Sedimentation Patterns and Transport Pathways Linking River Mouth to Remote Depocenters in the Ganges-Brahmaputra Delta, Bangladesh*

Kimberly G. Rogers¹ and Steven L. Goodbred, Jr.¹

Search and Discovery Article #50304 (2010)
Posted August 20, 2010

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

¹Earth and Environmental Sciences, Vanderbilt University, Nashville, TN (kimberly.g.rogers@vanderbilt.edu).

Abstract

The combined Ganges-Brahmaputra Rivers in Bangladesh (GB) deliver more than 750 million metric tons of sediment annually to the world ocean through a highly energetic coastal zone, where sediments are reworked daily by tides, winds, waves, and annually by seasonal monsoons and cyclones. Sediment delivery to the coast has kept pace with sea level rise since the early Holocene, allowing subaerial growth of the delta. However, the abandoned lower delta is disconnected from any major distributary source of sediments, and therefore relies on sediment delivery from the ocean side via tides, cyclones, and summer monsoons. The dispersal and transport mechanisms of these sediments beyond the river mouth have been only partially quantified. To further refine our understanding of the spatial and temporal distribution of sediment delivery to the lower delta, sediment traps were widely distributed across the abandoned delta just prior to the 2008 monsoon season, and recovered following cessation of floodwaters. Sediments recovered during the flood season were analyzed by gamma spectroscopy to determine whether they were fluvial- or marine-sourced. An innovative approach using short-lived radioisotopes as environmental tracers (\(^{7}\text{Be}\) and \(^{234}\text{Th}\)) was used to differentiate between sediments instantaneously delivered to the abandoned GB lower delta plain during the flood pulse and those reworked onto tidal islands by dry-season tides and waves. Initial results indicate much higher annual accretion rates than previously thought and differing delivery pathways between the traditionally named “active” and “abandoned” portions of the delta. These results and other recent studies are changing the way we view the exchange of sediment across the terrestrial-marine boundary by introducing major alongshore and onshore components of river-sediment dispersal.

Reference

Sedimentation patterns and transport pathways linking river mouth to remote depocenters in the Ganges-Brahmaputra Delta, Bangladesh

Kimberly G. Rogers and Steven L. Goodbred, Jr.
Earth and Environmental Sciences, Vanderbilt University
14 April 2010

Funding Provided by the National Science Foundation

Presenter's Notes:
Focus is on the transport and dispersal of sediment in the GB source to sink system, which is THE end-member example of a high-discharge, large braided river-delta system.
Organization

I. System
II. Transport processes
III. Strategy & Techniques
IV. Results
V. Conclusions
This is a satellite image of the entire GB S-to-S system, with the Himalayas in the north, the Bay of Bengal opening to the south, the beautiful Tripura Fold Belt and Indo-Burmese Range on the east, and India on the west. In the center of this image, you can clearly see the confluence of the Ganges and the Brahmaputra in the center of Bangladesh.

Most folks working in the G-B system have focused either on the fluvial processes shaping the subaerial portion of the delta, or on the marine processes shaping the rapidly prograding foresets and the prodelta of the subaqueous clinoform...as well, there has been a modest amount of work done to understand the morphodynamics of a submarine canyon that incises the shelf in the Bay of Bengal. My work is aimed at filling a critical missing link in the S2S story of these large-scale, tidally dominated continental Margins by focusing on the estuarine transition zone where the fluvial, oceanographic and climatic processes interreact and overlap to disperse sediment across the shelf and to depocenters that are widely separated from the active river mouth. My talk today will zoom in on one of these remote depocenters, the subaerial part of the abandoned delta. This work has been motivated by the need to better understand the linkages between the delta plain and the inner shelf. Within the S2S framework, one could think of the river mouth as the source and the lower delta plain as the sink.
Ganges-Brahmaputra
Delta System

Depositional setting:
1. **Bengal Basin**: largest depositional feature by volume (Kuehl et al. 1989)
2. **2nd Largest combined sediment discharge**:
   \[ Q_{s\,\text{wet}} \approx 992 \times 10^6 \text{ tons/y} \]
   (vs. \( Q_{s\,\text{dry}} \approx 93 \times 10^6 \text{ tons/y} \);
   *Amazon*: \( \approx 1150 \times 10^6 \text{ tons/y} \)
   *Mississippi*: \( \approx 250 \times 10^6 \text{ tons/y} \)
3. **Fine-grained**:
   60% silts and clays (50% of \( Q_s \) is bedload)
4. **Abandoned lower delta plain**:
   siltation of Ganges offtakes = no landward sediment source

**Presenter’s Notes:**
This is a map of the study area, showing the location of Bangladesh and the three rivers that are the conduits for sediment from the Himalayas to the Bengal Basin. There are several salient points that can be made about the depositional system, including the point that contributions by these rivers have created the largest depositional feature on earth, by volume; they have the largest combined sediment discharge, 50% of which is bedload and is almost an order of magnitude greater in the five months of the summer monsoon wet season; sediment discharge is predominantly silts and clays. Sediment delivery to the coast.
Presenter's Notes:
Here is a conceptual process model of the forces that may directly contribute to delivery and reworking of sediment on the inner shelf from the river mouth to the western delta.
Our focus here is on the flood pulse. This model can be applied to different margins—not just GB. General S-to-S—how tidally controlled delta systems mass-transfer: critical zone is dynamic interface between marine and fluvial.
Southwest Asian Monsoon

River Discharge:
80% of water and 95% of sediment discharged during SW monsoon

80% of water and 95% of sediment discharged during SW monsoon

Presenter's Notes:

During summer, the Indian subcontinent heats up, creates powerful convection, and large-scale air flow rushes in to replace the ascending air masses. This is known as the southwest monsoon, characterized with winds blowing from southwest, over the Arabian sea. These winds pick up tremendous amounts of moisture that is released over the land as drenching rains.

The Indian Ocean is so different because: First, its northern boundary does not extend beyond 25°N. Second, it is not bounded by a "solid" coastal eastern boundary, as the Atlantic and Pacific Oceans are. Next, it is split into two basins - the Arabian Sea and the Bay of Bengal. Thus the Indian Ocean does not have the currents to transport and discharge heat to higher latitudes. The two-basin split of the ocean is a recipe for wind patterns unlike any other over the other oceans where more stable trade winds patterns are observed.

Massive discharge leads to: Coastal flooding; Elastic flexure/isostatic loading; Rapid seasonal subsidence.

Tectonic activity is as active and timely as monsoon floods.
Monsoon set up and relative sea level rise

**Sea Level:**

~0.5 cm/yr relative SLR

*(Additional 80 cm setup from onshore monsoon winds)*

*Presenter's Notes:*

~0.5 cm/yr relative sea-level rise; 80cm elevation difference between summer and winter monsoons.
Significant tide deformation within deltaplain channels...

- ~2 hour phase delay
- ~1 m amplification of flooding tide
- ~2 hour flood-dominant asymmetry

Tidal Fluctuations at Hiron Point and Mongla in Nov 2007

- Water Level (m)
- Dates: 11/9, 11/10, 11/11

80 km

Hiron Point

Mouths of the Ganges
Sampling strategy: spatial

- Direct measurements: sediment traps
- 2 coastal sites (E & W); 2 ~80km inland sites (E & W)
- 3 transects x 4 stations; up to 500m from creek bank
- Variety of stream orders
Sampling strategy: temporal

- Monsoon season deployment
- Gamma Spectroscopy
- $^7$Be measurements
- Cosmogenic radioisotope ($t_{1/2} = 53.3$ days)
- Particle reactive; preferentially sorbs to fine-grained sediment
- Tracer of terrestrially sourced flood-pulse sediments
Direct Measurements: lower delta plain
Accretion associated with seasonal flood pulse

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC pipe</td>
<td>PVC pipe</td>
</tr>
<tr>
<td>Ceramic tile</td>
<td></td>
</tr>
<tr>
<td>Brick dust</td>
<td></td>
</tr>
<tr>
<td>Turf carpet</td>
<td></td>
</tr>
</tbody>
</table>
Presenter's Note:
East vs. west, coastal vs. inland.
Mass Flux (g/cm²)
• ~1 cm/yr average accretion rate
• ~1/3 of sediments derived from seasonal plume dispersal

Presenter’s Notes:
Of 48 stations, all received sediment during the monsoon pulse. All depositional, cohesive, low-energy material; no evidence of deposition from time of collection to retrieval of traps. ~10,000km² (including India).
$^7$Be inventory

Site 1
Site 2
Site 3
Site 4
**Presenter’s Notes:**

Activity values are commensurate with flood-season suspended sediment in river discharge and offshore plume. Surface sediments from tidal creeks adjacent to stations: values within range of monsoon activities–river to offshore to tidal creeks to sample sites. Entire range of activities for channels and surface are on same order as those of monsoon ss values (sic). Note that not all have max values; there is some dilution! But the point of this slide is to illustrate the values of samples are similar to flood-pulse values. From source to sink–from river to offshore; somewhere between river and floodplain, there is some dilution. Mean activity value is ~1/2 max value…as discharge to coast, it is reworked. WHY are western sites highest? Tidal channel evolution…when young/abandoned from the river, they are being scoured and reworked. Older creeks in equilibrium, with no scouring. Temporary storage in adjacent channels.

Orange is range of suspended sediment $^7$Be values during peak monsoon flood, with some direct samples falling within the range; others below are assumed to be diluted.
Presenter’s Notes:

Each site (except site 1): full range of accumulation and AND 7Be tagged to sediments present. Three sites in different areas are showing similar ranges in mass flux and 7Be. As increase in mass flux, higher 7Be inventories, must be from ss. Notice similar accretion rates, but NO 7Be; two sediment sources. Transport length; direct throughput during flood pulse. Sites: increase sediment, increase inventory = flood pulse, but in a mixture of resuspended and flood-pulse sediments. Still ~1cm/yr.
Conclusions

Rapid accretion of ~1cm/yr:
- **double** SLR of ~5mm/yr
- accounts for ~10% of discharge, or ~100 x 10^6 tons of sediment

Accretion is tightly coupled with flood pulse
- emphasizes importance of 80cm monsoon setup
- flood-dominant tidal asymmetry

Accreted material may be a mixture of “fresh” flood pulse + reworked “older” material, ala temporary depocenter

Local patterns are variable, but track according to overbank, etc.