Earth and Planetary Science Letters 478 (2017) 89–101

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

# Post-glacial climate forcing of surface processes in the Ganges–Brahmaputra river basin and implications for carbon sequestration

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ARTICLE INFO

*Article history:*
Received 11 March 2017
Received in revised form 15 July 2017
Accepted 9 August 2017
Available online xxxx
Editor: D. Vance

*Keywords:*
Indian Monsoon
Bengal Fan
paleoclimate
sediment provenance
biomarkers
stable isotopes

ABSTRACT

Climate has been proposed to control both the rate of terrestrial silicate weathering and the export rate of associated sediments and terrestrial organic carbon to river-dominated margins – and thus the rate of sequestration of atmospheric $CO_2$ in the coastal ocean – over glacial–interglacial timescales. Focused on the Ganges–Brahmaputra rivers, this study presents records of post-glacial changes in basin-scale Indian summer monsoon intensity and vegetation composition based on stable hydrogen ($\delta$D) and carbon ($\delta^{13}$C) isotopic compositions of terrestrial plant wax compounds preserved in the channel–levee system of the Bengal Fan. It then explores the role of these changes in controlling the provenance and degree of chemical weathering of sediments exported by these rivers, and the potential climate feedbacks through organic-carbon burial in the Bengal Fan. An observed 40‰ shift in $\delta$D and a 3–4‰ shift in both bulk organic-carbon and plant-wax $\delta^{13}$C values between the late glacial and mid-Holocene, followed by a return to more intermediate values during the late Holocene, correlates well with regional post-glacial paleoclimate records. Sediment provenance proxies (Sr, Nd isotopic compositions) reveal that these changes likely coincided with a subtle focusing of erosion on the southern flank of the Himalayan range during periods of greater monsoon strength and enhanced sediment discharge. However, grain-size-normalized organic-carbon concentrations in the Bengal Fan remained constant through time, despite order-of-magnitude level changes in catchment-scale monsoon precipitation and enhanced chemical weathering (recorded as a gradual increase in K/Si* and detrital carbonate content, and decrease in $H_2O^+$/Si*, proxies) throughout the study period. These findings demonstrate a partial decoupling of climate change and silicate weathering during the Holocene and that marine organic-carbon sequestration rates primary reflect rates of physical erosion and sediment export as modulated by climatic changes. Together, these results reveal the magnitude of climate changes within the Ganges–Brahmaputra basin following deglaciation and a closer coupling of monsoon strength with OC burial than with silicate weathering on millennial timescales.



## 1. Introduction

Silicate weathering, carbonate precipitation, and organic carbon (OC) burial in marine sediments, are the main mechanisms for sequestering atmospheric $CO_2$ over a range of timescales. The efficiency of these processes has long been mechanistically linked to climate, in particular temperature and rainfall, such that increased atmospheric $CO_2$ sequestration under warm and wet conditions would act as a negative feedback, thereby contributing to global climate regulation. Rivers export silicate weathering products and terrestrial OC to the ocean, while river-dominated margins account for the majority of the global burial flux of OC, illustrating their disproportionate role in the global carbon cycle (Hedges and Oades, 1997). Over glacial–interglacial timescales, climate has been proposed to control the rate of export of terres-

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http://dx.doi.org/10.1016/j.epsl.2017.08.013
0012-821X/

**Abbreviations**

| | | | |
|---|---|---|---|
| B–A | Bølling–Allerød interstadial period (14.7–12.7 ka) | LG | Late Glacial (24–18 ka) |
| BoB | Bay of Bengal | LH | Lesser Himalaya |
| FA | fatty acid | NH | Northern Hemisphere |
| G–B | Ganges and Brahmaputra | OC | organic carbon |
| H1 | Heinrich Event H1 (18–15 ka) | SoNG | Swatch of No Ground |
| HCO | Holocene Climatic Optimum (10–6.5 ka) | THB | Trans-Himalayan Batholith |
| HHC | High Himalaya Crystalline | TSS | Tethyan Sedimentary Series |
| ISM | Indian Summer Monsoon | YD | Younger Dryas (12.9–11.7 ka) |

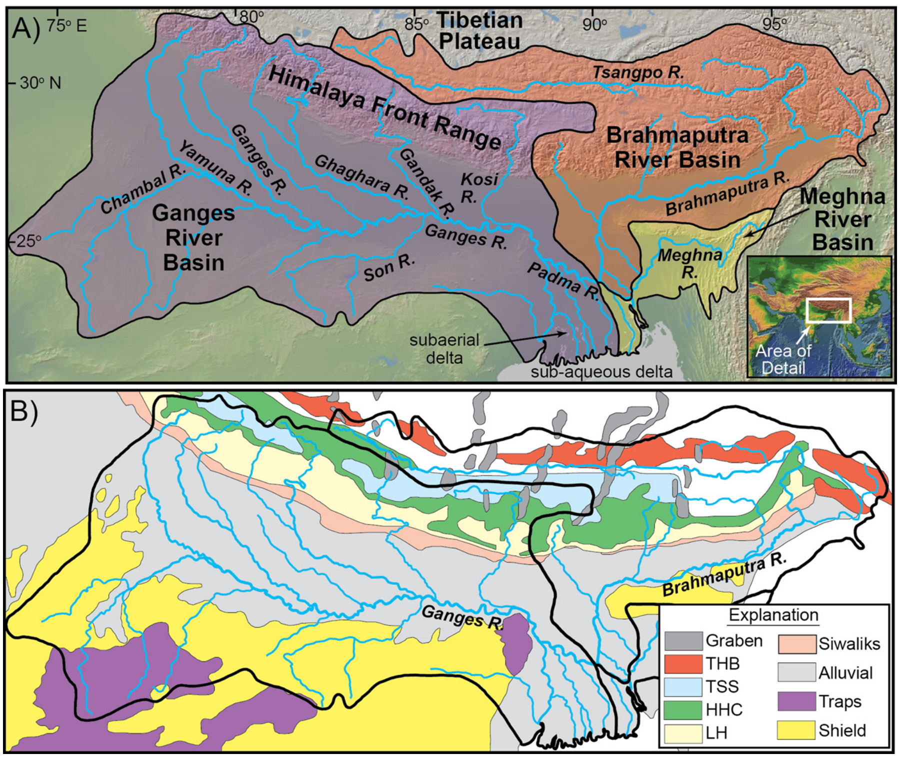


**Fig. 1.** (A) Major features and tributaries of the Ganges–Brahmaputra (G–B) drainage basin. Background topographic image from GeoMapApp. (B) Geologic map of the G–B basin showing locations of the major terranes (modified from Galy et al., 2010). THB: Trans-Himalaya Batholith, TSS: Thetisian Sedimentary Series, HHC: High Himalaya Crystalline, LH: Lesser Himalaya.

trial sediment and OC to these depocenters (Ludwig et al., 1998; Galy et al., 2015), as well as rates of chemical weathering, which exert a primary control on carbon sequestration (e.g., West et al., 2005). Heretofore, few studies of large (continental-scale) systems have directly quantified in an integrated manner how past climate change has impacted the basin-scale weathering degree of silicate minerals exported to the coastal ocean, or the competency of those systems to export and bury OC, let alone both.

The Ganges and Brahmaputra (G–B) rivers, which drain the vast majority of the Himalayan range and Southern Tibet (Fig. 1A), convey the world's largest fluvial sediment load to the Bay of Bengal (BoB), resulting in the deposition of the world's largest delta (Kuehl et al., 2005) and the world's largest reservoir of terrigenous sediments ($\sim 2.9 \times 10^{16}$ tons; Curray et al., 2003). Despite the generally low OC concentration in G–B sediments (typically $<1\%$), the G–B rivers are currently the largest single supplier of biospheric OC to the world's oceans (Galy et al., 2015). Coupled with excellent OC preservation in Bengal Fan sediments (Galy et al., 2007) and modest silicate weathering rates in the G–B basin (Galy and France-Lanord, 1999), this makes OC burial the leading carbon sequestration mechanism in the G–B system at short (~1000 yr) through long (~10 myr) timescales (France-Lanord and Derry, 1997; Galy et al., 2007). Changes in Himalayan erosion driven by climate variability over the last 20 kyr are thus expected to have played a role in the global carbon cycle – specifically the magnitude of carbon sequestration – following the last glacial maximum (21–19 ka). Here, we use a sediment record from the Bengal Fan following the last glacial maximum to 1) reconstruct hydroclimate variability (i.e., monsoon intensity) and attendant paleovegetation changes in the G–B basin and, 2) evaluate how these variations in monsoon strength have affected weathering processes as well as sediment and carbon export (and burial) within the G–B basin/Bengal Fan system.

## 2. Regional setting

### 2.1. The Indian Summer Monsoon as a driver of sediment and carbon export to the Bay of Bengal

Water and sediment discharge from the G–B rivers are largely controlled by intense precipitation associated with the Indian Summer Monsoon (ISM), a coupled ocean–atmosphere–land climate system driven by cross-equatorial pressure gradients and amplified by land-sea thermal gradients and resulting low-level advection of