IODP Expedition 354: Bengal Fan

Site U1450 Summary

Background and Objectives

Site U1450 occupies a central position at 8°0.42′N and 87°40.25′E in the east–west transect across the Bengal Fan at 8°N. It is located at equal distance from Site U1451 above the Ninetyeast Ridge and Site U1455 above the 85°E Ridge. The overall thickness of the fan reaches ~4 km in this location (Curray et al., 2003). Neogene sediment thickness decreases toward the two ridges, which is likely the result of ongoing deformation on both ridges during Neogene times (Schwenk and Spiess, 2009). At this central position of the transect, the Upper Miocene and Pliocene–Pleistocene sections of the fan appear to be most expanded and were inferred to contain a higher resolution record as well as accumulating on average coarser grained material. The shallow section at this site is one of the seven, ~200 m thick sites of the 8°N transect to constrain the middle Bengal Fan architecture in space, time, and sediment delivery rates during the Pleistocene. The deeper section at this site will document the delivery mechanisms of the fan as well as the climatically and tectonically influenced sediment supply from the Himalaya during the Neogene. Changes in the source regions in response to tectonic processes and climatic interactions in the Himalayan basin are expected to be reflected in the sediment mineralogical and geochemical compositions and geochronological data as well as by integrating accumulation rates across the transect.

Principal Results

Half-length APC (HLAPC) coring, combined with 4.8 m advances with no coring, was essential to combine sufficient recovery in difficult lithologies with reasonable drilling time to reach down to 812 mbsf. This approach proved to be particularly efficient to recover loose sand that is otherwise washed out during RCB or XCB coring. Because of remarkably low lithification of the sediment formation, this HLAPC approach permitted piston coring down to 550 m, although seven HLAPC cores were taken below this depth, the deepest at 688 m.

As for other transect sites, the sedimentary succession is dominated by turbidites of siliciclastic composition with detrital carbonate content between 5% and 10%. These have high accumulation rates (5–10 cm/k.y.) from the Upper Miocene to Lower Pliocene.

From the Pliocene to Pleistocene, turbidite accumulation peaks around 20–25 cm/k.y. These turbidites have close mineralogical and geochemical affinities with sand and silt sampled in Ganges, Brahmaputra, and Lower Meghna rivers. They carry all the mineral characteristics and major element composition characteristics of river sediments derived from high grade metamorphic rocks of the Himalayan range. The representation of sand (41%) in Site U1450 cores matches well the grain size spectrum expected from river derived detrital material, and bias by turbiditic transport may be minor. As downhole logging at this site has not been possible due to poor hole conditions, it remains difficult to estimate the exact proportion of sand, silt, and clay in this hole. Over the whole section, the mineralogical and chemical composition of the turbidites as the prevailing lithology appears almost uniform, but detrital carbonate content tends to gradually increase below the Pliocene to reach concentrations twice as high as in modern rivers. This suggests either an evolution in eroded lithologies and/or a change in weathering conditions. Another distinctive, more carbonate-rich lithology is represented by about ten relatively thin hemipelagic intervals composed of calcareous clays. They correspond to periods of slow accumulation at the site when pelagic deposition is significant enough to be identified, but is still diluted in variable proportions by a fine clay component. The affinity of this clay material with the fine grain plume that can be generated by surrounding turbidity currents assumed to originate from canyons and the slope offshore Bangladesh remains to be determined by geochemical and clay mineralogical approaches. These low accumulation intervals allow precise geochronological work and will be important for the evaluation of accumulation rates. Testing their continuity across the transect will be a key element for the integrated study of the fan construction dynamics as well as the long-term detrital sedimentary input utilizing seismic correlation across the transect.

Site U1450 represents a reference section for shore-based studies of the erosion of the Himalaya during the Neogene. The detrital sediments cored here present little evidence for evolution over the last 8 Ma suggesting rather steady conditions of erosion in the Himalayan basin. This would require a major mountain range undergoing fast erosion and a monsoonal climate that allows rapid transport to inhibit weathering of the sediment in the floodplain. Unlike in the distal fan cored during ODP Leg 116 (Cochran et al. 1989), Site U1450 sediments show no clear change in accumulation rate, grain size, and clay mineralogy from 7 to 1 Ma. This suggests that the smectite-rich fine turbidites recorded in the distal fan for this time period (Bouquillon et al. 1990) relate more to a change in the channel and turbidite routing to the distal fan rather than to a change in Himalayan erosion. Site U1450 also covers the interval of expansion of the C_4 flora (i.e. savanna to the expense of forest) recorded in both the distal and the middle fan (Galy et al. 2010). Sediments recovered at Site U1450 will allow detailed studies of this process and its possible connection with climate changes or erosion conditions.

Operations

Site U1450 consisted of two holes. Hole U1450A (10–17 February) was cored to 687.4 m using primarily the HLAPC system alternating with short (4.8 m) advances without coring. The full-length APC and XCB systems were used in the shallow and deepest portions of the hole, respectively. Due to very low recovery at depth with the XCB system, we pulled out and planned for deeper penetration coring and logging a second hole later in the expedition. Overall, 282.7 m of core was recovered for the 444.7 m cored in Hole U1450A. Hole U1450B (7–11 March) was drilled without coring to 608.0 m, and RCB cored continuously from there to 811.9 m. Coring in Holes U1450A and U1450B overlap from 608.0 to 677.8 m. This deeper section cored 203.9 m and recovered 46.7 m of sediment (23%). Downhole logging was attempted with a triple combo tool string. On the way down, the bottom of the tool string encountered an obstruction at 133.7 m and became stuck, likely in a collapsing sand layer. After the tool string was released, a short section of logging was acquired and deep logging of the hole was abandoned.

Lithostratigraphy

The overall dominant lithology for Site U1450 (84% of total recovered material) is siliciclastic and comprised of fining-upwards sequences of fine sand, silt, and clay (i.e. turbidites), as well as homogenized sands and mixed silt-clay layers. These turbidites carry major and trace minerals characteristic of Himalayan rivers and of high grade metamorphic rocks of the Himalaya. Clay assemblages are illite and chlorite, which are indicative for the same rivers. Siliciclastic units alternate with at least 10 units of calcareous clay sediments (16% of total recovered material). The thickest continuous calcareous clay intervals are in Unit III, and consist of 5.14 m in Core U1450A-34F and 4.8 m in Core U1450A-36F. Sediments give way downhole in Hole U1450B to increasingly more lithified material (e.g. limestones and claystones) from 627.50 m CSF-A to the base of recovered material. Additionally, Site U1450 contains three volcanic ash layers. Recovered sediments from Site U1450 were subdivided into 24 lithostratigraphic units based on lithological and paleontological characteristics obtained through macroscopic and smear slide analyses, and physical property measurements.

Lithological differences between units and variations in grain size and bed thickness reflect cycles of proximal turbidity current channel activity and abandonment. Sand intervals may represent inter-levee “sheet flows”, while finer-grained fractions are more likely preserved in levee deposits. Bioturbated calcareous clays represent times of local channel-levee inactivity with reduced and finer siliciclastic deposition. They reflect a relative increase in the contribution of biogenic origin from the pelagic zone. Many intervals of calcareous clay material show repeated sequences of color-graded beds which can occur due to increased entrainment of siliciclastic material, changes in water column productivity, or changes in the oxidation/reduction horizons of the pore water. In Hole U1450B, intervals dominated by calcareous and/or clayey material become increasingly lithified with depth, and many are intercalated with very thin to thin silt or siltstone layers. Plant fragments occur throughout the cored section, more commonly in silt and siltstone intervals, though a few sand-dominated units also contain macroscopic organic material. At the top of Hole U1450A there is an 18 cm thick ash layer that presumably corresponds to the ~75 ka Toba volcanic eruption which produced widespread tephra deposits across the Bay of Bengal (e.g. Gasparotto et al., 2000).

Biostratigraphy

Calcareous nannofossil and planktonic foraminiferal biostratigraphic analyses were conducted at Site U1450 and resulted in the identification of 18 biomarker events. These events were used to construct four foraminferal and 11 nannofossil biozones, providing excellent age control extending back to the Late Miocene. The recovery of a Late Miocene succession achieves one of the key objectives of this expedition, including sediments that may contain the C_4 photosynthetic flora expansion (Galy et al., 2010).

The succession of biostratigraphic zones at this site appears continuous as no significant nannofossil biostratigraphic hiatuses were observed, indicating that the fan has been accumulating sediments, albeit at highly variable accumulation rates, since the Late Miocene.

Paleomagnetics

A preliminary paleomagnetic study was conducted on 36 of the 86 cores collected from Hole U1450A, comprising 108 archive half section and 52 discrete sample measurements. Sandy and/or deformed intervals were not measured. Polarity zones corresponding to the Jaramillo and Cobb Mountain subchrons were identified in a calcareous ooze unit in Core U1450A-36F (173.40–174.60 m and 175.62–175.88 m CSF-A, respectively). An additional pair of reversals was observed in Core U1450A-52F (248.38 and 248.51 m CSF-A), but the polarity chron to which they belong has not yet been identified. The thickness of the Jaramillo and Cobb Mountain polarity zones in Hole U1450A suggests an accumulation rate for the calcareous ooze interval similar to that in Site U1449A (~1.5 cm/k.y.).

Physical Properties

Physical property data were acquired on Site U1450 cores, including density, magnetic susceptibility, *P*-wave velocity, natural gamma radiation, and thermal conductivity. The data are mostly of good quality, but the results from disturbed and partially filled sections are less reliable, as described below.

The physical properties at Site U1450 primarily reflect lithological variations, with downcore compaction having a relatively minor effect. Using the principal lithological name from the core description, which assigned six types of lithologies, average physical properties were calculated. From the 319 m total core recovery (39.6%), sand accounts for 131 m (41%), silt for 46 m (14%), clay for 72 m (22%), calcareous clay for 45 m (14%), claystone for 13 m (4%), calcareous claystone for 6 m (2%), and limestone (7 m), with additional thin ash layers. In general, sands and silts have the highest density and *P*-wave velocity, sands have the highest magnetic susceptibility, clays have the highest natural gamma radiation, and calcareous clay generally has the lowest values in all of the measurements. Some of the sand-rich intervals were difficult to recover and were often fluidized, which sometimes resulted in incompletely filled core liners; this had the effect of giving unexpectedly low gamma ray density, magnetic susceptibility, and natural gamma radiation values. Cores that had inflow of core material (“suck in”) also likely have lower than expected values in these physical properties due to volume reduction.

Geochemistry

Detailed pore water measurements show that four hydrological units in the middle fan can be distinguished based on sulfate, phosphate, silica, magnesium, potassium, calcium, and alkalinity content. Carbonate contents of bulk sediments vary widely from 1.2 to 63.2 wt% $CaCO_3$, reflecting contrasting depositional environments and significant contributions from detrital carbonates. Turbiditic sediments have low carbonate content, with values roughly doubling (from an average of 3.8 wt% to 7.3 wt%) around 600 m CSF-A. This transition, occurring during the Pliocene, most likely reflects a change in detrital carbonate supply. A similar change is also observed at Site U1451 and can be deduced from DSDP Leg 22 Site 218 TIC data (Von der Borch et al., 1974). Overall, total organic carbon content (TOC) is low with an average value of 0.4%. Within turbidites, TOC broadly co-varies with Al/Si ratios—a proxy for sediment grain size and mineral composition—reflecting preferential association of organic matter with clays previously documented in both the modern Ganges–Brahmaputra river system, and in active channel-levee sediments in the Bay of Bengal deposited over the past 18 k.y. (e.g. Galy et al., 2007). But the TOC budget is likely to be also affected by the frequent presence of woody debris concentrated in the lower part of many turbiditic sequences. In turbiditic sediments, the major element composition (e.g. Fe/Si and Al/Si) closely matches the chemical composition observed in sediments from the actual Ganges–Brahmaputra river system for both the trend and the range of variation (e.g. Galy and France-Lanord, 2001). At the low end of Al/Si ratios, the lack of significant difference suggests that extreme sorting documented in rivers coarse bed sediments is also generated by turbidity current at Site U1450. Conversely, the clay-rich end-member recovered at Site U1450 appears slightly more aluminous (and likely finer) than surface suspended sediments from the Lower Meghna River.

Microbiological subsampling of sediments and pore waters at Site U1450 included establishing a microbial cell counting method, with further processing of the samples to be performed following the expedition.

Downhole measurements

Five downhole measurements with the advanced piston corer temperature tool (APCT-3) were taken in Hole U1450A, ranging from 4.6°C at 86.3 m DSF to 13.5°C at 318.1 m

DSF. These return a geothermal gradient of 38°C/km, which appears to be in the expected range.

Stratigraphic summary

Lithologic and physical properties results confirm the expectation that Site U1450 contained a high proportion of sand in the recovered cores; it may be even higher in the formation. Like at Site U1449, the match between these data sets and seismic facies and horizons will allow us to assign broad lithologic categories to the seismic units, and thus extrapolate throughout the seismic data set and between Expedition 354 drill sites. These data also allow identification of major depositional processes which can be integrated to reconstruct the stacking pattern and evolution of fan deposition.

As Site U1450 reaches back to 8 Ma at 812 m DSF, a precise seismic stratigraphy will be established postcruise, based on major hemipelagic units and associated distinct seismic reflectors. These will be used to estimate accumulation for various subfan units in time slices on the order of several hundred thousand to millions of years, one of the main cruise objectives. Site U1450 is located in a key position between the two other deep penetration Sites U1451 and U1455.

Recovering material of sufficient quality had been a challenge during Expedition 354, particularly at Site U1450 due to the high proportion of sand. It had been unexpected that the consolidation state of sands apparently did not change much with depth. While loose sand was recovered by APC all the way down to refusal depth (560 and 630 m DSF, respectively), XCB and RCB provided little or no recovery of sand. Likely the sand proportion is underrepresented in cores from the deeper section of the site. Based on discrete sample measurements of density and porosity, a downhole trend of porosity loss can be observed, but from lithologic observations we can infer that consolidation state is different for different grain sizes. Clay shows a gradual transition to claystone with depth, with increasing *P*-wave velocities and densities downhole. However, sand could not be recovered in any more consolidated state within the entire 800 m cored section.

Based on biostratigraphic and paleomagnetic data, the Upper Miocene to Lower Pliocene portion is characterized by a relatively uniform accumulation, averaging to 5–10 cm/k.y. From the early Pliocene to the Pleistocene, fan accumulation has intensified (~20–

25 cm/k.y.), accompanied by a transition from more silt- to sand-dominated lithologies. Fan deposition has ceased at this site since 300 ka.

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