Drilling a late Holocene record of earthquakes in the submarine delta of the Ganges-Brahmaputra

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Abstract
The Ganges-Brahmaputra delta in Bangladesh is the main depocentre for the sediments derived from Himalayan denudation. The delta is positioned at the tectonically active boundaries of the Indian, Asian and Burmese plates. The possibility of severe earthquakes at the subduction zone in eastern Bangladesh is a major geohazard that is poorly quantified. The submarine delta clinoforms with an annual accumulation rate of up 10 cm can be used as an archive for these earthquakes which can liquefy the uppermost sediments in the submarine clinoform wedge. The resulting downslope flow generates homogeneous and distorted sediments that can be used as an indicator for the earthquakes. Based on the recent accumulation rates, the age of the four uppermost disturbed units corresponds to strong earthquakes affecting the plate boundaries of the Bengal Basin at 1762, 1885, 1897, and 1918 or 1950. Thus, the submarine delta contains a valuable archive of the subduction related earthquakes, which could be assessed by shallow hydraulic piston coring.
Recovering cores along a series of 50 m-holes at the transition from topset beds to foreset beds can provide overlapping chronologies from which a more than 2000 year-long record of earthquakes can be constructed. This will expand the short historic record and can be used to determine the recurrence rate of these devastating events.

Furthermore, climatic changes and anthropogenic influences on vegetation and weathering of the drainage area during the last 2000 years can be investigated. In addition, the river system has had numerous natural shifts and avulsions in historic times that altered the positions of the mouths of the Ganges and Brahmaputra Rivers, with their distinctive mineralogy. Bangladesh is at considerable risk from climate change and rising sea level. A longer record would aid in evaluating future risks.

Regional Setting and Previous Work

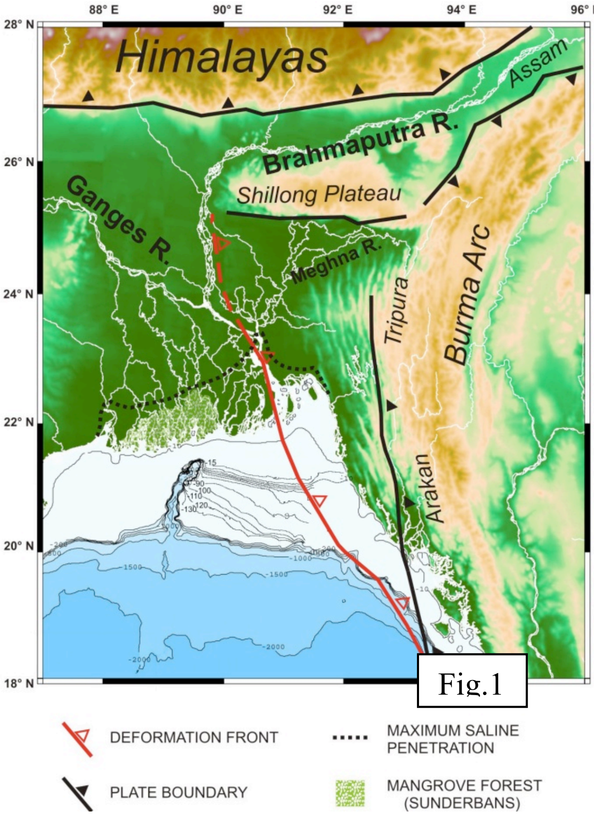

Fig.1

The delta of Bangladesh has been accumulating since the Oligocene on the northwestern border of the Indian plate, which collides northwards with the Asia continent and subsides eastwards under the Burmese plate (Fig.1). Numerous major earthquakes originate along these sutures and are threatening the southern river delta. The historical record of earthquakes is only a few hundred years long and more data are needed for a long-term risk assessment.

The rivers Ganges-Brahmaputra annually transport one to two billion tonnes of terrigenous material from the Himalayas to the Bengal deltaic plain. The material reaching the southern delta as bedload or in suspension consists mainly of fine sand, silt and clay. A significant part of this material is deposited in the submarine delta (Michels et al., 1998). Sedimentation rates in the clinoform beds of the submarine prodelta range between 10 and 0.1 cm per year and consequently the prodelta progrades 15 m per year (Michels 1998, Palamenghi submitted). Delta progradation has started 7000 years ago from a position far inland (Goodbred & Kuehl, 2000). Offshore from the present fluvial plain, a 25 km to 100 km broad subtidal plain has accreted in water depths less than 15 m (Fig. 1). With a slope of 0.2 to 0.3 degree the modern front of the submarine delta merges to the middle shelf surface at 80 m water depth mainly covered by relict sediments. In seismic records the prograding submarine delta is formed by clinoforms with distinct topset, foreset and bottomset beds (Fig. 2).

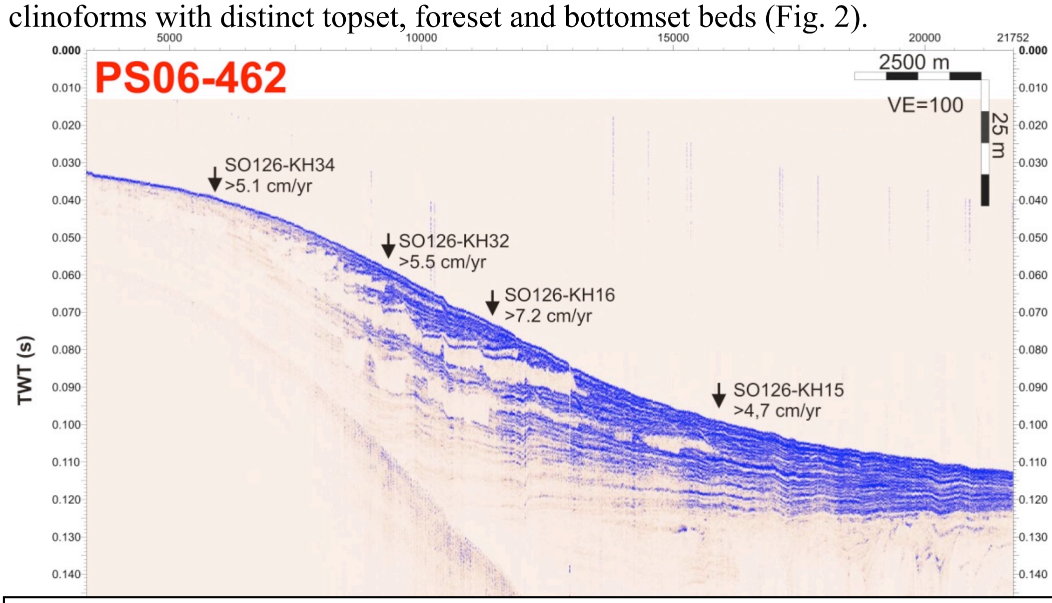

Fig.2 N-S echosounder profile across the clinoform beds of the central submarine delta

Sediments vary from fine sand in the topset beds to fine sand plus mud in the forest beds and finally to mud in the bottomset beds. Cm-thick layers of laminated fine sand are interbedded with burrowed dm-thick mud sequences of the foreset beds (Michels, 1998). The mud occasionally contains small shells of bivalves, gastropods and echinoderms. Some sections of the sampled sequence consist of homogenous mud (Kuehl et al. 2005). These sections appear in the seismic profiles as acoustically transparent units (Fig. 2) which are present in the entire submarine delta front, but are more prominent in the eastern parts. The four youngest layers can be laterally traced in the foreset beds over a distance of about 200 km. Their thickness laterally varies rapidly, especially in the upper and lower transition zones of the foreset beds. In profiles normal to the slope, the top of the transparent layers often forms a staircase-like structure in the foreset beds. The layers usually thin in the bottomset beds.

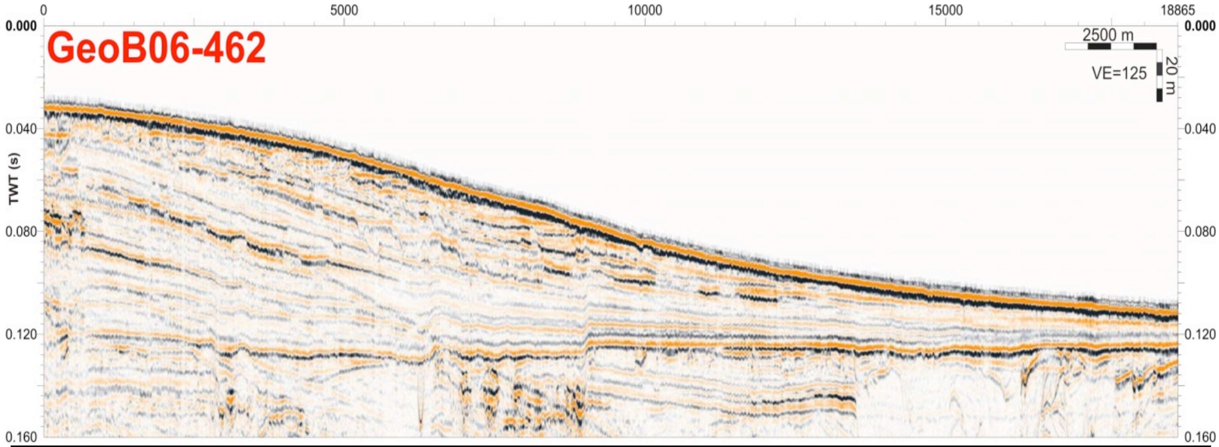

Fig. 3 N-S multichannel seismic profile across the central clinoform of the submarine delta, same position as sediment echosounder profile in Fig. 2

These acoustically transparent and homogenous units (TU) are assumed to be caused by high-energy events liquefying the youngest sediments in the foreset beds. The mobilized sediment is assumed to move short distances downslope thus forming the distinct terraces and run-out tongues. The flow distorts and deforms the underlying sediments by overloading and lateral stress producing the irregular shape of the lower boundary.

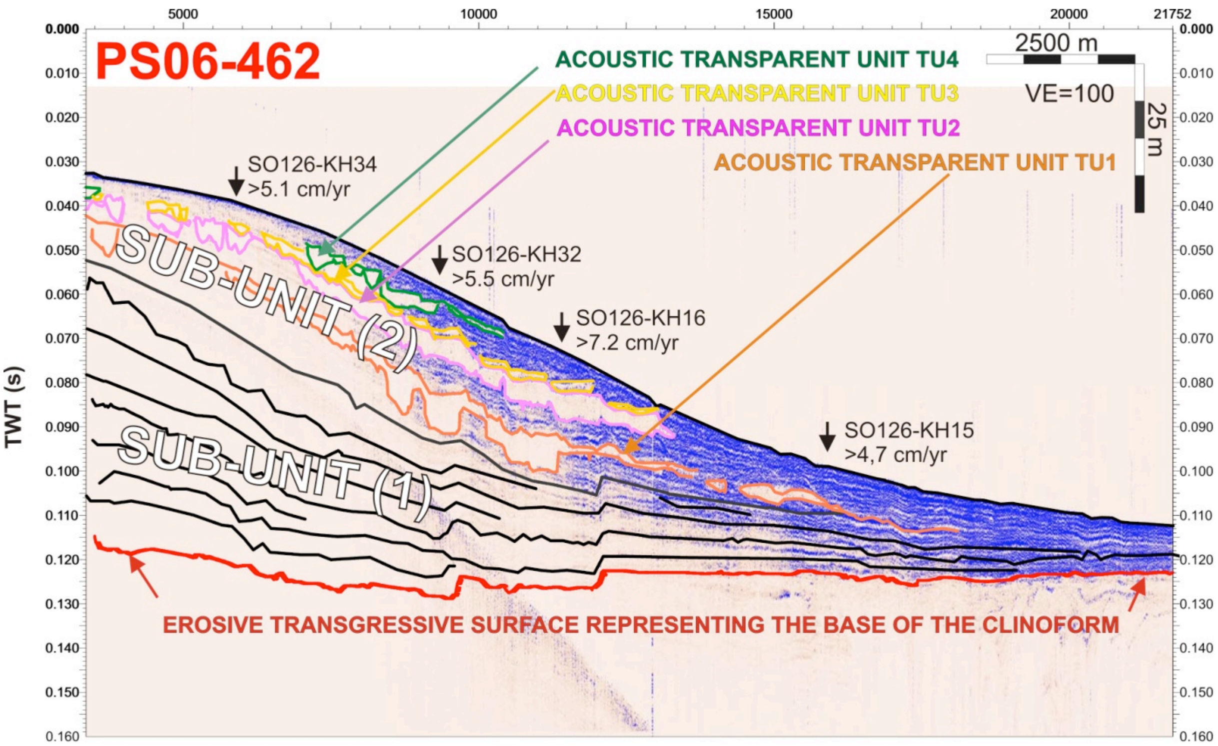

Fig. 4 Interpreted seismic profiles across the clinoform of the central submarine delta

Based on sedimentation rates determined by ^{210}Pb and ^{137}Cs chronologies for the last 100 years (Suckow et al. 2001), the layers appear with a average frequency of approximately once every one hundred years and they are much rarer than the tropical cyclones which cross the submarine delta with an average rate of 1.5 event /y. Consequently, the cyclones can be excluded as the process triggering the flows. In addition, cyclones will not affect the entire submarine delta over a distance of 200 km and the more pronounced appearance of transparent layers in the eastern profiles can also not be explained by cyclones, which mainly hit the centre of the submarine delta. Consequently earthquakes are assumed to be the most evident trigger for the liquefaction and the formation of the transparent units (TUs).

TU1, which is most pronounced layer, is most probably caused by the Arakan Earthquake in 1762, which trusted with an 8.8 magnitude the eastern part of the Bengal Shelf (Cummins 2007, Steckler et al, 2008) and thus occurred in the direct neighbourhood of the submarine delta. The extrapolation of the sedimentation rates from the last 50 years approximately confirm the age of this layer with 250 to 300 years before present. TU2 is separated from the TU1 by 4-5 meters of stratified foreset beds corresponding to about 100 years of normal sedimentation. The correlation of the upper TUs is more ambiguous, as no datable cores are available. Taking the short, 50 km - distance from the epicentre to the prodelta front, TU2 may assigned to the Manikganj Earthquake (magnitude 7.0) in 1885. 12 years later, the Great India Earthquake in 1897 (8.7 magnitude) affecting the Shillong basement block in northern Bangladesh has probably caused the much smaller TU3, which directly overlies the TU2. Finally the uppermost TU4 is mostly buried by a few meters of foreset beds and therefore could be related to the 7.6 Srimangal Earthquake in 1918 affecting the Sylhet Basin or to the 8.4 Assam Earthquake in 1950. In any case, the sediments of the submarine delta contain a sequence of earthquake-related liquefication deposits, which could be used to study the recurrence rate of major earthquakes for a long-term risk assessment. Especially the older subunit 2 (Fig. 4) contains more transparent layers extending the earthquake record by several hundred years beyond the historical one.

Expected outcome

The recurrence rate of earthquakes along the subduction-collision zone in Bangladesh and northeastern India can be established for the last 2000 years to improve the risk assessment of the delta in Bangladesh.

Furthermore the geochemical composition of cored sequences can be used to understand the linkages between late Holocene natural monsoonal dynamics, weathering history, and the expansion of agriculture in the drainage area of the rivers.

Steps to achieve the goals

Defining drill sites to obtain a continuous record:

The acquired seismic multichannel and sediment echosounder data will be used to map the distribution of transparent layers and to define drill sites in the foreset beds with a representative inventory. New high-resolution multichannel seismic profiles would be needed to image the foreset beds buried under the thick cover of the outer sandy topset beds in water depth of about 10 m to 20 m.

Drilling the foreset beds to recover a complete record of transparent layers by hydraulic piston coring:

Drill sites must be placed in direction of the N-S progradation of the submarine delta with a distance of about 5-10 km in the respective centre of the foreset beds where the transparent layers are best developed. A stacked record of transparent layers combined from a series of 50 m-deep cores is needed to recover the entire inventory. Two profiles each with 4-5 cores in the central and the eastern parts across the outer submarine delta are required to reliably investigate a period of about 2000 years.

Dating the transparent layers:

Exact dating is a crucial point in this project. ^{14}C dating of marine shells and of selected terrestrial or marine biomarkers with very short residence time could be a powerful tool.

Reading the environmental signals:

For the environmental studies of the extraction of marine organic components and their isotopic and compositional analysis could reveal changes in productivity, temperature and salinity. The geochemical composition of the terrigenous fraction will indicate changes of weathering intensity onshore and thus reflect the climatic conditions onshore. Mineralogical, isotopic and elemental signatures will be used to determine shifts in fluvial input. The IODP INVEST proposal by SPIESS et al. to drill the sediments in the shelf canyon contains more details about the environmental targets.

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