Deltaic Processes in Cubits Gap Area Plaquemines Parish, Louisiana.

Frank A. Welder

*Louisiana State University and Agricultural & Mechanical College*

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A Thesis

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in The Department of Geology

by

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ABSTRACT

About one hundred years ago, the Mississippi River near its mouth broke through the left bank and poured vast quantities of water and sediment into a bay which formed an arm of the Gulf of Mexico. This breakthrough is called Cubits Gap Crevasse. At the time, the shoreline was only a few hundred feet from the river bank. As the bay began to fill with sediment, a network of channels developed in the newly growing land mass. Each channel or pass had to cut its way through these deltaic deposits in order to obtain an avenue by which it could transport more sediment to the retreating Gulf. Where the turbid river water met the Gulf, sediment was deposited as a bar across the mouth of each pass.

The land mass enlarged as each channel grew seaward by eroding the upstream side of its bar and depositing on the downstream or Gulf side. Then, as now, a pass shoaled as the water flowed up and over the bar. Frequently a channel would split at its mouth to form two passes, each of which, in turn, eventually bifurcated again. Some of the passes rejoined to form one channel. The over-all effect was a braided network of channels.

Thus the passes of Cubits Gap have built the shoreline some twelve miles seaward of its original position. At the same time, many of the earlier-formed passes have "silted up" and been abandoned. Others have changed from the wide shallow streams over the bars to deep narrow channels upstream.

Maps made by the Federal Government and aerial photographs
make it easy to illustrate the history of Cubits Gap Area since the early part of the 19th century. Since many of the present channels are no larger than ordinary rivers, it has been possible for the writer to observe and survey certain bar and channel features. Field work has yielded data and observations which, coupled with an exhaustive coverage of geologic and engineering publications, may explain how this part of the delta has evolved.

The writer has also had field experience on other stretches of the Mississippi River, especially near Vicksburg, Mississippi. This has made it possible to make a general comparison between the upper river and the delta.

It is hoped that the principles herein developed can be applied any place where water flows through alluvium of its own deposition.
FOREWORD

This study was made in conjunction with a project conducted by the School of Geology at Louisiana State University under the auspices of the Office of Naval Research, Contract N7 onr 35608, Task Order NR 088 002. The Navy provided aerial photographs which were used freely in mapping, orientation and field interpretation.

The summer of 1951 was spent in a general reconnaissance of the coast of Louisiana. From February to September, 1952, field work was concentrated in Plaquemines Parish, Louisiana. The summer of 1953 was spent in checking specific problems in the region.

Between June 1951 and December 1953, the writer visited the mouth of nearly every distributary of the Mississippi River as well as most of the bayous, bays, lakes, islands and beaches in the region of the lower delta. In Cubits Gap Area, ten days were spent in February 1952, six days in November 1952, six days in January 1953, five days in June 1953 and six days in November 1953. In addition, the writer worked one week in the Batiste Collette area, three weeks in the Jump area and three weeks in the Garden Island Bay area.

Transportation was usually provided by a 14-foot outboard motor boat. A small can nailed to the end of a sounding rod was used in bottom sampling. Channel profiles were made by stretching a calibrated line across the streams and taking rod or lead line readings at the desired horizontal intervals. All sub-surface information was obtained by hand auger.
INTRODUCTION

General

Cubits\(^1\) Gap Crevasse is located near the southeastern end of Plaquemines Parish, Louisiana, on the left bank of the Mississippi River, about three miles upstream from Head of Passes (Plate I). From the crevasse or opening in the river bank emanates a network of channels flowing eastward to the Gulf of Mexico. Through these channels, the river has transported and deposited much of its sedimentary load to form over one hundred miles of land and fresh water lakes, on a site formerly occupied by the Gulf. This sub-delta complex is herein referred to as Cubits Gap Area (Figure 1).

The crevasse today is over 3000 feet wide, and carries, via Main, Octave and Raphael Passes, over 100,000 cubic feet of water per second during flood stage (Figure 2). The latest charts show a maximum depth of over thirty feet in the crevasse.

Geology and Topography

Geologically, the sediments in the area, as well as in the entire parish, can be classified as Recent in age. The mouth of the river was presumably near New Orleans many hundreds of years ago, and has migrated seaward toward the southeast nearly one hundred miles. In so doing, it has left behind old deposits which form the two zones of land and marsh on either side of the river from New Orleans to the mouths of the passes.

\(^1\)The word is also spelled Cubitt on some maps.
Figure 1. The lower delta of the Mississippi River. Cubits Gap Area is outlined by red dashes. Scale: 1" to 16,000'. (Courtesy Edgar Tobin Aerial Surveys).
Figure 2. Cubits Cap Crevasse showing Main, Octave, Brant and Raphael Passes (left to right). Note the abandoned channels. The Mississippi River, in the foreground, flows from left to right. Most of Pilottown, Louisiana, is shown in the right foreground.
Only a small portion of Plaquemines Parish is sufficiently high above sea level for habitation or cultivation. These tracts are confined to the banks of present and past river channels. Here natural levees have been formed above the surrounding lowland by deposition of sediment from flood overflow water. The elevation of a natural levee is determined by the maximum elevation to which the river can rise during flood stage. Under natural conditions, the levee elevations would range from about 17 feet at New Orleans to sea level at the mouths of the passes.

The construction of artificial levees or dikes along each side of the river, from about Venice, Louisiana, upstream (see Plate I), has made bank overflow and, hence, natural levee growth, impossible. Today sediment is being deposited only downstream from the distal ends of the artificial levees.

As a rule, most of the trees in the parish grow on natural levees, since this is the only place where ground water level is not at, or within a few inches of, the surface. The adjacent lowlands consist of either lakes and ponds, or marsh, which are each year becoming more brackish as the region subsides in respect to sea level. This is strongly reflected in the changing edaphic conditions.

Subsidence

Near New Orleans, the effects of subsidence of the land are relatively imperceptible, but downstream the rate of sinking increases rapidly. Corthell (quoted by Le Baron, 1905) observed that an old brick building in the lower delta was subsiding at a rate of 0.05 feet per year. Shaw (1913, p. 17) says the rate is 0.1 feet per year at the mouth of South Pass; Dent (1921, 13/11) says 0.3 inches per year. In the summer of 1952, the writer visited the site of a cemetery of the old pilot town of Balize on the left
bank of Balize Bayou, a distributary of Southeast Pass. What had been the site of firm habitable land was then a soft cane marsh through which protruded several tombstones, one of which was dated 1858. Probing showed a firm surface about four and a half feet below sea level. Assuming the levee elevation was only at marsh level in 1858, this would indicate a rate of subsidence of at least 0.04 feet per year.

**River Statistics**

Since all topographic features in the region originate through and are directly related to the Mississippi, some facts about the river should be considered. Immediately upstream from Cubits Gap Crevasse, the river is nearly 4000 feet wide and attains depths exceeding fifty feet.

To some extent, the river is in flood for about nine months of the year. On the average, it begins to rise in late November, reaches a crest in April, and recedes to low water by late August (Figure 3).

Holle (1952, p. 119) gives the following discharge figures:

"At mean low water, about 3 feet above mean sea level on the Carrollton Avenue gage, the discharge at New Orleans, 103 miles above the Head of Passes, is about 300,000 cubic feet per second. At normal stages, about 9 feet above MSL on the Carrollton gage, the discharge is about 600,000 c.f.s. At flood stage, about 17 feet above MSL on the Carrollton gage, the discharge is about 1,000,000 c.f.s."

The gage at the Head of Passes reads over 5 feet above MSL at flood stage and near zero at low water.

A comparison of the above figures shows that, in flood stage, the water surface slopes from an elevation of 17 feet at New Orleans to 5 feet at Head of Passes, a distance of 103 miles. The hydraulic gradient is 0.11 feet per mile.

At Head of Passes, the river trifurcates into the three principle passes, which flow to the Gulf of Mexico. The largest, Pass a Loutre,
STAGE HYDROGRAPH
CARROLLTON GAUGE, NEW ORLEANS
AVERAGE HYDROGRAPH FOR PERIOD 1901-1929

DATA FROM U.S. ARMY ENGINEERS

Figure 3.
is 15 miles long and flows eastward, splitting into several smaller passes. Southwest Pass is 21 miles long and flows southwestward. The smallest, South Pass, is 14 miles long and flows southeastward. The maximum recorded discharges in c.f.s. for these passes during the 1950 flood were 410,000; 354,000; and 166,000 respectively. Of the total discharge of the river, Pass a Loutre carries about 37 percent, Southwest Pass about 29 percent, and South Pass about 15 percent. The remaining 19 percent is carried through Cubits Gap and other outlets (Holle, 1952).

Current velocities in the passes may exceed 6 feet per second (Waterways Experiment Station, 1939A).

When discharge is low, dense salt water from the Gulf enters the mouths of South and Southwest Passes, which have been artificially deepened for navigation. The salt water moves upstream in the form of a wedge below the lighter river water. If river stage remains below 3 feet on the Carrollton gage for an appreciable length of time, the wedge will move up the river beyond New Orleans (Holle, 1952, p. 119). The shallow bars at the mouths of the other passes prevent the intrusion of salt water except during times of high wind.

Off the mouths of the major passes, littoral currents flow mostly from east to west at velocities up to one foot per second.

Tides

At Head of Passes, the maximum lunar tide effect is about one foot, and at the ends of the passes it is 2-4 inches more. Even at New Orleans, about two inches of tidal effect manifests itself. Similarly, the lakes, ponds and bayous of the marshes are exposed to tides, the effect decreasing with distance from the Gulf. High tide occurs only once a day.

Stronger than lunar tides are water level fluctuations caused by
wind. Persistent winds cause a "piling up" of the water where confined, and a lowering of water level when not confined. At the mouth of a pass, strong Gulfward wind can expose newly-formed levees at low river stage (Figure 4). The prevailing wind is from the southeast.

Climate

The climate in Plaquemines Parish may be described as subtropical and is determined by the latitude and proximity to the warm water of the Gulf of Mexico. The northern Gulf waters have an average temperature of 64° F. in February and 84° F. in August. At Burrwood, near the mouth of Southwest Pass, the average annual temperature is 70.8° F. The average annual precipitation is 59 inches. Killing frosts, which are exceedingly rare, seldom occur after January. From December to May, the river water sustains a temperature of about 47° F., which is usually colder than the air temperature. Thick river fogs thus arise, particularly when southerly winds prevail, and cause a menace to navigation.
Figure 4. Newly-formed levees exposed at the mouth of a small pass. The breaker zone can be seen in the background as a thin white line. (November 22, 1952).
HISTORY OF THE AREA

Origin

Sometime in the early 1860's, the Mississippi River broke through its left bank and began to introduce great volumes of water and sediment into Bay Rondo, an arm of the Gulf of Mexico. Exactly how and when this came about is somewhat problematical. Mitchell (1883, p. 2304) states that it "originated during the late war from a cut made by the Navy through the bulkhead of a fisherman's canal to provide a boat passage to oyster". Ockerson (1877, p. 34) merely says it formed in 1862. This date is also used by Patterson (1877, p. 43), who describes the cut as a boat passage through a strip of marsh not over 400 feet wide, that separated the river from the bay. Local residents of Pilottown agree that the crevasse began from a ditch dug through the levee by the daughters of Cubit. During low river stage, the women stretched their nets across the ditch to catch catfish coming out of the river. The following flood probably scoured the ditch to crevasse proportions.

The approximate hydrography of Bay Rondo prior to the crevasse must be taken from Capt. Talcott's map of 1838 (Plate II, Figure 1), which appears to be the only one available prior to 1862. The one-fathom line was then about a mile from the river, the two-fathom line about four miles, and the four-fathom line about seven miles. Longshore currents must have carried some sediment from the mouth of Pass a Loutre into the bay, where wave reworking formed the reefs near Robinson Point.

When the crevasse was first developing, the river in flood stage
stood about three feet higher than Gulf level and was separated from this body of water by about 1000 feet of levee and marsh. From this, Gillmore (1882, p. 2728) computes the initial gradient as being fifteen feet per mile. The gradient of the river at flood stage was then about 0.1 feet per mile. Current velocities in the crevasse must have been very high, causing tremendous turbulence and accompanying erosion and slumping. By 1868, the Gap was 2427 feet wide and in 1875 had increased to 2746 feet with a maximum depth of 132 feet (Mitchell, 1883, p. 2302).

Subsequent changes in the crevasse are shown on Table 1. The Gap continued to widen until 1898 or thereabouts and became stable. As the Gap grew in width, it also shoaled. Apparently it reached a maximum depth of over 130 feet in 1875, after which it began to fill. The present recorded maximum depth on hydrographic charts is about 33 feet.

There were no discharge measurements available before 1898, and the one made in that year is thought to be inaccurate. Later measurements show no definite trend toward a diminution or increase of flow through the crevasse. It should be pointed out that in 1915, the crevasse carried 12.5 percent of total river flow (Schultz, 1915, p. 2581), and in 1952, it carried 12.4 percent.

**Bar and Channel Development**

While the crevasse was rapidly growing in width and depth at the expense of the river bank, the water flowing into Bay Rondo was carrying a heavy sediment load. As it encountered the quiet bay, the turbid water spread concentrically away from the Gap. Current velocity was checked, and the sediment was deposited as a large bar about the Gap. The distance from the deep, confined crevasse channel downstream to the widespread shoal was only a matter of a few hundred feet (Patterson, 1875, p. 45).
<table>
<thead>
<tr>
<th>YEAR</th>
<th>MAXIMUM DISCHARGE SEC.-FT.</th>
<th>WIDTH OF CREVASSE</th>
<th>MAXIMUM DEPTH</th>
<th>PERCENT OF TOTAL RIVER DISCHARGE</th>
<th>REFERENCE</th>
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<tr>
<td>1868</td>
<td>2427 FT.</td>
<td></td>
<td></td>
<td></td>
<td>MITCHELL (884)</td>
</tr>
<tr>
<td>1875</td>
<td>2746 FT.</td>
<td>132 FT.</td>
<td></td>
<td></td>
<td>MITCHELL (884)</td>
</tr>
<tr>
<td>1876</td>
<td>120 FT.</td>
<td></td>
<td></td>
<td></td>
<td>MITCHELL (884)</td>
</tr>
<tr>
<td>1877</td>
<td>OVER 3000 FT.</td>
<td>130 FT.</td>
<td></td>
<td></td>
<td>PATTERSON (877)</td>
</tr>
<tr>
<td>1893</td>
<td>ABOUT 3100 FT.</td>
<td>73 FT.</td>
<td></td>
<td>HYDROGRAPHIC CHART MISS. RIVER COMM.</td>
<td></td>
</tr>
<tr>
<td>1898</td>
<td>156,000</td>
<td>3240 FT.</td>
<td>72 FT.</td>
<td>MISS. RIVER COMM. (1925)</td>
<td></td>
</tr>
<tr>
<td>1915</td>
<td>63,490(3)</td>
<td></td>
<td>12.5</td>
<td>SCHULTZ (1915)</td>
<td></td>
</tr>
<tr>
<td>1922</td>
<td>137,000</td>
<td></td>
<td></td>
<td>MISS. RIVER COMM. (1925)</td>
<td></td>
</tr>
<tr>
<td>1943</td>
<td>130,380</td>
<td></td>
<td></td>
<td>MISS. RIVER COMM. (1943)</td>
<td></td>
</tr>
<tr>
<td>1947</td>
<td>110,780</td>
<td></td>
<td></td>
<td>MISS. RIVER COMM. (1947)</td>
<td></td>
</tr>
<tr>
<td>1952</td>
<td>125,030</td>
<td>3100 FT.(2)</td>
<td>33 FT.(3)</td>
<td>12.4 PERSONAL COMMUNICATION MISS. RIVER COMM.</td>
<td></td>
</tr>
</tbody>
</table>

(1) AVERAGE DISCHARGE.
(2) MEASURED FROM AERIAL PHOTOGRAPHS.
(3) HYDROGRAPHIC CHART, MISS. RIVER COMM.

**TABLE I**

CUBITS GAP CREVASSE RIVER STATISTICS, 1868-1952
As the bar grew vertically in the slack water zone, it became an obstruction to flow, the current being forced to cut channels through it in order to maintain discharge. By 1870, several channels were defined (Plate II, Figure 2). All were shallow and wide. At the mouths of these passes, sediment deposition continued, and each channel, in extending seaward, was constantly cutting through the ever-growing bar.

The 1877 chart (Plate II, Figure 3) shows Main Pass as the dominant channel, its bar extending much farther seaward than the others. Depths in all the passes were still very shallow. As they grew in length, the passes began to narrow and deepen in the upper reaches, while at the mouths, the channels flared or "belled" as the water was forced to flow up and over the bar. Every distributary of the Mississippi River does this, the channel being several times wider at the mouth than upstream.

The depth over the bar appears to be roughly proportional to the size of the distributary. The passes of Cubits Gap have bar depths of about two feet during flood stage, with the exception of Main Pass which is about four and a half feet deep on its bar.

With seaward growth, a pass undergoes another important change. Sooner or later it reaches a point where it can no longer cut through the bar, and splits into two new channels which may or may not be of equal size (Figure 5). After bifurcating, the two new passes continue the seaward migration, each building its own bar and cutting through it, exactly as the main channel had done, and eventually bifurcating again. With continued bifurcation in a crevasse network, one channel will begin to converge upon another as the two grow seaward. If the timing is right, they will arrive at some point simultaneously and merge into one channel. If, on the other hand, a pass encroaches upon the upstream limits of another, it
Figure 5. Mouth of Dead Woman Pass at extreme low stage.
The small distributary on the right will stay open only a short time.
Vegetation is beginning to grow on the right levee. (November 22, 1952).
cannot cut through the natural levee of the latter and is deflected. The map of 1900 (Plate II, Figure 4) shows Raphael Pass encroaching upon the left bank of Pass a Loutre and being turned northeastward, since it had no chance of scouring a channel through the levee.

As passes diverge away from a point of bifurcation and move seaward, there is left between the two channels an area into which overflow waters carry less and less sediment. This is to be expected because floodwater, which tops the channel banks, leaves not only the bulk of its load but also the coarsest-grained sediment on the natural levees. The comparatively small amount of sediment carried into the inter-levee area is very fine-grained. Generally, such areas are enclosed by rejoining channels (see Figure 6) and cut off from the sea to become sites of fresh water lakes or marsh.

By these processes of channel extension, bifurcation and rejoining, Cubits Gap Area enlarged. By 1900, the passes were about eight miles long and advancing into the Gulf at a rate of about 0.15 miles per year (Figures 7 and 8). Twenty years later, the lengths had increased to 10 miles, but the rate of advance had diminished to approximately 0.05 miles per year. At present, the average length is slightly over eleven miles. Although there has been no appreciable change in the amount of discharge through the Gap since 1900, the rate of extension of the passes has steadily declined from an early rate of nearly 0.3 miles per year to the present rate of about 0.02 miles per year. This is due to the expanding delta front and the increasingly deeper water into which the passes are transgressing. To move a unit distance horizontally, each pass must now fill a greater volume with sediment. In addition, longshore currents in the deeper water probably tend to carry away more of the finer bar material.
Figure 6. An inter-levee lake nearly isolated by the advancing passes. A narrow passageway connects it with the Gulf.
FIG. 7 CHANGES IN LENGTHS OF MAIN AND OCTAVE PASSES
FIG. 8 CHANGES IN RATES OF EXTENSION OF MAIN AND OCTAVE PASSES
The Major Passes of Cubits Gap

Of the many channels that formed in the early history of the crevasse, only three are now extant. They carry all the water and sediment discharged through the crevasse and bifurcate downstream to form a network of smaller channels. Where they leave the Gap, the channels are confined by natural levees which rise about four and a half feet above mean low water. Downstream, the levee heights decrease and at the mouths of the passes become zero. Willow trees grow on most of the levees but become scarce downstream and disappear within a few miles of the Gulf.

The three channels are Main, Octave, and Raphael Passes.

Main Pass

From the beginning, Main Pass has carried the greatest discharge of the Gap. The 1870 map (Plate II, Figure 2) shows it being far wider than any of the other passes. According to the survey of 1876 (Mitchell, 1884, p. 2303) the pass, near its head, was 2943 feet wide and had an average current velocity of 1.7 feet per second.

During the high flood stage of 1922 when the Gap was discharging 137,000 c.f.s., Main Pass carried 72,300 c.f.s. or 52.7 percent. Its width was then 1496 feet, its mean depth 13 feet, and its mean current velocity 3.72 feet per second (Mississippi River Commission, 1925).

The 1952 maximum discharge through Main Pass was 74,900 c.f.s., 7.4 percent of total river flow and nearly 60 percent of Cubits Gap flow. The average width was about 1200 feet with depths ranging from 15 to 20 feet.

Main Pass is the only major channel which has not developed long-lived distributaries of appreciable size (Plate II, Figure 5). Two small channels, one at Mile 4.5 and the other at Mile 7 (downstream from the
crevasse), flow off the left bank carrying a small fraction of Main Pass discharge. Down to Mile 8, no distributaries have of late flowed off the right bank. Here Wiltz Bayou was open until about ten years ago but has since silted up at its head and carries no flow (Figure 9).

With seaward growth, Main Pass has tended to develop larger distributaries. At Mile 8.5, Mile 9, and Mile 10, large distributaries flow off the right bank as the main channel veers northward. At about Mile 10.5 the channel again bifurcates, the right branch apparently being the largest ever developed off Main Pass. It appears to carry about thirty percent of the discharge and is over 1000 feet wide at its head. About a mile downstream, it shoals and splits into two smaller channels.

Main Pass is now about 11.5 miles long and flows in a north-easterly direction for nearly nine miles and then turns northward. The last two miles trend slightly west of north.

Octave Pass

Both Brant Bayou and Octave Pass carry discharge directly from the Gap, but about three miles downstream they merge and retain the name Octave (Plate III). According to the 1922 discharge figures, Octave carried a maximum of 22,600 c.f.s., 16.5 percent of total flow through the Gap. The mean depth was 14.8 feet, the width 447 feet. Brant then discharged 26,800 c.f.s. or 19.6 percent of total Gap flow. Its mean depth was 12.3 feet, the width 693 feet.

The 1951 measurements were quite similar to the 1922 figures. Octave carried 16,700 c.f.s. or 13.6 percent of total flow and was 435 feet wide. Brant carried 28,400 c.f.s. or 23 percent of the total and

1The word is often spelled Octaves.
Figure 9. Wiltz Bayou, an abandoned distributary of Main Pass. Flow in Main Pass is from left to right. (November 22, 1952).
was 700 feet wide. Apparently, the two channels have changed very little in size and relationship to each other.

Below the junction of Octave and Brant at about Mile 4, the pass bifurcates. The right channel takes the name Twenty-Seven Pass and a mile farther splits and gives rise to Flatboat Pass which re-divides into several lesser channels, all of which have been abandoned. Robinson Pass (see Figure 10) was open until 1936 and Blue Wing Pass until 1932 (Plate III). Robinson formerly flowed into Raphael Pass, the junction being still visible. Flatboat averages about seventy feet in width and is about twelve feet deep.

Twenty-Seven Pass, below its fork with Flatboat, again bifurcates, but this time the smaller right fork retains the name. A bar is building across the head of this smaller channel, and its width seems to be diminishing. It is now about 11 feet deep during flood stage.

Dead Woman Pass, the left fork of Twenty-Seven Pass, has a deep channel (20 feet in places) and receives additional discharge downstream from Octave Pass via two feeders, Buoy and Japan Passes. Near its mouth, it gives rise to a small channel off its right bank which shows little promise of remaining open for long.

At the Octave-Scarabin fork, a bar is forming across the head of the latter. Downstream, Scarabin re-divides, the right channel being Japan (Figure 11). The left branch, which is closing up, retains the name Scarabin and continues to the Gulf without further bifurcations.

Downstream, Octave Pass gives rise to Gasper, Bienvenue and Contrariety Passes. The lower end of Octave was abandoned around 1943 (Plate III).

**Raphael Pass**

During the early years of the crevasse, Raphael Pass was extremely
Figure 10. Robinson Pass, an abandoned distributary which formerly flowed off the right bank of Flatboat Pass. Flow in the latter is from right to left. (November 22, 1952).
Figure 11. Fork showing Japan Pass flowing toward the lower left hand corner. Scarabin flows from left to right. The vegetative zone along the left bank of Scarabin is an environment of rapid sedimentation. Octave Pass can be seen in the background. (April 10, 1954).
wide and shallow, its banks poorly defined. Mitchell (1884) shows it as being 5600 feet wide, shoaling in the middle to one foot, and having a mean depth of 5.5 feet. In 1922, it was 631 feet wide, had a mean depth of 10 feet, and a maximum discharge of 15,300 c.f.s., 11.2 percent of the flow through the Gap. By 1942, its width had diminished to 371 feet with a mean depth of only 8 feet. The maximum discharge was 7289 c.f.s., 6.8 percent of Gap flow.

The size and discharge capacity of the channel has diminished considerably in the last quarter of a century. At its head, floating logs accumulate on a shoal which is growing across the channel and obstructing flow. Navigation into the pass from the Gap should not be attempted at low river stage by boats drawing over three feet of water.

Below Mile 3.5, Raphael narrows and deepens and at Mile 4.7 gives rise to Joe Brown Pass on its left bank. This pass is only 60 feet wide and has a maximum depth of 7 feet at low river stage (Figure 12). About three and one half miles downstream, it rejoins Raphael and a few hundred yards farther, the relict channel of old Robinson Pass, still partially open here, also rejoins Raphael.

Several minor channels emanate from Raphael near its mouth, but none seems capable of attaining any degree of permanency.
Figure 12. Left bank of Joe Brown Pass looking downstream. The levee is about three feet above the water level at this low stage of the river. (November 28, 1952).
SEDIMENT AVAILABLE

Type of Sediment

The lower delta region is essentially an environment of fine-grained sediments. Holle (1951, p. 123) considers a typical sample of suspended load to consist of 2 percent very fine sand, 48 percent silt, and 50 percent clay. He has also estimated that bed load may be as high as 25 percent of the total transported load. As yet, there is no way of verifying this figure, although studies of channel bed and bar samples are very informative as to the grain size of the coarser transported sediment.

Cumulative grain size curves taken from sample analyses of the Waterways Experiment Station (1935) indicate the type of sediment found on the bottoms of the major passes. Samples from the bottom of Southwest Pass show essentially two grain size groups (Figure 13). The first, which for convenience of discussion will be called Group A, consists of poorly sorted clay and silt. The second, Group B, is a fine, well-sorted sand. In South Pass, bottom sample analyses show an almost identical arrangement of the two groups (Figure 14).

The apparent consistency with which these two sediment types occur seems to indicate that there are two environments on the floors of the channels. Sand waves have been observed and measured on the bottom of the river at Vicksburg, Mississippi (Lane, 1940). The presence of such features in the lower delta may account for the occurrence of sediment Group A, as the fine material in the troughs of the waves, while Group B
BOTTOM SEDIMENTS

SOUTHWEST PASS MILE 1069 TO MILE 1090
GRAIN SIZE ANALYSES

Figure 13. DATA FROM ARMY ENGINEERS
BOTTOM SEDIMENTS

SOUTH PASS MILE 1070 TO MILE 1085
GRAIN SIZE ANALYSES

DATA FROM ARMY ENGINEERS

Figure 14.
would represent the coarser sediments found on the crests of the waves. In sounding with a rod at certain localities in Cubits Gap Area, the writer felt what seemed to be sand waves with amplitudes of about one foot.

This division of the bottom sediments into two groups is also well reflected in samples taken from the heads of the passes in Cubits Gap (Figure 15). Grain size and sorting appear virtually identical to that of the sample of South and Southwest Passes.

Perhaps the most interesting sediment analyses come from the barrier beach developing between the mouths of Northeast and Southeast Passes (see Plate I for location). This area is probably exposed to more wave reworking than any other sediment environment in the lower delta. Yet the nine samples fall precisely into the sorting and size range characteristic of Group B of the other localities (Figure 16).

From these analyses, two conclusions may be drawn: (1) Group B represents the coarsest and best sorted sediments in the lower delta; (2) this sorting is accomplished both by river currents acting on the channel beds and by sea waves reworking bar deposits.

As shown by Figure 15, the type of sediment entering Cubits Gap Crevasse is much like that found in the larger passes. Just how much of the coarser sediment eventually reaches the mouths of the passes of Cubits Gap is conjectural. The Army Engineers around 1907 constructed a sill in two parts, one of which extended across Main and Octave Passes, the other extending across Brant Bayou and Raphael Pass (Ruffner, 1908). This sill consisted of a willow mattress 100 feet wide held down by rocks. Today the minimum navigation depth over the sill in Main Pass is well over ten feet. There is no evidence as yet that this sill had any effect on sedimentation at the lower ends of the passes.
BOTTOM SAMPLES

VICINITY OF HEADS OF CUBITS GAP PASSES

GRAN Size ANALYSES

Figure 15. DATA FROM ARMY ENGINEERS
BEACH SEDIMENTS
COMPOSITE OF NINE SAMPLES
BARRIER BEACH NEAR NORTHEAST PASS
GRAIN SIZE ANALYSES

Figure 16.
DATA FROM ARMY ENGINEERS
Obviously, the passes have continued to build seaward since 1907 (Figure 7). Although the rate of advance has gradually decreased (see Figure 8), there is no reason to associate it with construction of the sill.

In November, 1953, the writer visited the mouth of Bienvenue Pass to study the sediments of the bar (Plate II, Figure 5). The river and Gulf were unusually low at the time, leaving much of the normally submerged bar and levees exposed (Figure 17). The pass had recently begun to bifurcate, and the two newly-formed channels were cutting through the bar. Between them, near the point of bifurcation, sedimentation had built up that portion of the bar referred to as the middle ground. The shape of the middle ground resembles the Greek letter delta.

Samples taken in the area were located by an alidade and plane table survey (Figure 18). Results of grain size analyses are shown on the cumulative curves which employ the same sample numbers of the survey map (Figure 19). Samples 1, 2, and 3 are shown as Curve A and indicate that the bar material consists of 3-15 percent fine sand, 70-85 percent silt, and the rest clay.

Bar Sample 4 (Curve B on Figure 19) was taken at the site of Sample 3, but only the top 0.3 foot was scraped off the bottom. It is indicative of the fine-grained, partially colloidal material which collects during low stage when the bar becomes a brackish environment. Most of this fine-grained material is flushed out by the next flood, but thin films of it may remain. On the normally submerged natural levees, the sediments consist of layers of slightly argillaceous silt about an inch thick alternating with comparatively darker layers of silty clay about an eighth of an inch thick. The alternation probably represents the two salinity
Figure 17: Mouth of Bienvenue Pass during extreme low river stage. The pass is bifurcating into two near-equal sized channels. Vegetation is growing on the levees far enough upstream to be exposed most of the time. (November 22, 1952).
CONTOUR MAP OF BAR & MIDDLE GROUND
MOUTH OF BIENVENUE PASS
SURVEYED NOV. 29, 1953

Figure 18.
BAR SEDIMENTS
GRAIN SIZE ANALYSES

A. COMPOSITE OF:
1. MIDDLE GROUND SAMPLE NO. 1, 0.0-1.0 FT.
2. BAR SAMPLE NO. 2, 0.0-1.5 FT., WATER DEPTH: 1.0 FT.
3. BAR SAMPLE NO. 3, 0.3-1.0 FT., WATER DEPTH: 4.0 FT.

B. BAR SAMPLE NO. 4, 0.0-0.3 FT., WATER DEPTH: 4.0 FT.

C. BAR SAMPLE NO. 5, 0.0-1.0 FT., WATER DEPTH: 1.5 FT.

Figure 19.
environments, fresh and turbid during flood stage, brackish and fairly clear during low stage.

Sample 5 (Curve C of Figure 17) was taken at the outer edge of the bar just before it begins the steep slope seaward (Figure 18). A slight wind from east-southeast was creating waves which broke just inside the 2-foot depth line. In this breaker zone, the bar deposits were unusually hard and firm, much like those found on the barrier beach between Northeast and Southeast Passes (Figure 16). In contrast, walking on the middle ground and on the bar immediately south and east was accomplished with difficulty. Sorting of coarse sediment was taking place in the breaker zone, the finer grained material being carried into deeper water. Curve C (Figure 19) shows the material to consist of about 50 percent fine sand with very little clay-size material.

One sample cannot be taken as conclusive but certainly indicates that sand is carried to the mouths of Cubits Gap Passes.

Quantity of Sediment

Since the large-scale river study by Humphreys and Abbott (1861), many estimates have been made as to the amount of material transported by the Mississippi through the passes. Russell (1936, p. 162), after reviewing the results of many such studies, opines that a figure of 2,000,000 tons per day, on the average, might be a conservative estimate. Holle (1952, p. 123) uses, as a working basis, an annual sediment load of 500 million tons annually.

If the annual average discharge through Cubits Gap Crevasse be assumed as 10 percent of total river flow, it may be reasonable to assume that 10 percent of the sediment load of the river is carried through the crevasse. Then, using Russell's estimate, the amount of sediment carried
annually into Cubits Gap Area would be about 73,000,000 tons. Using Holle's figures, it would be about 50,000,000 tons.

By superimposing a 1952 topographic map on Capt. Talcott's hydrographic survey of 1838 (Plate II, Figure 1), it was possible to make a crude isopachous map showing the quantity of sediment deposited in Cubits Gap Area since the crevasse formed (Plate IV). No allowance was made for subsidence of the area after 1838 nor for compaction of the sediments deposited since 1862. Certain trends, however, do stand out. The natural levees have been the sites of greater deposition than have the inter-levee low areas. In addition, the passes in building seaward have developed bars which have progressively thickened, as outlined by the 32-foot isopachous line. The area of thickest sediments lies at the mouths of the passes and moves seaward with them. It is unfortunate that the zone of maximum subsidence could not also have been determined.

From the information on the isopachous map, calculations show that approximately 1,200,000,000 cubic yards of sediment have been deposited since 1862. Using a conversion factor of 1.5 tons per cubic yard, yields a total of 1,800,000,000 tons of sediment. Over a ninety year period (1862-1952), the rate would be 20,000,000 tons annually. This is less than one half of either estimate given by Russell or Holle. The discrepancy arises from several factors: (1) no allowance was made for subsidence which may be as much as ten feet per century; (2) no allowance was made for the fine clays which may have been carried out of the area; and (3) the map itself does not cover the entire area in which sedimentation has occurred.
SEDIMENTARY AND HYDRAULIC PRINCIPLES

Although this discussion makes little attempt at a mathematical approach to fluid hydraulics, several basic definitions should be introduced. The Waterways Experiment Station (1939, p. 2) clearly defines three basic terms which should be thoroughly understood:

*Sedimentary load.* All solid materials transported by the flowing water. (Dissolved and colloidal materials are not included in this conception of the sedimentary load.)

*Suspended load.* That portion of the sedimentary load which is not in frequent contact with the river bed.

*Bed-load.* That portion of the sedimentary load which is in frequent contact (by sliding, rolling, or saltation action) with the river bed.

In addition, the term hydraulic gradient is used in referring to the slope of the water surface. The term hydraulic radius is used as Leopold (1953) defines it, "the cross-sectional area of flowing water divided by the length of the wetted perimeter."

The hydraulic conceptions presented deal with a stream flowing in material of its own deposition. Such a stream flows in reaction to the acceleration due to gravity. The maximum speed of flow is limited by the frictional resistance offered by the bed in which the stream flows. As Eads (1882, p. 2769) says, there is an "intimate relation between the quantity of sediment carried in the water and the velocity of the current. If we increase or decrease the current from any cause, we increase or decrease the quantity of sediment carried by the river."

The total energy or power of a stream, as represented by its
ability to transport and scour, is directly proportional to the shear stress exerted by the flowing water on the bed of the channel. This shear stress, or flow friction, sets up eddies which are responsible for holding sediment in suspension. Using the formula from Leighly (1932, p. 2), the stress is defined by

\[ F = mgJ \]

where \( J \) is the hydraulic slope of the stream, \( m \) is the mass of a prism of water effecting a given unit area of the stream bed, \( g \) is the acceleration due to gravity, and \( F \) is the shear stress exerted on the unit area of the stream bed. The material forming the surface of the stream bed is in a condition of stress close to the maximum that it can stand without movement. If the force \( F \) be increased, part of the stream bed must go into motion to restore equilibrium. Likewise, a decrease in stream energy must cause some of the transported load to be deposited. Thus, the stream, under a given set of conditions, tries to adjust its channel shape to attain a maximum mean current velocity and a minimum resistance to flow.

Therefore, the most efficient channel form must have a maximum cross-sectional area and a minimum wetted perimeter. It can be shown mathematically that a channel with rectangular cross-section will have the ideal form when its width is twice the depth. Even more efficient will be the channel of semi-circular shape having the same width-depth ratio. This geometric shape probably constitutes, or very nearly approaches, the optimum form that could theoretically exist. Actually, the most efficient channel form that can be attained in nature is governed by the type of material composing the channel bed and by the energy of the stream.

If, in a given cross-section of a stream channel, lines could be drawn connecting the points of equal current velocities, the position of the
lines would outline a zone of maximum current velocity. A broad, shallow channel would, of necessity, have this high velocity zone near the bottom. This condition would generate strong eddies of turbulence acting on the stream bed. The energy from the eddies would be directed either toward scouring of the bed or toward the transportation of bed-load. If sufficient bed-load were available, there would be no appreciable or consistent scour nor lowering of the level of the stream bed. Instead, stream energy would be used up in the transportation of bed-load. Friedkin (1945, p. 14) says, "The only reason why an alluvial river with an erodible bed does not deepen its channel is that sufficient sand enters the channel to use up its sand-moving capacity."

If, however, little bed-load were available and eroded material from the stream bed could be carried as suspended load, stream energy could be directed at scouring and deepening the channel. The amount of suspended load would increase although, according to Wright (1936), fluid viscosity would thereby increase also. This would reduce turbulence to some extent.

As the bed of the channel was lowered, the zone of maximum velocity would descend, though not as fast as the bed. The distance of the maximum velocity zone from the bottom would increase. Thus the shear stress exerted on the bottom would diminish with increased depth. Some of the material formerly carried as suspended load would now be transported as bed-load. As the channel became deeper, the coarser material would drop out of suspension and be added to the bed-load. This would set a limit to the power of the stream to deepen itself.

Simultaneously as the channel deepened, its form ratio would approach the optimum, and its efficiency would increase. The channel would be able to discharge the same amount of water through a smaller cross-
sectional area. Therefore, if discharge remained the same, some of the original cross-sectional area would no longer be needed. Slack water zones would develop adjacent to each bank as the channel grew deeper. In these zones sediment would be deposited and the channel would narrow as it deepened.

While the channel grew deeper and narrower in approaching the ideal form, the transverse slopes of the banks would increase. Beyond a critical point, depending on the strength of the material composing them, the banks would begin to cave. This would introduce more material to be transported. Energy formerly applied to deepening the channel would then have to be directed toward carrying the new material. Grain size and stream energy would determine how much of this newly-deposited material could be carried as bed-load and how much as suspended load.

Obviously, the strength of the material through which a stream flows will determine the form ratio of the channel. Coarse, unconsolidated sediments cannot be expected to sustain steep banks. In such cases, the caving bank is added to the bed-load of the stream. In order to carry large amounts of bed-load, the stream must have high current velocities acting on the bottom. According to Lane (1937, p. 137), "Conditions that require high velocities acting on the bottom, as compared to those that may be permitted to act on the sides, require high ratios of bed width to depth." Therefore, such channels can be expected to be wide and shallow with high current velocities and high bed-load. This type of channel is characteristic of the Mississippi River near Vicksburg, Mississippi, and upstream where the sediments are predominantly coarse-grained.

The typical distributary of the lower Mississippi Delta is just the opposite. It flows through silt and sand made cohesive by the abundance
of clay-size particles. Its channel is relatively deep and narrow and its bed-load is probably relatively low because most of the material is fine-grained and can be carried in suspension by low current velocities. Since the shear stress on the bed of a deep channel is less than that of a shallow channel, the bed-load available to and carried by the distributaries of the delta is fine-grained in size. As yet, no one has found a satisfactory method for measuring the amount of bed-load carried by the Mississippi River at any particular locality.

Although the optimum channel form is a semi-circle, it can be shown mathematically that a large stream is more efficient than a small stream, other factors remaining equal. If the discharge of a stream be increased, the cross-sectional area will increase at a greater rate than the wetted perimeter, or frictional surface. As a result, there will be increased current velocity and consequently an increased capacity for discharge (Eads, 1882, p. 2772). Similarly, a decrease in discharge will result in an increase of the ratio of frictional surface to cross-sectional area. Current velocity, and thereby discharge capacity, will decrease.

It has been pointed out that the passes in the lower delta frequently bifurcate as they build seaward. By the above principles, there will be a definite loss in transporting efficiency by this division of flow. Gillmore (1882, p. 2726) states it very clearly:

"It is a well-established law of hydraulics that the ratio of frictional resistance per unit volume increases if the sectional area be diminished by an island into two channels, the water flowing in them would encounter more frictional resistance than it met with while flowing in a single channel. Hence the currents through these channels would be more sluggish."

Therefore, the new distributaries formed through bifurcation would have to have much higher gradients than the main channel in order to
maintain the same discharge capacity. As Bayley (1876, p. 313) puts it, "The less the quantity of water flowing the greater is the slope required for its discharge at a given velocity." Actually, the newly-formed distributaries do not achieve any advantage in gradient. Instead, the gradient of both the main and subsidiary channels decreases as the streams build seaward.

Large channels obviously discharge more efficiently than small channels. If, through bifurcation, one of the new passes is considerably smaller than the other, from the moment of its creation, the smaller pass will be less able to transport sediment carried into it from the trunk stream.
ALLUVIAL PROCESSES

In the previous section some of the sedimentary and hydraulic principles of river alluviation were discussed. The application of these principles is essential in describing the processes which were operating during the creation and development of Cubits Gap Area.

Early Stage

Cutting of the Crevasse

The river water which first began to pour through Cubits Gap Crevasse during flood-stage attained very high current velocities. Accompanying turbulence must have been almost violent. In their monumental river study, Humphreys and Abbot (1861) observed many crevasses along the Mississippi River in which velocities and turbulence were so high that it was impossible to measure either depths or discharge. They found, as a rule, that the size of a crevasse increased rapidly through slumping of the river banks.

Mitchell (1884, p. 2303) thought the large channel dimensions in Cubits Gap Crevasse to have been caused more by slumping than by bottom scour. By the 1876 survey, he shows that the cross-sectional area across the crevasse was 119,000 square feet, while the total cross-sectional area in the passes was only 58,748 square feet. From this, he judges that the crevasse had much more area than it needed, and therefore, could not have been the product of scour alone. Caving would then account for the anomaly.

In forming conclusions about the early stage of crevassing, one might say that the hydrostatic head must be such that it yields an unusually
high current velocity. Resistance to flow causes extreme turbulence which results in scour and bank undercutting with rapid widening and deepening of the channel. The width appears to increase very rapidly for a short time and then stabilize, a large crevasse requiring a greater length of time than a small one to reach stability.

Bar Building

The sediment-laden water flowing through the crevasse passed rapidly from the deep, confined channel to the still, saline water of Bay Rondo. The fresh river water spread radially, floating upon the denser salt water. As it moved gulfward, the fresh water acted as a wedge lying on top of the salt water and thinning seaward. The salt water, of course, underlies the fresh as a complementary wedge petering out upstream, the boundary or interface between the two layers usually being sharp. Along the interface, current velocity and transporting power of the turbid water is reduced and sediment is deposited concentrically about the mouth of the channel.

Since the mouths of the passes in Cubits Gap are so close together, the individual bars have merged to form a near-continuous advancing front. The site of the bar, in relation to the mouth of the pass, is illustrated by Figure 18. During low river stage, the bar is exposed to wave action and considerable reworking takes place (Figure 19).

Students of the Mississippi River have long sought to determine exactly how deposition occurs at the mouths of the passes. Ellet (1851) thought that when fresh water flows out upon salt water, the friction between the two density layers tends to drag the upper part of the salt water seaward. On the bottom, replacement is effected by a counter flow of salt water from the Gulf. Where the immoving salt water reverses its
direction to flow gulfward with the fresh water, a "dead" velocity zone is
created. Sediment is deposited here. The bar, then, is derived from ma-
terial previously deposited in the Gulf and carried landward by the salt
water current moving along the bottom.

Cartwright (1852) agreed with this theory, holding that river
bars are marine rather than fluvial.

Stein (1852), however, opposed Ellet's explanation. He contended
that the salt water current moving landward along the bottom was not strong
enough to produce a bar. Furthermore, the bar material did not appear to
him to be a mixture of sea and river sand. Later, Stein (1860) postulated
that the expansion of the stream at its mouth caused bar formation. The
resulting reduction in current velocity permitted the deposition of sediment.

Barton (1918, p. 100) thought the location of the river bar was
determined by deposition of colloidal matter, which acted as an agglutinant,
holding the sediments together.

According to Humphreys and Abbott (1861, p. 478), the fresh water
enters the Gulf and rises, and spreads upon the salt water at an angle in-
versely as the strength of the current. At the place of meeting between
the two density layers, there is a dead angle beyond which the bed-load
cannot be carried. A bar is produced.

Bates (1953, p. 2136) says about the same thing. He shows a den-
sity contrast of 0.015 to 0.020 between the two layers. He adds that, "the
turbid Mississippi River water would have to carry more than 10 times as
much sediment as it does today during extreme flood stage if it were to
develop a density comparable with that of the nearshore water which it
enters." His profiles of the salt water-fresh water interface demonstrate
perfectly the increase in interface angle with increase in stream discharge
He points out that the "bar builds upward until the least channel depth is enough to establish a balance during the flood stage in which the outflowing river water keeps the intruding salt-water wedge just seaward of the crest of the transverse bar."

Apparently Bates means that the depth over the bar is proportional to the discharge. This condition prevails throughout the lower delta at the mouths of all passes not artificially controlled. If discharge during rising floodstage were not strong enough to push the salt wedge seaward, deposition would occur mostly in the lower reaches of the channel rather than on the seaward side of the bar. With increased discharge, the site of deposition moves downstream across the bar, and scour will rule at the site of former upstream deposition. The scoured material will be carried downstream and deposited on the outer side of the bar. Therefore, sediment deposition and salt water invasion balance each other and cause the bar to be constructed high enough to exclude salt water during floodstage.

In February 1952, during flood stage, the writer took several salinity readings in the Cubits Gap passes at depths down to ten feet. None showed any trace of salinity.

During low river stage in November 1952, strong, persistent, northeasterly winds blew Gulf water into the passes causing a reversal of flow. The current velocity was about two feet per second. The water was clear and strongly saline. Any sedimentation taking place at the time would have been in the form of colloidal flocculation. This condition probably cannot be considered important in bar formation since most of the colloidal material is removed by subsequent floods.

Smith (1909, p. 729) sums up the process of bar building by simply stating that, "The fundamental principle of all delta formation is
the law that the amount of material carried by a stream decreases with decreasing stream velocity."

**Development of Passes**

The broad, concentric bar at the mouth of a pass is characterized by an environment of low current velocity and rapid sedimentation. Turbid water emerging from the confined channel must flow up over the bar and spread laterally. The bar obstructs flow and causes the channel shape to change from deep and narrow to shallow and wide. The Army Engineers in a survey of South Pass found that, near its mouth, the channel was 3400 feet wide and had a mean depth of eight feet (Mitchell, 1875). The mean velocity was 0.66 feet per second, and the cross-sectional area was 24,600 square feet. At a station 8000 feet upstream, the width was 712 feet, the mean depth 24 feet, and the mean current velocity 1.3 feet per second. The cross-sectional area was 18,270 square feet. As the water flowed up the ramp of the bar, the current velocity diminished to one half its former value. Mean depth decreased three times, and width increased five times. Mitchell noted that the expansion of the stream was primary and stated that, "the increase of sectional area is seen to be a necessity growing out of the increase in wetted perimeter, which reduces the velocity by friction." The fact that mean depth has diminished in much less ratio than the width has increased probably reflects the condition of inequilibrium of the channel form at the downstream station.

Apparently the main force of the turbid water flow is directed straight ahead along the axis of the channel and is expended against the upstream side of the bar. The concentration of force on a small portion of the bar results in scour. Thus, while sedimentation takes place on the seaward side of the bar, scour takes place on a portion of the upstream side. In adjusting its shape to a minimum amount of resistance, the channel
becomes deeper and narrower in the manner described under Sedimentary and Hydraulic Principles.

The process of channel extension is illustrated on Plate V (Stage 1). Turbid water, flowing from between the confining banks of the pass, moves over the bar whose crest lies between the 2-foot depth lines. The channel at range BB' is wide and shallow. Scour occurs on the bottom and deposition on the sides. The letters B and B' mark areas of natural levee growth where bar building was formerly active. These levees slope under water downstream and extend well out to the bar where they lose identity. When the newly-formed levees become permanently exposed at mean water level, vegetation begins to appear (Figure 5).

Upstream at range AA', the channel is better developed because it has had more time to become narrow and deep. The adjacent levees are also better developed than those at the downstream range.

Stage 2 (of Plate V) shows the bar and mouth of the pass some distance seaward of the Stage 1 position. At ranges AA' and BB', the channel has matured through the usual processes of bed scour and bank accretion. Growth of the respective natural levees has accompanied channel development. Therefore, as the channel gets deeper and narrower approaching the optimum form ratio, the levees build higher and wider with successive floods. With increased height, the levees are better able to confine flood waters which must rise a little higher each year to top the levees. Thus the maximum stage difference is always greater upstream.

**Inter-levee Low Areas**

As a pass moves seaward, the process of bar building moves with it. Upstream, the process is no longer operative. However, the old bar material remains where it was originally deposited, except where scoured out by the deepening channel. On either side of the mature channel, old
bar deposits act as the foundation upon which natural levees are built.

Flood water usually tops the banks by only a few inches and current velocity is quickly reduced by friction (Figure 20). The majority of the material in suspension, as well as the coarsest sediment, is deposited within a short distance of the banks to form natural levees. Vegetation also increases flow friction and causes deposition to be more concentrated near the channel banks (Figure 21). Mr. Mark Delesdernier of Pilottown, Louisiana, keeps livestock on the levees of some of the passes. He noticed that when the cattle ate off most of the cane, the levees grew wider.

Only the finest-grained sediments are transported beyond the environment of levee building and earlier bar deposition (Figure 6). Since there is also much less sediment here than near the banks, the inter-levee area is typically lower in elevation than the adjacent levees (Figure 22). These areas are usually the sites of lakes or ponds. If general subsidence is great, as in the lower delta, the bottom of an inter-levee lake subsides faster than deposition can take place. A borehole in the lake (see Figure 6) would show a few inches of silt and clay-size particles grading down sharply into the coarser bar material. Farther upstream, the top of the old bar formation has had more time to subside, and the overlying clay layer will be thicker.

A cross-section showing this relationship has been constructed from shallow subsurface data (Figure 23). The boreholes were put down across the levee of Octave Pass into Goose Island Pond (see Index Map, Plate III, for location). In the cross-section, the fine sand shown at depths of 12-15 feet probably represents the bar material that was reworked and sorted in the breaker zone. If its original depth at the time of reworking were about two feet, subsidence would be on the order of ten feet
Figure 20. The right bank of Dead Woman Pass immediately downstream from the fork with Twenty-Seven Pass. The river is in high stage and there is about three inches of water on the crests of the levees. (Photograph by James Morgan, June 5, 1953).
Figure 21. Octave Pass flowing toward the bottom of the page. The small distributary flowing to the left is Contrariety Pass. Casper Pass flows to the right. (November 22, 1952).
Figure 22. Mouth of Scarabin Pass. Dead Woman Pass in the background flows from right to left. The inter-levee low area between the two passes is still open to the Gulf but receives little sediment. (November 22, 1952).
CROSS SECTION THROUGH A NATURAL LEVEE

Figure 23.
since the mouth of Octave Pass was at this site. Above the sand layer, the silt and clay layer represents the last active coarse-grained sedimentation. The overlying dark, organic clay is the material carried into the inter-levee low area by feeble, overflow currents. The wedge of silt and clay extending over the organic clay probably indicates that the levee has been growing wider and encroaching upon the inter-levee area. At the time of borehole drilling, the levee had been stripped nearly bare of vegetation by cattle, permitting more coarser-grained particles to be carried farther into the inter-levee low area.

The levee material lying above mean water level is oxidized. The absence of oxidation below this level suggests that in this particular case, chemical reduction took place rapidly.

Bifurcation

A chronological illustration of the history of Cubits Gap Area shows that every pass building seaward periodically bifurcates and gives rise to new channels (Plate II). Sometimes the new distributaries are about equal in size and branch from the trunk stream at about equal angles (Figure 17). In other cases, one channel is considerably smaller than the other and invariably branches from the main channel at high angles. Observations of many examples of bifurcation show that usually the smaller the distributary, the greater will be the angle of divergence from the trunk stream (Figure 24). Such distributaries are short-lived and soon fill up with sediment. Likewise, the larger the distributary, the less will be the angle of divergence from the trunk stream.

The actual splitting of the main channel takes place on the bar. A typical example is shown on Plate V. As previously described, the pass grows seaward by continually cutting an extension of the channel through the bar by concentrating the force of flow on a part of the upstream side.
Figure 24. Two small, high-angle distributaries flowing off the right bank of Contrariete Pass, are doomed by the great mass of sediment confronting them. In the right background is the mouth of Scarabin Pass. (November 22, 1952).
of the bar. If the force is directed along the axis of the channel, and if the bar material is erodible, then the pass will grow seaward normally. If, on the other hand, it cannot scour the bar along the channel axis, the force will be expended wherever the bar is more easily eroded. In Stage 2 (Plate V), the force of flow was split and deflected to either side of the bar area marked middle ground. While the two redirected lines of force were cutting channels through the bar, current velocity on the shallower middle ground diminished. This area of non-erosion later built up above mean water level in the same manner as natural levees do.

The discussion leaves two major questions unanswered: (1) What causes the concentrated force of flow to be split and realigned? (2) Why is there no consistent size ratio between newly developed passes?

Latimer (1854, p. 19) thought that bifurcation was caused by,

"prevailing winds, which from north around to southeast, set either directly or obliquely into the mouths of these eastern passes, forcing the discharging current first to one side and then to the other, causing the formation of middle grounds and consequent division."

Cartwright (1858, p. 449) recognized that the bars form obstacles which the stream must breach. Stein (1860, p. 76) considered the flaring of the channel mouth as primary, and the bar the result. He says,

"The shoal is generally formed in the line of current because here exists the greatest velocity and it is in this line that the coarsest and heaviest materials are borne and pushed along by the water at the bottom. As soon as the velocity is reduced by the expansion of the stream, these coarser and heavier materials become stationary and form a nucleus for the accumulation of other material."

Leighley (1932, p. 15) describes two centers of maximum turbulence within a channel cross-section. He found that a,

"distinct tendency toward the division of the area of maximum in two parts in the deeper portions of the streams appears in all cases............this double
maximum in the cross-section may have significance in the development of double channels and of anastomosing in streams flowing in beds of unconsolidated material."

Bates (1953, p. 2144) explains bifurcation in the following manner:

"Because of the parabolic shape of the plane jet and the subsequent lunate shape of the bar formed, the cross-sectional channel area of the stream is certain to be reduced even though the mouth of the stream flares to a width about 1.5 times the channel width a short way upstream. In such cases, if the velocity of outflow is to remain constant along the channel even though the outlet is blocked by a bar, it is necessary that the master channel split at or from the bar site into two or more distributaries."

Actually, the velocity of outflow does not remain constant. If it did, there would be no deposition of sediment. The writer has been out nearly every natural distributary in the lower delta and, in each case, observed a reduction in velocity at the channel mouth. Thomas (1905, p. 122) described the situation very well by saying, "The splitting up of the river into a number of divisions reduces the velocity of the current and in consequence its power to keep open a channel."

It should also be pointed out that as the channel flares, there is a definite increase, rather than decrease in cross-sectional area. The natural levees bordering the channel, diverge and lose identity as they slope seaward, so that the cross-sectional area of the channel theoretically increases to infinity. Under the heading Development of Passes, a survey of South Pass was mentioned (Mitchell, 1875). It clearly illustrates the tendency for channel cross-sectional area to increase, and current velocity to decrease at the mouth of a pass.

In studying bifurcation, it should be recalled that a channel loses efficiency when it splits. Eads (1882, p. 2771) shows a theoretical channel splitting equally, all three channels having the ideal semi-circular
cross-section. Although the total area of the two distributaries equals that of the main stream, the wetted perimeter or frictional surface increases by 41 percent. Water in the smaller channels cannot flow as fast or transport as much sediment as the larger channel. There is a definite loss in efficiency through bifurcation. Therefore, it must be concluded that passes do not bifurcate to help themselves; they bifurcate because they cannot help themselves. This implies an outside agent which hinders normal channel development and partially nullifies or deflects the effect of concentrated stream flow against the bar. This agent may be an inherent tendency for current flow to split, as Leighley suggests; it may be a force which creates an obstacle to flow, or a realignment of the direction of flow.

During high river stage, a pass deposits on the Gulf side of the bar and scours on the upstream side. As river stage falls, the transporting power of the pass decreases and the rate of sedimentation probably reaches a maximum on the bar. Fowler (No Date, p. 2) makes the following observation concerning the Mississippi River:

"The turbidity curve does not conform to the discharge curve, frequently being greatest on a falling river. An explanation of this is that the floods of the Eastern tributaries usually crest earlier, with far less turbidity at corresponding stages, than the Western tributaries. As might be expected, the greatest deposition of silt always occurs on a falling stage, at which time the amount of silt being dropped from suspension is at a maximum while the movement of the bed-load is slowing down."

If this set of conditions also obtains for the lower delta, by the end of a flood period, material will have been placed on the bar without ever having been effectively exposed to river scour. When the pass becomes active again, it will have to adjust itself to the new material obstructing flow. If the flood that follows is unusually low, the scouring
force on the bar will also be low and the pass may not be able to make
this adjustment. Bifurcation will probably result.

During the months between floods, current velocity over the bar
is low and may even be reversed by wind. Gulf waves breaking against the
bar not only rework the sediment but may actually pile up large quantities
of bar material. The Army Engineers have experienced some difficulty of
this nature at Southwest Pass before jetties were built. Burwell (1874,
p. 792) gives this account:

"In 1839, Captain Talcott, under instructions of the
War Department, attempted to open the Southwest Pass
with the ordinary bucket drag. No permanent improve­
ment was effected, for during a single night of storm
'twice as much mud' was driven by the Gulf waves into
the pass as he had taken away. A towboat association,
under the direction and at the expense of the Federal
Government, attempted to open the same pass. They used
the rake and harrow, and after working a year they
opened a channel of 18 feet in depth for a distance
of about 8000 feet. This remained open a short time,
and was prematurely and permanently closed by a single
storm."

Quinn (1877, p. 55) makes a more analytical observation on the
effects of wind:

"The form of the bar is greatly influenced by several
forces, such as winds, waves and counter-currents. If
a current flows from left to right across the mouth of
the pass, looking seaward, the material will be deposited
in a greater quantity on the right hand side of the pass
and vice versa. If the winds influence the counter­
currents, then the direction of the prevailing winds
will determine upon which hand the greatest deposits
will occur. The waves have a tendency to flatten the
bar and fill up all channels across it. The seaward
slope of the bar is greatly influenced by the combined
action of the currents and waves, being steeper on the
side from which the currents come. If the effects of
the counter-current are not continuous, the result is
that the channel across the bar is more or less de­
flected by the deposits on the side opposite that from
which the currents arrive, and is more or less inclined
toward the side from which the counter-currents proceed
or against the counter-current. The advance of the bar
will not be symmetrical with the axis of the pass. If,
however, the counter-currents are feeble, the advance of the bar will be more or less symmetrical with respect to this axis.

Because the water over the bar of a small pass is more shoal than that of a large pass, the sudden accumulation of a ridge or pile of sediment by wave action would be much more critical at the mouth of the smaller pass. Furthermore, the force of fresh water flow exerted against the newly-formed obstacle would not be as strong in the smaller pass. Perhaps this is why small streams usually bifurcate more frequently than large ones, other factors remaining equal.

In deltas where the bar material is coarser grained than that of the Mississippi, the inability of the sediment to maintain bank slope will create a condition of instability in channel position. The addition of large amounts of sediment to the channel through bank caving can obstruct flow and cause rapid realignment of flow direction. If this should occur near a point of bifurcation, realignment could bring about the abandonment of a channel which was otherwise capable of maintaining flow. Deltas of this type usually experience frequent shifting of the main channels. The Rio Grande was probably such a delta when it carried normal discharge.

The fact that Pass a Loutre is the only one of the three major passes flowing into the direction of the prevailing wind may account for its tendency to bifurcate more frequently than South or Southwest Passes. The only well developed barrier beach in the lower delta lies between Northeast and Southeast Passes. Although Pass a Loutre has had to extend itself into the prevailing wind, it still discharges more water than any of the other passes.

Octave and Raphael Passes flowing eastward encounter more wind opposition than Main Pass. This may explain why Main Pass carries so much
more discharge and why it has never bifurcated to form lasting distribu-
tories of consequential size.

In summing up the more important aspects of bifurcation, the
following items seem most pertinent:

1. Only passes building seaward bifurcate.
2. Channel efficiency decreases through bifurcation.
3. Passes bifurcate because an obstacle causes the
   force of the current to be split or deflected.
4. The force of fresh water flow is greater at the
   mouth of a large pass than at the mouth of a
   small pass. Therefore, water depth on a bar is
   proportional to the size of the pass.
5. The greater the angle of divergence of a distribu-
   tary from the trunk stream, the less will be the
   discharge in the distributary, other factors re-
   maining equal.
6. Passes flowing into the prevailing wind bifur-
   cate more frequently than others.

From these, the following general conclusions are drawn: A pass
bifurcates when it can no longer cut a single channel through the bar.

Bifurcation arises from the realignment or the splitting of the force of
flow due to some agent capable of deflecting the current. Such an obstacle
would be most likely caused by, (1) wave action piling up and concentrat-
ing sediment, (2) rapid accumulation of material at a critical location
through bank slumping (in environments of coarse sediment), and (3) accumu-
lation of logs on the bar.

Re-joining

As passes grow seaward and bifurcate, two distributaries may
converge upon each other as they cut through the bar. If they meet, the
resulting channel will be more efficient than either of the two smaller
ones because of the increased discharge. This merging or re-joining of
passes occurs frequently and encloses an inter-levies low area, usually
isolating it from tidal effect. Thus the environment of an inter-levies
area changes from brackish to fresh. Many such examples are shown on
Plate II.

Since channel extension occurs mainly during floods, two converging passes may not quite meet by the time flood stage ceases. Between the mouths of the two passes, an opening from the inter-levee area will remain (Figure 22). Through this passage, tides will regularly move water back and forth between the sea and the large inter-levee lake. If the mouths of the two passes approximate each other closely enough in position, the tidal passage will be narrow, and the tidal currents stronger (Figure 6). Deepening of the passage may temporarily develop a better channel than is present in either of the adjacent passes. One such example exists near the intersection of Dead Woman and Japan Passes but has so deteriorated that it can barely be seen on Figure 1.

During later flood stages the two passes usually merge with the tidal passage and move seaward. The passage may, however, remain open for many years after it is no longer directly connected to the Gulf, although tidal effect diminishes as distance to the sea increases. The outlet of Delta Bend into Casper Pass illustrates this situation (Plate II, Figure 5). Fluctuations in river stage periodically carry turbid water in and out of the inter-levee area and, in some cases, cause deposition of sediment, in the form of a miniature or reverse delta, just inside the restricted opening. Such an example exists in the Jump (see arrow in Southwest corner of Figure 1).

Sometimes converging passes neither merge nor develop effective tidal passages. If one pass is ahead of the other, the slower-building pass not only has to cut through the bar but through the ever-growing levee of the first pass. Usually the slower-building pass is simply deflected away from the obstruction, and it cuts a channel along the path of least
resistance. Raphael Pass in its early growth was thus deflected by the left bank of Pass a Loutre (Plate II, Figure 4). The left distributary of Casper Pass seems to be deflecting one of the small outlets from Main Pass (Plate II, Figure 5).

**Subsidence**

No area on the Gulf coast is sinking beneath sea-level as rapidly as the lower delta of the Mississippi River. It can be safely assumed, therefore, that the bottom of Bay Rondo was subsiding prior to the origin of Cubits Gap Crevasse. The first sediments introduced into the area after 1862 were fine-grained, pro-deltaic clays which grow thicker seaward (Fisk, 1952, p. 540). The clays are of very high water content. When bars and levees later formed on top of this soft material, compaction ensued and subsidence of the surface resulted. Thus the sinking of the topographic features of Cubits Gap, below sea-level, can be related to both regional subsidence and local sediment compaction.

In the discussion of Inter-levee Low Areas, Figure 20 was interpreted as showing a subsidence of a sand layer by approximately 10 feet since the mouth of Octave Pass was at that location. From Plate II, it appears that this date would be around the year 1885. This yields a rate of subsidence of nearly 0.15 feet per year.

Since natural levees develop by growing from below sea-level to several feet above, they would have to receive at least 0.15 feet of sediment per year to maintain their elevation. Mr. Mark Delesdernier of Pilot-town, Louisiana, estimates that over an inch of sediment is deposited each year, on the average. When levees can no longer receive these annual deposits, they rapidly sink into the marsh (Figure 25).

The inter-levee areas also strongly reflect subsidence. Bottoms
Figure 25. An abandoned channel far downstream from its point of divergence from the trunk stream. The levees have subsided below the marsh and only vegetation marks the limits of the partially filled channel.
of enclosed lakes usually subside much faster than they can be maintained by sedimentation. Hence the older lakes are deeper than newly-formed lakes, other factors being equal. Minout Pond, formed early in the history of the area, is about six feet deep (Plate III). Dead Woman Pond, about eight miles downstream, is only two feet deep.

Since the natural levee is the site of more sedimentation than the inter-levee low area, it is also probably the site of greater subsidence. Unfortunately, it was not possible with the drilling equipment available to penetrate the sub-deltaic complex of Cubits Gap Area. Therefore, it cannot be stated where the rate of subsidence is greatest or whether there is a change in the location of the zone of maximum subsidence. However, the passes are progressively moving into deeper water and the bars must progressively overlie thicker pro-delta sequences. For this reason, it is believed that the rate of subsidence is greatest at the mouths of the passes.

Later Stage

Channel Closing

Introduction.—A comparison between Figures 4 and 5 of Plate II, shows that many of the passes active in 1903 had "silted up" and were no longer carrying discharge in 1952. Despite subsidence and filling, many such passes are still discernible today on maps and aerial photographs (see Figure 1). In the field, these old passes are marked by vegetative persistencies and by the channels themselves, in various forms of deterioration. Field surveys and aerial photograph study show that filling occurs according to a definite pattern based on principles of sedimentation.

At the head of a closing channel, filling is accomplished by comparatively rapid deposition of coarse material which had probably been
transported as bed-load. Downstream, filling is slower since less bed-load can be carried that far by the weakening current. The channel is first filled at the head, leaving an open channel downstream which gradually fills with finer material deposited from suspension (Figure 26). Grass, hyacinth and logs begin to accumulate as current velocity grows more feeble. When flow ceases altogether, the natural levees can no longer receive annual overflow deposits and eventually sink beneath the marsh (Figure 25).

Examples of Closing.—The process of channel abandonment can be seen in progress at several locations in Cubits Gap Area, the fork of Dead Woman and Twenty-Seven Passes probably affording the best example (Figure 27). The fork lies about six miles downstream from the crevasse (see Plate III for location). The writer visited this spot on various occasions between February 1952 and November 1953, and made plane table surveys showing the changes which have taken place (Plate VI).

In January 1953, the river was at low stage and current velocity was low (Plate VI, Figure 1). A bar was building downstream from the right bank across the head of the smaller pass. The bar is well outlined by the 8-foot depth line and is also reflected by the 10 and 12-foot depth lines. Accretion to the right bank had recently taken place, mostly around point A but also upstream and downstream from there. The bar was partially blocking the entrance to Twenty-Seven Pass, deflecting the main thread of the current toward the opposite bank. Near point B, the bank was unusually steep and showed signs of recent slumping. Realignment of the current had caused a reverse eddy to form near point A where the current actually flowed upstream next to the bank. Downstream, the main thread of the current returned to mid-stream and the channel cross-section became symmetrical.
Figure 26. An abandoned, partially filled channel. Roseau cane (*Phragmites communis*) is growing on the sunken levees and alligator weed (*Alternanthera philoxeroides*) is accumulating in the channel which is still five feet deep.
Figure 27. Fork of Dead Woman and Twenty-Seven Passes. Flow is toward the observer. The straight lines are marsh buggy tracks. (April 10, 1954).
At the time of the following survey, in June 1953 (see Plate VI, Figure 2), river stage was about two feet higher than it had been the previous January. Lunar tides were causing fluctuations in river stage and current velocity. During high tide, the river topped the levee crests by 2-3 inches (see Figure 20), but fell 4-5 inches during low tide leaving a veneer of newly-deposited silt and mud exposed on the levees.

The bar building across the head of Twenty-Seven Pass had grown considerably since the survey of January 1953, as shown by the 8-foot depth line. The 4-foot depth line had moved farther away from the right bank both upstream and downstream from point A. The main thread of the current veered around the bar and was directed against the opposite bank near point B. The bank had retreated about three feet, through undercutting and slumping, since the first survey. Near point A, the reverse eddy was more in evidence than it had been at low stage. Downstream, the bed of the pass, according to the depth lines, appeared unchanged. In Dead Woman Pass, however, the depth lines show that bottom scour had taken place with increased discharge.

This same closing pattern is exhibited at the fork of Scarabin and Japan Passes (see Plate III for location). A survey on June 5, 1953, showed a bar building downstream from the left bank across the head of the smaller pass (Figure 28). Along the left bank, just upstream from point B, marsh vegetation was growing in the zone of recent accretion (see Figure 11). Opposite from point B, the right bank of the smaller pass was being undercut, and slumping was in evidence. In cross-section AA' (Figure 28), the position of the zone of maximum current velocity indicates that the current had been deflected against this bank as the bar built downstream across the smaller channel.
LEGEND

DIRECTION OF CURRENT
RIVER BED DEPTH

CONTOURS IN FT. (CONTOURS
OMITTED WHERE NOT NEEDED)
PROFILE LINES FROM
WHICH CONTOURS WERE
ESTABLISHED

SCALE

25 0 23 30 75
FEET

CONTOUR MAP

OF

SCARABIN-JAPAN FORK
SURVEYED JUNE 5, 1953

CURRENT VELOCITY READING IN FEET PER SECOND
ACROSS PROFILES A-A', B-B', C-C'. SCALE IN FEET
RIVER STAGE: 2 FEET ABOVE MEAN LOW STAGE.

DATA

SOFT NEWLY DEPOSITED MATERIAL

SEA LEVEL

CONTOURS 1.31 1.30 1.29 1.28 1.27 1.26 1.25 1.24
STAGE: 1.23 1.22 1.21 1.20 1.19 1.18 1.17 1.16

SEA LEVEL

SCALE

25 0 23 30 75
FEET

CURRENT VELOCITY READING IN FEET PER SECOND
ACROSS PROFILES A-A', B-B', C-C'. SCALE IN FEET
RIVER STAGE: 2 FEET ABOVE MEAN LOW STAGE.

DATA

SOFT NEWLY DEPOSITED MATERIAL

SEA LEVEL
The form ratio (maximum depth divided by width) of each channel is shown in parentheses beside each cross-section traverse. Although the small channel is closing, its form ratio more closely approximates the optimum than that of either of the other two channels. However, cross-section BB', which clearly shows accretion to the left bank, reveals that current velocity in the larger channel exceeds that of the other channels. The greater size of the large channel compensates for its inferior form ratio. Apparently the greatest disadvantage of the closing pass is the fact that it is smaller.

A third example of channel abandonment is the fork of Flatboat and Robinson Passes (Figure 10). According to local residents, Robinson Pass became closed to small draft boats around 1936 and has since completely closed at its point of divergence from Flatboat Pass (Figure 29). Overflow water from Flatboat Pass is now forming a natural levee across the head of the abandoned channel although a small ditch still remains, showing the position of last active flood flow which connected the two passes. This ditch is better seen in flood time (Figure 30). Down Robinson Pass, it assumes the form of the old channel in which clumps of cut-grass are growing. Lines of willow trees mark the zones where levee-building formerly took place.

Several hundred feet down Robinson Pass, the old channel becomes wider and more marked, showing that filling has not been complete. About two thousand feet downstream, the channel is nearly twenty feet wide and about four feet deep. The natural levees lie at about marsh level, having subsided about two feet since the channel was abandoned.

Boreholes in the middle of the old channel (see Plate III for location) show a wedge of coarse sediments at the head which thin out
Figure 29. Looking down the abandoned channel of Robinson Pass from its point of divergence from Flatboat Pass. The willow trees mark the original position of the levees and the small clumps of cut-grass (Zizaniopsis miliacea) grow in the deepest part of the remaining channel. Photograph taken in late summer of 1953 during low river stage.
Figure 30. Looking down the abandoned channel of Robinson Pass from its point of divergence from Flatboat Pass. The stagnant water in the foreground represents the small ditch which last connected the two passes. Photograph taken in February, 1952, during high river stage.
downstream while the complementary, overlying wedge of finer material grows thicker (Figure 31). This situation closely resembles the results obtained by Fisk (1952, p. 109) on channel filling elsewhere. The change from coarser sediments to finer is well shown by grain-size analyses of samples taken from the boreholes (Figure 32).

The Closing Process.—Although the grain-size distribution of the sediments which fill a channel has been well investigated, scientific literature contains very little information concerning the actual process by which a channel is filled and abandoned. Humphreys and Abbot (1861, p. 468) noticed bars at the point of separation of certain passes from trunk streams. They concluded that such bars form during the low-water period but gave no explanation as to the source of sediment.

Rehbock (1929) and Matthes (1933) show that most of the bed-load is diverted into a distributary branching at a high angle from the trunk stream. Vogel (1934) mentions the reverse eddy which often forms at the head of closing channels. His observations agree with those of Turnbull and Kolb (1953, p. 19), who state the, "Division of suspended load appears to be proportional to the division of flow." Other workers have contributed data and principles which make it possible to explain the closing process.

A typical example of channel abandonment in the lower delta is represented schematically on Plate VII. Water flowing from the trunk stream into the right distributary undergoes a reduction in current velocity as field observations bear out. Consequently, the ability of the current to transport sediment is diminished and deposition must ensue. Since the reduction in velocity occurs at the head of the distributary, this will be the site of maximum deposition. The coarsest material, which is probably
SCALE IS IN FEET
VERTICAL EXAGGERATION = X 10

LEGEND

WATER
CLAY
SILT-CLAY
FINE SAND

FLATBOAT PASS

OXIDIZED ZONE

NO. 1

NO. 2

NO. 3

CHANNEL FILL SILT-CLAY

CHANNEL FILL SILT AND FINE SAND

LONGITUDINAL CROSS-SECTION DOWN ROBINSON PASS

Figure 31.
CHANNEL FILL SEDIMENTS
GRAIN SIZE ANALYSES

1. BOREHOLE NO. 1, DEPTH: 7.0 - 8.0 FT.
2. BOREHOLE NO. 2, DEPTH: 2.0 - 3.0 FT.
3. BOREHOLE NO. 3, DEPTH: 2.5 - 3.0 FT.

Figure 32.
carried as bed-load, will be the first to drop out.

At the fork of Dead Woman and Twenty-Seven Passes (Plate VI, Figure 1), samples were taken from the upper two inches of the bar and channel bed and analyzed for grain size (Figure 33). Sample C, taken at a water depth of 13 feet, is about fifty percent fine sand. A slight increase in current velocity would send this material into motion downstream along the channel bed. Therefore, it is probable that during high river stage, sediments of this size comprise all or part of the bed-load.

Sample B was taken at a water depth of 5 feet on the crest of the bar (Plate VI, Figure 1). The analysis represented by Curve B (see Figure 33) indicates only a trace of sand and about eighty percent silt. Curve A is from a sample from the crest of the natural levee a short distance upstream and contains about seventy percent silt and no sand.

From these data, it appears that there is a direct relationship between the grain size of the sediment and the depth of the water in which the sediment is deposited. Therefore, the material on the crest of the river bar will be finer-grained than that on the outer edges of the bar in deep water.

In Stage A (Plate VII), water flowing through a cross-section of the main channel first encounters the slower current of the right distributary at point X (rather than say, at point Y). If the decrease in current velocity at this point is sufficient, deposition of sediment will proceed rapidly and a bar will begin to form.

As this bar grows out across the channel, the main thread of the current is forced over toward the bank at Y in order to enter the channel (Plate VII, Stage B). The resulting realignment of flow causes a greater force to be directed against the left bank. In this manner the angle of
LEVEE AND BOTTOM SEDIMENTS
GRAIN SIZE ANALYSES

A. CREST OF NATURAL LEVEE OF OCTAVES PASS AT MILE 2, DEPTH: 0 - 1.0 FT.
B. BAR ACROSS HEAD OF TWENTY SEVEN PASS, WATER DEPTH: 5.0 FT.
C. BOTTOM OF DEAD WOMEN PASS, WATER DEPTH: 13.0 FT.

Figure 33.
divergence between the closing channel and the trunk stream increases as filling proceeds.

The realignment of flow causes a dead zone to exist where current velocity is low. The contrast between this zone, at X, and that at Y, creates the reverse eddy shown by the arrows. This reverse current which is so apparent at the surface, may not exist at depth where it is probably replaced by a downstream component.

Most of the bed-load carried into the closing pass is deposited on the bar. Downstream, the channel is filled by sediments coming from two sources: that carried in suspension from the trunk stream and that supplied by the caving bank at point Y. Since the bank material is generally fine-grained, it will probably also be carried in suspension and deposited evenly along the bed of the channel.

As the head of the pass closes (see Plate VII, Stage C), discharge and current velocity decrease. The transported load diminishes in quantity and in grain size. By the time closing is effected, only a narrow ditch marks the position of last flood flow and the trunk stream soon constructs a natural levee across the head of the old channel (Stage D). Over this levee, the current carries only fine-grained sediments which slowly drop out to form a clay plug in the old channel. The old levees, no longer able to perpetuate themselves, sink into the marsh.

Speed of Channel Abandonment.—The time required for complete abandonment of a distributary apparently depends on four factors: (1) difference in size between the two distributaries; (2) original alignment of flow; (3) flood discharge; and (4) type of alluvium composing the bed and bank.

In the lower delta, the relative size of a pass is determined at the time it is created through bifurcation of the trunk stream. If one
distributary is considerably larger than the other, it will have a dis-
tinct hydraulic advantage, in that it can maintain higher current velocity
even though the gradients are equal. The greater the difference in size,
the greater will be the rate of closing of the smaller channel.

From another point of view, closing probably takes place slower
in large rivers than in small rivers. Southeast Pass has been closing
for several generations as evidenced by the changes which have taken place
at its point of divergence from Pass a Loutre. The entrance to Southeast
Pass has progressively moved down Pass a Loutre by accreting to the right
bank and erosion of the left bank. It will probably require several gener-
ations for the pass to close under natural conditions.

Likewise, the crevasse channel through the right bank of Pass a
Loutre into the sub-deltaic complex of Garden Island Bay is gradually
closing (Plate I). This channel has been open since about 1893 but can
no longer maintain current velocity as high as that in Pass a Loutre. As
expected, at the entrance to the channel, accretion occurs on the right
bank and erosion on the left bank (Figure 34).

Also determined at the time of bifurcation is the direction of
flow alignment, or the angle of divergence, of the distributaries from the
trunk stream. Large distributaries generally form at low angles of diver-
gence and small distributaries nearly always form at high angles. Perhaps
the high angle causes a proportionately high amount of bed-load to enter
the smaller channel (Rehbock, 1929, and Matthes, 1933). A mass of water
in motion tends to remain in motion along a straight line. In making the
turn into the high angle distributary, much stream energy is lost through
the expenditure of centrifugal force against the downstream bank opposite.

Another point to consider is that distributaries, which diverge
Figure 34. Pass a Loutre Crevasse into Garden Island Bay. Pass a Loutre in the foreground, flows from right to left. The protruding right bank of the crevasse directs flow against the left indented bank as closing proceeds. (April 10, 1954).
at high angles, do not take the shortest distance across the bar to open water (Figure 24). They must cut through the bar at an angle, making the distance much longer than that taken by the larger channel (Figure 35). Having a lower current velocity, the small pass cannot possibly do this and quickly fills up at the head.

The third factor governing the rapidity of channel closing is flood discharge. Most streams are virtually dormant during low stage, and transport very little sediment as bed-load. It is in flood stage, when bed-load movement is most active, that channel closing takes place. Therefore, a stream which is at low stage most of the year would not be able to fill a distributary rapidly. Likewise, if the difference in flow discharge between high and low stage is not very great, channel closing will be relatively slow.

Outside of flow alignment, the most important factor controlling the speed of channel abandonment is the type of alluvium through which the stream flows. If the alluvium is fine-grained, as it is in the lower delta, bank caving will be negligible. Bed-load, both in quantity and grain-size, will be small and the channel will have a high form ratio. If, however, the stream flows through coarse material as the Mississippi River does far upstream, bank caving will be prevalent, bed-load will be high, and the channel will have a low form ratio.

The writer was fortunate in being able to study channel abandonment on such a stretch of the Mississippi River about fifteen miles downstream from Vicksburg, Mississippi (Figure 36). Compared to that of the lower delta, this channel is shallow and wide. The banks, which are composed generally of coarse, easily eroded sediment, sometimes retreat over a hundred feet in a single flood and keep the river supplied with large
Figure 35. Small, high-angle distributaries diverging from the right bank of a relatively much larger pass. The channels must cut through the bar (shown in lighter color) to reach the Gulf (shown in darker color). By the end of the following flood stage, they will no longer exist. (November 22, 1952).
Figure 36. The closing channel of Oak Bend at its fork with Diamond Cut-off.
quantities of bed-load. In the lower delta, bank caving and erosion are rare and bed-load probably constitutes a much smaller percent of total transported load. This contrast in stream characteristics between the two river environments is greatly reflected in the manner in which the channels are abandoned. Although the resulting land forms are vastly different, the hydraulic principles remain unchanged. For this reason, an example of channel abandonment, under conditions of rapid bank erosion and high bed-load is presented.

The entire flow of the Mississippi River was formerly concentrated in the channel called Oak Bend (Figure 36). In 1933, the Army Engineers dredged a shorter route, Diamond Cut-off, which soon developed high current velocity and enlarged rapidly. As it did, it progressively carried more of the total discharge of the river at the expense of Oak Bend channel. Flow into this old river channel began to undergo current velocity reduction and bed-load was deposited near point B. As discharge diminished, the bar, B, grew southward across the head of the channel decreasing the cross-sectional area. Water entering Oak Bend had to make a sharper turn to skirt the bar. The resulting realignment tended to direct the force of flow against a more limited sector of the left bank near point A, where erosion and slumping became more concentrated. Between 1937 and 1948, this bank retreated nearly half a mile.

Since discharge into Oak Bend was much less than the original amount, the channel was actually changing its pattern to that of a smaller stream (Friedkin, 1945, p. 9). Erosion at point A afforded a sudden supply of bed-load which the weakened current could carry no farther downstream than point C. At this spot, where bank caving had been predominant before the cut-off of 1933, a point bar began to form. As it grew, the bar deflected
the current toward the right bank at point D, where the current began to erode old point bars formed when the stream was much larger.

Thus a secondary meander pattern develops, the smaller bends being transmitted downstream as far as the weakening current can carry bed-load. Beyond that, only finer suspended sediments are carried, and filling results in clay plug formation. Eventually bar B will close the head of Oak Bend, but until then the channel will continue to adjust itself to diminishing discharge by gradually assuming a smaller meander pattern.

Further contrast in channel closing between the lower delta and the river near Vicksburg is illustrated by Plate VIII. Bar formation at B (Stage 1) directs current against the opposite bank at A, where undercutting takes place, the eroded material being carried downstream to point C (Stage 2). Meanwhile, the left distributary enlarges and increases its discharge causing diminution of flow through the closing channel. The growing bar at C deflects the weakening flow toward the opposite bank at D, where erosion takes place (Stage 3). As the stream grows smaller, it is no longer able to carry eroded material from the bank at A downstream to point C, but deposits it at point E (Stage 4). This causes further realignment of flow direction and the current is directed against point F. Sediment eroded from this bank is carried downstream and deposited as a point bar adjacent to the former cut-bank D. If readjustment is rapid, segments of older channels may be left isolated as at D by the change in flow position.

In this fashion, the meander pattern grows smaller as sites of erosion and deposition change (Stage 5). The process finally ceases when the bar B builds across the old channel and becomes the location of natural levee formation associated with the trunk stream.
A comparison between Plate VII and Plate VIII shows that in the lower delta the secondary meander pattern does not form. The small amount of bed-load carried into the channel is dropped at the head, which is the only place that flow realignment takes place. Resulting erosion of the opposite bank does not supply the channel with sufficient bed-load to form a second point bar downstream. Therefore, the weakening current flows in a straight line rather than assuming a meander pattern.

It can be concluded then that the geomorphic pattern displayed by a stream in the process of abandonment is a reflection of the type of material through which the stream flows. Other factors remaining equal, closing occurs more rapidly in channels flowing through coarse material than those flowing through fine material.

Cause of Closing.—As shown previously, deposition of sediment across the head of a distributary is the result of current velocity reduction. Therefore, any agent which tends to oppose current flow is at least partially responsible for channel abandonment.

Humphreys and Abbott (1861, p. 469) suggest that storms might raise Gulf level on one side of the delta, forcing most of the discharge through the passes on the opposite side. A pass flowing into the wind would have a reverse gradient and could not carry sediment beyond the head of the channel. They also considered shoaling at the mouth by storm waves as a potential cause of abandonment. In addition, they mention log jams. The writer has seen log rafts at the heads of three small, closing channels in the lower delta. Since they create friction, the logs must have helped slow the current to some extent. However, most of the closing passes are not hindered by any logs at all.

The effect of pass re-joining on the flow efficiency of the
channels upstream was also considered. Twenty-Seven Pass, which was shown closing at the point of divergence from Dead Woman Pass, flows into Flatboat Pass (see Plate III for location). A survey of the junction of these passes shows no obstruction to flow from Twenty-Seven Pass into the main channel (Figure 37). It is a matter of interest that the combined cross-sectional areas of Twenty-Seven and Flatboat Passes (408 and 848 square feet respectively) exceeds that of the main channel (1158 square feet). It carries the same amount of discharge as the two smaller passes through a smaller cross-sectional area. Despite the low form ratio of the main channel, flow efficiency increases through the merging of the two tributaries. Therefore, it appears that re-joining of channels is probably an aid rather than a deterrent to flow.

It is interesting to note that in such cases, a stream can be completely filled at its head, yet at its lower end, where it re-joins a second pass, the channel will remain open for many years. Apparently the dead water left standing in the downstream segment of the abandoned channel prevents fresh, turbid water from entering at the lower end. Therefore, sedimentation and filling take place very slowly.

Effects of Closing.—Any change in the flow factors, such as gradient, discharge, current velocity, etc., sets up a state of inequilibrium which must be compensated for by a change in channel form. It has been shown that channels decrease in size in response to a decrease in discharge. Likewise, an increase in discharge must cause an increase in channel cross-sectional area.

To study the effect of discharge variation on channel form, the writer made transverse surveys at strategic points across several passes (see Plate III for locations).
LEGEND

DIRECTION OF CURRENT
RIVER BED DEPTH CONTOURS
IN FT. (CONTOURS OMITTED WHERE
NOT NEEDED)

PROFILE LINES FROM WHICH
CONTOURS WERE ESTABLISHED

JUNCTION OF TWENTY SEVEN-FLATBOAT PASSES
AT LOW RIVER STAGE
NOV. 27, 1953
AVERAGE HEIGHT OF LEVEE: 1.8 FT
Profile 2 was made across Flatboat Pass just upstream from the point of divergence of old Robinson Pass. The channel was 105 feet wide and had a maximum depth of 11.5 feet (Figure 38). The cross-sectional area was 784 feet. Downstream, at Profile 1, the channel was only 86 feet wide but 12.5 feet deep. The cross-sectional area was 771 square feet. Obviously the channel at Profile 1 had not yet adjusted itself to the additional discharge derived from the abandonment of Robinson Pass. The current velocity here was greater since the cross-sectional area was less than that upstream. The bottom was being scoured to a depth out of proportion to width, and therefore bank caving resulted (Figure 39).

This stretch of Flatboat Pass is particularly interesting because of the stream pattern created by closing of old distributaries (Figure 40). Channel bends formed during the original process of bifurcation give the impression of meandering because three distributaries, Robinson and Bluewing Passes and an unnamed pass which used to flow off the right bank of Flatboat, have closed, subsided and deteriorated to varying degrees (Plate III).

Turning to Raphael Pass, Profile 7 shows a channel 291 feet wide and 8 feet deep (Figure 38). Sedimentation along the banks is narrowing the channel in response to decreasing discharge caused by the afore-mentioned shoaling at the head of Raphael. Profile 6 downstream gives a width of 164 feet and a depth of 13 feet. Apparently the closing of Adolph Clark Pass increased the discharge through this part of the pass, and compensation through bottom scour resulted.

At Profile 3, the cross-sectional area of Joe Brown Pass was 282 square feet while Profile 5 yielded 1,539 square feet for this value across Raphael. The sum of the two is 1,821 square feet. The cross-sectional area
PROFILE NO. 1

PROFILE NO. 2

PROFILE NO. 3

PROFILE NO. 4

PROFILE NO. 5

PROFILE NO. 6

PROFILE NO. 7

LEGEND

WATER

SOUNDING POINTS

profiles measured normal to stream banks

soundings corrected to mean low water

horizontal and vertical scales in feet

vertical exaggeration 2.5X

STREAM PROFILES

CUBITS GAP

see index map for locations

Figure 38.
Figure 39. Looking upstream at the caving left bank of Flatboat Pass three hundred yards below the point of divergence of old Robinson Pass. The fisherman is standing on the levee crest which is slightly over two feet above mean low water. (November 28, 1953).
Figure 40. Looking down Flatboat Pass, the old abandoned distributaries of Robinson and Bluewing Passes and an unnamed pass formerly flowed off the right bank at the points where Flatboat makes sudden left turns. The over-all effect is a pseudo-meander pattern. (November 22, 1952).
is only 1,710 square feet at Profile 6 and indicates again that forking of a channel diminishes over-all discharge efficiency.

At Profile 4, the channel is 258 feet wide and only 9 feet deep. The wide, shallow form probably reflects the decrease in discharge through the upper part of Raphael Pass and Robinson Pass.

On a much larger scale, the crevasse at Cubits Gap in 1862 quickly deprived the river of about ten percent of its discharge. The decrease in discharge meant a decrease in ability to transport load, and the river began to shoal downstream from Cubits Gap. Surveys show that between 1872 and 1876, shoaling of the bottom averaged 0.5 feet per year (Marindin, 1880). If Cubits Gap Crevasse were artificially closed, the compensating effect would be bottom scour of the river downstream. The concept of confining flow to maintain depth was used by Eads in the construction of the highly successful jetties at the mouth of South Pass in 1879. He strongly emphasizes the principle that, for every change in the amount of discharge through a channel, a state of inequilibrium is set up which tends to cause a compensating change in the form of the channel.

**Final Stage**

The sub-deltaic area of Cubits Gap is becoming more mature as the passes grow seaward at an ever diminishing rate and decrease in hydraulic gradient. The effort of each pass to extend is, in itself, abortive. As Gillmore (1882, p. 2729) expresses the situation:

"Every addition to the length of the separate channels which are now forming through the sub-delta, flattens their slope and consequently, these currents will become too sluggish to transport the sediment contained in the water, and it will be dropped at the upper or river ends of these channels, and they will be finally shut off entirely from all connection with the main river."
At each former point of bifurcation, the smaller distributary eventually closes, other factors remaining equal, and rejuvenates the complementary distributary with an increase in discharge. Through the progressive elimination of the smaller pass at each fork, flow gradually becomes concentrated in a few channels and finally into one.

In Cubits Gap Area, Raphael Pass will soon close if natural conditions prevail. Scarabin, Twenty-Seven and Flatboat Passes will close and contribute more discharge to Dead Woman Pass. Then, either Octave or Dead Woman will close, the surviving pass being forced to compete with Main Pass.

Unless Cubits Gap Crevasse is itself closed, Main Pass will eventually acquire all the discharge from the Gap. Since it carries slightly over one half of total flow at present, the closing of Octave and Raphael Passes will nearly double the flow through Main Pass. It will continue to build seaward, bifurcating to form small, short-lived distributaries and occasionally larger and more lasting ones. Upstream, where the channel is older and more mature, distributaries will be closing. Simultaneously, the channel form must adjust to the added discharge by deepening. In response, bank caving will widen the channel, and destroy remnants of old abandoned distributaries at points of divergence from the main channel. The zone in which natural levee building takes place must also migrate laterally, and natural levee deposits will build out on top of the adjacent inter-levee lakes or marsh areas (Figure 23). In such places, boreholes through the levee would disclose the presence of the buried marsh or lake.

With concentration of discharge, and the accompanying adjustment in channel form completed, the pass will behave as an ordinary river. If the material composing the bank is easily eroded, a slumping and caving
will supply the channel with an abnormal sediment load. Realignment of flow will direct the current against the opposite side and a cut-bank will result. In time, the stream will develop a meander pattern in proportion to the amount of discharge. As the channel migrates laterally, it will destroy or bury the levees and channels of the original deltaic, anastomosing pattern.

If, on the other hand, the bank material is fine-grained and not easily eroded, as in the lower delta, bank migration through undercutting and slumping will be very slow. However, the tendency for the stream to meander will be present and with sufficient time, point bars and cut-banks will appear. Cubits Gap Area will probably be cut off from the main river before this stage is reached.

The tendency to concentrate flow is also displayed in the crevasse area associated with the Jump (see Plate I), a break through the right bank of the river formed around 1839 (Ockerson, 1899, p. 34). Where many distributaries once carried flow to the Gulf of Mexico, only the main channel and a few of its branches remain, and they no longer carry sufficient discharge to build seaward. At the mouths of the abandoned channels to the west, the coast is rapidly retreating before the waves.

While a pass remains active, the depth of the water over the bar at its mouth is largely determined by the discharge of the channel. As discharge dwindles and finally ceases, the influence of wave action becomes more important and eventually dominant. Waves breaking across the bar attempt to adjust depth to the new base level and a beach begins to form. With continued wave action, the beach develops and moves inland.

In the lower delta, where subsidence is rapid, levees of abandoned passes sink below marsh level permitting the lakes and ponds of the
inter-levee areas to expand and connect. Passageways between the lakes and the Gulf develop into tidal channels that carry flow back and forth between lake and sea as the tide fluctuates. Fresh-water environment changes to brackish and then to saline. The area of former deltaic sedimentation becomes a shallow bay across which the barrier beach moves inland.

In areas where subsidence is slow or negligible, the anastamosing or braided pattern of bifurcating and re-joining passes remains visible except where actually destroyed or covered by other agents. Aerial photograph study shows that this pattern also exists in other areas along the coast of Louisiana where distributaries of the Mississippi River once flowed. Old channels, long since silted up and abandoned, are flanked by natural levees which stand above the marsh and enclose adjacent inter-levee low areas. The levees slope under the marsh downstream but may be distinguished for some distance by vegetative trends. In many cases, these old channels act as tidal streams and carry brackish water back and forth in response to fluctuations in Gulf level.
APPLICATION OF PRINCIPLES
TO GEOLOGIC HISTORY OF THE LOWER DELTA

Through the application of hydraulic and sedimentary principles, it has been shown that streams tend to concentrate discharge in one channel in order to attain maximum efficiency of flow. This is made possible through the abandonment of the least efficient passes, a "survival of the fittest" so to speak. The tendency to eliminate unnecessary channels is taking place in Cubits Gap Area where total discharge from the river into the area has not changed appreciably since 1862. This tendency to concentrate flow is taking place in the crevasse area of the Jump where total discharge has greatly diminished since 1839. This same tendency to concentrate flow by the abandonment of unnecessary channels also takes place in areas of deltaic sedimentation where total discharge into the area is increasing.

This last situation is illustrated by an area in Plaquemines Parish immediately downstream from New Orleans, where a network of abandoned distributaries emanates from the vicinity of Belle Chasse (Plate IX). The branching, re-joining channels closely resemble the anastamosing stream pattern characteristics of Cubits Gap Area (Fisk, 1947, Vol. II, Plate 4, Figure 7). The natural levees, near Belle Chasse, are up to 300 feet wide, and reach heights of two and a half feet above general marsh level. They support dense tree growths. The adjacent inter-levee low areas consist of ponds and marsh which form sharp vegetative breaks with the trees on the levees. Downstream, the levees slope under the marsh and gradually lose
all trace of having once existed.

The topographic similarity between this channel network and that of Cubits Gap may also indicate similar geologic histories. Apparently a lower marshland or embayment once existed between Bayou Barataria and Bayou Terre Aux Boeufs (see Plate IX for location), at a time when the Mississippi River was flowing in a course due east from New Orleans into what is referred to as the St. Bernard Sub-delta (Russell, 1936, p. 114, and Fisk, 1952, p. 52). Flow from the river into this lowland probably began as a crevasse with rapid development of a large number of distributaries (Russell, 1936, p. 194). By the time this new deltaic front had built down to about Point a La Hache, many of the earlier formed distributaries upstream had closed, confining discharge to one or two main channels. The amount of discharge from the main river was obviously increasing. From about Point a La Hache downstream, channel bifurcations gave rise to larger distributaries such as Bayou Grande Chenier, Grande Bayou and others which were progressively abandoned as the main channel moved southeastward.

In the vicinity of Empire, a series of buried beach ridges, ten to twelve feet below marsh level, trend southwestward and converge toward Pt. Chenier Ronquille where they are found at the surface (Plate IX). Apparently the difference in elevation at the two localities is due to the higher rate of subsidence nearer the river. Despite the increasing depth of burial, from Pt. Chenier Ronquille toward the river, these old ridges determine the present drainage pattern of the superimposed tidal channels which flow in the old swales.

The ridges were probably formed when the mouth of the river was near Empire, much in the manner that similar ridges are forming today at the mouths of the Sabine, Appalachian and Brazos Rivers (Odom, 1953).
Prolonged periods of low river stage would expose the river mouth and adjacent coast to wave action and a beach would form. During the following flood stage sediment would be deposited seaward of the newly-formed beach protecting it from subsequent wave action. Reworking of the new material would create another beach ridge seaward of the first. Down the coast the alternating seasons of deltaic sedimentation and wave action associated with high and low river stage would be less and less effective, and normal beach conditions would exist.

Perhaps the ridges represent a period of time, say fifty years, when the river, at flood stage, could scarcely build seaward and was dominated by waves until it eventually acquired more discharge from upstream closing of distributaries and abandonment of the St. Bernard river course. The domination or partial domination of the river mouth by waves during low river stages could have been brought about by a sudden rise in sea level or by a large-scale drought which temporarily reduced the power of the stream to build seaward.

With further concentration of discharge, the more mature channel upstream from Point a La Hache must have enlarged considerably and at the expense of its banks. Slumping and caving widened the channel and natural levee deposits began to be laid down on the adjacent marsh and levees of the old distributaries. Boreholes in the right and left banks of the present river levees, from Belle Chasse down to Point a La Hache, show that the levees consist of tough, oxidised, silty clay, five or more feet thick which, in places, overlie old marsh deposits. The destruction or burial of old topographic features adjacent to the growing river would account for the fact that no traces of pre-European cultures have been found on the banks of the present day river, although many mounds and artifacts have been located on the levees of the original distributaries a short distance from
the Mississippi.

Upstream from New Orleans, the Mississippi River has developed a mature meander pattern which gradually dies out eastward along the old St. Bernard course. The present river below New Orleans flows in a relatively straight course because it has not had the time to develop such a pattern in the type of material through which it flows. The tendency to meander is, however, present. River reconnaissance at low stage reveals the presence of point bars forming on the inside of the gentle river bends. The writer had great difficulty landing a shallow draft boat in such places where the bottom sloped off very slowly. Invariably the banks opposite are steep and being undercut by the stronger current. In many places, artificial levees have been destroyed by bank erosion, necessitating the construction of new ones set back from the river. The influence of bank material on the rate of meander development is seen in that stretch of the river from a point about three miles upstream from Empire to a point about three miles downstream from Buras (Plate IX). Here the river has formed its two bends farthest downstream. Here also, it flows through the soft erodible sands and silts of the buried beach ridges. These bends are located on the northern and southern boundaries respectively, of the area of these buried ridges.

West of the Mississippi River, Bayou Barataria marks the course of a former river channel having extremely well developed meander bends (Plate IX). The size of the bends and the width of the abandoned channel indicate that it was probably not carrying all of the discharge of the Mississippi system. Obviously, the meander pattern is much more mature than that shown anywhere along the river below New Orleans today. This, in addition to borehole evidence, makes it appear that Bayou Barataria once
carried a large amount of flow into the Gulf prior to the time of occupation of the present channel. The last downstream trace of Bayou Barataria disappears along the northern edge of Barataria Bay. If the history of this channel is duplicated by that of the present river below New Orleans, some distance downstream, the Barataria meanders became less developed, and finally, bifurcation gave rise to several passes. Much of the evidence probably lies deeply buried today. It can certainly be inferred that Bayou Barataria once extended much farther seaward than the present coast of Louisiana, and that subsidence and wave action have destroyed surficial evidence of its sub-delta.
CONCLUSIONS

Summary

Local conditions of sea currents or steep continental slopes can be extremely important, but most river mouths are embayed because the rivers have not carried enough sediment to build seaward in the face of rising sea level. The fact that some small rivers, like the Trinity and Guadalupe of Texas, have just recently filled enough of the embayed portion to acquire seaward moving arms or fronts probably indicates that the over-all rate of sea level rise has decreased in relation to the capacity of rivers to build deltas. If worldwide conditions remain stable for, say, three hundred years, many of today's estuaries will become protruding deltas.

Conceivably, sea level rise since the last glacial stage may have once been sufficiently rapid to create an embayment at the mouth of the Mississippi River which extended far upstream, perhaps beyond Baton Rouge, Louisiana (Fisk, 1952, p. 63). At any rate, the Mississippi has, for a long time, been winning its battle with the sea. The combination of such factors as subsidence, continental slope, climate, tide, ocean current, wind, river gradient and discharge, type of alluvium, etc., associated with the delta of the Mississippi River, is undoubtedly different from that of any other delta in the world. Other rivers have achieved deltas, but not like that of the Mississippi, which has been able to form a single channel paralleled by two narrow land strips protruding far out into the sea where it finally splits up to give a "bird's foot" appearance.

Other deltas have main channels which build seaward for a while
but are rapidly abandoned as the river, upstream, cuts through one bank and forms a new channel to the sea (Fisk, 1952, p. 96). This process, diversion, has not been elaborated on since it rarely occurs in conjunction with the latest sub-delta of the Mississippi. Diversion is a common phenomenon in rivers characterized by coarse sediment and high current velocity. No one channel is able to achieve or even approach an optimum form ratio under such sedimentary conditions, and as the river builds seaward, the loss in gradient quickly accentuates the inefficiency of the channel. Upstream, shoaling by the river in an attempt to raise its water surface and thereby its hydraulic gradient, is suicidal. The channel becomes obstructed and during flood stage, the river tops its banks and seeks a shorter route to the sea.

The Rio Grande River, which is characterized by very coarse sediments in its lower reaches, has thus diverted its flow many times as can be seen on maps and aerial photographs. Strangely enough, most of the diversions have taken place within a limited geographic area near Brownsville, Texas. Possibly along this stretch of the Rio Grande, maximum stage difference and hydraulic gradient have always reached a critical point or relationship when the river had built a certain distance seaward. Thereafter, diversion was inevitable. Near the mouth of such a delta, diversion could not occur because maximum stage difference and therefore hydrostatic head, are not adequate.

Diversion, in another form, occurs when a river encroaches upon a former channel or some other river and finds a more efficient route to the sea. Fisk (1952, p. 99) employs this method of diversion in attempting an interpretation of the history of the Mississippi River.

The ability of the Mississippi River to establish and maintain
one channel extending so far beyond adjacent shorelines is due mainly to the fine-grained character of its alluvium. The ability of the sediment to maintain stable banks and develop channels of relatively high form ratios has prevented the river from acquiring high bed-load through bank caving. Thus the channel has not been obstructed upstream. In addition, the maximum stage difference of the Mississippi River, say, a hundred miles upstream from its mouth, is not nearly as high as it is on rivers having loads of coarse-grained sediments. Therefore, the hydrostatic head necessary for cutting a new river course will be found relatively far upstream. For these reasons, the writer believes that under conditions similar to those of today, the Mississippi in the past has tended to concentrate flow in one channel which built far out into the sea before being abandoned through the relatively rare process of diversion far upstream.

Through extensive field work and library research, the writer has attempted to assimilate and employ basic principles in the study of deltaic sedimentation in a limited area of the lower Mississippi Delta. Although the hydraulic and sedimentary variables change frequently from one river to another, these principles can be applied anywhere in the interpretation of the processes and geologic history of any specific alluvial or deltaic region.

**Recommended Research**

The age, shape, thickness and nature of the delta of the Mississippi have often been speculated upon, but few facts have been brought forward. Although oil companies have drilled hundreds of wells in the region, the available logs do not describe the sediments at the shallow, critical depths. Some limited amounts of data have been acquired and interpreted (Fisk, 1954).
The sub-deltaic complex built by Cubits Gap Crevasse is probably a miniature copy of the Mississippi Delta proper. In working with simple equipment, the writer was able to obtain only very shallow subsurface information. Yet, even this showed a consistency in sediment zones which could be definitely related to specific environments and modes of origin. Unfortunately, boreholes\(^1\) never penetrated beyond the coarse-grained bar material into the fine-grained, marine, pro-delta sediments. Deep boreholes, say 50-80 feet, could probably penetrate the bar and pro-delta material and reach what perhaps could be identified as the bottom of Bay Rondo before the crevasse. Possibly water content and faunal analyses of the fine sediments with increasing depth would be informative. Certainly a structural contour map and an accurate isopachous map would yield much concerning the rate of subsidence and any possible shift in the zone or zones of maximum subsidence.

Actual field study of sedimentation should ideally be accomplished by daily observations over a period of several months. Aerial photographs, plane table surveys, bar traverses, grain-size and faunal analyses, salinity readings, study of bedding in undisturbed samples, current velocity readings and variations with respect to river stage, wind and lunar tide, etc., would furnish the answers to many questions.

Where field examples of active alluvial and deltaic processes can be found, they are preferable to laboratory models for obvious reasons. To provide a comparison of the topographic forms and dominant processes between a delta of fine-grained sediments and one of coarse-grained sediments, the writer suggests that the above observations be made wherever an active delta

\(^1\)Boreholes below 30 feet were extremely difficult to drill by hand in the relatively coarse sediments.
can be found having conditions different from those of the lower Mississippi and, if possible, unaffected by the works of man.

From experience, the writer can state without qualification that future research of this nature will accomplish very little without an organized and integrated program of intensive field work supported by well equipped and well manned laboratories.
SELECTED BIBLIOGRAPHY

Alexander, B. S. (1875) Improvement of mouth of the Mississippi River, 44 Cong., 1 sess., H. Doc. 1, Appendix S10, 948-956.


Burwell, Wm. M. (1874) Memoir of the Delta Canal, from the Mississippi River below St. Philip, into the Gulf of Mexico, near Isle au Breton, Appendix R 15 b, Report, Chief of Engineers for 1874: 792-801.


Dent, Elliot J. (1921) Notes on the Mouths of the Mississippi River, Unpublished manuscript from U. S. Engineers Office.


________ (1952) *Geological Investigation of the Atchafalaya Basin and the Problem of Mississippi River Diversions*, vol. 1, Vicksburg Miss., Waterways Experiment Station, 145 pp.


Fowler, Major (no date) *The Development of the Passes of the Mississippi River*, Reproduced from a typewritten copy in the library, Waterways Experiment Station, Vicksburg Miss.

Friedkin, J. F. (1945) *A Laboratory Study of Meandering of Alluvial Rivers*, Vicksburg Miss., Waterways Experiment Station, 39 pp.


Hjulstrom, Filip (1934-35) Studies of the Morphological Activity of Rivers
as illustrated by the River Pyris, Bull. Geol. Inst., Univ. Upsala,
25: 221-525. No. 4.

_________ (1939) Transportation of Detritus by Moving Water, from a
symposium, Recent Marine Sediments edited by Parker D. Trask, Amer.
Assoc. Petr. Geol., Tulsa, Okla.

Holle, Chas. G. (1951) Sedimentation at the Mouth of the Mississippi River,
Proceedings of Second Conference on Coastal Engineering, Houston,
Texas. Published by the Council on Wave Research, Part 2, ch. 10,
pp. 111-129.


Humphreys, A. A. and Abbot, H. L. (1861) Report upon the Physics and
Hydraulics of the Mississippi River; upon the Protection of the
Alluvial Region against overflow; and upon the Deepening of the
Mouths: based upon Surveys and Investigations made under the Act
of Congress Directing the Topographical and Hydrographical Survey
of the Delta of the Mississippi River, with such Investigations
as might lead to Determining the most Practicable Plan for securing
it from Inundation, and the best Mode of Deepening Channels at the
Mouths of the River, Philadelphia (J. B. Lippincott) U. S. A., Engrs.,
Prof. Paper No. 4. 490 pp.


Kisselii, John E. (1941) The Concept of the Graded River, Jour. Geology,
49: 561-588.


and Eden, E. W. (1940) Sand waves in the lower Mississippi

Latimer, W. K. (1854) The Mouths of the Mississippi, De Bow's Review, 17:
15-25.

Le Baron, J. Francis (1905) The Reclamation of River Deltas and Salt Marshes,
with discussion by E. L. Corthell, L. J. Le Conte, Richard Lamb and

Leighly, John B. (1932) Toward a Theory of the Morphologic Significance of

_________ (1934) Turbulence and the Transportation of Rock Debris by


Mississippi River Commission (1925) Results of Discharge Observations, 1878-1923.

_________ (1943) Stages and Discharges, Mississippi River and its Outlets and Tributaries, War Dept., Corps of Engineers, U. S. Army, Vicksburg, Miss. p. 223.

_________ (1947) Stages and Discharges, Mississippi River and its Outlets and Tributaries, War Dept., Corps of Engineers, U. S. Army, Vicksburg, Miss.

_________ (1951) Stages and Discharges, Mississippi River and its Outlets and Tributaries, War Dept., Corps of Engineers, U. S. Army, Vicksburg, Miss.


Ockerson, J. A. (1899) Improvement at Southwest Pass, Mississippi River, 55 Cong., 3 sess., H. Doc. 142, 34.


Quinn, James B. (1877) History of Attempted Improvements of the Mouth of the Mississippi River, 55 Cong., 3 sess., H. Doc. 142, 52-62.


Vogel, Herbert D. (1934) Movement of bed-load in a Forked Flume, Civil Engr., 4: 73-77. No. 2.


Waterways Experiment Station (1935) Studies of River Bed Materials and their Movement, with Special Reference to the lower Mississippi River, Paper 17, Vicksburg, Miss., Waterways Experiment Station. 161 pp.


(1939) Study of Materials in Suspension, Mississippi River, Tech. Memo. 122-1, Vicksburg, Miss., Waterways Experiment Station. 27 pp.


BIOGRAPHY

Frank A. Welder was born in Victoria, Texas, in 1923. He attended St. Joseph's High School of that city and graduated in 1940. During World War II, he served with the Army Air Force in the United States and Europe. In 1949 he received a B.S. in Geology from the University of Texas and two years later an M.S. from Louisiana State University. The following two and a half years were spent in research on the deltaic region of Louisiana. During this period he spent six weeks at sea with an oceanography expedition under the direction of Dr. Maurice Ewing of Columbia University. He also served the Attorney-General of the State of Louisiana in litigation involving the Mississippi River near Vicksburg, Mississippi.

At present he is associated with the Ground Water Branch of the U. S. Geological Survey in Central Texas.
Fig. 1 1838 DELTA OF THE MISSISSIPPI RIVER FROM THE ORIGINAL SURVEY BY A. TALCOTT 26 CONG., 1ST SESS., S. DOC. 7:447-559.
CHRONOLOGICAL DEVELOPMENT OF CUBITS GAP

SCALE

0 1 2 3 4 5

STATUTE MILES

SURVEY, Fig. 3 1877 FROM COAST CHART NO. 194, USC & G SURVEY, EDITION OF 1885.
FIG. 4  ABOUT 1903  FROM  COAST CHART NO. 194, USC & G SURVEY, EDITION OF 1914.
ISOPACH MAP OF CUBITS GAP SEDIMENTS

LEGEND

CONTOUR INTERVAL: 4 FT.

- - - - - PRESENT CHANNEL POSITIONS

SCALE

0 1 2 3
MILES
STAGE 2

CHANNEL EXTENSION AND BIFURCATION
SCHEMATIC DEVELOPMENT

LEGEND

- Exposed new land above mean low water
- Stage 1 contours superimposed on stages 1 & 3
- Stage 2 contours superimposed on stage 3
- Submerged middle ground bar
- Direction of current

FEET

SCOUR BETWEEN STAGES 1 & 2
DEPOSITION BETWEEN STAGES 1 & 2

COMPOSITE CROSS SECTION OF STAGES 1, 2 & 3

PLATE V
CONTOUR MAP OF RIVER BED

DEAD WOMAN PASS—TWENTY SEVEN PASS FORK CUBITS GAP AREA
SURVEYED JAN 29 1953

SCALE

FEET

LEGEND

HIGH WATER CHANNEL EDGE
LOW WATER CHANNEL EDGE
DIRECTION OF SURFACE CURRENT
RIVER BED CONTOUR LINES CORRECTED TO MEAN LOW STAGE
PROFILE LINES FROM WHICH CONTOURS ARE ESTABLISHED

NOTE: 2 FOOT CONTOURS OMITTED
CONTOUR MAP OF RIVER BED
DEAD WOMAN PASS—TWENTY-SEVEN PASS FORK
CUBITS GAP AREA
SURVEYED JUNE 5 1953

SCALE

LEGEND

- HIGH WATER CHANNEL EDGE
- LOW WATER CHANNEL EDGE
- DIRECTION OF SURFACE CURRENT
- RIVER BED CONTOUR LINES CORRECTED TO MEAN LOW STAGE
- PROFILE LINES FROM WHICH CONTOURS ARE ESTABLISHED

NOTE: 2 FOOT CONTOURS OMITTED
SCHEMATIC SHOWING CHANNEL ABANDONMENT

LEGEND

- [ ] WATER AT MEAN FLOOD STAGE
- [ ] BANK LIMITS AT MAXIMUM FLOOD STAGE
- [ ] CONTOUR LINES
- [ ] ORIGINAL BANK LIMITS OF STAGE 1 SUPERIMPOSED ON OTHER STAGES
- [ ] ENCLOSED DEPRESSION
- [ ] THALWEG & DIRECTION OF CURRENT
FORMER STREAM PATTERN OF PLAQUEMINES SUBDELTA