Reports

Mississippi Deltaic Wetland Survival: Sedimentation Versus Coastal Submergence

Abstract. *Seasonal sedimentation, measured with the aid of artificial marker horizons, was markedly different in deteriorating as compared with stable marshes in the Mississippi River deltaic plain. Deteriorating marshes receive most sediment during storm events, whereas stable marshes receive substantial amounts of sediments during the spring river flood. The deteriorating marshes are accreting at a faster rate (1.5 centimeters per year at streamside, 0.9 centimeter per year at inland areas) than the stable marshes (1.3 centimeters per year at streamside, 0.6 centimeter per year at inland areas). However, relative to local apparent sea-level rise as measured by tide gauges in each area, the deteriorating marshes are not maintaining their intertidal elevation as well as the stable marshes. These results indicate the importance of considering accretion relative to submergence.*

This report documents the differences in the mechanisms of sedimentation at two wetland locations in the Mississippi deltaic plain; these locations represent two distinctly different stages of the delta development cycle of this river. Data show that the seasonality of sedimentation is an indication of the relative success of these marshes in maintaining their elevation.

The success with which these marshes maintain their intertidal elevation is dependent on riverine input, as basinal sedimentary processes are insufficient to combat the effects of apparent sea-level rise (subsidence plus true sea-level rise) and wave erosion. Present management strategies largely deter the dispersal of riverine sediment over this deltaic plain, which contains approximately 40 percent of the coastal wetlands in the United States and is linked to the largest fishery and fur harvest in North America.

The Mississippi deltaic plain was formed by several overlapping deltaic sequences that began developing ~ 7000 years ago (*1*). Upstream diversions throughout the late Holocene period, a process that ensured a net gain of wetlands in the region, switched the locus of sedimentation approximately every thousand years (*1*). Wetland deterioration (disappearance) is characteristic of the abandonment of the delta lobes and results from a dominance of subsidence and other erosional processes. Thus, the Mississippi deltaic plain is a complex mosaic of delta lobes in various stages of a progradation-deterioration cycle, with most lobes presently reflecting some stage of deterioration.

Most of the information on the sedimentary processes of the Mississippi deltaic plain has been obtained from interpretation of previously deposited and preserved sedimentary sequences (*1*). Short-term processes have received relatively little attention.

Our study was conducted in the marshes surrounding Barataria Bay (BB) and Fourleague Bay (FB); BB (19°30′N, 90°W) is an interdistributary basin between Bayou Lafourche, a previous Mississippi River course, and the Mississippi River, and FB (29°20′N, 19°10′W) is an estuary dominated by the Atchafalaya River, an active Mississippi River distributary. The potential for continued major accretion in the BB marshes effectively ceased with the damming of Bayou Lafourche at its juncture with the Mississippi River in 1904 and the subsequent construction after the 1927 flood of the artificial levee system along the Mississippi River (*2*). However, FB is in proximity to the Atchafalaya River, which presently debouches the bulk of its sediment load into Atchafalaya Bay.

Accretion was measured as sediment accumulation on white-clay marker horizons at eight sites in BB (*3*) and 14 sites in FB (*4*). These sites included both streamside and inland locations. The horizons in BB were laid down in July 1975 and examined four times per year during 1975 through 1977, and in winter and summer during 1978 through 1979. The FB sites were established in spring 1981 and examined in September 1981 and March and May 1982. Noteworthy phenomena that occurred during the study period included the following: an exceptionally high spring flood in 1979 (*5*); an exceptionally low spring flood in 1981 (*5*); and the passage of a hurricane over and a tropical storm near BB in July 1979.

The seasonality of sediment inputs at the two sites was markedly different (Table 1). Although hurricanes, tropical storms, and winter storms contributed most of the vertical accretion to BB marshes, the annual river flood was the single major depositional factor in FB marshes.

Hurricane and tropical storm activities in BB marshes deposited 36 percent of streamside and 40 percent of inland total accumulated sediments. Sedimentation during these events, which occurred during a single summer, shifted the seasonality of deposition for the entire 4½-year monitoring period.

Sedimentation not induced by hurricanes in BB marshes was caused primarily by winter storms (Table 1). In contrast, the annual flood cycle during 1981 and 1982 contributed 91 and 69 percent of streamside and inland sediments, respectively, to FB marshes (Table 1).

The annual sedimentation rates in both BB and FB marshes were significantly higher (0.05 level) at streamside than at inland locations (Table 2). The BB marshes had higher, although not significant, annual sedimentation rates than FB

Table 1. Seasonal sediment inputs (percent of net accumulation) at streamside and inland marshes. For Barataria Bay, the data for 1975 through 1979 include the effects of a hurricane and a tropical storm.

Season	Barataria Bay				Fourleague Bay (1981–1982)	
	Streamside		Inland		Streamside	Inland
	1975–1978	1975–1979	1975–1978	1975–1979		
Summer	14.0	43.9	14.8	45.5	48.7	51.9
Fall and winter	72.7	48.5	75.3	49.0	8.9	31.2
Spring	13.3	7.6	9.9	5.5	42.4	15.9

Table 2. Apparent sea-level rise (ASLR) and mean accretion rates (±95 percent confidence interval) at streamside and inland (in centimeters per year) locations; N.A., not available.

Data base	Streamside	Inland	ASLR
	Barataria Bay		
With hurricane (4 years)	1.5 ± 0.4	0.9 ± 0.2	
Without hurricanes (3 years)	1.1 ± 0.3	0.6 ± 0.2	1.23
~ 17 to 20 years from ^{137}Cs (*7*)	1.35	0.75	
	Fourleague Bay		
No hurricanes (2 years)	1.3 ± 0.6	0.56 ± 0.3	0.85
~ 17 to 20 years from ^{137}Cs (*8*)	N.A.	0.66	

marshes at both streamside and inland locations (Table 2).

The Mississippi River directly introduced sediments into BB intermittently over the past 4600 years and fairly consistently over the past 1000 years by way of its present and ancestral courses (*1*). Direct sediment input should have decreased throughout a period of several centuries, as the present course of the Mississippi River was abandoned for a more favorable gradient to the sea—the Atchafalaya River. The construction of levees on the Mississippi River and the clearing and the dredging of the Atchafalaya River have accelerated the loss of Mississippi River sediments to BB and deposition in the Atchafalaya system (*6*). Thus, BB marsh elevation is maintained by an input of organic detritus and by the resuspension and deposition of the existing sediment pool in water bottoms adjacent to the marshes as a result of total flooding. Although these resuspension and deposition processes occur in FB marshes also, the Atchafalaya River delivers new sediments to the entire system by overbank deposition during major riverine floods.

An important finding of this study was the major shift in the source and seasonality of sedimentation in marshes with and without a riverine sediment source. Only FB marshes presently have a significant annual flood input. Although the sedimentation rates in BB marshes appeared to be higher than those in FB marshes, we found that, when hurricane and tropical storm inputs were subtracted (which should be equal in both areas on a long-term basis because both marshes have a similar proximity to the coastline and an equal probability of being affected by tropical storms), sedimentation rates in BB marshes may actually be lower than those in FB marshes, and most of the sedimentation in BB marshes typically occurs in the winter (Table 1).

The difference in the relative importance of the spring flood in BB and FB marshes shows that the Mississippi River system is no longer a direct source of sediments for BB. During the historically average flood of 1982, a substantial amount of sediment was deposited on FB marshes. Even during the second largest Mississippi River flood since 1950, in the spring of 1979, there was no substantial deposition in BB.

The mean annual sedimentation rates of 1.5 and 0.9 cm for streamside and inland BB sites, respectively, are in accord with the accretion rates of 1.35 and 0.75 cm/year obtained for the BB saline marsh based on ^{137}Cs dating (*7*) (Table 2). Likewise, a mean annual sedimentation rate of 0.56 cm/year for inland sites in FB marshes is comparable with 0.66 cm/year obtained from ^{137}Cs dating at five inland sites in FB marshes (*8*). However, these annual sedimentation rates are several times to an order of magnitude greater than those along the U.S. Atlantic Coast (*9*). Greater streamside than inland sedimentation rates are found in Gulf and Atlantic Coast marshes (*7, 9*); these results are supported by laboratory studies (*10*).

Hurricanes and winter fronts are major depositional and erosional agents in both study locations. On average, 5.7 winter fronts pass through the area each winter month (*11*), and the annual probability of a hurricane passing within 80 km of the area is 12 percent (*12*). Storms elevate water levels and resuspend sediments (*13*), which are then deposited in the marshes. Storms can also generate high-velocity flows over marsh surfaces, causing the redistribution of previously deposited sediments (*14*). However, these energy-intensive events also resulted in wave-induced lateral erosion at three BB sites and one FB site and vertical erosion at eight FB sites.

The rate of subsidence and sea-level rise also affects the observed sedimentation patterns. Crustal downwarping and related tectonic processes associated with sedimentary loading, as well as the compaction of the thick sequence of Mississippi deltaic sediments, result in high subsidence rates in the Mississippi deltaic plain (*1*). The combined subsidence and eustatic rates of sea-level rise for BB and FB marshes, based on tide gauge analyses of the past three decades, are 1.23 cm/year (*3, 15*) and 0.85 cm/year (*16*), respectively (Table 2). The difference is presumably caused by a thinner (hence more stable) Holocene sedimentary sequence in the FB area than in the BB area. Aggradation in relation to apparent sea-level rise is closer to a balanced state in FB marshes, despite an absolute aggradation rate that is lower than for BB marshes. This relation points out an obvious flaw that arises when one compares absolute marsh aggradation rates at different locations without factoring in local variations in coastal submergence and emergence.

The continuous deterioration of BB inland marshes, which represent the bulk of the marsh area, will increase the open-water areas, thereby subjecting streamside marshes to lateral scour by wave activity. The transformation from marsh to open bay cannot be halted unless there is a reintroduction of riverine sediment.

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A Nitrogen Pressure of 50 Atmospheres Does Not Prevent Evolution of Hydrogen by Nitrogenase

Abstract. *The effect of a partial pressure of nitrogen of 50 atmospheres (5065 kilopascals) on the hydrogen evolution reaction of nitrogenase has been investigated. Evolution of hydrogen was not blocked completely by 50 atmospheres of nitrogen in any of four experiments; rather, 27.3 ± 2.4 percent of the total electron flux through nitrogenase was directed toward production of hydrogen. The ratio of hydrogen evolved to nitrogen fixed was close to 1:1, which implies that hydrogen evolution is obligatory in the fixation of molecular nitrogen by nitrogenase.*

Nitrogenase catalyzes the reduction of N_2 to NH_3 and consists of two electron-transferring proteins, dinitrogenase reductase (iron protein) and dinitrogenase (molybdenum-iron protein). Nitrogenase is found in strictly aerobic, microaerophilic, facultative, and strictly anaerobic prokaryotes, and, depending upon the organism and the growth conditions, these organisms may acquire energy heterotrophically or photoautotrophically (*1*). Dinitrogenase reductase transfers a single electron at a time to dinitrogenase (*2*) with the concomitant hydrolysis of two molecules of adenosine triphosphate (ATP) to yield two molecules of adenosine diphosphate plus orthophosphate (*1, 3*). Dinitrogenase, with its multiple iron-sulfur centers and its FeMoco prosthetic group or groups (*4, 5*), both stores electrons and transfers reducing equivalents to substrates (*4*).

Nitrogenase evolves H_2 and reduces N_2 to NH_3 (*6, 7*). Uptake hydrogenases present in many nitrogen-fixing bacteria can recycle H_2 evolved by nitrogenase and recover part of its energy as ATP or reducing equivalents, or both (*7*). In experiments with cell-free nitrogenase from *Azotobacter vinelandii*, Rivera-Ortiz and Burris (*8*) observed a Michaelis constant (K_m) of 0.136 atm for N_2 and showed that increasing the partial pressure of N_2 (pN_2) between zero and 1 atm decreased H_2 evolution significantly. Extrapolation of their data for moles of H_2 evolved versus pN_2 to infinite pN_2 indicated that most of the electron flux through the enzyme was directed toward NH_3 formation but that H_2 evolution still accounted for 13 to 23 percent of the electron flow. These results implied that infinite pN_2 was unable to block evolution of H_2 completely. In addition, their observation that the percentage of the electron flux allocated to H_2 evolution was near the theoretical 25 percent predicted by a stoichiometry of one molecule of H_2 evolved per one molecule of N_2 fixed suggested that the ratio of H_2 evolved to N_2 fixed might be 1:1 at infinite pN_2. Recently mechanisms for nitrogenase catalysis have been proposed that assume one molecule of H_2 is evolved per molecule of N_2 fixed (*9*). However, as far as we know, no one has tested the prediction of Rivera-Ortiz and Burris (*8*) experimentally to determine whether their extrapolation is justified or whether evolution of H_2 is prevented by a very high pN_2. In this report we present the results of experiments that test the effect of 50-atm pN_2 on the H_2 evolution reaction of nitrogenase.

Azotobacter vinelandii OP was grown in a 300-liter fermentor on the nitrogen-free medium described by Strandberg and Wilson (*10*). The nitrogenase proteins were purified by the method of Hageman and Burris (*11*) to specific activities of 2100 and 1864 ± 181 nmole of acetylene reduced per minute per milligram of protein for dinitrogenase reductase and dinitrogenase, respectively. Protein was determined by the method of Goa (*12*) with bovine serum albumin used as a standard. Nitrogenase concentrations were selected to avoid any dilution effect (*13*), and reactions were conducted with a 20-fold molar excess of dinitrogenase reductase over dinitrogenase. These precautions ensured maximal electron flow through dinitrogenase during the reactions. High electron flow rates favor reduction of N_2 and decrease formation of H_2 (*11*). Product formation was linear for the period of the assays.

The high-pressure reaction vessel (Fig. 1) consisted of a 22-ml reaction vessel made of 316 stainless steel with a

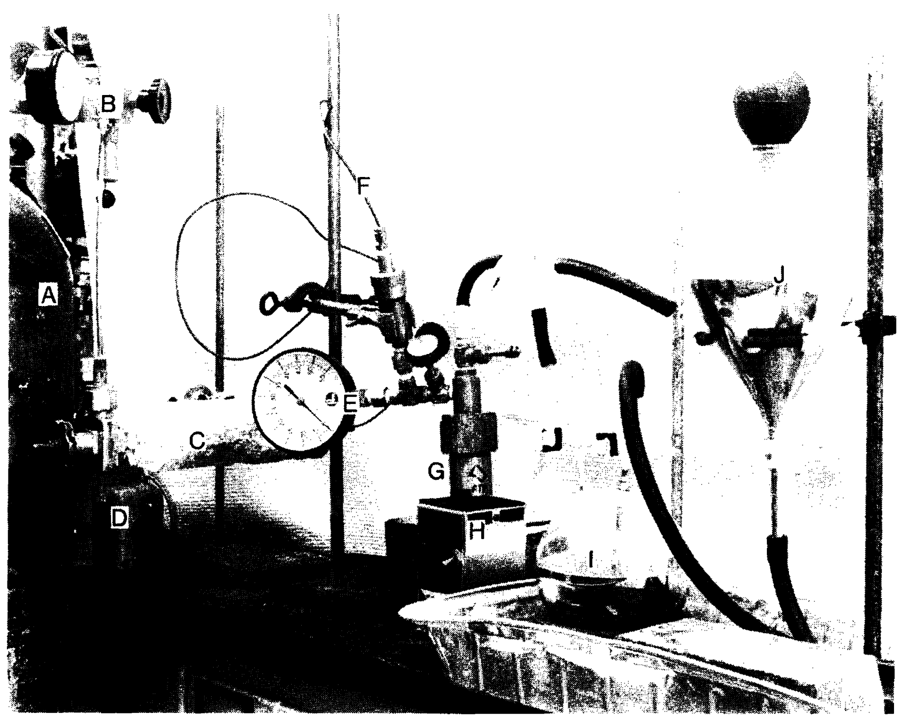

Fig. 1. High-pressure reaction bomb and apparatus built by Sanford Anderson: *A*, tank filled with 70 to 100 atm of high-purity N_2 (Linde); *B*, regulatory valve; *C*, 160°C BASF catalyst in a lecture bottle wrapped with asbestos and Nichrome wire; *D*, variable transformer for adjusting the temperature of the BASF catalyst; *E*, 55-atm Parr gauge; *F*, copper introductory line; *G*, reaction bomb; *H*, magnetic stirrer; *I*, glass vessel filled with mercury for the collection of reaction product gases; and *J*, glass vessel for the collection of displaced mercury.