K. Woods and P. R. Mabrey, Geology Branch. The study was accomplished under the general supervision of Mr. W. J. Turnbull and Mr. W. G. Shockley, Chief and Assistant Chief, Soils Division, respectively.

Acknowledgment is made to the following organizations and individuals for their courtesy in furnishing information utilized in this study: Mr. George T. Cardwell and Mr. Rex R. Meyer, Ground-Water Division, U. S. Geological Survey; Mr. Roger Saucier and Dr. James P. Morgan, Coastal Studies Institute of Louisiana State University; Louisiana State Highway Department; Goldstein, Parham and LaBouisse, and Herbert A. Benson - George J. Riehl, Architects; Eustis Engineering Company and Palmer & Baker, Inc., Consulting Engineers; The Mississippi River Bridge Authority.
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Directors of the WES during the preparation and publication of this report were Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.
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SUMMARY

This report maps the distribution of soils which border the Mississippi between river mile 189 and Head of Passes in southeast Louisiana with special regard to their engineering significance. The subsurface disposition of depositional environments and their associated soil types are shown on 34 subsurface profiles. The text describes the physiographic and geologic development of the area studied, summarizes physical and engineering characteristics of the engineering soil types mapped, and discusses some of the effects of geologic factors on river migration.
PART I: INTRODUCTION

Background

1. The ever-increasing rate of industrial and cultural development along the banks of the Mississippi River between Baton Rouge, La., and the Gulf of Mexico during the past two decades has focused national attention on the economic potential of this lower 230 miles of the river. Among the more obvious advantages of the region are its bountiful supply of natural hydrocarbons, and the river which serves both as an artery for cheap transportation and as a source of large quantities of fresh water. Disadvantages include frequent foundation problems in the soils which have formed in the very recent geologic past and, again, the river—in this instance because of its flood potential. It is safe to say that river engineering developments, largely the responsibility of the U. S. Army Corps of Engineers, have progressed to the point where danger of flooding is only a very remote possibility. Planning, building, and maintaining flood control, navigation, and bank stabilization projects are important aspects of continued development of the region, and proper implementation of such projects requires that the Corps have readily available data of various kinds on this lower reach of the river. Among the most important of these data is an adequate knowledge of the soils which compose the bed, banks, and near-bank areas, and of the engineering characteristics of these soils.

2. This report is concerned specifically with the bed, bank, and near-bank conditions between Donaldsonville and Head of Passes, an area lying almost wholly within the deltaic plain of the Lower Mississippi Valley. Delineation of soil conditions in the deltaic plain has gradually progressed from blind correlation between borings to progressively more valid interpretations based on geologic inference. Geologic studies by Fisk* in the 1940's developed the general history of the Mississippi

* Raised numbers refer to similarly numbered entries in the list of selected references at the end of this report.
Alluvial Valley, and devised a comprehensive classification for those environments of deposition characterizing the middle and upper portions of the valley. This classification has been developed and used to excellent advantage in interpreting engineering soils since that time. The terms point bar, braided stream deposit, swale, clay plug, etc., some of which were introduced into the literature by these references, are now widely accepted, and the recognition of these environments is a requisite for the proper engineering and geologic interpretation of borings in the valley. These studies by Fisk and others\(^3\)\(^7\) established the fact that in southeast Louisiana an ancient horizon—the Pleistocene—with relatively high strength characteristics underlies the normally softer wedge of Recent sediments, but the sediments were collectively classed as deltaic plain soils.

3. Little further work was done on the deltaic plain deposits in the 1940's, but early in the 1950's many advances were made in recognizing and delineating some of the many environments of deposition that make up this enormous wedge of sediment.\(^1\)\(^9\),\(^4\)\(^7\) Names such as prodelta deposits and interdistributary clays were introduced into the literature. In 1958 the U. S. Army Engineer Waterways Experiment Station (WES) published a report by Kolb and Van Lopik\(^5\)\(^3\) which described and classified the deltaic plain environments from the standpoint of their associated engineering soil types. Only those environments comprising volumetrically significant and characteristically different units of soil were described and classified. Although established nomenclature was used wherever possible in this classification, some new terms, e.g. intradelta deposits, were introduced.

4. This classification was based partially on a previously published report by Kolb and Van Lopik\(^5\)\(^2\) which interpreted borings made for the Gulf Outlet Channel, and its validity and utility are substantiated in the present study. In general, the basic concepts involved in this classification of environments are well justified. Only a few soil conditions encountered in the many borings made or collected from other sources and analyzed for this study did not fit these basic concepts. There were some instances where anomalous conditions were found, however; e.g. the occurrence of clay units where the present concept of deltaic plain formation dictated that only coarser materials should exist, or the presence of low-strength soils where only high-strength soils are expected. It is
inevitable that this should be so since a great deal remains to be learned concerning the methods and sequence of deposition in the deltaic plain. Nevertheless, studies such as the one reported herein permit a systematic reconstruction of the complicated history of deltaic plain deposition. They permit a reconstruction of soil conditions between often widely spaced borings based on increasingly sound inference rather than blind correlation of soil types between borings. They suggest sound working hypotheses based on geologic origin or environment to explain radical variations of engineering properties in soils which otherwise appear to be similar. As Terzaghi and Peck point out, "Two clays with identical grain-size curves can be extremely different in every other respect. Because of these conditions, well-defined statistical relations between grain-size characteristics and significant soil properties such as the angle of internal friction have been encountered only within relatively small regions where all the soils of the same category, such as all the clays or all the sands, have a similar geological origin."

**Purpose of Study and Scope of Report**

5. The primary purpose of the present study is to map the engineering soil types in the immediate vicinity of the Mississippi River from the vicinity of Donaldsonville, La. (plate 1), to the Gulf of Mexico and to show their distribution in plan and profile. This has been done in plates 3-39; plates 3-10 show distribution of depositional types in plan, and profiles of the sections indicated on these plates are shown in plates 11-39. Plate 2 gives a detailed legend for the symbols and abbreviations used in plates 3-44. The text of this report (a) outlines the physiography, the cultural development, and the most recently reconstructed geologic history of the study area; (b) describes the distribution, and the physical and engineering characteristics of the sediments; and (c) briefly considers the effects of these sediments and other geologic factors on river migration.
6. The area under consideration in this study is that part of southeastern Louisiana bordering the Mississippi River between river miles 189 and 2 (above Head of Passes), or from 16 miles upriver from Donaldsonville, La., to Head of Passes (plate 1). Topographically, the area is one of negligible relief. Highest elevations are found close to the present river channel and reach el 30* upstream from Donaldsonville. Lowest elevations are in artificially protected areas and natural depressions in the marsh or swamp. Elevations of -6 are found in certain portions of New Orleans. Normally, such depressions are filled with water (as in the myriad lakes and shallow bays which characterize the vast, flat, near-sea-level marshlands of southeast Louisiana).

7. Topographic features of paramount importance are the natural levees which flank the present course, abandoned courses, and distributaries of the Mississippi. The natural levees slope gently from crest to toe, varying in width from 1/4 to 5 miles. A natural levee with crest at el 25 near Donaldsonville typically slopes to el 5 in a distance of 4 miles. The slope is concave upward, flattening with distance from the river. The area between the 5- and 10-ft contours is usually as great as that between the 10- and 25-ft contours.37 At the landside toe, the natural levee grades imperceptibly into the marsh or swamp. Hardwood forests characterize the swamps and once covered most of the natural levee areas; grasses and sedges and small bodies of open water are typical of marsh. Cultivation is confined almost exclusively to the high, well-drained natural levees. Drainage and reclamation of swamp areas, in some instances, extend the cultivated areas beyond the limits of the natural levees.

8. Prior to the construction of artificial levees, the natural levees were being extended both laterally and vertically by natural river processes. Such extension was probably very slow except in the extreme lower reaches of the river, where new natural levees were being formed.

* All elevations are in feet referred to mean sea level.
along the distributaries. As these new terminal levees formed and the channel was extended, stage variation at a given point upstream increased slightly and the height of the natural levee kept pace, the height adjusting to flood heights. During floods, muddy water would seek out a slight topographic low in the confining natural levee and a shallow crevasse would form. In other instances, lengthy stretches of the natural levee would be inundated, with only a few elongate islands remaining above the floodwaters to mark the highest portions of the natural levee. This permitted gradual alluviation of the natural levees, and as floodwaters subsided, crevasses were filled and the height once more adjusted to flood height. Counteracting this process were gradual subsidence, brought about by compaction and regional sinking of the land surface beneath the levee, and the erosion of the levee slope by rainfall. The result of these opposing processes was a balance between levee height and width and the height of floods.

9. The construction of artificial levees has interrupted these natural processes. Natural levees are no longer overtopped by floods, and landward extension of these ridge areas has ceased. The soil underlying the natural levees continues to consolidate, and the weight of the artificial levee locally increases the rate and amount of this consolidation. Drainage projects designed to extend the arable land beyond the toe of the natural levee have lowered the water table, causing additional subsidence. Rainfall continues to erode the natural levees, and the material carried away by erosion is not replaced by sediment-laden floodwaters. The net result is the lateral growth of the swamp and marsh environments and the gradual narrowing of the natural levees.

The River

10. The Mississippi River is narrow and deep from Donaldsonville to Head of Passes. Its width seldom exceeds 3/4 mile. The lowest riverbed elevation of record, -208 at Fort Jackson (plate 1) near Head of Passes, was recorded in a 1949-1952 survey. Other low points in the river include elevations of -202 at Bonnet Carre (plate 1) and -204 at mile 60. Minimum thalweg depths average 60-70 ft. Generally, the river becomes
progressively less sinuous from Donaldsonville to New Orleans and is almost straight after rounding English Turn just downstream from New Orleans. Survey records indicate that migration of the bankline has been very slow. Early river surveys map a feature called Claiborne Island at river mile 189 (the upstream limit of the study area, plate 3). This island once had the distinction of being the farthest downstream of any in the Mississippi. At the time of the 1895-1896 survey it had been incorporated in the bar at the upper end of Philadelphia Point, and what is now the last downstream island in the Mississippi, Bayou Goula Towhead, began to form at river mile 195.

11. Stages on the Mississippi vary from 37 to 1 ft msl at Donaldsonville, from 20 to -2 at New Orleans, and from 10 to -2 at Fort Jackson near Head of Passes. Discharge at New Orleans varies from a minimum of 79,000 cfs, to 600,000 cfs at normal stages, to 1,250,000 cfs at a river stage of 20. It is estimated that, with the Morganza and Bonnet Carre Floodways above New Orleans in operation, the maximum river stage at that city can be limited to 20.

12. Materials carried in suspension are estimated as 544 million tons annually. Quantities of bed load carried to the Gulf are variously estimated as from 2 to 25 percent of suspended load volumes. 19, 21, 50

13. A salt-water wedge enters the river during low river stages, and the tidal effects have been reported as far upstream as 35 miles above Baton Rouge during extreme low water. At a discharge of about 800,000 cfs the fresh-water currents have sufficient force to completely eliminate the salt-water wedge from the river channel and from all but the extreme seaward end of the passes. 21

Artificial Levees

14. According to Elliott, the first artificial levee on the Lower Mississippi River was built at New Orleans in 1727. The levee was 5400 ft long, 3 ft high, and 18 ft wide at the top. Contrast this with the present levee upstream from New Orleans which is in some places 30 ft high and close to 5000 sq ft in cross-sectional area.

15. By 1735 the levee lines on both sides of the river extended from about 30 miles above New Orleans to a point approximately 12 miles
below the city, and by 1812 the levee system had been extended to Baton Rouge on the left bank and beyond that on the right. Crevasses through these levees were a common occurrence. With the completion of more and larger levees, flood stages reached new heights. New Orleans was inundated several times, and there was considerable concern that the riverbed was being silted in between the levees. It was soon recognized, however, that these new flood heights were a natural result of confining the river between levees. Where once the river had been able to spread out across the natural levees, thereby lowering stages, it was now confined to a narrow zone between the artificial levees. River depths remained essentially constant.  

16. Crevasses as well as flood heights changed in character. Those through the natural levees had carried water at relatively low velocities down gentle, natural-levee backslopes, often spilling thin sheets of water over miles of natural levee. When the artificial levees, which impounded water to greater heights, were ruptured—as they often were—the water rushed through narrow openings at high velocity, digging scour pools at the crest and spreading the material out in large fans on the landward sides of the natural levees. A major factor in the widening of natural levees after the construction of the artificial levees was these crevasses, and crevasse fans are a common physiographic feature along the lower river.

17. In 1858 the levees on both sides of the river extended as far downstream as Pointe a la Hache (plate 1). Levee construction essentially ceased and existing levees deteriorated during and immediately after the Civil War. With the creation of the Mississippi River Commission in 1879, however, a new era in levee construction and maintenance began. By 1882 all levee lines were repaired, and levees extended as far south as Fort Jackson on both sides of the river. These levees have since been extended to about 10 miles above Head of Passes.

18. In 1915 a disastrous Gulf storm occurred at a time peculiarly favorable for damaging the levees below New Orleans, as the river was at bankfull stage below that city. Waves broke over the levees with sufficient volume to carry boats and drift logs completely over them. Wooden wave-wash fences and concrete facing placed on the levees for their protection were destroyed or damaged. A total of about 18 miles of levee was
practically obliterated, and about 95 additional miles were damaged.¹²

19. The Mississippi River flood of 1922 caused apprehension for the safety of New Orleans, and as a result a relief outlet was constructed by the removal of the left bank levee from just below Pointe a la Hache to Buras or roughly between river miles 45 and 25. However, siltation in this outlet is rapidly destroying its usefulness.

20. Crevasses continued to plague the lower river until the early 1920's. In the study area, the last crevasses occurred, or were made artificially to alleviate floodflows, in 1927. Fig. 1 shows crevasses occurring between Baton Rouge and the Gulf from 1903 to 1927. Plates 3-10 show more detailed locations of some of these crevasses and some of the major crevasses prior to that time.*

Fig. 1. Crevasses occurring on lower river, 1903-1927, according to Elliott¹²

* An apparent discrepancy between Elliott’s data shown in fig. 1 and data shown on quadrangle maps occurs at the bend just downstream from New Orleans. Poydras crevasse as shown on the St. Bernard quadrangle and in plate 7 is labeled Mon Plaisir crevasse by Elliott. Elliott shows Poydras crevasse as having occurred on the north side of the bend.
21. Bank recession within the study area has been small compared with the rapidly migrating banks upstream (see discussion in Part V). Because of the topographic features which limit the usable land and the relative stability of the river channel, the principal urban and industrial sites are concentrated on the high ground adjacent to the river. Near Donaldsonville, for example, the average elevation of both riverbanks is approximately 22 and the elevation of the lowlands on either side of the river at a distance of 3 miles from the riverbank is only about 5. The average distance between riverbanks and adjacent lowlands seldom exceeds 2 miles between Bonnet Carre and New Orleans, and is less than 1/2 mile between New Orleans and Head of Passes. Thus, industrial sites and population centers are concentrated close to the river's edge where slight river migration can cause considerable damage, and bank protection must be provided because it is impracticable or uneconomical to retire the levee. About 19 miles of revetment have been constructed between Donaldsonville and the Gulf since 1878, most of it since the early 1930's. About 1 mile of revetment protects the banks at Reserve (river mile 138), about 1-3/4 miles have been placed at Kenner (river mile 114), another 2-1/2 miles at Avondale Bend (river mile 108), about 13 miles in the New Orleans Harbor area, about 1/4 mile at Port Sulphur (river mile 39), and about 1/2 mile at Buras (river mile 25). Revetment has apparently been effective in preventing further migration of the river at these points.
PART III: GEOLOGIC HISTORY

22. Situated in the Mississippi River deltaic plain near its northern margin, the area under consideration is composed primarily of sediments of Recent origin. These sediments, representing deposition under environments ranging from fluvial to marine, are part of a seaward-thickening wedge which overlies the Pleistocene Prairie formation. According to Fisk, this is the youngest of four Pleistocene terraces in Louisiana, each resulting from deltaic deposition during interglacial periods. The Prairie formation is generally accepted as being pre-Late Wisconsin in age and was originally estimated to be 70,000 to 100,000 years old.

23. Throughout most of the study area, the Prairie formation lies buried beneath Recent sediments at elevations ranging from near zero in the northern portion of the area to approximately -600 near Head of Passes. It does outcrop at the surface, however, in the extreme northwestern part of the study area (about 5 miles north of Donaldsonville) in the form of a generally east-west trending, coastwise terrace (see fig. 3, page 13, and plate 3). Both the terrace and the buried surface slope toward the south or southeast at approximately 3 ft per mile.

24. In order to understand the events which led to the onlapping and burial of the Prairie surface by Recent sediments as well as the nature of these sediments themselves, it is necessary to review the Recent postglacial sea level rise. Although a rise in sea level accompanying the retreat of the Wisconsin ice sheets is generally accepted in principle, its duration and magnitude are still quite controversial.

25. As a result of initial investigations in the Lower Mississippi Valley, it was concluded that sea level at the glacial maximum (about 40,000 years ago) was at least 400 ft below its present stand, and that it steadily rose and achieved its present level about 5000 years ago. A maximum low stand of about 450 ft below present msl is now generally recognized, but dates varying from 18,000 years to more than 35,000 years ago have been advanced for this stage.

26. Recent interpretations of late Quaternary events in south Louisiana and the Gulf Coast region have been presented by McFarlan.
Broecker, and Curray. McFarlan's ideas are based on an analysis of Carbon-14 dates of 117 samples taken from the Recent and 5 samples from the Pleistocene. He postulates that sea level was 450 ft below present msl prior to 35,000 years ago. As the ice sheets melted and retreated northward, sea level is believed to have risen to 250 ft below present msl at some time prior to 35,000 years ago. According to McFarlan, sea level remained at this elevation for at least 18,000 years; then, about 18,500 years ago, ice began to retreat once more and sea level began a new rise (fig. 2).

Fig. 2. Various interpretations of sea level rise with time

27. Broecker and Curray do not agree with the hypothesis of the stillstand of sea level at -250 ft msl during an 18,000-year interval. Broecker, for example, notes that the front of the mid-continent ice sheet is dated as having advanced from north of Lake Erie to southern Ohio between 25,000 and 18,000 years ago. This implies a drop in sea level during that period, after which the ice sheet began its final retreat and sea level a relatively uninterrupted rise to its present level. Curray presents evidence gathered from detailed bathymetric studies along the Texas and Mexican coastal shelves to support his arguments. Of particular interest are isolated remnants of cemented beach rock and coquina 8 fathoms deep near Freeport, Tex. Shells in this shoreline feature are assigned radiocarbon dates of 30,000 years. Based on this and other information,
Curray (fig. 2) postulates a sea level only 25 ft below its present level 30,000 years ago. In contrast, Frye and Willman\(^20\) postulate a sea level about 150 ft below present level about 25,000 years ago. According to Curray, soundings and bottom samples show no widespread development of submerged deltas or extensive terraces at the 250- to 300-ft depth range as might be expected if McFarlan's hypothesis is correct. All four investigators are fairly well agreed that the time sea level began its last rapid rise was between 18,000 and 20,000 years ago. McFarlan believes this rise began from a depth of 250 ft below present msl; the others believe it began from levels ranging from 350 to 450 ft below present msl.

28. Broecker postulates an abrupt warming in climate about 11,000 years ago, and an accelerated rate of rise in sea level since that time. Curray, basing his ideas on radiocarbon dates and distribution of sediment characteristics reflecting current directions and configuration of the Texas shelf as it was 7000 to 15,000 years ago, believes there was a cyclic fluctuation of sea level during that time interval. Frye and Willman's studies, based on glacial advance and retreat, suggest a similar but more pronounced cyclic fluctuation during the same period. The time at which sea level reached its present stand, according to these sources, varies from 5000 years ago to about 3000 years ago. McFarlan cites evidence to indicate that sea level rose 17 ft during the interval between 5650 and 3000 years ago.

29. Sedimentation was probably an insignificant factor in the study area prior to the time the sea reached 200 ft below present msl. Most of the area stood high above sea level, and erosion was the predominant process. The greatest entrenchment occurred to the west and south. The axis of this entrenchment is shown in fig. 3. Until the sea rose to within 200 ft of its present level, only coarse fluvial materials were being deposited within the deepest portions of this trench. As the sea continued to rise, fluvial sediments were undoubtedly reworked and redeposited by marine processes near the ancient shoreline, but it was probably not until some 10,000 years ago, when sea level was only tens of feet below its present stand, that marine and fluvial-marine sediments of any consequence were deposited on this old erosion surface. Prominent among the marine environments identified in the subsurface are sand beaches which now lie
Fig. 3. Abandoned Mississippi River distributary systems, southeast Louisiana
beneath the waters of northern Lake Pontchartrain and one particularly prominent sand ridge which lies beneath New Orleans (see fig. 13, page 50). Carbon-14 dating of samples from the base of this sand ridge suggests an age of 4500 years. Archaeological studies by McIntire indicate that the bar remained a prominent surface feature, a site of Indian habitation, until 1500 to 2000 years ago.

30. The history of fluvial deposition in the study area is closely associated with shifts of the Mississippi River deltas. Fig. 3 shows the position of the major courses and distributaries abandoned by the Mississippi in southeast Louisiana. This figure and the brief reconstruction of delta history which follows are based on references 3, 14, 17, 19, 29, 30, 47, and 53. The oldest delta which may have occupied the region was that associated with the Maringouin course of the Mississippi which McFarlan dates as having been active 5000 years ago. Faint traces of what may be abandoned Maringouin distributaries are found south of Donaldsonville and were probably responsible for the first wave of prodelta clays to have been deposited in the region. The Teche course, occupied about 3800 years ago, was confined to the western part of the valley and the southern part of the deltaic plain. The effect of Teche sedimentation in the area along the river from Donaldsonville to New Orleans was probably negligible. Many of the prodelta clays along the river south of New Orleans, however, are undoubtedly of Teche origin.

31. The first major advance of the Mississippi River into the study area occurred about 2800 years ago when the river abandoned its Teche course and occupied its La Loutre course. This course corresponds in most respects to the present river position from Baton Rouge to Poydras (plate 1). From there it extended eastward to the vicinity of the Chandeleur Islands (fig. 3), forming the extensive St. Bernard delta. Major abandoned distributaries associated with the La Loutre course are the Bayou Metairie system trending northeast through New Orleans, and the Barataria system which flowed due south from New Orleans toward Barataria Bay. The Barataria at one time may have carried all, or at least a significant portion, of the river's flow.

32. McFarlan notes that the Carbon-14 age determinations for the Lafourche system trending southeast from Donaldsonville suggest that it
was first occupied 1500 and abandoned 600 years ago. In all probability the Lafourche never carried the full flow of the Mississippi. The earliest dates of occupancy of the Plaquemines-Modern system south of New Orleans are about 1200 years ago. The present delta at Head of Passes began to form about 450 years ago.
PART IV: DISTRIBUTION, AND PHYSICAL AND ENGINEERING CHARACTERISTICS OF SEDIMENTS

Presentation of Data

Maps

33. Surface distribution of sedimentary environments in the study area is mapped in plates 3-10 as a gray overprint. None of these environments form truly significant thicknesses of sediment. The thickest is the natural levee which reaches a maximum of some 20 ft. The swamp and marsh types delineated on the landward sides of the levees consist of organic deposits seldom more than 10 ft thick. The boundaries between the natural levees and between the swamp and marsh types are transitional and variable. Local subsidence, regional subsidence, severe windstorms, and cultural improvements affect these boundaries from decade to decade. More significant are the environments which these surface deposits overlie and largely mask. These are shown in black and include (a) the Pleistocene, the surface of which is contoured in feet below mean sea level, (b) the point bar, (c) several buried beaches, and (d) abandoned courses and distributaries.

34. Data used in the preparation of this report consisted principally of the logs of numerous borings made within the study area. In addition to borings made in the past by the U. S. Army Engineer District, New Orleans, boring logs were available in the files of the Geology Branch, Waterways Experiment Station, the Coastal Studies Institute, Baton Rouge, La., and from engineering firms, water-well drillers, and seismic companies. This information was supplemented by 32 borings made specifically for the project by the New Orleans District and approximately 30 auger borings made by the Ground-Water Division, U. S. Geological Survey, at Baton Rouge, La. Boring data were freely exchanged between the two government agencies, and geological interpretation was often based on a cooperative effort by geologists from both organizations.

35. Not all the locations of borings available in the files of the Geology Branch, WES, are shown in plates 3-10. However, the most reliable, and/or those used as the basis for interpretations are located. An exception to this occurs in the New Orleans area. Here boring data are so
numerous that only locations of selected borings are included. For locations of many additional excellent borings in this area, see plate 4A of reference 53. So many borings have been made in the New Orleans area during the past several years that it has been impossible to analyze all these data and include the results in this study.

Cross sections

36. Subsurface distribution of sedimentary environments is shown in plates 11-39. Boundaries of the environments, logs of the borings used to delineate these environments, and much of the available engineering information on each of these borings are shown in black. Inferences as to the lateral and vertical continuity of soil types, based on the distribution of the sedimentary environments, are shown in gray. Plates 40-44 contain logs of borings not utilized in sections. Locations of these borings are also shown in plates 3-10.

Text

37. The most comprehensive treatment of the deltaic plain environments, their associated soil types, and engineering characteristics are presented in reference 53. Observations and generalizations made therein are readily applied to the soils along the Mississippi from Donaldsonville to the Gulf. The reader desiring a reasonably thorough understanding of the discussion on the pages that follow should be familiar with the contents of the above-referenced report. To condense the textual presentation herein, familiarity with the contents of that report was assumed and each environment of deposition is discussed in the same order in which it was discussed therein. This permits elimination, in most instances, of the description of the depositional process forming each environment and much other pertinent data, so that items peculiar to the study area can be described more fully.

38. In keeping with this, fig. 4 is a modification of a similar figure in reference 53 that summarizes some of the ranges of physical and engineering properties to be expected in the environments of deposition in the deltaic plain. Only those environments found within the study area are included in fig. 4. Percentages of lithologic types and ranges of engineering data have been modified in a few instances to reflect conditions peculiar to the study area.
39. In the discussion which follows, the Pleistocene deposits are treated as a unit. Discussion of the Recent is divided into the broad categories of fluvial, fluvial-marine, marine, and paludal environments. These are further divided into individual environments of deposition mapped in plan or in profile in plates 3-39. Only those environments identified within the study area are discussed. And, because of the nature of the study, emphasis is placed on those facets of environment development which have greatest effect on stratification and engineering properties of the soils.

The Pleistocene

40. Boring data collected and analyzed for this study have permitted considerable refinement of the contours of the buried Pleistocene surface, particularly where this surface lies at depths of less than 150 ft. Fig. 5 shows contours of this surface developed from the latest available information. Compare this map with plate 4 of reference 17 (1955) and reference 14 (1944). Noteworthy is the minor amount of dissection that characterizes the shallow shelf of Pleistocene material which slopes southward beneath Lakes Maurepas and Pontchartrain and much of the deltaic plain of southeast Louisiana. Earlier maps based on fewer data included numerous deep reentrants or entrenchments of this shelf. Erosion during the time of lowered sea level was thought to have thoroughly dissected it. This does not seem to be the case, because the shelf is relatively undissected and although locally uneven, major entrenchments are few. Steepest slopes are on the southwest border of the shelf where the Pleistocene surface drops fairly rapidly toward the axis of deepest entrenchment, an axis that trends roughly in a northwest-southeast direction a few miles west of Houma, La.

41. Following the rise of sea level after retreat of the Pleistocene ice sheets and the inundation of the Pleistocene surface with fluvial and deltaic deposits, gradual subsidence slowly tilted this shelf toward the south. The tilt of this surface now averages 3 ft per mile. The only other modification of this shallow shelf has been its entrenchment by the Mississippi River. This began some 2800 years ago with the development of
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### REMARKS

- Natural levees form on aggradation terraces, often on the outside of bends, where current velocities are low. They are composed of fine-grained sediments and are generally well-sorted.
- Point bars form on the inside of bends, where current velocities are high. They are composed of coarse-grained sediments.
- Prodelta clays form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Intradelta clays form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Interdistributary deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Abandoned distributary deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Abandoned course deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Swamp deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Marsh deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Sandy beach deposits form on the shorelines of estuaries, where sediments are deposited in a low-energy environment.
- Bay-sound deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Nearshore gulf deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Estuarine deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Backswamp deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Substratum deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.
- Pleistocene deposits form in the estuaries of river mouths, where sediments are deposited in a low-energy environment.

### LEGEND

- **Gravel (20-60 mm)**
- **Sand (2-0.05 mm)**
- **Silt (0.05-0.005 mm)**
- **Clay (0.005 mm)**
- **Organic Material**
- **Shell**

*Values range indicate the degree of variability in the type of deposit. The degree of variability is based on the Unified Soil Classification System.*

*Shearing strengths are based on unconfined compression tests.*

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**Fig. 4.** Typical properties of depositional types—Donaldsonville to Gulf.
Fig. 5. Contours on top of Pleistocene in feet below mean sea level. Broken contours based on very limited data.
the St. Bernard and subsequent deltas toward the east and southeast. The
deltas were areas of rapid deposition, and they buried the Pleistocene
shelf beneath greater thicknesses of sediment. As the deltas advanced
seaward, however, the trunk stream began to scour deep into the underlying
Pleistocene deposits, so that the bed of the present channel and a large
portion of its banks consist of Pleistocene deposits. This is the condi-
tion from river mile 157 at College Point to about 25 miles south of New
Orleans. The width of this entrenchment is controlled by the amount of
river migration, which nowhere exceeds 3 or 4 miles. The trench is too
narrow to be shown in fig. 5. In plates 3-7, its width is indicated by
the lateral extent of point-bar deposits. Shallow Pleistocene contours on
these plates are terminated wherever they touch the river or flanking
point-bar deposits. Contours greater than average depth of river scour,
i.e. el -150, are extended across the point-bar areas.

42. The existence of the Pleistocene in the bed and portions of the
banks of the river has a significant effect on river migration. The ratio
of river distance to airline distance between Baton Rouge and College
Point, for example, is 2:1. The ratio of river distance to airline dis-
tance between College Point and New Orleans is only 1.3:1. The river-
airline distance ratio is even smaller downstream from New Orleans where
the Pleistocene lies at a depth too great to form the riverbed. However,
the straightness of the river channel south of New Orleans is attributed
to its youth and to the fact that here the bed and banks of the river con-
sist of cohesive prodelta clays almost as nonerodible as the Pleistocene.
See Part V for further discussion of this topic.

43. The importance of the Pleistocene in foundation design is self-
evident. The deltaic plain soils overlying this horizon are for the most
part of low strength. Consequently, many of the heavier structures in the
study area are founded on piles reaching the Pleistocene. Since some of
these piles extend well into the Pleistocene materials, a knowledge of the
type and lateral distribution of soils and the distribution of strengths
in the Pleistocene is essential. Recognizing and establishing the eleva-
tion of this horizon in the subsurface are important in any foundation
investigation in the deltaic plain.

44. Previous studies⁵³ point out the following criteria as aids in
distinguishing the Pleistocene in boring returns: (a) Color of the sample typically changes from dark gray, blue gray, or black to an oxidized, mottled yellow or tan. In some cases the color change is to light, greenish gray. (b) Usually a marked decrease in water content occurs. (c) There is a distinctive stiffening in soil consistency and a decrease in rate of penetration of sampling devices, an indication of increase in soil strength. (d) Calcareous concretions are typical.

45. These distinguishing characteristics are generally in accord with the data on logs of borings examined in the present study. Areas where a determination of the Recent-Pleistocene contact is sometimes difficult include embayments or estuaries in the old Pleistocene surface during the time of lowered sea level, where the present Mississippi River has scoured deep into the Pleistocene surface, and where this surface is deeper than el -150. Many reentrants or embayments in the Pleistocene surface must have acted as estuaries for considerable periods of time while sea level was at its lowest stand or while it was rising. The result was that little oxidation of the contact took place. Where oxidation did take place, oxidized strata may have been removed by further entrenchment of the estuary.

46. A similar situation occurs where the present river and its abandoned courses have cut channels into shallow Pleistocene deposits. The upper, thoroughly oxidized zones in such instances are often entirely removed by fluvial scour, and except for a slightly greenish cast and usually—but not always—a higher strength, the material may be hard to distinguish from Recent deposits. Whenever the Pleistocene is at a depth greater than 200 ft, the boundary between Recent and Pleistocene deposits may be difficult to establish.

47. The depth of oxidation of the Pleistocene deposit varies considerably. Oxidation is deepest where the Pleistocene is very close to the surface; mottled tan or yellow colors are found to depths of 50 ft or more in the Pleistocene. Boring MS-8, in section H, plate 17, illustrates this. This boring encounters Pleistocene at el 0. Tan oxidized colors are found to el -55. Partially oxidized material with greenish-gray colors, and gray unoxidized material are found to el -115. Tan colors begin again at el -115 and extend to el -145; greenish-gray colors are found to
el -170; and gray unoxidized material to el -188, the bottom of the boring. This boring is fairly typical of Pleistocene materials. Very stiff to stiff consistencies are characteristic of the oxidized or partially oxidized Pleistocene; stiff to soft consistencies are typical of the unoxidized gray Pleistocene.

48. This correlation of consistencies and strengths with oxidation is expectable. The reasons for the erratic distribution of the zones of oxidation are only partially understood, and the phenomenon occurs in nearly all borings penetrating the Pleistocene in the study area. As the depth at which Pleistocene is encountered in a boring becomes greater, the thickness of the upper, oxidized zone decreases. Where the Pleistocene is found at elevations below -100, tan colors are often lacking entirely and greenish-gray colors predominate. Where the Pleistocene is deeper than el -150, both tan and greenish-gray colors may be absent at the Recent-Pleistocene contact. Here variations in consistency, cohesive strength, water content, and the occurrence of concretions become important diagnostic characteristics.

49. The great thickness of oxidation where the Pleistocene occurs at shallow depths is understandable. It probably reflects the greater depth to water table in such areas during the time of lowered sea level and the much longer time they were subaerially exposed and subjected to oxidation. There is also reason to believe that where the Pleistocene occurs at elevations of less than -50, it was never subjected to the marine erosion accompanying rising sea level during waning glaciation, the shallow surface having subsided and been covered with a protective blanket of deltaic deposits. Where the Pleistocene occurs at greater depths much of the oxidized part of this surface was probably removed by wave action. Differential depths of marine erosion may account for the fact that tan oxidized deposits sometimes mark the contact between Recent and Pleistocene deposits even where it occurs at depths as great as -400 ft msl. In other instances tan deposits are absent when this horizon is found at depths as shallow as -150 ft msl.

50. Why oxidized zones occur at great depth in the Pleistocene, as is the case in boring MS-8, is unexplained. Erratically spaced, oxidized Pleistocene strata are found sandwiched in with unoxidized
Pleistocene strata in almost all of the borings which penetrate very deeply into the material. In the borings shown in plates 11-44, there is a slight indication that a second zone of oxidation may occur—as it does in boring MS-8 (plate 17)—at about el -100. This is the grossest sort of generalization, however. There also is some slight tendency for the deeper, oxidized zones to be more prevalent in the coarser grained materials. It is possible that the Pleistocene was once uniformly oxidized to great depths, and that the erratic distribution of oxidized zones is the result of selective chemical reduction of certain strata. It is also possible that erratically disposed, oxidized zones are buried Pleistocene natural levees or similar environments that were oxidized at the time of deposition. Regardless of the causes of this phenomenon, the engineer should be aware that relatively soft, unoxidized zones that may be important in foundation design do occur in the Pleistocene.

51. It should be remembered that the Pleistocene is considered to be an ancient alluvial-deltaic plain of an ancestral Mississippi River, and that the lateral and vertical distribution of soil types of which it is comprised are just as complexly interfingered as those of the Recent deposits. The occurrence of shells in samples taken from the Pleistocene beneath southeast Louisiana suggests that the present deltaic plain overlies an ancient Pleistocene deltaic plain with similar environments of deposition and similar associated soil types. Data are far too scarce to attempt to reconstruct the paleogeography of this ancient deltaic plain; however, it undoubtedly contained thick wedges of prodelta clays, buried sand beaches, bay-sound deposits, and other environments characteristic of the present deltaic plain. Ancient rivers probably meandered across its surface and left behind abandoned courses flanked by point-bar deposits. The purpose of recreating this hypothetical situation is to emphasize the fallacy of correlating soil types between widely spaced borings in the Pleistocene. As in the case of the Recent deltaic plain deposits, widespread correlation would be very misleading without identifying the environment of deposition in which the Pleistocene material has been laid down.
Fluvial Environments

52. Fluvial environments of deposition flanking the Mississippi River from Donaldsonville to the Gulf consist of natural levee, point-bar, abandoned distributary, abandoned course, backswamp, and substratum deposits. Because of the configuration of the Pleistocene surface in the study area as discussed in the preceding paragraphs, the backswamp and substratum environments are found only as far downstream as river mile 157 at College Point. It will be recalled that it is here the present Mississippi River leaves the major valley entrenched in the Pleistocene and trends east-southeasterly across a shallow, relatively uneroded Pleistocene shelf. Downstream from this point sediments can be subdivided into those characteristic of the deltaic plain; upstream, sediments are generally divisible into those characteristic of the alluvial plain.

Backswamp

53. The use of the term "backswamp" is decreasingly appropriate downstream from Baton Rouge. A thick fine-grained topstratum, comparable to the backswamp upstream from Baton Rouge, overlies a sand and gravel substratum; however, as far upstream as Baton Rouge occasional layers of shell are found in borings sampling this unit, suggesting that the area was covered in fairly recent times by waters of shallow bays or sounds. Occasional sandy units also occur that suggest an intermingling of backswamp and deltaic plain environments of deposition far more complex than the simple buildup of backswamp clays in floodplain depressions. This is even more pronounced in that part of the study area between Donaldsonville and College Point. Here a fine-grained topstratum overlies a well-defined substratum, but shell layers and coarse-grained strata are frequently intercalated with more characteristic fat clays. The term "backswamp" is used in subsurface sections in this area (plates 11-18), but with reservations. Downstream from College Point the term is entirely inappropriate.

Substratum

54. Although the concept of a substratum of fluvial sand, or sand and gravel, underlying a fine-grained topstratum is basic to understanding the stratigraphy of the Recent deposits in most of the Mississippi Alluvial Valley, it introduces complications in the area under investigation.
In the latitude of Donaldsonville substratum sands are found only below an elevation of about -100. From College Point (river mile 157) to well south of New Orleans, the ancient Pleistocene surface often lies at depths of less than 100 ft. Substratum sands, therefore, were not deposited on this shallow shelf. South of New Orleans the Pleistocene is encountered at progressively greater depths, reaching a depth of about 600 ft at Head of Passes. But here, too, the concept of a fluvially deposited, coarse-grained substratum is inappropriate since materials lying directly above the Pleistocene were deposited for the most part in a marine environment.

55. Consider contours of the Pleistocene surface in fig. 5. Note that the deepest part of the Mississippi River entrenchment trends south-eastward about 15 miles west of Houma, La. Substratum sands fill this trench, and the top of the sands occurs at progressively greater depths in a downvalley direction. The top of the unit is also believed to be at progressively greater depths to the east and west of the axis of entrenchment. Coarse materials deposited in a braided stream environment in the substratum should be concentrated along the axis of greatest entrenchment. Coarse materials carried east and west of this axis were enveloped and incorporated with the marine environments associated with a rising sea level.

56. In keeping with this, note that section I (plate 18), which crosses the river at College Point, is the farthest downstream of the sections on which the term substratum is used. In the areas bordering the river downstream from this point the term is not applicable.

57. Borings encountering the substratum between Donaldsonville and College Point show it to consist predominantly of poorly graded fine sand. Fig. 6 summarizes data on borings encountering the substratum in this area. The data are assembled in 20-ft increments of depth. Notice the high incidence of poorly graded fine sand (SP) between el -100 and -140. Although gravel content increases appreciably with depth, the substratum is markedly finer grained than the substratum at comparable depths at, say, Old River near the Louisiana-Mississippi border. Fig. 6 also shows estimated ranges of permeabilities for each 20-ft increment of substratum. These ranges are based largely on experience with materials of comparable
grain size in other portions of the Lower Mississippi Valley. Notice the reasonably high permeabilities in the lower portion of the substratum despite the persistence of fine-grained sand. The high permeability of these sands is generally corroborated by wells pumping from substratum deposits in the Donaldsonville area where yields of from 1400 to 2100 gpm have been measured with specific capacities averaging more than 40 gpm per ft of drawdown.

58. The most prevalent conception of the nature of the wedge of coarse-grained sediments in the substratum is that it consists of an uninterrupted sequence of progressively coarser materials with depth. If Broecker's and Curray's interpretation of events, discussed in Part III, is accepted, this should be the case. If McFarlan is correct in assuming a long--at least 18,000-year--stillstand of sea level, there should be a reasonably well-marked change in the nature of the substratum deposits at about el -250, or at a somewhat greater depth consistent with regional subsidence since that time. A fine-grained topstratum should have been preserved in some instances, and sand density should increase markedly below this horizon.
Fig. 7. Grain-size distribution of samples taken from the substratum in boring MS-4 (see plate 11 for graphic log of boring)

59. Fig. 7 shows grain-size distribution curves from five samples from the substratum encountered in boring MS-4 (section A, plate 11). Note the poor gradation of the fine sand samples at el -109 and -129. Note also the skip-grading in the sand-and-gravel units at el -149, -169, and -179. Coarse to medium sand sizes are curiously lacking, a characteristic found in the majority of the samples available from the substratum in the study area. Whether this material consists of finely stratified layers of poorly graded fine sand between layers of poorly graded gravel, or of fine sand intermixed with the gravel is unknown. In the former case, permeability should be high. In the latter case, the permeabilities may be much lower than indicated in fig. 6. Based on the effective grain size ($D_{10}$) of the sand-and-gravel units, for example, a permeability of only $500-600 \times 10^{-4}$ cm per sec should be expected.  

60. The strange lack of medium and coarse sand sizes has been observed in many fluvialite sediments. Udden, 45 Wentworth, 57 Einstein, Anderson, and Johnson, 11 Hough, 23 Pettijohn, 34 and Sundborg 40 have observed this fact and attempted to explain it. Some suggest that the process of weathering of the source rock and the process of wear during transport produce a sediment wherein certain grain sizes are more common than others,
mainly because certain grain sizes, among them the medium and coarse sand sizes, are mechanically unstable. Sundborg suggests that the reason lies in the selective transportation of material by flowing water. He bases his conclusions on work by Shields who postulated that "the ratio of the force exerted by flowing water along the bottom to the resistance of a layer of sand grains is a function of the ratio of the grain size to the thickness of a laminar sublayer." Based on this theoretical approach and some laboratory experimentation, Sundborg concludes that "when gravel grains have been worn down to a size of about 5-6 mm, the transportation of them by the stream becomes more relentless, and they are often prevented from coming to permanent rest until they have been worn down to a size of 1-2 mm or less. This may well be an important cause of the general deficiency of particles in the interval 1-6 mm."

It is possible that the lack of coarse and medium sand sizes in the substratum substantiates Sundborg's views; that the substratum was laid down by braided streams which permitted finer and coarser materials to remain behind, but selectively sorted the intermediate sizes for deposition farther downvalley. If this is true, there should be a concentration of medium and coarse sand sizes in the more southerly areas of the entrenched valley, in those areas where this particle size eventually reached the then-lower sea level. This hypothesis is obviously not valid on today's Lower Mississippi. Coarse and medium sand sizes are found in only insignificant quantities in the point-bar deposits which flank the channel in the study area and are essentially absent in the delta. It is inconceivable that such sizes could be worn by attrition to fine sand sizes in the 180 miles of river transport between Donaldsonville and the Gulf. The lack of such sizes must, therefore, be attributed to the very small quantities of such sand sizes that reach this lower portion of the river. The reasons for the lack of gravel sizes in the Lower Mississippi have been discussed elsewhere. Apparently the process of selective sorting and deposition so effective in eliminating gravel sizes in the lower river has also winnowed out the larger portion of the coarse and medium sand sizes. It would be interesting to study the occurrence of coarse and medium sand sizes in point-bar deposits successively farther upstream from Donaldsonville and to contrast this with the occurrence of
similar sizes in bed material samples. A knowledge of the prevalence of skip-grading, which involves a lack of coarse and medium sand sizes in the substratum, might also prove of considerable value in the study of sediment transport problems.

**Point bar**

62. One of the most abrupt and significant of the changes in soil type along the river in the study area is that between the silts and sands of the point bar and the older deposits which border and underlie them. Point bars flank the present river or abandoned courses of the river, and normally occur on the insides of bends to which the sandy deposits accrete as the bends grow. Recognition of point-bar deposits is, therefore, relatively simple where boring logs are available, even though natural levee deposits often effectively mask the arcuate markings which help to identify point bars on aerial photographs in the central and northern portions of the valley. Most of the borings made expressly for this study were located to help identify these deposits and to delineate their extent.

63. A tabulation of more than 2000 samples from point-bar deposits between Donaldsonville and the Gulf indicates that close to 50 percent consist of poorly graded fine sand. Fig. 8 shows grain-size curves of

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**Fig. 8.** Percentage of soil types in point-bar deposits in study area and grain-size distribution of typical deposit
materials at various depths within the typical point bar, the characteristic increase in grain size with depth, and the percentage of soil types normally found within the point-bar deposits along the lower 190 miles of river.

64. Other than this characteristic increase in grain size in a given point bar with depth, few unifying generalizations can be made. For example, examination of the borings available in the study area shows no decrease in sand with distance downstream, or increase in clays. Depths to sand are highly variable, and soil types change rapidly both horizontally and vertically. An important point to consider in interpreting borings made in point-bar deposits is that lateral correlation based on borings spaced at distances greater than 200 ft is not recommended. For this reason subdivision of the finer grained upper portions of the point bar is not attempted on most of the subsurface sections accompanying this report. An exception is in the basal one-third to one-half of the point-bar deposit, where experience has shown that a fairly clean, fine-grained, homogeneous sand can be expected.

65. The nature of the coarser deposits in the point bar is illustrated in fig. 9. The photographs are of samples taken from a 6-in.-diameter continuously cored boring made just downstream from New Orleans. Note the intricate small-scale stratification characteristic of the SM-type soils, i.e. samples 12-B and 14-B. This stratification is apparently the result of the arrangement of the deposits in alternating, paper-thin layers of silt and fine sand. Mixing these layers in the laboratory results in the classification of the material as an SM soil. Cross-bedding, thin laminations, and thin, dark, organic strata are common. The photograph of sample 12-B shows some of the thin layers of granular organic fragments. Such very thin organic layers and fine flecks of organic matter are found disseminated throughout the point-bar deposits; however, segregation of peat in any considerable quantity is not considered either typical or significant. Occasional peats observed in some of the point-bar borings (see plates 13 and 17) are probably pieces of rotting wood or water-worn organic pellets that are so limited volumetrically that they are considered to have little effect on consolidation or strength characteristics of the material.

66. Sample 14-B in fig. 9 shows remarkably warped strata sandwiched
Fig. 9. Details of stratification in point-bar deposits sampled in boring MS-32A at English Turn
between essentially level strata. This probably resulted from folding of the strata after deposition, possibly at the time of deposition of the strata that overlie the warped sequence. Sample 22-A illustrates the massive bedding characteristics of the thick section of poorly graded fine sand typical of the basal portions of the point-bar deposit. Only at the very bottom of the point-bar deposits, in sample 30-C, is there a reoccurrence of noticeably thin stratification. Shells found in this sample suggest that this may be a transitional environment between the point bar and the underlying Pleistocene. The effective grain size, $D_{10}$, of the basal sand section ranges between 0.80 and 0.18 mm. Horizontal permeabilities should range between 100 and 800 cm per sec $\times 10^{-4}$. *

67. In the Philadelphia Point bend just upstream from Donaldsonville (plate 3) and in the Laplace area (plate 5) a very silty sequence of deposits has been tentatively identified as point-bar deposits, and is shown with a different symbol than the rest of the point-bar materials in the study area. These materials are notably finer than the normal sandy point-bar deposits, consisting of inappreciable amounts of sand and more than 75 percent silt. Arcuate markings characteristic of point-bar deposits help to identify these areas on aerial photographs. At Geismar (plate 1) these markings are particularly well preserved. The Carville quadrangle, a portion of which is shown in fig. 10, shows many of these trends as curved lowlands on the floodplain surface. Note particularly the curvature of the swampy lows at Southwood, the one followed by New River, and the series trending northeast just downstream from Geismar. The direction and curvature of these markings conform very poorly with the curvature and size of the present Mississippi. The stream which made them may have been an appreciably narrower stream with a considerably tighter meander loop. In all probability the silts which are found in these areas were left by a small stream such as the Yazoo, which is believed to have once entered the Gulf at this point at the time when the Mississippi occupied its Teche course on the other side of the alluvial valley (fig. 3). On the other hand, the above-mentioned markings may also have been left by an early distributary of the Mississippi--a stream which was eventually enlarged to the size of

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* Based on an extension of the curve shown in fig. 17 of reference 51.
Fig. 10. Distribution of silty and sandy point-bar deposits near Philadelphia Point upstream from Donaldsonville, La.
the present Mississippi. The remnants of deposits left by such a stream should occasionally be preserved along or closely adjacent to the present river, and undetected remnants probably occur as far downstream as New Orleans.

**Natural levees**

68. The height, thickness, and width of the natural levees flanking the Mississippi River decrease markedly between Donaldsonville and the Gulf. Similarly, the grain size of the material comprising the levee generally decreases in a downstream direction. Fig. 11 is a schematic representation of typical height, width, thickness, and soil type from river mile 186 to 20 above Head of Passes. Borings selected for this diagram were chosen wherever possible from those located near the crest of the natural levee where the coarsest materials are normally found. The levee decreases rapidly in elevation and thickness and generally decreases in grain size with distance landward from the crest. This diagram does not attempt to show the actual distribution of soil types in 166 miles of natural levee, but rather the change in the percentage of each soil type with distance.
downstream. The boring at mile 186, for example, begun at el 28, encountered randomly distributed soil types of which 50 percent were CL, 25 percent ML, and 25 percent SM (see plate 2 for definition of symbols). The thickness of the natural levee deposit in this instance was 18 ft. The boring at mile 20, on the other hand, begun at el 4, penetrated 12 ft of natural levee deposit, and samples consisted entirely of CH soil.

69. The width of the natural levee varies between 4 and 2-1/2 miles between Donaldsonville and New Orleans and narrows perceptibly south of the city, an indication of the youth of the channel south of New Orleans. It is interesting to speculate on the future of the natural levees in those extreme lower reaches of the river protected by artificial levees. Protected from overbank flow during high-water periods by the artificial levees, the natural levees have ceased to grow. Normal subsidence of the area because of consolidation of the soft deltaic plain deposits has been augmented by the weight of the artificial levees. Natural levee widths in these lower regions of the river are becoming less, and unless fill materials are brought in to build up these gradually subsiding areas, saline-to brackish-water marsh will eventually cover the natural levee areas landward of the artificial levees. For example, the natural levee has almost completely disappeared just upstream from Potash (see plate 9, mile 41), in marked contrast to the width of the natural levee in the unprotected Pointe a la Hache Relief Outlet on the other side of the river.

70. The size of the natural levee upstream from New Orleans has probably remained essentially the same for many hundreds of years. Increase in height results chiefly from gradual extension of the mouth of the stream seaward, and since the distance from Donaldsonville to the distal ends of the St. Bernard delta was somewhat comparable to the present distance from Donaldsonville to the Gulf, it is doubtful if the height of these levees has increased appreciably since the abandonment of the St. Bernard delta. Crevasses increased the size of the natural levee locally. Before the construction of the artificial levees, however, these crevasses were probably more frequent but less spectacular than crevasses since that time. Notable local extensions of the natural levee accompanied the recorded crevasses. Location and dates of many known crevasses are shown in plates 3-10 and fig. 1. One of the more spectacular results of crevasses
through artificial levees was the creation of deep scour pools immediately landward of the crevasse. Depressions still mark the locations of many of these scour pools. Little is known concerning the types of material with which they are filled.

71. The strength of natural levee deposits is high. The characteristic range of strength of the cohesive soils is between 800 and 1200 lb per sq ft based on unconfined compression tests. Desiccation and oxidation of these materials after deposition undoubtedly account for this high strength. Of interest in this connection are buried natural levees, occasionally located by borings, which retain considerable strength even though now submerged beneath the water table. Such buried natural levee horizons are probably most common in that part of the study area upstream from Laplace, since most are thought to be correlative with the ancient Maringouin system of the Mississippi which occupied this area many years before the formation of the present river channel and the St. Bernard and subsequent deltas (fig. 3). Saucier has identified one such buried natural levee in the vicinity of Reserve (see section L, plate 21). Very carefully logged borings made in this area have identified two well-developed natural levee systems flanking the Mississippi. The landward ends of these levees are separated by an organic swamp or marsh deposit. Riverward, the two natural levees lie one on top of the other and reach a maximum thickness of 35 ft. An interesting feature is that each has an upper, oxidized zone and a lower, unoxidized zone. Whether the lower zones were never oxidized, or whether they were oxidized and later chemically reduced is unknown. Unfortunately, no data are available concerning comparative strengths of the two natural levee systems. Field determination of consistencies indicates a roughly comparable strength for the oxidized portions of both levees.

Abandoned courses and distributaries

72. The development and abandonment of courses and distributaries in the study area are essential parts of the geologic history of the deltaic plain (Part III). Known and many inferred positions of such features are shown in plates 3-10 and fig. 3. Abandoned courses are few in number and were large enough to have left markings fairly easily distinguishable on the floodplain surface. Abandoned distributaries are much more difficult to recognize and delineate, but they are often of considerable importance.
in foundation problems. They tend to cut haphazardly across other deltaic
plain environments of deposition where soils are fairly homogeneous, and
when abandoned they leave behind narrow ribbons of sediment ranging from
50 to 500 ft in width and from 10 to 100 ft in depth. Discontinuities such
as these in otherwise homogeneous strata are often difficult to locate on
aerial photographs, and unless a boring happens to be located in such a
deposit, may be entirely missed in foundation explorations.

73. Unfortunately, abandoned distributaries are most difficult to
recognize where their recognition is most important--in areas close to the
present river. Here they are invariably covered and completely masked by
natural levee deposits. Experience has shown that the most successful
method for locating these features on airphotos is to begin by carefully
studying the marsh or swamp areas and to work toward the river. The aban-
doned distributary can usually be traced with some degree of success in the
marsh, and although it will be completely masked within 2 or 3 miles of the
river, the trend of the abandoned feature can be estimated. Fortunately,
meanders are relatively rare in distributaries, and once a trend has been
established in the marsh this trend can be extended along a fairly straight
or gently arcuate path where it is masked by overlying natural levee
sediments.

74. The size or importance of the deposits filling an abandoned dis-
tributary is difficult to ascertain on aerial photographs. Small, recently
abandoned distributaries often are better marked than large, significant
distributaries abandoned for some time. The considerably larger number of
distributaries mapped downstream from New Orleans (plates 7-10) than up-
stream is partially a reflection of this. Only three abandoned distribu-
taries are shown in plates 3-5. The farthest upstream is north of Laplace
in plate 5. This distributary once trended northward between Lake Maurepas
and Lake Pontchartrain and is undoubtedly the cause of the slightly higher
land which separates these two water bodies. Faint markings of a system of
distributaries presumably associated with the ancient Maringouin course of
the Mississippi are mapped in the lower right corner of plate 5 and contin-
ued eastward in plate 6. The position, and even the existence of this sys-
tem of distributaries are controversial. The third abandoned distributary
system mapped upstream from New Orleans is the well-marked Bayou Metairie
which trends northeasterly through New Orleans.

75. There are undoubtedly more abandoned distributaries in the area covered by plates 3-6 than are shown; however, it is believed that these features are not as common in this portion of the river as they are downstream from New Orleans. In all probability the gradually subsiding Pleistocene shelf was well covered with sediments long before the advent of the Mississippi River and its distributary systems some 2800 years ago. Carbon-14 dating of marine sediments overlying the Pleistocene shelf indicates dates in excess of 10,000 years. It is quite probable that except for the earliest deltaic distributary system left by the Mississippi-Maringouin course, very few distributaries existed upstream from New Orleans; it is also probable that the St. Bernard established its earliest course over a marshy land area and did not begin to bifurcate into a significant distributary system until it reached open water along its eastward trend in the vicinity of New Orleans. Distributaries were apparently directed predominantly eastward and southward in the New Orleans area, and northward upstream from New Orleans.

Fluvial-Marine Environments

76. Pages 31-45 of reference 53 describe the formation and the physical and the engineering characteristics of the three principal environments falling in a fluvial-marine category: the prodelta, the intradelta, and the interdistributary deposits. Data collected and analyzed for the present study confirm the validity of this classification and the conclusions concerning these environments summarized in the above-mentioned reference.

Prodelta deposits

77. Prodelta deposits are the first of the terrigenous sediments introduced into a depositional area by an advancing delta. Although widely distributed by wind, marine, and fluvial currents, there is a gradation of prodelta silty clays into prodelta clays with distance from the mouths of active distributaries. In profile this depositional sequence is manifested by a normal gradation upward in the prodelta clay sequence from fine to coarse, in this instance from the finest clays to silty, and rarely, sandy clays.
78. Prodelta deposits are distributed in plan as a relatively uninterrupted stratum beneath the shallow water of offshore southeastern Louisiana. Lenses of this environment extend inland beneath the land areas, but greatest thicknesses occur in the offshore areas. The thickness varies generally with the depth to Pleistocene; the greater the depth to this ancient sedimentary horizon, the greater the thickness of prodelta deposits. The thickness of the prodelta materials along the river in the study area increases progressively downstream. Likewise, the depth to the top of these clays and silty clays increases progressively downstream. Fig. 12 shows the elevation at which the top and the base of the prodelta clays can be expected to occur between New Orleans and 20 miles above Head of Passes. Note that the thickness of the prodelta clay increases from about 40 ft at New Orleans to more than 120 ft at river mile 20. In this lower section of the river a large proportion of the bed and banks of the channel consists of fat, cohesive, prodelta clays as is indicated by the thalweg of the river superimposed in fig. 12.

Fig. 12. Thickness of prodelta clays and the relation of these deposits to river depth south of New Orleans (river mile 95)
79. The predominant soil type associated with the prodelta environment is fat clay (CH). Studies of more than 1000 samples from this environment show it to consist of 96 percent fat clays. A further subdivision, based on an adaption of the Unified Soil Classification System to fine-grained soils (see plate 2), indicates that 79 percent of prodelta deposits consists of the finest of the fat clays, the CH classification. Natural water contents of these materials range from 30 to 90 percent dry weight, and their unit weight ranges from 92 to 118 lb per cu ft. Cohesive strengths of the prodelta clays are relatively high, the characteristic strength being between 200 and 700 lb per sq ft. Cohesive strengths greater than 1000 lb per sq ft are not uncommon and characteristically increase with depth.

Intradelta and interdistributary deposits

80. The location of intradelta materials is largely controlled by the position of the ancient distribution which gradually built the land areas seaward as the distributaries developed and were eventually abandoned. The most important of the intradelta materials are found along the largest of these abandoned distributaries, some of which were eventually occupied by abandoned courses or the present course of the river. Soft interdistributary deposits are found between them. Experience has shown that a certain pattern recurs in the lateral distribution of deposits that aids considerably in interpreting borings. Interdistributary clays interfinger laterally with the coarser intradelta materials. These, in turn, invariably contain a narrow wedge of sediment left by the abandoned distributary which transported the sands and silts of the intradelta deposit to the Gulf. It should be remembered, however, that abandoned distributary deposits are not confined exclusively to narrow ribbons of sediment within the intradelta materials. Crevassing of main channels above ancient abandoned heads-of-passes permitted many distributaries to develop which cut channels into interdistributary clays for considerable distances before they reached open water where they could build and begin to develop a course through their sand-silt intradelta deposits.

81. Where interdistributary clays overlie prodelta clays directly, a distinction based solely on visual examination of samples and the more
elementary engineering characteristics is also sometimes difficult. Among distinguishing features are consistencies, associated soil strengths, and water contents. Consistencies in the interdistributary materials are usually logged as soft or very soft. Consistencies in the prodelta materials are characteristically medium to stiff. Water contents in the interdistributary materials are typically higher and strengths decidedly lower. While prodelta materials are normally consolidated, with strength increasing consistently as depth and pressures increase, interdistributary clays are often underconsolidated. Cohesive strengths at depths as great as 200 ft are sometimes strikingly low, e.g. on the order of 300 lb per sq ft, and although strengths tend to increase with increasing depth, the trend is very erratic and inconsistent. It follows that the older the distributary system with which the interdistributary environment is associated, the more closely the clays approach normal consolidation. The most diagnostic of the criteria that can be used for determining the usually gradational contact between the interdistributary and prodelta environments is the occurrence of marine microfauna and macrofauna in the latter. Although shells are sometimes associated with the interdistributary environment, they are rare and usually restricted to brackish-water types.

**Paludal Environments**

82. The surface distribution of the paludal or swamp and marsh environments which border the river in the study area is shown in plates 3-10. Marshes are flat expanses of grasses and sedges which occupy large areas adjacent to the natural levees, particularly downstream from New Orleans. Swamps are characterized by dense growths of trees and are most common in the lowlands flanking the natural levees in the upstream areas. The distinction between the two environments, it will be noted, is based primarily on vegetation. Distinction between subunits or types of swamp or marsh is also based on vegetation, and since vegetative type is very sensitive to the salinity of the water within which it grows, the names of marsh types mapped in plates 3-10 reflect the fresh, brackish, or saline nature of the surrounding water. There is some question as to the validity of such a classification for engineering soils purposes. However, increase in
salinity is often associated with sedimentation or subsidence phenomena which have a decided effect on depositional characteristics. More data are needed to test the usefulness of this classification for engineering purposes.

83. The origin and physical characteristics of swamp and marsh environments in the deltaic plain of southeast Louisiana are comprehensively treated elsewhere.\textsuperscript{16,33,37,53,55} The discussion which follows summarizes what is known of the general lithologic characteristics of each of the paludal environments mapped in plates 3-10. The generalizations made are based on a number of soil profiles taken in each of the environments described; however, as stated above, much more data should be collected and analyzed before these generalizations are accepted.

**Fresh-water marsh**

84. This type of marsh typically consists of a vegetative mat underlain predominantly by clays and organic clays. It occurs as a band along the landward border of the marshlands and in areas subject to repeated inundation by fresh water. Fresh-water marsh occurs extensively near Head of Passes (plate 10) and the inland areas upstream from New Orleans. Typically, an upper, 1-ft-thick mat of roots and other plant parts grades into a fairly soft organic clay which becomes firmer and less organic with depth. Peat layers are common, but are generally discontinuous. Organic content generally varies from 20 to 50 percent.

**Flotant**

85. Flotant, or floating marsh, occurs close to the right bank of the river near Head of Passes (plate 10) and near Poverty Point (plate 8). It consists of a vegetative mat underlain by watery, organic ooze. The soils sequence of a typical flotant area consists of a 5-in.- to 15-in.-thick mat of roots or other partially decayed vegetative matter with some mixture of finely divided mucky materials, underlain by from 3 to 15 ft of finely divided muck or organic ooze grading to clay with depth. The ooze often consolidates with depth, and grades into a black organic clay or peat layer. Organic content of this type of marsh is typically high, usually greater than 50 percent.

**Fresh-to-brackish-water marsh**

86. This type of marsh, as well as its saline to brackish
counterpart, characteristically borders the natural levees of the river south of New Orleans. A typical soils sequence consists of, first, a 4-in. to 8-in.-thick mat of roots and other vegetative debris together with finely divided mucky materials. This is underlain by 1 to 10 ft of coarse- to medium-textured fibrous peat. This, in turn, is often underlain by a fairly firm, blue-gray clay and silty clay with thick lenses of dark gray clays and silty clays high in organic content. It is estimated that only 10 to 20 percent of fresh- to brackish-water marsh deposits consists of inorganic materials.

Saline- to brackish-water marsh

87. This type of marsh typically consists of a 2-in.- to 8-in.-thick mat of roots, stems, and leaves, underlain by a fairly firm, blue-gray clay with a few roots and plant remains. Tiny organic flakes and particles are disseminated throughout. Clays become less organic and firmer with depth. In contrast to other marsh types, a fairly high percentage of inorganic materials imparts some degree of stability to the material. The silt-fine sand content may range as high as 30 percent. Organic clays make up an average of 50 percent of the deposit, and peat content normally ranges between 15 and 20 percent.

Inland swamp

88. Inland swamps in the study area occur almost exclusively in the tree-covered lowlands adjacent to the natural levees. The last such environment along the Mississippi River occurs just downstream from New Orleans. The presence of logs, stumps, and arboreal root systems in the swamp deposits usually permits their identification. Swamp deposits normally consist of less than 30 percent organic material, which occurs principally in the form of organic and highly organic clays; however, peat and layers of decayed wood are not uncommon. Inorganic content is a reflection of the proximity of the stream that supplies, or once supplied, clays during over-bank flow, and organic content can be expected to increase and inorganic content to decrease with distance from such a stream.

Mangrove swamp

89. Only a few small areas of mangrove swamp have been reported in the study area. Most of these border Quarantine Bay (plate 9). There are
conflicting reports concerning the nature and extent of this mangrove area. Apparently, it is ephemeral in nature, bushy mangrove periodically being replaced by grassy marshland. For this reason mangrove areas in plate 9 are shown with an overprint of saline- to brackish-water marsh. Deposits left by death and decay of the mangrove growth should, however, resemble deposits in mangrove swamps elsewhere in southeast Louisiana. A typical soil sequence in such areas consists of a thin layer of dark gray to black, very soft, organic silty clay covering and forming the matrix for a tangled, interlocking root zone which averages 5 to 12 in. in thickness. Numerous nodular roots project above the surface for a few inches. A thickness of at least 5 ft of organic-rich clays, silts, and sands is typical below this upper layer.

Engineering characteristics

90. Marsh and swamp deposits almost always present problems in foundation engineering. Their high organic content and associated high water content make them very compressible. One of the more striking properties of some marsh deposits is their rapid consolidation immediately upon application of load, such as an embankment. Consolidation and subsidence continue for a long period of time at a gradually decelerating rate. Artificial levees in some areas of south Louisiana, particularly along the East Atchafalaya Floodway, have sunk into the underlying swamp and marsh deposits to such an extent that there is twice as much levee below the surface as there is above.

91. In many instances the marsh at the surface consists of a mat of roots and grasses underlain by materials which afford no support at all. A person breaking through such a mat can sink waist-deep in ooze. Metal probes 15 ft long will often sink out of sight under their own weight once the surficial mat has been penetrated. In excavations in marsh areas, a common tendency is for organic oozes, detrital peats, and soft organic clays to flow laterally into open cuts. Spoil from cuts must be spread over as wide a base and as far as practicable from the excavation where such conditions exist. If highly organic materials, particularly peats, are placed in an embankment, shrinkage is considerable, often as much as two-thirds of their former volume.
92. Marine environments of deposition form only a minor portion of the materials in the bed and banks of the river between Donaldsonville and the Gulf. At least our present knowledge of the distribution of marine deposits in the study area indicates that they are volumetrically unimportant. To date, only the basal nearshore-gulf deposits and an equivalent estuarine horizon, the buried beaches, and the bay-sound environment have been identified in the study area. See reference 53 (pp 71-89) for a discussion of the marine environments of deposition in southeastern Louisiana.

Nearshore-gulf, estuarine, and bay-sound

93. These three environments consist essentially of shell-bearing sandy and silty deposits. The nearshore-gulf deposits form a horizon which may or may not be present on top of the Pleistocene, its formation and preservation apparently having been dictated by the effect of marine erosion as sea level rose and inundated the Pleistocene surface. It is identified in most of the deeper borings in New Orleans and downstream from New Orleans (see sections R through DD, plates 26-37). Thicker, analogous deposits fill the numerous drainageways carved into the Pleistocene prior to inundation. These drainage courses formed gullies or reentrants within which, again depending on the rapidity of rise in sea level, sediments were probably laid down under estuarine conditions. Sediments in section W, plate 30, are interpreted as estuarine deposits from el -100 to -160. The upper 10 to 20 ft of this deposit contains clays and, incidentally, wood that has been dated by Carbon-14 methods as being 10,000 years old, an age agreeing well with current hypotheses concerning the waning glacial rise in sea level. Bay-sound deposits are identified only in the New Orleans area where conditions existed for the formation of a bay or sound behind the large barrier beach that trends through New Orleans (see following paragraphs).

Beaches

94. Buried beaches are an integral part of the mass of Recent sediments forming the deltaic plain. As additional data are collected, numerous environments of this sort will undoubtedly be identified and delineated.
At the present time, however, only two zones of beach development have been identified in the area studied. One such zone occurs between river miles 20 and 30 near Head of Passes. Most of the evidence for its occurrence is derived from surface indications. There is a well-developed series of abandoned beaches in the marsh to the southwest of this area. The trend of these beaches becomes indistinct eastward, the surface indications finally disappearing entirely beneath the wedge of the Mississippi fluvial-marine sediments. Few subsurface data are available to substantiate the location of the major sand ridges in this beach zone. Poorly logged shot-point borings indicate a sandy sequence in this region, and surface probes by Welder 56 have encountered sands identified as part of this beach system.

95. An extensive buried beach in the New Orleans area, on the other hand, has not only been delineated, but enough data are now available to contour the deposit. The contours, shown in fig. 13, are based largely on work by Saucier. The profile is developed from borings made by Palmer and Baker. Note how the abandoned Metairie distributary hugs the southern edges of the buried beach. Obviously, this feature largely controlled the position and development of this distributary. A cursory examination of the considerable amount of grain-size, density, and other information available for borings penetrating this buried beach suggests that the generalizations made concerning deltaic plain beaches on pages 78-83 of reference 53 are essentially true. Further study of the sedimentary features of this beach and its physical and engineering characteristics is beyond the scope of this report, particularly since most of the beach lies beyond the limits of the study area. However, further study of the data available should be rewarding.
Fig. 13. Contours on top of buried beach in New Orleans area in ft msl and the configuration of a portion of this feature in profile.
PART V: SOME EFFECTS OF GEOLOGIC FACTORS ON RIVER MIGRATION

96. Migration of the river in the study area is negligible when compared with that of the river upstream. The narrowness of the river in its lower reaches, its great depth, and its limited lateral movement have been attributed to the great thickness of deltaic plain clays within which it must meander. The control of prodelta and interdistributary clays on river migration is well illustrated in the long, almost meanderfree reach of the river south of New Orleans (river mile 0-78). River migration in this portion of the channel is insignificant. The areal extent of point-bar deposits, which reflects the extent of migration, averages only 25 to 30 acres per river mile.

97. Two additional factors are equally important in assessing the rate of migration of the lower reaches of the river. One is the length of time the channel has been occupied; the other is the existence of tough Pleistocene deposits into which the river must scour its channel. That part of the river between river mile 189 and Bayou La Loutre (mile 82, plate 1) has been an active channel for more than 2500 years, and meanders are well established. The river downstream from mile 82 is considerably younger--on the order of 1000 years old or less--and meanders are only in the early stages of development. Comparison of point-bar volumes between river mile 189 and English Turn (mile 78) illustrates the importance of the Pleistocene in controlling river migration. Between miles 189 and 157, point-bar areas average more than 450 acres per mile. Between miles 157 and 78 the average is about 200 acres per river mile. In the first reach, the river is meandering in backswamp clays and substratum sands; in the second, the river must migrate in durable Pleistocene clays which in some areas reach almost to the surface and form a natural revetment against local migration.

98. Of interest are two bends which interrupt an otherwise almost straight channel between English Turn and Head of Passes (see plates 9 and 10). These bends occur near Fort Jackson where there is evidence that buried sand beaches lie across the path of the river and form bed and banks less resistant to river erosion than the cohesive clays which normally characterize the river in its lower reaches. Migration apparently
initiated at the points where the path of the river crosses the buried beaches, and is concentrated just downstream from these points. Sand picked up at the beaches is deposited short distances downstream causing a bar around which the thread of current migrates. This causes erosion of the bank opposite the bar, and the point-bar area develops laterally and downstream from the particular sand deposit where it was initiated. Careful study of these anomalous bends might shed considerable light on the perplexing and controversial problem of how and why meanders originate.

99. An interesting parallel to this lower portion of the Mississippi River is the Gota River of Sweden. This river has a comparable gradient and is also forming its channel in deep, cohesive clays. Its channel is deep and narrow with widths ranging between 200 and 500 ft and depths between 75 and 50 ft, the greater depths corresponding to the narrower widths. Compare this with a maximum depth on the order of 200 ft and a minimum width of 2500 ft in the lower reaches of the Mississippi. Suspended load in the Gota is almost nil; bed load is confined to inch-thick layers of sand and gravel that sporadically blanket the clay bottom in certain reaches of the river. There is no meandering and no noticeable tendency toward bank widening. Coarse bed load seems to be carried downstream to the delta without any tendency to segregate, to build bars, or to initiate meanders. The stream is thus a natural flume which is gradually being deepened by attrition--by the slow scouring action of coarse bed load particles on the cohesive clays at the bed of the stream.*

100. The Lower Mississippi can be considered as a similar flume, but fine sand is being fed into its upper end at a prodigious rate, both as bed load and as suspended load. The amount of such fine sand can be roughly estimated based on figures by Holle and others. Of the 544 million tons carried yearly in suspension, approximately 7 percent consists of sand. Add an estimated 10 percent of the suspended volume as the amount of sand being carried as bed load, and the total reaches some 90 million tons of sand carried to the Gulf each year by the Mississippi River. This volume corresponds fairly closely to the rate of growth of the sand "fingers" or intradelta deposits associated with the distributaries at Head of Passes.  

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* Personal communication from Dr. Ake Sundborg, Institute of Geography, Uppsala University, Uppsala, Sweden.
Of the 90,000 million tons of sand carried by this lower reach of the river in the past 1000 years, it is estimated that less than 20 million tons of sand remain behind in the point-bar deposits which border it.

101. This small amount of point-bar deposition is striking. Point-bar growth in the central and upper portions of the alluvial valley is sometimes more than 1000 ft per year. Migration of bends between Donaldsonville and the Gulf averages less than 4 ft per year.* From the preceding paragraph, it is obvious that this slow growth is not due to lack of sand. It must be attributed to the interrelated effect of such factors as (a) a distribution of velocities capable of keeping fine sand moving downstream; (b) the nonexistence of slack-water areas capable of permitting such fine sizes to be permanently deposited; and (c) the innate resistance of the cohesive banks along the stream to erosion and migration.

102. Point bars form where the river deviates from a straight course. If the deviation is gentle, velocities are fairly uniform throughout the channel cross section; or, at least, they are sufficient to continue to move fine sand, and bar growth is so slow as to be nearly imperceptible. Sharp deviations from a straight-line path permit more rapid bar growth, and along the lower river are associated with such phenomena as faulting, distributary selection, and the location of a coarse deposit along the path of the stream. Faulting, such as has apparently occurred at the large bend just downstream from New Orleans, can radically influence the direction of the stream, causing it to follow an angular pattern which eventually becomes rounded and sinuous through bank erosion and bar building. However, few faults are known to affect the lower river. Fairly sharp deviations from a straight-line path can also occur where the river, in developing its distributary system, selects a distributary for final occupancy which branches at a considerable angle from the general direction of the main channel. This, again, is an abnormal situation since a large angle of bifurcation from the main channel is one of the primary reasons for the

* Some bends within this reach migrate much more rapidly. The bend at Philadelphia Point (plate 3), for example, has moved an average of 25 ft per year for the past 25 years. Revetting has been very effective in controlling certain active bends (see paragraph 21). Major bends in the New Orleans area were migrating at a rate of as much as 10 ft per year before they were revetted.
river's ultimate abandonment of a distributary. 47,56 A third reason for development of a bend is the occurrence, entrainment, and deposition of relatively coarse materials, such as might exist in a buried beach along the course of the stream.

103. Once the bend is established maximum velocities hug the outside of the bend, and minimum velocities on the inside of the bend are low enough for occasional deposition of fine sand and silt. The point bar grows at a gradually increasing rate as the curvature of the bend increases, and the incidence of low velocities at the bar increases.

104. But, as has been previously stressed, this rate of growth is remarkably slow in the study area. The essentially straight reaches can be expected to remain straight for decades. The sharpest bends, the most upstream bends, and bends opposite or immediately downstream from a bank cutting into easily erodible point-bar deposits can be expected to migrate most rapidly. In the study area, the river is cutting into point-bar deposits principally between river miles 181 and 188 upstream from Donaldsonville (plate 3), and since this is predominantly silty point-bar material, the products of bank erosion contribute little to overall bar building downstream. Where it scours deeply enough to intercept the substratum, the river picks up sand that might, occasionally, be coarse enough to contribute to overall downstream bar building. But even this source is lost downstream from College Point. The sand available for the river to carry in its lower reaches is of such small grain size that nearly all of it is carried almost uninterruptedly to the delta. There is thus no reason to believe that the rate of river migration will change within the next century, or several centuries, from the very slow rate that has characterized the lower river in the past.

105. In summary, migration of the Mississippi River channel between Donaldsonville and Head of Passes has been affected by such factors as (a) length of occupation, (b) the extensive occurrence of clays forming its bed and banks, particularly of Pleistocene clays, (c) the occurrence of bends caused by faulting or formed during seaward growth of the delta, and (d) the occasional occurrence of coarse or easily erodible materials in the path of the stream. Samples of bed material, the material which forms the point-bar areas, and most significant of all, the material
comprising the delta, show that nothing coarser than fine sand is introduced into the lower river channel in any significant quantities. The preponderance of the bed load and suspended load is carried to the delta without contributing to the growth of the point-bar areas. Finally, the rate of migration in the lower river has been and should continue to be very slow.
PART VI: CONCLUSION

106. Plates 3-39 show the distribution of engineering soils which border the Mississippi between river mile 189 and Head of Passes in plan and profile. Interpretations shown on these plates are based on all available boring data, and although many of the details of the disposition of soils units have yet to be learned, the broad outlines have been fairly well confirmed and delineated. An increased knowledge of the sedimentary sequence will result from further analysis of boring data and a better understanding of the geologic history of and the depositional processes active in the deltaic plain. The engineering soil types can be readily and advantageously associated with the environment within which each was deposited. Delineation of environments of deposition permits reasonably accurate estimates of subsurface soil types, typical ranges of many of their physical properties, and their distribution in plan and profile. Conversely, physical properties of soils encountered in boreholes are sufficiently diagnostic so that environments within which they were deposited can usually be determined. This permits reconstruction of buried environments based on fewer and more carefully located borings.

107. Some significant points learned in this investigation are as follows:

a. The Mississippi River flows across a buried "shelf" of shallow Pleistocene deposits between College Point (river mile 157) and English Turn (river mile 78). This shelf is far less dissected than was thought heretofore. The elevation of this horizon between the two points mentioned varies from about 0 to -150.

b. The concept of backswamp deposits underlain by coarse substratum deposits is not applicable in interpreting logs of borings downstream from College Point. Instead, boring information must be interpreted solely in terms of environments characteristic of the deltaic plain.

c. Point-bar deposits form fairly significant wedges of sediment flanking the river as far downstream as New Orleans. Only minor point-bar areas occur between New Orleans and the Gulf. No trend toward a decrease in grain size in a downstream direction was noted in the point-bar deposits. An expected slight increase in grain size with depth was noted. Point-bar deposits consisting almost entirely of silt are found in some areas. The fineness of the deposit,
the position of the deposit with respect to the more characteristic sandy point bar, and the tight curvature of the meander scars left by these deposits suggest that they are older deposits left by a smaller stream than the present Mississippi.

d. The existence of a well-defined buried beach trending through the New Orleans area has been fully confirmed and its extent and thickness mapped. The surface of this feature is contoured in fig. 13.

e. Prodelta clays form a homogeneous wedge of fine-grained sediment encountered at an elevation of -40 in the New Orleans area and at -90 near Head of Passes. The unit thickens from approximately 40 to 140 ft within the same distance.

f. River migration is most noticeable between river miles 189 and 156 where the river is cutting into substratum sands, backswamp clays, and silty point-bar deposits. Migration is less rapid where the river must cut its channel into the Pleistocene deposits between river miles 156 and 78. Migration of bends between Donaldsonville and the Gulf averages less than 2 ft per year. There is no reason to believe that the rate of river migration in the lower river will increase markedly from the very slow rate which has characterized it in the past.
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Unified Soils Classification System

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Consistency for Cohesive Soils

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Detailed Legend for Plans and Sections
DISTRIBUTION OF DEPOSITIONAL TYPES
RIVER MILE 90.0 TO 118.0

NOTE: SEE PLATE 4A OF WES TR NO. 3-483
FOR ADDITIONAL BORING DATA

PLATE 6
Plate 7

Legend:
- Inland Swamp
- Fresh to Brackish Water Marsh
- Point Bar
- Abandoned Course or Distributary

See Plate 2 for complete legend.

Distribution of Depositional Types
River Mile 61.5 to 90.5
Scale in Miles
DISTRIBUTION OF DEPOSITIONAL TYPES
RIVER MILE 22.3 TO 44.0
SCALE IN MILES

PLATE 9
DISTRIBUTION OF DEPOSITIONAL TYPES
RIVER MILE 1.7 TO 24.0

SCALE IN MILES

PLATE 10
NOTE: SEE PLATE 2 FOR COMPLETE LEGEND AND PLATE 3 FOR LOCATION OF SECTION.
NOTE: SEE PLATE 2 FOR COMPLETE LEGEND AND PLATE 3 FOR LOCATION OF SECTION.
BASED ON HARD-RIGGER BORINGS AND ORIGINAL INTERPRETATION MADE BY ROGER SAUCIER, LOUISIANA STATE UNIVERSITY.

NOTE: SEE PLATE 2 FOR COMPLETE LEGEND AND PLATE 4 FOR LOCATION OF SECTION.
NOTE: SEE PLATE 2 FOR COMPLETE LEGEND AND PLATE 8 FOR LOCATION OF SECTION.
NOTE: SEE PLATE 2 FOR COMPLETE LEGEND AND PLATE 7 FOR LOCATION OF SECTION.

SECTION U

PLATE 28