Exploring the role of organic matter accumulation in delta dynamics

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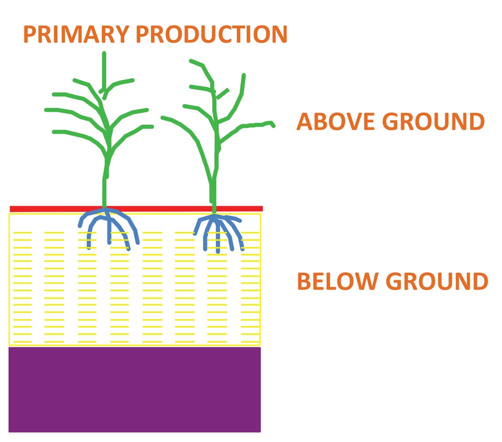
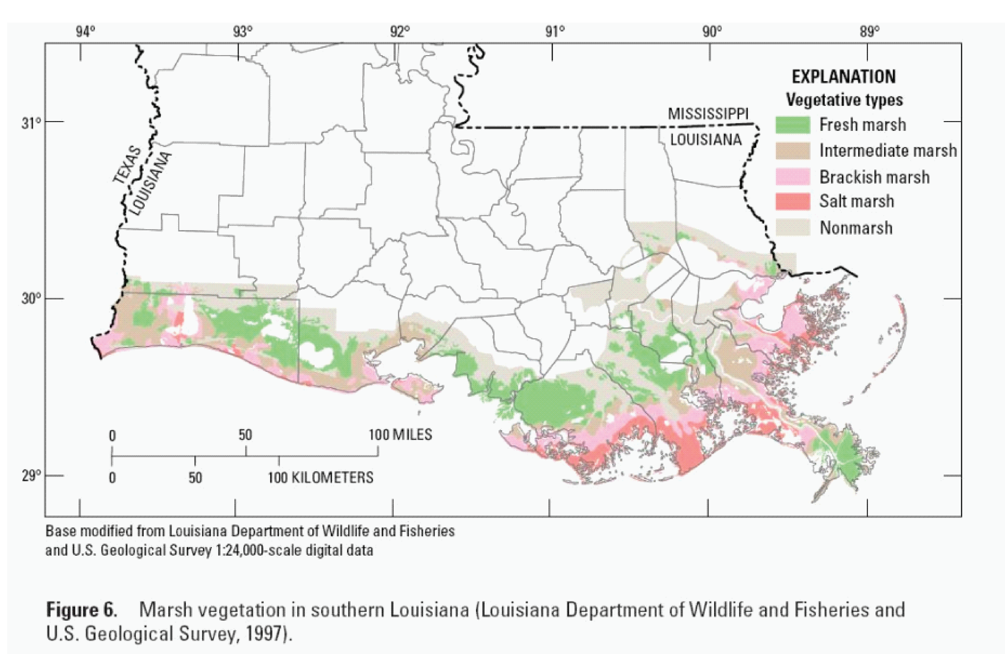
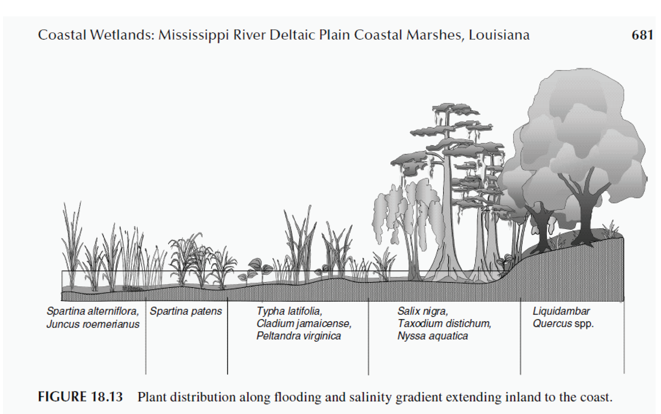
Why do we need to include organic matter in delta evolution models?

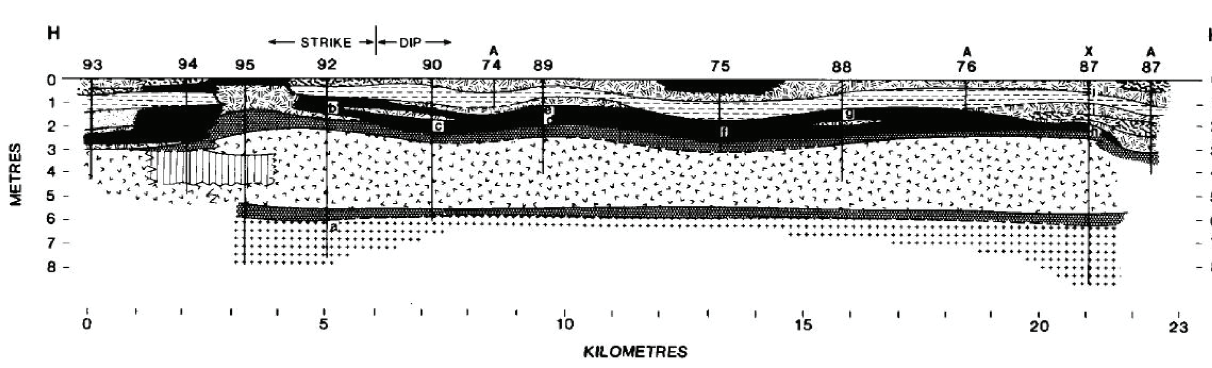
1. Coastal wetlands are among the most productive systems in the world (at the level of rainforests). A significant fraction of the organic biomass comes from bellow-ground (root network).
2. In many deltas, soil organic carbon plays a small but significant role in building the delta sediment column.
3. The dynamics of carbon storage and destruction are different according to the ecosystem.
4. The boundary between marshes is dynamic and its movement is strongly coupled to the evolution of the delta surface.
5. Organic-rich sediment (i.e., peat) dynamics have been recently identified in the literature as a new potential control of coastal evolution at the salt marsh scale, and at the whole-delta scale.







Reddy and DeLaune 2008



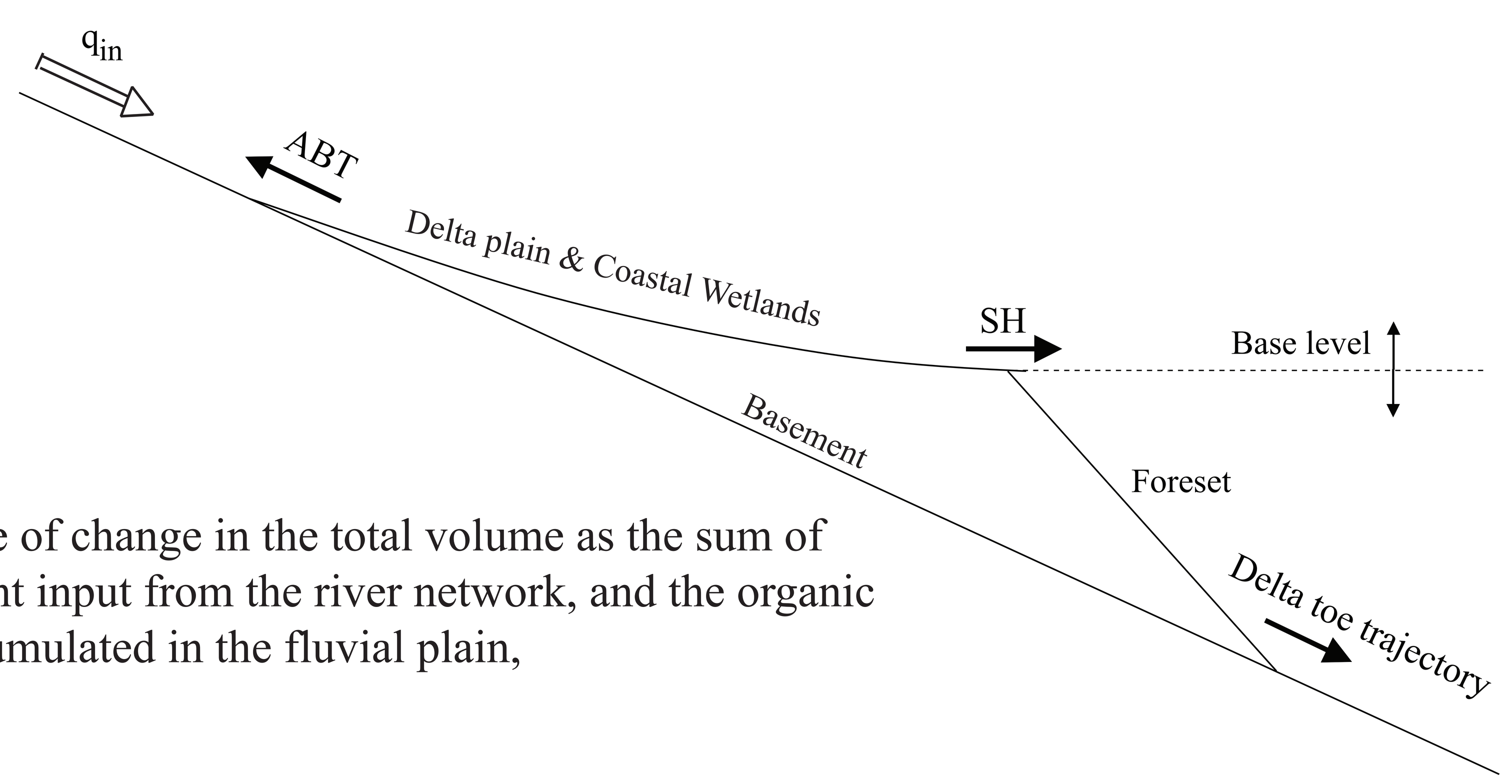
Stratigraphic cross section in barataria basin, Mississippi delta. The black layer is the peat accummulated (>75% organics) [Kosters et al. 1987]

Objectives

1. Develope a 'lumped' model framework aimed at averaging the critical small scale biological processes that control the accumulation of organic soils in deltaic environments.
2. Use this model to explore the role of peat on the average delta dynamics.

Modeling Framework

Current modeling efforts based on a sediment mass balance as expressed by the Exner equation have proved to be a useful approach for modeling the average dynamics during delta formation. Such models involve a balance among inorganic sediment supply, sea-level rise, and subsidence. To date, however, these models do not include the accumulation of organic matter in the delta plain.



We define the rate of change in the total volume as the sum of inorganic sediment input from the river network, and the organic matter (peat) accumulated in the fluvial plain,

$$\frac{dV}{dt} = q_{in} + q_{org}$$

$$V^{new} = V + \Delta t(q_{in} + q_{org}) \xrightarrow{\text{fixed Geometric shape}} \text{ABT and SH positions}$$

Assuming a point organic sedimentation rate given by: $v_{org} = \min(\dot{Z}, P)$

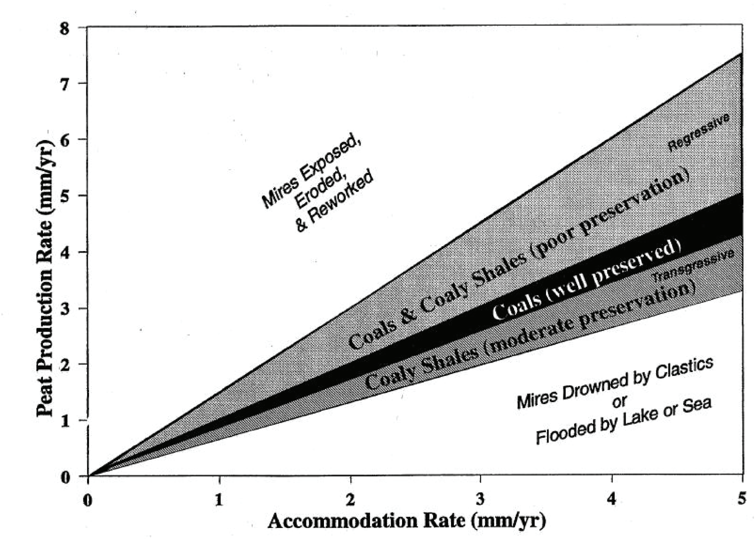
$P > \dot{Z}$ the excess peat is rapidly decomposed via aerobic respiration (i.e., oxidation) and does not bury in the system.

$P < \dot{Z}$ it is assumed that the shape is preserved by filling in the shortfall with the available inorganic sediment input.

Integrating accross the entire delta plain: $q_{org} = \int_{ABT}^{SH} v_{org}\,dx = \int_{ABT}^{SH} \min(P, \dot{Z})\,dx$

Model validation: Comparison with coal observations

Coal geologists have observed that the fundamental control of peat/coal accumulation at the sedimentary basin scale is the ratio between the rate of base-level rise and the peat accumulation rate. Multiple modern and ancient sedimentary environments (marine and non-marine) preserve the largest volume fraction of peat (coal) deposits when the overall accommodation rate approximately equals the peat accumulation rate.



Bohacs and Suter 1997

The response of peat accumulation to various accommodation/peat accumulation ratios. The percentages of peat ash are by mass. Modified after Bohacs and Suter (1997)

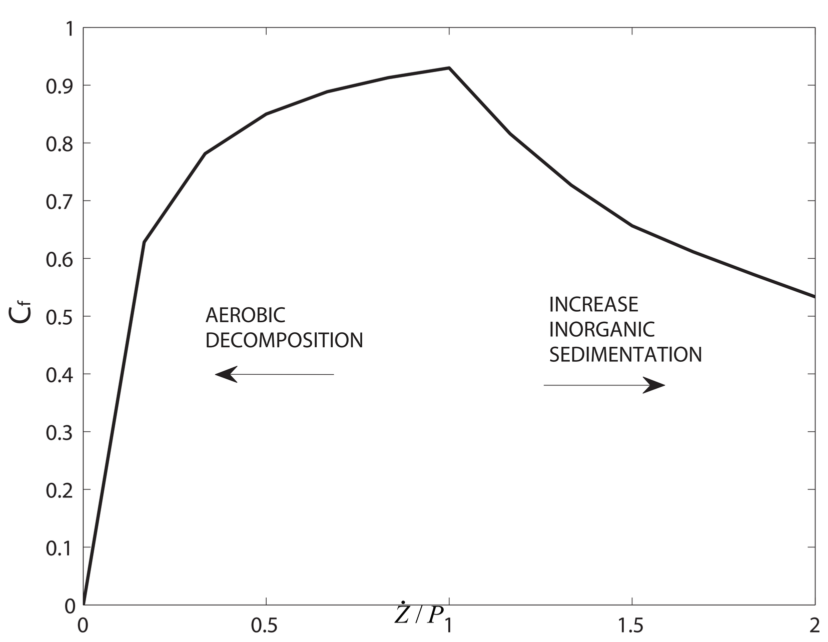
Accommodation/peat accumulation ratio	Depositional response
< 0.5	No significant peat formation
0.5 to 1.0	Impure peat due to oxidation and weathering
1.0 to 1.18	Optimum peat stage (< 20% ash)
1.18 to 1.53	Well-preserved peaty sediments (25–75% ash)
> 1.53	No significant peat formation

Diessel et al. 2000

The model can explain the observed coupling between the accommodation/peat accumulation ratio and the fraction of buried peat/coal deposits.

$$\text{Carbon fraction} = \frac{\int q_{org}\,dt}{\text{Volume fluvial plain}}$$

The shape of the plot can change for different the parameter values, but in all cases the maximum is occurs at the same location.



Role of peat dynamics on average delta dynamics

First we recognize the role of salinity in the rate of peat accummulation *P*. Significant differences have been observed in different deltaic systems such as Mississippi Delta [Kosters et al. 1987] and the Ebro delta [Ibañez et al.2010]. Such imbalance can be explained by the differences in decomposition rate between both regions; in the near-shore saline region sulfate reduction is the predominant pathway of anaerobic decomposition, whereas in the inland fresh region methanogenesis prevails.

Anaerobic decomposition:

Sulfate reduction: $SO_4^{2-} + 8e^- + 10H^+ \rightarrow H_2S + 4H_2O$

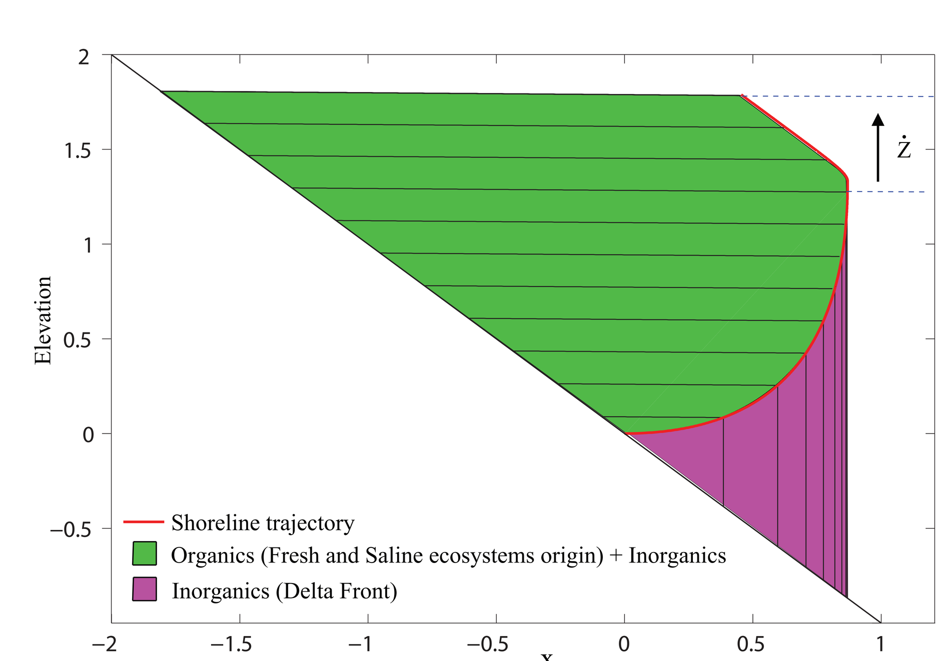
Methanogenesis: $CO_2 + 8e^- + 8H^+ \rightarrow CH_4 + 2H_2O$

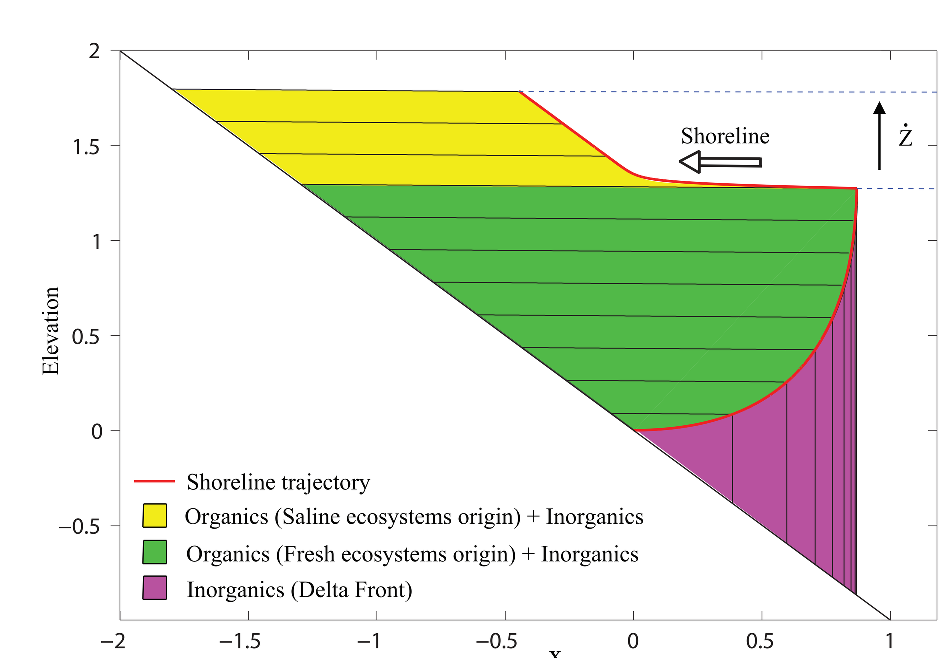
Volume balance:

$$V^{new} = V + \Delta t(q_{in} + \min(\dot{Z}, P_f)\cdot f + \min(\dot{Z}, P_s)\cdot s)$$

where Pf and Ps are the average rate of peat accumulation in fresh and saline environments, f and s are the length of the fresh and saline environments. From this equation it is clear that the fresh-salt boundary might play an important role on the total volume balance, and therefore on delta evolution.

Below we present a case example in which the system is largely affected by the dynamics of the fresh-salt boundary. The system undergoes a constant sea-level rise in both plots. In the left plot the entire delta plain remains fresh, whereas in the right plot at a given point in time the fresh water inputs are shut down, and there is a sudden invasion of saline ecosystems.





Conclusion

The presence of peat in the sediment column can significantly alter large scale delta dynamics. In particular, an imbalance in peat accumulation rate controlled by biogeochemical processes can enhance shoreline transgression. This work highlights the need to develop models of organic sedimentation in the delta plain at large time and space scales to complement current delta evolution models.