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Research paper

# Luminescence dating of delta sediments: Novel approaches explored for the Ganges-Brahmaputra-Meghna Delta

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ABSTRACT

Deltas where luminescence dating is most essential due to organic-poor geologic records are also those where it is often most challenging due to unsuitable luminescence properties of quartz grains, associated with rapid production of young clastic sediment. One example is the Ganges-Brahmaputra-Meghna Delta (GBMD), where Himalaya uplift drives erosion, production, and delivery to the delta plain of poorly sensitized quartz sand. Luminescence dating of fluvial deposits may be further complicated by partial bleaching prior to deposition. Here, we use GBMD quartz and polymineral sediment, including sand and silt fractions, with constrained depositional ages between a few years and a few centuries to test novel approaches to luminescence dating of fluvial deposits in an otherwise challenging setting. This produces the first delta-wide assessment of GBMD sediment luminescence dateability. We use a new multiple-signal SAR (MS-SAR) bleaching index (BI) to explore zeroing of the luminescence signals of sediment prior to deposition and to quantify the IR, pIRIR, and TL residual doses of GBMD polymineral silt with well-reset BSL signals. This test establishes BI values that can be used to identify sufficient bleaching of Holocene sediment with unknown depositional ages, thereby improving confidence in quartz silt dating. We find that GBMD quartz sand is unsuitable for luminescence dating in most localities. By contrast, GBMD silt is sufficiently bleached and has universally suitable luminescence characteristics, enabling dating of GBMD deposits up to the Last Glacial Maximum. Our findings in the GBMD establish methodology for obtaining and validating luminescence ages for fluvial deposits in challenging settings with unsuitable quartz sand.



## 1. Introduction

The development of luminescence dating has enabled studies of fluvial and deltaic processes not previously possible with radiocarbon and other methods (Wallinga, 2002a; Rittenour, 2008). However, as luminescence dating is more widely adopted, shortcomings in its global applicability have become clear. Establishing comprehensive knowledge of the geographic limitations of luminescence dating based on the availability of suitable quartz (e.g., Preusser et al., 2006; Lukas et al., 2007; Lawson et al., 2012) and likelihood of resetting prior to deposition (Stokes et al., 2001; Olley et al., 2004; Singarayer et al., 2005; Wallinga and Bos, 2010; Shen and Mauz, 2012) is of paramount importance. Developing accurate and robust methods for those regions where coarse-grain quartz optically stimulated luminescence (OSL) dating is not feasible (e.g., Lukas et al., 2007; Madsen et al., 2011; van Gorp et al., 2013) provides a major challenge to the luminescence community.

Here, we explore the utility of luminescence dating for the Ganges-Brahmaputra-Meghna Delta (GBMD), Bangladesh (Fig. 1). The GBMD is the second largest and the most populated delta on the planet, with 150 million inhabitants. High population density, increasingly recurrent and severe flooding from multiple sources, and strain on infrastructure and livelihoods (Brammer, 2014) make the GBMD highly susceptible to crises associated with 21st century

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sea level rise acceleration (Syvitski et al., 2009). Yet, due to a wealth of largely Himalaya-derived fluvial sediment (Milliman and Syvitski, 1992; Goodbred and Kuehl, 1999; Sarker et al., 2003) which may serve to offset sea level rise (e.g., Paola et al., 2011) and a relative lack of preexisting hard infrastructure which could otherwise impede nature-based engineering (Jones et al., 2012) the future of the delta may be quite positive if it is managed in a thoughtful way that employs and accommodates natural processes (e.g., Stive et al., 2013).

Establishing reliable geochronological methods for the GBMD is necessary for understanding processes relevant to delta management, such as river avulsion timescales, rates and patterns of sediment deposition and subsidence, frequency of high-magnitude earthquake events, and tropical cyclone recurrence intervals. Further, the GBMD is an excellent example of a system in which establishing new chronologic methods is essential due to complications associated with radiocarbon dating (Suckow et al., 2001). Lessons from this delta can be used to guide dating in other settings.

### 1.1. Dateable deltas

The optimal approach to dating Holocene-aged delta deposits is a function of the composition of the delta's geologic record and the luminescence suitability of its clastic fraction (Fig. 2). The necessity for luminescence dating of Holocene deltas may be roughly indicated by sediment yield because this influences the degree of formation and preservation of organic-rich units. Clastics are more efficient than in-situ organics at accreting to fill accommodation space over geologic timescales (e.g., Törnqvist et al., 2008; Shen et al., 2015). Therefore, in deltas with high sediment yield, clastics will rapidly fill the available space resulting in organic-poor geologic records. Deltas with low sediment yield on the other hand, provide opportunities for peat formation resulting in more organic-rich geologic records.

Many fundamental questions about delta evolution can be satisfied through well-established radiocarbon dating techniques in organic-rich deltas, such as the Rhine Meuse Delta, Netherlands (e.g., Törnqvist and Van Dijk, 1993; Berendsen and Stouthamer, 2000). By contrast, luminescence dating is essential in organic-poor deltas, such as the GBMD where in situ organics (e.g., peat) are limited within the 50–90 m thick Holocene package (Goodbred and Kuehl, 1999) due to the high lateral mobility of sediment-laden channels that rework the floodplain in the upstream reaches (Wilson and Goodbred, 2015), widespread oxidation of organics during the dry season, and dilution by clastics and flushing via tidal exchange in the lower reaches (Allison et al., 2003). The Mississippi Delta is an example of a delta that falls in the middle of these extremes; peat is prevalent and clastic subdelta packages are generally bounded by peats (Fisk, 1952; Kosters and Suter, 1993; Törnqvist et al., 1996, 2008), so many broad questions can be answered through radiocarbon dating (e.g., timespan of fluvial system activity, Törnqvist et al., 1996). However, luminescence dating is needed to obtain direct chronologies of clastic deposits related to high energy processes and events (e.g., sedimentation rates and patterns, Shen et al., 2015).

The organic-poor deltas in which luminescence dating is essential are also those in which luminescence dating is often the

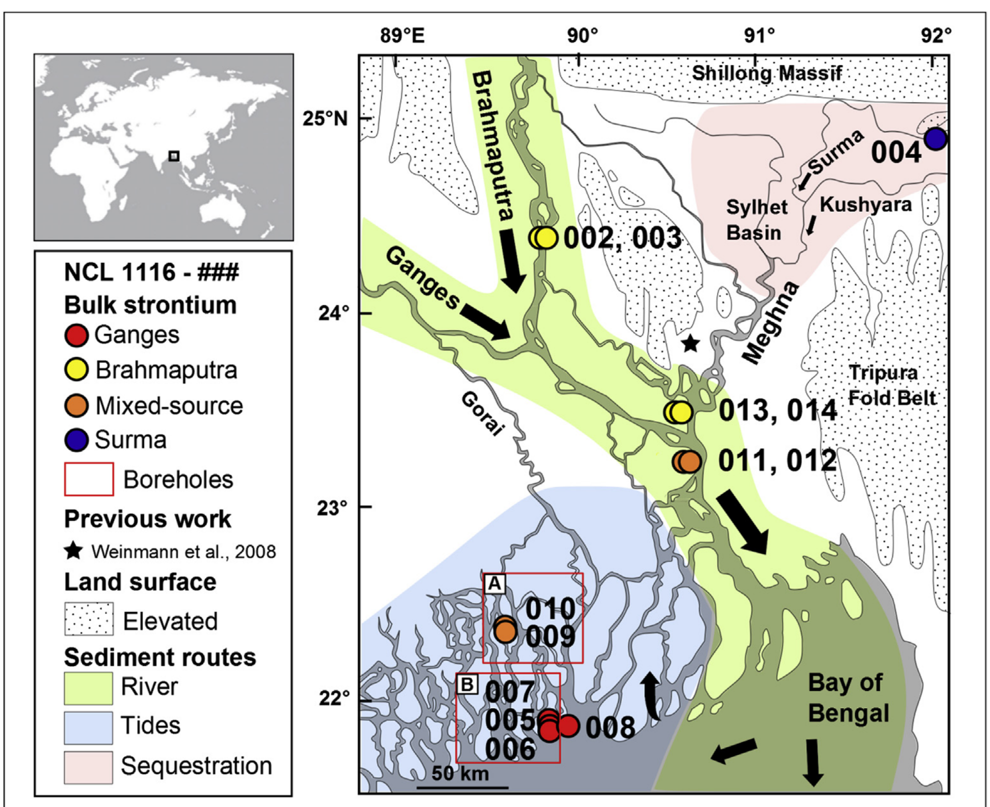


**Fig. 1.** Sample locations in the GBMD, with relevance to sediment pathways (shaded) and relative sediment flux (black arrows) following Wilson and Goodbred (2015), tectonically or otherwise-elevated features (stippled) following Goodbred and Kuehl (2000), and previous OSL work. Samples are labeled with NCL code and strontium-provenance is indicated by marker color. Red boxes enclose samples obtained from boreholes including KHLC (A) and Katka-A archaeological site (B) borings, while all other samples are from cutbanks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)