EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 84 NUMBER 44

4 NOVEMBER 2003

PAGES 469–484

Biogeochemical Implications of Levee Confinement in the Lowermost Mississippi River

PAGES 469, 475–476

With the recent formation of the Center for River-Ocean Studies (CeROS) at Tulane University in Louisiana (see http://www.tulane.edu/~ceros) and the emerging state-federal partnership that is creating river diversions to combat coastal land loss, increased attention is being paid to the lowermost Mississippi River, from Baton Rouge to the Gulf of Mexico, as a critical juncture and storage area for sediment particles and bio-active compounds.

CeROS scientists, working with the U.S. Geological Survey and the National Oceanic and Atmospheric Administration, have undertaken a detailed re-assessment of the channel floor and water column of this region using geophysical and biogeochemical data collection, combined with historical data sets.

Among the early results of these studies is evidence of increased remobilization of relict fluvio-deltaic strata containing peat layers rich in organic carbon (OC) from the channel floor since this section of the river was confined by levees. Such confinement and rapid downcutting of the river is at odds with the meandering and subsiding delta front that is typical of a sediment-rich, low-relief river like the Mississippi. However, anthropogenic control of the lowermost reach of many rivers, large and small, has become increasingly common worldwide, due to efforts to minimize destructive flooding.

Historical Background

The levees along the lowermost Mississippi were constructed in response to major floods in 1912, 1913, and 1927, the latter of which inundated over 67,000 km^2 from Illinois to the Gulf of Mexico, killed 200 people, and displaced 600,000 others. The levees, constructed and maintained by the U.S. Army Corps of Engineers (USACOE), are designed to confine floods larger than the 1927 flood within the channel. Additional water is diverted through a series of emergency spillway structures. A byproduct of confining large floods to the river channel was predicted to be accelerated river flow velocities that would deepen the river bed by erosion. A high-resolution comparison of USACOE bathymetric studies conducted throughout the 1900s allowed for an estimate of river down-cutting (Figures 1 and 2).

There appears to have been a phase of rapid deepening in part of the lowermost Mississippi following levee construction, with a pivot point in bathymetric change between shallowing (accretion) upriver of New Orleans, and deepening (erosion) further downriver. Our studies reveal that areas of the Mississippi River channel below New Orleans have experienced significant down-cutting since 1893, yielding large volumes of aged organic carbon, particularly from peat layers, to the northern Gulf of Mexico.

Rivers are a significant source of terrestrial organic matter to the world ocean, particularly old (^{14}C-depleted) particulate carbon [*Hedges et al.*, 1997]. Terrestrial inputs of organic carbon to the continental margin of the northern Gulf of Mexico are high compared with other coastal margins of the U.S. because of the significant water and sediment discharge and large drainage basin of the Mississippi-Atchafalaya River system. Holding ponds, dams, and agricultural development have resulted in major changes in the quantity and character of sediments supplied by the drainage basin [*Meade et al.*, 1990]. In addition, Mississippi Delta wetland loss rates have accelerated overall in the 20th century (peaking at 11,000 ha/yr in the 1960s [*Dunbar et al.*, 1990], which has been attributed to a host of natural and man-made causes, including subsidence and channel dredging. All of these changes have the potential to affect the character of carbon reaching the margin.

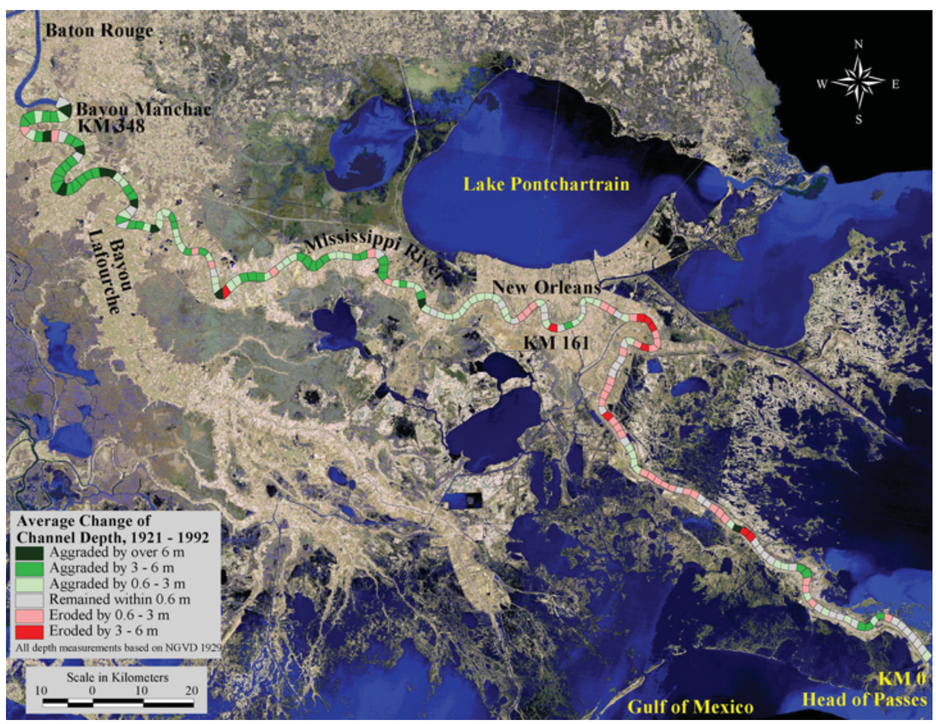

Fig. 1 Bathymetric change in the Lower Mississippi River, 1921–1992. The average change in channel depth of the Mississippi River from Head of Passes (river km 0) to Bayou Manchac (river km 348) from 1921–1992 is plotted on an aerial image of southeastern Louisiana. There is an observed trend of shallowing (accretion) above New Orleans, and deepening (erosion) of the channel downstream of New Orleans. Data intervals on river represent one-mile increments, as was the format of data collection by the Mississippi River Commission and the USACOE.

BY J. J. GALLER, T. S. BIANCHI, M. A. ALISON, L. A. WYSOCKI, AND R. CAMPANELLA

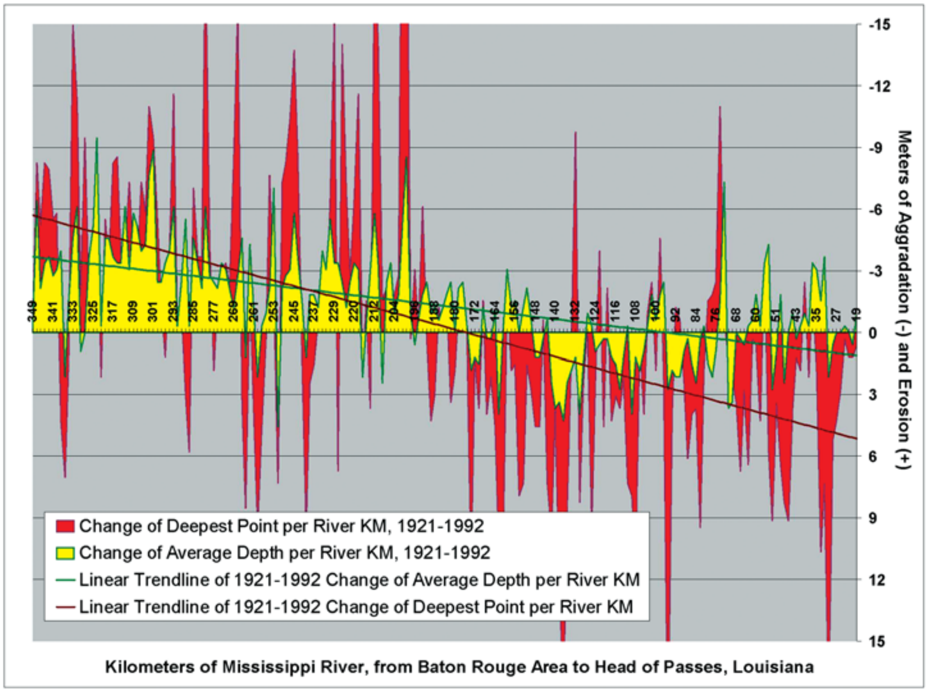

Fig. 2. 1921–1992 bathymetric change by average depth per km and deepest point per km. While there is a high degree of variability in change of deepest point per river km, there is a general pattern of aggradation upstream of New Orleans (river km 161) and erosion downstream of New Orleans, as is supported by the trend lines. The change in average depth per river km shows less variability between river kilometers, and also demonstrates aggradation above New Orleans, and erosion of the river channel below New Orleans.

Channel Incision in the Lowermost Mississippi

In the present study, eight historical bathymetric data sets of the lower Mississippi River (Baton Rouge to Head of Passes), collected between 1893 and 1992 by the Missisippi River Commission and the USACOE, were processed, geo-referenced, adjusted for differences in vertical datums and stage, corrected for errors, interpolated, and differenced for both average depth and deepest point per river km. Results from 1893 to 1921 show little bathymetric change, but between 1921 and 1948, the lower Mississippi River aggraded from New Orleans up to the Baton Rouge area (kms 160–348), and eroded from New Orleans down to Head of Passes (kms 160–0), at rates of roughly 1 m per 50 river km (Figures 1 and 2). The pattern abated as the century progressed. These differences of depth measurements between the late 19th and late 20th centuries may reflect a host of contributing factors, including levee and spillway construction, river straightening, rising sea level, salt water intrusion, dredging, soil erosion rates, subsidence, and/or underlying geology.

The timing of the downcutting phase, immediately following the construction of artificial levees after the 1927 flood, suggests it can be chiefly attributed to accelerated channel flow during high discharge, and the development of a new downstream elevation gradient equilibrium. Sidescan sonar, CHIRP sub-bottom seismic data, and sediment cores collected seasonally throughout the 2000 and 2001 flood years show that relict strata of various ages are exposed during high discharge on the lowermost Mississippi channel bottom, or are found below a thin and discontinuous, migrating sand sheet. This is not an unusual case, as relict outcrops have been observed in the lower reaches of a number of rivers of varying size and gradient such as the Amazon, Hudson, Ganges-Brahmaputra, and Santa Clara.

The erosion rate of relict strata and the magnitude of particulate carbon release is a function of either lateral migration or down-cutting. Lateral migration rates in unrestricted rivers are system-specific, but are typically higher in sediment-choked braided systems than low-gradient meandering systems like the lower Mississippi [*Nanson and Croke*, 1992]. Although significant river channel down-cutting in the absence of lateral migration typically occurs on $\geq 10^3$ year time scales in response to base-level change, many large rivers today have been confined by flood control levees similar to the Mississippi system, which likely accelerates the process. We conclude that there are likely wide variations between rivers in the magnitude and age of particulate carbon released by channel erosion.

The stratigraphic succession of the Lower Mississippi Valley and adjacent deltaic plain has been extensively studied, and has shown that the river incises multiple fluvio-deltaic units from modern to late Pleistocene (~35,000 yBP) in age, with older units exposed upstream at the same river depth due to a regional seaward stratigraphic dip that exceeds the downriver gradient of the river's surface. A notable feature in this stratigraphic succession is the presence of peat-rich layers up to ~9 m thick deposited above the dense, oxidized late Pleistocene low-stand unconformity, and located stratigraphically below two Holocene age lobes of the eastern Mississippi delta [*Stanley et al.*, 1996]. The base of the peat layers is the time-transgressive early Holocene marine flooding surface above which organic-rich coastal sediments accumulated while the Mississippi River occupied the Teche delta complex further to the west from ~5,500 to 3,800 yBP. This peat unit was overlain after about 3,600 yBP by the onset of St. Bernard deltaic lobe formation as it grew seaward. A second widespread peat layer was deposited in southeast Louisiana on top of the St. Bernard lobe strata in inter-distributary environments when the Mississippi River occupied the LaFourche delta lobe further west, before switching back eastward to bury the second peat layer below the Plaquemine-Modern deltaic lobe strata after ~1,300 yBP.

Using a compilation of 92 borings through the stratigraphic units underlying the lowermost Mississippi River [*Stanley et al.*, 1996] and historical bathymetric data, it was possible to precisely locate where the peat layers outcrop in the Mississippi River channel for subsequent field sampling. It was found that the peat layers intersect the river channel over an area of 22.93 km^2, beginning 54 km above the Head of Passes, and extending upriver to river km 163. The exposure of peat-rich layers is as much as 42% of the channel per river km, with maximum exposure occurring near New Orleans, and decreasing downriver as a result of the layer's seaward dip.

Biochemical Implications

Grab samples and gravity cores were collected from three stations that had been surveyed by geophysical methods in the lower Mississippi River near New Orleans to examine the organic characteristics of the relict strata being incised. Samples were obtained of the peat layer from two stations that were composed of low-grade peat (< 25% organics) containing coherent root structures and vertically intact plant stems. The peat samples yielded radiocarbon ages of 3,580 ± 60 and 2,140 ± 50 radiocarbon years before present (yBP) with $\delta^{13}C$ values of -25.0 ppt. The third sample was from a gray clay layer located stratigraphically immediately above the 3,580-yr-old peat in the gravity (Kasten-type) core. A bulk carbon analysis on the disseminated organic matter in the sediment returned an age of 4,210 ± 70 yBP with a $\delta^{13}C$ value of -24.6 ppt. A deep scour in the channel outcropping at 45 m water depth that lies stratigraphically below the peat layers was also sampled. Here, dense grey clay was retrieved that gave a radiocarbon age of 32,580 yBP ± 400 with a $\delta^{13}C$ value of -25.0 ppt. This sample is from Pleistocene strata lying below the glacial lowstand Wisconsinan erosional unconformity, as well as the Holocene marine flooding surface.

The amount of organic carbon and nitrogen in the different organic matter samples from the lower river stations ranged from 1.5% to

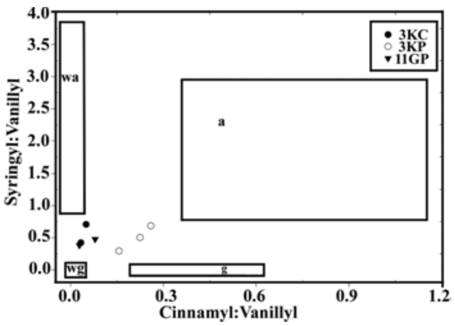

*Fig. 3. Plots of lignin compositional ratios syringyl:vanillyl vs. cinnamyl:vanillyl in sediment samples collected from the lower Mississippi River. The boxed areas represent compositional ranges of major vascular plant tissue: wa = woody angiosperm; a = non-woody angiosperm; wg = woody gymnosperm; and g = non-woody gymnosperm. These ratios indicate that significant amounts of lignin in both the river and GOM were derived from angiosperm tissues. Moreover, the low C/V ratios indicate that this is likely a mixture of woody and non-woody sources and contains a significant woody signature, which agrees with work from recent sediments in the lower river and Louisiana shelf [*Bianchi et al.*, 2002]. Macroscopic fossil fragments of woody twigs and non-woody marsh plant materials were also present in the samples, further corroborating this mixed biomarker signature.*

10.6% (mean = 4.9 ± 4.0) and 0.093% to 0.817% (mean = 0.359 ± 0.325), respectively. Molar carbon: nitrogen (C:N) ratios ranged from 14.9 to 19.4 (mean = 17.7 ± 1.9). The Λ_6 and Λ_8 values ranged from 1.29 to 6.87 and 2.79 to 7.06 (mean = 3.36 ± 2.31), respectively. Ratios of vanillic acid/vanillin (Ad/Al)v and syringic acid/syringaldehyde (Ad/Al), shown to be indicative of the diagenetic state of a sample [*Hedges et al.*, 1988], ranged from 0.34 to 0.62 (mean = 0.46 ± 0.12) and 0.33 to 0.52 (mean = 0.41 ± 0.08), respectively. These ratios are surprisingly low for their age and further support, along with the presence of macroscopic fossil remains, that some of these materials were buried relatively quickly with minimal decay.

It is well accepted that most of the "old" terrestrially-derived carbon delivered to the ocean by rivers is from eroded soils in the upper drainage basin, with minimal inputs from local sources on the coasts (e.g., marshes, swamps) [*Goni et al.*, 1998: *Raymond and Bauer*, 2001]. In particular, the northern grasslands of the U.S are believed to be the dominant source of "old" C_4 non-woody materials delivered to shelf/slope sediments in the northern Gulf of Mexico from the Mississippi River [*Goni et al.*, 1998]. Other work has suggested that there is a large fraction of woody C_3 vascular materials delivered to shelf regions in the northern GOM from local lowland forests and swamps [*Bianchi et al.*, 2002]. However, while these sources are generally regarded as being modern in age, relict sources within the lower Mississippi River could provide both an "old" and woody signature that could contribute to the OC composition of shelf sediments in the northern Gulf of Mexico.

Despite the importance of these environments in terms of sedimentary carbon, there remains a fundamental lack of understanding on the different terrestrial carbon sources within the watershed, and how they relate to the age and composition of particulate carbon that is ultimately delivered to the oceans. Despite the patchiness of exposed relict sediments in the lower Mississippi River, their relative importance to the total annual flux of POC to the coastal ocean may be important, and if nothing else, warrants further study. Using USACOE historical bathymetry surveys and three-dimensional models of the peat layer orientation, it was estimated that 366,857 m^3/yr were eroded from these peat layers in the lower river from 1921 to 1992. Using the measured average carbon content of the peat layers (6.6%) and wet peat density of 887 kg/m^3 [calculated from dry density; *Holm et al.*, 2000], it is estimated that 1.81 x 10^9 mol C were eroded from these layers annually.

Given that other relict units of a variety of geologic ages and carbon content are likely exposed in the Mississippi channel floor upriver of our study area, it can be concluded that the erosion of these units has an influence on the character of terrestrial POC entering the northern Gulf of Mexico. The likely presence of relict, organic-rich strata underlying other rivers around the world and subject to incision leads to a cumulative importance that should not be overlooked These findings shed new light on the dynamics of organic carbon cycling in river-dominated margins; there has been renewed interest in these regions with respect to their potential importance in carbon sequestration as it relates to global climate change.

Acknowledgments

Funding for this study was provided by the Office of Naval Research, the Center for Bioenvironmental Research at Tulane and Xavier universities and the Gulf Coast Association of Geologic Societies. The authors would like to thank the two reviewers for their helpful comments.

References

Bianchi, T.S., S. Mitra, and B.A. McKee, Sources of terrestrially-derived organic carbon in lower Mississippi River and Louisiana shelf sediments: implications for differential sedimentation and transport at the coastal margin, *Marine Chemistry, 77*, 211–223, 2002.

Dunbar, J.B., L.D. Britsch, and E.B. Kemp III, Land loss rates: Louisiana chenier plain, *Technical Report GL-90-2*, 21 pp., U.S. Army Corps of Engineers, New Orleans, La., 1990.

Goni, M.A., K.C. Ruttenberg, and T.I. Eglinton, A reassessment of the sources and importance of land-derived organic matter in surface sediments from the Gulf of Mexico, *Geochim. Cosmochim. Acta, 62*, 3055–3075, 1998.

Hedges, J.I., R.G. Keil, and R. Benner, What happens to terrestrial organic matter in the ocean? *Org. Geochem., 27*, 195–212, 1997.

Hedges, J.L., W.A. Clark, and G.L. Cowie, Organic matter sources to the water column and surficial sediments of a marine bay, *Limnol. Oceanogr., 33*, 1116–1136, 1988.

Holm, G.O., C.E. Sasser, G.W. Peterson, and E.M. Swenson, Vertical movement and substrate characteristics of oligohaline marshes near a high-sediment, riverine system, *J. Coastal Res., 16* (1) 164–171, 2000.

Meade, R.H., T.R. Yuzyk, and T.J. Day, Movement and storage of sediment in rivers of the United States and Canada, in *Surface Water Hydrology*, edited by M.G. Wolman and H.C. Riggs, pp. 255–280, Geological Society of America, Boulder, Colo., 1990.

Nanson, G.C. and J.C. Croke, A genetic classification of floodplains, *Geomorphology, 4*, 459–486, 1992.

Raymond, P.A., and J. Bauer, Riverine export of aged terrestrial organic matter to the North Atlantic Ocean, *Nature, 409*, 497–500, 2001.

Stanley, D. J., A.G. Warne, and J.B. Dunbar, Eastern Mississippi delta: late Wisconsin unconformity, overlying transgressive facies, sea level and subsidence, *Engineering Geology, 45*, 359–381, 1996.

Author Information

J.J. Galler, T.S. Bianchi, M.A. Alison, L.A. Wysocki, and R. Campanella, Tulane University, New Orleans, La. For more information, contact John Galler; E-mail: jgaller@tulane.edu.