

Geologic Conditions Beneath the New Orleans Area

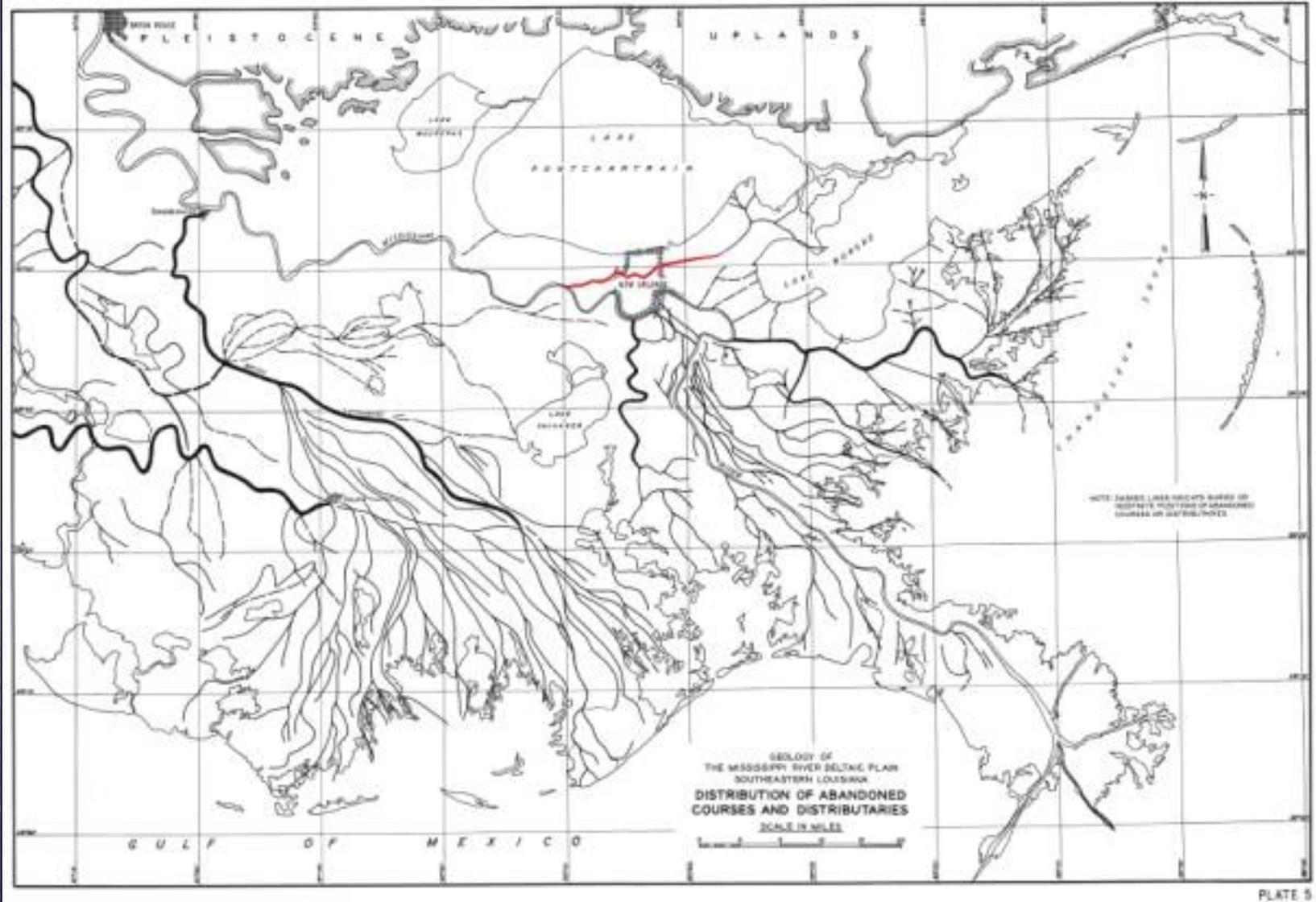
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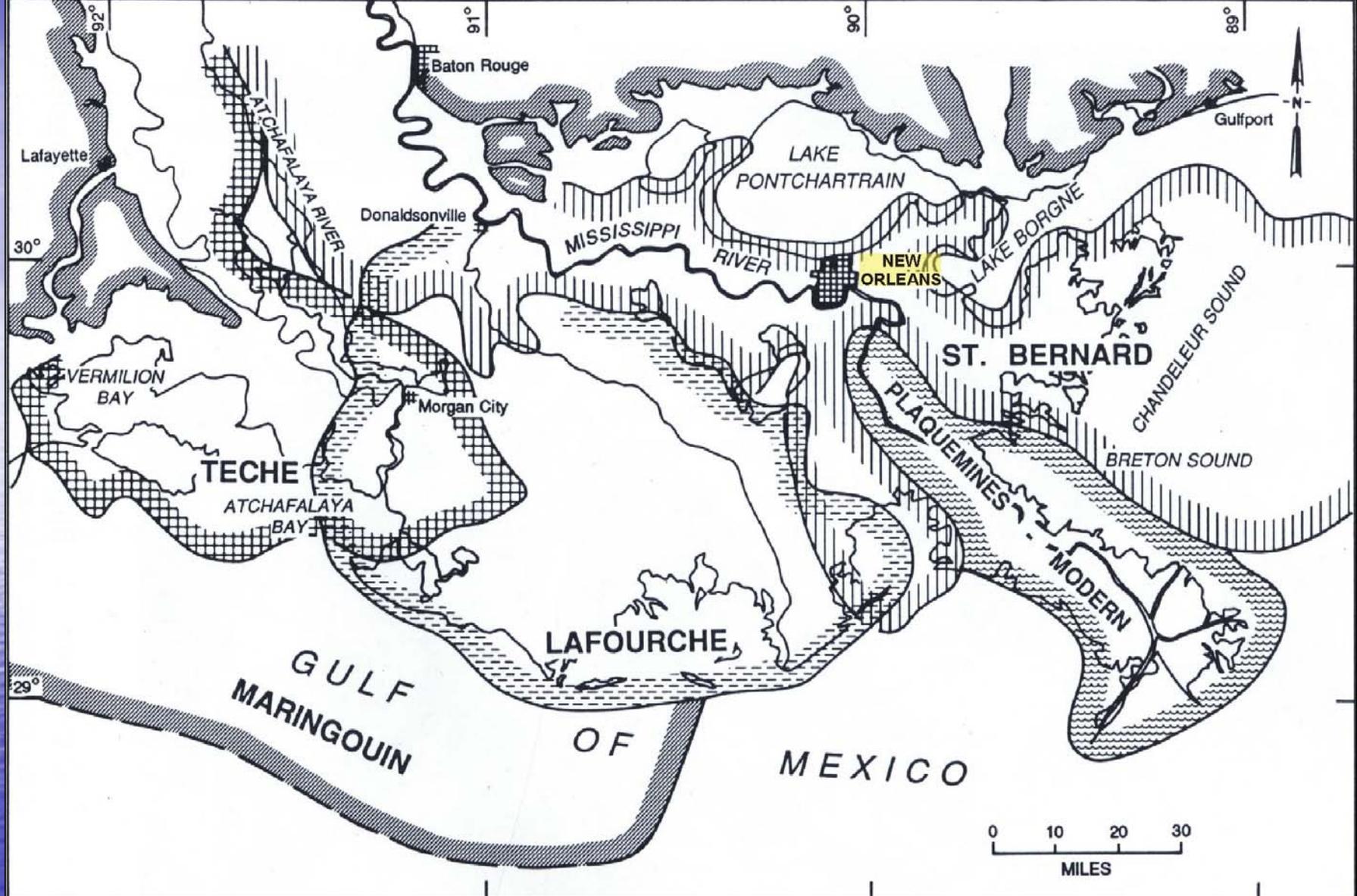
Natural Hazards Mitigation Institute

University of Missouri-Rolla

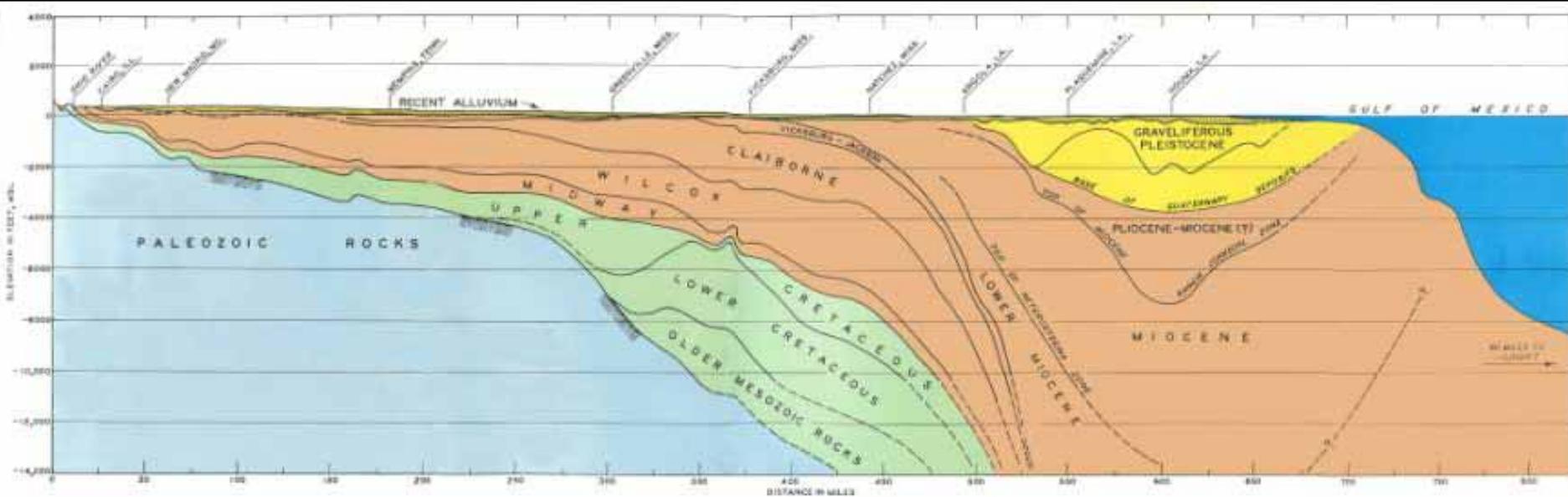




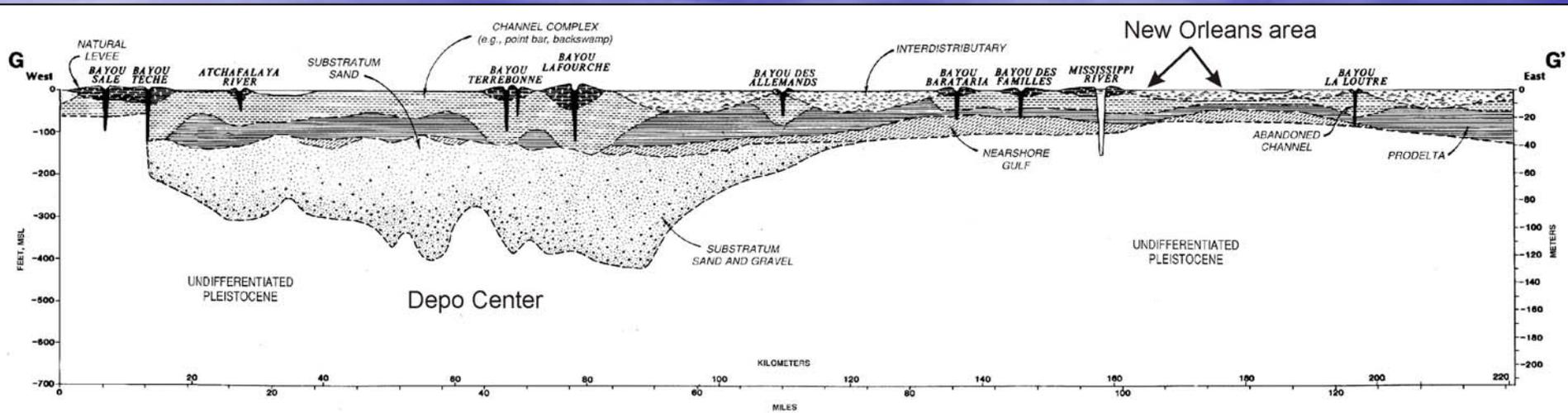
- Areal distribution of abandoned channels and distributaries of the Mississippi River. The **Metairie Ridge distributary channel** (highlighted in red) lies between two different depositional provinces in the center of New Orleans.



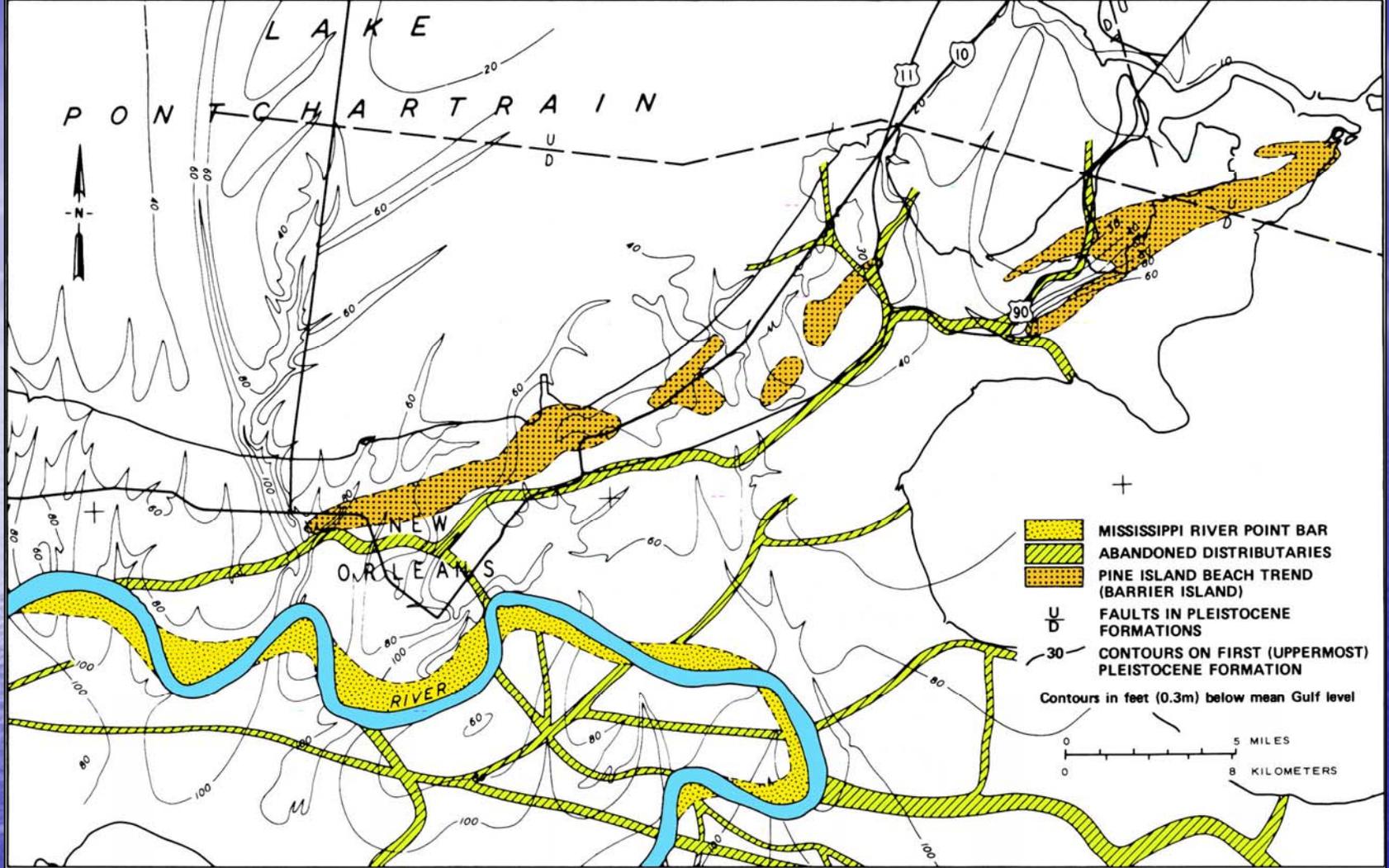
- Major depositional lobes identified in lower Mississippi Delta around New Orleans.



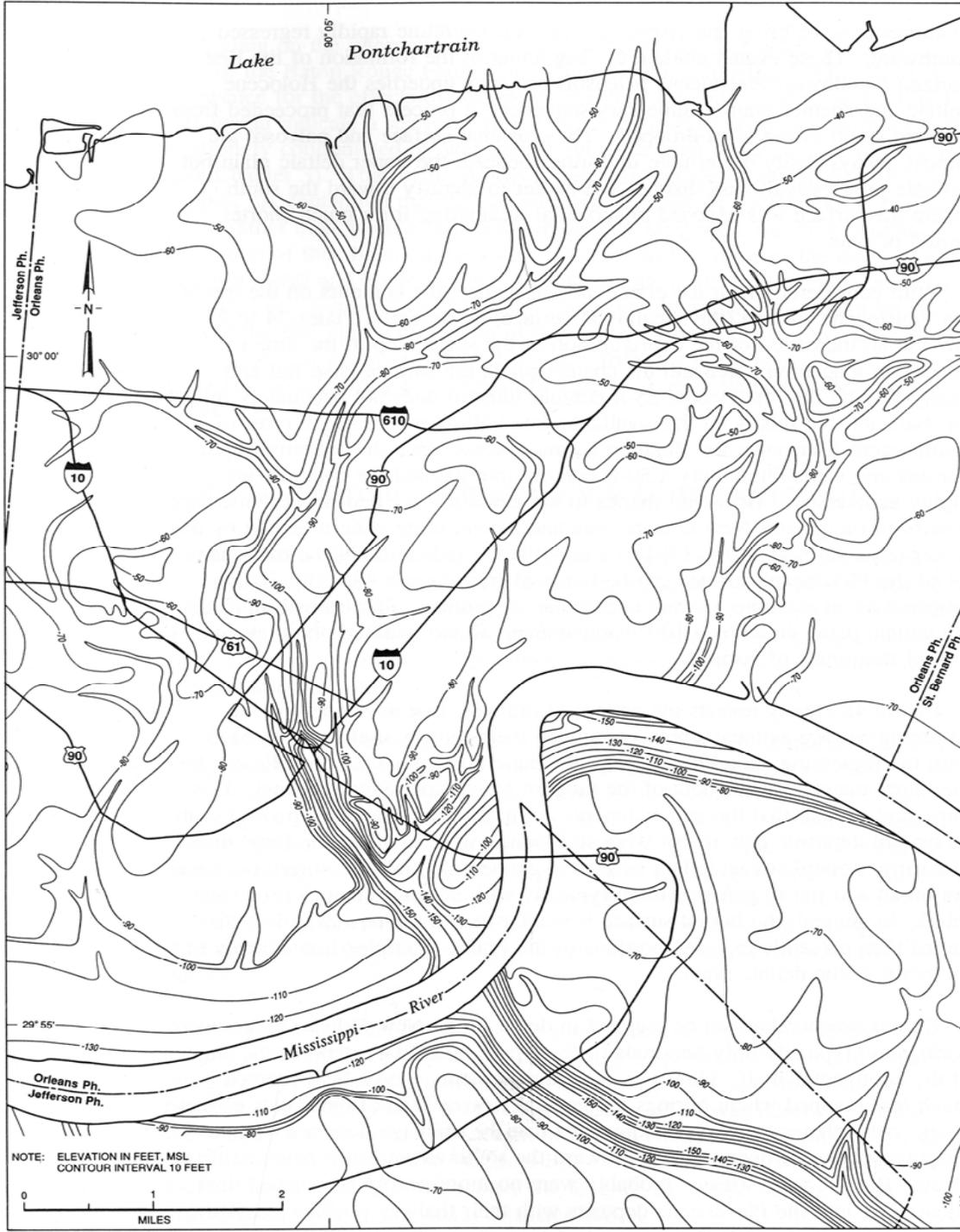
- North-south **geologic cross section** through the central Gulf of Mexico Coastal Plain, along the Mississippi River Embayment.
- Note the axis of the **Gulf Coast Geosyncline** beneath Houma, LA, southwest of New Orleans. In this area the Quaternary age deposits reach a thickness of 3600 ft.



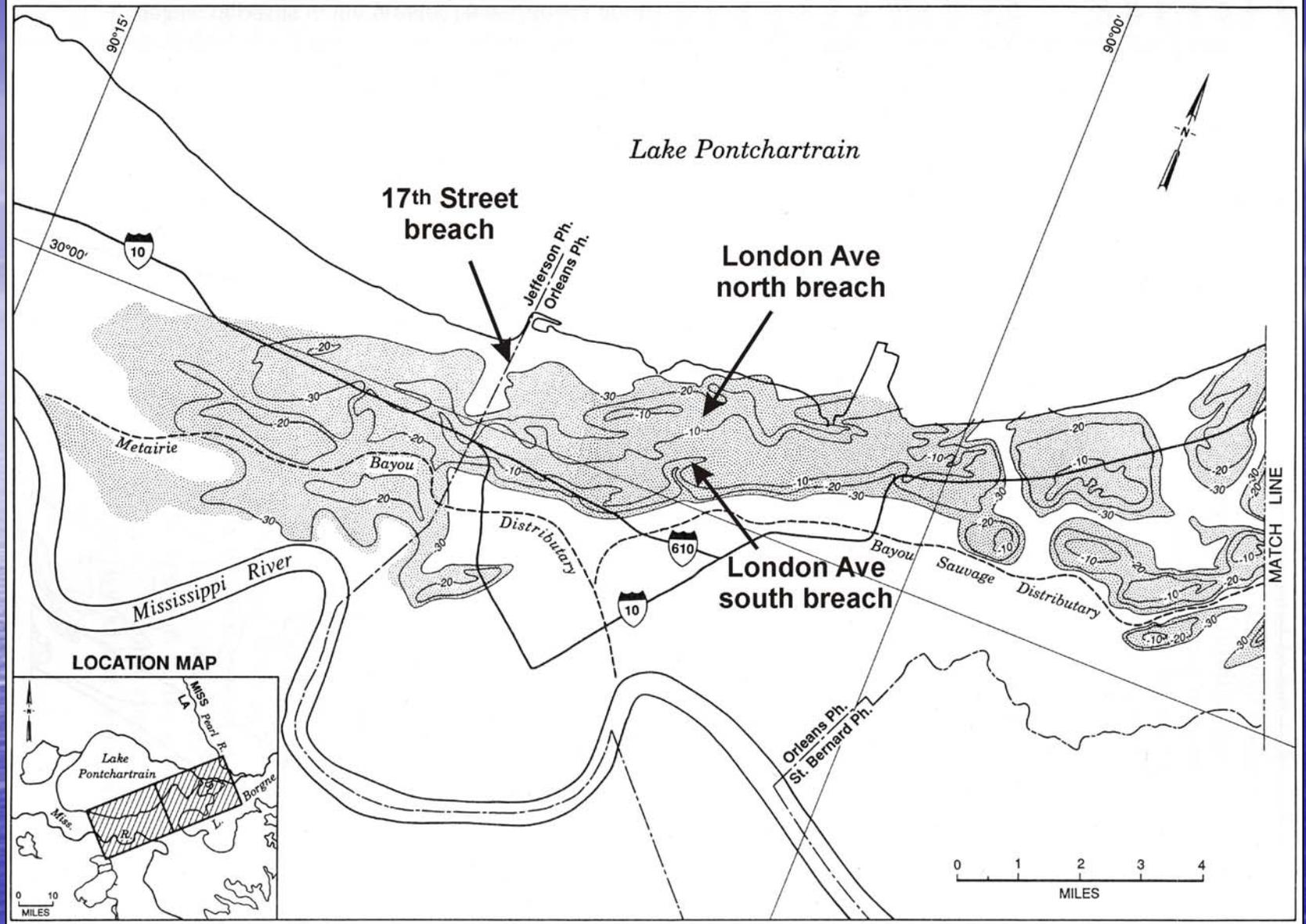
- Transverse cross section in a west to east line, across the **Mississippi River Delta** a few miles south of New Orleans, cutting across the southern shore of Lake Borgne.
- **New Orleans** is located on a relatively thin deltaic plain towards the eastern side of the delta's depositional center, which underlies the Atchafalaya Basin, west of New Orleans.



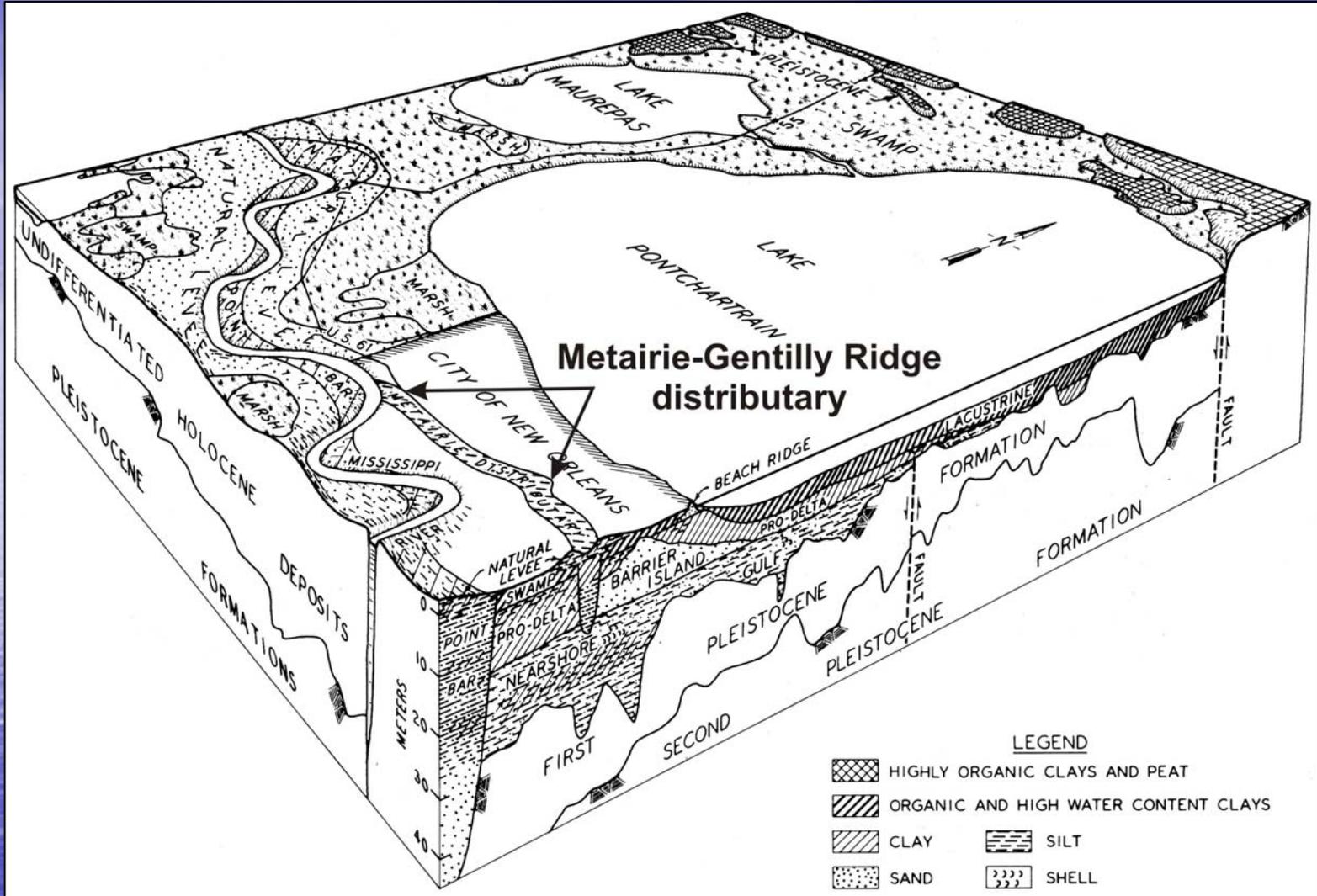
- Pleistocene geologic map of the New Orleans area. The yellow stippled bands are the principal distributary channels of the lower Mississippi during the late Pleistocene, while the present channel is shown in light blue. The Pine Island Beach Trend is shown in the ochre dotted pattern. Depth contours on the upper Pleistocene age horizons are also shown.



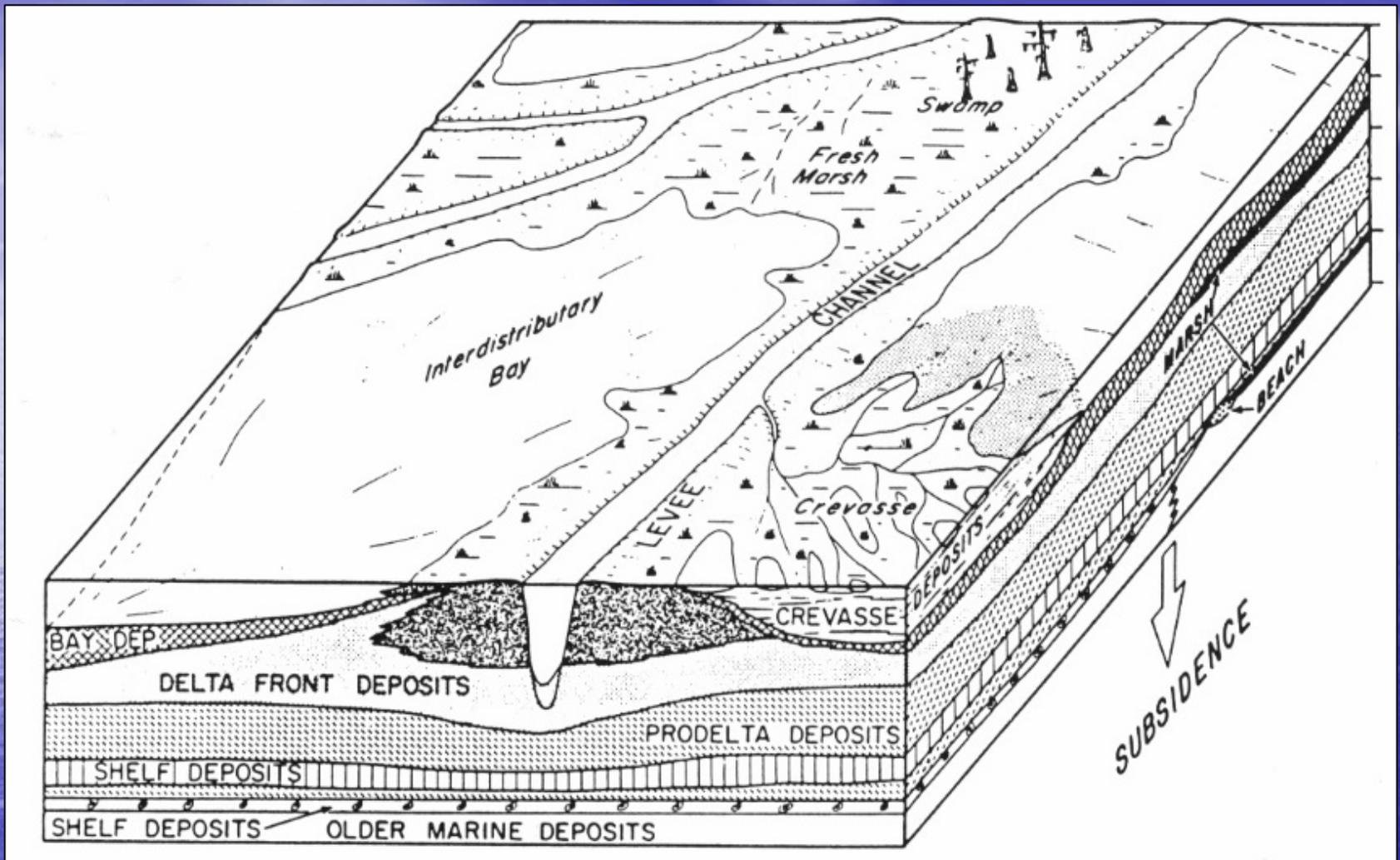
- Contours of the entrenched surface of the Wisconsin glacial age deposits underlying New Orleans.
- Note the well developed channel leading southward, towards what used to be the oceanic shoreline. This channel reaches a maximum depth of 150 feet below sea level.



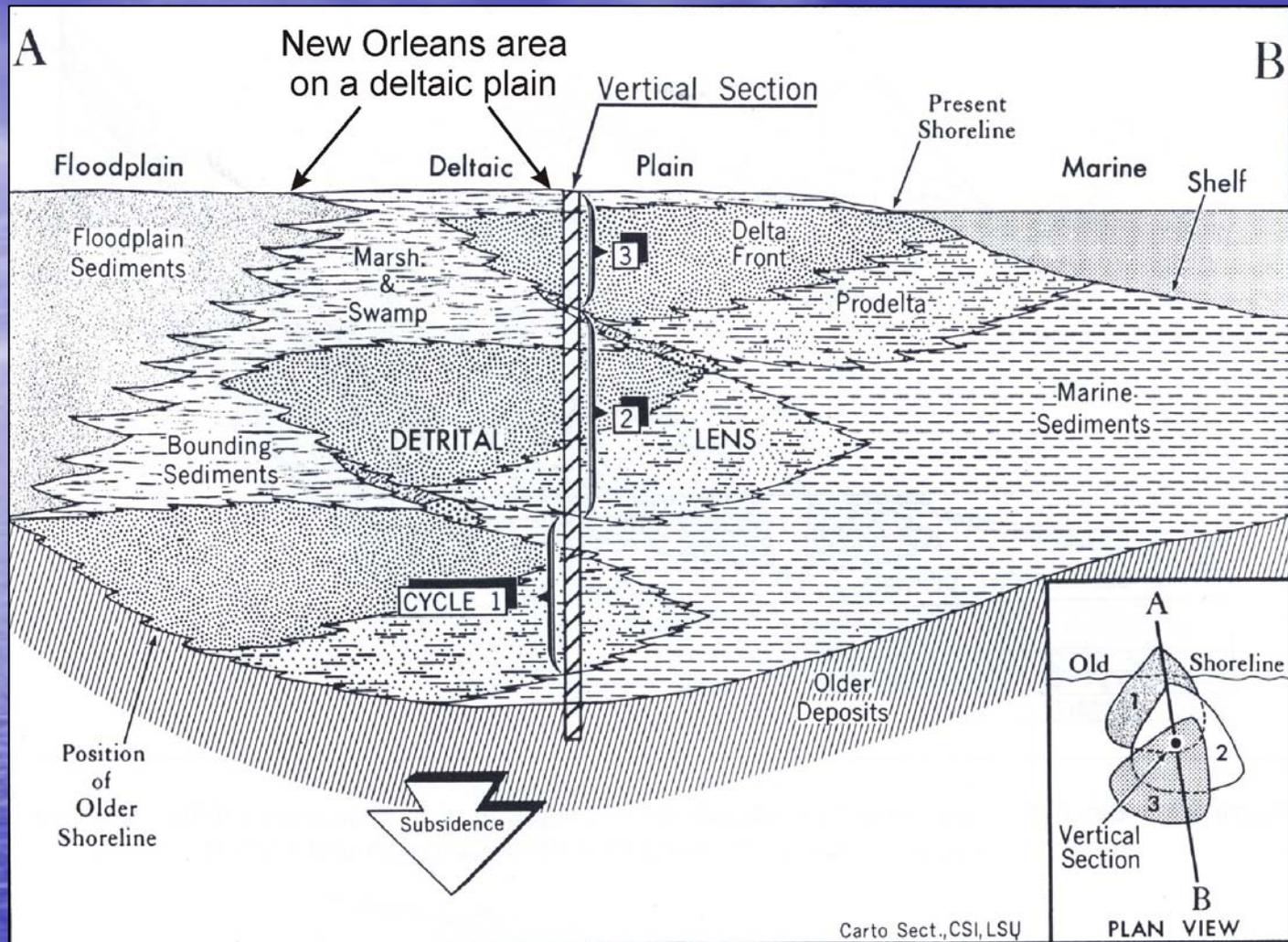
- Areal distribution and depth to top of formation isopleths for the **Pine Island Beach Trend** beneath lower New Orleans.



- Block diagram of the geology underlying New Orleans. The principal feature dividing New Orleans is the **Metairie distributary channel**, shown here, which extends to a depth of 50 feet below MGL and separates geologic regimes on either side. Note the underlying faults, beneath Lake Pontchartrain.



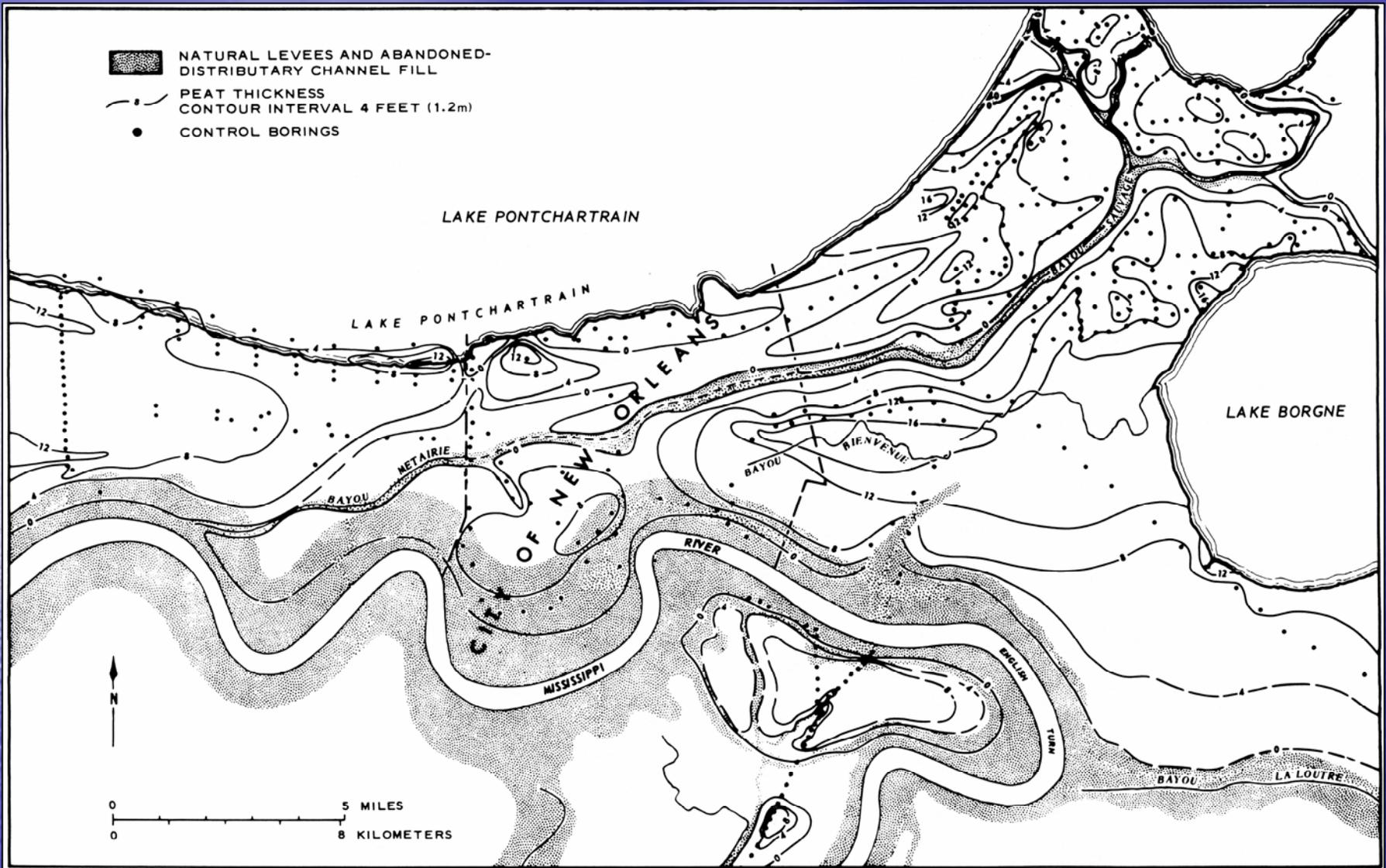
- Block diagram illustrating relationships between **subaerial and subaqueous deltaic environments** in relation to a single distributary lobe. The Lakeview and Gentilly neighborhoods of New Orleans are underlain by interdistributary sediments, overlain by peaty soils laid down by fresh marshes and cypress swamps.



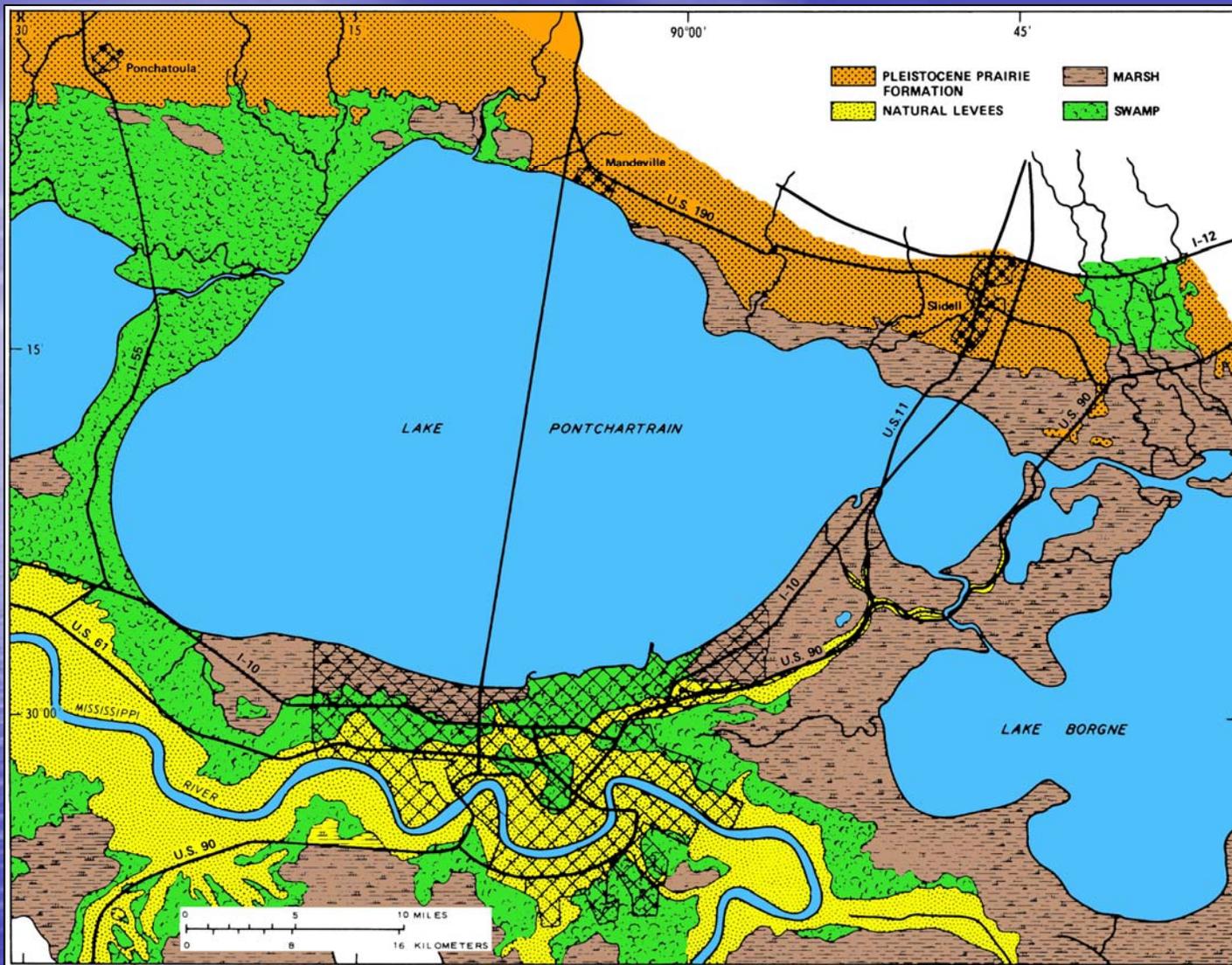
- **Sedimentary sequence** caused by overlapping cycles of deltaic deposition, along a trend normal to that portrayed in the previous figure. As long as the distributary channel receives sediment the river mouth progrades seaward.
- The Lakeview and Gentilly neighborhoods lie on a **deltaic plain** with marsh and swamp deposits delta front deposits closer to Metairie-Gentilly Ridge, the nearest distributary channel.



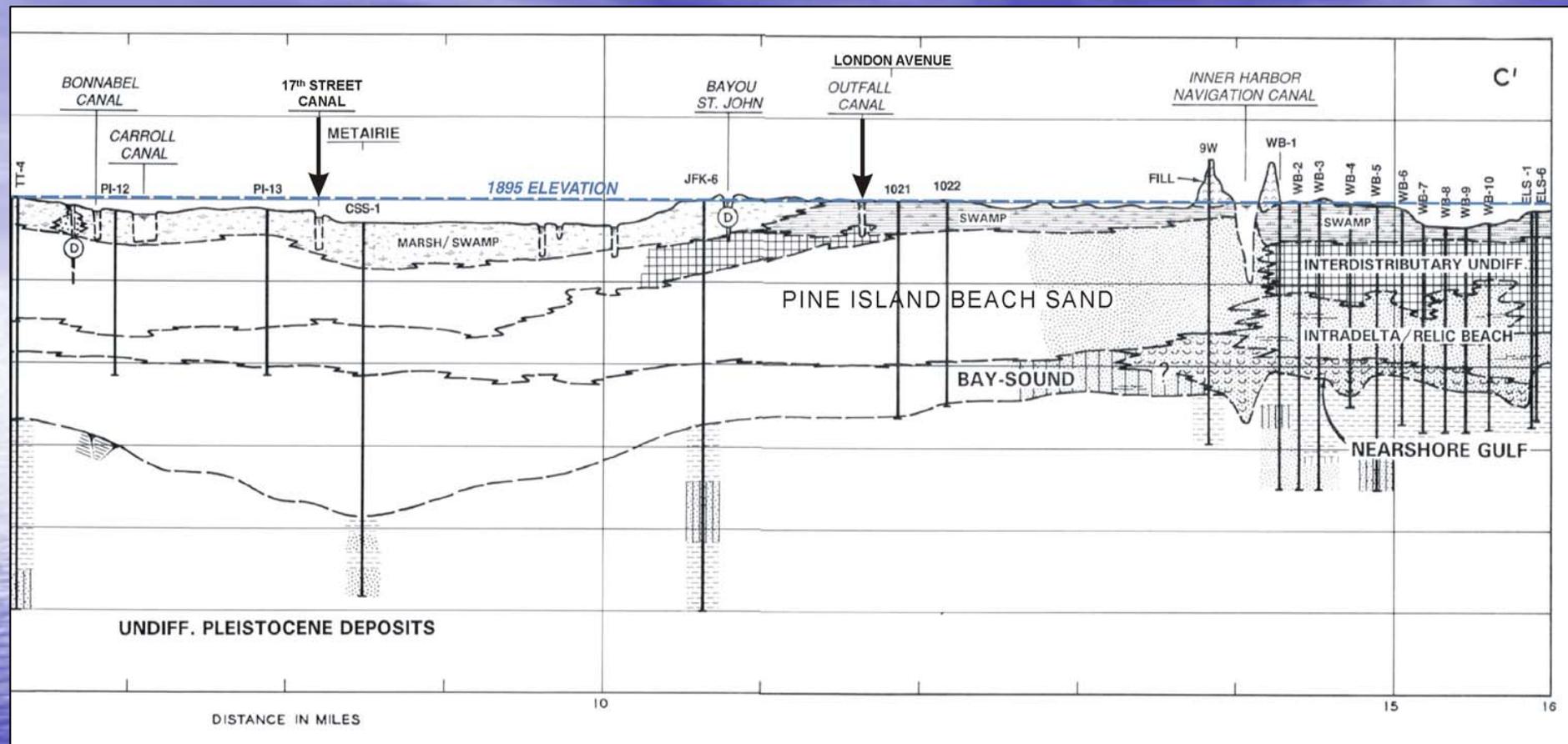
- Portion of the 1849 flood map showing the mapped demarcation between **brackish and fresh water marshes** along Lake Pontchartrain. This delineation is shown on many of the historic maps, dating back to 1749.



- Distribution and apparent thickness of surficial peat deposits in vicinity of New Orleans.



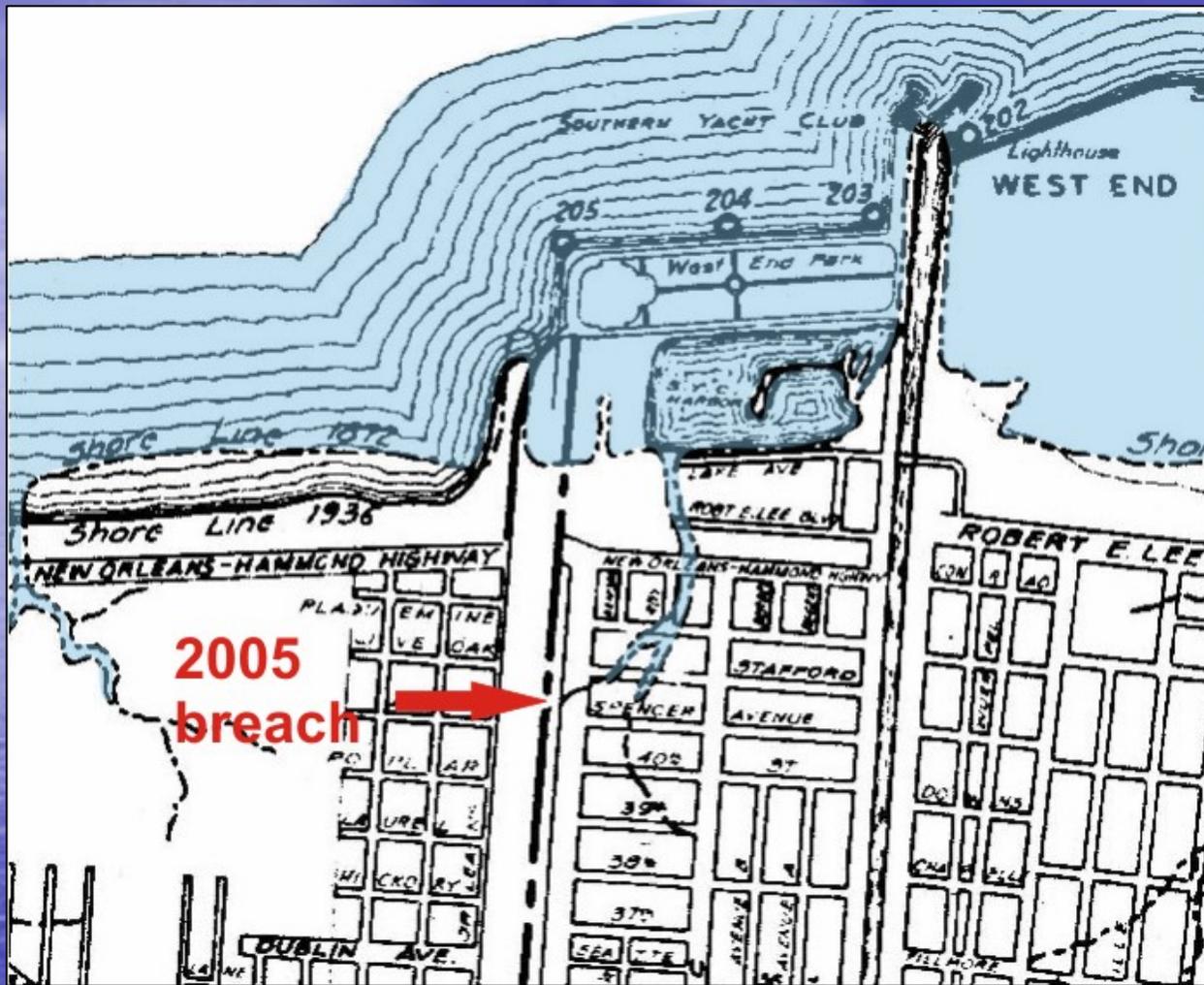
- Geologic map of the greater New Orleans area. The sandy materials shown in yellow are natural levees, green areas denote old cypress swamps and brown areas are historic marshlands. The stippled zone indicates the urbanized portions of New Orleans.



- Geologic cross section along south shore of Lake Pontchartrain in the Lakeside, Gentilly, and Ninth Ward neighborhoods, where the 17th Street, London Avenue, and IHNC levees failed during Hurricane Katrina on Aug 29, 2005. Notice the apparent settlement that has occurred since the city survey of 1895 (blue line), and the correlation between settlement and non-beach sediment thickness.



- Wood and other organic debris was commonly sampled in exploratory borings carried out after Hurricane Katrina throughout the city.
- This core contains wood from the old cypress marsh that was recovered near the 17th Street Canal breach. Organic materials are decaying throughout the city wherever the water table has been lowered, causing the land surface to subside.



- Overlay of 1872 map by Valery Sulakowski on the WPA-LA (1937) map, showing the 1872 shoreline and sloughs (in blue) along Lake Pontchartrain. Although subdivided, only a limited number of structures had been built in this area prior to 1946. The position of the 2005 breach along the east side of the 17th Street Canal is indicated by the red arrow.

17th St. OUTFALL CANAL LEVEE BREAK CROSS SECTION LOCATIONS



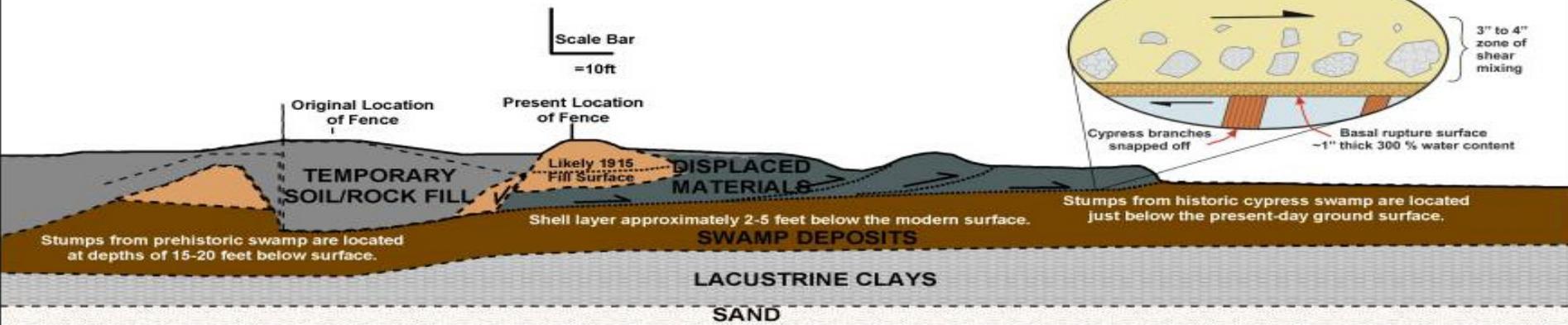
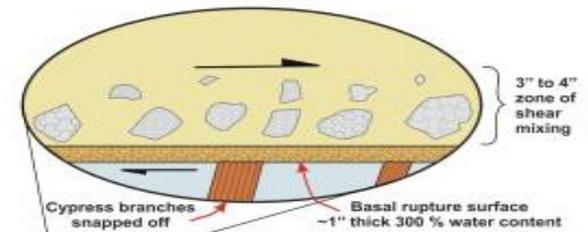
- Aerial photo of the 17th Street Canal breach site before the failure of August 29, 2005. The red lines indicate the positions of the geologic sections.

**17th St. Canal Levee Break Cross Section, South
After Construction of USACOE Temporary Embankment Fille and Sheet Pile Wall
-From Intact Levee Block To Yard With School Bus**

LEGEND

-  Materials From Translated & Intact Portions of Levee Embankment - Silty clays
-  Temporary Embankment Materials - Mainly crushed limestone
-  Displaced Materials - Mostly swamp deposits with peat and highly organic clays containing cypress wood & roots
-  Old Swamp Deposits - Layers of highly organic clay with peats, humus, cypress wood & roots, a layer of shells, and some silt/fine sand lenses.
-  Lacustrine Clays - Contains silt/fine sand lenses with crushed shells near the base of layer
-  Sand - Contains some fines and broken shells - Hole bottom @ 36'

DETAIL OF SLIDE PLANE

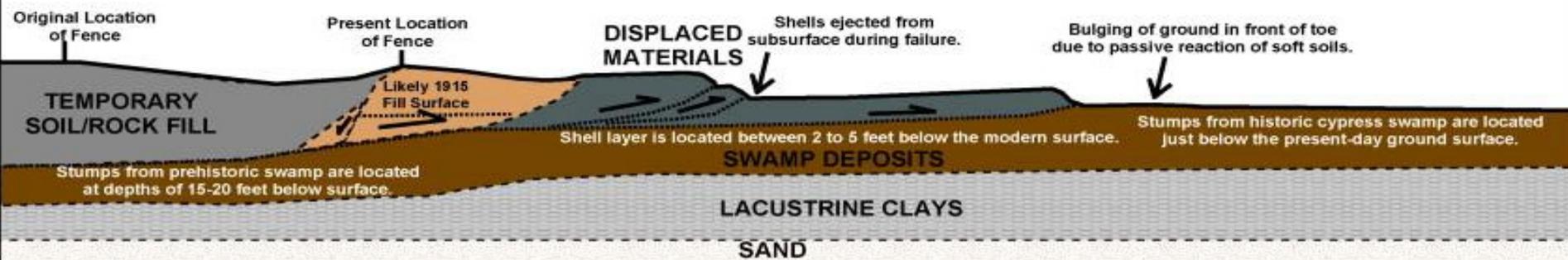
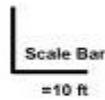


- West-to-east geologic cross section through the **17th Street Canal failure** approximately 60 feet north of the northern curb of Spencer Avenue, close to the yellow school bus. A detailed sketch of the basal rupture surface is sketched above right.
- The slip surface was about one inch thick with a high moisture content (watery ooze). A zone of brecciation 3 to 4 inches thick was above this. Numerous pieces of cypress wood, up to 2 inches diameter, were sheared off along the basal rupture surface.

17th St. Canal Levee Break Cross Section, North
-From Intact Levee Block Between Two Houses Affected By Failure

LEGEND

-  Materials From Translated & Intact Portions of Levee Embankment - Silty clays
-  Temporary Embankment Materials - Mostly crushed limestone
-  Displaced Materials - Mostly swamp deposits with peat and highly organic clays containing cypress wood & roots
-  Old Swamp Deposits - Layers of highly organic clay with peats, humus, cypress wood & roots, and some silt/fine sand lenses
-  Lacustrine Clays - Contains silt/fine sand lenses with crushed shells near the base of layer
-  Sand - Contains some fines and broken shells - Hole bottom @ 36'

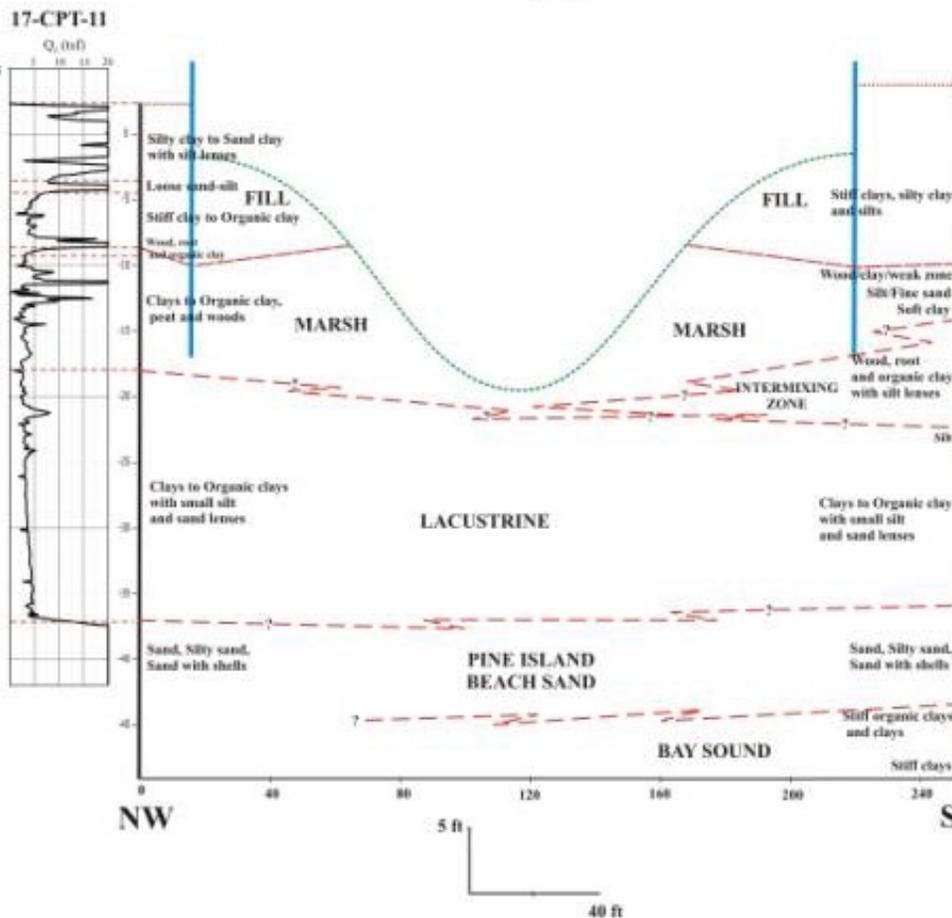


- West-to-east geologic cross section through the 17th Street Canal failure approximately 140 feet north of the northern curb of Spencer Avenue.
- Large quantities of bivalve shells were extruded by high water pressure along the advancing toe thrusts. Note the slight back rotation of the distal thrust sheet.

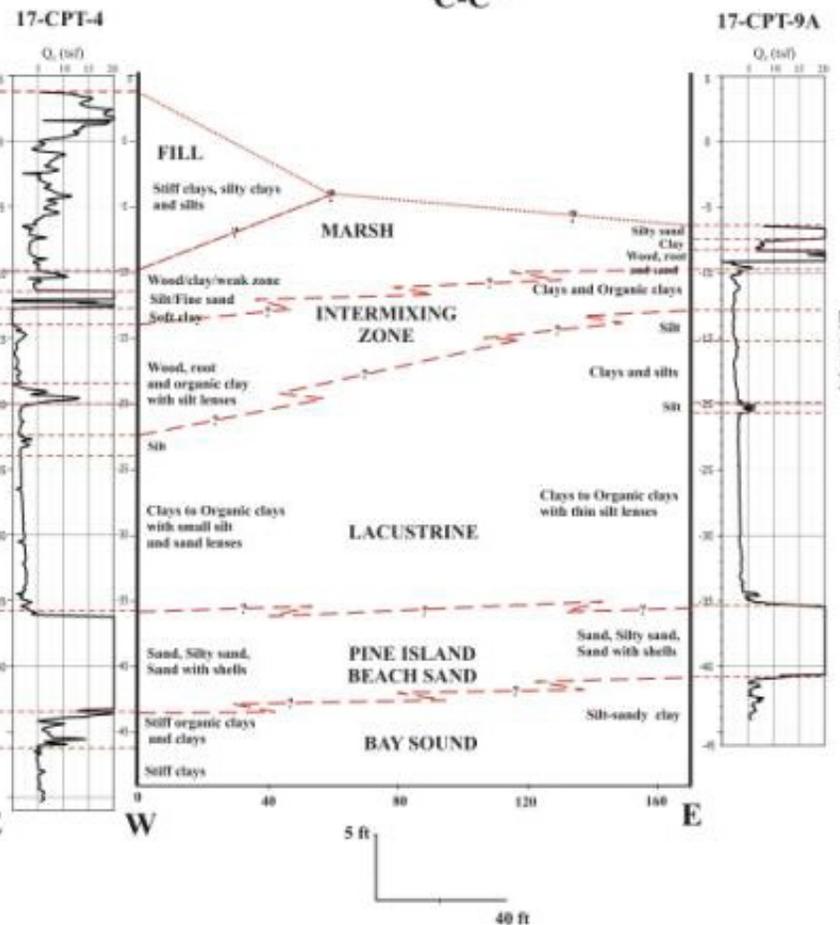


- Bivalve shells ejected by high pore pressures emanating from toe thrusts on landside of failed levee at the 17 Street Canal (detail view at upper left). These came from a distinctive horizon at a depth of 2 to 5 feet below the pre-failure grade.

17th Street Canal Cross-section
B-B'



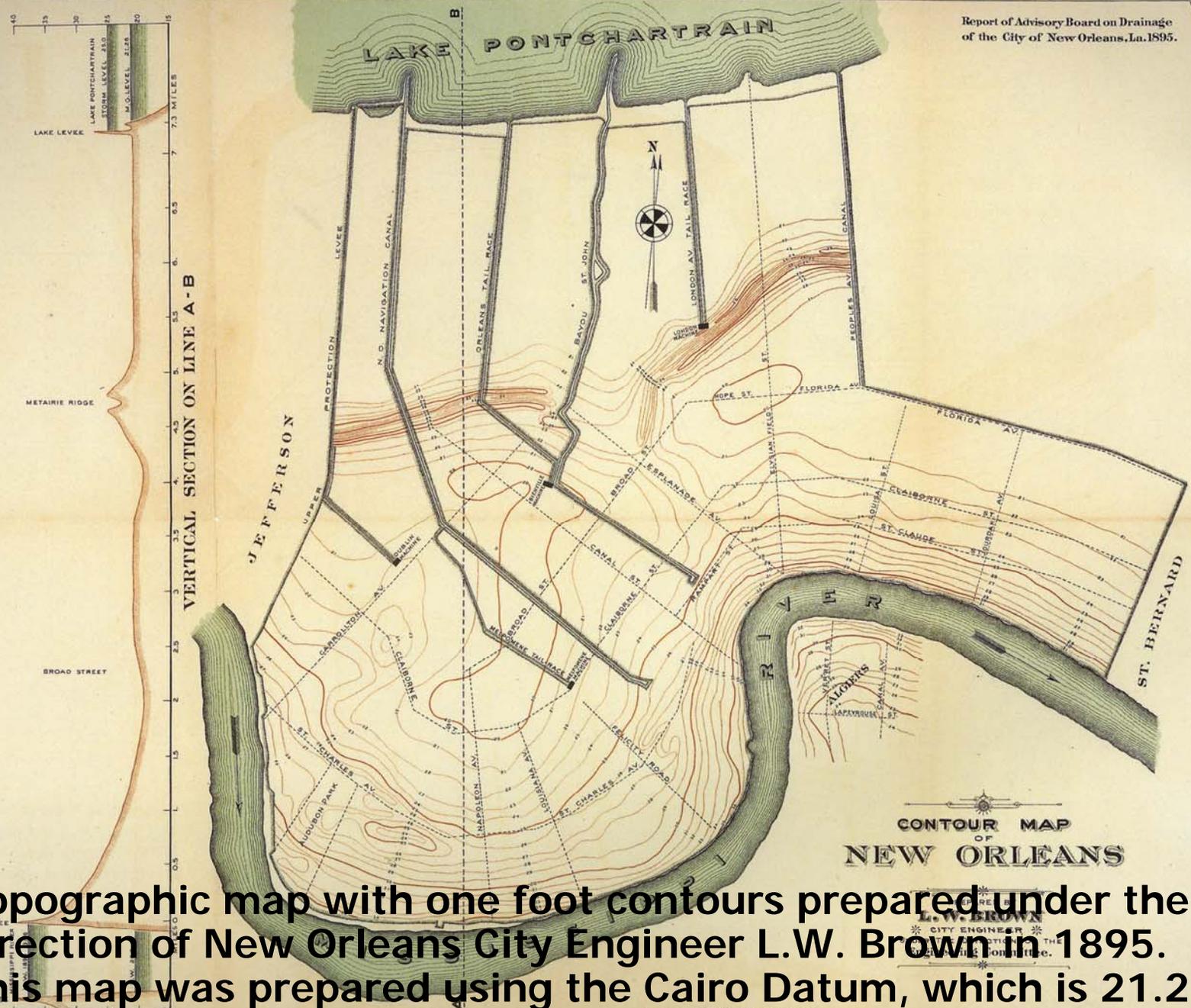
17th Street Canal East Bank Cross-section
C-C'



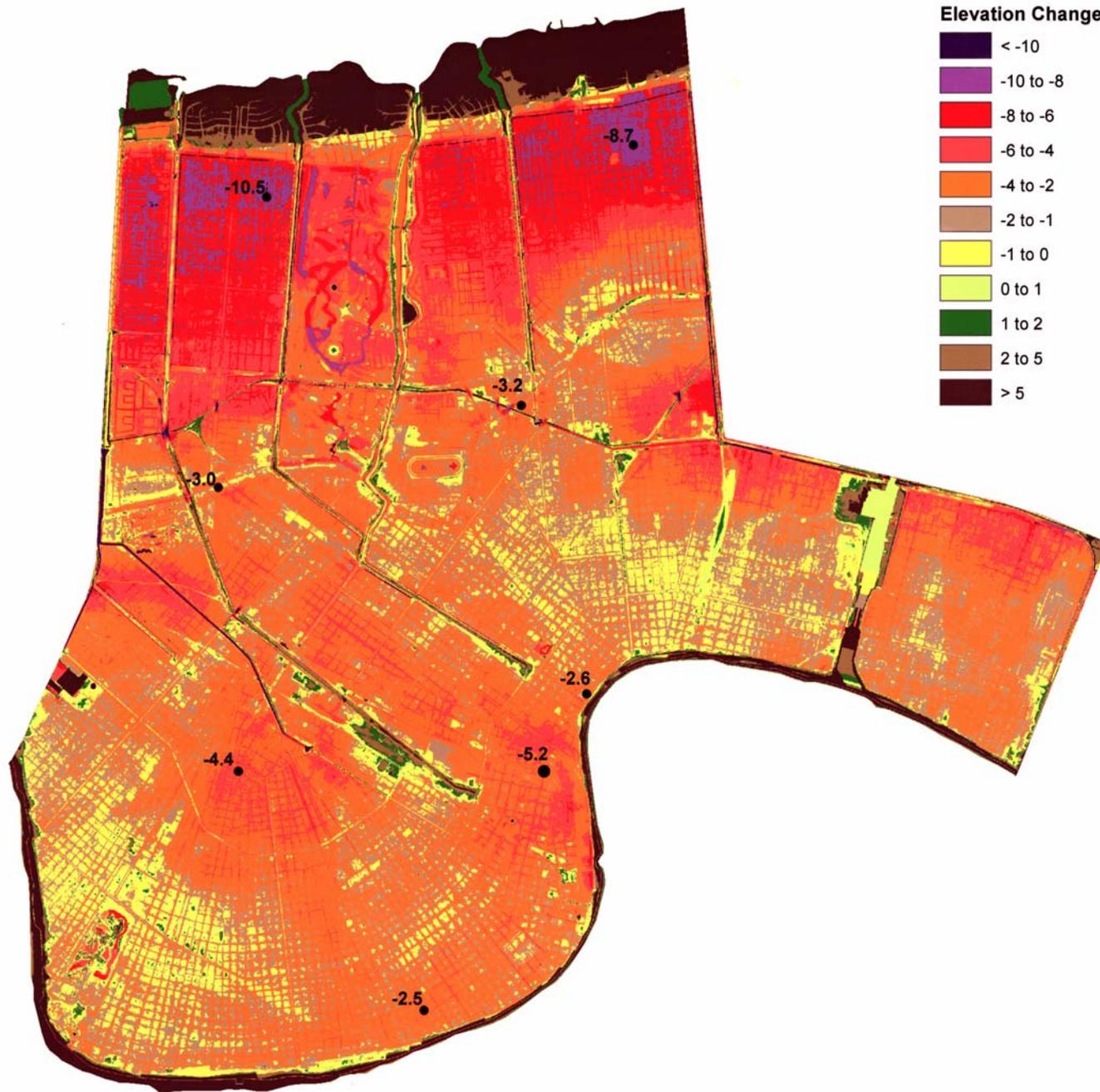
- Stratigraphic interpretations and cross-canal correlations in vicinity of the 17th Street Canal breach on August 29, 2005. The swamp much appeared to be thinning northerly, as does the underlying Pine Island Beach Trend. The lacustrine clays appear to thicken southward, as shown.
- The approximate positions of the flood walls (light blue) and canal bottom (dashed green) are indicated, based on information provided by the Corps of Engineers (IPET, 2006).

SOURCES OF GROUND SETTLEMENT

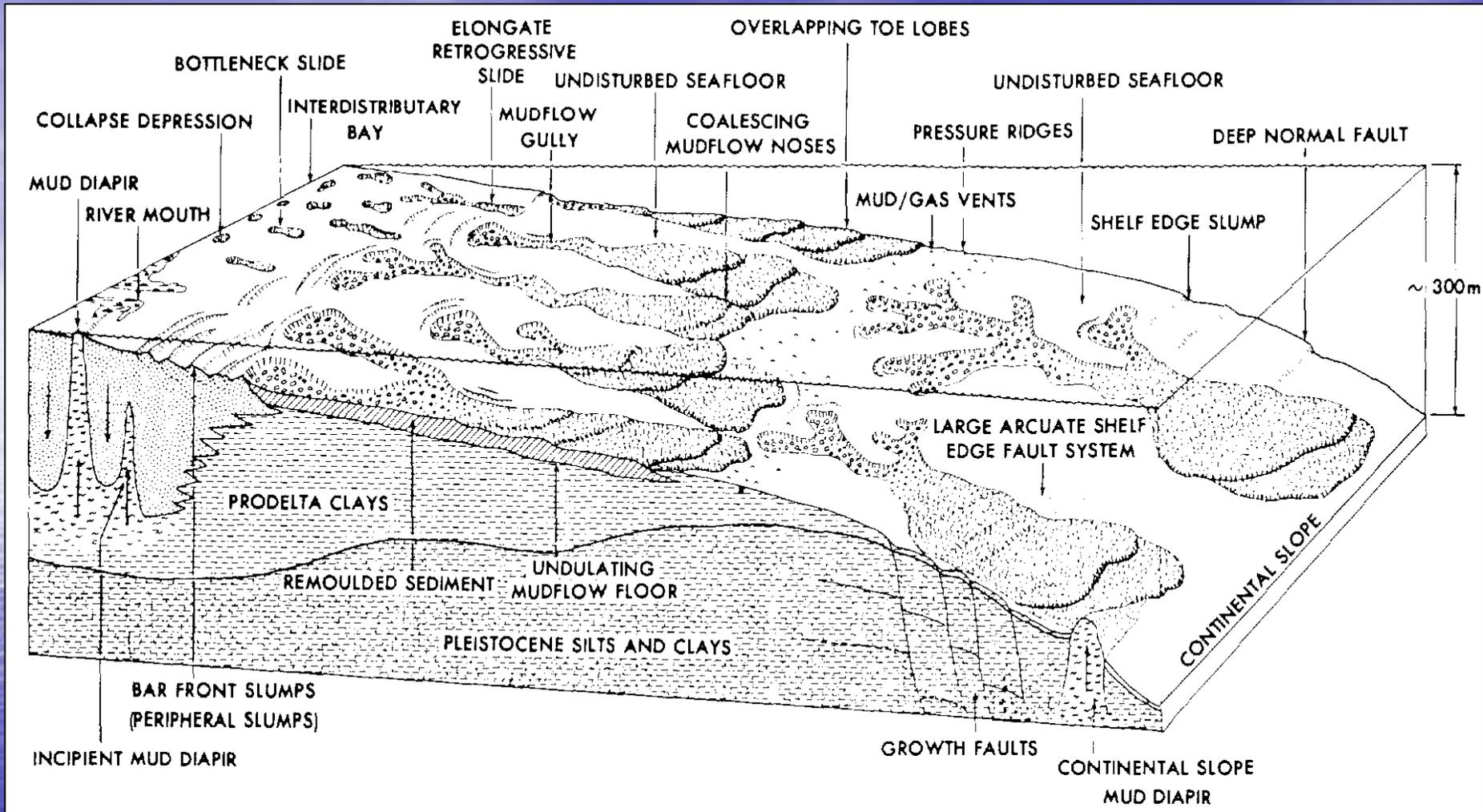
- **The causes of historic settlement are a contentious issue in coastal Louisiana**
- **There appear to be many different causes, summarized in the following slides**



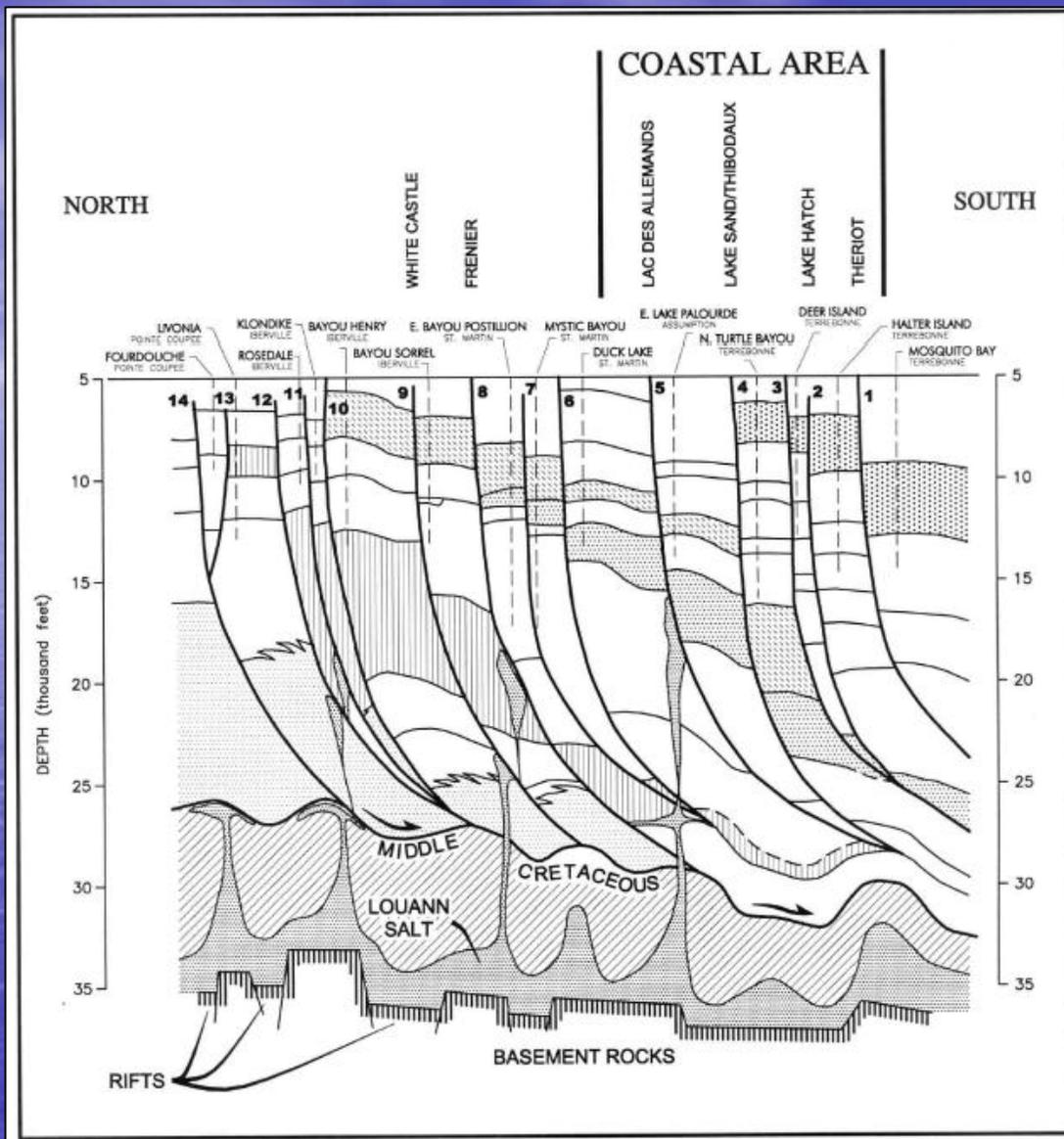
Topographic map with one foot contours prepared under the direction of New Orleans City Engineer L.W. Brown in 1895. This map was prepared using the Cairo Datum, which is 21.26 feet above Mean Gulf Level



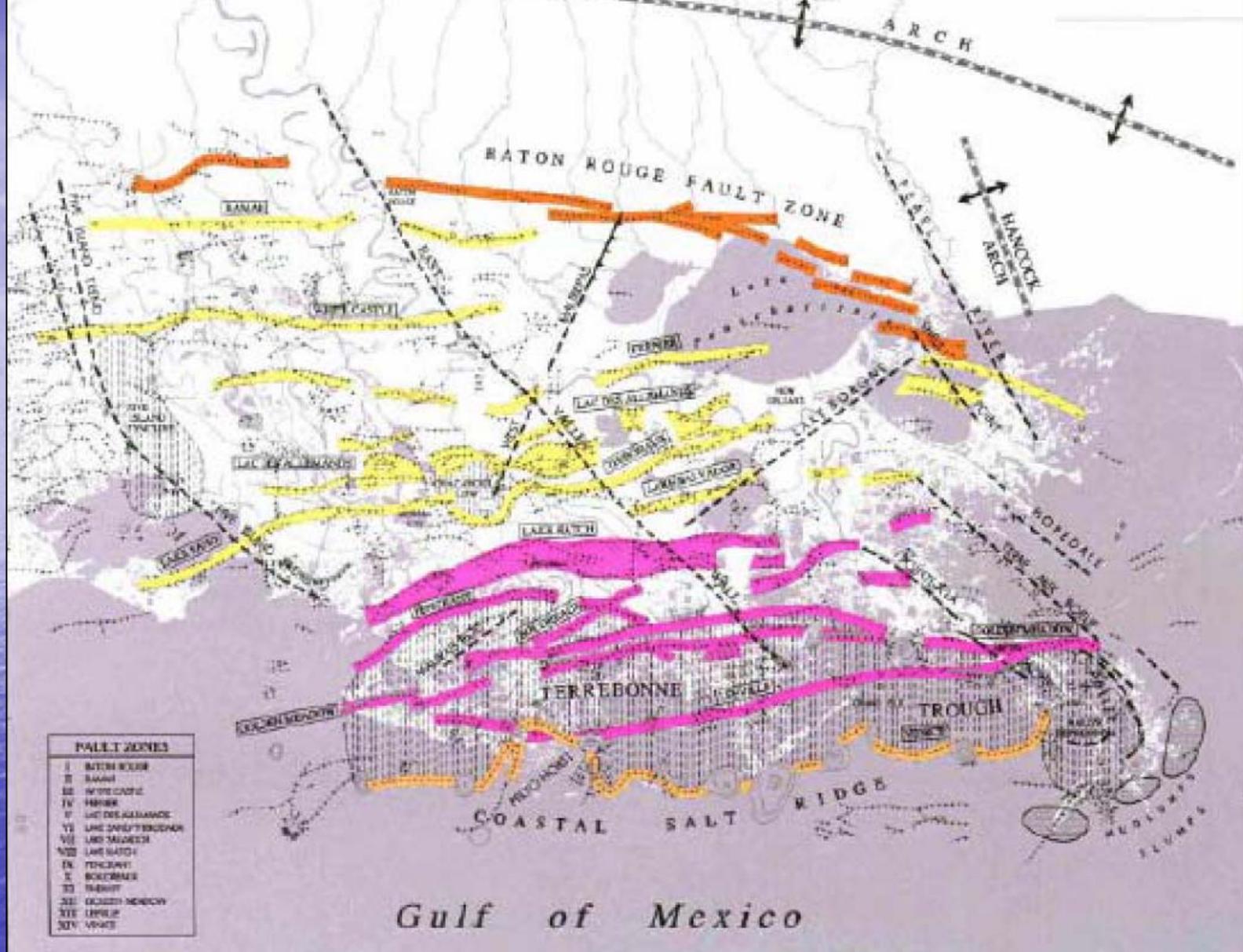
- Map showing relative elevation change between 1895 and 1999/2002, taken from URS (2006).
- The net subsidence was between 2 and 10+ feet, depending on location.



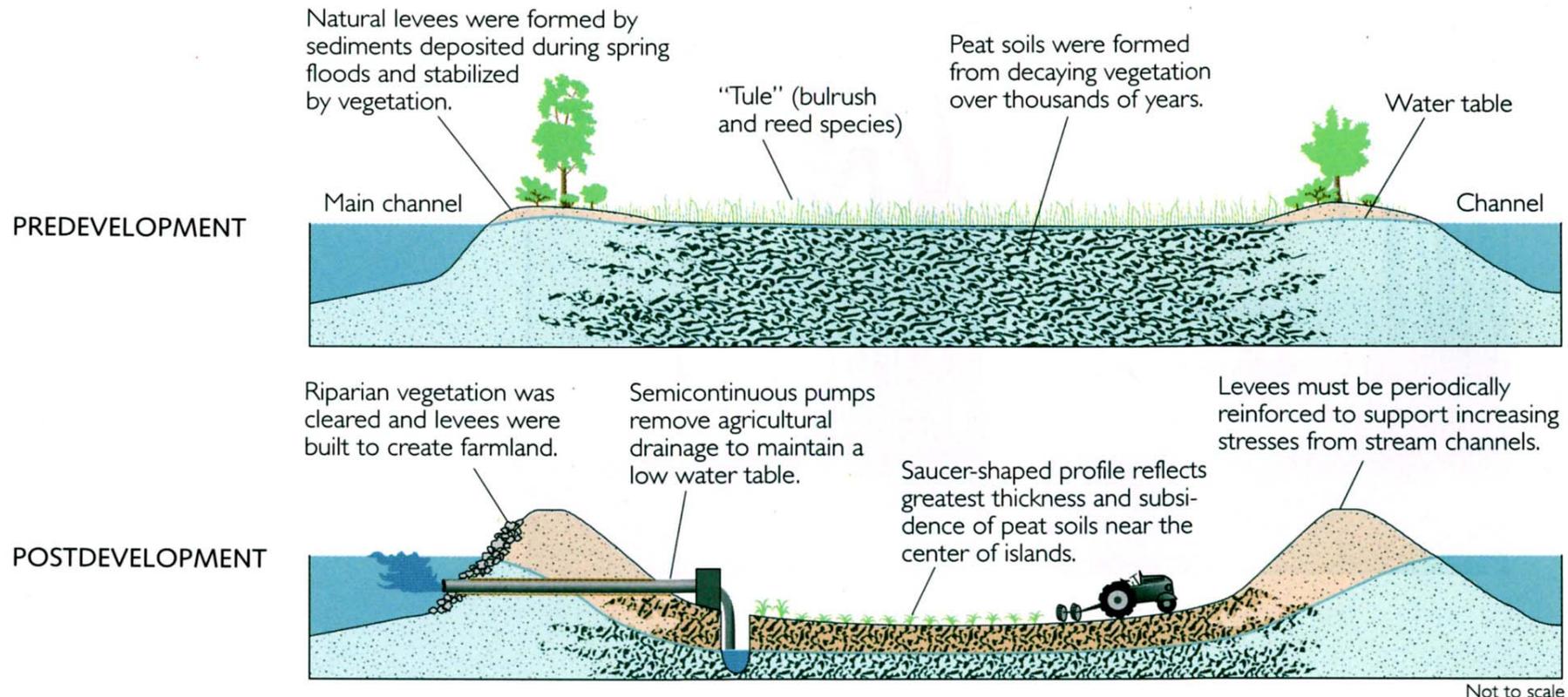
- Block diagram illustrating various types of **subaqueous sediment instabilities in the Mississippi River Delta**, taken from Coleman (1988).



- Geologic cross section through the Gulf Coast Salt Dome Basin, taken from Adams (1997). This shows the retrogressive character of young lystric normal faults cutting coastal Louisiana, from north to south. The faults foot in a basement-salt-decollement surface of middle Cretaceous age (> 100 Ma).



• This plot illustrates the en-echelon belts of **growth faults** forming more or less parallel to the depressed coastline. The Baton Rouge Fault Zone (shown in orange) has emerged over the past 50 years, north and west of Lake Pontchartrain.



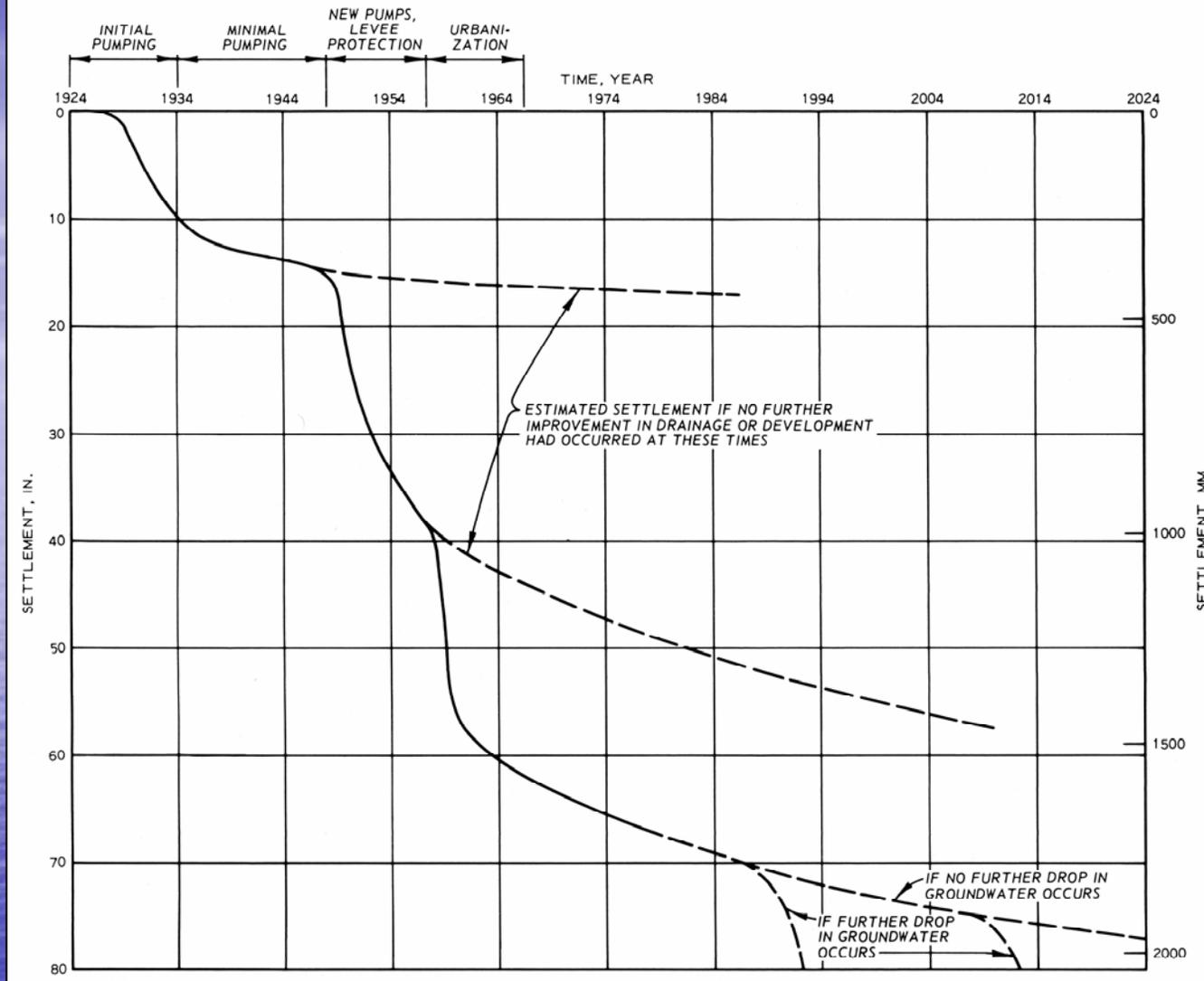
- Lowering the water table increases the effective stress on underlying sediments and hastens rapid biochemical oxidation of organic materials, causing settlement of these surficial soils.



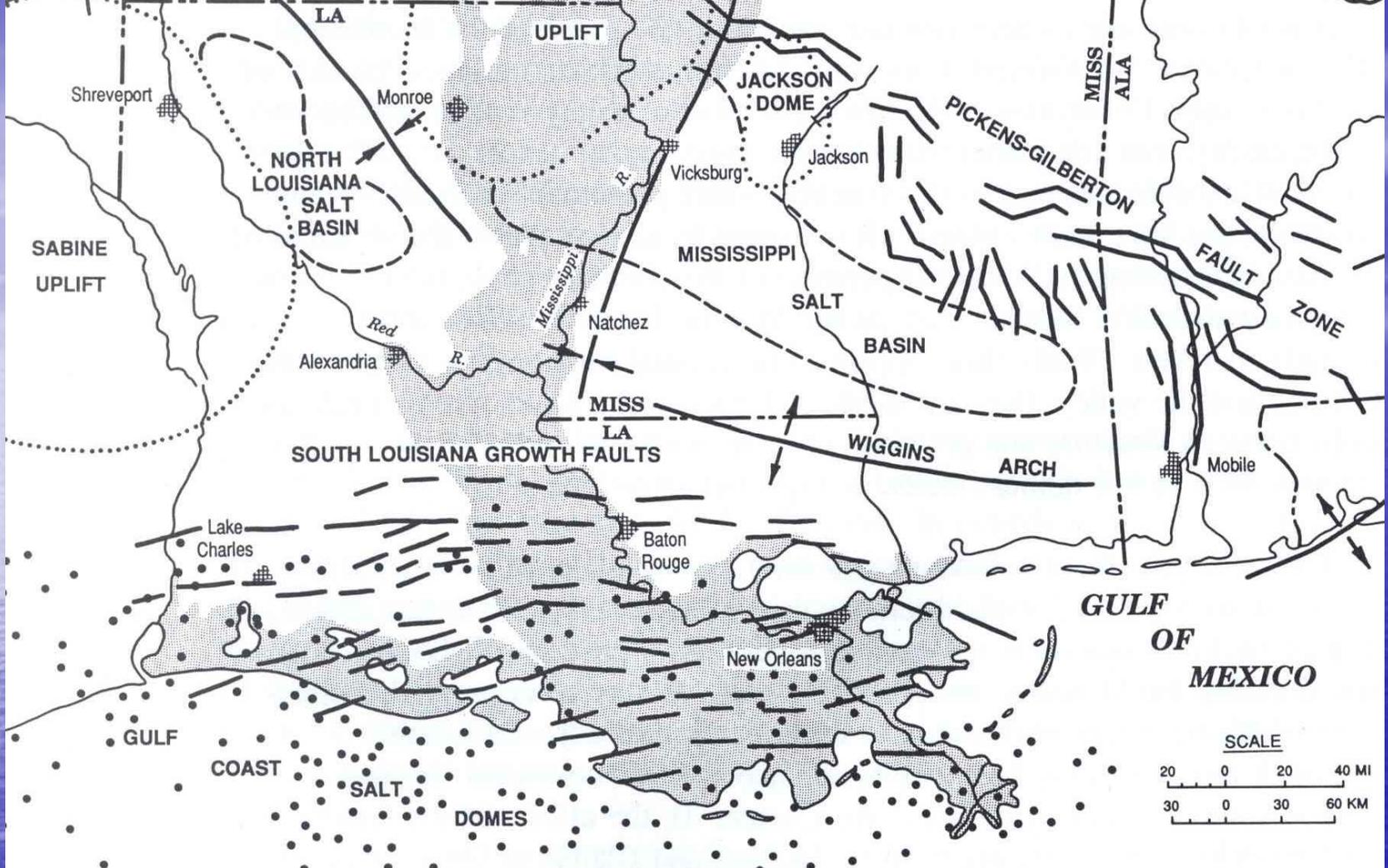
- The upper photo shows gross near-surface settlement of homes in the Lakeview neighborhood, close to the 17th Street Canal breach. Most of the homes were constructed from 1956-75 and are founded on wood piles about 30 feet deep.



- The lower photo shows protrusion of a brick-lined manhole on Spencer Avenue, suggestive of at least 12 inches of near surface settlement during the same interim.



- Record of **historic settlement** in the town of Kenner, which is characterized by 6.5 to 8 feet of surficial peaty soils.
- The steps in these curves were triggered by **groundwater withdrawal** for industrial use and urban development. This area was covered by dense cypress swamps prior to development.



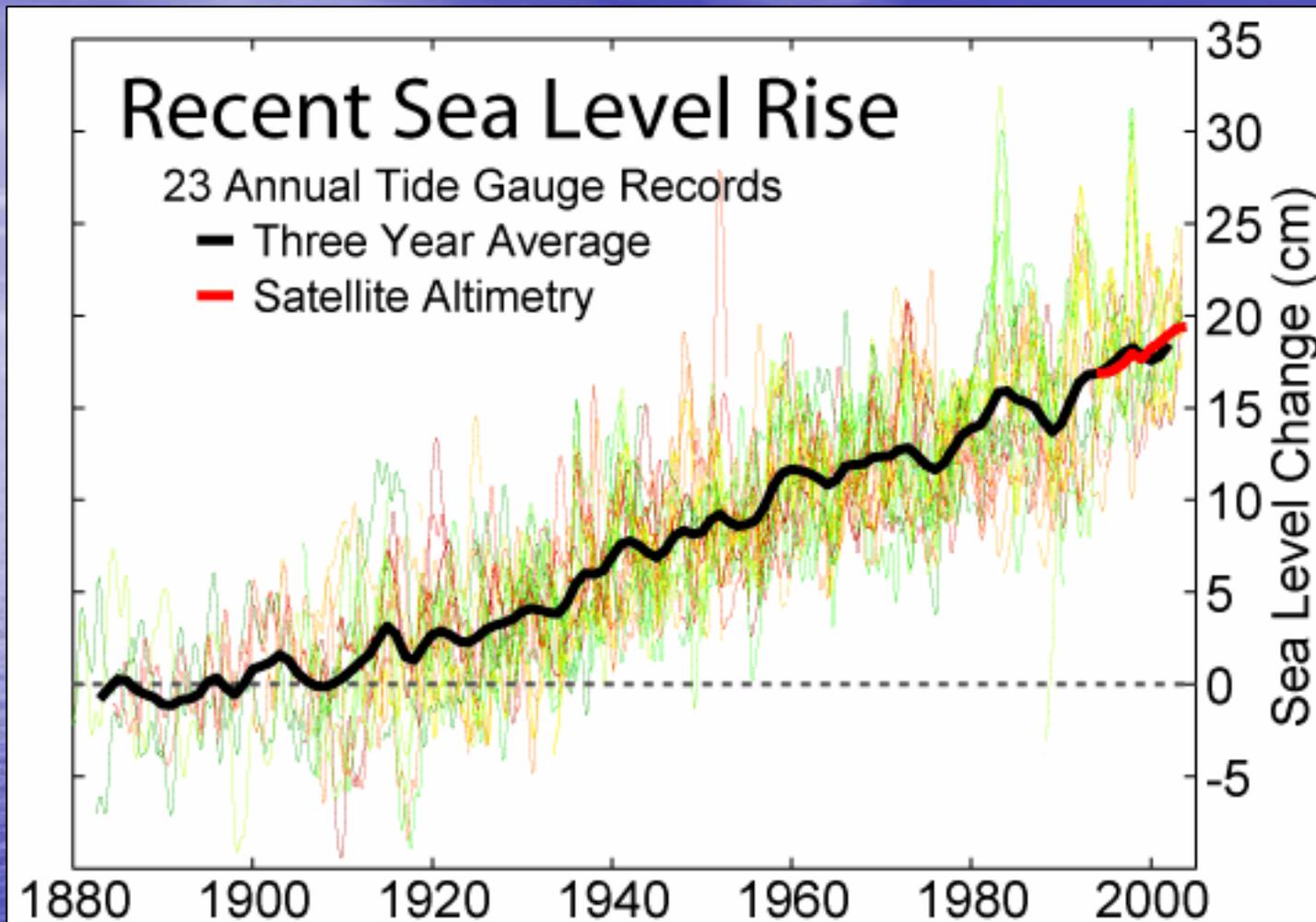
- Structural geologic framework of the lower Mississippi River Delta.** Growth faults (solid black lines) perturb the coastal deltaic plain, as do salt domes (shown as dots). This study did not uncover evidence of growth faults materially affecting any of the levee failures from Hurricane Katrina, although such possibility exists.

Mechanisms of Ground Settlement -1

- **Elastic deformation** of Mississippi Delta from silt deposition (isostasy)
- **Tectonic compaction** caused by formation of pressure ridges and folding
- Subsidence on seaward side of **lystric growth faults**
- **Drainage** of old swamp and marsh deposits increasing stress on underlying clays
- **Biochemical oxidation** of peaty soils

Mechanisms of Ground Settlement -2

- **Consolidation of compressible soils** caused by surcharging with fill
- **Surcharging** by structural improvements
- **Reduced groundwater recharge** because of increase in impermeable surfaces
- **Extraction of oil, gas, and water** causing pressure depletion
- **Solutioning** of salt domes and **seaward migration** of low density materials (salt and shale)



Coastal land loss in Louisiana is also exacerbated by **sea level rise**, which is currently averaging about 12 inches per century.

CONCLUSIONS-SETTLEMENT and LAND LOSS

- Coastal Louisiana is losing between 25 and 118 square miles of land per year
- The approximate rate of subsidence is about 4.2 ft per century, while sea level rise is about 1 ft per century
- The soft, compressible materials underlying much of New Orleans provide poor foundations, which are sensitive to drainage and loading.
- Ongoing ground settlement and sea level rise have combined to create a tedious situation, whereby flood control infrastructure must continually be improved and elevated to provide a consistent level of protection.

CONCLUSIONS-SITE CHARACTERIZATION

- Most of greater New Orleans is underlain by several layers of cypress swamp deposits
- These materials are highly permeable and compressible, with a dry density lower than water
- These materials commonly contain numerous weak horizons, often containing thin lenses of flocculated clay; all of which were found to exhibit strain softening
- This strain softening causes a significant loss of shear strength; sometimes diminishing to near zero.

CONCLUSIONS – COST BENEFIT RATIOS

- If the Corps of Engineers had authorized about \$10 million more for detailed subsurface exploration and insitu soil testing beneath the flood wall additions erected in the last 25 years;
- They might have prevented \$100 billion in flood damages
- This would have netted a cost-benefit ratio of 100,000 to 1