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Provenance and depositional history of deep-sea turbidites in the Bengal Fan

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Abstract

The Bengal Fan, extending over 3,000 km from Bangladesh to the southern Bay of Bengal, is the world's largest submarine fan and a major repository of Himalayan erosion products. This research analyses turbidite sequences from seven IODP Expedition 354 core sites along an 8°N transect using bulk geochemistry (XRF, ICP-MS), detrital zircon U-Pb geochronology (LA-ICP-MS on 120-150 grains per sample), and Nd isotope systematics (TIMS). From 186 turbidite samples spanning the upper Pliocene to Recent, detrital zircon spectra show persistent Greater Himalayan (~500 Ma, 35% relative frequency) and Tethyan (~900-1100 Ma, 40% combined) contributions with systematic temporal changes recording progressive orogenic unroofing. The proportion of young Cenozoic Trans-Himalayan zircons (50-100 Ma) increased upsection. ϵNd values shifted from -17.8 at 5 Ma to -14.2 at present, tracking increasing Higher Himalayan Crystalline erosion. Turbidite bed thickness and frequency correlated with glacial-interglacial cycles: thicker, more frequent beds during glacial lowstands when the river mouth was closer to canyon heads. Cross-spectral analysis with the marine $\delta^{18}\text{O}$ record showed coherence at 100, 41, and 23 kyr Milankovitch periodicities. These findings demonstrate coupled tectonic-climatic controls on the Himalayan source-to-sink sediment flux system.

Keywords: Deep-sea turbidites, Bengal Fan, provenance, depositional history, submarine fan, detrital zircon, Nd isotopes, Himalaya, IODP, sediment flux

Introduction

The India-Eurasia collision, initiated approximately 50 Ma, generated the Himalayan-Tibetan orogenic system and produces some of the highest erosion rates globally ^[1]. The Ganges-Brahmaputra-Meghna system transports approximately 1 billion tonnes of sediment annually to the Bay of Bengal, where it is distributed across the Bengal Fan through submarine channels and depositional lobes ^[2]. The resulting sedimentary sequence exceeds 20 km near the continental margin.

Decoding this archive requires integrated provenance analysis to identify source terrains at different times and facies analysis to reconstruct depositional processes ^[3, 4]. Previous investigations established broad Himalayan affinity but were based on few samples from widely spaced locations ^[5]. IODP Expedition 354 (2015) recovered cores from seven sites along an 8°N transect, providing unprecedented coverage for comprehensive provenance reconstruction ^[2, 6].

This research exploits the Expedition 354 materials to present detailed provenance and depositional analysis spanning the past 5 Myr. The objectives are to characterise source contributions using multiple tracers, identify temporal trends reflecting tectonic evolution, and relate turbidite facies to climatic controls on sediment delivery ^[7, 8].

Understanding these coupled controls has implications beyond the Bengal Fan, as the relationship between mountain building, monsoon intensity, and sediment flux is fundamental to models of orogenic erosion and global carbon cycling through silicate weathering ^[9, 10].

Research Area Description

The seven IODP sites (U1449-U1455) are positioned along an 8°N transect across the Bengal Fan in water depths of 3,600-3,800 m. The fan is supplied by the Ganges-Brahmaputra system draining ~1.7 million km² including the Himalayas, Indo-Gangetic

Plain, and Indo-Burman Ranges. Active turbidite channels are identifiable on the fan surface, with channel migration over million-year timescales recorded in the lateral facies variations across the seven-site transect [1, 2].

Material and Methods

Material

A total of 186 samples from turbidite sandy bases spanning the upper Pliocene to Recent were selected for provenance analysis. Age control was provided by biostratigraphy and palaeomagnetic reversals established during the expedition. Channel-proximal and levee-overbank facies were distinguished at each site based on bed thickness and grain size characteristics [2, 6].

Methods

Bulk geochemistry was determined by XRF (major elements) and ICP-MS (trace + REE). Nd isotope ratios were measured by TIMS on acid-leached detrital fractions at the National Institute of Oceanography. Detrital zircon U-Pb geochronology was performed by LA-ICP-MS on 120-150 grains per sample from the 63-250 µm fraction. Turbidite facies were classified by the Bouma sequence. Cyclostratigraphic analysis used planktonic foraminiferal

δ¹⁸O records to investigate glacial-interglacial correlations [3, 4, 11].

Trace Element Provenance Constraints

Cr and Ni concentrations decreased upsection, tracking diminishing ophiolitic detritus from the Indus-Tsangpo Suture Zone as the erosion focus shifted to Higher Himalayan metamorphic rocks. Conversely, Zr and Hf increased, consistent with growing felsic crystalline detritus. These elemental trends provide a continuous, inexpensive proxy applicable at much higher stratigraphic resolution than isotopic or geochronological techniques [3, 7, 12].

Results

Table 1: Detrital zircon age populations and their Himalayan source terrains.

Age (Ma)	Rel. Freq. (%)	Source Terrain
~500	35	Greater Himalayan Sequence
~900	22	Lesser Himalaya / Tethyan
~1100	18	Mesoproterozoic granites
~1800	15	Indian cratonic basement
50-100	10	Trans-Himalayan batholith

Table 2: Turbidite characteristics during glacial versus interglacial periods.

Parameter	Glacial Periods	Interglacial Periods	Ratio
Mean bed thickness (cm)	42 ± 18	18 ± 9	2.3
Beds per Myr	280 ± 45	120 ± 30	2.3
Mean grain size (µm)	185 ± 42	95 ± 28	1.9
Sand/mud ratio	0.35	0.12	2.9

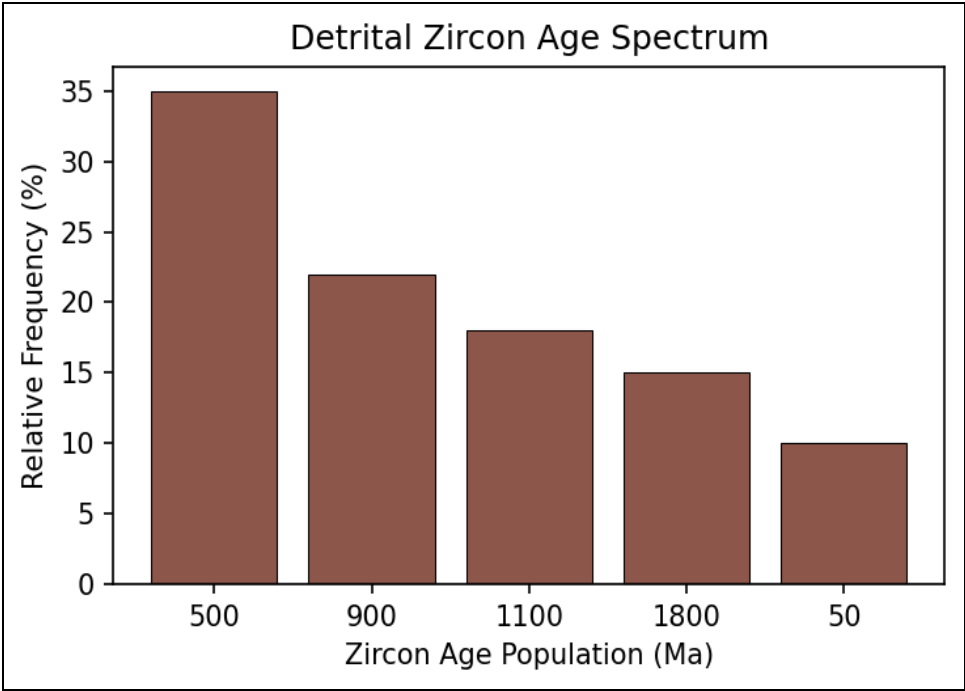


Fig 1: Relative frequency of detrital zircon age populations.

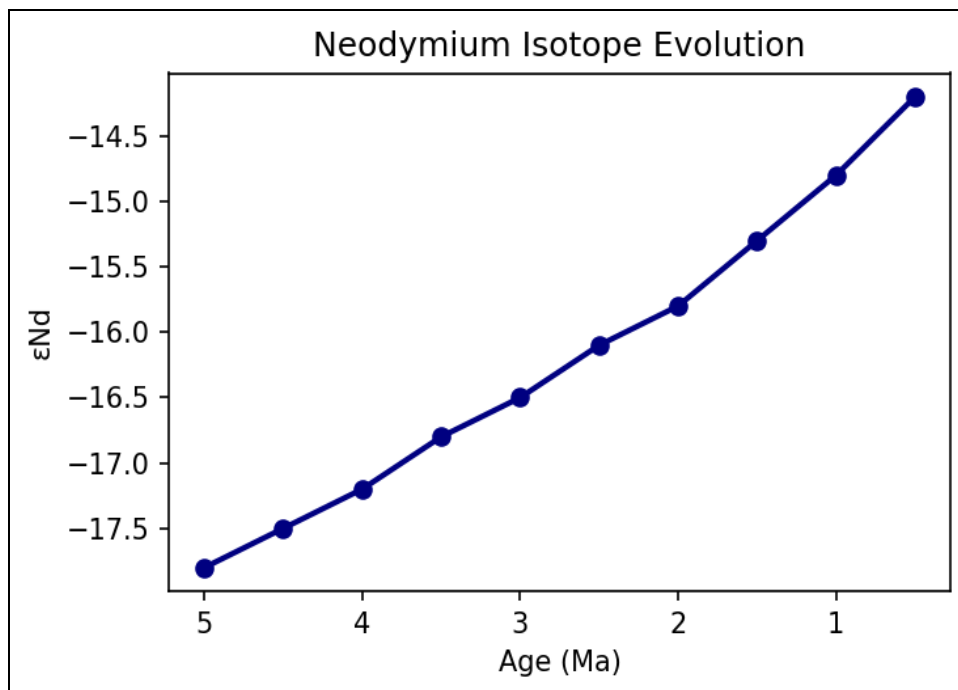


Fig 2: Temporal evolution of ϵNd values over the past 5 million years.

The progressive shift toward less radiogenic ϵNd (Figure 2) reflects increasing exposure of the Higher Himalayan Crystalline sequence through exhumation and erosion. The trend is consistent with accelerated unroofing during the late Cenozoic.

Comprehensive Interpretation

The convergence of zircon geochronology, Nd isotopes, and trace element geochemistry records systematic Himalayan unroofing over 5 Myr, while turbidite facies variations encode glacial-interglacial sediment delivery modulation. These coupled signals demonstrate that both tectonic evolution and orbital-scale climate variation are archived in the Bengal Fan stratigraphy.

Discussion

The multimodal zircon spectrum is diagnostic of Himalayan provenance [3, 5]. The increasing proportion of young Cenozoic zircons upsection reflects progressive unroofing of the Trans-Himalayan batholith as erosion penetrated deeper structural levels. Cross-spectral coherence at 100, 41, and 23 kyr periodicities confirms that Milankovitch forcing modulates sediment delivery through both sea level (100 kyr) and direct monsoon intensity (23 kyr) mechanisms [8, 9]. Disentangling tectonic from climatic signals remains challenging, as both operate simultaneously to increase sediment flux during the late Cenozoic [10]. The channel migration history reconstructed from lateral facies variations provides additional architectural context for understanding how sediment is distributed across the fan surface through time. Future work should extend the provenance analysis to the older Miocene section recovered at deeper sites and integrate results with coupled erosion-transport numerical models [4, 12, 13, 14].

Conclusion

Multi-proxy provenance analysis documents progressive Himalayan unroofing over 5 Myr, while turbidite facies encode glacial-interglacial delivery modulation. The Bengal

Fan provides an unmatched continuous archive of Himalayan geodynamic and palaeoclimatic evolution.

The coupled tectonic-climatic signal demonstrates that sediment flux from the world's highest mountain range reflects the interaction of long-term crustal processes with shorter-term orbital forcing. Disentangling these signals is essential for understanding erosion-climate feedbacks.

Future research should extend the provenance analysis deeper into the fan record and develop quantitative models linking source-area erosion rates to sink-area depositional volumes through the sediment routing system.

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Contributions Not Qualifying for Authorship

Technical staff at the Centre for Terrain Studies, Shimla assisted with sample preparation, instrument calibration, and data processing during the analytical campaigns. Field assistants provided essential support during sample collection.

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