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The Bengal Fan - Geomorphology and Sediment Distribution

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The Bay of Bengal is a large but relatively shallow embayment of the northeastern Indian Ocean. It receives a significant amount of freshwater and sediment, approximately 2000 million tonnes annually, from the Himalayan and the Indian peninsular rivers during the North East (NE) and the South West (SW) monsoons, respectively. The sediment flux to the bay is among the highest globally due to its size, location, and the catastrophic deposition of sediments. Long paleo-synoptic reconstructions and paleomonsoon interpretations from sediment cores in the Bay of Bengal are limited. This is largely because the enormous sediment load that enters the Bay through river discharge occurs under high-energy conditions, making it challenging to retrieve turbidity-free and undisturbed sediment cores. However, some recent reports (Ponton et al., 2012; Tripathy et al., 2014) have documented variations in paleoclimate and geochemical cycles from the Last Glacial Maximum to the late Holocene period in the Bay of Bengal. Sedimentological and geochronological studies conducted on the eastern Bengal shelf studied by Kuehl et al. (1989) revealed that the highest sediment accumulation from the Ganges-Brahmaputra river system occurs near the head of the Swatch of No Ground, which is located west of the present river mouths of Ganges-Brahmaputra. Additionally, Kolla and Rao (1990) analyzed sediment sources from the Bay of Bengal and reported high quartz and low calcium carbonate percentages adjacent to the Indian subcontinent, likely due to a substantial influx of terrigenous clastics. Furthermore, investigations on the mineralogy and heavy minerals in sands suggest that sediments of the western Bengal Fan, characterized by high levels of smectite, sillimanite, and garnet, are derived from peninsular Indian

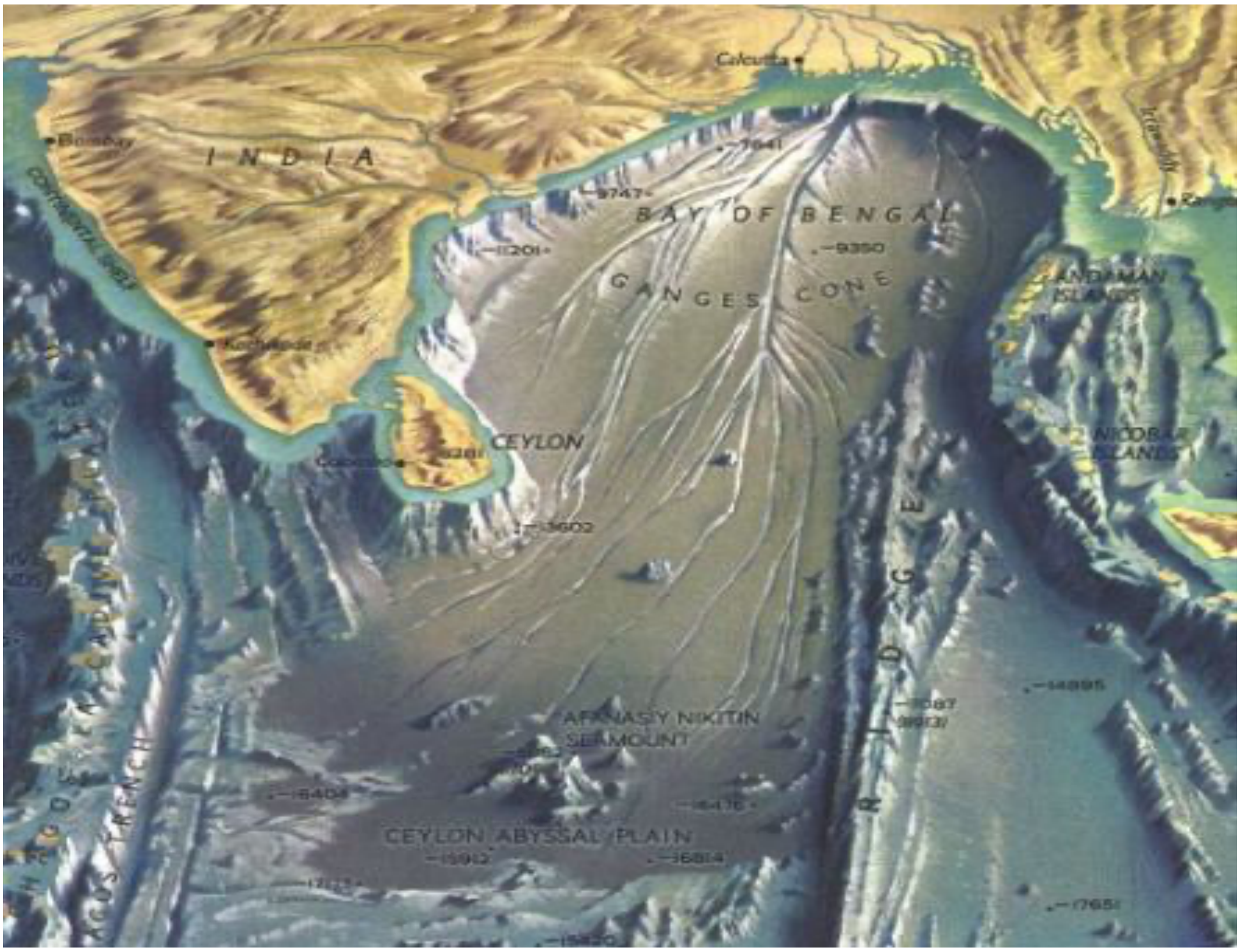

Fig. 1. Bengal Fan - from Alchetron - The Free Social Encyclopedia

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rivers. In contrast, sediments from the rest of the fan, which are high in illite, hornblende, and epidote, come from the Himalayan rivers. Isotopic and clay mineral investigations by France-Lanord et al. (1993) were carried out to understand the evolution of the Himalaya since the Miocene era. Their findings indicated that the narrow range of isotopic values throughout the deposition history implies the source of the Bengal Fan sediments has remained consistent since the early Miocene, despite changes in sedimentation rates, sedimentary facies, tectonic history, and climatic conditions.

The Bengal Fan, also known as the Ganges Fan, is a vast depositional feature (Fig.1) formed by turbidite sedimentation from the Ganges and Brahmaputra River systems. It was first identified as a submarine fan by Dietz (1953). Located in the northeastern Indian Ocean, the Bengal Fan is the largest submarine fan in the world, stretching approximately 3,000 kilometers in length and 1,000 kilometers in width (Curray et al., 2003; Xue et al., 2019). It extends from its apex near the Bengal shelf at around 20° N to its distal end at 7° S in the Bay of Bengal. The fan has a thick accumulation of sediments, which can reach up to 16.5 kilometers in thickness, covering the entire basement and making the ocean floor bathymetry virtually featureless. Its total volume is estimated at 12.5 million cubic kilometers, making it one of the most voluminous sedimentary deposits on Earth.

This submarine fan originated during the Eocene epoch due to the ongoing tectonic collision between the Indian and Eurasian plates. This collision resulted in the uplift of the Himalayas and triggered significant erosion and sediment transport. Curray and Moore (1971) and Einsele et al. (1996) in their papers documented the relationship between uplift and erosion of the Himalayan Mountain chain, and the growth of the Bay of Bengal deep-sea fan on the basis of geophysical and sedimentological observations. Further, the mmineralogical studies (Crowley et al., 1998) of Deep Sea Drilling Project (DSDP) Site 218 cores, shallow piston cores, and dredge samples recovered from various locations across the fan confirm the obvious importance of Himalayan erosion to fan sedimentation (Kolla and Biscaye, 1973; Bouquillon et al., 1989). The fan receives substantial amounts of terrigenous materials from the Himalayas through the Ganges-Brahmaputra system, as well as from the Indian peninsula via the Godavari and Krishna rivers, and from the Burma range. The occurrence of smectite-kaolinite rich crustal sources for these sediments includes the Deccan Trap basalts of central India and Precambrian high-grade metamorphic and igneous terrains exposed in central/southern India and Sri Lanka (Goldberg and Griffin, 1970; Kolla and Biscaye, 1973).

The sediments from the Himalayas are primarily delivered through the active Swatch of No Ground submarine canyon on the Bengal shelf, which feeds into a single active fan valley. The “Swatch-of-No-Ground” submarine canyon connects to only one active fan valley system at any time, without apparent bifurcation over its 2500-km length (Emmel and Curray, 1983). The Swatch of No Ground, a prominent submarine canyon incising the Bengal shelf near the river mouths, serves as the primary conduit for channeling the riverine sediment directly to the Bengal Fan through episodic mass flows. Additionally, the sediment contributions are influenced by seasonal surface ocean currents under the influence of the Indian monsoon (Xue et al., 2019; Sun et al., 2020) and the sediment source-to-sink system in the Bengal Fan, including climate modulation of terrigenous sediment input (Tripathy et al., 2014; Liu et al., 2019), were also investigated. Some studies revealed the spatial distribution of surface sediments (Li et al., 2017; Sun et al., 2019, 2020), while others are limited to continental shelves and river mouths (Weber et al., 2003; Chauhan et al., 2005; Bejugam and Nayak, 2016a, 2016b, 2019a, 2019b; Kangane et al., 2019, 2021a, 2021b; Nayak et al., 2022). Numerous descriptions of modern submarine fans have been published over the last few decades, and various models for their formation and growth have been proposed (Normark, 1970; Bouma et al., 1985; Shanmugam and Moiola, 1988; Normark et al., 1993; Piper and Normark, 2001; Shanmugam, 2016).

The Bengal Fan displays a cone-shaped morphology typical of submarine depositional fans. It originates near the Ganges-Brahmaputra delta and expands southward into a broad depositional lobe. This lobe transitions from the proximal upper fan to the distal lower fan across abyssal plains (Curray et al., 2003), which feature a gently sloping surface. The surface slope of the Bengal Fan varies, with steeper gradients of about 1:200 in the upper fan and flatter profiles of less than 1:2,000 in the distal areas. This variation influences sediment distribution patterns, illustrating the gradual decrease in confinement and energy from the proximal to distal regions. Key geological processes have shaped the evolution of the fan. These include tectonic subsidence in the underlying Bengal Basin, which accommodated thick sediment piles due to flexural loading from the Himalayan thrust belt, and eustatic sea-level fluctuations that influenced delta progradation and the efficiency of turbidity currents. The growth of the fan occurred in distinct phases, characterized by three major subfan cycles from the Miocene to the Pleistocene. Each cycle was by channel incision, aggradation, and avulsion that redistributed sediments across the fan's expanse (Gong et al., 2022). These cycles reflect episodic shifts in depositional locations, where channels incising during periods of high sediment flux, built levees through aggradation, and abandoned older paths via avulsion to initiate new subfans, resulting in a stacked architecture of channel-levee-lobe systems (Gong et al., 2022).

In the upper fan, near the Ganges-Brahmaputra Delta, the seafloor is dominated by steep submarine canyons and incised channels, including the active Swatch of No Ground canyon, which serves as the primary conduit for sediment transport (Curray et al., 2003). These features give way to broad channel-levee complexes. The upper fan morphology includes a fan-shaped network of sinuous channels, with terraces and over banks resulting from lateral migration and avulsion events dating back to the last glacial stage (Kolla et al., 2012). The middle fan is characterized by meandering channels that exhibit fluvial-like geometries, transitioning from erosional incision to a-gradational channel-levee systems, with multiple complexes separated by unconformities (Schwenk and Spiess, 2009). Terminal depositional lobes form at channel termini, where sediment sheets accumulate from levee breaching, contributing to the fan's lobate structure over distances of several hundred kilometers (Schwenk and Spiess, 2009). Toward the distal fan, the topography smooths into vast abyssal plains, interrupted by subtle sediment mounds, debris flows, and abandoned channels that remain partially open. Buried channels are prominently visible in high-resolution seismic profiles, indicating past migration pathways now overlain by thin turbidite sheets. These features reflect waning sediment energy.

The sediments of the Bengal Fan are predominantly composed of fine-grained turbidites, consisting mainly of silt and clay with interbedded sands derived from Himalayan erosion. Stratigraphically, the Bengal Fan exhibits a progression from Miocene basal sands to Pliocene-Pleistocene muds, with total sediment thickness reaching a maximum of 16.5 km (Blum et al., 2018) near the continental slope and tapering distally. In recent years, paleoclimate research from Bengal Fan sediment cores has illuminated the evolution of the Indian monsoon and associated sea-level fluctuations, with oxygen isotope records offering insights into circulation patterns in the Indian Ocean.

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