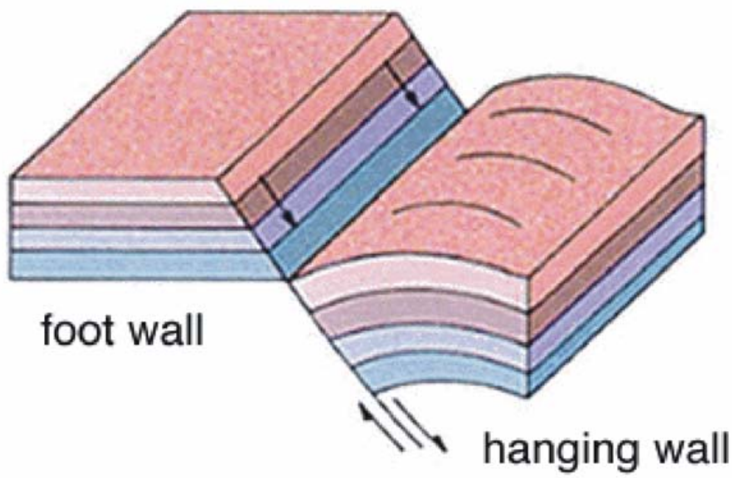
Baton Rouge Geological Society

Natural and Anthropogenic Subsidence Impact on Louisiana Coasts Symposium



January 24, 2008

Energy Coast & Environment Building
Louisiana State University
Baton Rouge, Louisiana

Hosts:
Louisiana Geological Survey

Petroleum Technology Transfer Council

Baton Rouge Geological Society

Compiled by Douglas Carlson

Presentation Schedule

Theme One: Subsidence in coastal Louisiana

9:00 am R. Eugene Turner, Charles S. Milan and Erick M. Swenson **Volumetric changes in coastal marsh soils**

9:30 am Alexander S. Kolker, and Mead A. Allison **Bathymetry, Subsidence and Sediment Deposition in Barataria Bay: Towards a Holistic View of Recent Changes**

10: 00 am T.A. Meckel, Uri S. T. Brink and S.J. Williams **Sediment compaction rates and subsidence in deltaic plains-Numerical constraints and stratigraphic influences**

10:30 am break

Theme Two: Fluid withdrawal's impact on subsidence

10:50 am T.A. Meckel, Uri S. T. Brink and S.J. Williams **Subsidence rates from fluid withdrawal and potential impact in southern Louisiana**

11:20 am Jeffrey A. Nunn **Land Surface Subsidence Caused by Seasonal Groundwater Withdrawal in Southwestern Louisiana**

11:50 pm Lunch

Theme Three: Mississippi River Delta Plain Subsidence: Patterns and Causes I

1:20 pm Mark A. Kulp, Torbjorn E. Tornqvist and Michael D. Blum **Patterns and Causes of Mississippi River Delta Plain Subsidence As Recorded by Varied Approaches to Measurement**

1:50 pm Clint Edrington, Michael, D. Blum, Jeffrey S. Hanor, and Jeffrey Nunn **Long-term subsidence and compaction rates: the Michoud Area south Louisiana**

2:20 pm Torbjorn E. Tornqvist and Scott J. Bick **Millennial-scale vertical movements of the Pleistocene basement underneath the Mississippi deltaic plain**

2:50 pm break

Theme Four: Mississippi River Delta Plain Subsidence: Patterns and Causes II

3:10 pm Juan L. Gonzalez and Torbjorn E. Tornqvist **The role of glacio-isostatic adjustment in coastal Louisiana**

3:40 pm Torbjorn E. Tornqvist**,** Davin J. Wallace, Joep E.A. Storms, Jakob Wallinga, Remke L. van Dam, Martijn Balaauw, Mayke S. Derksen, Cornelis J.W. Klerks, Camiel Meijneken, Els M.A. Snijders, and John W. Day Jr. **Compaction of Holocene strata as a premier driver of Mississippi Delta subsidence**

4:10 pm Michael D. Blum, and Jonathan H. Tomkin **The Flexural Ups and Downs of Mississippi Delta: Significance for Understanding Subsidence History**

4:40 pm Michael D. Blum and Mark A. Kulp **Mississippi Delta Subsidence, Sea-Level Rise, and Sediment Supply: A Perspective from the Stratigraphic Record**

Authors

First author for abstracts are noted by bold numbers.

Theme One: Subsidence in coastal Louisiana
January 24, 2007
9:00 am to 10:30 am
Dalton Wood Auditorium

Moderators:

Chacko John
Louisiana Geological Survey

and

Donald Goddard
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Volumetric changes in coastal marsh soils

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Changes in coastal wetland sediment volume causes subsidence and arises from organic decomposition, compaction of solids, and de-watering; each of these processes may change with age and as the loading of new organic and inorganic material varies. Here we address two questions using a variety of field-based sampling programs examining dated marsh soils and their organic and inorganic contents.

Ques. 1): What controls the variability in accretion rate downcore? The variability in the vertical accretion rate within the upper 2 m was determined by assembling results from concurrent application of the ^{137}Cs and ^{210}Pb dating techniques used to estimate sediment age since 1963/4, and 0 to ca 100+ years before present (yBP), respectively. The relationship between ^{210}Pb and the ^{137}Cs dated accretion rates (Sed_{210} and Sed_{137}, respectively) was linear for 45 salt marsh and mangrove environments. Sed_{210} averaged 75 % of Sed_{137} suggesting that vertical accretion over the last 100+ years is driven by soil organic matter accumulation, as shown for the pre ^{137}Cs dated horizon accumulation rate. A linear multiple regression equation that includes bulk density and Sed_{137} to predict Sed_{210} described 97 % of the variance in Sed_{210}. Sediments from Connecticut, Delaware and Louisiana coastal environments dated with ^{14}C indicate a relatively constant sediment accretion rate of 0.13 cm•yr^{-1} for 1000 to 7000 yBP, which occurs within 2 m of today's marsh surface and equals modern sea level rise rates. The most intense rates of change in soil volume in organic-rich salt marshes sediments, therefore, is neither in deep or old sediments (>4 m; >1000 years), but within the first several hundreds of years after accumulation.

Ques. 2): How have the constituents changed with age? The average changes in organic and inorganic constituents downcore for the last 200 years are nearly equal for 58 dated sediment cores from the northern Gulf of Mexico. These parallel changes downcore are best described as resulting from compaction, rather than from organic matter decomposition and point to the role of organics, not inorganics in building and sustaining established marshes. This conclusion is supported by the fact that the soil volume occupied by organic sediments + water in healthy salt marsh wetlands is >90%, and that slight changes in hydrology causes large changes in subsidence rates.

Bathymetry, Subsidence and Sediment Deposition in Barataria Bay: Towards a Holistic View of Recent Changes.

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Subsidence is widely recognized as a driver of land loss in the Mississippi Delta. However, given the paucity of stable benchmarks there are relatively few system-scale measurements of subsidence for the past century when land loss rates were highest. Here we present regional estimates of subsidence for Barataria Bay, a large interdistributary basin in the Mississippi Delta. Subsidence rates were determined by comparing results from present-day bathymetric survey with historic bathymetric maps, while correcting for the recent sediment deposition. Bathymetric maps were determined using single-beam sonar. Profiles of $^{210}Pb_{XS}$, 137Cs, and $^{206}/^{207}Pb$ reveal decadal-scale changes in sediment accumulation, that typically range from 0.5 - 1.0 cm/yr. Subsurface stratigraphic images, determined using CHIRP, suggests significant regional variability in subsidence that may be coupled to decadal changes in sediment accumulation. These lines of evidence suggest that there is substantial spatial and temporal variability in subsidence rates across this prominent feature of the Mississippi Delta.

Sediment compaction rates and subsidence in deltaic plains-Numerical constraints and stratigraphic influences

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Natural sediment compaction in deltaic plains influences subsidence rates and the evolution of deltaic morphology. Determining present rates of subsidence of the uppermost stratigraphic (land) surface due to compaction of the underlying shallow stratigraphy (hereafter referred to as ‘compaction rate’) requires site-specific detailed knowledge of subsurface geotechnical properties and depositional history. Despite many existing shallow borings, few appropriate stratigraphic and geotechnical data are available for site-specific calculations. To overcome this lack of knowledge and to incorporate geologic heterogeneity relevant for regional evaluation, we numerically forward model the incremental sedimentation and compaction of stochastically-generated stratigraphies with geotechnical properties typical of modern depositional environments in the Mississippi River delta plain. We employ the compaction calculations of Kooi and de Vries [1998], which solve one-dimensional, multi-lithology compaction models using a finite difference technique. Using a Monte Carlo approach to generate a variety of stratigraphies considered representative of Holocene accumulations in southern Louisiana, the range of present probable compaction rates for stratigraphies with compacted thicknesses 0-150 m and accumulation times 1-20 k.y. varies, but maximum rates rarely exceed 5 mm/yr. The fastest compacting model stratigraphies are composed primarily of peat and bar sand (compactable and hydraulically transmissive combination), while the slowest compacting stratigraphies are composed of pro-delta mud and natural levee deposits (less compactable and transmissive). Modelled present compaction rates do not correlate consistently with cumulative modelled net subsidence, recent modelled sedimentation rates, or the thickness and facies of the most recently deposited layer, making generalizations of compaction behavior at a specific site difficult without appropriate stratigraphic data. Geographic locations with observed subsidence rates greater than modeled (predicted) maximum probable shallow sediment compaction rates are likely to be influenced by additional processes (e.g. fluid withdrawal, faulting, etc.). Both of these processes have been verified to contribute to subsidence at specific locations, but not regionally.

Theme Two: Fluid withdrawal's impact on subsidence
January 24, 2007
10:50 am to 11:50 am
Dalton Wood Auditorium

Moderators:

Rick McCulloh
Louisiana Geological Survey

and

Thomas Van Biersel
Louisiana Geological Survey

Subsidence rates from fluid withdrawal and potential impact in southern Louisiana

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Groundwater withdrawal enhances sediment compaction by lowering fluid pressures and increasing vertical effective stress. Potential subsidence impacts from groundwater withdrawal are well known, and have been implicated as an important process contributing to subsidence in southern Louisiana. Yet direct observations of subsidence rates associated only with this process (i.e. isolating the component from fluid withdrawal) in the delta plain are rare. However, water use statistics for Louisiana are available (Sargent, 2002), and can be compared to water use from other locations where subsidence rates from groundwater withdrawal have been directly measured. Significant subsidence has been associated with anthropogenic water use in the Houston, TX area (Gabrysch and Coplin, 1990), where high quality observational subsidence rate data are available. Data from 13 extensometer stations in Galveston and Harris counties (N=5,305 observations from 1974-2006) illustrate net subsidence caused by shallow water withdrawal and recharge. Six of the extensometers measure total compaction (base of instrument is below deepest water production) and seven measure a portion of total compaction (base of instrument above deepest water production). For the Houston extensometer data, 50% of measured short-term (e.g. monthly) subsidence rates are <20 mm/yr, and 90% of the observations are <80 mm/yr.

If the assumption is made that shallow stratigraphies respond similarly (i.e. are geomechanically similar between Texas and Louisiana coastal plain), groundwater use comparisons between parishes in southern Louisiana and the Houston area can be compared in the context of induced subsidence. Fluid withdrawal rates (extraction per square mile) in southern Louisiana have historically been lower than the Houston area. Therefore, it does not seem likely that the high subsidence rates determined for the Houston extensometers apply regionally in southern Louisiana. Groundwater use in Louisiana for all parishes in the study area (southern Louisiana) totaled <420 million gallons per day in 2000. Maximum Houston area (only Galveston and Harris counties) withdrawal was 456 million gallons per day in 1976. Normalizing water use to parish/county land surface area, only Orleans Parish (includes city of New Orleans) has historic water extractions similar to the maximum Houston area (Harris and Galveston counties) extractions; other parishes in southern Louisiana had water volume extractions per square mile far less than the historical withdrawal rates of Houston area counties. Groundwater use in Orleans Parish has declined in the past few decades and recharge rates are high. In 2000, water use in Louisiana was dominated by surface sources (84% of ~10,400 million gallons per day total; Sargent, 2002). Consequently, the contribution to historic and present regional subsidence rates from groundwater withdrawal in Louisiana should be significantly less than the distribution of rates observed for the regions surrounding Houston. Local effects may be significant; subsidence from groundwater use is documented near Baton Rouge (Nunn, 2003), with modeled subsidence rates of 1-18 mm/yr. However, regional subsidence rates over the last few decades in southern Louisiana are unlikely to be dominated by shallow water withdrawal processes.

The impact of deep fluid withdrawal on subsidence remains an extremely controversial topic. Fluid withdrawal from deep hydrocarbon formations can contribute to subsidence, as many case studies in the Gulf Coast and globally have illustrated. While the cumulative volume of oil produced in southern Louisiana parishes is substantial (>13 billion barrels since 1945; including co-produced waters increases this volume substantially), the potential impact of any regional depressurization at such great depths on subsidence and geologic processes in Louisiana remains under investigation. The high frequency of water-drive production in the Louisiana Gulf Coast suggests long-term subsurface pressure declines may be marginal. Southern Louisiana oil volumes produced have consistently decreased from ~446 million barrels in 1970 to ~55 million barrels in 2005 (natural gas production follows a similar trend). However, time lag effects of such substantial withdrawals that could impact surface elevation change may or may not be significant, but have not yet been fully explored.

Land Surface Subsidence Caused by Seasonal Groundwater Withdrawal in Southwestern Louisiana

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According the U.S. Geological Survey, Vermillion, Acadia, and Jefferson Davis Parishes in Southwest Louisiana withdrew on average more than 450 million gallons of ground water per day in 2000. The primary aquifer in this region is the Chicot Aquifer. Water enters the groundwater system in Southwest Louisiana as recharge in an outcrop area north of Acadia and Jefferson Davis Parishes. Water moves downward and southward by topography-driven recharge. As water moves south, pressure head increases due to the weight of water updip in the aquifer. Most of the groundwater withdrawn in Vermillion, Acadia, and Jefferson Davis Parishes is used for irrigation of agricultural fields and the use is Seasonal. During the growing season, water usage is much higher than average and water levels in wells can drop by more than 12 meters. After the growing season, water withdrawals decline and water levels in wells largely rebound to their pre-growing season levels. In addition, there has been a slow long-term decline in water levels in the Chicot aquifer due to over pumping both for irrigation and industrial use. Most surface subsidence due to groundwater withdrawal is believed to be the result of clay compaction rather than compaction of the aquifers themselves. As water pressure levels decrease in major aquifers in response to pumping, water also drains from interbedded clay confining layers. The weight of overlying sediments causes clays to compact. The clay compaction effect on surface subsidence due to long-term groundwater level declines has been well documented in Houston, Texas; Las Vegas, Nevada; Sacramento Valley, California; and Venice, Italy. While water levels in aquifers due to seasonal withdrawals may recover, water levels in adjacent confining layers do not. The lower permeability of clays causes them to progressively drain with each seasonal cycle of groundwater withdrawal. Thus, permanent surface subsidence is possible by this mechanism.

Theme Three: Mississippi River Delta Plain Subsidence:
Patterns and Causes I
January 24, 2007
1:20 pm to 2:50 pm
Dalton Wood Auditorium

Moderators:

Marty Horn
Louisiana Geological Survey

and

Dan Tomaszewski
U.S. Geological Survey, Baton Rouge Office

Patterns and Causes of Mississippi River Delta Plain Subsidence As Recorded by Varied Approaches to Measurement

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Subsidence of the Mississippi River delta has been a topic of curiosity for more than a century. During this time it has been recognized as a fundamental phenomenon of the region, affecting delta plain evolution and the resulting stratigraphic framework through relative sea level rise that influences trends of deposition, erosion, and land loss and land formation. Despite subsidence being documented for decades as a societal hazard associated with living on the delta plain, increased scientific and public attention regarding the patterns and causes of subsidence has only occurred recently. The contribution of subsidence to high rates of wetland loss and coastal erosion is not yet fully understood, but because of its impacts to the coastal zone, quantifying its effects is a high priority in coastal research. Moreover, the challenges of living along a subsiding, locally-leveed deltaic plain will become increasingly evident, as the predicted rate of sea-level rise accelerates. The difficulty in quantifying causative mechanisms of subsidence reflects the complexity and variability of the phenomenon itself.

Early researchers qualitatively recognized the role of subsidence because of documentation of submergence of former subaerial deltaic platforms within human life spans, as well as the discovery of anomalously thick stratigraphic successions that implied crustal-scale downwarping across multi-million year time frames. During the last several decades, quantification of subsidence has been attempted through analysis of tide-gauge records, benchmark re-leveling surveys, global positioning system data, Cenozoic chronostratigraphic relationships, and burial depths of radiocarbon-dated peat horizons adjusted for paleo-sea levels, along with several numerical modeling approaches. Each of these methods of analysis is however uniquely different with regards to the temporal and spatial patterns of subsidence that they record. Each measurement method provides meaningful subsidence information, but only relative to: 1) the datum against which recorded motion is referenced, 2) the temporal range of a measurement interval, and 3) the inherent measurement errors. On the basis of currently available measurement techniques, published subsidence rates can be considered to reflect either long (millennial scale or greater), medium (centennial-scale) or short (decadal) term motions. This variability requires that investigators carefully consider the intended use of published rates and fully consider the measurement and analysis techniques used to establish the rates.

An array of mechanisms has been identified as probable contributing factors to delta plain subsidence, including compaction of strata, fault movement, and regional or even continental-scale isostatic adjustments. Each of these mechanisms is likely to contribute to vertical motion on distinctly different spatial and temporal scales. For example, on the basis of geotechnical data the largest amount of total sediment compaction for a recently deposited stratum would occur soon after burial due to rapid dewatering and become less important through time. Short-term measurement methods are therefore likely to capture the “snap shot rate” of compactional subsidence. This is in contrast to long-term measurement methods that may contain an initially rapid compactional subsidence signal that has become progressively diluted as other longer-term subsidence mechanisms become dominant in long-term records.

Recognizing the range of temporal variability in measurements as well as the contribution of different mechanisms to net subsidence is fundamental to interpreting the underlying causes of vertical motion, understanding the significance for coastal zone evolution, and developing scientifically sound mitigation efforts for regional land restoration.

Long-term subsidence and compaction rates: a new model for the Michoud area, south Louisiana

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This thesis examines the stratigraphic record of the Michoud area of East New Orleans, Louisiana to address questions concerning the magnitude of, and processes leading to subsidence. The conclusions under review are based on recent geodetic studies, which challenge the widely held position that modern subsidence is a primary function of shallow sediment compaction; geodetic studies contend subsidence rates are an order of magnitude greater than previously accepted rates, deep-seated faulting is the dominant mechanism driving subsidence, and compaction rates of pre-Holocene strata are approximate to Holocene sediment compaction rates. Testing these conclusions involved constructing a structural cross-section of the Michoud area using well logs, chronostratigraphic data, and fault picks, so as to evaluate differential motion along specific faults through time. Employing ages and corrected depths of three key subsurface horizons, long-term (Middle Miocene to Present) time-averaged subsidence rates are calculated: rates range from -0.140 to -0.177 m/kyrs. It is considered inappropriate to compare subsidence rates from this thesis with geodetically derived subsidence rates, because the difference in scale of resolution for respective techniques is so great. Nevertheless, this subsurface, structural model supports reactivation of local faults, including any recent movement on the Michoud Fault, to be a transient phenomenon related to rapid Quaternary sediment loading. It is permissible, however, to compare compaction rates, a component of subsidence, from this thesis with geodetically derived compaction rates of pre-Holocene strata. Using a standard decompaction technique, this thesis derived mean long-term compaction rates for strata residing above the Middle-Miocene *Bigenerina Humblei* horizon: rates range from -0.0704 to -0.0914 m/kyrs (-0.0704 to -0.0914 mm/yr), which are two orders of magnitude less than geodetic, pre-Holocene strata compaction rates. Thus, the discrepancy in compaction rates raises questions into the accuracy of the geodetic data and subsidence rates previously interpreted for the Michoud area.

Millennial-scale vertical movements of the Pleistocene basement underneath the Mississippi deltaic plain

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Tectonic subsidence in and near the Mississippi Delta is commonly believed to be a consequence of lithospheric flexure due to ongoing sediment loading by the deltaic depocenter. Classic work by Harold N. Fisk c.s. suggested that lithospheric flexure occurs near and seaward of the present shoreline, implying relative tectonic stability in most of the deltaic plain. This pattern of deformation is strikingly similar to more recent observations from the Nile Delta.

Relative sea-level (RSL) data covering the past ~8500 years from three study areas in different portions of the Mississippi Delta enable an assessment of whether significant differential crustal movements have occurred. Our sea-level index points were obtained from basal peat that accumulated during the initial transgression of the pre-existing, consolidated Pleistocene basement, thus ruling out the role of compaction of Holocene strata. The study areas differ in their distance to the present shoreline and their structural position relative to growth-fault systems. The rationale of our analysis is that given spatially uniform eustatic and glacio-hydro-isostatic signals, any offset between the three RSL records can be attributed to differential tectonic subsidence rates. The extremely favorable conditions for sea-level research on the US Gulf Coast (largely due to the low tidal range) and the long time span of observation allow us to calculate vertical movements with exceptionally high accuracy and precision. Our results show that differential crustal movements among the three study areas have been on the order of ~0.1 mm/yr only. In addition, our data show that a previously identified major growth fault system has seen very limited activity during this time interval, at least near our study areas.

We compare our new evidence with a recently published compilation of RSL data from the Caribbean, to a large extent based on data from carbonate platforms (e.g., Florida, Bahamas) that are widely believed to be tectonically very stable. All our sea-level index points nearly coincide with the Caribbean data, suggesting that considerable parts of the basement underneath the Mississippi deltaic plain are surprisingly tectonically stable. However, the well-documented high subsidence rates in and near the birdfoot of the Mississippi Delta indicate that different conditions prevail there. Overall, our findings corroborate Fisk's studies more than 50 years ago, and we infer that the rapid rates of wetland loss in coastal Louisiana are to a large extent due to compaction of the thick Holocene strata as well as human action, like artificial drainage (which accelerates compaction), the dredging of canals, and the extraction of subsurface fluids.

Theme Three: Mississippi River Delta Plain Subsidence: Patterns and Causes II
January 24, 2007
3:10 pm to 5:10 pm
Dalton Wood Auditorium

Moderators:

Douglas Carlson
Louisiana Geological Survey

and

Jeffrey Hanor
Department of Geology and Geophysics
Louisiana State University

The role of glacio-isostatic adjustment in coastal Louisiana

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The problem of land subsidence in coastal Louisiana is controversial not only in terms of driving mechanisms, but also with respect to the rate at which it is occurring. Quantifying the relative contribution of tectonism, glacio-hydro-isostasy, and sediment compaction, the principal forces driving subsidence in coastal Louisiana, is fundamental to the success of any coastal restoration project and to cope with future sea-level change.

We have assembled an exceptionally dense relative sea-level (RSL) chronology for the western Mississippi Delta using basal peat as a tracer of sea level. This new record contains 28 sea-level index points that encompass the period from 600 to 1600 AD. Linear regression analysis yields a long-term rate of RSL rise of 0.55 mm/yr for the 1000-year time window covered by the data. This long-term trend reflects the interplay of tectonism, glacio-hydro-isostasy, and eustasy since RSL records derived from basal peat are essentially compaction-free. Our long-term rate of RSL rise is at least an order of magnitude lower than compaction-free subsidence rates reported from the same area by geodetic leveling data. However, it is in agreement with recently published, longer (~8500 years) RSL records that cover much of the Holocene at various localities across the Mississippi Delta and that show that tectonic subsidence rates in our study area are on the order of 0.1 mm/yr only.

In accordance with several geophysical model predictions, we hypothesize that glacio-isostatic adjustments along the north-central Gulf Coast, specifically forebulge collapse due to melting of the Laurentide Ice Sheet, dominate the 0.55 mm/yr rate of RSL rise. This contention is supported by the following observations. The difference between the 20th century trend of RSL rise for the north-central Gulf Coast (2.1 mm/yr) as recorded by the Pensacola, Florida, tide gauge (this tide gauge primarily captures a combination of the eustatic and glacio-isostatic signals) and the best available estimate of eustatic sea-level rise for the 20th century (1.7 ± 0.3 mm/yr), yields ~0.4 mm/yr. This number compares favorably with the rate of RSL rise derived from our basal-peat record. It should be noted that our analysis assumes a negligible eustatic sea-level contribution during the 1000-year period covered by our RSL chronology. Overall, we infer that for considerable portions of coastal Louisiana glacio-isostasy may be a bigger player than tectonic subsidence, yet both are likely to be overwhelmed by compaction rates of Holocene strata, as well as anticipated rates of future eustatic sea-level rise.

Compaction of Holocene strata as a premier driver of Mississippi Delta subsidence

Torbjörn E. Törnqvist & Davin J. Wallace, Department of Earth and Environmental Sciences, Tulane University, 6823 St. Charles Avenue, New Orleans, LA 70118-5698, tor@tulane.edu, Joep E.A. Storms, Jakob Wallinga, Remke L. van Dam, Martijn Blaauw, Mayke S. Derksen, Cornelis J.W. Klerks, Camiel Meijneken & Els M.A. Snijders, Department of Physical Geography, Utrecht University, P.O. Box 80115, NL-3508 TC Utrecht, The Netherlands, and John W. Day, Jr., Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803

The adverse consequences of coastal subsidence (accelerated relative sea-level rise, shoreline erosion, and wetland loss) and its threats to coastal populations are widely recognized. The Mississippi Delta has become the poster child of coastal hazard following the devastation from Hurricane Katrina, partly attributed to the loss of vast wetlands that could have served as a buffer against storm surge. Several recent studies have focused on the wide variety of components that are believed to contribute to subsidence in the Mississippi Delta and adjacent coastal Louisiana, ranging from lithospheric processes to the compaction of relatively shallow materials. Compaction of Holocene strata is commonly considered to be an important contributor to subsidence, as evidenced by monitoring studies over timescales up to a decade that employ a combination of surface elevation tables and marker horizons. However, surprisingly little is known about compaction rates over centennial to millennial timescales, whether in coastal Louisiana or elsewhere. Recent stochastic modeling constituted a significant advance in this context and suggests that compaction rates in coastal Louisiana, while substantial, are likely less than 3 mm/yr.

We set out to verify these model results by means of shallow subsurface data. Using >100 up to 15-m-deep boreholes from an area that surrounds the upstream reach of Bayou Lafourche, a precursor of the Mississippi River, we measured the deformation of a ~1500-year-old, originally near-horizontal swamp peat bed that was buried by up to 12-m-thick overbank deposits. Differential compaction due to the loading by this mud-dominated deposit was considerable and locally measured as much as 6 m. These findings provide a unique opportunity to quantify compaction rates over relatively long timescales. We find that averaged compaction rates (primarily of peat) can be as high as 5 mm/yr, values that exceed the recent model predictions mentioned above. It is conceivable that over decadal to centennial timescales compaction rates can locally be 10 mm/yr or more. Thus, compaction is capable of accounting for a large proportion of the exceptionally high rates of land surface subsidence, relative sea-level rise, and coastal wetland loss in the Mississippi Delta. Our results are also consistent with InSAR-derived rates of land subsidence, believed to be dominated by compaction due to artificial drainage, in the New Orleans metropolitan area.

The Flexural Ups and Downs of Mississippi Delta: Significance for Understanding Subsidence History

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Land-surface dynamics in the Mississippi delta region are linked to vertical motion of the landscape, Gulf of Mexico (GOM) sea-level change, and rates of deposition. This presentation introduces a new element to vertical motion, a cyclical flexural uplift and subsidence due to sediment unloading and loading at glacial-interglacial timescales. During the last glacial period and early deglaciation, when sea level was low, meltwater discharge from North American ice sheets drove Mississippi valley incision, with valley filling and delta construction during Holocene sea-level rise. Isostatic models indicate the sediment volumes removed and replaced were sufficient to induce large-scale flexural uplift of the delta region and adjacent GOM shoreline followed by subsidence. Modeled uplift and subsidence of the late Pleistocene-Holocene contact exceeds 10 m in the load center, with rates of ~1mm/yr, and the effects extend over distances of >150 km from the valley margin along the GOM coast.

Model predictions of cyclical uplift and subsidence are important to reconstructions of Holocene sea-level change along the GOM coast. Recent studies of basal-peats that onlap the Pleistocene-Holocene contact within the delta region are interpreted to represent continual relative sea-level rise through the late Holocene, and to represent a record of sea-level change for the northern GOM as a whole. One implication of this interpretation is that the pre-Holocene depocenter is stable and not subsiding. By contrast, data from the Texas and Alabama coasts have been interpreted to indicate sea level reached present elevations by ca. 6 ka, and was 1-2 m higher than present during the middle and late Holocene. Data from the Texas and Alabama coasts have been discounted because of lack of agreement with data from the delta region. However, modeling results show that records of sea-level change should vary alongshore due to the pattern of flexural uplift and subsidence, that data from the delta region cannot provide anything more than a very localized record of relative sea-level change, and that the Alabama and Texas coasts are sufficiently distant to be largely unaffected by the unloading and loading in the delta region. Hence, there is no evidence that sea level has risen along northern GOM coast over just the last 1-2 kyrs, at least not until the post-Little Ice Age historic period. Instead, sea level may have been higher than present from 3-2 kyrs BP, and the well-known late Holocene deltaic progradation may have taken place during a period of GOM sea-level fall.

Basal-peat data from the delta region cannot provide a record of sea-level change. However, they are critical to the subsidence debate: they should be reinterpreted as a century- to millennial-scale record of load-induced subsidence of the pre-Holocene depocenter. Basal-peat data suggest maximum deep-seated subsidence rates of ~1 mm/yr for the latitude of New Orleans, an order of magnitude lower than rates from some geodetic measurements. The extreme rates measured by some geodetic techniques should be considered transient, they are not representative of the recent geologic past, and they should not be projected to the future.

Mississippi Delta Subsidence, Sea-Level Rise, and Sediment Supply: A Perspective from the Stratigraphic Record

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Modern land-surface dynamics in the Mississippi delta region are linked to subsidence, sea-level change, and rates of deposition. This presentation is a first-draft perspective on future subsidence, sea-level change and sediment supply, viewed from the stratigraphic record and the Mississippi sediment dispersal system as a whole.

Land-surface subsidence integrates processes that operate over different spatial and temporal scales. Much discussion revolves around rates and mechanisms measured by geodetic techniques vs. rates and mechanisms interpreted from the stratigraphic record. However, these measurements are not inherently contradictory: in fact, measurement of subsidence rates almost certainly follows a pattern typical of most geologic processes, where rates decrease as the time scale of measurement increases, because transient high-magnitude events become increasingly less significant, and time-averaging becomes increasingly more important. Contrary to accepted wisdom, it can be argued that relevant rates and processes for future coastal restoration efforts are not those captured by short-term geodetic techniques, but rather those that characterize timescales of 10^2-10^3 yrs, as defined in the late Holocene stratigraphic record. The extreme rates measured by some geodetic techniques during the last few decades are not representative of the previous century or millennia, and should not be extrapolated to the next century or millennia.

Over timescales of 10^2-10^3 yrs, modeling efforts linked to the Holocene stratigraphic record suggests that subsidence the pre-Holocene depocenter is dominated by isostatic adjustments to Holocene sediment loading, and is likely <1-2 mm/yr. Shallow processes are dominated by compaction of Holocene strata, and vary spatially in accordance with recent depositional history, but are mostly likely ~1-3 mm/yr at the latitude of New Orleans, increasing in the basinward direction, and significantly higher only in the region of the modern shelf-margin delta. Summing up shallow vs. deep-seated contributions to subsidence results in estimates of 3-5 mm/yr for the latitude of New Orleans, with higher rates farther basinward.

On the one hand, these rates are not as dire as those measured from some geodetic techniques, and can likely be mitigated on a local basis by current short-term engineering plans. On the other hand, even conservative rates present a long-term mass balance problem that is underappreciated. For example, estimates of global sea-level rise for the next century range from ~3-8 mm/yr: the space created by combined subsidence and sea-level rise by the year 2100 will take >200 yrs to fill with sediment delivered by the Mississippi River in its current state, where ~70-80% of the natural load is trapped behind ~50,000 dams within the drainage basin. Century-scale sustainable coastal restoration within south Louisiana cannot be seriously addressed without discussing long-term plans for restoration of the continental-scale Mississippi sediment dispersal system to a state that produced the landscape and stratigraphic record in the first place.